Administrative Office:

Dorfstr. 22b, OT Staakow
15910 Rietzneuendorf-Staakow
Germany

Tel: +49 (0)35477 4969
e-mail: info@lta-solutions.co.uk

Argument for Development of an LTA Aerial Crane

Original: 27 May 2012
Rev B: 5 Dec 2017

Author: Charles Luffman

Discussion

Reliable aerial cranes to cost effectively deliver and/or extract outsized seriously heavy payloads from remote sites far from any infrastructure or population centre and often in regions with difficult conditions (from tropical to arctic) are needed by industrialists and those involved in mining, oil, gas, timber and similar businesses. They also are needed for ad hoc purposes such as derailed train recovery or disaster area support and to use for construction purposes. The aircraft must be environmentally compatible, where they would not upset the ecology of the regions served. Serious heavy payloads for transport perhaps may be defined as greater than 50 tonne and up to say 1000 tonne.

Roads and rail systems to access remote areas are rather expensive to develop and maintain. This is well known from examples such as the ice roads prepared each year to serve population centres in northern parts of Canada; where these now are unreliable due to climate change. Yet areas of interest to industrialists go much further, so these highways would serve no other purpose but theirs, becoming a burden. But, in any case, any highway or rail line cuts a swathe through the region that does upset the ecosystem. Also, payloads of 1000 tonne need good infrastructure to start with and the transport vehicles need special design with many wheels to spread the weight so that the ground can bear it. Then in harsh isolated climatic conditions with perhaps tunnels, bridges and so forth; really, it's not a viable way to go!

If one could go by air this would obviate many problems. Of course, there are no existing aircraft that could readily transport a 1000 tonne payload, despite the huge investment in them, so any type selected should have the potential to be scaled up and developed for this purpose. However, there are aircraft that already can transport over 50 tonne payloads. Aircraft that perhaps may access such remote sites are:

- Transport aeroplanes
- Special VTOL winged types like the Harrier (AV-8B) and Osprey (CV-22)
- Helicopters
- Balloons
- Airships

Transport aeroplanes such as the C-17 Globemaster III, which can carry up to 77.5 tonne of cargo distributed over up to 18 pallets, generally may fly over remote regions and drop supplies using parachutes, but use a runway to take off and land (needing infrastructure) and can't be arranged for vertical ascent or hover. They also are very expensive. Some transport aircraft types also may use floats or be designed to settle onto and take off from water, but this depends on a sufficient expanse of clear calm water being available – usually not. But in any case, aeroplanes have limited hold sizes and centre of gravity limits, so are not suitable to deliver or extract outsized heavy items, which must be carried internally for aerodynamic reasons to avoid affecting aeroplane flight. It also is unlikely that they would be scaled up for 1000 tonne payload purposes, where they appear to have reached economically viable largest sizes. Producing bigger types for the industrialists' special purposes, where the cost of development would be many billions, then makes the idea preposterous! And the damage to the ecology of the region from the 3 km runway to land on would be worse than a road or rail system, also because it needs such ways to bring the equipment, materials, people and infrastructure in to make it.

Helicopters and special VTOL winged types really are not in the league for heavy lift transport operations of anything near the starting weight for this exercise (50 tonne), where normally they max out at about 10 tonne and there are just a few that go up to about 20 tonne payload capability. They perhaps would be useful as personnel carriers and for transport of essential supplies, but are not worth considering any further because of the inability to scale these types up. This is due to physical limitations of rotors/thrusters. They are not viable as serious heavy lift transporters and also have limited range/endurance!

Balloons, which are lighter-than-air (LTA) aircraft, often are dismissed without thought by many people, but they can in fact be designed to lift and carry 1000 tonne payloads quite easily. They also are quite cheap to develop compared with their heavier-than-air (HTA) counterparts (aeroplanes and helicopters). They already have been used for logging operations and the author took a leading role in the development of a large spherical gas balloon (AirCrane) used to carry a c50 tonne tank, as shown right, so are worth consideration.

