Industrial training report
Buildair Engineering & Architecture

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1 Introduction

This report reviews all the tasks performed during my industrial training in the company *Buildair Engineering & Architecture (Buildair)*. In this section the scope of the company is stated and the tasks carried out are briefly described.

1.1 Scope of the company

Buildair designs, construct and deploy temporary inflatable structures mainly used as shelter for airplanes, helicopters or even emergency situations. The technology of these inflatable hangars involves multiple inflatable tubes (as much as the length the hangar) surrounded by a skeleton of different types of textile straps. During the deployment the tubes are inflated at low pressures (between 20 and 30 mbar) and fixed to the ground by means of mechanical anchorages (Hilti® type) or dead loads (sand ballast bags).

1.2 Main tasks summary

Due to the commercial nature of the company, I was not involved in a proper research project. Instead of this, I worked hand-by-hand with the Engineering Department according to their requirements. It has to be said that at my arrival, the company was designing two hangars. Thus, the majority of my work has been related with these two projects:

- H20 Summit Polska: 20 meters interior span inflatable hangar.
- H35 Airbus Military: 35 meters interior span inflatable hangar.

The main tasks carried out around these two projects were 3-D structural analysis of the hangars and their parts using RamSeries and 2-D and 3-D CFD analysis using Tdyn. Other complementary tasks are commented below.

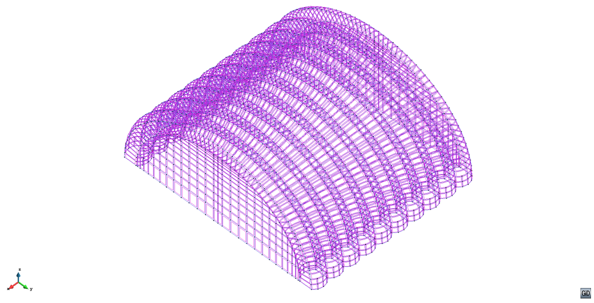
2 Structural simulations of inflatable structures

The original idea of my supervisor was to do a parametric study of all the hangars present in the catalog of Buildair. However, we both agreed that it would be much more interesting to carry out the CFD studies that are explained below. Despite this, I performed several structural simulations, specially during the first moth of my industrial training, related with the two projects mentioned in the previous section.

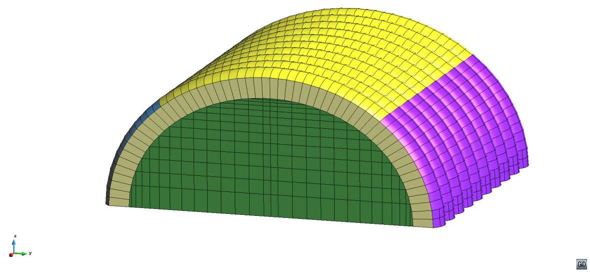
2.1 Particular features of the simulation of inflatable structures

Due to their recent apparition, it is interesting to comment a few words regarding the main features of the simulation of inflatable structures. During all the industrial training, the structural simulations were carried out using the solver Ramseries. Ramseries is a FE environment capable of solving lots of structural problems in 2-D or 3-D.

As can be guessed, the simulation of inflatable hangars must be done in 3-D since they have a multidimensional behaviour. Regarding the element type, the most suitable one to simulate the textile material of the tubes is the membrane element. Thus, this membrane elements can be viewed as a sort of shell that cannot resist compressive loads but suffers from wrinkling. On the other hand, the straps skeleton surrounding the tubes is modeled with cable elements since it is made with textile material which only resists tensile loads. Figure 1 depicts two screenshots of the structural simulation of the H35 hangar with Ramseries.



(a) Geometry representation.



(b) Renderized representation.

Figure 1: H35 Ramseries structural simulation screenshots.

On the other hand, it is also a must to comment that no contacts are considered for the sake of simplicity and computational cost. This assumption means that the cables are in some sense embedded in the textile, which is not the case in the reality (in field tests it has been possible to see that some strap regions are not perfectly contacting the textile). Moreover, this no contact assumption also implies to double the thickness of the textile in the contact regions between tubes (henceforth called ribs).

