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**A Dissertation on  
Buoyancy and Load Exchange for Heavy Lift Airships**

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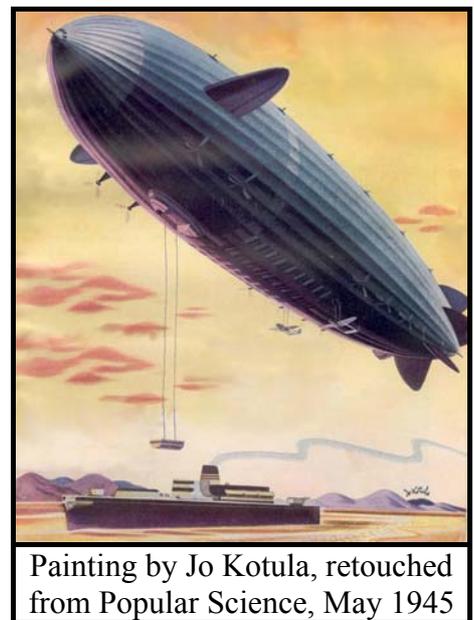
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**Foreword**

This document explains buoyancy and ‘load exchange’ and the benefits of using ballast for heavy lift ‘Transport Category’ airships that normally would operate near equilibrium between buoyancy and weight. However, a few other things involved (alternatives and the circumstances today) also need clarification so that readers will understand associated issues.

The industry today generally is struggling to re-emerge from former times (so small) and is beset with things to deal with that hinder growth. The basic principles, know-how and needs also either weren’t properly understood or realised, where precious information was lost when the industry up to 1960 ended and the involved technical people then died; needing to be recovered.

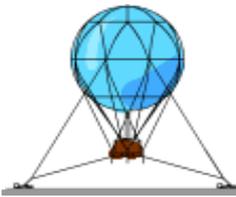
We all have a time to be, where the know-how can be lost again. The author gained his own expertise from working 1981 onwards in the re-emerging airship industry trying to help it become successful, so knows the issues; needing sensible projects, better ways and investment to continue. Who’s ready for it?



Painting by Jo Kotula, retouched from Popular Science, May 1945

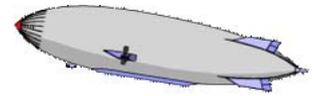
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#### 1. Introduction and General Considerations

Balloons and airships are lighter-than-air (LTA) aircraft. They mainly become and remain airborne through buoyancy (aerostatic lift), resulting mostly from their aerostat and just being in the atmosphere. In fact all bodies in the atmosphere experience the effect, but normally it isn't noticed due to being ineffective compared to body weight. In water, which has much greater density, the effect is noticeable; where some people can float without movement. In air it needs the aerostat to make flotation possible. Their aerostat thus is a flotation aid, normally not used by heavier-than-air (HTA) types.

Aerodynamic lift is the way that heavier-than-air (HTA) aircraft (i.e. aeroplanes and helicopters) achieve flight. The lift is created by forcing an aerodyne, wing (aerofoil) or blade through the atmosphere in such a way that a resulting pressure distribution forms around them with a net effect able to support the aircraft's weight. So, like an aeroplane accelerating along a runway, when airspeed is sufficient the aerodynamic lift developed becomes adequate to overcome its weight, allowing takeoff, then supported essentially by air. Helicopters also develop aerodynamic lift by forcing their rotor blades to circulate with angular velocity that, when fast enough, enables sufficient lift to be generated for them to takeoff and become fully airborne. Therefore, because buoyancy experienced by HTA aircraft is so little, there's a transitional stage from them being almost entirely supported through legs, skids or floats, by the surface they rest on (ground-borne or water-borne) to being airborne when aerodynamic lift combined with any vertical thrust generated is sufficient to support their weight.

The aerostats of airships as aerodynes also develop some aerodynamic lift in a similar way, which can be used to counteract differences between buoyancy and weight (+ or -). Classic airships (those with a cigar shaped aerostat or hull form) generally use up to about 10% aerodynamic lift for this purpose and new so called hybrid types are arranged with a hull form and/or wings for say 40% total lift.

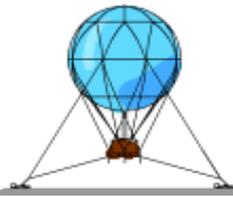
However, by comparison with aerodynamic lift, buoyancy is a gift of nature (fact of physics) that arises, as well as weight, due to gravity. The gift is flotation without power; where, in effect, it provides an opposite ascensional force to weight on all bodies immersed in the atmosphere (not in space) generally in accordance with Archimedes' principal. This states that "a body floating or submerged in a liquid is buoyed up by a force equal to the weight of the liquid displaced". Although the atmosphere is gaseous, it behaves in many ways as a fluid; so, when the weight of the body in the atmosphere is as light as or lighter than the air it displaces, buoyancy is able to cause flotation or, when it exceeds the body's weight, to cause it to rise in the atmosphere (similar to flotation in water). However, the weight of displaced air by most bodies is very small (about 0.7 kgf for people) nowhere near enough to lift them and where people generally don't think about air as having any weight.

In fact weight is a force related under Newton's second law and his universal law of gravitation to the product of a body's overall mass and gravity. Mass is a quantitative term concerning the amount of material with inertia the body has; whereas gravity is an attractive effect between a body with mass and the earth, urging them towards each other – causing acceleration. Archimedes is unlikely to have known the relationship or about gravity, even though its effect is apparent, being somewhat before Newton's time. Even so, just how gravity arises is still a topic for physicists to fully define.

Nonetheless, after LTA aircraft begin to float they instead become airborne without any movement (entirely supported by the atmosphere) and this remains so until their weight once again exceeds the buoyancy experienced, which for LTA gas filled types usually is for their entire operating life. They therefore don't normally land when descending to ground level and so must instead be restrained to prevent them from floating off.

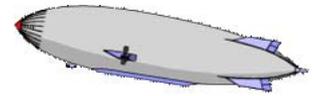
LTA aircraft thus harness gravity for flight while their HTA counterparts use applied force to defy it. A major benefit of this is that LTA aircraft don't normally require energy to become, remain airborne and ascend in the atmosphere, whereas HTA aircraft do.

Nonetheless, for transport between ground points through the air, all aircraft must overcome aerodynamic resistance (drag) to make headway, which generally needs an energy source and where



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the resistance experienced depends on airspeed, air density, aircraft profile and frontal area size. Even so, the atmosphere is rarely still, so transport instead may occur by intelligently riding the air currents without airspeed (so no headway through the air) as free balloons do – thus harnessing the natural energy stirring the atmosphere, as sailors do. Even so, an airship with dirigible capabilities (so powered) is able to ply a directed course, as necessary, against the vagaries of the atmosphere's movement. Depending on ability to support weight with buoyancy, they also still may sail as a drifting raft on a routine basis; providing a reliable least energy method for transport – although unidirectional (UD) types turn and then drift broadside to wind if uncontrolled (due to unstable characteristics).

Now, it should be appreciated that weight and buoyancy are complementary but opposite effects that occur naturally. Buoyancy in the atmosphere can be greater than weight if the main displacement-body (the aerostat) mainly is filled with something of very low density that is LTA or if one could evacuate the air, leaving just a very thin lightweight airtight shell. However, evacuation in the lower atmosphere then either would result in it being crushed by atmospheric pressure or it would be too heavy to float (if the shell was designed to resist atmospheric pressure) so is impractical.

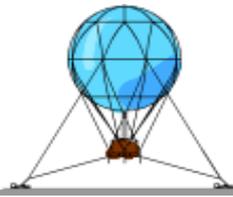
Better to fill it with an LTA material able to push back with equal or greater effect to support the shell (the main reason for using LTA gas). If the LTA gas provides positive differential pressure it also tensions the shell (stabilising it). The shell then may be an envelope of very lightweight thin flexible airtight material (a membrane) that also contains the gas. Such envelopes become stiff through pre-tension this way, able to behave as structural members to carry other things (including payloads), so is a useful non-rigid technique; where the envelope and LTA gas act together as components of the aerostat, which otherwise wouldn't float or be LTA. To better understand the relationships associated with buoyancy see the author's articles<sup>i</sup>, published by the Airship Association<sup>ii</sup> in their journals.

One also should appreciate that normally, when things are weighed in the atmosphere, what one gets is an effective weight rather than a true weight; where the effective weight is the true weight less buoyancy. Because buoyancy normally is small compared to weight it usually is neglected (forgotten about and most often not even realised). That's OK for many things, but for LTA purposes it's not OK!

