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Analysis performances of UAV airships

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Abstract. Flying on Archimedes principles carried out with propulsion systems has never been abandoned; the current stages prove the maturity of this modern aeronautics sub-domain. The references highlight the importance of airships, and specialists in the field offer new opportunities in terms of use and capabilities of this type of aircraft in modern airspace. Military Air Force missions have reconfirmed the importance and efficiency of this type of aircraft.

The article includes an aerodynamic analysis of quasi-stationary flight and low speeds in the case of inflatable airships type UAV in different atmospheric conditions, which analyze the influences of flight conditions on the performances of this type of aircraft used for data acquisition in areas of interest.

Acronyms

LTA	Lighter-Than-Air Vehicles	EO-IR	Electroptical-infrared
CBRN	Chemical, biological, radiological and nuclear	ISR	Intelligence, Surveillance, and Reconnaissance
C4	Command, Control, Communications, Computer	ATB	Aerostat Test Bed
FOB	Forward Operating Bases	PGSS	Persistent Ground Surveillance System
C-IED	Counter- Improvised Explosive Device	PTDS	Persistent Threat Detection System
RAID	Rapid Aerostat Initial Deployment	REAP	Rapidly Elevated Aerostat Platform
STMPAS	Small, Tactical, Multi-Payload Aerostat System	TARS	Tethered Aerostat Radar System
DoD	Department of Defense	QRC	Quick Reaction Capability
COMMS	Communications Management System	ISA	International Standard Atmosphere
JLENS	Joint Land Attack Cruise Missile Defense Elevated Netted Sensor System		

1. Introduction

1.1. History and evolution

The first flight with an airship was conducted by Henri Giffard, above Paris in 1850, see Figure 1, initial efforts to build such lighter aircraft as air pressurized a flattened envelope, then balloons were used inside the main envelope what which constituted the initial concept of partitioning, since these internal balloons have yielded in many cases used pressurized envelopes inside a semirigid or rigid structure.

There are two types of Lighter Aircraft (LTA): balloons that cannot handle airflows and guides with an aerodynamic concept that allows them to operate independently of airflow movement.

The airships are classified according to the propulsion system (propulsion, non-sprinkler) and the envelope construction type: the rigid type (zeppelin) having a metal frame (which maintains the form of the vehicle) with a flexible material, see Figure 2; the flexible type having a balloon-like coating, its shape being maintained by the gas pressure in the interior and the semirigid type composed of a flexible airship but having a fixed pocket under the gas envelope.

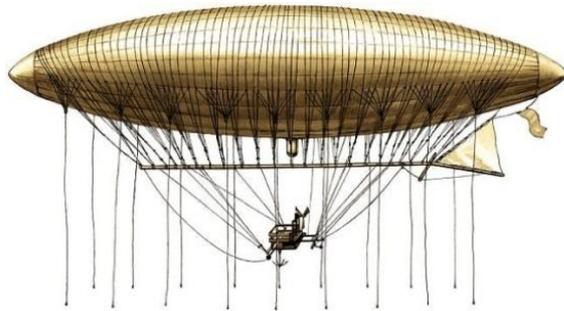


Figure 1 Henri Giffard Airship, [1]

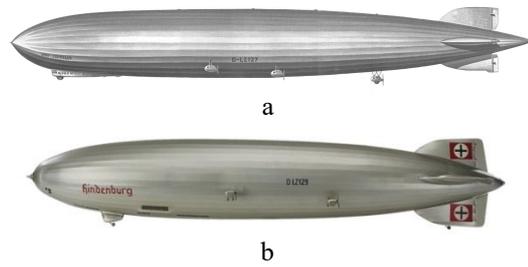


Figure 2 Airship with rigid structure(a.Graf Zeppelin, b. Hindenburg)

In Figure 3 we highlighted some historical landmarks and the constructive types of the airships, [2, 3, 13 and 16].