Finally, it is interesting to spend some words regarding the convergence, which is affected by the large deformability of this kind of structures. As a consequence, it is mandatory to use an incremental loads analysis combined with some type of stabilization. The stabilization present in Ramseries introduces an extra term in the main diagonal of the stiffness matrix, which is very bad conditioned in membrane problems. Thus, both the stabilization factor and the stabilization steps have to be wisely chosen to drive to the expected solution.

2.2 Structural simulations performed

As has been commented before the main purpose of the simulations performed was the structural design of the H20 and H35 hangars. In general terms, the simulations were mainly used for assessing the resistance of both the textile membranes and straps according to the EC standards. However, since at my arrival to the company the first design stage was completed for both projects, I was involved in more particular tasks such as:

- Maximum snow load assessment (H20).
- Maximum lateral wind assessment for avoiding the contact between the hangar and the wings of the design plane (H35) (figure 2).
- Anchorages design of front and rear doors (H35).

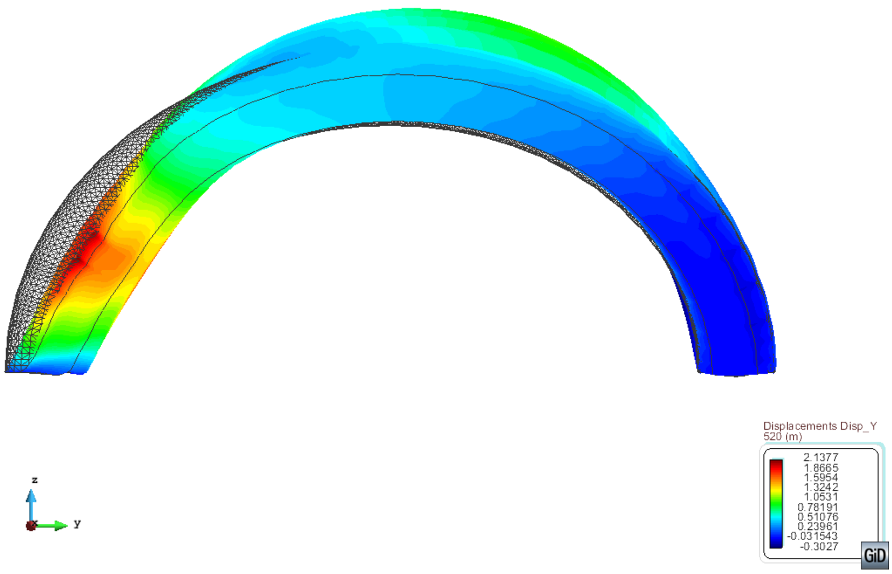


Figure 2: H35 lateral displacements under 120 km/h lateral wind.

Despite the fact that I was not present during the structural design of the hangar, the previously commented tasks were more than enough to learn how to perform numerical simulations of inflatable structures. Moreover, it is interesting to comment that all the simulations performed have been done from an industrial point of view, what is to say to simplify things as much as possible without losing the representativity of the models. To apply this concept of "practical simulation" has been quite interesting.

Finally, despite the fact that it is not closely related with the structural simulation of the hangars, it is a must to comment that during my industrial training some field tests of the H35 hangar were carried out (figure 3). My supervisor encouraged me to work with him in these tests. Being able to put the hands on what was previously simulated was an enriching experience. Indeed, it was quite interesting to assess the real behaviour of the structure and to compare it with the simplifications taken in the simulations.

(a) Inflation procedure. (b) Interior view.

Figure 3: Photographs of the H35 field tests.

3 CFD analysis of inflatable structures

It can be asserted that the CFD analysis of inflatable structures has been the spinal axis of my industrial training. The necessity of performing CFD analysis came from the fact that the engineering department required more knowledge about the air flow around an inflatable hangar in order to confirm their assumptions.

Moreover, the EC loads that had been considered are an interpretation (EC does not account for inflatable structures) and appeared to be too conservative. This was not a problem from the strength of materials criteria but it led to extremely oversized ground anchorages. In case of mechanical anchorages this can be easily overcome using larger screws. However, in case of anchorages made with sand ballast bags, the oversizing enters in conflict with the portable philosophy of these kind of hangars.