However, it appears that many LTA people so far haven't fully realised the physics involved, generally accepting formulae and practices contrived that for most purposes yield satisfactory results. The explanation thus is difficult, where the author found no readily available LTA theory after Archimedes based on true weight methods for LTA aircraft – so different to marine engineering practice.

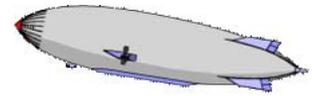
Previously and whether people realised or not, effective weight (as weighed in the atmosphere) generally was used in calculations. It thus appears that air was treated as being weightless and that the LTA gas used to inflate envelopes (was hydrogen, but now usually helium) was treated as a lifting substance (i.e. called the "lifting gas"), since it rises in air (i.e. displays buoyant properties and is difficult to weigh). The notion that LTA gases have lifting properties is wrong, but the methods work on a practical level for static analysis purposes if one also uses an effective value for buoyancy developed (instead of using true buoyancy). It's like using the Celsius scale for degrees of temperature (where an arbitrary zero point and graduation scale was set based on the freezing and boiling temperatures of water). However, it complicates the formulae unnecessarily and causes confusion!

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- i A1: Buoyancy and the Real Reason for Filling Airships with Gas.  
A2: More on Buoyancy - Aerostatics.  
A3: Yet more on Buoyancy (Aerostatics) - Altitude Effects.  
A4: Even more on Buoyancy (Aerostatics) - Pressure and Temperature Effects.  
A5: Still more on Buoyancy - Aerostatic Control.  
A6: Further Buoyancy Matters - Compression & Heat.  
A7: The Concluding Buoyancy Saga - Control.
- ii Website: [www.airship-association.org](http://www.airship-association.org)



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The way buoyancy is applied on bodies in the atmosphere is as an overall upward pressure due to atmospheric pressure. Atmospheric pressure arises due to gravity, attracting the atmosphere's molecules towards the earth's centre. It diminishes from a maximum at the lowest levels of the earth's surface (about  $1.013 \times 10^5 \text{ N/m}^2$ ) to zero at the edge of space. This is logical since the weight of a column of air above any point diminishes as the column's height reduces with increased altitude. Bodies in the atmosphere therefore experience greater atmospheric pressure on their lower surface than they do on their upper surface. Integrated over a body's surface this provides the net upward force that we know as buoyancy. Buoyancy thus is an indirect complementary effect of gravity.

If solid objects were light enough (like a new Aerogel material produced that is LTA) they would float in the atmosphere, as logs do in water. However, such materials unlikely would be called a lifting-solid and would only be useful if they could be fashioned plus have other properties enabling payloads to be carried. Airship methods that use an aerostat filled with an LTA gas currently provide a more effective way to reduce the vessel's overall weight (including the gas) so that it can float with excess lift while also providing strength and shaping to carry other parts and disposable loads.

Airships thus use a large amount of LTA gas to provide very low density volumetric bulk, needed to support flexible envelopes (or gas cells/bags), which in turn displace the quite low density outer air for buoyancy. Since buoyancy is proportional to the volume of air displaced, if one doubles the linear dimensions of the aerostat, then buoyancy increases by a factor of  $2^3 = 8$ . However, the aerostat's weight mainly is proportional to surface area if the LTA gas filling them has very low density (compared to air), so this only increases by a factor of  $2^2 = 4$ . Efficiency as a load carrier therefore improves with greater size. Large size with appreciable inertia (including the LTA gas and the Munk<sup>iii</sup> factor for entrained air causing added mass) also is good to stabilise airships against disturbances, where they don't react to inputs so easily (as for marine vessels).

## 2. Heavy Lift Airships (HLAs)

Although not for heavy lift purposes yet, needing Transport Category certification, new airships have been developed under less stringent categories and successfully operated commercially since the 1980s. They helped the industry to regain competence to a certain extent, advancing the state of the art with introduction of better materials, systems and production methods since the golden years before. The new airships also were developed under strict procedures for quality control to standards agreed by the authorities consistent with the aircraft industry. However, success is limited with few still operating.

Even so, mining, oil, gas and logging industries have interest for a regular way to access remote sites and move heavy loads in and out of them, so there's a commercial need for HLAs to serve the purpose. Depending on design, such airships may provide services as aerial cranes at particular sites/regions or as long range freighters. However, whether types developed should be produced for both purposes perhaps would be pushing the fragile industry at this stage too much.

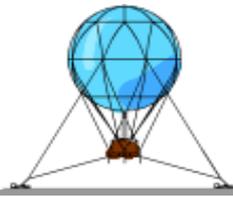
This is evident from CargoLifter AG's failure as a business in 2002 after spending €300 million attempting to realise the goal in Germany, but needing €billions. They tried to develop an enormous classic airship<sup>1</sup> (illustrated right) with a UD cigar profile that essentially was a non-rigid design, but also had a keel. It failed due to the over ambitious objectives, risk and costs when further financial investment was denied.



Indeed, any other complex design like theirs will take €billions to develop due to the issues that must be solved and the aviation authority regulations imposed – equivalent to those for other large aircraft. They also will be at least 10 to 20 years in development before reaching an acceptable certified standard under transport category rules for commercial operations unless a simplified way is adopted.

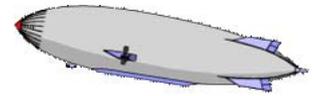
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<sup>iii</sup> Chapter 3 “Aerodynamics” by Prof Ian Cheeseman of book, “Airship Technology”, 2<sup>nd</sup> Ed. pages 34 – 37 about Apparent Mass.



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Rigid Airship Design BV<sup>2</sup> (RAD) in Holland was another company at about the same time as CargoLifter that also failed. They were attempting the development of another classic type, but based on RAD principles from the past (like the *Hindenburg*). Insufficient finance to continue also led to their bankruptcy without producing the design.



SkyHook International Inc, Canada, in cooperation with Boeing<sup>3</sup> is another company that later revealed plans for such developments, but doesn't appear to be proceeding (stalled since about 2010). Their design (right) adopted a classic non-rigid airship approach attempted by Piasecki (the PA-97



Helistat<sup>4</sup>, left) that ended catastrophically<sup>5</sup> in 1986 killing one of its pilots. Resulting from Boeing input, the SkyHook design (initially spherical) perhaps evolved to use a similar cigar shaped aerostat to



enable longer range, so then needed tail surfaces and was rearranged with two sets of propellers. One propeller set was for general movement and position control, while the other was for vertical lift to raise and carry payloads (36.3 tonne over just 320 km). The vertical rotors (4 off) appeared to be based on technology from the CV-22 Osprey<sup>6</sup>. If ever produced it would be very heavy on fuel and thus only good for short range duties. But, in any case, Boeing will need to solve the dynamic structural and balance issues of its configuration, needing substantial investment.

In addition, Hybrid Air Vehicles Ltd<sup>7</sup> (HAV) in the UK has been developing a hybrid airship for heavy payload transport purposes. They started the design as a rather big aircraft for military surveillance purposes at about 6.1 km altitude. Now, airships are not really suitable at that altitude for such transport operations due to reduction in air density (and so air displacement) where, depending on the region (tropical, temperate or arctic) the relative density is about half that for sea level – thus halving the buoyancy capability that otherwise would be possible near ground level (if the gas fill then is increased).



Transport airships therefore should operate with low altitude – say 0.5 to 1 km high. However, since air density is relatively high in the lower atmosphere, aerodynamic drag also is high. For types (like hybrids) using aerodynamic lift instead of buoyancy, since drag rises with angle of attack (necessary to increase aerodynamic lift), they will need greater power. Then there are the further issues of aerial crane or long range freighter to consider. Why bother developing a sophisticated hybrid airship for heavy underslung payload transport purposes that will be inefficient and so expensive, which also compromises stability and control of flight? These perhaps are issues for HAV to answer if they remain in business after the recent deflation incident of their prototype.

