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Load Exchange

An explanation and things to consider for LTA aircraft

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Introduction

Lighter-than-air (LTA) aircraft (balloons, airships and so forth) generally use a 'load exchange' procedure to replace payload weight with ballast or vice versa for maintenance of airborne weight, necessary to counter buoyancy when setting payloads down or picking them up.

This is because aerostatic lift (buoyancy), developed from displacement of the atmosphere by an LTA aircraft's aerostat, doesn't just disappear like the aerodynamic lift of heavier-than-air (HTA) winged aircraft (aeroplanes) or rotorcraft (helicopters) when they land and power down (becoming ground-borne); so remain afloat (airborne), unless the buoyancy developed is somehow sufficiently destroyed, countered or controlled. If payloads were just set down as for HTA aircraft, without load exchange, then the airship would ascend – forced upwards due to then excess lift after losing weight. Therein lies the issue! Is buoyancy a benefit or a problem?

A few years ago, an eminent USA military chief made profound poorly grounded damaging remarks about this LTA aircraft matter with regard to airships in particular that have resonated ever since; seriously affecting world opinions and the fledgling industry's growth – encouraging it down routes to make new types more like HTA aircraft and putting people off airships to the extent that the industry now is failing and may not survive if things don't change.

The subject involves aspects of physics and LTA aircraft development that many people don't understand properly but, because of the remarks and the damage caused, needs redress.

This document is to do that, but also addresses the subject to help people understand the issues involved and the right way to overcome them.

Background

Classic form (cigar shaped) unidirectional (UD) airships were first introduced over a concerted development period of about 40 years (beginning c1900) but then faded out almost completely by 1960. This cessation largely was due to lack of sympathy for their great size (necessary as atmospheric displacement vessels) resulting in relatively high cost and long periods for development before entering regular service, unable to compete with then smaller quickly produced HTA types. Due to their size and delicate nature, they also were relatively slow and prone to damage from poor behaviour in variable weather (with numerous incidents) so perceived as unsuitable for most military purposes. The result was that they didn't get the support for full development (to overcome issues) so were discarded from lack of care for the needed things they were most suitable for before the chance to fully prove themselves or become mature. The technology then was lost when the design/engineering people involved died.

A revival of the industry for largely commercial purposes was attempted towards the end of the last century, but against fixed unhelpful attitudes from former times. Not even 0.01% of the $£€billions invested in HTA aircraft development was provided for airships. The revival was based on previous UD types, but with modern materials and systems. The particular UD form was simply accepted; where it was thought to be good from historical usage to minimise drag for continuous powered flight between different points and where load exchange was considered normal. After all, ships (mainly UD) have used such methods for 1000s of years, where sailors understand flotation and the need for load exchange – so don't make a fuss about it.

As a result of the way things developed, the foibles of previous UD airships wasn't really addressed, so the technology only advanced with respect to better materials and systems now available. In overall terms, the airship industry thus still is quite immature, needing further progressive developments to regain former capability and to begin solving outstanding issues; where load exchange is only one of the aspects to address.

However, it faces hostile, impatient, hypocritical and selfish attitudes from many people entrenched in HTA methods that doesn't help; but where the HTA aircraft sector did get the benefit of continuous support to the mature state it is today – now dominating the scene. Even so, because the HTA sector now is mature, it's clear that it has failed to provide a cost effective or any way for a number of things that LTA aircraft could do with relative ease if the circumstances were different; such as long endurance operation over weeks (rather than hours) and serious heavy aerial crane duties. It's also now clear that things have changed, because new large HTA aircraft cost dearly and take long periods to develop.

The hypocrisy of the situation is that HTA aircraft spend long periods on the ground being tanked with many tonnes of expensive fuel (greater than the amount of benign ballast needed by LTA aircraft for load exchange) then dumped after burning the finite resource (so not sustainable) straight into the atmosphere with little regard for the effort involved and the harm done!

The problem is that the airship industry hasn't reached a state of maturity yet to be self sustaining, still needing traditional methods for people to learn and to rise from (including load exchange). When capable, better ways then may be introduced, including ways to obviate (if possible – probably not) or (if necessary) introduce acceptable load exchange methods – although what's not acceptable about load exchange isn't clear.