It would have been easy to scale the AirCrane up for much bigger/heavier payloads because the physical relationships work favourably, where aerostatic lift capacity (buoyancy) is proportional to volume and volume is proportional to diameter cubed. Also, balloon weight is proportional to surface area, which is proportional to diameter squared. So basically, balloons get more efficient as size increases and a little bit bigger enables a lot more lift capability!

If the AirCrane's balloon (60 m dia) had been doubled in size (so 120 m dia), possible with modern materials, it would have been capable of carrying payloads at least 8 times bigger (i.e. 440 tonne, but probably over 500 tonne because of better efficiency) so well above the lower limit and not much bigger to achieve the upper limit. In addition, balloons enable vertical ascension or descent without much infrastructure (no runways) so could access and be launched from remote sites. However, they are not dirigible (able to be directed in flight on a specific course), so not ideal for transport.

The AirCrane was a fully tethered unmanned ground towed system (like a horse drawn barge). As such it wasn't a viable transport system. If strong winds were encountered it needed to be anchored, since aerodynamic drag on the balloon (high for spheres) easily would overcome the tow vehicle's weight, pulling it over and dragging it with it (unless massive, like a ship). However, towed by intended large helicopters in the same medium (air) it perhaps could be managed. But this has many safety issues, which are very difficult to address. It makes far more sense to add means for propulsive control and make it dirigible - i.e. turn it into an airship.

Airships from their start (before 1900, when things got going in earnest) basically were developed from balloons arranged with power, propeller and guidance systems to make them dirigible, so able to be used for transport. As LTA aircraft, their load carrying capability thus also scales in the same favourable way, where they can be designed to carry 1000 tonne payloads; so they are an obvious choice over all other aircraft types for the purpose. Indeed, there have been proposals for even bigger types with greater payload tonnage, which may be possible – but let's stick with doable targets for the time being and where blue sky objectives should be held off until achieving initial goals at the lower end of the scale (50 tonne).

A company that set up in Germany (the home of Zeppelins) realised the potential of airships for heavy payload transport and tried seriously to do it. That ended 31 July 2002 after spending about €300 million of investors' money (but needing billions), when the company closed without building the prototype due to inability to obtain further funding.

So why is there still interest in an airship solution and what went wrong with the unidirectional (UD) transport airship design in Germany? Well, there's still interest because LTA aircraft are the only viable/logical way to fulfil the objective in a cost effective way and the particular UD airship attempted was wrong for the purpose, which basically is what went wrong. No doubt there were a host of other things that were wrong, such as:

- lack of knowledge and skills to start with
- proceeding from a zero technology base to the world's biggest aircraft project too quickly (few interim stages)
- blindly driving the design in a singular way as a classic UD type without knowing if it was suitable
- building infrastructure (the hangar) and employing many staff too soon (draining finance)

The list perhaps goes on, but these are not reasons to turn away from a new LTA proposal. Rather, they are lessons learned that would not be repeated, providing reasons for a more likely successful outcome. Also, not everything was wrong with the German arrangements, where they were right that:

- an airship designed for the purpose is a viable way to fulfil the objective that should be developed
- it needs an aircraft approved organisation with qualified staff
- infrastructure (large hangars, test facilities, IT systems, offices, etc) and trials are necessary

Their marketing/sales activities, plans for operations and goals for point to point movement of payloads up to 160 tonne also were good. In addition, but at a late stage, they accepted advice from seasoned airship people subsequently employed (leading to additional unplanned costs) that enabled a better way to be established, but unfortunately too late to save the company from disgrace and, in some people's opinion, compounding things.

