Airship. March 2004 (143), Pp. 14-17. ISSN 1353-1891.

Airship-assisted Space Launch

Dr. Marin D. Guenov* and Vincent Peyron**

Introduction

Being lighter-than-air, airships do not seem to be an obvious platform choice for dropping of heavy objects. We have challenged the idea and this paper presents the summary of a speculative concept which utilises airships as a reusable first stage of a space launch system. The inspiration behind the concept was that if not much cheaper, the airship-assisted space launch will be environmentally friendlier- an argument which is likely to become even more important with time. During the development of the concept we have used as a base for comparison the Orbital Sciences Corp. *Pegasus XL* concept, which is currently the single operational aircraft-based space launch system.
Alongside the challenges of estimating weight and cost of the very large airship required (approximately 728,000 m^3), the work presented in this paper concentrates mainly on the process of releasing the space launch vehicle from the airship.

Space launch

Pegasus XL is a relatively small rocket (24 t mass and 450 kg of payload) which is carried by an L-1011 Tristar aircraft called the Orbital Carrier Aircraft (OCA). The release of the rocket occurs at an altitude of 11.9 km and at a speed of 244 m/s (approximately Mach 0.8). Five seconds after the release, the first stage of the rocket ignites and Pegasus XL starts to accelerate and subsequently climbs to lower earth orbit (LEO) using the other two stages of the rocket.
Airships are much slower than aircraft and the rocket cannot be released from airship at a velocity of 244 m/s. However, basic propulsion calculations show that it would be possible for the large airship to achieve 55 m/s at the time of the release of the rocket, since this phase was estimated to last only about two minutes and takes place at high altitude where the air density and hence the drag are lower. Using the equation for the conservation of the potential and kinetic energy (see Fig .1) it was estimated that the rocket should be released from airship at a higher altitude of 14.8 km in order to attain the same initial energy.

$$\frac{1}{2}mV_{10}^2 + mgh_1 = \frac{1}{2}mV_{20}^2 + mgh_2$$

V_{10}=244 m/s: release velocity from aircraft
V_{20}=55 m/s: release velocity from airship
h_1=11,900 m: release altitude from aircraft
h_2=14,800 m: release altitude from airship
m=24 t mass of the rocket

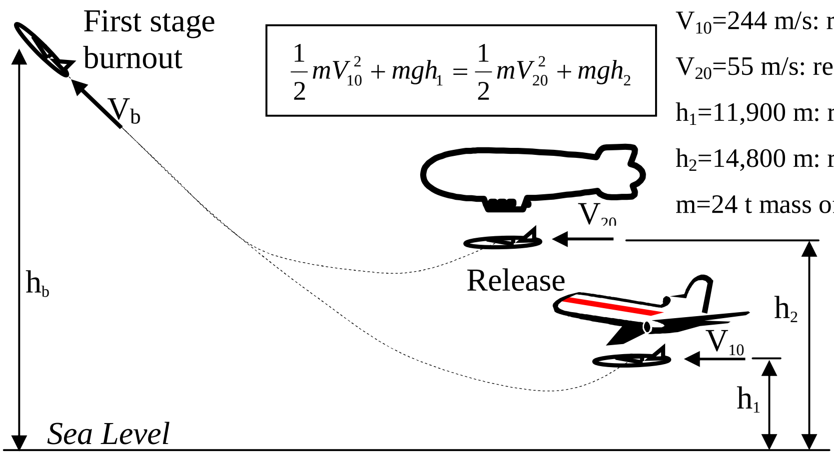

Figure 1. Release altitude and velocity of Pegasus XL versus Airship

Even with this higher release altitude, the calculations of the flight path of the rocket during the first stage have shown that it is necessary to add some extra propellant (6.5%) in order to achieve the same conditions of altitude and velocity at the burnout of the first stage. This can be explained by the lower efficiency of rocket engines at lower speed. Fortunately, the extra rocket fuel needed was within the capacity of the existing launch vehicle and thus no modifications were necessary.

* Senior Lecturer; Dept. of Power, Propulsion and Aerospace Engineering, Bld. 83, Cranfield University, Bedford, MK43 0AL; UK
** MSc Student.

Release phase

The release of the rocket is one of the crucial phases of the airship-assisted space launch mission since the airship has to accelerate up to 55 m/s and react to the sudden loss of mass that occurs when the rocket is dropped.