Lift

Free flight needs a self generated way to develop sufficient lift (an upward force) to counter or overcome an aircraft's total weight (also a force, but downwards) for climb and to remain safely airborne. Ways to develop lift include:

- Up thrust - typically from propellers, jets, rocket units
- Aerodynamic - from flow effects in the atmosphere over wings or rotors and/or the aircraft's body
- Aerostatic - from displacement of the atmosphere that the aircraft is in

The first method is energy intensive, costly and dependent on finite refined fuel resources to continue. It also involves complex system methods to function properly that must be available and work reliably.

Depending on the way things are configured, aerodynamic lift is a more sustainable way to fly, but that generally needs a powered means for motivation to get the flow necessary to remain airborne. It also is a tricky method with foibles (stability issues) that requires attitude to be maintained and reliable systems that function without concern, and doesn't suit hover (except rotor craft).

The last method is a gift of nature that is passive, so doesn't need power for movement to function (only to ply a particular course) that is reliable and without limit for sustained flight. However, due to atmospheric circumstances (low density) it can't be achieved without exceptionally lightweight means for great displacement volume (i.e. an aerostat).

Each method thus has benefits and foibles that must be balanced to achieve and maintain safe flight, which usually isn't easy to do in a way that doesn't cause excessive weight escalation that then also must be overcome to fly.

Aircraft for particular uses thus may be and are developed through pursuit of each method, which also may be mixed to a certain extent to achieve hybrid solutions. Indeed, HTA aircraft use both thrust and aerodynamic methods to function; but it is only airships that use all three methods (not generally realised) because their aerostat also is an aerodyne (a lifting body).

Even so, when using aerostatic lift there is inevitable large size that limits airspeed (due to drag) and one must be mindful of associated characteristics (including the need for load exchange and variable weather effects) for safe operation, where most incidents occur at ground level when not underway. One also must be mindful of potential issues from changes to basic established arrangements that then cause problems; discovered after changes are made (such as instability from shape changes).

Reliable aircraft generally only become available through progressive development, where people learn what the issues are and then introduce further changes to extend capability or improve things. However, there's no point in military chiefs getting upset about airship load exchange when it's evident what those who do really want is greater and quicker destructive capability with less vulnerability and who have very little interest in aircraft development for anything else!

For those who do have interest in the capabilities of airships in other ways and the issue of load exchange, read on!

Buoyancy

Buoyancy is the static lift developed from displacement of the fluid medium (a liquid or gas) that a displacement vessel (or body) is in. For ships it's their hull and the medium concerned is water (buoying the vessel up). For airships it's their aerostat and the medium providing buoyancy is the atmosphere (air).

The fundamental principle, postulated by Archimedes over 2000 years ago, is not different for ships and airships! However:

1. the medium they are in is different, so the resulting buoyancy is different – proportional to the displaced volume of the medium, its density and the gravity experienced (i.e. the displaced medium's weight).
2. ships float on the medium's surface (partially immersed) while airships are fully immersed in it (like submarines).

Notes:

- For equal displacement volume and gravity experienced, where water density = 1000 kg/m^3 and the international standard atmosphere (ISA) for air density = 1.225 kg/m^3 at sea level, then air provides 1.225/1000 = 0.001225 times less buoyancy per m^3 displacement than water. The capability also reduces for higher altitudes, because air density reduces with height. This is why it is so difficult to get useful buoyancy (sufficient to counter airship weight) from the atmosphere for flight with a reasonable payload fraction, why an airship's aerostat must be big and why airships are best designed for low altitude.
- When a ship's weight increases it normally sinks a little, causing greater displacement and thus greater buoyancy that automatically compensates and keeps the vessel afloat on the water's surface. However, because airships are fully submersed in the atmosphere to start with, there is no such compensating increase to counter increased airship weight. Thus, either ballast must be released to reduce airship weight or another type of lift (aerodynamic or thrust) must be used to restore equilibrium. Airship pilots normally compensate with aerodynamic lift, which is easy and similar to aeroplanes to apply.

