HIGH ALTITUDE POWERED LIGHTER-THAN-AIR VEHICLE AS REMOTE SENSING PLATFORM

Masahiko Onda

Mechanical Engineering Laboratory,
Agency of Industrial Science and Technology,
Ministry of International Trade and Industry,
Namiki 1-2, Tsukuba City, Ibaraki 305 Japan

ABSTRACT

In order to tackle global environmental problems such as destruction of the ozone layer or climatic changes due to atmospheric temperature increase, the acquisition of plentiful and precise data is necessary. Therefore, a means of conducting long-lasting high-resolution measurements over broad areas is required. A feasibility study has been made on a high altitude (20km), super-pressured helium-filled PLTA (Powered Ligher-than-Air) vehicle as an ideal platform for environmental observation. It has a long service life and carries a larger payload than an artificial satellite. This PLTA platform uses an electric propulsion system to maintain position in space against wind currents. The thruster is driven by solar power acquired from solar cells. For night use, solar energy is stored in regenerative fuel cells.

This study focuses on energy balance and structural analysis of the hull and platform. The platform is capable of conducting high resolution remote sensing as well as having the capability to serve as a telecommunications relay. The platform could replace a number of ground-based telecommunications relay facilities, guaranteeing sufficient radio frequency intensity to secure good quality telecommunication transmittal. The altitude at which the platform resides has the lowest wind flow in the lower stratosphere, and permits viewing from the ground within a 1,000km range. Because this altitude is much lower than that required of an artificial satellite, the measuring resolution is a couple of thousand times higher than with artificial satellites. The platform can also be used to chase typhoons and observe them from their sources in tropical regions.

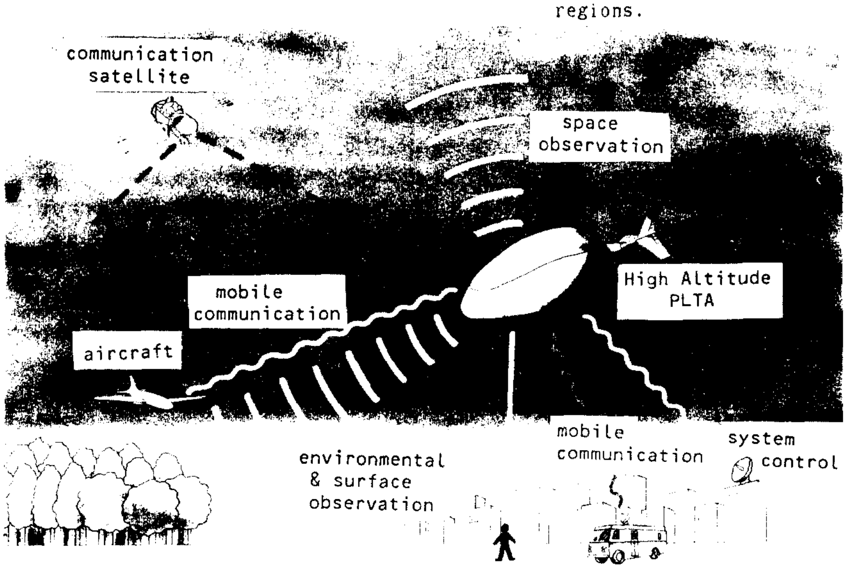

Fig.1 High altitude super-pressured PLTA platform for remote sensing and communication relay

Table 1 Various aerospacial platform characteristics

Item \ Plat-form	Satellite (LANDSAT)	High alti. aircraft	Low alti. aircraft	Free balloon	Tethered balloon	High alti. PLTA
Altitude	900km	12km	3km	50km	5km	20km
Measuring width	100-200km	10-30km	-10km	100km	-20km	-200km
Coverage area	Large (185km sq.)	Medium	Small	Large	Small	Large
Observation cycle	Every 18 days	As necessary	As necessary	As necessary	Constant	Constant
Time-series data acquire	Easy	Difficult	Difficult	Difficult	Easy	Easy
Emergence	Not	Possible	Possible	Not	Possible	Possible

INTRODUCTION

A proposal to develop an unmanned stratospheric powered LTA platform was made by a study group consisting of 20 researchers from some of Japan's foremost companies in April 1990. The group was formed as an affiliated association to the Ministry of International Trade and Industry (MITI). The platform is expected to contribute to solutions for global environmental problems, and has potential for telecommunications relay. The study is now being conducted under collaborative research between the association group and our laboratory, and funding from the government is expected to continue in order to bring this concept to a reality. Another group under the Ministry of Post and Telecommunications is conducting a study to determine the optimal concept for a high altitude flying platform by the end of fiscal 1991. Table 1 shows characteristics of various available aerospacial platforms including the proposed stratospheric PLTA platform. The unmanned PLTA does not use a rocket to reach its operating altitude, and is therefore considered less expensive than the artificial satellite systems in terms of payload capacity, and is also less hazardous to the environment.

