Noise prediction of a new generation aerostat

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The wood or wind turbine markets, to name two examples, are confronted to the obstacle of having to transport heavy loads to and from areas that are accessible with difficulty. Airborne transportation is a solution. In this frame, a new generation aerostat is being developed, in partnership with Flying Whales. In order to make possible a commercial success of this kind of vehicle, the increasing sensitivity of people to aircraft noise has to be taken into consideration. If one wants to comply with future noise regulation applicable to this kind of aerostats, the noise impact for different operating conditions has to be estimated. Classic procedures like cruise, take-off and landing, as well as stationary flights are considered and evaluated. The aerostat is equipped with two propulsive propellers, four hovering propellers and two additional propellers for lateral control. The propulsive and control propellers are mounted vertically, the hovering propellers horizontally. Operating conditions will lead to flights above grounds with steep slopes and possibly dense vegetation. In this paper preliminary noise evaluations are presented for the most standard operating points that should occur. Given the sources' characteristic noise directivity, the vertically mounted propellers radiate directly into the field below the aerostat, where, in case of a stationary flight, people will be at work, loading the aerostat. The hovering propellers however radiate away from the aerostat, reaching maximum levels on the ground several hundreds of meters away from the aerostat itself, depending on the emission altitude and the ground slope. The relative contribution of each source depends on the operating condition. A parametric study helps to identify leads for noise reduction at the ground.
Keywords: aerostat, propeller noise

1. Introduction

Markets dealing with wind turbines or wood are in search of a more efficient way of transporting their goods. For now, tree trunks for instance, after being harvested, have to be moved by terrestrial transportation means to their location of processing. Especially in mountainous regions, the transportation of heavy loads can represent a problem that could be lifted by replacing trucks by aerostats.

If aerostats are to be commercialised, they will have to find their place in the already existing air traffic regulation system. One of the potential obstacles is the environmental impact; indeed they must not exceed acceptable noise levels.

A first preliminary aerostat design was developed, in partnership with Flying Whales. Being able to carry 60 tons of material and fly around 115 km/h, it will be approximately of 160 x 40 x 70 m size. The results presented in this paper on an eight-propeller configuration are preliminary calculations of tonal noise and will serve as reference test case. Ongoing discussions have led to an optimized propeller configuration with a total number of 32 propellers.

2. Noise calculation code

For the evaluation of the aerostat's noise impact on the ground, the in-house ONERA tool CARMEN-FLAP is used. CARMEN is a System Noise Prediction Tool making it possible to predict the sound pressure level footprint during a whole rotary wing aircraft trajectory simulation [1,2]. It is composed of three modules: acoustic source models, installation effects and atmospheric propagation.

The noise source model used in this study, a tool called FLAP, includes a set of analytical models for predicting the noise radiated by a helicopter main and tail rotors, simple propellers etc. Its main difference with the ONERA more advanced HMMAP computation chain [3] is a lower CPU runtime and a much lower input data requirement, allowing its use at a preliminary stage in the design of new concepts. Its characteristics are obtained by a less fine modeling and the use of usual values for the input data. On the other hand, this low level of modeling makes it difficult to obtain an estimate in absolute levels, so it is preferable to make comparisons in relative levels to observe the trends [4].

The installation effects module calculates the interaction of the waves emitted by the sources with the structure of the aircraft that can reinforce or mask the radiation. In the case of the aerostat we assume that the skin is perfectly transparent to acoustic waves. As a result, we do not consider masking or reflections for this case study.

This last module makes it possible through ray-tracing to propagate the sound from the aircraft to the ground taking into account meteorological effects, atmospheric absorption, the Doppler effect etc. In the case of this study, several calculation hypotheses are made. We consider a standard atmosphere, at 20 ° C, without wind. We also assume the flow entering the propellers to be perpendicular to the propeller. Upward winds that could rise up the slope are therefore not taken into account.