- The atmosphere (unlike water) is compressible, so varies in state due to changes in temperature, pressure and constitution. Its density therefore may change as the airship's flight progresses, causing buoyancy to change. Such changes also are normally countered with aerodynamic lift (positive or negative), but pilots also need the means to reduce weight (by dumping ballast) or to reduce displacement (to reduce buoyancy) should this be necessary.
- It's a myth and thus a fallacy that the LTA gas in an airship's aerostat is a lifting substance providing buoyancy, as it's only used to support the aerostat's envelope (for non-rigids) or gas cell membrane (for rigids) as a component of the aerostat. An LTA gas is used because of its lower weight but high bulk property to occupy (fill) a space, which must be contained and is part of the airship's overall weight that also must be supported by externally applied buoyancy. Releasing it thus reduces the airship's airborne weight. However and more importantly, because its container (the aerostat's envelope or gas cell membrane) is flexible, when gas is released the displacement reduces due to collapse of the containment vessel – reducing buoyancy by a greater amount.

Buoyancy Control

It should be appreciated now (if not before) that buoyancy arises as an external effect from the atmosphere on the airship rather than an internal effect of the LTA gas used as part of the system (or item, i.e. the aerostat) to cause atmospheric displacement. The cause and effect aspects are important things to understand if a way to control buoyancy is to be found; then only useful if the weight of systems necessary (added) for the purpose isn't prohibitive.

When considering buoyancy one also should understand how it arises, which it appears (until explained) most people don't properly know (including LTA aircraft engineers) but is obvious when 'the penny drops'. To cut a long story short and to cover aspects not considered so far, it's due to acceleration (gravity – the cause) and is a complementary effect like inertia!

In fact, it's similar but opposite in action to weight, the result (effect) of gravity (the cause) with units of acceleration. Let's not go further into this because physicists don't fully understand gravity yet, but people should appreciate that, if the acceleration isn't vertical then buoyancy will instead be in a direction opposite to the acceleration direction and where gravity may not be the only acceleration to consider; needing vector summation to establish overall magnitude and direction.

OK, what stems from this is that buoyancy and weight are a complementary pair with interdependence. In LTA practice, people often talk about lightness (when weight is less than buoyancy) or heaviness (when weight is greater than buoyancy). However, negative lightness is heaviness and negative heaviness is lightness. Also, when weight = buoyancy or when both heaviness & lightness = 0, we have equilibrium (EQ)! Weight control therefore may be thought of as complementary to buoyancy control and used instead – hence load exchange!

What results from this is that people should understand there are numerous ways to 'skin the cat' and one shouldn't condemn things because of opinion, especially before understanding all the facts/circumstances. Load exchange is a nuisance for LTA aircraft operators to undertake, but it's a way to achieve things (like serious heavy lift aerial cranes) that currently don't exist. Such aerial cranes also are unlikely if attitudes don't change and opinionated people in positions of authority continue to withhold support because of trivial misconceived notions. When such aerial cranes do exist we can then work on nuisance aspects like load exchange to improve matters.

But we're not done yet, because the chaos resulting from the drive to make new airships more like HTA aircraft needs to be settled through further consideration. Regrettably funding now also is denied if the industry doesn't 'toe the line', so some people have embarked on unwise projects with significant risk of failure either to find other ways to configure airships that ostensibly obviate need for load exchange (so more like HTA aircraft) or/and indeed to introduce methods for buoyancy control. However, they appear to be misconceived for the purposes needed because, as just explained, buoyancy control is equivalent to weight control – i.e. load exchange.

One cries out for sanity to prevail, where people appear unable to see the wood for the trees. We can only do the best we can, trying to continue and be successful with the little we have!

So-called Buoyancy Control Methods

It would be useful for most airship operations if the need for load exchange could be reduced through other means of control. In fact, some airships with vectored or vertical thrust capability can manage operations with reduced need for load exchange, but usually not for the whole payload. Rotor lift for the whole payload, not surprisingly, has been tried; but without great success, because it didn't lead to much except bad opinion from a catastrophic failure when attempted! The method thus has problems to solve.