This phase starts with the airship cruising at 25m/s at an altitude of 14.8 km (release altitude). At this stage the mass of the airship together with its payload is estimated at 114 t with static heaviness of 6.5 t. To compensate the static heaviness and maintain a level flight at constant speed the airship flies at an incidence (Figure 2 (a)). Subsequently the thrust is increased to accelerate the airship up to 55 m/s. This acceleration is achieved in level flight and lasts about 80 s (Figure 2 (b)). After about five seconds in level flight at 55 m/s, the rocket is released. The mass of the airship plus its payload is instantaneously reduced from 114t to 90t. As the buoyancy is still the same, the airship is subjected to a vertical acceleration of 2.1 m/s² and begins to climb at a static lightness of 17.5 t. To counter this climb, a pull down manoeuvre is initiated to generate negative angle of attack and hence a negative aerodynamic lift force. This was calculated to be insufficient and required -25° vectored thrust. Despite these measures the airship would keep on climbing for a few more seconds since the necessary manoeuvres cannot be done instantaneously and because of the airship's own inertia (Figure 2 (c)). Twenty seconds after the release of the rocket, the airship stops climbing. At this stage it is at an altitude of 14.9 km. This is relatively close to the ceiling of 15 km. The descent begins immediately in order to utilise the relatively high velocity of 54.5 m/s needed to generate the required negative aerodynamic lift. This necessitates that the angle of attack and the angle of vectored thrust are maintained negative (Figure 2 (d)). Once the vertical component of velocity is close to its normal value (-5m/s), the angle of vectored thrust is progressively reduced, which is compensated by increasing the negative angle of attack. Four minutes and twenty second after the release, the descent is stabilized at a rate of 5m/s at a velocity of 23 m/s and the airship is at an altitude of 13.7 km (Figure 2 (e)).

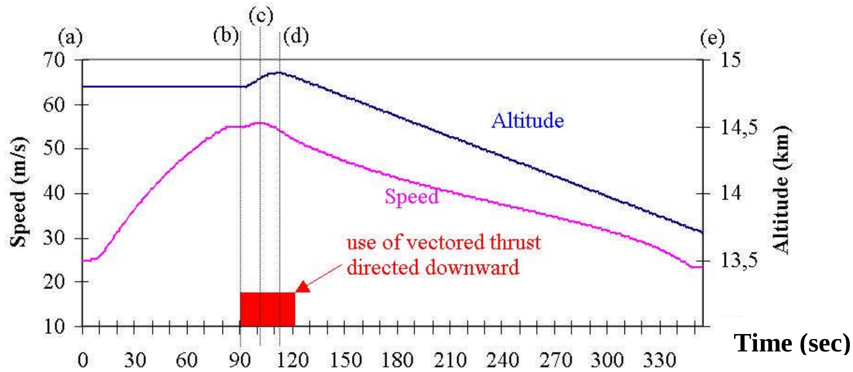

Figure 2. Evolution of flight conditions during release phase

Launch and ground operations

With airship-assisted space launch two types of mission can be performed: the "baseline" mission and the "ferry" mission. In the baseline mission the airship takes off and lands from its main base that is close to the rocket assembly building. During the ferry mission the rocket is assembled and mated to the airship at the main site. The airship then flies to a launch site. This would be necessary for orbit inclinations which may not be achievable from a single launch site due to latitude and safety reasons. The airship is also intended to take off and land vertically by applying vectored thrust in order to simplify the ground operations at both sites. The mooring system used at the main site is inspired by a system initially designed for aerostats and then tested for smaller airships (Christoforato, 1997). The airship is moored by its nose cone to a fixed mast and it is free to rotate around it. There is also a mooring line that restrains pitch motions of the airship. This line is attached at one end to a strong structure point of the airship behind the location of the rocket and to a trolley carriage at the other. The trolley travels on a circular I-beam rail which has the mooring mast at its centre. This allows for free rotation of the airship and also makes the attachment of the rocket to the hull easier.

The mooring system of the secondary site can be much simpler since the rocket is already mated to the airship and no important operations are undertaken there. The only requirement is to have an area with enough clearance to operate the airship. This is potentially an advantage over the aircraft since the L-1011 requires a large runway. Furthermore in the case of the airship the secondary site can be mobile, for example, a very large sea platform (e.g. a retired super-tanker or a large semi-submersible structure)

The airship

In order to perform a space launch mission the airship should be capable of lifting its own mass plus the mass of the rocket (24 t) to an altitude (pressure height) of 15 km where the gas cells will be full. The ratio of air density at 15 km to sea level is 0.16, which means that the gas cells have to be 16% full of helium at takeoff. This low percentage demands a fairly large and light airship- a formidable technological challenge. Initial calculations showed that the airship should be about 10% larger than the Cargo Lifter CL160 in terms of linear dimensions.

