DOI: 10.13009/EUCASS2022-4555

Adaptative structures: the key for future airship certification A challenge for light flexible structure and predictive control

*Yves Gourinat * and Laura Christon **
** ISAE-SUPAERO – Université de Toulouse*
10, avenue Édouard Belin BP54032 31055 Toulouse Cedex 4 France

Abstract
The major challenge for certification of airships remains in the dynamic instability of large flexible structures. Progress in this area is in line with current aerospace programs for cryotechnic flying wings and heavy space vehicles, and general control of light structures. Recent developments that combine generalized predictive control with hybrid dynamic models (shell-fluid meta-modes) open up perspectives that now make airship certification feasible. The thermodynamics of the gust and turbulence could thus be mastered on a large scale, by combining complex models in real time, anticipatory turbulence measurements by Lidar, and direct implementation in the electric flight controls.

1. Introduction - The scientific context of NewAerospace

In the - essential - perspective of the durability of aerospace structures, the active and passive control of flexible structures is a major challenge for which decisive progress has been made recently by active and passive solid dynamics.

These improvements are due to several fundamental changes in the way we think, which are not without resistance. But the issue is central, since it concerns nothing less than the development of a truly sustainable aviation.

The first bridge is the one that connects mechanics (solid and fluid) on the one hand to information sciences in their most fundamental aspects of observability and controllability. In fact, this bridge is based on the full application of the four principles of thermodynamics, both in the physical domain and in the domain of information management (measurement and control).

These developments have led to the full integration of Generalized Predictive Control (GPC) in the preliminary design of structures and associated embedded systems. The second decompartmentalization is regulatory. Indeed, in the challenge of moving from space qualification (cryotechnics for example) to aeronautical certification, it is essential to jointly optimize the performance and reliability of the system as a whole.

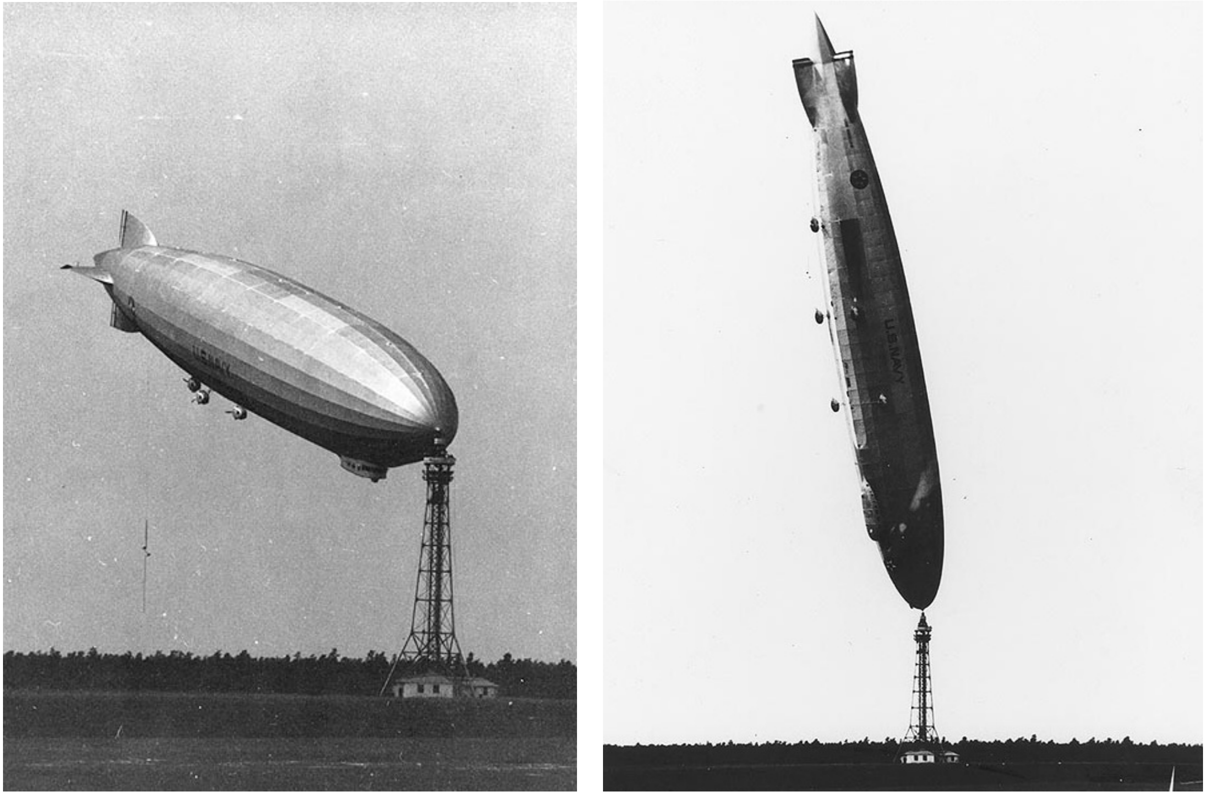
In this context, taking into account the scientific advances recently made in these fields, it becomes possible to consider the realization and the certification of an operational aerostat certifiable under certain conditions.