Aerodynamic lift also can be used to manage imbalance between buoyancy and weight, but needs airspeed for the purpose. Airships (like gliders) get airspeed when stationary or holding position over a ground point if there's wind, but it's not reliable, often unsteady and can't be readily controlled. Also, when airspeed is low, airships (and aeroplanes) lose aerodynamic control. Such aerodynamic methods thus may be discounted for control purposes when picking up or setting payloads down, as the wind instead usually causes problems due to unsettling effects, rather than helping to manage things.

Buoyancy control thus appears to be a desirable attribute if it can be achieved and performs well enough without significant escalation of aircraft weight for the purpose. In fact, airships do have limited capacity for buoyancy control, where:

- Thermal (hot air) methods, used by many balloons and some airships, can be adopted
- Pressurisation methods are in vogue at the moment
- Gas release is an option, used by rigid airships in the past

Development of any of these or other methods that may arise needs finance and good reasons for gas filled airships to adopt them. However, before this, there needs to be an airship industry that is able, sustainable and can benefit from such development. People therefore should consider priorities before imposing demands on an industry that is failing through lack of support.

With regard to thermal methods, air is the medium one is trying to displace; so it makes little sense to use it in a gas filled airship (even heated) because its weight is prohibitive – i.e. doesn't work well enough. If one uses hot air the aerostat's size must be bigger and thus heavier (also with added heater weight). The heat also degrades properties and the method risks fire. A poor choice!

Pressurisation methods currently are being touted and sponsors have provided funds for development, but who may have been poorly advised. Expert scientific advice is needed, because it appears these developments are ill-conceived and likely to fail; where they may depend on fantasy rather than physics to function. It's true that they are based on a potential method that can be demonstrated in a simple way without great effect, but people don't seem to appreciate the scaling effects and prohibitive systems weight involved to do more. The concept perhaps is in the same category as that promoted by Francesco Lana de Terzi (ca 1631 - 87) and his vacuum spheres (i.e. a fallacy). People still promote this potential as an ideal, despite being told why it doesn't work!

Gas release still is an option, but is a one way process. A way for this to work is 1) fly to the pickup site with ballast, then 2) perform load exchange, picking the payload up and dumping the ballast (water) to maintain EQ, then 3) fly to the delivery site, then 4) set the payload down while dumping gas to reduce displacement (and so buoyancy) to maintain EQ, then 5) return to base where the airship is topped up with gas and ballast. Who's prepared to dump helium or use hydrogen for that purpose?

Airships more like HTA aircraft

Another route that's in vogue at the moment is the development of what people call hybrid airships (i.e. airships that use a significant amount of aerodynamic lift to remain airborne) so more like HTA aircraft. It's not a new concept, but has recently gained popularity through efforts by Roger Munk to find a solution that doesn't rely so much on the need for load exchange and perhaps enables airships to be managed on the ground like HTA aircraft. Roger's hybrid airship designs near the turn of the Century used broadened aerostats to get more aerodynamic lift as a UD lifting body. Others added wings instead and some adopted both methods.

While Roger enabled the airship industry's rebirth generally he sadly died in 2012, so can no longer lead. His unmanned hybrid models demonstrated non-rigid ways to produce and stably fly such aircraft, proving that they are viable at a small size.

However and following his departure, like CargoLifter, there has been a rush to develop huge variants before building the industry base to support them. What it proves is that there's a definite desire for the capability, but at what cost? It's feared that those leading the drive for hybrid type SkyFreighters are, due to inevitable high costs for development under 'large aircraft' transport category regulations, vulnerable to similar dramatic failure if they don't find a way to sustain the effort necessary; which extends beyond certification and service entry.

Even so, the concepts have merit and it may be a way that works, but proof of the pudding will be in the eating, when it may be that things don't work as well as hoped and new problems arise from the changes made that were never envisioned.