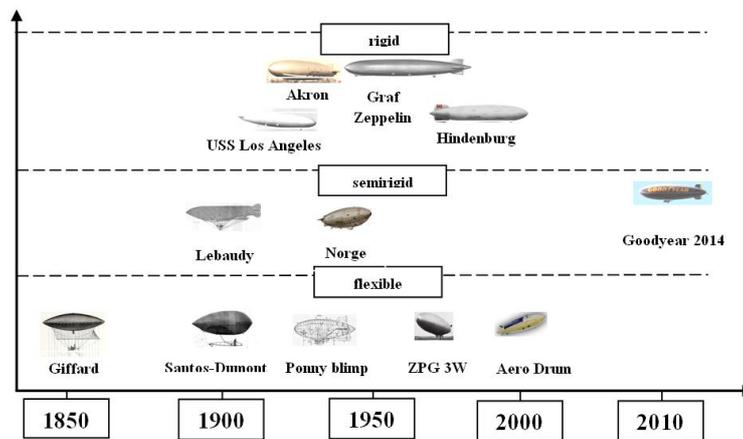


Figure 3 Airships categories in timeline

1.2. Missions and areas of use

UAVs have confirmed their usefulness especially in missions given in areas of interest by military and civilian users. Stability qualities of the LTA unmanned aerial platforms directly favored the quality of the data provided by the sensor sensors (EO-IR, atmospheric, radar, CBRN sensors) that made it possible to carry out C4 or ISR military missions such as border security, surveillance of areas port (maritime and river), critical infrastructure protection (see Figure 4) or civil uses: sports and cultural events, communication routes, natural disasters and environmental protection.



Figure 4 LTA systems, [4]

1.3. Current projects and development trends

For the military area, according to the literature [8], we can recall the most important uses of this type of unmanned LTA air vector, such as for elongated envelope aerostats:

- High Performance Systems Testing and Sensors (ATB - Raven, JLENS - Tethered Communications Inc.), see Figure 5a;
- Framework for ISR missions as a real-time PGSS for force protection and FOB protection, threat detection system for long-term ISR missions (real-time FOB protection and C-IED support (Lockheed Martin), RAID aero systems for panoramic surveillance missions (manufactured by TCOM) for early warnings of possible threats but also tactical information or small, compact (see Figure 5b) REAP systems, fast and recoverable, mobile systems for ISR - STMPAS;
- aerial platforms for long-range detection and monitoring and state borders (TARS systems owned by DoD);



Figure 5 Airborne aerial platforms, a.JLENS program, b.REAP aerostat, [8].

For propelled airships:

- Airborne C4ISR low altitude overhead navigation for the development of the Air Force Rapid Response (QRC) capability by integrating local or distributed multisensory for real-time and post-mission information analysis;
- Flight Demonstrator for long and high altitude ISR and COMMS missions with a payload of approximately 900kg (HALE-D airship), see Figure 6a;
- Low-cost concept (Hi-Sentinel) for military security missions (communications relay and border protection), see Figure 6b.



Figure 6 Airborne aerial platforms, a. HALE-D airship, b. Hi-Sentinel airship, [8].

According to the specialty references, research trends [8, 14, 15, 16, and 17] converge to the approach of new concepts for Archimedes envelopes such as semi-flexible envelopes with inflatable ribs, hybrid semi-flexible envelopes (see Figure 7) or multi- determines aerodynamic and operating behaviors at higher levels.



Figure 7 Future hibrid airship, [8]

2. Aerostatic and aerodynamic elements of the airship

2.1. ISA Atmosphere

LTA aircraft depend on the principle of buoyancy, the density of the displaced and displaced fluid; we have in Table 1 the properties of the standard atmospheric at sea level.

Table 1. Properties of the ISA atmosphere

Properties	Value	Properties	Value
Temperature T_0	288,15 K (15 ⁰ C)	Pressure p_0	101325 N/m ²
Density ρ_0	1,225 kg/m ³	Cinematic viscosity	1,5x10 ⁻⁵

Where pressure and density are temperature dependent at a given altitude, and the temperature gradient is temperature dependent:

$$T = 288.15 - 0.0065 \cdot h \quad (1)$$

Where h is the height and air density:

$$\rho = \rho_0 \cdot \left(\frac{T}{T_0}\right)^{4.3} \quad (2)$$

And the pressure is:

$$p = p_0 \cdot \left(\frac{T}{T_0}\right)^{5.3} \quad (3)$$

And the net load force L_N is:

$$L_N = g \cdot V_G \cdot (\rho_G - \rho) \quad (4)$$

Where V_G is the gas volume, ρ_G is the gas density.

The properties of the gases that can be used are listed in Table 2 and Figure 7.