2. Technological and regulatory challenges

The main obstacle that has continually compromised the certification of large airships up to now is the dynamic control of very large structures. Indeed, the concept of a rigid airship can only be relative, and history shows that all large balloons have been destroyed for dynamic reasons (gusts, landing, turbulence).

Here arises a major problem related to the scale of the structure. Indeed, in dynamic similarity of Froude - which governs the structural modes and fluid-structure interaction - the stabilization of a large structure is extremely complex, it is a major challenge.

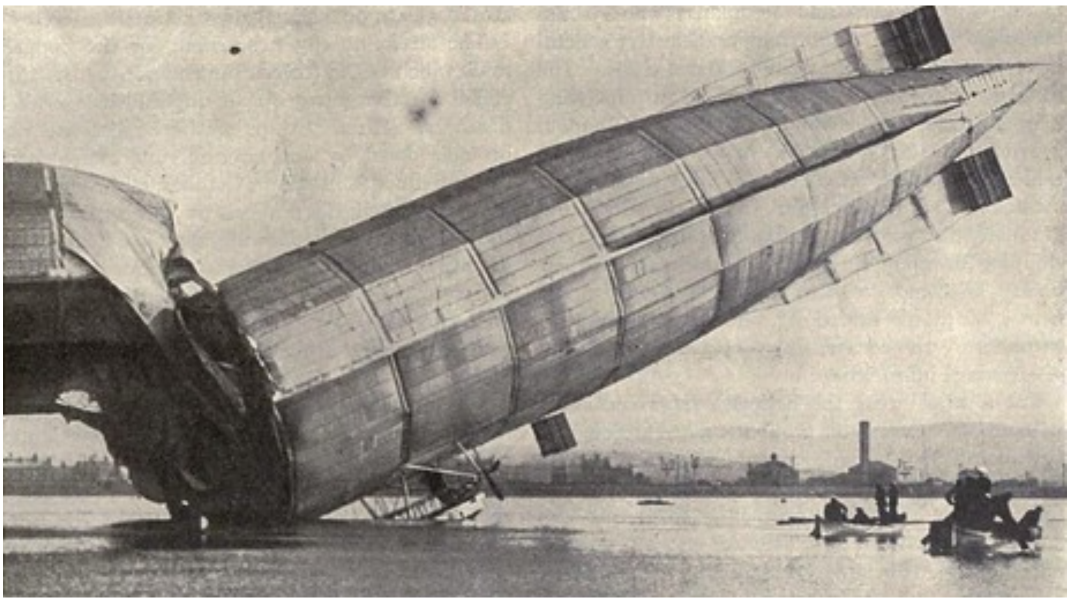
DOI: 10.13009/EUCASS2022-4555



Ground incident, USS Los Angeles (ZR-3), Lakehurst Aug.25 1927

This is due both to kinetic problems related to inertia (including rotations, effects too long ignored) and also to bifurcation instability (buckling or warping) related precisely to the slender character of large structures.