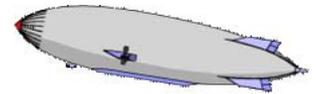
Then there's SkyLifter's<sup>8</sup> development proposal for a completely new type of non-rigid airship that would operate more like a dirigible balloon than a classic airship to consider. It has a lenticular aerostat (so round discus shape instead of a cigar form) to minimise drag and a suspended pod (the systems and crew module) hanging low below, providing pendulum stability. As such it may routinely drift with air currents (as balloons do) without power. Its arrangement also is good for aerial crane purposes (balanced and evenly spreading load without high bending effects) but is not an obvious choice for regular long range freight runs on a specific course. Nonetheless, using air currents intelligently, it is a low energy approach that does have long range long endurance capability and it also has a propeller system able to hold a course (or a station) when necessary. Due to being more like a free balloon system it also is omni-directional (O-D), so doesn't have to face the wind direction and can turn on its vertical axis when undertaking load exchange. Its regular form also simplifies/solves things somewhat at ground level – allowing development in a quite easy, cost effective, quick and safe way.





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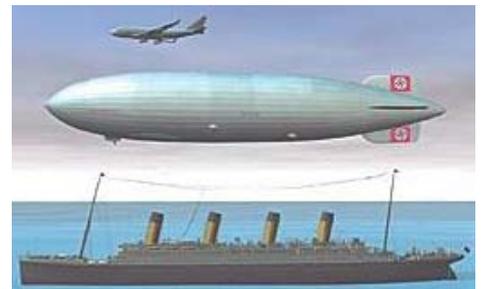
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OK, SkyLifter's design is the author's invention, so if others have a better way let's hear how they intend to reduce time and costs for development. Let's also hear how the technical issues will be solved, including ground arrangements, which need to be in a way acceptable to customers, operators, the aviation authorities and the public at large without further damage to the fragile industry!

Now, from scaling considerations, where airships become more efficient with increased size, and the technology base that has been re-established, HLAs are feasible, although they will require particular design to suit point to point purposes in the isolated locations they often would serve.

Transport category airships able to pick up, carry and set down heavy payloads with pseudo-VTOL hovering flight like helicopters between small sites anywhere of say initially 50 tonne and perhaps later 1000 tonne are considered to be worthy goals for most industrialists purposes. This is beyond the capability possible by HTA aircraft and most other transport vehicles without good infrastructure.

It should be appreciated that the baseline 50 tonne payload airship would be smaller than the world's previous biggest airship – the LZ129 *Hindenburg*<sup>9</sup> (200,000 m<sup>3</sup> displacement and 245 m long), which had a disposable load capacity of 102 tonne, including 65 tonne fuel and 40 crew, but still is a big project that must satisfy Transport Category regulations. Whilst considered to be doable, it therefore needs a careful strategy for development and enough finance for the purpose.



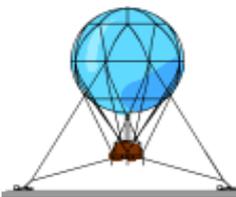
Transport airships thus will be rather large and need a way to counteract excess lift (determined from the difference between buoyancy and basic airship weight) after setting their payload down to prevent them heading dangerously for the upper atmosphere. Load exchange with ballast is known to be a reliable method for this purpose, but needs compatible systems to manage the heavy weights involved. There perhaps also are several other ways that may be used in the future instead to fully counteract excess lift; but such capability shouldn't be offered at the moment due to associated development risks and the fragile state of the industry worldwide, which first needs to gear up before attempting such a difficult exercise.

It should be recognised and is an industry norm that new projects shouldn't take on more than 2 new technology developments at the same time (i.e. keep it simple) since, by doing so, failure generally follows. Also, it's difficult because buoyancy doesn't just disappear as aerodynamic lift does when aeroplanes land, so there generally is no transition from being airborne to being at rest on the ground. Hence, with a baseline of 50 tonne to be set down, if it was released without a way to balance things then the airship would head for the heavens in an unstoppable way driven by the then 50 tonne excess lift – destroying itself catastrophically as a result. Any solution taken up therefore must be reliable.

Solutions may arise from a combination of things, including:

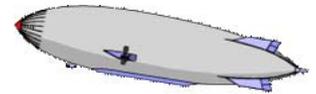
- Load exchange
- LTA gas release
- Aerodynamic Lift
- Vertical thrust
- Handling lines
- Weight or buoyancy control

However, bearing in mind that the *Hindenburg* was the result of over 30 years development effort, for an airship industry that currently is small and the finance needed to develop a transport category airship is substantial, it also needs a simplified approach in order to achieve the goal within a reasonable period and acceptable cost for investors. Some things therefore must change and perhaps be not developed until there's an airship type demonstrating suitability for the job that can be scaled up. There may be significant historical knowledge, but seasoned engineers with inventiveness and know-how in airship technology are scarce. Moreover, the HTA industry, although it largely has the means,



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so far has demonstrated little will or capability to develop such airships. It also has been found by the author that they don't have the mindset or knowledge for them – so lacking capability. The necessary ground infrastructure and operating businesses for them also is somewhat lacking! A strategy from the ground up thus is needed that avoids solving unnecessary multiple risk issues at the same time.

#### 3. Load Exchange

Ballast is a traditional and reliable way used for load exchange purposes since LTA gas filled types took to the skies (Charles, 1783); where, in order to pick up a payload, an equal weight of ballast is set down or conversely, in order to put the payload back on the ground, an equal weight of ballast is taken up, thereby maintaining equilibrium (balance) of the opposing forces – overall airship weight against buoyancy. It's an easy method to use, but some people are steadfastly against it (causing problems).

Now, it's clearly not convenient to exchange weight in this way (a nuisance), where ballast must be managed at each site visited, perhaps resulting in pits at one end and mounds at the other end of the supply route. However, in the absence of a better way to access small remote sites in isolated places anywhere without any infrastructure to support things or otherwise to move desired seriously heavy payloads (more than helicopters can manage) in and out of them, it transforms an impossible situation into something that is doable – so is not stupid. Also, if undertaken intelligently, useful back-load materials may instead be used as ballast.

If people who decry the method have a better way to fulfil the purposes then let's see their wondrous proposal. The author is in a sure position here, since if anything existed it already would be doing the job. Even so, with so much technology in our world today, there are many outspoken people in important positions (often with military interests) fixed on HTA ways who seem to think that because airships need ballast they aren't worth considering, but don't have viable alternative reliable aircraft to offer that would satisfy the need without load exchange in a cost effective or quick way. Such opposition unnecessarily impedes progress and is destructive – causing upset for the industry!

Ballast exchange thus should be seen as an inevitable need, at least in the short term, known to be readily doable from past practices – although will need mechanical handling methods to enable the objectives for such payloads. It at least enables HLAs to begin, which then may be put into service to find out if they really can fulfil the objectives effectively. They then may be further developed to improve efficiency and do more difficult things – perhaps without load exchange.

Water is considered to be one of the most easily managed ballast materials, since it can be quickly pumped using existing systems such as those installed in fire-fighter vehicles and with their standardised equipment. It also may be amassed in simple tanks or ponds. It certainly isn't worse than the situation for large airliners such as the Boeing 747-400 series, which have a fuel capacity of about 185 tonne – regularly dumped straight into the atmosphere each flight for many years, although usually after burning it. By comparison, managing and draining off 50 tonne of water (already achieved by the CL75 AirCrane<sup>10</sup>) is a no-brainer situation, although it may need to be treated first.

Alternatively, there are a number of cheap and readily available ballast materials that may be used instead, such as: sand, gravel, rubble, earth, rocks or perhaps snow. The ballast also could be prepared materials such as: concrete, bricks, timber, scrapped compressed vehicles, cement. In fact, practically anything with good weight! These would need to be amassed for pickup or disposed after set down from the airship. The airship also would need means for take up and to put the ballast down in quick balanced ways. If organised intelligently, the ballast materials often would be useful for many further purposes – so not just dumped, instead enabling spin-off industries similar to waste recycling.

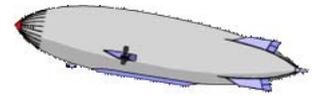
#### 4. LTA Gas Release

Perhaps an assured way to redress the imbalance issue would be to rapidly dump sufficient LTA gas, thereby reducing the displacement – destroying excess lift. The main problem here is that, without a method to decant the LTA gas into another container for later re-use, it's a single mission approach that wastes the precious commodity – where helium (used these days instead of hydrogen to avoid



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igniting it) is a rare earth gas (although not rare in the universe) difficult to obtain and keep. As a result, helium is expensive (in 2015<sup>iv</sup> about €15 per m<sup>3</sup>). Roughly, taking approx 1 kgf/m<sup>3</sup> displacement, the cost to get rid of 50 tonnef excess lift this way today thus would be near €1 million. Ouch!