Table 2. Gas properties, [9]

Gas	Density (kg/m ³)	Lifting force (N/m ²)	Observation
Hot air	0,906	3,14	inert, very cheap
Hydrogen	0,085	11,2	inflammable
Helium	0,169	10,2	inert, expensive

For helium, density is calculated based on percentage purity k:

$$\rho_{He} = (k \cdot 0,169 + (1 - k) \cdot 1,225) \quad (5)$$

To assess the aerodynamic forces acting on the airship, we have:

$$F_L = \frac{\rho \cdot V^2}{2} \cdot S \cdot c_L \quad F_D = \frac{\rho \cdot V^2}{2} \cdot S \cdot c_D \quad (6)$$

Where F_L is the carrying force, F_D forward resistance force (see Figure 8) and S is the projected surface area of the flexible envelope is considered to be horizontal and vertical. For the Archimedes force, S will be considered the envelope revolution area corresponding to the total volume for the flexible envelope is considered.

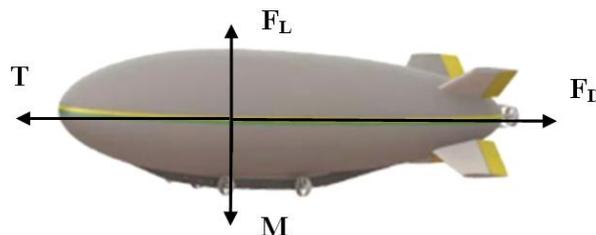


Figure 8 Forces of the airship, T-traction, M-mass, F_L-lift, F_D-drag

2.2. Sizing the flexible envelope of the airship

The design of the flexible envelope comprises the dimensioning of the flexible envelope and the calculation of the envelope, [9, 10, 11, and 12], as follows:

a. The dimensioning of the flexible envelope (Figure 9) includes the calculation of revolution areas, maximum sections and volume).

- dimensioning of the maximum surfaces and sections:

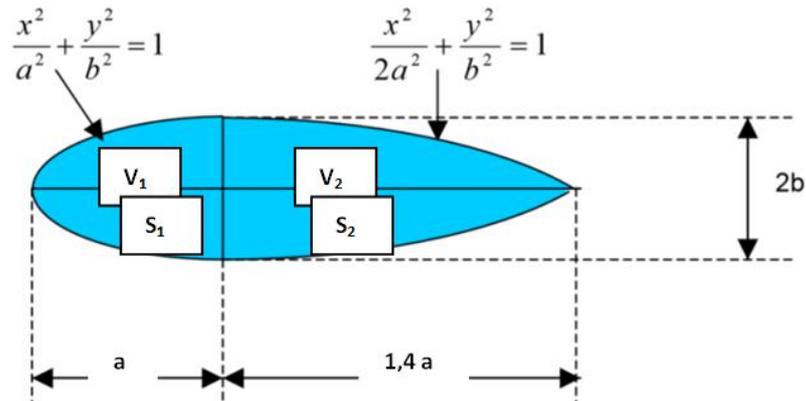


Figure 9 Flexible envelope dimensioning, [10]

The total area is:

$$S_T = S_1 + S_2$$

But from [9, 10] we have:

$$S_1 = \pi \cdot b \cdot \left[b + \frac{a^2}{\sqrt{a^2 - b^2}} \cdot w_1 \right] \quad (7)$$

Where w_1 is

$$w_1 = \sin^{-1} \frac{\sqrt{a^2 - b^2}}{a}$$

And

$$S_2 = \pi \cdot b \cdot \left[0,7 \cdot \sqrt{0,06 \cdot a^2 + 1,97 \cdot b^2} + \frac{2 \cdot a^2}{\sqrt{2 \cdot a^2 - b^2}} \cdot w_2 \right] \quad (8)$$