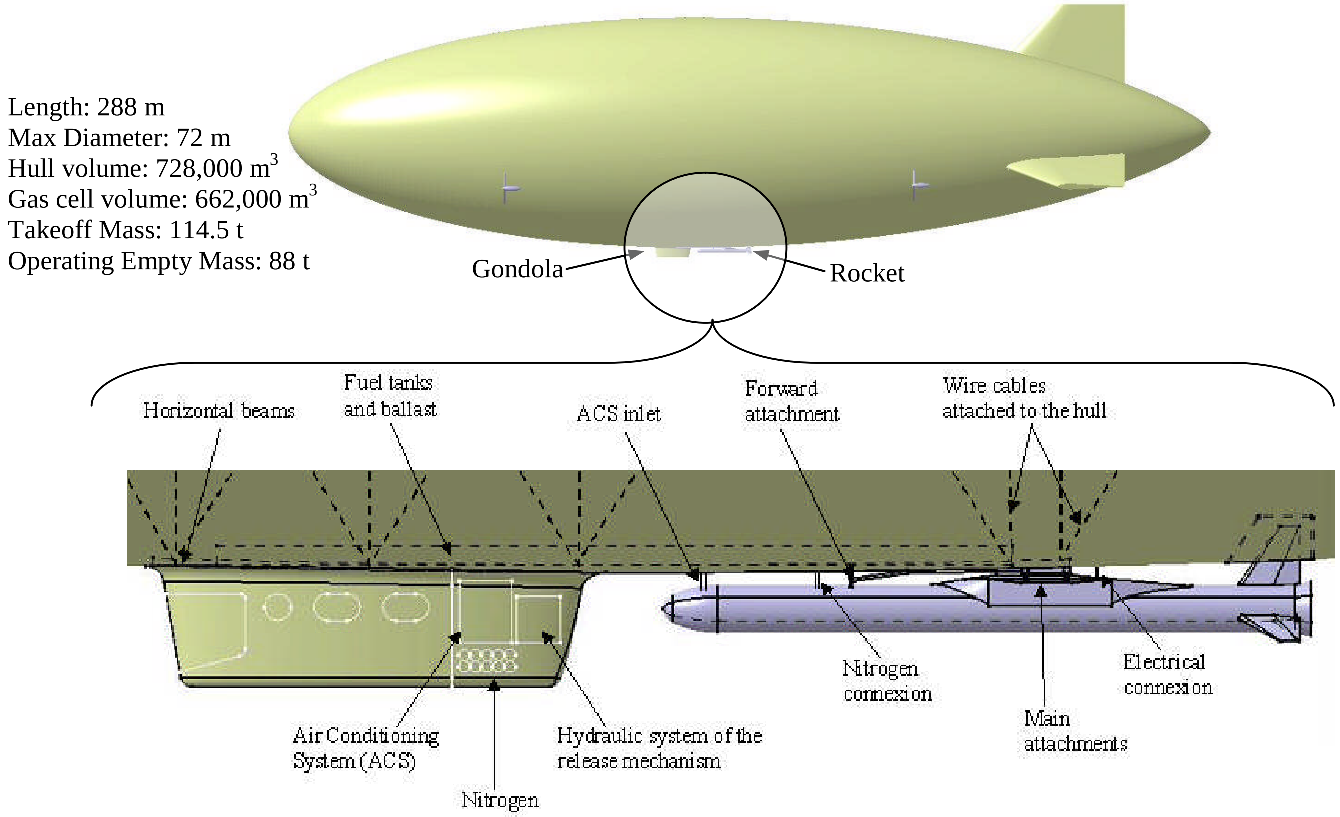

Figure 3. General arrangement of the airship and airship/rocket interface

With an inflation fraction of 16% and assuming that helium is used (purity of 98%), the buoyancy lift at takeoff is equivalent to 108 t. Thus the airship has a static heaviness of 6.5 t, which is acceptable since it is approximately equal to the usual value of 5% of the buoyancy.

Both semi-rigid and rigid configurations were considered, the preference being for the latter. In both cases the gondola and the release mechanism are mounted on the hull structure. An example is shown in Fig. 3.

The powerplant is composed of four identical turboprop engines, each generating a maximum rating power of 9,000 kW in order to cope with the acceleration of the airship during the rocket release phase. There are two engines on each side of the airship and they are attached to the hull structure. The engines are situated inside the hull and are linked to the propellers through right-angled gearboxes. These gearboxes are also used to reduce the revolution rate and increase the torque. The propellers are mounted on nacelles that can rotate from –90° to 120° to allow vectored thrust. (Yaw thrusters were considered for better controllability and manoeuvrability, but further studies will be needed to establish their size and location).