Now, under emergency circumstances, to keep the airship on the ground (especially while people evacuate), the aviation authorities require a way for quick and substantial reduction of buoyancy. Usually, this is a rip method that slits the aerostat's envelope over a long length, allowing all of the LTA gas to quickly vent. However, the authorities don't require a destructive method; where one may instead vent sufficient gas in an assured way to satisfy the need, but that doesn't damage the envelope (as it does with current practices, evident from the way the HAV prototype recently was lost). This then also may be a safety system to recover the situation should the payload be dropped inadvertently.

All it perhaps needs are secondary restraint lines and/or an additional upper envelope chamber (like a ballonet) to contain the LTA gas that would be vented plus means allowing it to discharge rapidly but safely. This could be via a set of upper reinforced apertures or valves and may be fan assisted. The question then is, how one minimises the cost for dumping so much LTA gas?

Well, the thing that springs to most bean counters' minds is to use hydrogen instead of helium. But do they have their thinking caps on when making such a choice, because it would be fully against current aviation authority rules, which don't allow it for such airships. Insurers also will find it difficult to accept, quite apart from flying in the face of public opinion fuelled by media images of the *Hindenburg* inferno and concerns for safety. It's a difficult call that could cost far more than the helium to otherwise vent; where more than just the airship asset could be lost. However, it's possible to mitigate the risk, so should be considered – just as hot-air burners for thermal balloons are, and where many gas balloons are filled with hydrogen.

Although difficult, a way to decant the LTA gas is preferable for load exchange. If it was released or pumped into tethered nursery balloons instead, then it may be captured for subsequent use or recovery using ground based systems. Ideas for this deserve further consideration.

Use of hot air or steam also may be considered, since these may be dumped at little cost. However, see the considerations in section 8, where use of these mediums involves further issues to solve.

## 5. Aerodynamic Lift

Aerodynamic lift generally is only available at a price for the fuel necessary to maintain airspeed, unless gliding methods are adopted. In fact, a proposal for an aircraft that combines LTA and HTA methods with gliding flight does exist (referred to as a "Fuel-less Gravity Powered Flight" aircraft<sup>11</sup>).

However, the physics and practicality of the arrangement are questionable – also difficult to demonstrate in a real way at a small affordable size. Nonetheless, as an intellectual exercise, the design incorporates interesting concepts that may be worth developing, partly considered in section 8 below.



High flying airliners on long distance routes take advantage of the thin atmosphere at the altitude they cruise (about 10.5 km), which reduces drag and enables high airspeed (needed to maintain lift in the thin air) making them efficient carriers. However, this only works for payloads contained within their slim form (also necessary to minimise drag), so doesn't work for outsized payloads.

Outsized payloads currently can only be airlifted if they're broken down into smaller pieces able to be contained or if they're carried externally. Even so, it would need a special type of aircraft like a helicopter to enable VTOL operations in and out of small remote sites without infrastructure. If one accepts clearing spaces and preparing landing strips for aircraft to land & takeoff then UD HTA or hybrid types would be options to consider.

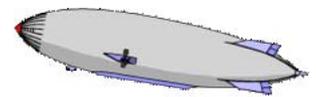
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<sup>iv</sup> Telephone enquiry with M. Bohn, Director of Engineering, SIXQ GmbH - [www.sixq.de](http://www.sixq.de)



# LTA Solutions

## Lighter-than-air Technology



### Buoyancy and Load Exchange for Heavy Lift Airships

In addition to UD ‘lifting body’ hybrid airships, new winged types similar to the Megalifter<sup>12</sup> (1970s) such as the Dynalifter<sup>13</sup> were produced & tested. Now, as heavy lift LTA transporters, all hybrids should operate in the lower atmosphere for best buoyancy; otherwise there’s little point being hybrid. However, by using an aerostat, they’re bound to be rather big, so will have high frontal and surface areas causing high drag in the relatively dense air and thus be slow compared to equivalent HTA types – although perhaps a little quicker than classic airships (depending on installed power).

Low speed aerodynamic characteristics thus will apply and so wings either will be quite long (like sailplanes) or take a delta form to improve overall aerodynamic lift in conjunction with improved body lift from the interaction that results. However, their overall weight must be low for buoyancy to overcome it. The wings and appendages (tail surfaces, gondola, etc) therefore can’t afford the weight of structure associated with high flying jet airliners, so will be rather fragile by comparison. Then, in often close proximity to the ground and with variable conditions (where they likely will behave in similar ways to classic UD airships that must face the wind) it wouldn’t be long before calamity strikes; Murphy’s Law<sup>14</sup>! Indeed, classic airships have a long history of incidents in this respect and winged hybrids would be more vulnerable – soon losing their appendages. Better to make them removable. The arrangements therefore would need a lot more consideration to safely manage necessary ground handling and maintenance work involving significant infrastructure.



Complexity also adds cost and the scaling laws for LTA aircraft require them to be big from the start, so building experimental types often is a Darwinian exercise of trial and error at great expense to evolve something on a random basis that may survive, rather than a strategy for development with good design practice. Lifting body types perhaps will fare better, since the fragile appendages are less obvious (although still there, e.g. tail surfaces). The concept promoted by HAV for hover skirts with reversible limpet action also may help to manage them (if it works reliably). The question then is whether the additional complexity for say 40% aerodynamic lift in forward flight is worthwhile?

If the infrastructure (an airport) to accommodate them is provided then perhaps yes, but they then will have to compete with other types that don’t need so much infrastructure (if any) and other vehicles that also take advantage of the infrastructure developed; where the ground systems brought in to build the airport then could use it along with anyone else.

One also has to question the logic of the considerable expense to develop such complex UD airships if the aerodynamic capability then isn’t used fully for heavy payloads, such as aerial crane operation, the only way possible at small remote sites without infrastructure or a large clearing? Fundamentally, aerodynamic lift needs airspeed, but airspeed is problematic to both develop (for necessary lift) or if it occurs from variable winds buffeting them when trying to hold an in-flight position over the payload pickup and set-down sites. UD Hybrids may be able to undertake limited duties this way, but weren’t designed to efficiently perform them, so not the best way.

This thus returns to the question of internal or external payload? Clearly, if the payload is external and the airship needs airspeed to develop aerodynamic lift for its carriage, it will cause additional drag (needing greater power to maintain adequate airspeed) making things difficult. Being in the airflow it also may behave badly as an aerodynamic body, perhaps needing ways to stabilise it, and will affect the normal airflow around the airship – perhaps also affecting its behaviour and needing further stability/control methods. But balloons don’t suffer from drag or stability issues due to zero airspeed!

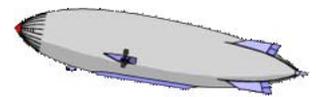
An example of an HTA aircraft carrying a large external payload is the Shuttle Carrier Aircraft<sup>15</sup> (SCA), an extensively modified Boeing 747 airliner formerly used to transport Space Shuttles. Some of the modifications may be apparent, where a method to fix the Shuttle in a particular position (to avoid imbalance) that also prevents movement (fixing alignment) was necessary. Another modification is the addition of vertical fins at the end of the horizontal tail planes,





# LTA Solutions

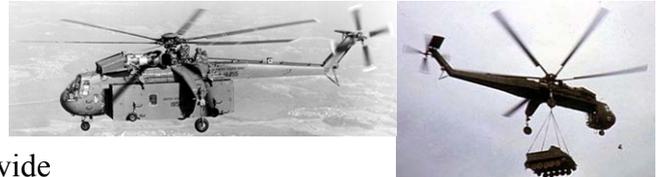
## Lighter-than-air Technology



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necessary due to changes in aircraft aerodynamic behaviour when carrying the Shuttle, which masks the main fin. Further modifications would have included structural reinforcement to distribute Shuttle weight and aerodynamic loads. However, the Shuttle perhaps was an easy exercise due to its own good aerodynamic shaping. This would not normally be the case for most payloads. High airspeed also exacerbates stability issues. The arrangement also needs a lot of infrastructure to manage things.

Another example is the Sikorsky CH-54 Skycrane<sup>16</sup>, but only able to carry a payload of just 9 tonne at a cruising airspeed of 200 km/h and range of 370 km.

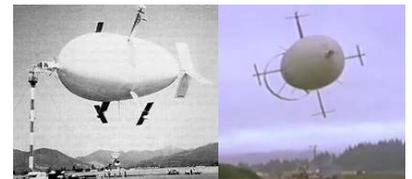


The first picture shows how it normally transports payloads, nested and fixed behind the cockpit to provide

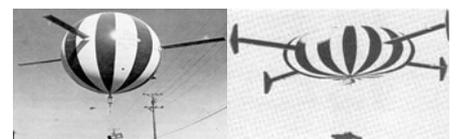
streamlining<sup>17</sup>. The second illustration shows it with a suspended payload (an armoured personnel carrier). However, in this configuration airspeed and range are somewhat limited.