What could go wrong? Well, apart from the absence of capable operators and necessary infrastructure:

- Due to size and relative low effective weight, they may behave like tumbleweed on the ground, needing ways to manage them in difficult conditions – so not like HTA aircraft.
- Costs of development to an acceptable standard under air law for the authorities to accept before entering regular service may be considerably more and it may take much longer than people imagine. The question to ask is, "what does it take for an equivalent HTA aircraft?" They then will be more expensive to buy, operate and maintain.
- They may not be able to compete with more simply based types that spring up.

The problem for the industry is that it has very little supporting basis or expertise to develop from, where unrealistic goals are set for development and where marketing relies on considerable speculation.

However, with regard to obviating load exchange, do they manage to do this? Well, one can't say definitely yet, as further development is needed to find out and it depends on what they're used for:

- As aerial cranes, probably not – because they must remain airborne in EQ for this (if they are able)!
- As freighters or passenger liners loading and unloading on the ground in a significantly HTA state, perhaps – but who cares if they're stable on the ground without moving?

Attitude

As well as the attempt to develop a very large cargo airship, CargoLifter in Germany from 2000 to 2002 with its own investors' funding enabled the detail design, construction and field tests of a very big towed dumb barge spherical balloon system (the CL75 AirCrane) for 50 tonne payloads. This was to demonstrate serious 'load exchange' and provide a relatively low cost method for the aerial carriage of outsized heavy goods that HTA aircraft can't manage, but that military chiefs desired. It needed a 'can do' attitude that was partially successful and took courage on the part of CargoLifter who dared to do it.

It successfully fulfilled the prototype's development and demonstrated the carriage of a Mine Clearance Panzer (a tank) of at least 50 tonne. The Panzer simply was driven onto the AirCrane's loading module, secured in position on its deck and then taken for a ride without fuss before returning, being released and then driven off with smiles on everyone's faces as they patted each others backs for the good job done. In the time the Panzer was secured on the loading module's deck (just a few minutes) and later released an equivalent weight of ballast (water) was respectively discharged and later pumped onboard (maintaining the state of aerostatic lightness needed for operation).

So what's the big deal about load exchange? It was effectively used in the AirCrane exercise for serious load pickup and set down purposes without upset. The issue thus appears to be just a hurdle in the minds of people who really don't understand the process. It's a nuisance rather than a problem, just like filling aeroplanes with kerosene!

However, CargoLifter failed to get support for further development. This failure was a matter of attitude that denies the world of such capability, where CargoLifter was blamed and left in ruin! Why on earth should anyone listen to people who just exploit and destroy things? If they're prepared to fire the bullet that kills then they should be prepared to stand as the target in the firing line with an alternative plan to shoot at! That's what happened with the R101, which tragically crashed after the R100's successful 2 way Atlantic crossing, but they still killed the programme and the industry afterwards (trashing everything) despite the hard earned technical advances gained.

If airships for serious purposes are to be developed, there needs to be more than just a 'can do' attitude; there needs to be a collective attitude of 'we will support and sustain the development, no matter the outcome'. However, people must accept that development involves risk that the developer shouldn't be expected to bear alone. If that's to be the way, then let's just say goodbye and forget the opportunities airships offer!

Otherwise, let's find a rational way free of opinionated nonsense to successfully develop them for the things people need that they would be best for and let's share the responsibility with benefit for all when success is reached.

So please, let's work together cooperatively (putting aside headstrong attitudes) to first put the airship industry back on its feet as a starting position to rise from without making trivia like load exchange the excuse for not doing anything!

Realisation

The way forward is transparent cooperation to bring about realisation in an acceptable way that benefits most people. But realisation of what and what for, and is load exchange to be accepted or not?

Additional aspects for people to consider include:

- Airship behaviour when conducting load exchange and
- How scale affects load exchange

These are subjects that one could write books about. However, the reason load exchange is on trial is to bring about realisation of the actual circumstances rather than what people imagine and often get wrong, so that the truth emerges and judgement (the decision about what to do) follows in an appropriate way.