In addition, there are internal fluid interactions (acoustics, ballooning, inertia) and external interactions (transient and permanent aerodynamics, rigid and flexible flight dynamics).



Vickers airship, shear instability (gust. shock)

The active control already applied to convertible helicopters, associated with specific high entropy materials and the temporal prediction of loads and their transient and cyclic impacts represent considerable but recent advances.

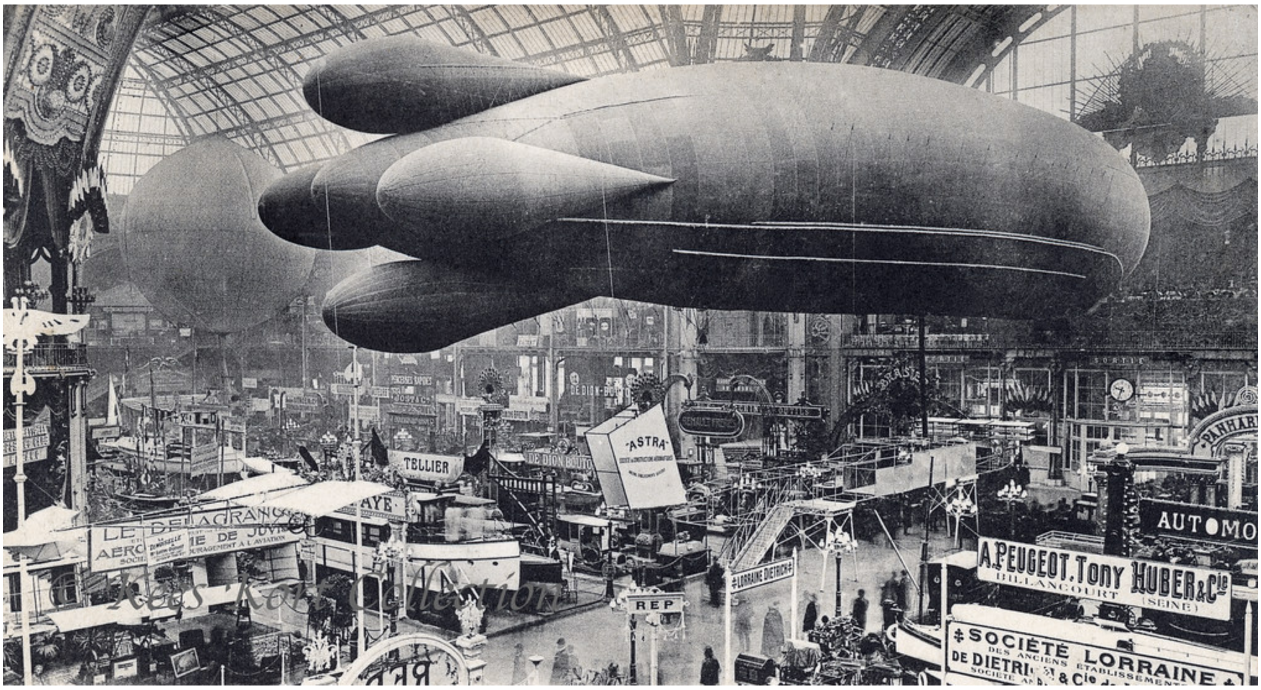
DOI: 10.13009/EUCASS2022-4555

This whole process is made possible by the emergence of high-level numerical and analytical models, integrating hull-fluid interactions and geometric and mechanical non-linearities. Thus, the algorithms developed for the electric flight controls implemented in aircraft and launchers can now consider building and qualifying a very large airship.

At this point, it is important to dispel a myth: the danger of the airship does not come from hydrogen, but from the dynamics. With one or two exceptions in the entire - epic - history of airships, all have perished in storms or through control errors. Obviously, a hydrogen tank should not be hit by an incendiary bullet, but the same is true of a kerosene tank (not to mention aviation gasoline...).