To sum up, the CFD analysis performed can be divided in two types according to their aim:

- 2-D CFD analysis: create a methodology for simplifying the computation of the anchorages.
- 3-D CFD analysis: get a deeper knowledge about the air flow around an inflatable hangar.

3.1 2D CFD analysis

As has been commented above, the purpose of these 2-D analysis was to create a simple and fast methodology for computing the ground anchorages or dead loads according to the CFD loads instead of the EC ones.

Hence, a set of 16 2-D CFD analysis were performed. This set contains four sizes of hangars present in the catalog of Buildair (H20, H35, H45 and H54), two different geometries (semicircular and elliptic) and two types of wind (frontal and lateral). Once all the models were computed, the pressure coefficients, based in the reference pressure of EC, were extracted in this way:

- Lateral wind: The hangar is subdivided in 12 sectors.
- Frontal wind: Only the front and back door pressure coefficients are extracted (it has been previously proven that lateral wind is more requesting in terms of anchorage).

With these pressure coefficient data a spreadsheet was prepared. In this spreadsheet the user selects the hangar and introduces the design wind speed to obtain the anchorage required according both lifting and sliding criterion.

Finally, it has to be said that, despite the methodology was prepared and ready to be applied, there was a surprisingly result that has to be further studied. This result appears under lateral wind in the leeward part of the hangar. In this region suctions are expected according to EC and literature but pressures appear instead. This was associated to the fact that in 2-D the assumption of extremely large hangar is taken and the border effects that generates a suction resultant does not appear (this conclusion was extracted by means of a 3-D model, in where suction appears as expected). However, a further study is pending to confirm this statement.

3.2 3D CFD analysis

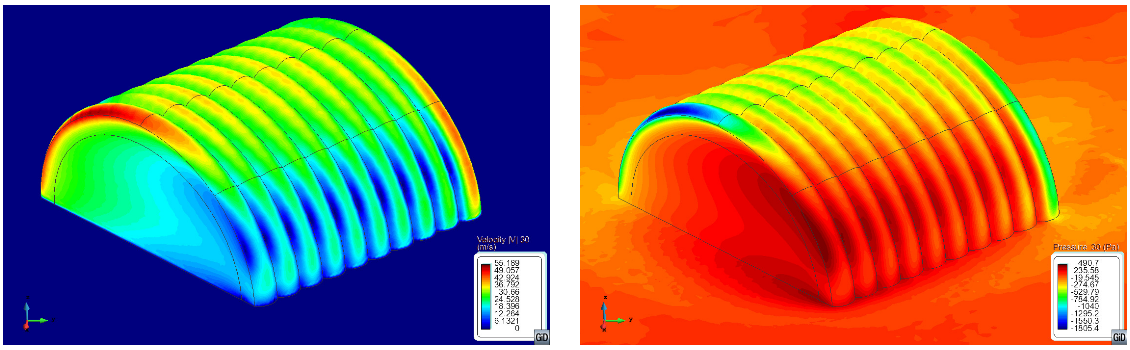
As it is already known, a 3-D CFD analysis is not as straightforward as other kind of computations. Therefore, lots of tests were carried out before obtaining the reference models that are presented in this section. Such tests were mainly related either with problem modeling aspects (e.g. the size of the computational box or the proper geometry of the hangar, specially in the opened hangar case) or with the time discretization parameters (reduce the computational cost without losing stability and representativity). Once the knowledge about 3-D CFD modeling was sufficient, the next models were computed and studied.

- H20 hangar: Lateral and frontal winds.
- H35 hangar: Lateral, frontal (opened and closed hangar) and 45°degrees (opened and closed hangar) winds.

The obtained pressure fields were compared with the ones given by EC for the closed hangar cases with frontal and lateral winds (other cases are not considered in the standards). It was observed that the obtained pressure fields have the expected distribution but the values of the CFD analysis were always between 2 and 3 times less than the EC ones. Hence, by means of these 3-D CFD analysis we were able to confirm that the EC loads are too restrictive and drive to oversized ground anchorages.