In view of the dimensions of the aerostat it was not possible to make a calculation including all propellers at the same time. Therefore each propeller is calculated separately and the sum of all the contributions is done during post-processing.

3. Preliminary aerostat and propeller design

A first round of design discussions lead to an aerostat design equipped with 8 propellers, composed of two propulsive propellers, four hovering propellers and two additional propellers for lateral control (see Figure 1 and Table 1 for coordinates, based on Flying Whales documents).

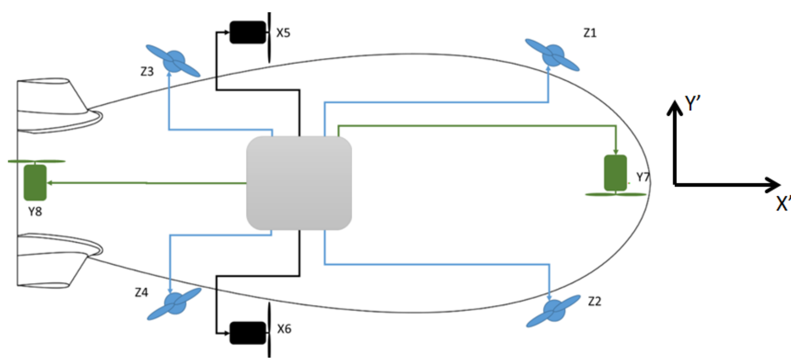


Figure 1: Propeller configuration

After a first round of calculations, it was decided, in concertation with Flying Whales, to implement propellers of 6 blades, turning at 500 RPM and generating 800 kW. An aerodynamic parametrical study was done, which delivered the input needed for the FLAP calculations: blade geometry, thrust, torque and RPM. Since in FLAP the thickness of the blade is important, but not so much the shape of the blade, NACA00XX (where XX is the relative thickness) were used for all propellers.

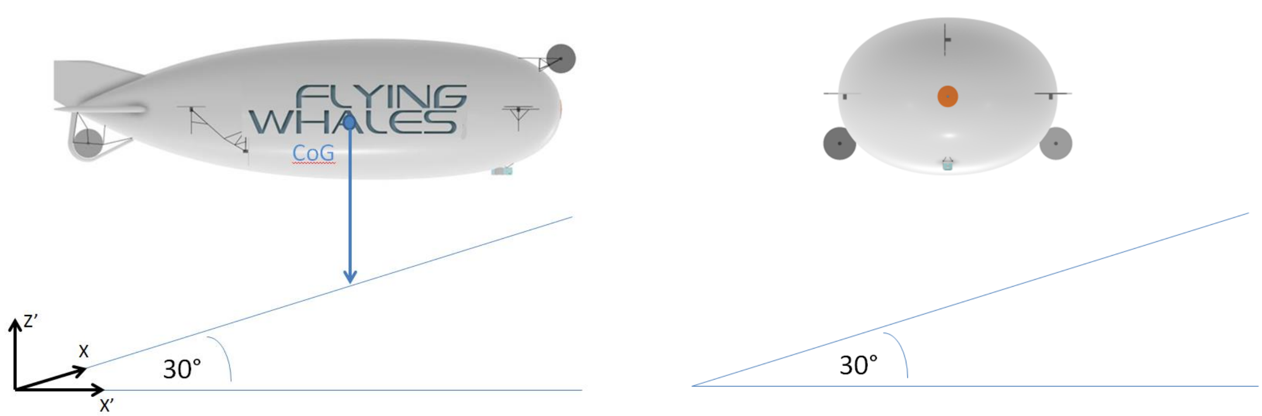
Table 1: Centre of Gravity and Propeller coordinates (the centre of the coordinate system being the nose of the aerostat)