Where w_2 is:

$$w_2 = \sin^{-1} \frac{1,4 \cdot \sqrt{2 \cdot a^2 - b^2}}{2 \cdot a}$$

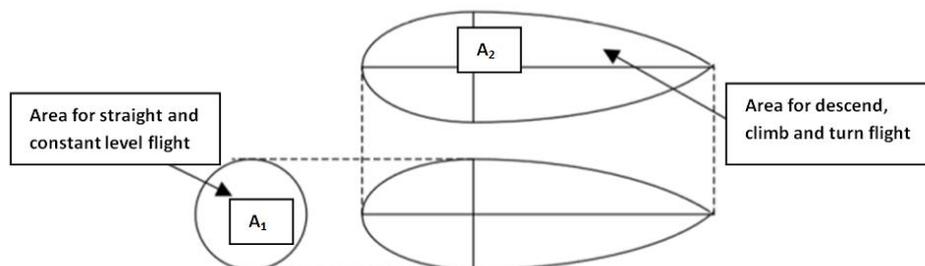


Figure 10 Maximum sections

The maximum sections are, see Figure 10:

$$A_1 = \pi \cdot b^2 \quad \text{și} \quad A_2 = \frac{\pi}{2} \cdot a \cdot b + 0,509 \quad (9)$$

From [9, 10] the total volume (see Figure 9) is:

$$V_T = V_1 + V_2$$

Where

$$V_1 = 0,67 \cdot \pi \cdot a \cdot b^2 \quad \text{și} \quad V_2 = 0,94 \cdot \pi \cdot a \cdot b^2$$

b. The calculation of the balance comprises the determination of the center of gravity and the buoyancy center, see figure 11.

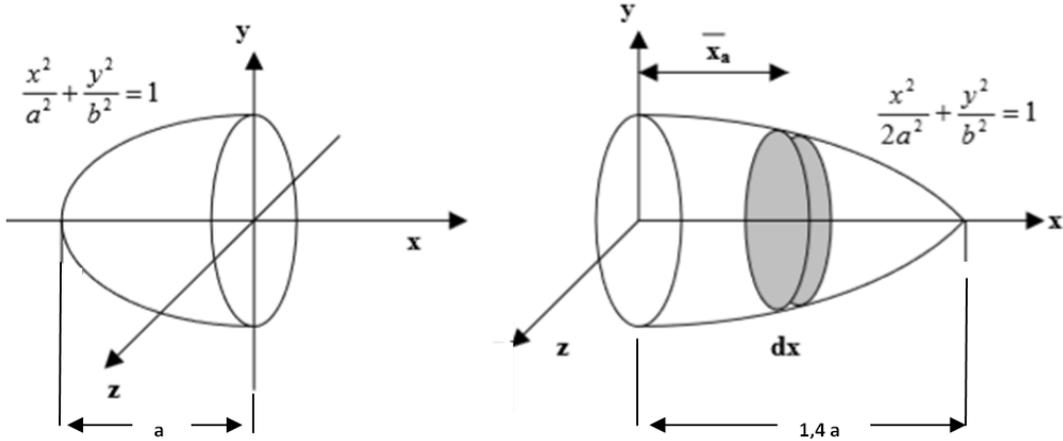


Figure 11 Flexible envelope balance

have:

$$\bar{X} = \bar{x}_1 \cdot V_1 - \bar{x}_2 \cdot V_2$$

where

$$\begin{aligned} \bar{x}_1 \cdot V_1 &= \int_a^0 x \cdot \pi \cdot r^2 dx = \int_a^0 \pi \cdot \left(x - \frac{x^3}{a^2}\right) \cdot b^2 dx \\ \bar{x}_2 \cdot V_2 &= \int_0^{1,4a} x \cdot \pi \cdot r^2 dx = \int_0^{1,4a} x \cdot \pi \cdot \left(1 - \frac{x^2}{2 \cdot a^2}\right) \cdot b^2 dx \end{aligned} \quad (10)$$

3. Aerodynamic analysis

3.1. Airship description

For an in-depth understanding of the behavior of the airship in quasi-stationary conditions and at low speeds, propose the aerodynamic concept of Figure 12 with the characteristics of Table 3.

