LOW COST TRANS-RIVER AERIAL-FERRY USING A NOVEL LTA SYSTEM

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Abstract

This paper deals with the conceptualization and design of a low cost aerial-ferry which would primarily be useful for crossing rivers and are un-crossable with a normal water-ferry because of multiple land portions in between. Conventional lighter-than-air vehicles like airships filled with helium or hydrogen are also ruled out because of the exorbitant costs. Hot-air offers an inexpensive solution to the problem, but its poor static-lift capacity manifests into outsized and impractical envelope volumes for large payloads. This endeavor solves the size and controllability issues of thermal LTAVs by addressing the points of volume-reduction by using steam and imparting controllability by using an innovative tether-propulsion system. A comparative analysis of hot-air, steam filled and hybrid balloon has also been carried out.

1 Introduction

Conventional means of transport like bridges, ropeways, tunnels, boat ferries, hovercrafts had been used for ferrying people across rivers. However the infrastructure related costs for permanent structures and operating costs of these vehicles are quite high. In many cases, these systems prove ineffective due to the changing fluvial patterns of the river. For this purpose, several transportation techniques including rigid modes of transportation i.e., permanent and semi permanent structures were studied in detail to identify relative merits and demerits. An analysis of their feasibility of their application in the Brahmaputra river basin was carried out. Based on this study, a novel LTA-system has been proposed, which is described in this paper. A low-cost trans-river aerial ferry was conceptualized that could be used as a means of transportation across rivers with inconsistent topographical and fluvial patterns. Such a vehicle will be beneficial particularly in flood-prone and undeveloped regions of developing countries devoid of adequate infrastructure to implement the aforesaid conventional but costlier modes of transport.

The state of Assam in India is divided into two parts by the river Brahmaputra. The width of the catchment area varies from 10 to 15 km, and is crossable only at a few limited locations. Currently there are three bridges over the entire river length of around1000km and the people desirous to cross the river have to spend lot of time, money and energy to do so.

For instance, if one desires to travel from North Lakhimpur to Jorhat (two places across the bank of river Brahmaputra) one has to travel all the way to Tezpur to cross the river. As shown in Fig. 1, this requires around 300 km of road travel, lasting nearly 8 hours, to travel across two towns that are at an aerial distance of around 50 km apart!

Fig. 1 Road from North Lakhimpur to Jorhat

This is the general scenario throughout the state of Assam and also in other underdeveloped & remote areas of India. It is envisaged that an aerial ferry capable of carrying a payload of 1500 kg would be able to carry around 15 people and their baggage across the river. The air-ferry is basically to be used only for crossing the river from points, across the river, which has road-connectivity to the rest of the region. This will be essentially a technology development and demonstration exercise which may be up-scaled for commercial purposes if found suitable from all angles, primarily, the safety.

2 Comparative Analysis of various concepts

This is section discusses all the conventional and unconventional means of transport which had the potential of addressing some of the problems and constraints of the North-eastern states and also delineates the disadvantages of implementation of these concepts in the region.

2.1 Rigid or Permanent Structures

The Brahmaputra-river has been traditionally considered to be extremely difficult for installation of rigid structures like bridges because of the very short working season of four to six months, high current and turbulent waters and the extensive river training works needed to establish control point. Besides, the area is highly seismic, thus underground tunnels are not viable.

Currently there are three bridges across the Brahmaputra River in Assam – the Saraighat rail-cum-road bridge at Guwahati, the Kalia Bhomora Road Bridge at Tezpur, and the Naranarayana Setu rail-cum-road bridge at Jogighopa. There is an increasing opposition to building bridges because of the growing environmental concerns. As a result the transportation problems of the North-Eastern Indian states have accentuated, leading to dis-industrialization. Moreover, though bridges do provide a permanent solution to such problems, they demand huge developmental costs and take very long time to put into operation.

Fig. 2 Photograph showing the redundancy of the bridge due to changing course of the river

As shown in Fig.2, some sections of these bridges prove redundant due to the changing course of the river. Moreover during heavy floods the water level exceeds the safety mark and as a result the bridges have to be closed for operation.