The cost and especially the world reserves of Helium (which is a fossil resource, because it is drawn from fossil reserves...) require us to reserve it for strategic uses such as microelectronics, chemistry or biology. The use of hundreds of thousands of cubic meters of Helium for aerostation is a luxury we cannot afford - from an environmental point of view.

We will have to fly with hydrogen, which we model perfectly (almost better than Helium...) and which is actually very old. Indeed, let's remember that Paris has known, throughout the 19th century, a perfectly safe network of lighting gas (for public lighting in particular), which gas is made up of at least 50% hydrogen. Moreover the balloonists were supplied directly on this network to inflate their balloons. And so we see a balloon with lighting gas in the middle of the Grand Palais (yes, indoors...) at the 1908 aerial locomotion show.



Paris Air-Show 1908, in “Grand Palais”

DOI: 10.13009/EUCASS2022-4555

3. Scientific locks

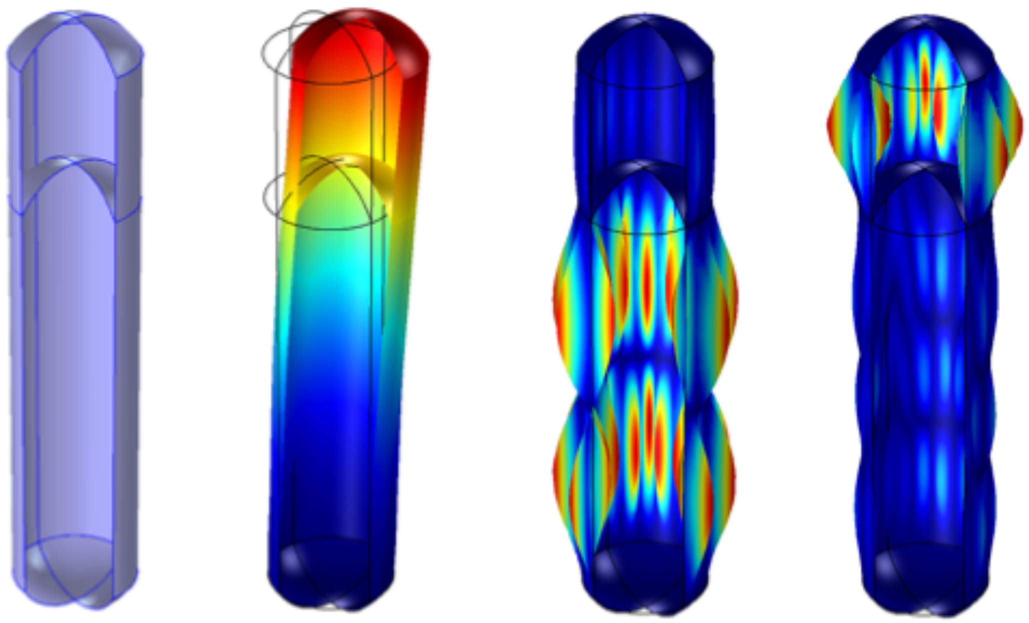
As far as active control is concerned, the current ability to integrate thermodynamic models of membrane-beam in internal aeroacoustic and external fluid interaction in numerical flight controls makes it possible to actively stabilize the structural dynamics. What is possible in the modal vibro-acoustic domain - and currently very well mastered for Newtonian fluids - is being mastered for explicit transient regimes.

The challenge here is the integration of the complete automation of the servo-control in large, highly non-linear structures. This process was initiated by the dynamics of hulls in their unstable deformations, and the emergence of complete models with global meta-modes - similar to those used on large telescope mirrors to compensate for atmospheric turbulence - is starting to provide robust algorithms for these flexible structures.