The AirCrane was a controversial project when started mid 2000, which most people in the German company initially felt was a waste of money (ending with about €15 million total spent on it). It was an experiment to help develop necessary LTA expertise and to demonstrate load exchange with a significantly heavy item (hence the tank). Nonetheless, after just a year and with a very small team it was designed and built. Then tests and handling trials ensued over another year, conducted initially in the hangar and later externally (moored about 1 km away from the hangar) until money to continue ran out (mid 2002). Apart from the world's biggest hangar, it was a significant LTA achievement, but was lost while under receiver management (who should have looked after things) during the company's closing month due to a storm, which it survived until wind speeds exceeded about 130 km/h (when the balloon burst – inevitable, because as an experimental system it was only designed to survive winds up to 100 km/h). There was no other real damage and it wasn't blown away, where its restraint method held it as intended. It could have been repaired and should have been in the hangar, as advised! Naturally, the incident and experience lead to further lessons of how to make an LTA project successful.

History shows us that classic airships took up a cigar shape to minimise aerodynamic drag and added rear tail surfaces (for stability and control) where this arrangement became a formula adopted thereafter by almost everyone. It also shows us that Zeppelin types significantly helped to shape things, which were arranged for military purposes – always a strong influence. Indeed, Zeppelins were used for various military actions during WW1 and airships developed in the UK, France, Italy and the USA all had mainly military purposes. Commerce really was secondary and where this still often is the case today, but why? Why aren't the captains of commerce acting for the world's benefit on this?

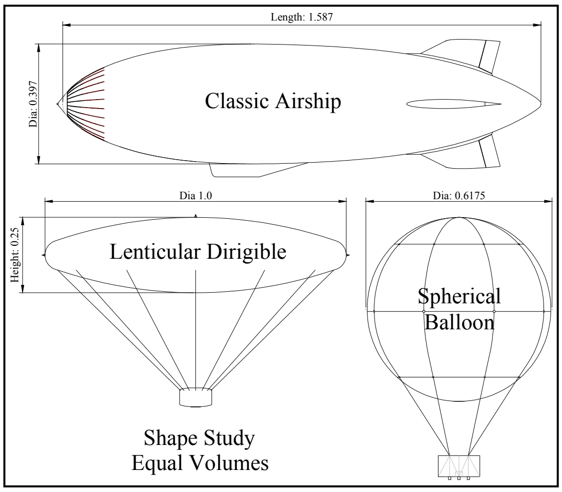
The classic cigar form is good to minimise drag, believed to enable highest speed and longest range or endurance under power. This suited military applications. However, due to adopting the cigar form, the omni-directional characteristics of balloons were lost, where they then had to face the wind or direction of flight. This also led to them being restrained from a mooring mast at their nose, causing weather-cock action. This was necessary to minimise loads but meant they would always move about (never still) making it difficult for maintenance and taking up a lot of space. They therefore cannot easily hold a particular ground alignment unless the wind happens to be in that direction or with essentially still air conditions. If they could be fixed it would be a lot easier, but that generally isn't viable for this type.

UD airships also need to carry their payloads within a nacelle for similar reasons to aeroplanes, to avoid aerodynamic problems. The German transport airship design involved a load frame for carriage and crane systems to raise/lower it into a nacelle - basically another 50 tonne of dead weight to deal with. The suspended weight therefore was over 200 tonne, needing a good way to spread this into the airship's aerostat, tending to break its back. Payloads thus also were limited in size and needed distribution to avoid balance issues. Holding station in variable gusting winds then was another significant problem, not really solved despite numerous thrusters, needing the airship to face the wind direction.

Fundamentally, when airships were first developed from balloons they weren't configured to suit the heavy lift goals expressed here needed for remote site payload supply and/or extraction; where they need to operate as aerial cranes in weather that any other crane with equivalent duties would operate. Why most people think that classic airships are an ideal choice for the purpose therefore is a mystery. It may be that they are worth developing for heavy payload haulage to suit other purposes, such as long range transport (demonstrated by Zeppelins in the 1920-30s). An airship type designed (rather than adapted) for the purpose that retains key benefits of balloons thus appears to be the way to go.