UD Hybrids need to use similar practices, but can't easily get lift as O-D helicopters to raise or deploy heavy payloads while holding an overhead position, so it would be back to traditional load exchange methods with ballast for the purpose. It makes no sense, where they're designed as aerodynes needing to carry payloads internally. They thus would be better as freighters rather than aerial cranes and need ground infrastructure to land, load, unload, and takeoff from customer sites.

Special airships with rotary wing methods to develop aerodynamic lift, such as the Cyclocrane<sup>18</sup> (1980s), also were designed & tested. This was arranged like a huge cycloidal propeller system. A prototype was built that demonstrated capability for aerial crane operations. However, it was a contraption with vulnerable appendages (like the winged hybrids) and rather difficult to manage at ground level. It also had poor failsafe characteristics, where failure of a single item easily would have lead to catastrophic loss of the whole airship for several reasons. A failure modes and effects analysis (FMEA) normally undertaken for new aircraft developments would have found many critical aspects for Murphy to use.



Variants such as Aerocrane<sup>19</sup> that instead rotated on a vertical axis also were investigated<sup>20</sup> but came to nought, perhaps for similar reasons. A major problem of these rotary types stems from rotating the aerostat as well as the wing systems, because this then develops

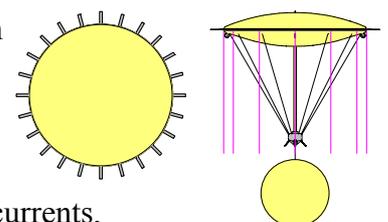


Magnus aerodynamic lift like a swerving football, which makes it difficult to manage in variable winds. It also makes it difficult for a pilot if the cockpit is poorly located or precariously suspended.

In fact, a prototype Magnus effect airship<sup>21</sup> also was produced and promoted for heavy lift transportation, proving the Darwinian approach that people will try anything before using logic to decide whether it makes sense. As usual, there's no magic or free meal when trying to develop aerodynamic lift, which needs airspeed and thus a source of power for motivation to achieve this, but where drag is high for spheres. It perhaps was good as a university student project, which it was, to learn about basic principles.



The author also indulged in a special type with his AeroRaft<sup>v</sup> proposal; an O-D lenticular aerostat arrangement with an independent equatorial Rotordyne for substantial uniform aerodynamic lift and thrusters to make it dirigible for heavy lift plus control purposes. It was arranged to keep things simple, basically designed as a free balloon with low central under-slung weight to remain upright and be able to routinely drift in air currents,

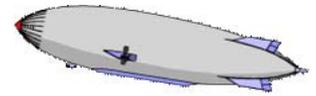


<sup>v</sup> Paper, "AeroRaft – The Alternative Aircraft for Heavy Lift Transport or Crane Use", Charles R Luffman, AIAA's 3<sup>rd</sup> Aviation Technology Integration and Operations (ATIO) Technical Forum, Denver, Colorado, USA, 17 – 19 November 2003, ISBN 1-56347-642-8.



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but also able when needed to precisely control movement and satisfy people's desire for an aircraft with serious heavy lift capability that obviates simultaneous need for load exchange. However, it remains as an intellectual exercise without development through lack of interest in the arrangement.

The author recognises that the Rotordyne, intended to operate on its own as an annular fan around the aerostat, is a high development risk item. Even so, the dirigible balloon arrangement isn't. This in fact can be produced and operated as derived proposals for SkyLifter<sup>vi</sup> show, without the aerodynamic lift augmentation system, which is what the rotordyne would provide if later developed and fitted.

Fundamentally, any aerodynamic lift augmentation system adopted must be effective to reliably counteract excess lift or weight in a steady way as heavy payloads are picked up or set down. The baseline objective is for at least 50 tonne aerodynamic lift to be developed up or down, which isn't easy (beyond helicopter ability). It also mustn't upset balance and be able to tolerate failures (including power failure). These objectives are very difficult for UD aircraft without forward airspeed.

However, the author's rotordyne was designed to develop such aerodynamic lift like a helicopter but both directly from the rotating fan blades and indirectly from the interactive effect of radial airflow induced over the aerostat's upper or lower surfaces, which then separates from the aerostat after passing through the Rotordyne. This causes low static pressure one side and high static pressure on the other side of the aerostat. The Rotordyne blades thus may be short stub wings and be effectively low speed, avoiding strong vertical drafts and high noise (unlike helicopter rotors).

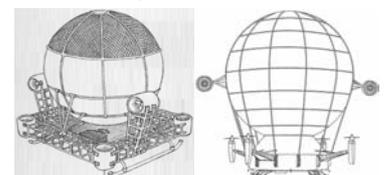
The benefit of the arrangement is that it may be tried and developed on a ground rig before using it on the aircraft. The aircraft also may be developed separately without so much risk, but will need load exchange methods until fitted with the Rotordyne.

**Postscript note:** Since this document's last publication (Rev A, 2015) another possibility to cause such aerodynamic lift without airspeed came to the author's attention, which perhaps has lower risk and an easier way for integration (instead of the Rotordyne) plus better failsafe characteristics; proving the adage that "there's always another way to skin the cat". This alternative is the FanWing<sup>vii</sup> method, which is a distributed-propulsion arrangement causing a trapped vortex inside a rotor casing with a cross-flow fan partially inside. This could be installed in sections around the aerostat's equator in a similar way and with similar effect to the Rotordyne, but replacing it.

The benefit is that the FanWing arrangement already has been developed and used successfully for aircraft flight, so is proven technology with little to go wrong, particularly as its fan blades (like a water paddle) are fixed. Installed in sections, it then also introduces desirable failsafe qualities for safe operation and ability to vary lift around the aerostat for other purposes. There thus are at least 2 ways to gain sufficient aero-lift (+ or -) for heavy payload lift without aircraft airspeed or load exchange.

## 6. Vertical Thrust

The Rocketdyne J-2 unit<sup>22</sup> produces about 102 tonne thrust to propel the third stage of a Saturn 5 rocket into space. Short lasting and rapid use of fuel, it's the sort of solution that the originator of the Skyhook concept<sup>23</sup> (shown below right) favoured, which had the thrust capacity needed. Actually, on his original sketches the concept included four vertical gas turbine shrouded fan units with an inadequately sized spherical gas balloon ostensibly like the CL75 AirCrane balloon (where his idea stemmed from) strapped to a frame with them to blast payloads skyward, similar to a VTOL flying test bedstead. The author is happy to reveal this charlatan's copycat methods, who never paid for work commissioned, but used designs provided for a patent application (International No.: PCT/CA2007/001505).



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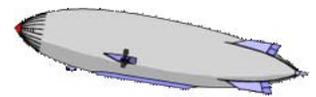
vi Briefing, "An introduction to Luffship Projects for SkyLifter", available from the below website,

vii Website: <http://www.fanwing.com>



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Boeing subsequently did a creditable job to organise things a little better (shown in section 2) now more like a classic airship, although in doing so lost O-D capability and increased complexity. Nonetheless, their stated capability for payloads of just 36.3 tonne up to 320 km merely serves to exemplify the gas guzzling cost and short range qualities of such methods; not as good as helicopters and a lot more expensive/vulnerable! And yes, the Skyhook originator was told it would be this way.

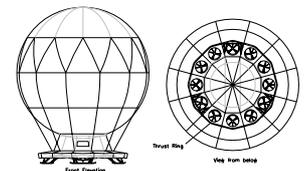
The use of force is a wasteful high energy approach that can go rapidly wrong without due attention to detail, which basically is what happened with Piasecki's Helistat. It's certainly possible, but isn't an especially sympathetic way for LTA aircraft, which need a least energy approach that works in harmony with rather than despite things. After all, airships are slow moving soft bodied giants unlike fast hard hitting jets, where it's better (more efficient) to accelerate a large quantity of air gently instead of a small quantity rapidly to cause the momentum change necessary for the purpose.