Specifically, hybrid models with a Lagrangian representation of Reissner membranes and shells (with local U, V, W deflections in the principal axes of curvature of the surface) coupled with an Eulerian volume parameterization of the fluid (with a p-fluctuation of pressure) lead to an explicit matrix of mass [M] and statics [K], and to an explicit hybrid matrix of impedance [Z].

The major challenge here is naturally the rectangular coupling block in each dynamic matrix. These processes are well known in the linear domain and in the linear representation (step-by-step), and in progress in the non-linear explanation. Current work related to cryogenic reservoirs and internal particle models related to these shells (granular and integral equation models) show excellent prospects in this field.

The development of models of large parachutes have also strongly contributed to these advances. Finally, the general but recent implementation of complete hull theories - in particular non-developable - is a factor of substantial improvements of the conceptual reliability of this type of thin structure.



LH2-Shell interaction, computed meta-modes for cryotechnic tank (Doc ISAE-SUPAERO)

Moreover, the integration - in the very thickness of structural shells - of non-linear dissipative polymeric materials - previously developed for noise control in plates - and external 3D observation for load anticipation now allow the truncation of gusts, shocks, resonances in real time, for safety, comfort and performance purposes.

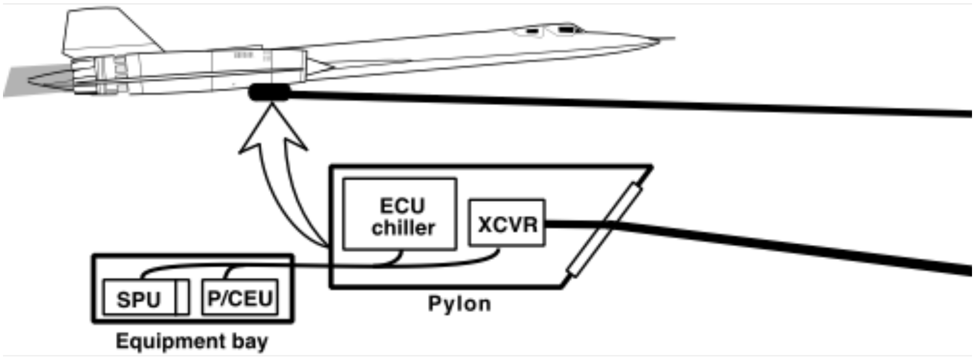
Great progress has been made recently in the dynamic conditioning of structures at medium frequencies - a few tens of Hz - thanks to the use of reinforced, interlocking materials, internal particle anti-resonance in honeycombs, and also to the integration of specific layers by Additive Manufacturing.

DOI: 10.13009/EUCASS2022-4555

4. Technological issues for observability & controllability of structures

These structures, well modeled and conditioned according to the latest advances, lend themselves, despite their flexibility and instability, to the extensive implementation of Generalized Predictive Control. Just as atmospheric turbulence is measured by a LiDAR to anticipate its effects on the light, and thus correct in advance the dynamic shape of the telescope mirror, so it is necessary to anticipate turbulence and gust upstream of the aircraft of the future. This will be very useful for the airplane and helicopter of the future, for reasons of performance, comfort and safety, but it is essential for the contemporary airship. It will not be operational without it, given the flexibility and dynamics involved.

The LiDAR has been installed on SR-71 with a 120 kg facility ; the principle of turbulence and gust prediction is demonstrated.



SR-71 LiDAR Test in flight (Doc.NASA)

The future issu is thus to combine this measure with predictive control. This consists in the anticipation of the dynamic response and counter-response, with an adapted model.

The challenge is here to integrate GPC process with high level models: shells with internal and external fluids, non-linear deflections with strong membrane – non-membrane couplings, thermodynamic effects including thermoelastic couplings and local convection, and – last but not least – real time evolution of the digital embedded model.

These approaches have already been implemented on aircraft in operation, for example on convertibles, and allow a triple decompartmentalization that is essential - and even vital - if we wish to develop an airship. The GPC capabilities on intricate configurations – including the gyroscopic flutter – has been demonstrated on gonfigurations close to the standard European ERICA concept.

