Materials Research Proceedings 69 (2026) 833-838 https://doi.org/10.21741/9781644904251-147

Assessing the Technical-Economic Feasibility of Unmanned Airships: Methodology and Case-Studies

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Keywords: Lighter Than Air, LTA, Airship, Cost Analysis, Cost Estimation, Business Case, Competitors, Unmanned Airships, UAV, Helicopter, Drone, Design

Abstract. This paper outlines a comparative analysis of acquisition, operation & maintenance and overall mission costs carried out on three test cases, where existing flying machines currently flying operational missions (specifically, a multi-copter UAV, a fixed-wing UAV and a manned helicopter) are compared to a novelly designed unmanned airship. The analysis was carried out designing a specific airship for each mission by employing a well-proven technique implemented in the Morning Star suite at Politecnico di Milano. Furthermore, costs are evaluated through estimation relationships accounting for the specific features of an airship, in a fashion suggested by cost estimation methods available for fixed-wing aircraft. The results allow for interesting comparisons, and show where a small-scale unmanned LTA may reduce the cost associated to procurement and operation compared to other flying platforms, while successfully capturing the same mission target as current solutions.

Introduction

The recent development of lighter-than-air (LTA) platforms for low-altitude missions, witnessed by the growing number of new companies offering services based on this type of machine (like Kelluu [1], HyLight [2], Roboloon [3] or FloFleet [4] in Europe), has been fuelled by the advancement of some key enabling technologies. Among them, electric motors for powering propellers offer a higher power-to-weight ratio compared to internal combustion engines. The adoption of these motors is especially advantageous on airships, since they can supply thrust for both propulsion and attitude control when suitably positioned in a distributed fashion, at multiple locations in an airship layout [5], [6], [7], [8], [9]. Additionally, the comparatively low expenditure of energy for propulsion and the reduced peak power required even in terminal maneuvers, compared to either fixed-wing aircraft or rotor-craft, make the sizing of the batteries far less penalizing than heavier-than-air platforms, both in terms of battery mass for the mission, and corresponding battery volume. Similarly, fuelled by the boom of the market of multi-copter UAVs over the past decade [10], effective on-board electronics constitutes a key enabler for unmanned LTAs, especially since the removal of the crew and crew-related masses (e.g. a cockpit, physical control stick and related power lines, etc.) from an airship starkly saves on its buoyant volume as well.

The combined use of these technologies is making LTA technically-viable solutions, with clear performance advantages especially in terms of endurance in forward flight and time-over-target in hovering or station-keeping phases, compared to other flying machines like fixed-wing aircraft (incapable of hovering) and rotor-craft (dramatically limited in terms of endurance and time-over target). However, even for those missions where LTAs could be employed from a technical stand-point, their consideration by potential industrial end-users is still hindered by an uncertainty on the costs associated with procurement or operation & maintenance (O&M).

In this regard, the present work aims to shed some light, by firstly introducing a simple analytic method for the most relevant components of the life cycle cost of a LTA platform for low-altitude use. Secondarily, this work provides a detailed analysis of three case studies, where the cost associated to flying machines currently operating a mission, namely a quadcopter UAV, a fixed-wing UAV and a manned helicopter, obtained as much as possible by processing relevant company data from actual operators, are compared to the outcome of a cost prediction made for an LTA capable of capturing the same mission target.

Methodology

Among the cost prediction methods [11], in the scenario at hand where practical realizations are still not many, a parametric estimation (PE) method [12] based on cost estimating relationships (CER) for sub-components of each major cost chapter has been adopted, trying to capture all major potential contributions to a specific cost. The advantage of a PE approach is that of binding cost estimation to quantities typically available at a preliminary design stage, like the break-down of take-off mass, the installed thrust, etc. [13], [14]. In order to feed CERs in the case of a LTA and obtain a cost prediction, it is possible to employ data on a LTA design solution obtained from a suitable preliminary design exercise (like volume, mass, etc.), considering a specific target mission. Such design exercise can be carried out in a largely automated fashion, thanks to consolidated procedures (Figure 1) available in the literature, bearing credible results once values pertaining to the mission at hand have been assigned [14], [15] [16], [8].