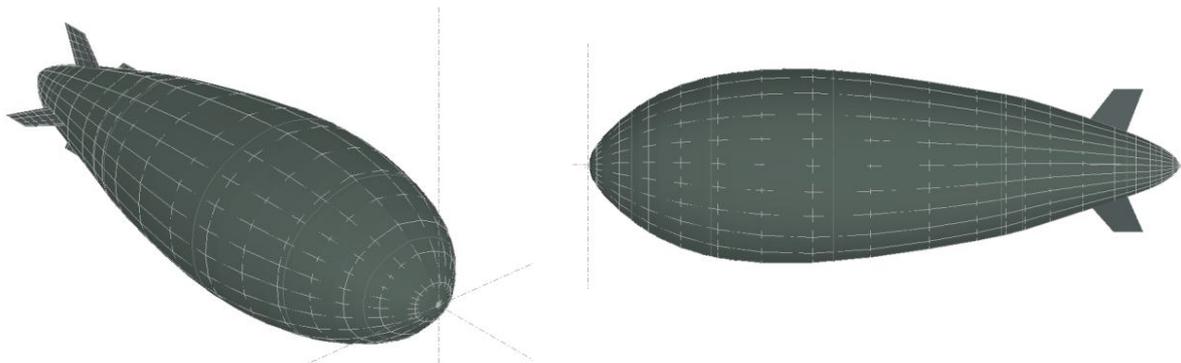


Figure 12 Airship aerodynamic concept

Table 3. Technical features [5]

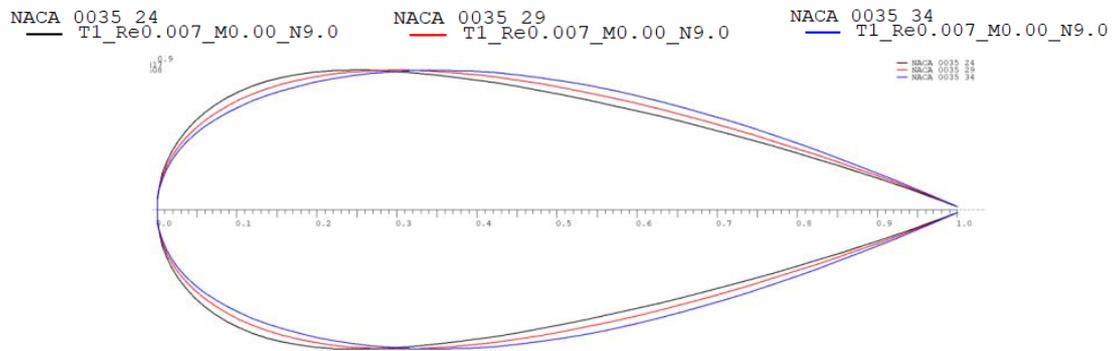
Features	Value	Features	Value
Lenght / diameter (m)	5 / 1,7	Lift capacity (kg)	1,2
Volum (m³)	8	Envelope	polyurethan
Fins	4	Max. helium loss	0,5% / day

3.2. Aerodynamic analysis

3.2.1. Aerodynamic 2D analysis

The Archimedean envelope of the airship equated to the NACA 0035 profile family, of Figure 13, profiles with a maximum thickness of 24% to 34% of the chord; the 2D equivalent profile analyzes comprising:

a. The geometrical stage, by defining the aerodynamic profiles used in the aerodynamic analyzes (NACA 0035 profile family) and comprising the determination of the maximum thicknesses, its position with respect to the attack board and the curvature value, [6, 7].

**Figure 13** Geometric definition of aerodynamic analysis profiles

b. The actual analysis stage containing the determination of the initial parameters listed in Table 4.

Table 4. Initial 2D analysis parameters

Parameter	Value	Parameter	Value
Nr. Reynolds	7000 ÷ 35000	Angle of attack	-5 ⁰ ÷ 15 ⁰
Iterations	100	Density	1,225 kg/m ³

Figure 14 shows the variation of the most important aerodynamic parameters of the NACA 0035 profile family.

Moving the maximum thickness to the escape board produces an increase in the value of the bearing coefficient (Figure 14a), an increase in maximum absolute values around the incidence of 10⁰. The coefficient of drag C_d, on the 0⁰-8⁰ range of incidence, is lower with (Figure 14b) but after 8⁰ the aerodynamic behavior of the C_d is reversed.

The increase in incidence and the movement of the maximum thickness to the runway causes higher C_m drop times see Figure 14c, and the C_l/C_d aerodynamic gliding ratio increases with the maximum thickness movement to trailing edge (C_l-like behavior).