2.2 Boat Ferries

The Brahmaputra River is only second to the Yellow-river in China with respect to amount of silt deposition per year. This excessive siltation means that the water level at many places is inadequate for ferries or barges to operate. Also, there are multiple-land portions in between the braided-rivulets; thus point-to-point (across the bank) boat-ferries cannot be operated without any disruption. Furthermore, the region is prone to severe floods and boats/barges cannot be safely operated during those times.

2.3 Aircraft and Air-cushion Vehicles

Aircraft and helicopters need infrastructural support in the form of airports and helipads; moreover the proposed range-requirement of this aerial ferry is too short for conventional aircraft operation. Additionally, the operating cost per seat-km of aircraft is too expensive for the target local population. Air-cushion vehicles like hovercraft, although extremely suitable for amphibian operations, are also not feasible due to their high operational costs. Furthermore, hovercrafts have proved commercially unviable in India in the past, even when used in Mumbai, where people have relatively higher disposable incomes.

Table 1. Properties – LTA Gases (Standard sea level data, for 100% pure gas)

Sr. No.	Gas	Density (Kg/m^3)	Specific Lift (kg/m^3)	COMMENTS		
				Safety	**Cost**	**Features**
1.	Hydrogen	0.090	1.203	Bad	Fair	Hazardous
2.	Helium	0.178	1.115	Good	V. High	Expensive
3.	**Hot Air (473 K)**	**0.293**	**1.000**	**Good**	**V. Low**	**Feasible**
3.	Hot Air (383 K)	0.921	0.303	Good	V. Low	Low lift
4.	**Steam (373 K)**	**0.640**	**0.653**	**Good**	**V. Low**	**Feasible**
5.	Methane	0.717	0.575	Bad	Low	Hazardous
6.	Ammonia	0.771	0.522	Fair	Low	Toxic

2.4 Lighter-Than-Air Vehicles

Lighter than air vehicles offer a flexible and inexpensive solution to the problem of low cost trans-river aerial ferry. These vehicles have a number of advantages over the conventional modes of transportation and infrastructure, the foremost being that they require very little support infrastructure. Also the costs involved in setting manufacturing and operation have been calculated to be much lesser. An added advantage of these systems is that they can be easily relocated in a matter of hours thus provide high usability even when the river changes course. They have VTOL and hovering capability and in addition to the proposed role of passenger transportation, these also have a multi-role capacity pertaining to tourism, surveillance and product-promotion. Details of airships and current level of airship technology is provided in [1].

Although LTA vehicles provide a range of advantages they have a few disadvantages as well. The estimated minimum expenditure for fabrication of an airship in India, satisfying the given payload and performance requirements with helium would be around half a million USD, which is quite high for an aerial ferry. Airships would require large hangers located at least at two places for storage and also a helium purification plant for basic gas requirements.

On the contrary, hot air balloons (HAB's) are much more effective from the costing point of view. The infrastructural costs for the storage of HAB's are almost negligible since they don't require large hangars for storage. A major drawback of this vehicle is that the lifting capacity as compared to airships is much lesser. Secondly, HABs are also quite prone to accidents, most of which lead to severe burn injuries, as investigated by Hasham et al. [2]. Hybrid configurations have also been suggested by several researchers, involving a combination of LTA vehicles and winged aircraft, e.g., by Spearman [3] for enhancing the lifting capability and stability. However all these concepts have their own host of problems which have to be tackled before they can be deployed safely.

3. Comparative Study of LTA gases

A study of properties of LTA gases has been carried out by Goodey [4] in order to identify their relative merits and demerits. The properties of these gases are listed in Table 1.

Hot-air at 200 ^oC has a specific static-lift capacity of 1 kg/m^3, which is very similar to hydrogen and helium; but the commonly used materials for HAB envelope viz., Nylon™ and Dacron™ disintegrate quite easily at these temperatures. For this reason, the hot-air inside an HAB is maintained at about 120 ^oC, which reduces its lifting capacity by about 70% to only around 300 g/m^3. Methane and ammonia are flammable and toxic respectively, and were thus ruled out of contention, though having better lifting-capacity than hot-air at 120 ^oC. However steam was shortlisted as another plausible option, because it gives more than double the specific-lift of hot-air.

4 Problem Formulation

Based on the transportation requirements of people on both banks of the Brahmaputra river basin, a problem statement was generated and plausible solutions were sought to meet the performance requirements listed in Table 2.