AMBIENT CONDITION OF THE PLATFORM

The airspace at an altitude of approximately 20 km above sea level has the lowest wind flows above the jet stream. The air density is 1/14 of that at sea level and the pressure is 50mmb. The average atmospheric temperature above Tokyo at this altitude is -56.5 degrees Celsius, and is almost constant over a 24 hour period and throughout the year. Average wind speed is 15 meters per second with a maximum speed of 36 mps (70 knots) in the winter time above the Japanese archipelago and its vicinities. Wind direction there is always westerly.

HIGH ALTITUDE FLYING AIRPLANES VERSUS A SOLAR POWERED LTA

Let us consider why a solar powered LTA is being proposed. In general, there are two types of structures for powered stratospheric platforms that are considered feasible: airplanes and LTA vehicles. Airplanes have certain drawbacks, one of which is referred to as 'the square and cubic principles'. As the size of an airplane becomes larger, its weight increases to the third order of the vehicle's length; whereas the lift increase produced by the wing is governed by the square of the vehicles size since wing area increases by the second order. Thus, the payload capacity of an airplane is limited in very low density atmosphere as the wing lift depends proportionally on air density. In the case of the LTA, the vehicle is supported by buoyant gases held in the hull. The buoyancy, created as a result of the Archimedean principle, increases with the hull volume or to the third order of the hull length. Therefore, a vehicle of this size and carrying this payload is much easier to augment even in low density environment.

The second drawback of the airplane is its structural configuration. Payload is placed in the fuselage which is connected to the main wing which creates the aerodynamic lift. The structure must endure the stress concentrations that result at the wind-fuselage junction. Meanwhile, the LTA hull is supported by buoyancy which also carries the payload. The stress concentrations are easily distributed by balancing the buoyancy and total weight.

Long endurance station vehicles in the stratosphere must have long lasting power supplies in order to maintain their position in space. There are two approaches to dealing with this: utilization of solar power and utilization of high-powerd microwave energy emitted from a ground-based station. Problems associated with high-powered microwaves include 1) radio frequency pollution along the wave path and in the vicinity of the power station, 2) limited operating range away from the ground-based power station, 3) low energy efficiency, and 4) the expense and constraints of constructing large power stations in urban areas. Solar power generated from solar cells on quantitative validity of utilizing solar power is presented in the following sections.

POWER FOR MAINTAINING SPACIAL POSITION

The stratospheric powered LTA should have a low drag coefficient to economize propulsion power. Required propulsion power at 50 mmb altitude is calculated based on 75% propulsion efficiency at a maximum wind speed of 36 m/s. Assuming a drag coefficient of 0.01 and a hull volume of 400,000 m3, this yields a required power of 150kw. In order to obtain this minimum drag coefficient, a boundary layer control" (BLC) hull is used on the platform. A schematic is shown in Fig. 2. The smaller the length/diameter ratio of the hull, the better the volume/weight performance of the hull. In this model, a length/diameter ratio of 3:1 can be realized to retain a drag coefficient of 0.01 confirmed by the BLC theory.

The platform needs a power source for the mission payload, which is assumed to be 6kw for observatory devices. This also includes maneuvering power, estimated to be approximately 5% of maximum propulsion power. Altogether, the time average power consumption on board is the same or less than the maximum required propulsion power.

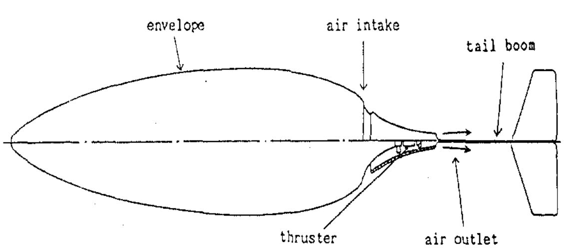

Fig.2 Stratospheric solar powered LTA platform with superpressured BLC hull(hull length 200m, total length 260m, maximum diameter 67m)

SOLAR POWER ACQUISITION AND STORAGE

Since the sky is always clear in the stratosphere, solar cells can continually produce electricity for up to a half day. We have examined several candidates for solar cells using power/weight ratio criteria. Results are tabulated in Table 2 . A 300w/kg for polycrystal silicon with 15% conversion efficiency was determined to have the most practical value. Solar power generation for daytime use and night time storage (total 450kw) requires approximately 1.5 tons solar cell weight.

Table 2 Various Solar Cell Characteristics

Solar Cells	Conversion Efficiency	Power/ weight	Cost
Amorphous Silicon	10%	2400w/kg	low
Melting Silicon	16-18%	300w/kg	
Policrystal Silicon	15%	300w/kg	low
In-P	20%	130w/kg	high

Generated electricity has to be stored in batteries for night time use. For this purpose, regenerative alkaline fuel cell batteries are a promising candidate given their operational life which is long enough to last for the duration of the platform's mission. Ni-Cd batteries, widely used for today's space missions, are quite heavy. Fig. 3 shows power and energy density characteristics of various regenerative batteries and internal combustion engines. The regenerative fuel cell system of a constant output power has a portion whose weight does not depend on power supply duration: these are the electrolysis subsystem, radiators, etc. Weight/power ratio of this portion is about 150kg/kw. The other variable weight portions are tanks and reactants (hydrogen and oxygen). Weight to power ratios of these portions are altogether 31kg/kw for 16 hours duration. Specifically, 300kw (charge) times 15kg/kw plus 150kw (discharge) times 31kg/kw becomes 9.2 tons.