The AeroRaft's design (see below website) stems from and was arranged in its particular way as a new airship type by the author for these very good reasons. Basically, it was a new heavy lift aerial crane proposal with transport capability that evolved from the AirCrane (the only aircraft ever to raise such a serious payload vertically off the ground by aerial means alone) and that had omni-directional flight characteristics. Through use of new cycloidal propellers and without external assistance under variable conditions with changeable wind direction later derived types thus should be able to hold a precise position with any orientation (easily able to rotate about their vertical axis in a controlled way) in a pseudo-hover situation to deliver or extract seriously large/heavy payloads practically anywhere. They thus may revolutionise transport possibilities, perhaps causing a paradigm shift in the way things are done.

Instead of a spherical balloon the AeroRaft has a lenticular helium filled aerostat. The lenticular form is good because it reduces drag for translation significantly (believed to be similar to that for the cigar form) while retaining good volumetric efficiency (not as good as a sphere but somewhat better than the cigar form), as shown right, so smaller than a classic airship.



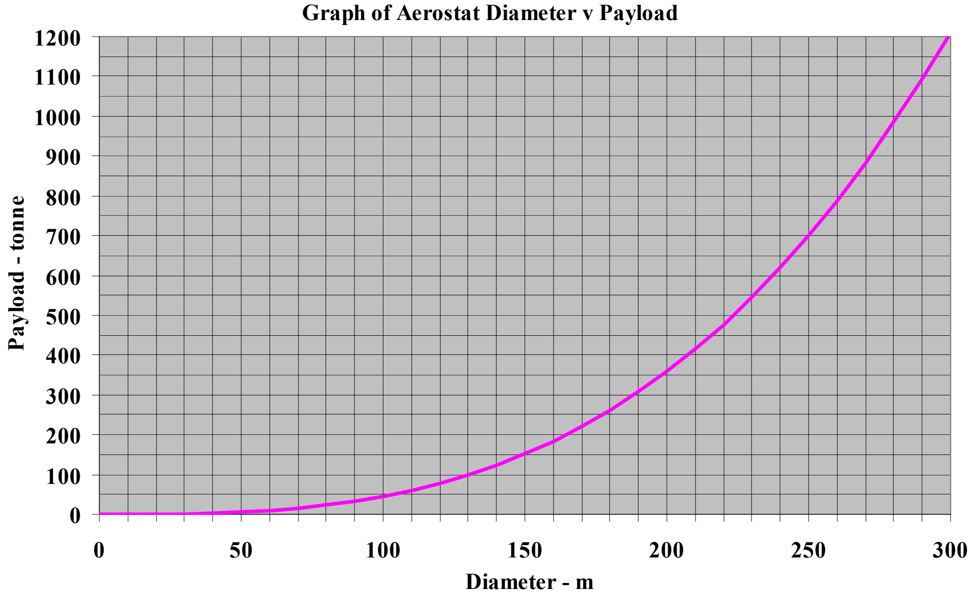
The main benefit of a spherical balloon with a hanging basket is its simplicity (little to go wrong), where the low suspended weight keeps it upright and it doesn't need to face any particular direction. The AeroRaft thus was arranged in a similar way; not needing fins to stabilise pitch and roll aspects, where it remains upright as a pendulum. It then only needed power and propeller systems to be added.

Heavy payloads and systems weight were carried by the under-slung module in an even way through the suspension system, minimising aerostat bending issues. It's considered to be a safe arrangement because, even if the aerostat lost ability to maintain its lenticular form, it would still act like a balloon or parachute.

Since hanging payloads also would be carried by a single crane line on the vertical axis below, balance (as a pendulum) is automatic, obviating load distribution issues. There were dynamic pitch roll conditions to consider, intended to be overcome by an automated thrust system, but these would not develop without an action to cause them and where it depended on airspeed. Balloons floating along with the wind don't have these problems because airspeed under such conditions essentially is zero. Balloonists do not feel any wind in their face even when drifting past ground points under strong winds at speed! The intention is to utilise winds in a similar way to balloonists for transport purposes, sailing the skies as far as possible instead of continuously driving on a direct course. Airspeed during transport therefore could be kept within limits suitable to maintain payload stability. Through route planning and weather mapping, ground speed however perhaps would be somewhat higher, enabling transportation reasonably quickly - quicker than a ship, train or lorry and without hand-off.

