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REMOTE SENSING L.T.A. PLATFORM

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A novel multi-purpose monitoring platform-LTA vehicle is presented with much improved kinetic performances together with its structural analysis and its scale model test data. This provides a useful mean of monitoring, exploring and remote sensing platform that flies over the wide range of atmosphere and can be used as a safe economic device.

I. Introduction

LTA(lighter-than-air) vehicles are ones that float in the air by buoyancy given by a lighter gas such as helium than the air of atmosperic density, and have the least possibility of a fall due to a stall caused by an engine shut-down or operational mistakes, which can take place on other heavier-than-air (HTA) aircraft that fly by the principle of aerodynamic lift. Kinds of LTA vehicles are classified in Table 1, which includes from free balloons to motorized airships. Since an LTA vehicle has a large buoyant gas bag, the motion of an LTA is sluggish. But as LTA can stay in the air without consuming large amount of energy like helicopters, energy efficiency is quite favourable as long as it flies at a rather lower speed. If a multi-purpose monitoring platform as a motorized LTA vehicle can be developed with much improved kinetic performance, it will provide a useful mean of monitoring, exploring and remote sensing platform that may be used as a very safe and economic device. In addition to an easily-handled LTA observation platform, if proper ground support systems are installed at the observation base, this will certainly augment the present observation and exploration capability. With this goal in mind, a novel remote sensing LTA platform idea is proposed together with its structural analysis results and its scale model test data.

II. Background

An airship, a kind of LTA vehicles have been forsaken due to the major reason that their operations are so costly. They also have a disadvantage in that they sometimes require more people as ground support staff than passengers for take-offs and landings, as well as for mooring operations. Another major reason is their cruising speeds. Also LTA vehicles may be considered much more

Table 1 A Classification of LTA Vehicles

- LTA vehicle
  - I. balloon (non motorized)
    - 1. free balloon
    - 2. moored balloon
  - II. airship (motorized)
    - 1. conventional (fully buoyant)
      - a. rigid
      - b. semi-rigid
      - c. metal clad
      - d. non-rigid
    - 2. hybrid (buoyancy + aerodynamic forces)
      - a. fixed-winged
      - b. rotored
      - c. rotor lift + aerodynamic effects to hull

vulnerable under rough weather conditions than heavier-than-air aircraft, and without huge hangers, night watches are compulsory.

As a result, such vehicles are rarely employed. However, LTA vehicles also possess a great many advantages including: 1) They produce little noise. 2) They don't require large launching fields. 3) They can remain stationary in the air. They are also well-suited for transporting heavy cargoes. Thus, if various improvements such as better maneuverability, automated launching and landing, and better prediction of unfavorable weather and winds can be implemented, it is thought that LTAs could be used for a wide range of purposes.

Advantages of motorized LTA as remote sensing platform to other vehicles

Since LTA is a bouyant vehicle, which travels within one fluid, it is not affected to its altitude no matter what atitude it takes even with abrupt changes. The range of altitude in which an LTA can fly is obviously limited to the atmospheric environment. But some celestial body observational free baloons are launched and float upto 50 km altitude above the surface of the earth. The followings are comparisons and advantages versus other remote sensing platforms.

1) LTA vs. airplane

An LTA vehicle gives ideal platforms to stay in the air with very small energy consumption far longer than any type of airplanes. It flies and floats in the air without making much noise and even it can have a good access to the ground surface objects and can get their specimens. It is also adequete to acquire atmospheric samples as it can float as the same speed as the atmospheric flows, which means that without disturbing atmosphere and that an LTA platform allows to get accurate atmospheric sampling. Airplanes have much limited altitude than LTA platforms.

2) LTA vs. helicoptors

Observational equipment on board helicoptors are exposed to vibration and noise due to helicoptors' inherent characteristics, which prevent usage of high resolution telescopic lenses. Helicoptors are also difficult to steer as an unmanned vehicle. Operational ceiling of helicoptors are much lower than the airplane. Their flight time is much shorter than airplanes although they can hover somehow in a turbulent air. Helicoptors manufactured and available in the "Western" world have a payload of at most 18 tons.