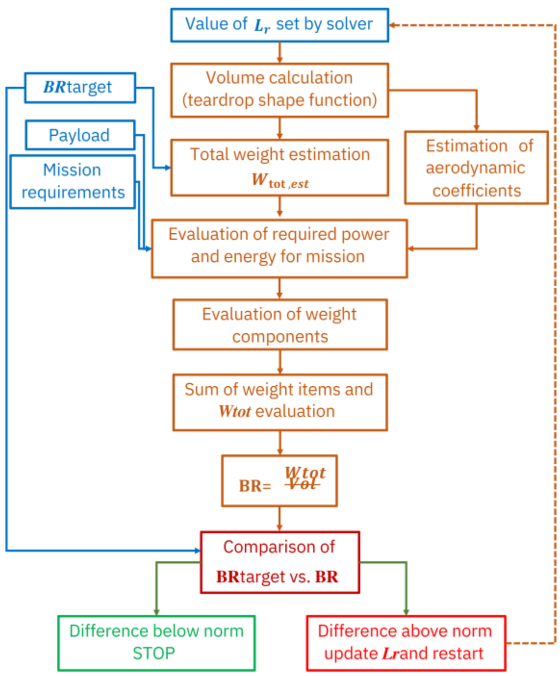

Figure 1 Schematic representation of the considered preliminary sizing algorithm for LTAs.

For some components of cost, a good commonality with respect to other applications in the industrial field can be expected (e.g. the cost of engineering). For components more typical to the LTA case, the build-up of simple CER has been attempted (especially for material cost), mostly based on current industrial data-sheets. Furthermore, CERs for research, development, test and engineering (RDTE) cost, as well as manufacture, have been considered for LTAs (Figure 2). Conversely, the estimation of O&M cost has been treated in a slightly different way for each case study at hand, on account of some specific features of each mission analysed, yielding the need for such customization.

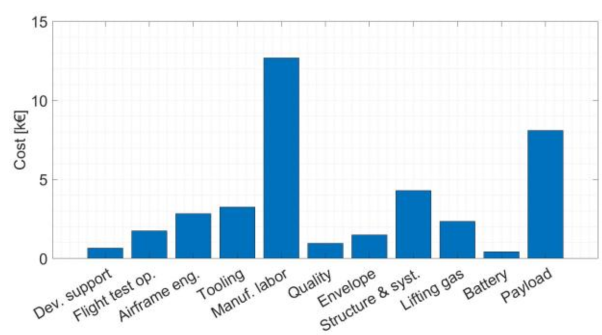

Figure 2 Example split of production cost for an LTA for solar plant inspection (for a production run of 50 exemplars).

Materials Research Proceedings 69 (2026) 833-838 https://doi.org/10.21741/9781644904251-147

Case studies and results

Three missions have been considered, among those currently flown by either UAV or manned machines (Figure 3), which could be flown by a low-altitude LTA at the current level of technology, and without the need for an unrealistically big sizing of the envelope. Care was taken to compare LTA solutions to existing ones flown only in fair weather, to increase the fairness of the analysis.

Figure 3 Competitors for LTA solutions: the DJI Matrice 210 RTK (left) employed for power-plant monitoring, the Tekever AR5 Evolution (center) for sea-life monitoring, and the Airbus AS350B3 (right) for pipeline inspection.

By knowing the target of the mission, a corresponding unmanned LTA UAV was designed for each of these missions, employing the design technique mentioned in the previous paragraph, implemented in the airship sizing suite Morning Star at Politecnico di Milano [15] [16].

Costs available from partners cooperating in this analysis was compared to values obtained from the methodology cited above, yielding the following results.

<u>*Solar power-plant inspection.*</u> This mission is currently carried out recurring to multi-copter UAVs, which overfly the plant from close distance with visual and infra-red sensors, looking for debris and dust accumulation and wear or damage to the cells. As a reference case for a quantitative analysis, the 87 MW plant of Trino Vercellese (VC) in Northern Italy has been selected. The corresponding LTA solution from the design method is reported in Table 1. The comparison of costs is portrayed in in Table 2. Here the cost per mission has been obtained from a depreciation scheme of 5 years for the quadcopter UAV (optimistic) and of 10 years for the LTA, corresponding to the life span of the envelope. It can be noted how the procurement cost is starkly in favour of the existing quadcopter solution. Yet the operation cost is much higher for that solution than for the LTA, on account of the much higher endurance of the latter. This in turns reduces the time for the mission from 4 days to 1 days, thus also significantly reducing the cost for the crew.

Sizing parameter	Value
Volume [m^3]	20.74
Length [m]	9.24
Fineness ratio [-]	4.02
Battery mass [kg]	1.55
Battery energy [kWh]	209.25
Total mass [kg]	25.66

Table 1 Design parameters for LTA UAV for solar plant inspection

Cost component	Acquisition cost [EUR per item]	O&M cost [EUR per mission]	Overall cost [EUR per mission]
Quadcopter	22,005	2,031	2,091
Airship	44,655	813	825

Table 2 Cost comparison between as-is and LTA solutions for solar plant inspection.