The method also is considered to be eco-friendly, as it minimises power for transport and thus fuel used. Emissions and costs therefore will be low. In fact, the AeroRaft was intended to have both diesel and solar power systems where, under daytime conditions it could accomplish transport under solar power alone. This is possible due to the lenticular aerostat's large upper surface, able to carry regular solar panels for the purpose. Approximately 30% of the total power requirement is possible this way. It should also be noted that it has a larger area for solar panels without orientation issues compared to UD airships.

A graph of the way payload scales against aerostat diameter under sea level conditions is provided right. This shows how larger future variants could be produced to provide much greater payload capability. Compared to the *Graf Zeppelin* (LZ-127, 237 m long, which in 1928 to 1937 regularly crossed the Atlantic between Europe & either North or South America, made polar flights and went round the world) an AeroRaft version with diameter of its length thus would be within range of the upper 1000 tonne goal, so is a viable future objective worth pursuing. It appears to be one of the only viable aerial ways that doesn't need a place to land for payload delivery or extraction!



Other advantages of the AeroRaft arrangement are that:

- It has vertical axis body of revolution symmetry enabling a high degree of standardisation for parts and features, minimising and significantly reducing costs for design, analysis, test and manufacture.
- It doesn't need stabilisers, elevators, rudders or any other type of aerodynamic method other than shaping and it also doesn't need nose stiffening or ribbing features against the air pressure head, so minimises parts count and therefore also weight and cost.
- It should be simple to control with omni-directional characteristics in any 3D direction using just its propellers without need to face the wind or flight direction, although this needs an automated system similar to multi-rotor drones - so the technology is available.
- New cycloidal propellers instead allow rapid thrust vectoring under full power through 360 degrees to control movement, so should also be able to effectively counter weather disturbances.
- It is compact (smaller than classic airships with a cigar profile), so takes up much less space.
- It may be rotated on its vertical axis (instead of flying around a circle) suiting payload pickup or placement needs.
- It may be simply fixed when moored and this helps in the gassing, assembly, maintenance, degassing & breakdown processes without a shelter.
- It may be routinely flown silently, as a free balloon (without being driven).

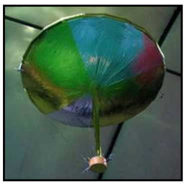
- When next to the ground, only the lower module takes up ground space – where the aerostat remains aloft (out of the way).
- It uses thrust and aerodynamic ways to counteract increased buoyancy or weight while underway.
- Being a non-rigid, there will be little to break and if envelope pressure was lost it should still continue on (perhaps a little slower).

The arrangement lends itself to ease of production with regular and standardised parts from existing suppliers. Although cycloidal propellers are new they are not difficult to develop. They are key to success and should fulfil the requirements better than screw propellers. Overall development costs are expected to be low compared with other aircraft for the purpose and although a large aircraft company would be useful, development can be managed with a relatively small design/engineering team.

Technology Background

As discussed above, the lenticular design stems from the AirCrane (a rather large gas balloon system) for which the author was Chief Engineer (2000 to 2002). As a ground towed test vehicle it proved viability of the idea to use a large balloon system for heavy payload purposes and helped establish the basis for future special transport types with aerial crane capability. It also helped with establishment of necessary infrastructure for mechanical handling, mooring and operation.

This encouraged the author to design the AeroRaft[1] as a new type, solving AirCrane issues, presented publicly in 2003. A company was formed in 2008 to produce a modified version (the LS-L150) with items of significant risk removed. This later led to a programme for development starting with an indoor R/C flying model (LS-L3 – Betty) of the basic arrangement with a 3 m lenticular aerostat.



The model proved that the concept is viable, demonstrated through successful flight control and carriage of a 0.5 kg suspended weight. A video showing Betty on its maiden flight (without adjustments to improve flying characteristics) subsequently was put on the internet[2].