Table 2. Performance requirements for the aerial ferry

Parameters	Requirements
Payload	1500 kg
Operating Altitude	250 feet AGL
Maximum speed	15 kmph
Range	15 km

Using a previously developed methodology [5], a feasibility study was carried out to arrive at the baseline specifications of an airship meeting the above requirements. The outcomes of this study are listed in [6], and are not being discussed here due to paucity of space.

After critical evaluation of the region of operation it was found out that there are some portions of the river basin where the bank to bank distance is les than 500 m. It was decided to explore a HAB based system for such regions, since longer ranges would require very high envelope volumes.

Hot-air Balloons (HAB) and Hot-air airships (HAA) are currently being used for product promotion, adventure sports and joyrides. The poor static-lift of hot-air manifests itself into huge HAB envelopes for even small payloads (2-3 passengers). Incorporation of propellers, engines etc. in order to impart motive-force and controllability lead to an increase in the system weight, thereby increasing the envelope volume further. These huge envelopes project a massive sail-area into the prevailing winds and thus the HABs are susceptible to drifting even in mild breezes. So, HABs and HAAs alike are used only during dusk or dawn and in calm wind conditions; they are only fair weather vehicles.

These operational constraints have ensured that hot-air based LTA-vehicles have always been losing contenders as serious modes of transportation. Thus, to address the 'availability' and 'reliability' criteria of a passenger transport vehicle, the 'design-statement' of the trans-river aerial-ferry was reduced to addressing the three main issues viz., reduction in envelope volume, provision of improved controllability and better propulsion characteristics, without much addition of parasitic weight.

5 Steam powered LTA vehicles

This section discusses the various steam powered LTA vehicle concepts and features that can address the problems and discusses the implementation issues pertaining to them. The idea of using steam as an LTA-gas has been around from the times of Leonardo Da Vinci, and it was advocated by Sir George Cayley and Sir Hiram Maxim. In recent times, use of steam an LTA gas has been successfully implemented by Goodey [4] and Bormann [7].

Steam balloons are better than helium balloons and hot-air balloons with respect to lift-performance. 1 m^3 of steam at 100 ^oC can lift about 650 g as compared to 300 g by Hot-Air. Thus, for the same payload, a steam balloon will have less-than-half the envelope-volume of a HAB. However, field experiments [4, 7] have indicated that droplets of condensed water increase envelope weight, and hence, water has to be re-evaporated, thus causing additional effort and costs.

5.1 Hybrid HA Steam Balloons

A prototype balloon shown in Fig. 3 called HeiDAS-UH [7] is currently in operation in Berlin and it solves the problems associated with steam by employing newly developed materials. A novel, ultra-light and flocked

Fig. 3 HeiDAS UH Prototype [5]

insulation material is used to maintain superheated steam enclosed in the envelope without allowing it to condense.

The drawbacks of a steam-balloon can be further circumvented by using a novel hybrid-balloon which combines the best features of both steam and Hot-Air balloons. This novel hybrid-balloon can use propane-burners, like a HAB and thus avoids the need of a heavy steam-boiler system aboard the trans-river-ferry vehicle. The ideology used here is to maintain the temperature of the enclosed steam to a constant level which will prevent a loss in lift as compared to traditional hot air balloons.

To achieve this, steam is held in an insulated gas container, typically a capsule constituting the upper spherical portion of the balloon. The lower conical-frustum holds hot air as shown in Figure 4.

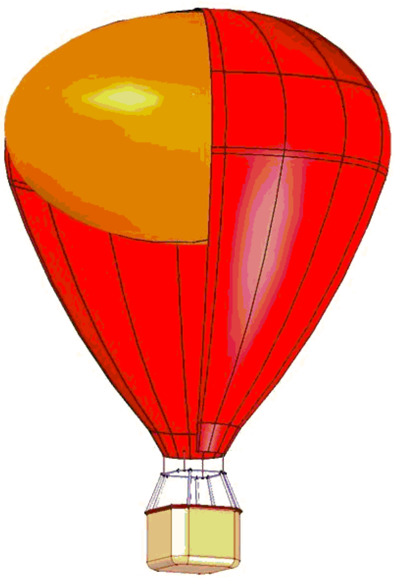

Fig. 4 Hybrid Balloon

In order to reduce the overall system weight, a propane burner can be used instead of a conventional steam boiler to heat the hot-air like in a HAB. This heated air also serves the purpose of maintaining the temperature of the steam thereby preventing premature condensation. Furthermore, the permeability problem of steam is solved by using specially developed experimental envelope material called HeiDAS Laminate.