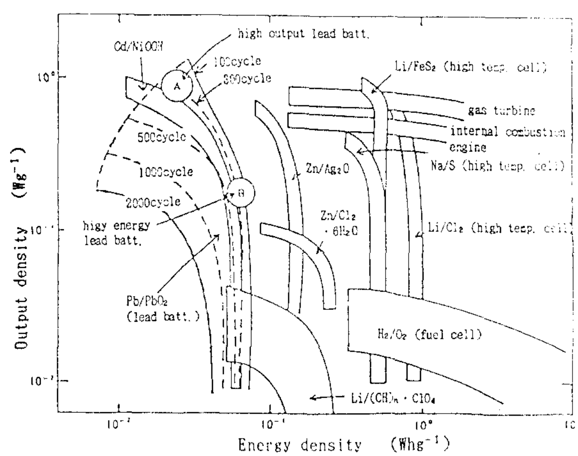

Fig. 3 Energy characteristics of batteries and engines

STRUCTURAL DESIGN

In this section, critical hull deformation conditions and hull strength are reviewed. The total static load configuration of the proposed super-pressured PLTA platform is shown in Table 3.

Table 3 Weight & Buoyancy Balance of Stratospheric PLTA

Total buoyant gas volume	400,000	m3
Total buoyancy	30	ton
Envelope weight	9.2	ton
Fuel cell(300kw 8h;day, 150kw 16h;night)	9.2	ton
Solar cell(450kw output)	1.5	ton
Power cables & Wiring	2.5	ton
Main motors(total 150 kw)	1	ton
Propellers & gears	1.2	ton
Mission payload	3	ton
Control equipment	0.6	ton
Empennage	1	ton
Reinforcement & empennage boom	0.86	ton
Total weight	30	ton

Weight can be properly distributed along the hull in order to maintain horizontal equilibrium. The static bending moment due to the mass distribution and buoyancy can be reduced to a minimum so as not to cause buckling of the thin-skinned hull. The rigidity of the hull is controlled by the internal buoyant gas pressure. The critical pressure which resists the static bending moment caused by buoyancy and weight is calculated regarding the location on the hull where the bending moment is imposed. The maximum static bending moment can be reduced so as to keep the critical pressure as low as several milimeters of water column pressure.

The aerodynamic pressure imposed on the platform nose is also only several milimeters of water column pressure due to the low air density.

The empirical gust load formula for conventional airship hull flying in the turbulant toroposphere is applied to determine the bending moment in the hull. Even with the application of such severe loading criteria, the required internal gas pressure necessary to bear the dynamic bending moment is only several milimeters of water column pressure.

The final and probably the largest load on the hull is the maneuvering moment, which is estimated using results of wind tunnel tests of a scaled model of the hull. Assuming appropriate maneuvering responses, the required internal gas pressure is only couples of 10s of milimeters of water column pressure.

Considering all of the above loading conditions, the internal gas pressure in the hull can be determined to be 80-100 mmaq using reasonable safety factors. The maximum hoop tension of the hull created by the gas pressure is 87kgf/cm.

Thus, the maximum hull hoop tension is on the order of 100-200kgf/cm using a reasonable safety factor. Textile of this strength can be manufactured using modern, high tension fabrics such as Kevlar or Vectran.

CONCLUSION

Research results on the feasibility of a stratospheric super-pressured powered LTA platform indicate great potential. The dimensions of this platform are approximately 200 meters in length, 400,000 cubic meters volume with total buoyancy of 30 tons and a 2-3 ton payload. Further study is required to determine validity of the boundary layer control effects, durability of the on-board solar power system, etc.

REFERENCES

1)Takehara, Z., "Developement and Trend of New Batteries", Energy and Resouces, Vol.8, No.4 1987

2)Kodama, T., "Present Status of Fuel Cell Development", Energy and Resouces, Vol.8, No.4 1987

3)Matsumoto, H., "Microwave Energy Transmission System for Solar Power Station", Energy and Resouces, Vol.9, No.3, 1988

4)Parsons, J. S., Goodson, R. E. & Goldschmied, F. R., "Shaping of Axisymmetric Bodies for Minimum Drug in Incompressible Flow", AIAA J. Hydronautics, Vol.8, No.3, July, 1974

5)Goldschmied, F. R., "Integrated Hull Design, Boundary-Layer Control and Propulsion of Submerged Bodies: Wind-tunnel Verification", AIAA 5th LTA Systems Conference, Anaheim, California, July 25-27, 1983