Flying indoors was all very well, but the real test was outdoors with a much larger test model, where adequate ground restraint and handling methods first needed proving. This lead to the design, production and flight tests of an 18 m tethered variant (LS-L18-V1.1 Vikki) designed to carry a 200 kg load. Vikki was successfully trialled in 2010, proving that the arrangements can be managed using its restraint system, which has been operated safely up to 35 m above the ground.

Following this, Vikki was rigged and tested with an under-slung payload module at another site (proving transportability). The aerostat system then was set up in various ways to test the mooring arrangements. After fulfilling the trials programme it was deflated, packed and put into storage, ready for relocation and further demonstrations or uses. It's still available to use.

1 Paper, "AeroRaft - The Alternative Aircraft for Heavy Lift Transport or Crane Use", by Charles Luffman, given at the AIAA ATIO Tech Forum, Denver, USA, No: AIAA-2003-6754, Nov 2003.

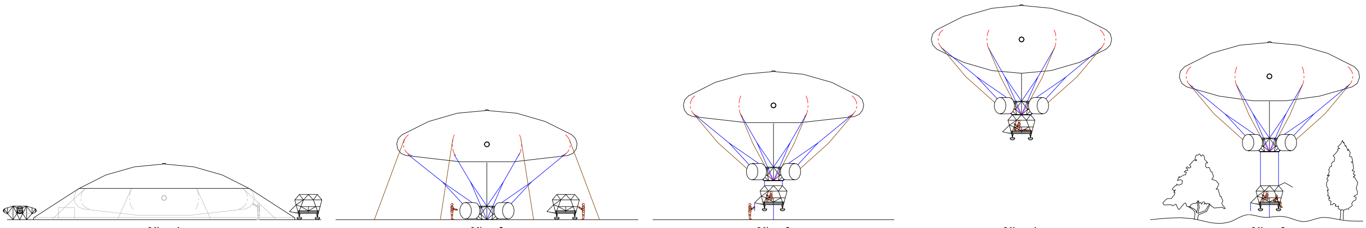
2 Website: http://www.dailymail.co.uk/sciencetech/article-1317510/The-giant-Skylifter-airships-carry-buildings-hundreds-miles.html

The tests proved that the design can be safely handled and restrained, both at altitude (under limited conditions) and next to the ground (under unlimited conditions) from leaving it unattended at its moorings overnight during a 2 week trial period without incident in all weather over the period.

The next stage was either to modify the aerostat, adding propeller arrangements, or to design and produce a bigger free flying version with greater payload capability to test and demonstrate unrestricted flight, where Vikki was planned to be developed as Nikki – a UAS R/C version.

Knowing that it essentially will be a balloon system when un-powered and the safe flight ability of such types, there was good reason for confidence in the arrangement to fulfil free flying aerial trials and then be developed as a SkyRover for regular work.

However, in 2011 a decision was made to develop the SkyRover through a new Malaysian company as a manned LS-L20 type at a slightly larger size able to be used with 200 kg payloads for patrol, as illustrated below. Although designed for manned operation, its control (which uses cycloidal propellers) was intended to be either autonomous or R/C with a pilot onboard or at a ground station.