An example of such a low energy approach is the ship elevator<sup>24</sup> serving the Eberswalde Gap located at Niederfinow, built 1927 to 1934 and about one hour by car 55 km northeast of Berlin in Germany. It raises or lowers fully loaded barges and ships still afloat in a water tub between the different levels of an old channel of the river Oder at 2 m above sea level to the Havel-Oder canal in the "gap" at 36 m above sea level, linking Berlin with the Polish Baltic city port of Szczecin. The water filled tub weighs about 4300 tonnef and it can accommodate ships up to 1000 tonnef. Huge counter weights balance the lift, which is run by just 4 quite small (75 hp) electric motors. That's impressive efficiency!



So, people who want to raise seriously heavy payloads directly with thrust as an aerial crane should think about ways to increase overall effectiveness, redundancy and compatibility (to maximise thrust but minimise the effect of individual failures and propeller efflux velocity).

They also should consider a low weight centralised efficient power system that minimises fuel use instead (bearing in mind that overall power system weight includes fuel that must be carried), perhaps as the Skyhook originator was advised with the rejected proposal right.



Now, thrust to raise or lower the payload (normally short term) is one thing but thrust to continuously support it during transport is another story that severely limits endurance and so range. A way to convert from vertical thrust to aerodynamic lift (like the Hybrid AeroSystems Inc<sup>25</sup> proposal, 1998) and/or preferably buoyancy for continued support would be better for long range transport, although the vertical thrust system then is just parasitic weight. Vertical thrust therefore will always be an inefficient way for transport that is short on range but high in cost, although may be used as a part of the overall airship if desired (not necessarily 100%). Thrust thus is useful and used to manage minor imbalance aspects.



## 7. Handling Lines

LTA aircraft normally have various lines used for ground handling, safety and restraint. Such lines also may be used for towing and payload management purposes from the ground instead of or with other pure aerial methods as an airship on its own, reducing need for load exchange.

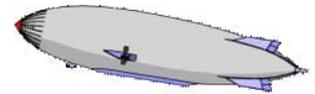
For example, the AirCrane was designed for aerial towing by helicopters<sup>26</sup>; where towing line tension from them at higher altitude helped to support overall weight (including the payload), maintaining a stable situation. AirCrane weight thus would have been greater than buoyancy, so would descend to the ground if released – although at a parachute drop rate. Such a technique also could be used to supplement airship operations, for example to help pick up heavy payloads and then get underway; after which and with airspeed, airship methods then could take over without tow line support. It's similar in principle to tug boats assisting large cargo ships to berth or get underway.





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Some of the activities in section 8 (next) may take a fair amount of time before they become effective enough, but the weather can change quickly, which could make things difficult if undertaking payload pickup or set down at the time – when restraint lines could help to steady the airship and or payload. This would need some ground infrastructure (anchors, winches or capstans and so forth) to support mechanical handling methods; basically similar to ship berthing and crane practices.

A sea anchor line also would be useful to help steady loading operations over water or to use for standoff purposes while waiting for conditions to settle, as ships do before entering a harbour if conditions are bad. Such techniques were used by airship pilots during WWI on coastal patrol, enabling them to stay out at sea for long periods – lurking until ready for action.

#### 8. Weight or Buoyancy Control

It should be appreciated from the introduction (section 1) that true weight and buoyancy are complementary, where an increase in airship weight or reduction of buoyancy from the atmosphere both cause imbalance between them with resultant downward force tending to make the airship sink. Similarly, an increase in buoyancy from the atmosphere or reduction of airship weight both cause similar imbalance between them but with resultant upward force tending to make the airship rise.

When the opposing forces balance there's a state of equilibrium, but imbalance either results in heaviness (tending to make the airship sink) or lightness (tending to make the airship rise). Of course, whether the airship does sink or rise also depends on other external forces that may be applied at the same time (i.e. positive or negative aerodynamic lift and/or vertical thrust and/or tension from lines).

Now, LTA gas release affects both airship true weight and buoyancy; where there's loss of mass and therefore gas weight loss as it vents. However and more importantly, depending on type:

1. those with a fixed geometry aerostat
  - a. using variable geometry ballonets
  - b. using variable geometry internal gas cells
2. those with a variable geometry aerostat hull-form

either compensating air to maintain aerostat form is taken in (type 1) increasing weight or, due to aerostat hull-form change (type 2) the displacement reduces, reducing buoyancy. The net effect is excess weight equal to the product of the volume of air (taken to be the same as the LTA gas volume released) and the difference in density between the air and the LTA gas under gravity.

The result thus is the same, where the effect is an increase in static heaviness tending to make the airship sink. Therefore, whether one sees the heaviness gain as a loss of buoyancy or increase of airship weight is unimportant, because the result is the same. It also will be found that the result is the same for an increase in static lightness tending to make the airship rise; so, whether one sees a lightness gain as a loss of airship weight or increase of buoyancy also is unimportant. Indeed, one can also say that increased heaviness is reduced lightness and vice versa, so are relative effects.

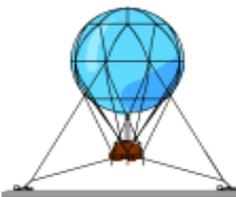
Now, the LTA gas and atmospheric air are compressible substances that behave in accordance with the gas laws. With constant mass (the quantity of LTA gas or the displacement) volume or density is proportional to temperature and pressure.

$$\text{i.e.:} \quad p_1 \cdot V_1 / T_1 = p_2 \cdot V_2 / T_2 \quad \text{So: } V_2 = (p_1 / p_2) \cdot (T_2 / T_1) \cdot V_1 \quad (1)$$

$$\text{or:} \quad p_1 / (T_1 \cdot \rho_1) = p_2 / (T_2 \cdot \rho_2) \quad \text{So: } \rho_2 = (p_2 / p_1) \cdot (T_1 / T_2) \cdot \rho_1 \quad (2)$$

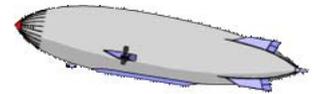
Where:

- p = pressure
- T = Temperature
- V = Volume
- ρ = density
- 1 = the original condition (before change)
- 2 = the later condition (after change)



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The thing to note is that the LTA gas and the displaced air generally act independently of each other as separated mediums by the aerostat's envelope (non-rigids) or outer cover (rigids). These provide some insulation or shielding from sunlight (warming) and other things such as water evaporating (taking latent heat, cooling). Due to thermal inertia, there thus is always lag between temperature changes of the outside air and the LTA gas (and/or air) in the aerostat, causing thermal imbalance.

If atmospheric temperature drops (as it does when a cold front passes) then buoyancy rapidly increases due to thermal imbalance (superheat), since the aerostat's contained gaseous substances are shielded and can't react to the change so quickly. The increase in buoyancy that occurs should be evident from equation (2), where air density increases under constant pressure. While the airship's volume is fixed, the displacement (mass of air) increases due to increased air density, providing additional buoyancy. Naturally, buoyancy would reduce in a similar way if the atmosphere's temperature suddenly increases.

Atmospheric change is practically impossible to control, so can be a nuisance if it varies a lot. Fortunately though and at relatively slow airspeeds compared with HTA aircraft, things don't change so quickly – allowing adjustments to be made to counteract the situation. Aerodynamic lift and vertical thrust also can be readily used to counteract such imbalance between weight and buoyancy.

Nonetheless, thermal imbalance also may be deliberate through use of a means to heat the air and/or LTA gas contained, causing superheat. From equation (1) it can be seen that, for a gaseous substance free to expand with constant pressure, volume increases due to superheat. However, the aerostat's envelope has fixed max volume. So, unless venting occurs at a compatible rate to the expansion, super-pressure will rise. Normally, air from the aerostat's ballonnet would be vented to prevent this, thus reducing contained mass and therefore weight, causing lightness that tends to make the airship rise.

This basically is how hot air balloons and thermal airships work, which don't bother with LTA gases (just charged with air instead). Then, when heated by the burner, some of the air discharges out through the open lower aperture – reducing overall mass and so contained air weight.

From equation (2) it can be seen that under this condition the density of the remaining air and/or LTA gas in the aerostat drops. For calculation purposes and taking the starting position for a thermal airship to be already filled with hot air, if one knows its density and volume then its overall weight may be calculated and set against the buoyancy from atmospheric displacement to determine the resulting lift in the same way that one may do if the aerostat instead was filled with an LTA gas.