ERICA European configuration for Tilt-design

These technologies will find a natural application in the Hydrogen Flying Wing, a future large-capacity aircraft at M~0.3 or 0.6, as well as in the heavy launcher of the future, but also for our airship.

DOI: 10.13009/EUCASS2022-4555

The first decompartmentalization is the integration of the flight controls from the first pencil stroke until the end of the structure's life. In other words, this is the integrated mechanical-automatic architecture.

The second break, linked to the first and already underway, is the fundamental link between performance and safety, that is to say that it is not only a question of no longer opposing the two, but also of considering that one cannot go without the other. It is in fact the same quality criterion. Finally, the third bridge is that of the vital link between architects, users and certifiers, with procedures, definitions and regulations moving forward together.

5. Conclusion - The New Certification

These scientific, organizational and communication evolutions between TRLs are underway; it is now possible to consider implementing these processes in the certification rules themselves for large airships, in agreement with airworthiness authorities, architects and operators.

This will include protection against gust, turbulence, but also untimely maneuvers. In fact, this is the culmination of more than thirty years of experience in improving the comfort of aircraft with electric wing controls. We must now integrate them into complex, thermodynamically unstable models and - above all - prepare the certification of these architectures.

The presence of new materials, not only amorphous and fibrous, but also partially ceramic, used for their thermodynamic properties, also leads to important progress in modeling which will benefit the whole aerospace sector, including aircraft and launchers.

This new regulation is probably the key to large airships operating for broad civil applications. It will not only generate significant activity, but also a significant shift towards sustainable development, both development and sustainability. It therefore goes beyond the strict domain of aerostats, but also has ramifications for air and ground vehicles in general.

DOI: 10.13009/EUCASS2022-4555

References

1. Pichault M, Vincent C, Skidmore G, Monty J. LiDAR-based detection of wind gusts: An experimental study of gust propagation speed and impact on wind power ramps. Journal of Wind Engineering & Industrial Aerodynamics 220, 104864, 2022.
2. Yoshiro H, Ryota K, Hamaki I. LIDAR-based Gust Alleviation Control System: Obtained Results and Flight Demonstration Plan. IFAC-PapersOnLine Vol.53, Issue 2, Pages 14839-14844, 2020.
3. Khamlia M. Contribution à la modélisation et la commande des dirigeables gros porteurs non-conventionnels. Thèse de doctorat de l'Université Paris-Saclay et de L'Ecole Polytechnique de Tunis, 2019.
4. Haouas E. Modélisation et commande d'un dirigeable gros porteur dédié au transport de matières premières. Mémoire MsC, École de Technologie Supérieur, Université du Québec, 2018.
5. Berger T, Tischler M, Hagerott SG, Cotting MC, Gray WR, Gresham J, George J, Krogh K, D'Argenio A, Howland J. Development and validation of a flight-identified full-envelope business jet simulation model using a stitching architecture. AIAA Modeling and Simulation Technologies Conference, AIAA 2017–1550, 2017.
6. Giesseler HG & Kopf M & Varutti P, Faulwasser T, Findeisen R. Model Predictive Control for Gust Load Alleviation. 27-32, 2012.
7. Dabo M. Commande prédictive généralisée non linéaire à temps continu des systèmes complexes. Thèse de Doctorat, Université de Rouen, 2010.
8. Mueller J, Gourinat Y, Ferrer R, Krysinski T, Kerdreux B. A Numerical Study on Active Control for Tiltrotor Whirl Flutter Stability Augmentation. Journal of the American Helicopter Society ISSN 0002-8711, Vol.51#3, pp.244-254, Jul.2006.
9. Dufour P. Contribution à la commande prédictive des systèmes à paramètres répartis non linéaires. Thèse de Doctorat, Université Claude Bernard - Lyon I, 2000.
10. Soreide D, Bogue RK, Ehernberger LJ, Bagley H. Coherent Lidar Turbulence Measurement for Gust Load Alleviation. NASA Technical Memorandum 104318, 1996.