One may ask why 'load exchange' is the subject on trial instead of 'airship behaviour', which certainly has been problematic in the past and does make load exchange difficult to do. Is airship behaviour thus the real issue that needs correction and is load exchange really only a nuisance that can be mitigated? Is the judge and jury impartial on this? People like Norman Mayer (died 3 Mar 2015 aged 98) could fairly judge this, but there's little support for the industry to continue and the know-how is being lost again.

Airship behaviour is affected by fundamental design choices, such as aerostat shape. For example, the decision to use a classic cigar form requires UD movement that must face the airflow direction to function properly, resulting in the need to weathervane when moored. In variable weather conditions with shifting wind directions the UD form is difficult to manage and, if trying to hold station and heading for load exchange, makes things almost impossible (even if the airship is provided with many thrusters) unless firmly fixed from the ground by external restraints and shielded from broadside draughts. The AirCrane had no problem with load exchange in variable weather because it had an omni-directional form aerostat that was fixed in a uniform way.

Scale is the elephant in the room! The problem is that people who see the potential at a small scale often then assume it works at a much bigger scale. However, bees don't exist at the size of elephants due to scale effects. Be that as it may, for airships, scaling up generally is good and works in a similar way to marine craft (boats and ships), so bigger may be better. For load exchange the greater inertia also helps to stabilise things.

Even so, while payload capability increases in proportion with volume (so by a factor of $2^3 = 8$ when linear size is doubled) the power and weight of plant, systems and vessels needed to compress gas in the aerostat to a level that would reduce displacement enough for full load exchange in a reasonable time is the sting in the tail that doesn't make sense. It's a black art (so not understood very well) bordering on black magic! If that's what people want then all that's necessary is for them to continue financing the gas compression airship programmes to squander the money. Yes, it's crass, but don't blame the airship industry! Alternatively, let's give the money to universities to investigate things and report impartially instead of organisations with a vested interest; and let's use it to teach and train people properly!

Luffships

SkyLifter Malaysia Sdn Bhd (SLM) was a relatively new company in the LTA aircraft business, started in 2010 to develop the Mk 1 SkyRover, a lenticular aerostat *Luffship* (LS-L20), illustrated below. It's a particular type of airship that the author of this document conceived with a view to solving past problems and lead its development, making possible things currently impossible – so providing LTA solutions. However, development depends on people who want to exploit the opportunities of such aircraft and who support the effort with finance, business arrangements and engineering expertise necessary for realisation.

Mk 1 SkyRover Visualisation

The Mk 1 SkyRover is an omni-directional type designed this way to:

- Hold station, altitude and heading (orientation) in variable wind without being upset.
- Reduce costs of development, production, acquisition, operation and maintenance through simplification (fewer parts), symmetry (fewer different parts) and ability to fly routinely as free gas balloons do or under power without complex UD airship practices.
- Launch and be captured vertically at small sites practically anywhere without necessarily conducting load exchange, enabled by rapid reaction vectored thrust using quad cycloidal propellers.
- Undertake operations in a way similar to helicopters, but with longer endurance and range, generally for purposes that HTA aircraft are unsuitable for.
- Enable technology and business development for future serious aerial cranes.

SLM was positioned to serve global needs in a new way that overcomes past airship issues. Load exchange is an issue for UD airships because of the way they behave in variable weather. It shouldn't be an issue for the Mk 1 SkyRover or subsequent Luffships based on the new technology because of its different ways; where a holistic approach was adopted for the design, including necessary ground infrastructure. The reasoning behind it stems from the classic airship industry, to find a better and more cost effective way to succeed. It also went back to the origins of LTA technology (i.e. balloons) to find the solution.

Lenticular *Luffships* are not intended to supplant classic airships, which still suit numerous purposes, but that are not suited (like aeroplanes) to activities needing steady, reliable position holding capability – such as that necessary for serious heavy lift aerial cranes. Indeed, the lenticular *Luffship* concept was formulated for that purpose, but it was found necessary to use supporting sustainable ways to develop the technology from the ground up. The Mk 1 SkyRover, based on models and tethered arrangements already tested, is the next step (as a first manned type) towards the goal of serious aerial cranes. There thus is a way to proceed that overcomes trivia and where load exchange isn't the issue upsetting things!