Now, whether one uses heat depends on the application and circumstances (what's available). Data at sea level for the main LTA gases possible is given in the following table<sup>27</sup>:

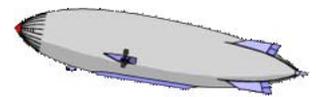
Gas	Symbol	Temp (°C)	Density (kg/m <sup>3</sup> )	Effectiveness %	Safety	Cost
Vacuum	-	-	0	100	Bad	High
Hydrogen	H <sub>2</sub>	15	0.084	93	Bad	Fair
Helium	He	15	0.169	86	V Good	High
Steam	H <sub>2</sub> O	100	0.587	52	Good	V Low
Methane	CH <sub>4</sub>	15	0.676	45	Bad	Low
Ammonia	NH <sub>3</sub>	15	0.718	41	Fair	Low
Hot Air	-	110	0.921	25	Good	V Low
		(Avg)	(Avg)			
Air	-	15	1.225	0	Best	Free

- A **vacuum** fundamentally is unrealistic, but included for completeness as an ideal goal.
- **Hydrogen** is the lightest gas, but generally isn't accepted by the authorities due to its flammability. Its use requires an exception of civil regulations to be granted (don't bank on it!).
- **Helium** is the next lightest gas. It's chemically safe (inert), but costly and may asphyxiate.



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### Buoyancy and Load Exchange for Heavy Lift Airships

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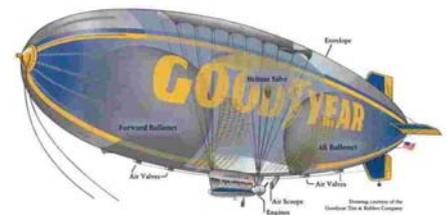
- **Steam** is quite light, not caustic or poisonous and is cheap plus odour-free. It can't ignite and is easily produced. However, it may scold and continuously condenses (needs re-boiling). It also requires a boiler for the initial large volume fill, which may be ground based.
- **Methane** has mediocre density (less than air), but easily ignites, as for hydrogen. Its use in aerostats thus would require a similar exception to the regulations.
- **Ammonia** is cheap, non-explosive & easy to supply, but has even more mediocre density (still less than air), is toxic, corrosive & malodorous.
- **Hot air** has density just a little lower than cold air. However, heating aids control of the contained air's weight when higher temperature causes higher density cold air to be expelled due to resulting expansion or imbibed when the contained air cools. Whilst readily available, it's an inefficient method that must be continually reheated with fierce burners, so also dangerous.
- **Air** at sea level is only included for baseline purposes.

HLAs need the best effectiveness and efficiency. Since heating air in the aerostat takes a long time to become effective, then causing degradation of material properties, and isn't efficient for heavy lift purposes (needing a significantly bigger aerostat) it isn't a good choice for them. Steam would be a better choice, but involves development risk (not used for airships before). Since hydrogen isn't permitted, helium thus is the best choice.

Heat perhaps still could be used to cause helium expansion (reducing density), needing a bigger ballonet, but would be a lot of fuss and bother for little gained – probably not enough to reduce weight sufficiently for the baseline 50 tonne payload to be raised and difficult to cool quickly when setting the payload down. But, in any case it would be weight of air expelled to raise the payload (when heat would be used to increase helium volume to maintain envelope super-pressure) and then weight of air taken in to subsequently set it down that made it work, which also would take significant time to effect when the airship must hold its in-flight position against changeable weather.

Under steady soaked conditions both the LTA gas and outside air may have the same temperature, but absolute pressure usually is different; where the LTA gas pressure normally is increased a little above atmospheric pressure to further stiffen a non-rigid airship aerostat's envelope, so has super-pressure. The way this normally is achieved is with an internal air cell called a ballonet.

Ballonets are designed to contain air taken in without becoming full, where the ballonet membrane is only a very light flexible barrier to prevent mixing, generally rising or falling to accommodate the quantity of air taken into the envelope. This air often is taken in using a fan or blower, used to establish and maintain envelope super-pressure, although it also may be from a direct ram-air source – either in the airflow around the aerostat or behind a propeller. Large automatic air pressure relief valves then allow air to vent – controlling the super-pressure to maintain a constant value.



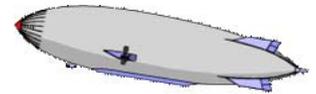
The super-pressure therefore compresses the air and LTA gas in the aerostat a little, increasing density and stretching the envelope a bit (increasing volume). So, with added mass (the air forced in to overfill the aerostat's envelope) weight increases a little. Depending on envelope material stiffness (ability to stretch) displacement and so buoyancy also increases a little. These are small effects (often neglected), but the net effect normally is increased heaviness tending to make the airship sink.

Taking this method a stage further has lead some people to think there's another way for weight (or buoyancy) control by raising super-pressure deliberately to further compress the contained LTA gas; thus enabling a greater quantity of air to be imbibed – increasing overall airship mass and thus weight (just as submarines do with water to sink). Then, if the airship needs to become lighter, air may be vented instead. However, if super-pressure is raised too much it would quickly lead to catastrophe through bursting the envelope – so needs additional pressure vessels designed to suit the purpose.



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The shell stress of a cylindrical pressure vessel (which cigar form envelopes mainly are) is proportional to the product of differential pressure and shell radius divided by shell thickness. The way weight control thus is thought to work is not by pressurising the envelope but by charging additional cylindrical chambers installed, either transferring the LTA gas or the ballonet air into them at high pressure, so that additional weight of air can be taken onboard. These chambers (probably tubular) therefore would have relatively low shell radius and good thickness. They also would be made with high stiffness, high tensile strength materials that are tough (don't suffer from knocks or scratches easily) that can sustain high stress without any likelihood of creep rupture. That's the concept!

Indeed, companies like VariaLift Airships<sup>28</sup> and Aeros have set up to develop types that use compressed gas or air methods. However, airship development for a new company is a risky business in its own right without the added risk of a new system development to contend with that has never before been undertaken to such an extent for LTA operations.



It's certainly interesting, particularly for SkyLifter, whose O-D lenticular types have an aerostat configuration with a relatively small diameter equatorial second chamber (a torus tube, like a bicycle wheel tyre's tube, as a chassis to maintain aerostat profile) designed to accommodate high pressure. Indeed, one of the reasons for this configuration was to enable investigation of air compression methods for weight control, but without parasitic weight from additional pressure vessels otherwise needed for such a system. The intention therefore was to first develop the new type and demonstrate heavy lift transport/crane methods with less to go wrong; since, if the basic design isn't good enough, then a gas compression system to vary weight would be superfluous.

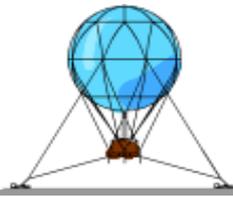
The idea to compress the LTA gas as a lifting substance stem from false reasoning to reduce buoyancy, where air imbibed as a consequence to maintain envelope form instead increases weight (similar to submarines taking water in to sink) later vented, reducing weight. Sure, the effect is equivalent to buoyancy loss or gain, but only to the extent possible with the gas fill charge contained (assuming it could all be compressed). Compressing air taken in instead of the LTA gas therefore is a more direct and unlimited way to proceed, easier to do with existing equipment (designed to pump air) leaving normal airship practices for LTA gas management unchanged.

Depending on how far one goes with compression methods (i.e. liquefaction or not) some of the issues to consider are:

- LTA gas compression is difficult and involves heavy plant (parasitic weight).
- Gas cylinders usually are very heavy thick walled steel vessels with high safety factors for robustness against incidental knocks, making them heavier than the gas contained!
- It takes time to compress enough gas before becoming effective.
- A means to dissipate heat (radiators) is likely (more parasitic weight).
- To liquefy may need serious refrigeration (further parasitic weight).
- There is danger from vessel rupture (for whatever reason – e.g. bullets).

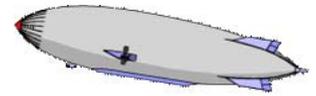
However, whether it will be possible to develop a system without too much parasitic weight that works quickly enough to compensate sufficiently for putting a payload down without delay is unlikely, since there are many aspects to consider and it needs specialist input. Some things that need to be considered are: cost, parasitic system weight added that must be carried, possible cooling needs, power, safety and so forth. It therefore doesn't look like a sensible way to adopt!

**Author's Rev A Note:** Until recently and in order to address the concept (under pressure from opponents of load exchange and because of advocates promoting such technology) a position to see if development of a system to at least partially compensate for payload weight set down using such compression methods was worthwhile, where the text originally (2012) was written with an open mind to the possibility. However, from subsequent 2014 analysis (written up in articles A5, A6 and A7 – see previous footnote on page 3), it was concluded that such compression methods are a fallacy to avoid!