<u>*Sea-life monitoring.*</u> This type of mission is nowadays flown with a fixed-wing UAV, which takes off from a suitable airstrip and flies to a monitoring area over high waters, where it spends most of the mission in a loiter, observing sea-life through electro-optical, infra-red or mirror-less digital camera sensors. As a reference case, the cetacean study mission carried out by a joint group including the Italian Coast

Materials Research Proceedings 69 (2026) 833-838 https://doi.org/10.21741/9781644904251-147

Sizing parameter	Value
Volume [m³]	49.36
Length [m]	12.34
Fineness ratio [-]	4.02
Battery mass [kg]	6.24
Battery energy [kWh]	805.95
Total mass [kg]	61.08

Table 3 Design parameters for LTA UAV for sea-life monitoring.

Guard near the Pelagos sanctuary in the Ligurian Sea in Northern Italy has been considered. The LTA solution designed for this case is significantly bigger than that for the previous one (Table 3). The LTA solution profits from the ability to take-off and land closer to the inspection target, thanks to the need for a reduced ground infrastructure. Furthermore, the lower emitted noise allows to capture good imagery while flying closer to the target (lower altitude) even when employing a cheaper and sensor suite *[17]*. In this specific analysis, the procurement cost of the fixed-wing UAV is extremely high compared to that of the LTA. Of course, such a rig may be very versatile and might be employed for additional missions than just the one considered here. The O&M cost for the LTA is low, thanks to the need for a minimal crew. Mixed with the lower overall mission range to be covered, as just commented, the overall cost per mission is starkly in favour of the LTA solution (Table 4).

Cost component	Acquisition cost [EUR per item]	O&M cost [EUR per mission]	Overall cost [EUR per mission]
Fixed-wing	1,460,000	4,642	5,042
Airship	96,241	826	852

Table 4 Cost comparison between as-is and LTA solutions for sea-life monitoring.

Pipeline inspection. This mission is currently flown typically with manned helicopters, crewed by two technicians with manual cameras, who inspect the pipeline in search of leaks and wear of the pipeline structure, while also checking the safety of the surroundings. The practical case of the Italian section of the Transalpine Oil Pipeline (TAL), linking Trieste (IT) to Ingolstadt (DE), has been considered for this analysis. The sizing results for an unmanned LTA solution on this mission are shown in Table 5. Notably, the overall sizing is generally similar to that obtained for the sea-life monitoring mission. The altitude on the target can be reduced with respect to that of a helicopter, on account of the lower noise emission of the airship *[18]*, *[19]*. Correspondingly, the quality (hence cost) of the optical sensors can be reduced. Table 6 shows the cost corresponding to the as-is and LTA solutions for the pipeline inspection mission. Similar to the previous test scenario, the acquisition cost is starkly in favour of the LTA (even though of course the helicopter can perform several more missions beside the one at hand). However, the LTA UAV is penalized by its low speed, which is inherent to a small-size LTA machine. For this reason, the LTA solution has been designed to cover only the outbound leg, which is flown in roughly one day. This saves on the cost of the pilot (which is hired for one day instead of two), but requires a rental truck to cover the return leg of the mission. The resulting O&M cost per mission, while keeping lower than for the helicopter case, is not so reduced as in other cases. The overall cost per mission is similarly penalized by this result.

Sizing parameter	Value
Volume [m³]	46.98
Length [m]	12.14
Fineness ratio [-]	4.02
Battery mass [kg]	6.07
Battery energy [kWh]	819.45
Total mass [kg]	58.13

Table 5 Design parameters for LTA UAV for pipeline inspection.

Cost component	Acquisition cost [EUR per item]	O&M cost [EUR per mission]	Overall cost [EUR per mission]
Helicopter	3,259,560	3,000	3,000
Airship	72,430	2,318	2,338

Table 6 Cost comparison between as-is and LTA solutions for pipeline inspection.

Conclusions

In this work we provided a first estimation of the acquisition, O&M and overall mission cost for innovative LTA UAVs, to be employed in replacement of existing flying solutions (specifically a multi-copter UAV, a fixed-wing UAV and a manned helicopter) on specific missions. A set of cost estimation relationships was established, based on the specific features of LTAs. The suite Morning Star was employed to preliminarily size a LTA for each specific mission. Interestingly, the comparison of cost showed a general advantage on the overall cost per mission of the LTA on these specific missions (selected on purpose as compatible with a LTA solution). However, procurement and O&M cost vary significantly from one case to another, and when considered separately, acquisition cost can be bigger for the LTA machine than for the existing platforms *[20]*. Future work should try to extend this approach further to include missions potentially flown by high-altitude airships (HAA).

Acknowledgements

The contributions of M. Perotti (EuroDrone), R. Basso (TAL), S. Airoldi (Tethys Research Institute), M. Bocken (Hylight), L. Braida and S. Dal Mas (EliFriulia), the Italian Coast Guard and the European Maritime Safety Agency are gratefully acknowledged. This work was partly funded by the IEC Pathfinder project IPROP under grant N. 101098900.

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