3) LTA vs. satellite

Stationary satellites can be a long enduring observational station but in the geosyncronous orbit in the distance of 36,000 km from the earth. Highest resolution which it can attain in the vicinity of the surface of the earth would be at most couples of hundred meters and in such a long communication channel there will inevitably be a great loss of power. For satellites which have lower altitude orbits have to travel around the earth with high speed as they become closer to the earth and therefore thier remote sensing resolutions have to have limitations. Above all launching a satellite costs a lot.

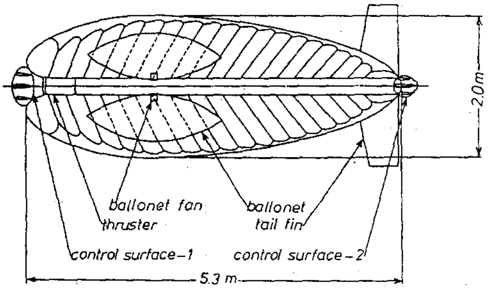

Fig. 1 Skimatic structure of a novel type LTA platform scale model

III. Proposed LTA Platform

A new type of LTA is being built with an opening duct in the middle extending from its front to its rear. Improved steering performance displayed by this type of LTA has been demonstrated with a scale model. The engine is placed inside this duct. The flow of the thruster's intake and outlet air is controlled by changing the orientation of control surfaces situated at the front and rear ends of the duct, resulting in improved control. A steering rudder is fitted to the LTA's tail, but when the platform is stationary, two sets of control surfaces in the duct can be used to change the orientation of the vehicle, both up and down and left to right, making it very maneuverable. In addition, part of the air flow inside the duct can be sent to the top and bottom of the LTA's interior to improve balance. This model features a collision resistant and noise abatement hull Under an appropriate control law the vehicle holds stability and benefits from enhanced maneuverability and performance. This type of LTA has its cockpit at the vehicle nose and cargo bays attached to both sides of its hull. The mooring points are allocated to three parts of the vehicle: the nose and both sides of the hull where the cargo bays are located.

IV. Vehicle Total Design Concept

LTA's envelope usually has axisymmetric oval shape and its finess ratios 1/2.5 - 1/4 would give maximum ratios of buoyancy vs. drag. The proposed buoyant-gas holding hull design aims at 1)augmented attitude controllability, 2)higher economic cruising speed, 3)lower power plant acoustic emission, 4)higher anti-collision safety, and 5) simplest mooring operation. This proposed structure also aims at various improvements:

1) that the aerodynamic center stays on the thruster vector line, which makes the vehicle's attitude control simpler and more effective,
2) that the thruster's intake air and downstream air attack directly against control surfaces, and thereby full power is preserved for active control, and at the same time distances between the vehicle C. G. and control surfaces can be retained large,
3) reduction of the drag coefficient by the thruster downstream application which transfers the boundary-layer separation point to the aft which realizes higher economic vehicle speed,
4) that anti-collision safety has been increased since objects placed outside of the hull such as a gondola and a thruster are all accomodated inside the hull,
5) that the pilot can have a wider command of ceiling and visibility,
6) that mooring operation is solely handled by the on-board pilot,
7) that divided payloads reduce the stress concentration to the hull and keep the vehicle C. G. location in the vicinity of the axis of the envelope, which makes the attitude controls more effective, and
8) that stress concentration to the hull is again reduced during the mooring and that the hull is always held in the holizontal position.

V. Scale Model

The scale model(Figure 2) is operated by radio-control, which enables five independent controls: two independent axis controls(pitch and yaw) each at the fore and aft ends by two sets of control surfaces plus a thruster's forward/reverse operation. The thruster consists of contra-rotating propellers driven by two DC motors. With this thruster, the vehicle attains approximately 7 meters per second as its maximum velocity.

Fig. 2 An experimental model of newly conceived LTA (The aft control surfaces are the former cruciform type.)

This reduction model's envelope is made of 50 micronmeter thickness polyethylene film by welding. The center duct is a 180 micronmeter polyester sheet seamed cylinder reinforced with glass FRP ribs. Major difficulties of this structural style is how to design and to build a duct with high rigidity and of minimum weight. External loads to this duct will be: 1)longitudinal forces imposed by fore and aft parts of the pressurized envelope film, 2)radial and axial tensions given by the catenary cables, 3)buoyant gas pressure, 4)aerodynamic pressure made by the thruster, 5)bending moments by the control surfaces and the power plant weight and its vibration, and 6)axial forces as reaction of the thruster. Among these, 4) has been found to be the most critical one, because when the thruster is swiftly switched from the maximum forward to the maximum reverse operation, it causes abrupt pressure drop inside the duct and in such a case it would squash the duct. But this tendency is totally depending on the thruster's response in case of this switching operation.

