INSTITUTE OF FUNDAMENTAL TECHNOLOGICAL RESEARCH
AND COMMITTEE ON MECHANICS
POLISH ACADEMY OF SCIENCES

7th European Conference on Structural Control

Book of Abstracts and Selected Papers

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WARSAW 2022

DESIGN OF ADAPTIVE AEROSTATS FOR SHORT-TERM MISSIONS

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1. Introduction

Recent technological advances in the lighter-than-air vehicles allow for constructing bigger and bigger structures such as High-Altitude Pseudo-Satellites (HAPS), e.g., airplane Zephyr S developed by Airbus, Russian airship Berkut or autonomous, multi-mission, stratospheric, French airship Stratobus. Long-term missions require periodic replenishment of lifting gas losses using additional gas storage tanks due to lack of gas-tightness of aerostat shell. On the other hand, for the application in short-term missions particularly at low and medium altitudes (e.g. for aerial monitoring), the adaptive aerostats with controllable chamber volumes without gas accumulators can be applied. Such adaptive aerostats based on telescopic sections (see Fig. 1a) and supporting tensegrity-like structures (see Fig. 1b) are presented in [1] and [2, 3], respectively. Application of slightly overpressurized chambers and adjustment of their volume allows to maintain constant aerostat altitude or change it in a controlled way, even in the case of small leakage of the lifting gas into the atmosphere.

Another type of adaptive aerostat reinforced by external coatings connected by inextensible belts (or tendons), is presented in Fig. 1c. The belts are elongated or shortened by remotely controlled electric devices. Excessive aerostat volume growth can be also restricted passively by application of belts with designed extensibility.

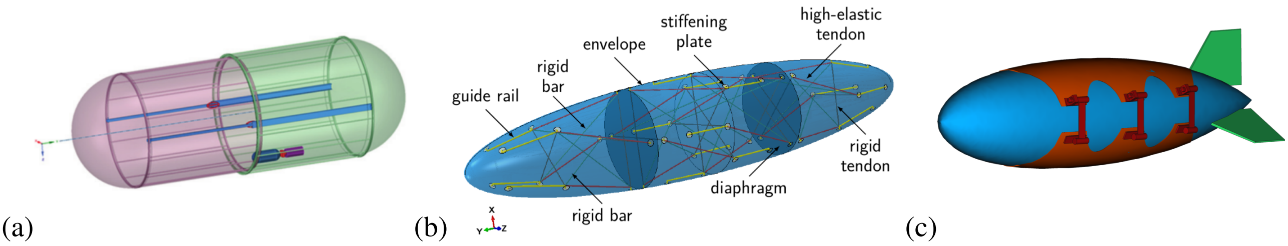

Figure 1: Schemes of adaptive aerostats controlled by: (a) telescoping sections, (b) tensegrity-like supporting structures and (c) belts connecting membrane reinforcement

2. Adaptive aerostats & volume measurement

The aerostat movement can be perturbed by different factors, e.g. diurnal temperature fluctuations and solar radiation, changes of wind speed and wind directions as well as lifting gas losses. The basic feature of adaptive aerostats is ability to change its shape and volume in order to control the motion in horizontal direction (H-mobility) and vertical direction (V-mobility). Therefore, the application of such aerostats is a very appealing solution. Generally, the volume V of the airship with telescopic-like sections, or with internal tensegrity-based structure, or with membrane reinforcement can be expressed by the volume control variable ε, defined differently for various types of adaptive aerostats. Equation of motion for the aerostat without propulsion system and constant total mass m_t can be written in the following form:

$$m_t \frac{d^2x}{dt^2} = -Q_{dh}\cos(\alpha), \qquad m_t \frac{d^2y}{dt^2} = -Q_{dh}\sin(\alpha), \qquad m_t \frac{d^2h}{dt^2} = -Q_g + Q_b - Q_{dv},$$

where the coordinates (x, y, h) and resulting forces are illustrated in Fig. 2a. In the above equation, the subsequent terms denote:

- weight of the aerostat: $Q_g = m_t\, g(h)$, where $g(h)$ is the altitude-dependent standard gravity;
- buoyancy force: $Q_b = \rho_a(h)g(h)V(\varepsilon, h)$, where $\rho_a(h)$ is the altitude-dependent air density and the volume V depends on the volume control variable ε;
- vertical aerodynamic force $Q_{dv} = sgn(v_v)c_x(v_v, h)\rho_a(h)A_v(\varepsilon, h)\frac{v_v^2}{2}$, where v_v is the vertical velocity, c_x is aerodynamic drag coefficient and A_v is the horizontal cross-section of the aerostat which depends on the volume control variable ε;
- horizontal aerodynamic force $Q_{dh} = sgn(v_h)c_x(v_h, h)\rho_a(h)A_h(\varepsilon, h)\frac{v_h^2}{2}$, where v_h is the vertical velocity and A_h is the vertical cross-section of the aerostat which depends on the volume control variable ε.

The aerostat volume is one of the key features influencing its altitude in operational conditions. Therefore, in order to prepare a reliable numerical model, the preliminary laboratory tests aimed at volume changes measurements has to be performed. In conducted tests the whole extensible aerostat polyurethane membrane is reinforced by a textile material reducing its excessive deformations as presented in Fig. 2b. The volume measurement is conducted using non-contact, optical method – stereo photogrammetry based on triangulation principle. The hardware part is composed of two cameras recording double picture of the model covered with dedicated markers, in order to reconstruct the three-dimensional surface.

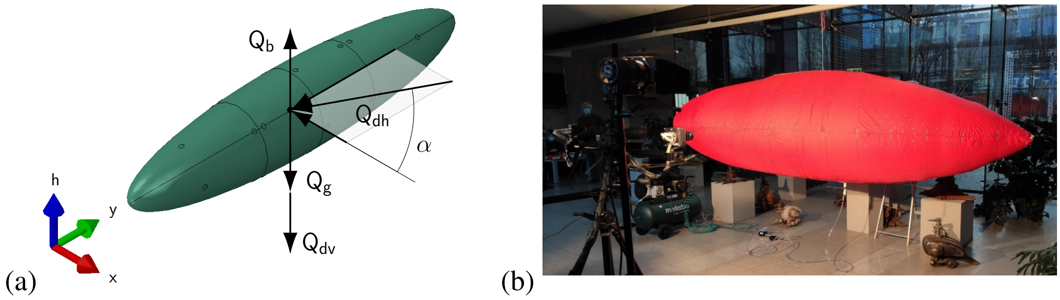

Figure 2: (a) Forces acting on the aerostat, (b) Model of the aerostat during volume optical measurement

3. Conclusions

In the article we discuss three types of adaptive aerostats with ability to control volume and shape using special construction and additional devices. Application of adaptive aerostats enables modification of the planned missions due to e.g. changing weather conditions, extension or shortening of mission duration or even enforced landing in emergency circumstances. Moreover, the applied additional devices facilitate hanging the payload and/or propulsion system. On the other hand, the added structures or devices contribute to the total mass of the airship which leads to decreasing payload or shortening of the operational time. The control mechanisms makes aerostat construction more complicated, and in the case of tensegrity structure may cause envelope damage, if one of bars is damaged or broken.

Acknowledgments The authors acknowledge the support of the National Centre for Research and Development and the National Science Centre, Poland, granted in the framework of the TANGO 4 programme (project TANGO-IV-C/0001/2019-00).

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