	X'	Y'	Z'
Z1	-13.02 m	-28.21 m	0 m
Z2	-13.02 m	28.21 m	0 m
Z3	-112.99 m	-29.52 m	0 m
Z4	-112.99 m	29.52 m	0 m
X5	-96.33 m	-29.61 m	12.94 m
X6	-96.33 m	29.61 m	12.94 m
Y7	0 m	0 m	-15.57 m
Y8	-144.5 m	0 m	10.5 m
Centre of Gravity	-67.7 m	0 m	8.6 m

4. Calculation set up

Several test configurations have to be evaluated to get an idea of the general impact of the aerostat on ground noise levels. Several altitudes, flight configurations and ground properties can and will be encountered during its missions. The extraction site will most probably be in mountainous environments, where the slope might be of varying importance. A representative value is chosen to be 30 degrees.

In the following chapters, the altitude is defined as the distance between the centre of gravity of the aerostat and the ground straight below (see Figure 2a).



a) Hover and transition configuration

b) Cruise configuration, front view

Figure 2: View of aerostat in 30° slope configuration

4.1 Hovering configuration

The simplest configuration to treat is the one where the aerostat is hovering above the site of extraction where the workers load the wood. The aerostat is aerostatically balanced; it therefore doesn't need the lifting propellers in order to stay in the air.

Two potentially noisy configurations are to be considered in the hovering position. One where the lateral propellers are at work either to change the lateral orientation of the aerostat or to counteract cross winds; and one with working lift propellers when for instance altitude changes are engaged.

4.1.1 Configuration 1: Lateral propellers only, 30° ground slope – altitude 50m

In the case where the orientation of the aerostat has to be modified, for whatever reasons, the power given to lateral propellers can go up to 800 kW. The propellers turn at 500 rpm.

In a situation where the aerostat is at 50 meters altitude and on a 30° sloped ground, the noise impact on the ground of each propeller is shown in Figure 3, the sum of both in Figure 4. The X coordinate corresponds to the projection of X' on the ground (which is at 30°, see Figure 2a)