V. Stractural Analysis

Figure 3 presents a structure analysis model for the finite element method(FEM). Static analysis calculations were carried out on this model data by the MARC and ANSYS programs. The number of total finite elements amounts to approximately 1800.

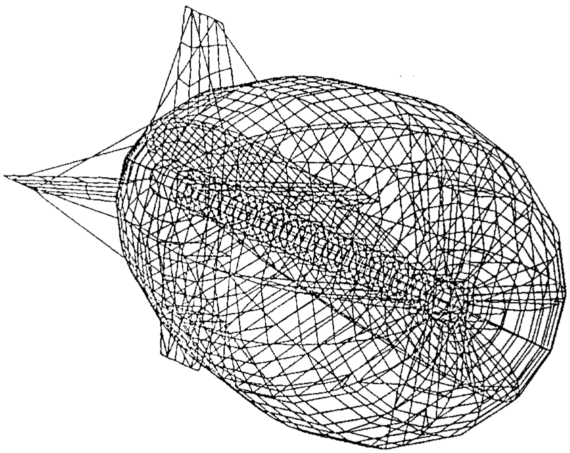

Fig. 3 An FEM model for the static deformation analysis

The finite element method model

The hull of this newly conceived LTA consists of an envelope(outer gas bag), four catenary curtains from its front to its rear with four sets of cables, four other partial curtains with cables located in its front, a duct and four tail fins. The envelope elements are assumed to have panel characteristics with very small bending rigidity, since the envelope skin is membrane. The cables are considered to be rods, which only hold axial loads but no bending loads with very small torsional rigidity.

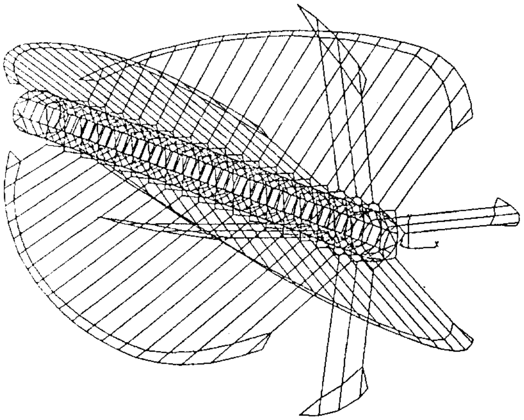

Fig. 4 Curtains, cables and duct ribs of the FEM model

Figure 4 shows two kinds of curtain sets with cables and a duct connected to them. The cable load is incurred from the duct through the cables up to the envelope skin. The catenary cables not only support the duct in the center of the envelope but also are needed to retain the heart-shaped sectional view of the envelope. The curtain height is determined on the supposition that the duct's static radial load should become higher from the center part to both the fore and aft ends with a parabolic distribution. Shape of tail fins and their locations are tentatively determined.

Boundary condition

The most conventional mooring method is that the vehicle nose is conected to the mast with a pivot and a landing gear supports the vehicle weight which is slightly over-loaded by sand balasts. But this method cannot prevent the upper movement of the hull caused by gusts or additonal buoyancy made by super-heating. As it is stated in Section 3, this model is moored with three points: the nose with a pivot and two side points where two cabins are located which allow only holizontal movements.

Load condition

Envelope gas pressure is so determined as to prevent possible envelope deformation in its nose part due to aerodynamic pressure. The boundary condition and load condition of this structural analysis are in that the vehicle is moored with its nose point to a mooring mast facing to the head wind and in that total buoyancy force is cancelled out with the vehicle's total equipped weight. Among load forces imposed to the vehicle is there internal pressure of buoyant gas which is a function of height above the sea level. The aerodynamic pressure is imposed on the outer surface of the envelope when steady wind attacks the vehicle moored.