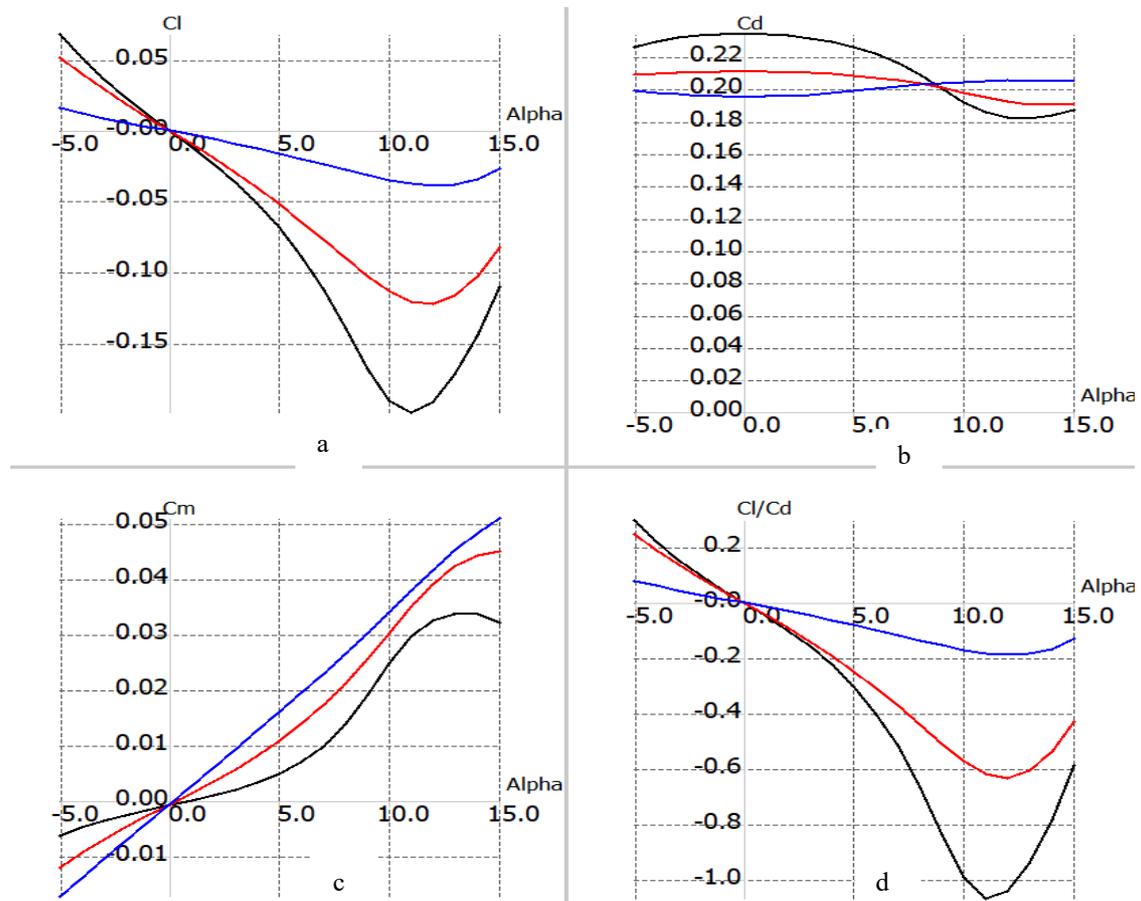


Figure 14 The aerodynamic coefficients of the NACA 0035 family, a. C_l – lifting coefficient, b. C_d – drag coefficient, c. C_m – Pitch moment coefficient, d. C_l/C_d – gliding ratio.

In the case for more accurate approaches of the calculation methods (numerical and computational for lift and drag estimation) can be adopted from [18, 19, and 20], for the pressure coefficients (c_p):

$$c_p = 1 - \left(\frac{u_t}{v_\infty} \right)^2 \quad (11)$$

Where u_t – tangential speed (for each control point) and v_∞ - flight speed.

3.2.2. 3D aerodynamic analysis.

These include cases of quasi-analytical analysis without taking into account the effect of archimedical forces. Analyzes are performed at a speed range of $0.1 \div 0.5$ m / s and a drift of 0° . The 3D geometry of the flexible envelope equipped with four ampoules approximates a NACA 0035 profile.

Figure 15a shows an increase in net values with increasing incidence angle, the maximum load bearing force generated by the flexible envelope corresponds to an incidence of 13° .

Very low side forces become negligible with increasing flight incidence (Figure 15b), the existence of lateral force values is due to approximate 3D design.