To perform airship-assisted space launch some specific systems have been added to the usual configuration of airships. First of all a release mechanism that is the structural interface between the rocket and the airship has been located behind the gondola. This mechanism is the same as the one used on the Orbital Carrier Aircraft. It is composed of four main hooks that sustain all loads and a forward attachment that reduces the movement and accelerations of the nose of the rocket. The gondola is pressurised and an air conditioning system has been added. Finally some additional equipment such as a

Launch Panel Operator station, a nitrogen purge and cooling system and CCTV have also been added to control and manage the rocket during its captive flight and launch.

Economic considerations

The difference in the space launch costs between launch from an airship and launch from an aircraft is due mainly to the difference between the respective Direct Operating Costs (DOC). The DOC of aircraft has been estimated using available figures for Boeing 767-300ER which is still in production and is very similar to L-1011. The estimates for the airship were based on extrapolates of available data for Cargo Lifter CL160 and smaller existing airships. The most important saving of using airship rather than aircraft may come from the depreciation cost assuming a lower acquisition cost of airship (at least US$ 80M) compared to aircraft (US$ 115M). The lower fuel consumption of airship provides an important saving. On the other hand airships have a higher insurance cost due to the low number of airships currently in operations. The maintenance costs of airship will also be higher since spare parts prices for the airship will be relatively high. It can be reasonably concluded therefore that from a purely economic point of view airship and aircraft are almost equivalent for space launch missions, while airship offers other advantages, notably lower noise and air pollution. In addition, an airship would offer more flexibility in terms of launch site location and ground operations. Additional usage with minimum reconfiguration of such a large airship may include missions for dropping of realistic scale models, advertising, or carrying freight.

Conclusions

This pre-conceptual study has shown that airship-assisted space launch may be feasible without the development of radically new technology. The system could compete successfully with aircraft for space launches since it seems to be equivalent from an economic point of view and offers other advantages such as a much lower level of noise and air pollution and more flexibility in terms of launch site location and ground operations.

The idea for an airship-based space launch came a few years ago (Guenov, 2000) when the forecast for the satellite market was still very optimistic (Pinland, 1997). Currently the forecasts predict that the biggest growth during the next couple of decades will be in space travel, especially for tourism (Futron corp., 2003). Reusable space vehicles for space tourism will be much heavier than the Pegasus rocket and will require even larger airships, despite that the release will take place at lower altitudes. Our initial calculations have shown that the release phase may not be possible without valving-off lifting gas. Currently this is not feasible because of the scarcity of Helium and the taboos surrounding the use of hydrogen as a lifting gas (ideally with fuel cells for propulsion). However, we remain optimistic. After all, very few believed in heavier-than air flight just over hundred years ago.

References

Christoforato, S. and Ashford, R. L. (1997). A new Airship Ground Handling System that Works, AIAA 12th Lighter-Than-Air Systems Technology Conference (June 3-5, 1997/San Francisco, California), AIAA-97-1435, Washington DC : AIAA, 1997.

Futron Corp. (2003). NASA Analysis of Space Concepts Enabled by New Transportation (ASCENT) study, http://www.futron.com, January.

Guenov, M.D. (2000). Airship-assisted Space Launch. Unpublished paper. Cranfield University.

Handler, G.S. (1997). Design Factors for an Economically Viable Airship. AIAA-97-1456. Collection of Technical Papers of the 12th Lighter-Than-Air Systems Conference. San Francisco, Ca, June 3-5, 1997.

Khoury, A.G. and Gillett, J.D. , Eds. (1999). Airship Technology. Cambridge University Press. Cambridge. UK.

Lewitt, E. H. (1925). The Rigid Airship. Sir Isaac Pitman & Sons Ltd., London.

Pegasus User's Guide. (2000). Orbital Sciences Corporation. Release 5.0. August.

Piland, W.M. (1997). Commercialization of the Space Frontier. IAF-97-IAA.1.3.01. Presented at the 48th International Astronautical Congress. October 6-10, Turin, Italy.

Peyron, V. (2003). Airship-assisted space launch : Interface Airship/Rocket and Airship Propulsion, MSc Thesis, Individual Research Project, College of Aeronautics, Cranfield University.

Schumann, U. and Wurzel, D. (1996). Aircraft Air Pollution – Research in Europe on Atmospheric Effects of Aviation. AIAA 96-0744. 34th Aerospace Sciences Meeting and Exhibit, January 15-18, Reno, NV, USA.