Results

In Figures 5 is presented the maximum principal stresses' distribution of the hull under the above load condition. From the preceding data, it is known that

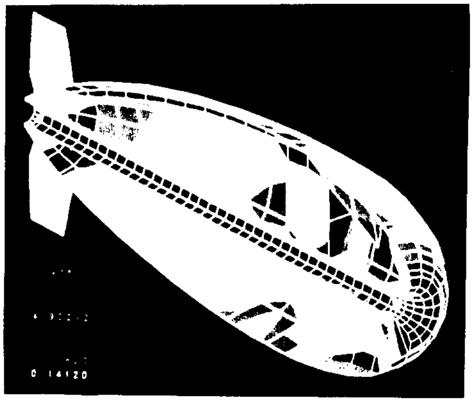

Fig. 5 Maximum principal stress distributions

approximately 10 percent from the fore duct end is exposed to the most severe stress, which coinsides to the physical phenomena as the above part tends to have a buckling dent at first under highly loaded condition. Figure 6 presents a wire frame model of the moored vehicle and its displacement when it faces to a steady head wind. The dotted line figure shows the vehicle in no wind condition. The solid line figure represents the displaced vehicle by the head wind. Figure 7 shows load vectors to grid points of the hull.

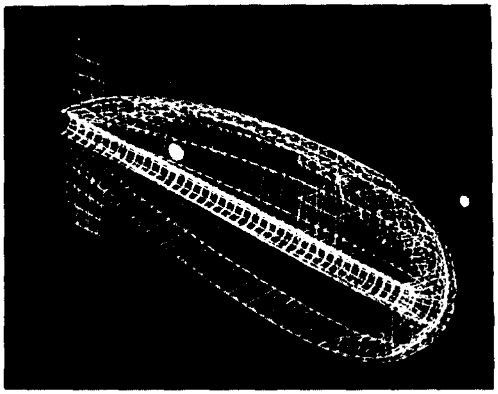

Fig. 6 Displacement of the moored vehicle by the head wind

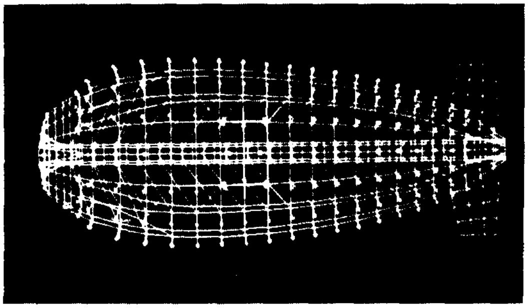

Fig. 7 Load vectors to grid points in the FEM model

VII. Active Stability Control Effects

Low Speed Attitude Control

For attitude control performance, as described above, two sets of control surfaces are installed, which are respectively located on the fore and aft ends of the center duct. These two sets of surfaces are so designed as to produce two axial control forces for pitch and yaw attitude controls, by receiving thruster intake and ejecting air flow. Each of the control surfaces is supported by a gimbal frame and this makes a two axial rotation of the supported control surfaces. A set of control surfaces is again made by two groups of three parallel aerofoils and each group's aerofoils cross to the other group's aerofoils perpendicularly. These control surfaces are supported at their aerodynamic centers by the gimbal and by stays from the center duct, which is shown in Figure 8, and a set of control surfaces is independently driven by two servomotors regarding its horizontal and perpendicular axes.

Fig. 8 Fore control surfaces installed at the fore duct end

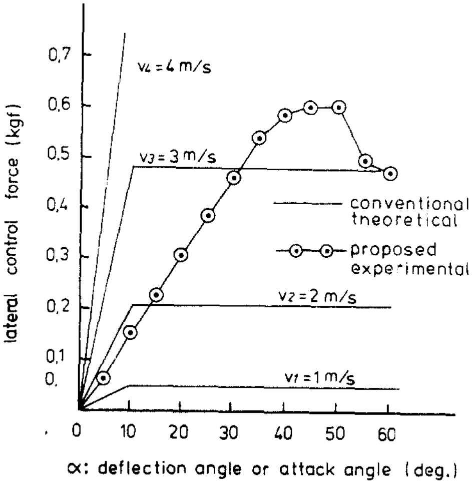

Fig. 9 Control surface deflection angle vs. lateral control force

In Figure 9, these novel control surfaces' performance data are shown, in which lateral control forces produced by two sets of surfaces are calculated as a combined value which is considered to be equivalent to the value at the aft end. The theoretical data show lateral forces which would be yielded by conventionally designed control surfaces whose area is determined by envelope length and volume. These data imply that with these novel control surfaces this experimental model can have a fairly good attitude control ability in the zero vicinity of air speed.