Regarding the closed hangar case under 45°degrees wind, it was quite useful for having an idea of the flux behaviour for this wind direction (figure 4), which is not present in EC. Furthermore, by means of this analysis we realize that the 45°degrees wind direction is the most restrictive in terms of the sliding ground anchorage criteria. This result is perfectly reasonable since the frontal projected area is maximum for 45°.

On the other hand, this 3-D CFD analysis collection were also performed to understand the opened hangar flow behaviour. Moreover, these opened door CFD analysis had two extra aims, firstly to assess how the bag effect is affecting the lifting and sliding resistance, and secondly to assess the loads in the back door when the hangar is opened. It has to be said that getting convergence and proper results of the opened hangars CFD models has been the roughest part of my industrial training due to the particular considerations that have to be taken into account during the geometry modeling and meshing.

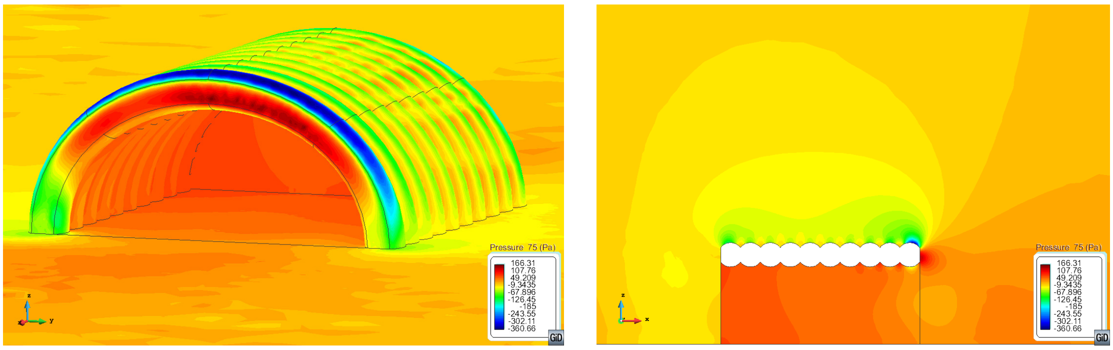


(a) Velocity field. (b) Pressure field.

Figure 4: H35 45°wind (90 km/h) results.

Figure 5 collects the pressure fields for the opened hangar case at 45 km/h. It was decided to fix this velocity since it is empirically known that the design velocity to open the hangar is around one half its design velocity. With these results, we concluded that:

- In terms of both global and local ground anchorage loads, the closed hangar at 90 km/h is slightly more restrictive than the opened one at 45 km/h.
- The rear door loads are between 2 and 2.5 times larger for the opened hangar case. However, this would not be a problem since the structural elements (tubes, junctures, ...) are designed according to EC standards, which are even more restrictive.
- The empirical law of the maximum door opening velocity is reliable.



(a) 3-D front view. (b) Cross section.

Figure 5: H35 opened front wind pressure field (45 km/h).

Finally it has to be said that a manual for performing CFD analysis of inflatable hangars was generated as well as several internal reports analyzing the obtained results.

4 Complementary tasks

This section briefly review some minor complementary tasks that are not closely related with the numerical simulation but were also performed during my industrial training. These tasks are the next ones:

- Creation of an automatic spreadsheet for obtaining the EC wind and snow loads particularized for the inflatable hangars case.
- Optimization and automatization of the tubes cross section design. Creation of a simple methodology to obtain the rib length and radius of the final tube starting from the equivalent diameter and the ratio between the final tube width and the equivalent diameter. This methodology allows to sketch the tube bases exactly and not approximately as was done before.

5 Acknowledgments

Finally, I want to officially acknowledge all the Buildair staff for this quite positive experience from both professional and personal points of views. Moreover, I want to acknowledge the company for financing my training in Compass software.

Last but not least, I want to give a personal acknowledgement to my supervisor Carles Estruch Tena, for always having time for setting the guidelines of my work, discussing results and for encouraging me to take the final decisions to solve the issues that appeared during my internship.