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In fact, Charles P Burgess warned about the fallacy in his book entitled *Airship Design*, published in 1927, so there was scepticism but hope for some benefit rather than none. Burgess' book still is often quoted today, so remains as a worthy exposé. See his chapter XI, page 285, entitled 'Common Airship Fallacies', which should be obligatory reading for opponents to airship load exchange and advocates of new airship methods. Of course, the author's own new methods are included, which have yet to be proven through test. However, the exercise shows how one now must regain know-how lost.

#### 9. Concluding Remarks

The main problem for the airship industry in general today is that it's small and substantially under funded, where investment has been rather limited compared to the HTA aircraft sector. It should be easy to understand why this is the case, since any manned airship development would be a large and thus risky undertaking due to their naturally big aerostat size. Then, when produced, they must compete with relatively small HTA aircraft that efficiently command the skies in almost every way, but don't cost so much to produce and operate.

Airships thus have limited market opportunities to exploit where they naturally would be the best way. Heavy lift transportation is one of them, where size matters and where they get better the bigger they are. The problem is how to start big, since the golden years of past goliath airships is long gone. How to convince people that this is the best way and that types produced will be efficient, safe and reliable is the issue. There has to be a leap of faith to set the ball rolling, after which things should work out.

However, a leap of faith in which direction:

- A classic airship?
- A hybrid airship?
- A dirigible balloon?
- Another new fangled type?

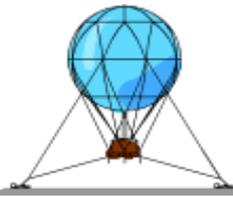
The author hopes that the preceding discourse helps to clarify things, as many will find them difficult to understand. Vested interest and fanciful false notions also may confuse matters. It should be appreciated that airships can be developed to fulfil heavy lift duties for both extraction & delivery of payloads in small remote locations and transportation over long distances, so is worth pursuing, but trying to serve both purposes or to also pursue several desirable new system developments for incorporation too soon also is folly.

A progressive way to evolve simply from small beginnings in doable stages with limited funding that doesn't risk everything at the same time thus is recommended. Dirigible balloons rather than sophisticated airships perhaps are the key to a successful outcome with new designs; where balloons were the first aircraft to fly and still are considered to be a reliable way to become airborne. Indeed, balloons are the most successful LTA type (produced and certainly used everywhere around the world). It perhaps may be said that "they are the most successful aircraft of all time".

Load exchange with ballast has been an effective and reliable method to manage buoyancy from the outset. It therefore should be adopted by any new airship development undertaken. However, this doesn't obviate other methods, which also should be developed to improve efficiency and safety for loading & unloading activities, as may be possible when sufficient funding is provided for the systems necessary. Load exchange with ballast at least gets the show on the road to check-out and demonstrate airship functionality, which should be the first priority.

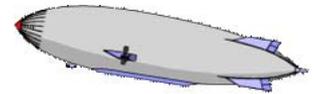
For further information about heavy lift aircraft checkout the author's paper:

"Heavy Lift Aircraft – More than one way to skin a cat!", given at the Colloque International AERALL, "Des Dirigeables pour l'Humanité Pour une stratégie de développement du Dirigeable", Les 29 et 30 Janvier 2004, Aeroclub de France.



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Also, with regard to the world's biggest successful heavy lift buoyant aircraft checkout the paper:

“The CargoLifter CL75 AirCrane”, given at the Airship Association's 5th International Airship Convention & Exhibition, Oxford, UK, 19 – 22 August 2004.

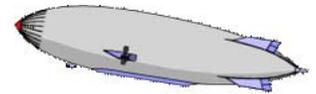
As a young engineer in the HTA aircraft industry the author was told by an experienced colleague that, “The impossible we do immediately. It's only miracles that take a little longer!” Maybe the penny will drop soon to further enable miraculous HLAs like the AirCrane – which did use load exchange, did launch without delay, was captured quickly and did transport a 50 tonne tank during its test phase, proving it's possible and showing the way to go.

Up ship!



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#### References

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- <sup>1</sup> Website: <http://www.cargolifter.com/company/history/>
- <sup>2</sup> Website: <http://rigid.tripod.com/0air1.html>
- <sup>3</sup> Presentation: The SkyHook HLV Aircraft: A Heavy Lift, Short Haul Vertical Transportation System, October 2009, by Kenneth L. Laubsch, Website: <http://www.isopolar.com/wp-content/uploads/2013/03/Kenneth-Laubsch-presentation-The-SkyHook-HLV-A-Heavy-Lift-Short-Haul-Vertical-Transportation-System.pdf>
- <sup>4</sup> Website: [http://www.piasecki.com/heavylift\\_pa97.php](http://www.piasecki.com/heavylift_pa97.php)
- <sup>5</sup> Website: <http://aviation-safety.net/wikibase/wiki.php?id=40405>
- <sup>6</sup> Website: <http://www.af.mil/AboutUs/FactSheets/Display/tabid/224/Article/104531/cv-22-osprey.aspx>
- <sup>7</sup> Website: <http://www.hybridairvehicles.com/>
- <sup>8</sup> Website: <http://www.skylifter.eu/>
- <sup>9</sup> Website: <http://www.toysperiod.com/blog/legends-and-myths/the-legendary-hindenburg-the-greatest-balloon-ever-built-voyages-and-tragedy/>
- <sup>10</sup> Brochure (small – 10.5 x 21 cm), “CL 75 AirCrane – The transportation balloon”, CargoLifter AG, Berlin, Germany.
- <sup>11</sup> Website: <http://www.fuellessflight.com/>
- <sup>12</sup> Book, “Airships for the Future”, William J White, Sterling Publishing Company, NY USA, 1976, ISBN 0-8069-0090-3.
- <sup>13</sup> Website: <http://dynamalifter.com/>
- <sup>14</sup> Website: <http://www.murphys-laws.com/murphy/murphy-true.html> for one account
- <sup>15</sup> Website: <http://www.nasa.gov/centers/armstrong/news/FactSheets/FS-013-DFRC.html#.VVyLzVLPNWw>
- <sup>16</sup> Website: <http://www.5rar.asn.au/gallery/skycrane.htm>
- <sup>17</sup> Website: [http://commons.wikimedia.org/wiki/File:Sikorsky\\_Skycrane\\_carrying\\_container\\_bw.jpg](http://commons.wikimedia.org/wiki/File:Sikorsky_Skycrane_carrying_container_bw.jpg)
- <sup>18</sup> Website: [http://issuu.com/robcrimmins/docs/the\\_cyclocrane/1?e=1398995/5345779](http://issuu.com/robcrimmins/docs/the_cyclocrane/1?e=1398995/5345779)
- <sup>19</sup> Website: <http://www.robcrimmins.com/balloon-logging/> but see articles on Aerocrane News and Pictures
- <sup>20</sup> Paper, “Aerocrane – A Hybrid Aircraft for Aerial Crane Applications”, Russel G. Perkins and Donald B. Doolittle, pages 571 – 584 of Proceedings of the Interagency Workshop on Lighter Than Air Vehicles, M.I.T. Flight Transportation Laboratory, USA, FTL Report R75-2, Joseph F Vittek Jr. Ed., Jan 1975.
- <sup>21</sup> Paper, “Development of the Magnus Aerospace Corporation’s Rotating-Sphere Airship”, J. D. DeLaurier, W. D. McKinney, W. L. Kung, G. M. Green, H. S. B. Scholaert, University of Toronto, Canada, AIAA Lighter-Than-Air Systems Conference, Anaheim, CA, USA, Ref: AIAA-83-2003, 25 – 27 July 1983.
- <sup>22</sup> Website: [http://en.wikipedia.org/wiki/Rocketdyne\\_J-2](http://en.wikipedia.org/wiki/Rocketdyne_J-2)
- <sup>23</sup> Website: <http://www.google.com/patents/US8167236>
- <sup>24</sup> Website: <http://www.brandenburg-tourism.com/detail/id/7582/theme/a-z.html>
- <sup>25</sup> Presentation: Introduction, H.J.Bothe, Hybrid AeroSystems Inc. (HASI), Alberta, Canada, 1 Mar 2002.
- <sup>26</sup> Illustration: CargoLifter, 2002.
- <sup>27</sup> Paper: Steam Balloons & Steam Airships, Thomas J Goodey, the Airship Association 3rd International Airship Convention, 2000.
- <sup>28</sup> Website: <http://www.varialift.com/>