High Speed Stability Control

A control-configured vehicle is designed unstable to reserve higher kinetic performances, and in order to attain stability active control is introduced. In this model, active control is realized by utilizing rate gyros, and appropriate control gains are searched through a number of computer simulation runs regarding the vehicle's longitudinal dynamics by the Runge-Kutta method.

The following formulae are the basic descriptions of the model's longitudinal motion. A simplified model of the vehicle and state variables and parameter values are indicated in Figure 10. In this way, any design features of the experimental model can be expressed by choosing parameter values of the described mathematical model. The vehicle's inertial moments are calculated as the algebraic sum of envelope film, buoyant gas, polystyrene foam made tail fins, gondola and envelope-volume-equivalent air as virtual mass.

$$\frac{W}{g}\cdot\dot{V} = (B-W)\cdot\sin\gamma + F\cdot\cos(\alpha+\delta) - D_e \tag{1}$$

$$\frac{W}{g}\cdot V\cdot\dot{\gamma} = (B-W)\cdot\cos\gamma + F\cdot\sin(\alpha+\delta) + L_e \tag{2}$$

$$I\cdot\ddot{\theta} = M_{CG} \tag{3}$$

where, W= weight, B= boyancy,
V= velocity, F= control force,
g= gravity, δ= control angle,
γ= flight path inclination,
α= angle of attack, D_e= drag(envelope),
L_e= lift(envelope), θ= vehicle pitch,
M_{CG}= vehicle moment regarding C.G.,
I= vehicle's moment of inertia re:C.G.

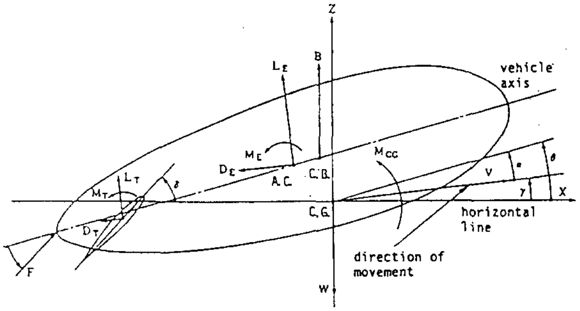

Fig. 10 Simplified model and physical value notation

Number of simulation runs are carried out on various different parameter values and their combinations. Among these, two phase plain diagrams in Figure 11 show two different transient responses regarding the vehicle's pitching motion; one for unstable and the other stable one after searching a stable combination of parameters. In these phase plain diagrams, the abscissae are pitch angle and the other coordinates indicate angular pitching velocity. In these simulation runs the thruster power is set to be almost maximum, and a minimum stabilizer surface area is introduced in order to attain a stability boundary to a level that search would find the optimum feedback gain of the rate gyro.

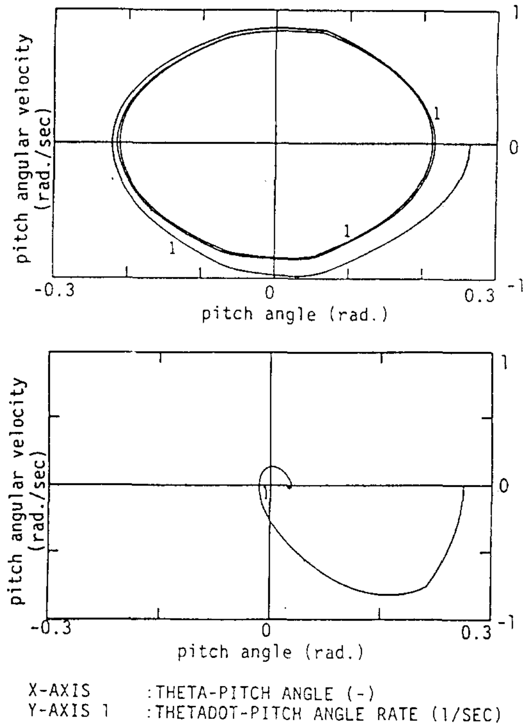

Fig. 11 Phase plain diagrams of pitching motion

VIII. Conclusion

A novel type of LTA hull with a new attitude control system was designed and its reduction model was fabricated and tested. Structual analysis was made by the finite element method. The combination of two control surfaces augments the vehicle's maneuverability at launching and landing speeds and the stability at higher cruising speed as well. The BLC effect was experimentally proven not unduly remarkable.