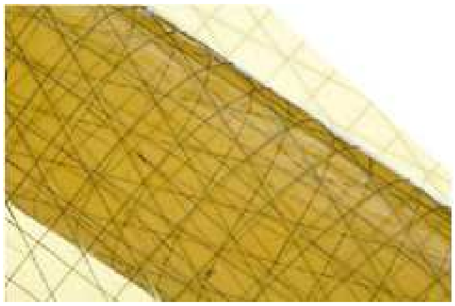

Fig. 5 HeiDAS Laminate

HeiDAS principally consists of two layers of high density fabric where in the inner layer is the laminate and the outer layer is a super-insulating flock material, as shown in Fig. 6.

Fig 6. Super-insulating Flock

The laminate help maintain the temperature inside the balloon to the required level whereas the super insulating flock material prevents any sort of condensation on the outer surface of the envelope. The above features effectively nullify the disadvantages of a pure steam powered balloon or airship.

5.2 Captive Hybrid HAB system

Due to their large volume and surface area, LTA vehicles lack controllability and are susceptible to drifting in even the mildest of winds. Incorporation of engines, propellers, and stabilizing surfaces rarely solve the problem. On the contrary, these components add to the structural weight of the craft which manifests itself into an even larger envelope-volume of the vehicle. It was surmised that a free flying LTA vehicle may not be operationally safe even in moderate wind conditions, keeping in mind the 'availability' and 'reliability' requirements. One method of controlling a balloon on air in gusty conditions is to tie it to the ground by a rope i.e. by mooring. This will be like a captive-balloon, which is usually connected via a cable to a winch system installed below ground level, effectively mooring the craft. For control of ascents and descents, the mooring winch is remote-controlled by the operator aboard the gondola or by operators in the ground. The trans-river ferry vehicle can be moored at four-points using four winches having two winches on each side of the river, as shown in Fig. 7.

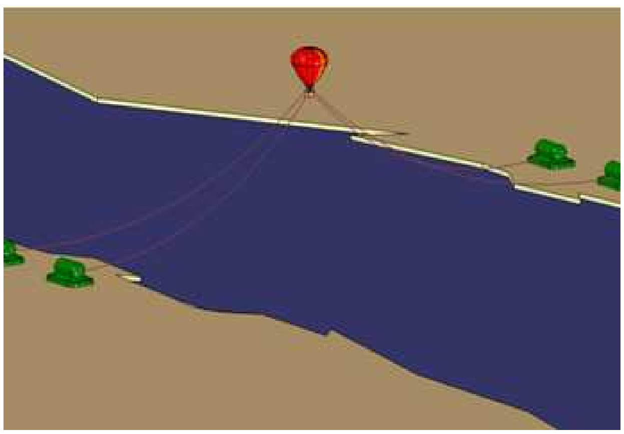

Fig. 7 Captive Hybrid HAB for Trans River Ferry

When the winches on one bank wind-in the cable/rope, the winches on the other bank unwind (release) the same, thereby effectively providing a propelling force which imparts a vehicle velocity equal to the winding-speed of the winches.

Besides the inherent controllability and simplicity of this idea, the other attractive angle is the possibility of using off-the-shelf items for implementing this scheme. Moreover, since this concept utilizes a HAB which is essentially captive, the requirements for certification of the design and operation of this system are likely to be far less stringent compared to those for free flying vehicles, such as airships. It is also possible to use a sophisticated tether-management-system (TMS) to provide constant tension to the cables and ensure that there is no drift of the vehicle due to wind-gusts, thereby providing a safe and comfortable flight even in turbulence due to thermals. Also, a TMS will provide adequate relief to the heavily loaded winches by avoiding any sudden force-transfer due to wind-gusts etc.

5.3 Sizing of Captive Hybrid HAB system

This section describes the assumptions made and procedure used for sizing of the system based on the chosen concept. Performance parameters and component masses of an existing hot air balloon viz., BB85Z from Kubicek Balloons [8] were obtained and used for system weight estimation.