The drag force F_x increases with absolute values (sign convention) as the incidence increases (Figure 15c).

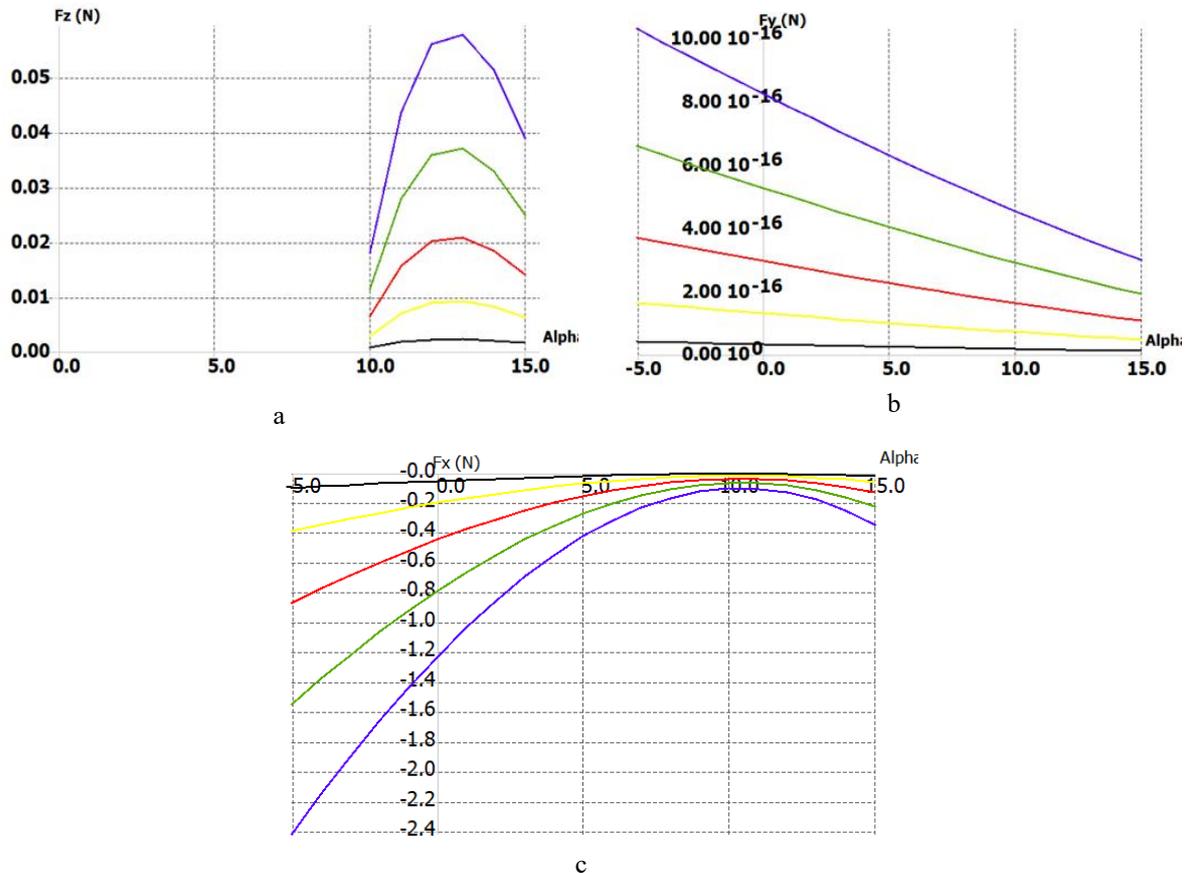


Figure 15 The aerodynamic forces on the flexible envelope (F_z – lift, F_y – lateral force, F_x – drag)

Conclusions

Current research in LTA robots continues to focus on command and control solutions, collision prevention, take-off and landing techniques, increased reliability and safety, human machine interface.

The development of on-board unmanned aircraft in the aerostatic concept offers tactical advantages to the beneficiary structures, especially in data acquisition architectures (weather forecasts, EO-IR) for providing automatic alerts.

From the presentation of theoretical parts and aerodynamic analyzes, the importance of the aerodynamic concept chosen for the flexible airships of the airships is obvious. The accuracy of design determines the approach of aerodynamic calculations that require the use of software tools with a higher degree of confidence. Although the software tool used has a number of calculation limitations, it provides credible benchmarks for the pre-design steps and subsequent low-cost approaches to CFD steps with commercial software tools and eventual aerodynamic testing.