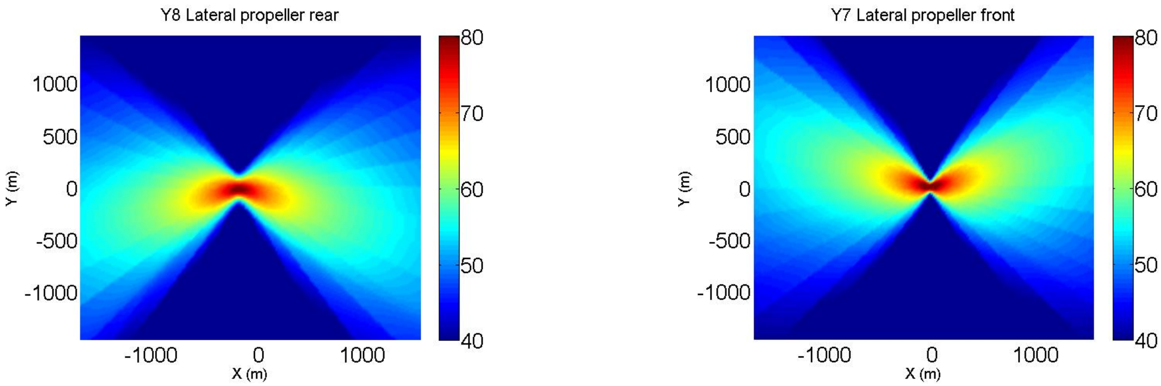


Figure 3: Tonal footprint in dB of rear and front lateral propellers Y at 800 kW

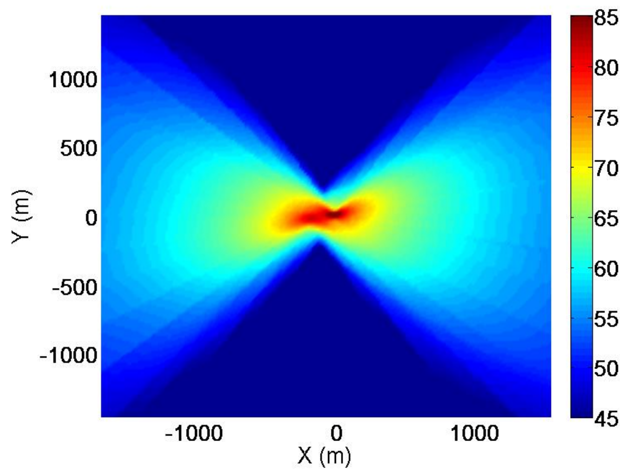


Figure 4: Total tonal footprint in dB for Configuration 1

The loading noise being not exactly symmetrical in the propeller plane, but radiating slightly to the back of the propeller, the installation and orientation of the lateral propellers have a non-negligible influence on the ground noise maps. As can be seen in the propeller configuration (Figure 1a), Y7 (front) is facing right while Y8 (rear) is facing left, which gives the total footprint a "wavy" asymmetrical aspect. The maximum level directly below the front of the aerostat reaches 85 dB, while at 1 km on the lateral side (Y [m] direction) the levels fall far below 45 dB. In the propeller plane (X [m] direction) the noise reaches further distances, at 1 km the levels are still up to 60 dB.

4.1.2 Configuration 2: Lift propellers only, 30° ground slope – altitude 50m

In the case of a gain in height, the lift propellers Z can reach 800 kW each. The four lift propellers work identically; only the distance to the ground, variable due to the slope, has a modifying impact on the footprint (Figure 5 and Figure 6).

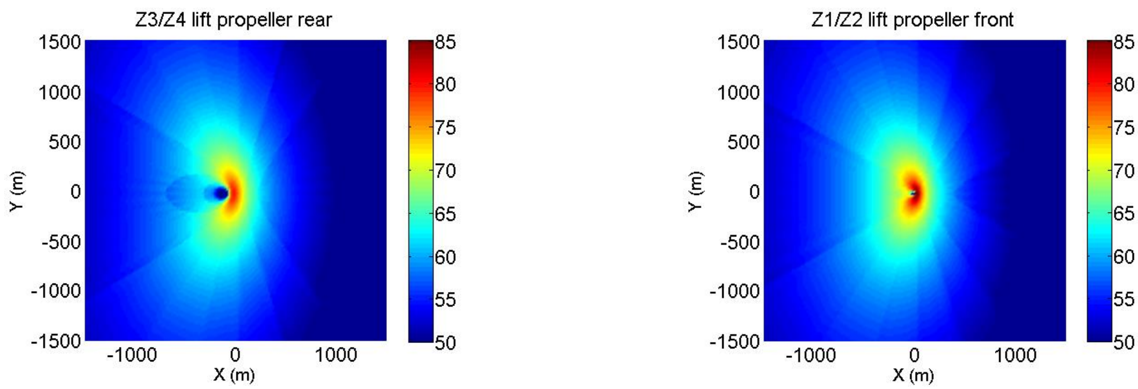


Figure 5: Tonal footprint in dB of rear and front lift propellers Z at 800 kW

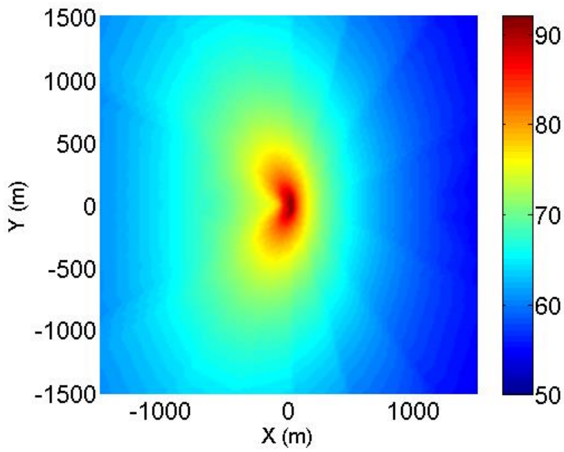


Figure 6: Total tonal footprint in dB for Configuration 2

The mountain slope leads to a bean shaped footprint with maximum levels of 92 dB below the aerostat, of course slightly shifted from the very centre because of the propeller directivities. The front propellers' footprint is more focalized, less wide spread than the rear propellers that are higher above ground and therefore emit on a larger surface. At 1.5 km lateral distance parallel to the mountain slope and downwards to the mountain (negative X), the levels still reach 65 dB. Upwards (up the mountain, positive X) the levels decrease more rapidly since the angle of incidence gets further from the propeller plane.