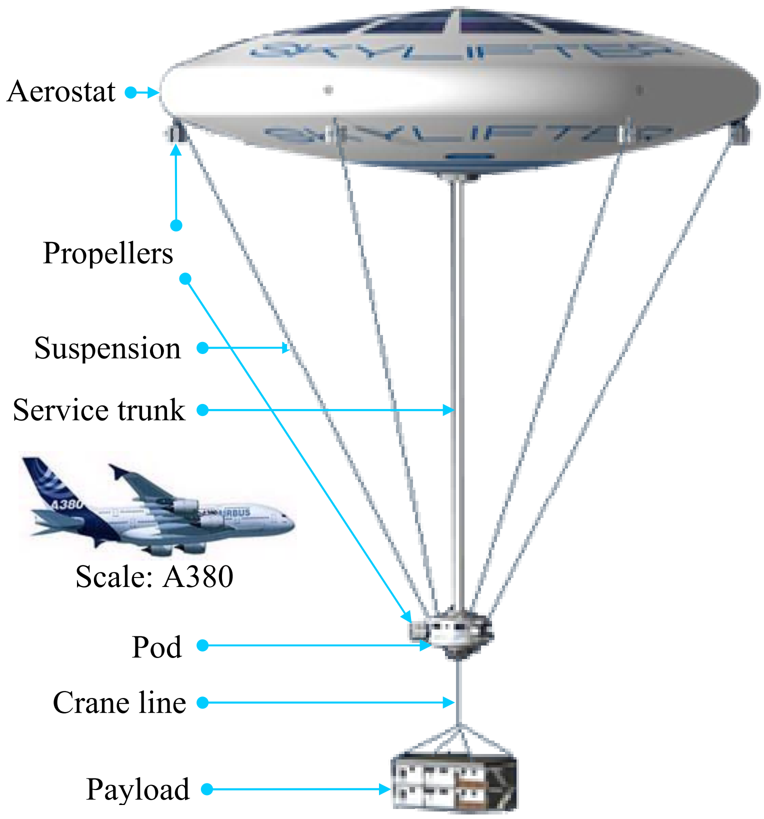


Its aerostat also doesn't have a ballonet, allowing the lower dished surface to flex instead, a further aspect that simplifies things; found to work from Vikki trials. Of course, if it later is found necessary to stiffen the lower membrane, this will be undertaken - but not necessarily with a ballonet system. Development is a process of design, trials and adjustments to address aspects that need change. Regrettably, perfection from the outset is an impossible dream but, with tolerance and continuous support the dream machine can be perfected to work reliably within tolerable limits. However, one has to start building and testing to find out how well it really works; where the LS-L20 should answer many questions in a low cost way about later aerial crane derivatives. There have been no fundamental design show stoppers so far, just detail teething issues. Nonetheless, it also depends on the parallel development of cycloidal propellers.

Cycloidal Propellers are new to the aircraft industry, but used for high manoeuvrability by tug boats – where they are known as Voith-Schneider propellers. Aircraft that fly continuously in one direction don't need them. Propeller control works in a similar way to helicopter rotor mechanisms, by changing blade pitch as they rotate. In this way, thrust may be directed rapidly to any direction required without reducing power. It's intended that they will be developed through specialists who already have successfully produced and undertaken tests relying on them for actual free R/C flight (not LTA) so understand the issues.

Mk1 SkyRover (LS-L20)

The plan then is to use the LS-L20 core design team to project manage development of larger types in a progressive way in doable steps with further types (LS-L50 SkyLugger, LS-L100 SkyPorter – see website) leading to the LS-L150 SkyHoister and beyond, perhaps needing to be undertaken through an established large aircraft development company. This would start when there's sufficient resource and maturity to responsibly produce the world's biggest aircraft – fulfilling the goal for viable serious aerial cranes, which typically may be arranged as illustrated by the AeroRaft or the commercial derivative illustrated below.



LS-L150 (SkyHoister) Concept

Concluding Remarks

The AeroRaft concept design and later derivatives were established in a credible way; where initial developments to verify the concept and solve issues before embarking on such a big aircraft programme have been undertaken. Second stage developments to build a technical team and establish capability in a manageable way also has been undertaken; where the Mk 1 SkyRovers formal PDR design/engineering phase has been completed - so ready to produce a prototype.

All projects undertaken are intended to become products to earn revenue, grow from and support bigger things in sustainable ways. LTA Solutions is ready to engage with parties interested to help fulfilment of the objectives with funded participation. The future is SkyHoister, as shown above. The aim is to enable delivery and/or extraction of practically anything anywhere as soon as possible. It just needs funding in a responsible way.

Contact details are given on the first page to register interest, etc. Further information on the website below.