Table 3. Data for BB85Z Kubicek balloon [8]

Parameter	Value
Envelope Volume	8500 m^3
V_{max} (Operating Condition)	17 m/s
Capacity	15 passengers
Envelope weight	295 kg
Basket weight	350 kg
Twin burner pack weight	22.7 kg
Fuel Tank weight	61.4 kg

Assuming that the system would consist of two-twin burners and three fuel tanks, the system weight was estimated to be 874.4 kg.

Assuming a lifting capacity of 300 g/m^3 volume, the Gross Lift can be estimated to be 2550 kg. With a payload of 1500 kg, this results in a net lift of 175.6 kg. But, this net lift has to also take into account the mass of the ropes/tethers.

A market survey revealed that a 3-strand polypropylene rope of 14 mm diameter has specific weight of 8.6 g/m. Thus, if the river basin width was 100 m, we would need around 400 m of tether, weighing 35.5 kg. Thus, the net free lift will be 140.1 kg, which would result in tension in the tethers and hold them taut.

However, this free lift reduces drastically as the width of the river basin in increased, as shown in Table 4. It can be seen that the free lift goes negative when the river basin width increases to 500 m.

Table 4. Variation of HAB Free lift with river basin width

Basin Width (m)	Tether Weight (kg)	System Weight (kg)	Free Lift (kg)
100	35.4	909.9	140.1
200	70.9	945.3	104.7
300	106.4	980.8	69.2
400	141.8	1016.2	33.8
500	177.3	1051.7	-1.7

Assuming the shape of the HAB to be spherical, the aerodynamic force on it was estimated to be 8917 kg, while operating in an ambient wind speed of 17 m/s under standard sea level conditions. Thus each of the four tethers would be subjected to load of 2229 kg. The tethers were reported to be able to carry a breaking load of 2600 kg with a factor of safety of 1.5, hence they were considered to be adequately safe.

The free lift available will be much higher for steam filled balloon and Hybrid Balloon, as shown in Fig 8.

6 Conclusions

It can be concluded that a tethered and winched HAB system can provide a low cost transportation solution for transporting a payload of 1500 kg across rivers such as Brahmaputra, at places where the river basin width is upto around 400 m wide. Use of modern technology such as steam filled balloons can improve the payload capacity, or increase the crossable river basin width to more than 1.0. If proprietary material such as HeiDAS can be used, the performance of the system can be further increased, and river basin as wide as 1.7 km can also be crossed, albeit with a cost penalty.

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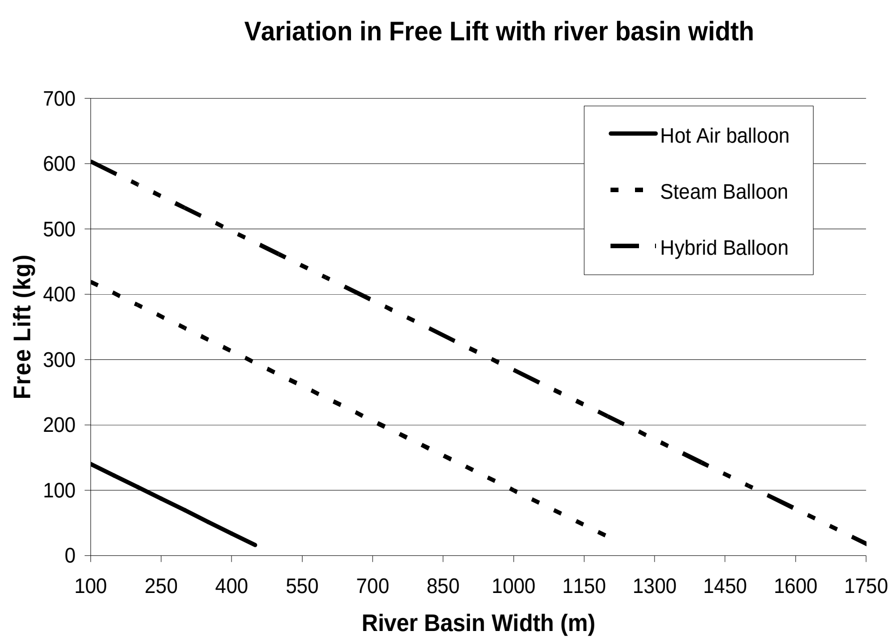

Fig. 8 Free lift for various types of balloons

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