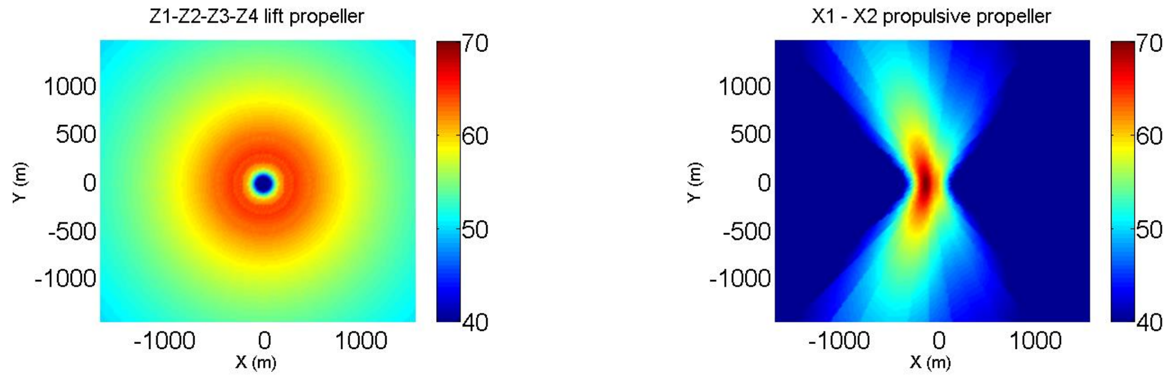
The propellers are reversible; an altitude change towards the ground will therefore lead to slightly lower values in the footprint.

4.2 Transition and Cruise

4.2.1 Configuration 3: Transition, 0° ground slope – altitude 150m

In the case of transition between hovering and advancing configuration, there is a phase where the X and Z propellers can function at the same time, before the aerostat even moves. If we consider 800 kW on the propulsion propellers and 400 kW on the lift propellers, with a zero advancing velocity, the noise footprint presents itself as shown in Figure 7 and Figure 8.

The 0° ground slope leads to a perfectly circular footprint of the lift propellers, which function at the same height at same power. The propulsive propellers face to the right (positive X), therefore the sound is slightly radiated to the back. The total footprint has a clear circular aspect with levels of 60 dB going as far as 1 km from the centre of the aerostat. The highest levels, around 72 dB, are however still encountered below the propulsive propellers.



a) b)

Figure 7: Tonal footprint in dB of a) the four lift propellers Z at 400 kW, b) the two propulsive propellers X at 800 kW