Further aerodynamic and stability analyzes can be approached in the conditions of a fly-by-angle flight and at the specific airspeed approach speeds. These numerical instrumentations may take into account the effect of mass and ground conditions on the onboard mass concentrations (propulsion, onboard sensors).

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References

- [1] <http://thepandorasociety.com/the-first-steam-powered-airship> , consulted at 12.01.2018
- [2] <http://www.airships.net/hindenburg/lz129-hindenburg-detailed-history/>, consulted at 14.01.2018
- [3] Ladislav D'Orcy, *D'Orcy's airship manual*, New York, The Century co., 1917, 243p.
- [4] *Defense Acquisitions: Future Aerostat and Airship Investment Decisions Drive Oversight and Coordination Needs*, Report to the Subcommittee on Emerging Threats and Capabilities, Committee on Armed Services, U.S. Senate, 2012, available at <http://www.dtic.mil/dtic/tr/fulltext/u2/a570004.pdf>
- [5] <http://www.rc-zeppelin.com/outdoor-rc-blimps-5m.html> , consulted at 18.01.2018
- [6] *** *Guidelines for XFLR5 v6.03*, 2011, 71p.
- [7] Prisacariu V., Cîrciu I., Boşcoianu M., *Flying wing aerodynamic analysis*, REVIEW OF THE AIR FORCE ACADEMY, 2/2012, Braşov, Romania, ISSN 1842-9238; e-ISSN 2069-4733, p 31-35.
- [8] Office of the Assistant Secretary of Defense for Research and Engineering, Rapid Reaction Technology Office, *Lighter-than-air vehicles*, 90p, available at http://www.defenseinnovationmarketplace.mil/resources/Final_LTA_report.pdf, 2012
- [9] Gabriel A. Khoury, and J. David Gillett., *"Airship Technology"*, Cambridge University Press, United Kingdom, 2000
- [10] MINI AIRSHIP PATROL CRAFT, National University of Singapore, 2003, U006270J11, available at <http://dynlab.mpe.nus.edu.sg/mpelsb/AEG/airship/thesis.pdf>
- [11] Technical manual of Airship aerodynamic, War Department, Washington, SUA, TM 1-320, 1941
- [12] Joseph B. Mueller, Michael A. Paluszek, *Report - Development of an Aerodynamic Model and Control Law Design for a High Altitude Airship*, American Institute of Aeronautics and Astronautics, 2004, 17p
- [13] Ladislav D'Orcy, *D'Orcy's Airship Manual*, The Century Co., New York, 1917
- [14] Daniel Nachbar, John Fabel , *Next generation thermal airship*, Skyacht Aircraft, Inc., 2003, available at <https://pdfs.semanticscholar.org/0d1a/348775e5b2f0065188d70b3f05e71fdd5cd8.pdf>
- [15] Kirilin A., Boldyreva A., *Functional capabilities of new generation transport airships gas-air system*, 10th International Airship Convention, Friedrichshafen 2015, 10p, ID: 380005, disponibil la www.dglr.de/publikationen/2015/380005.pdf
- [16] Kirilin A., *Do new generation airship change a paradigm in transport logistics?* , 10th International Airship Convention, Friedrichshafen 2015, 10p, ID: 380017, available at <http://www.dglr.de/publikationen/2015/380017.pdf>
- [17] Barry E. Prentice, Robert Knotts, *Cargo Airships: International Competition*, Journal of Transportation Technologies, 4/2014, p.187-195, available at <http://dx.doi.org/10.4236/jtts.2014.43019>
- [18] Rotaru C., Cîrciu I., Boscoianu M., *Computational methods for the aerodynamic design*, Review of the Air Force Academy, 2(17)/2010, ISSN:1842-9238, p43-49.
- [19] Anderson, Jr., John, D., *Fundamentals of Aerodynamics*, Fourth Edition, McGrawHill, New York, USA, 2007;
- [20] Rotaru C., Edu Raluca Ioana, *Lift capability prediction for aerodynamic configurations*, Review of the Air Force Academy, No 3 (27) 2014. ISSN:1842-9238, p.57-62.