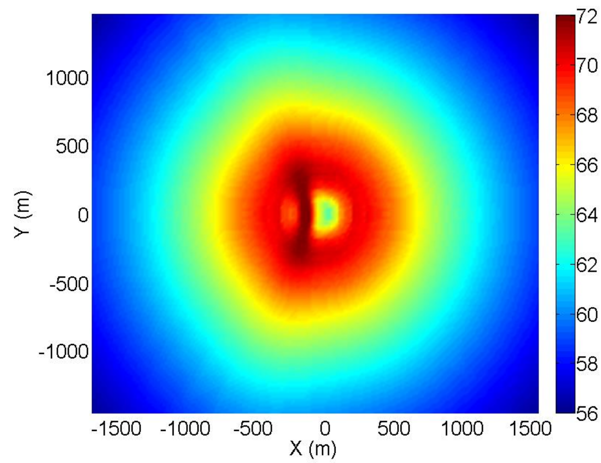


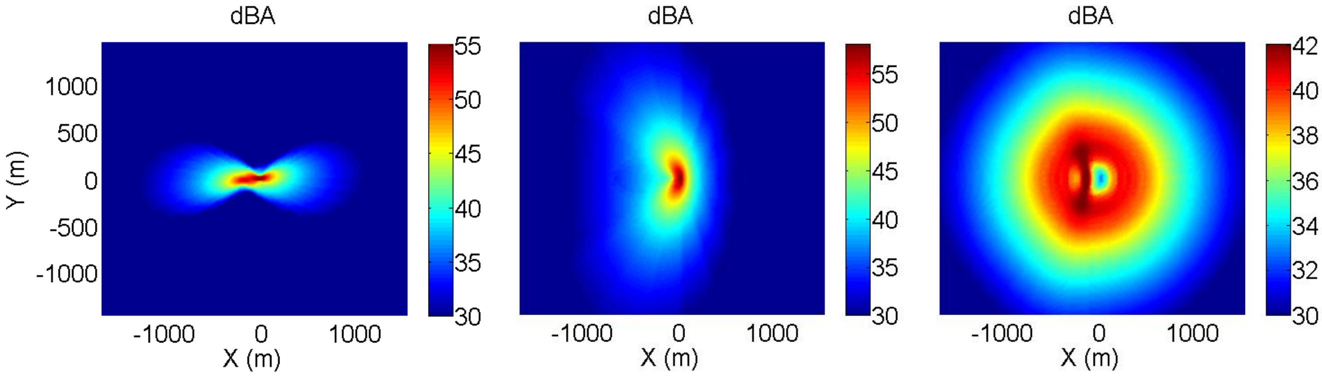
Figure 8: Total tonal footprint in dB for Configuration 3

4.2.2 Configuration 4: Cruise, 0° / 30° ground slope – altitude 150 m / 600 m

Levels at take-off and landing are important for the surroundings of the hangar. Furthermore the path between hangar and extraction site might overfly populated regions. Noise levels therefore also have to be checked for flyovers at different altitudes. To cover two encountered configurations, a 150 m altitude flyover over a 30° ground slope and a 600 m altitude flyover over a 0° ground slope are evaluated. In both cases the X propellers are set to 800 kW each, while neither Y nor Z propellers are at work. The advancement of the aerostat happens parallel to iso-altitude lines (Figure 2b).
The noise footprints and their analysis will be shown during the Conference.

5. Discussion

The above tested configurations are shown in dB. Displaying the results in dBA alters extremely the noise levels. Indeed the frequency range of the radiated sound is extremely low for a 6 blade propeller at 500 RPM, the BPF being 50 Hz. The A-weighting therefore drastically reduces the contribution of the, initially, most energetic tones and the final tonal levels on the ground never exceed 60 dBA for hovering configurations and 42 dBA for transitioning configurations (Figure 9).



1) 2) 3)

Figure 9: Total tonal footprints for Configurations 1), 2), 3) in dBA

Broadband propeller noise is not included yet, due to the current lack of validation of the models. Depending on the considered configuration, one can expect changes in the footprint when adding the broadband noise contribution. Indeed, in configurations where only vertical propellers are at work (X and Y), the self-noise (main broadband contributor), will stay below tonal noise levels, even expressed in dBA. When the horizontal propellers are working, however, the shadow zone, right below the propellers, will receive non negligible levels of self-noise. For the complete evaluation all noise sources will be considered. The same tendencies should be obtained when considering installed propellers. Indeed, aerodynamic perturbations created by structures (arm support….) surrounding the propellers will be responsible for an additional noise radiation at higher frequency and radiating mainly out of the propeller rotation plane. However, taking into account this kind of contribution is out of the scope of this preliminary study.

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