EFFECT OF ROUGHNESS ON THE AEROACOUSTIC PERFORMANCE OF ROTOR NOISE AT LOW REYNOLDS NUMBER

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ABSTRACT[*]

The actual and future multiplication of unmanned aerial vehicles (UAV) in urban settings calls for a better understanding and optimization of the aeroacoustic noise produced by their rotors. This phenomenon is associated with low Reynolds numbers, compared to what is usually seen on helicopters for example. At these Reynolds numbers, both tonal and broadband components are present, and the question of the transition to turbulence in the boundary layers (in particular on the pressure side) is of critical importance. In this experimental study, the use of 3D printing techniques allows for the comparison of multiple rotor models, with an emphasis on roughness heights, their influence on boundary layer transition and on the final emitted noise. Measurements are performed in an anechoic chamber and include noise levels around the rotor and thrust levels.

Keywords: *aeroacoustics, rotor noise, roughness, boundary layer transition.*

1. INTRODUCTION

Noise production is a large matter of concern for unmanned aerial vehicles (UAV) applications [1]. When looking specifically at quadcopter micro air vehicles, the Reynolds numbers (based on chord length) tend to be lower than on helicopter rotors, typically between 10^4 and 10^5. This field is largely discussed across the community, and some experimental benchmarks have already been performed in order to get a better grasp on the phenomena involved in noise production [2,3].

Moreover, the roughness of an airfoil is known to have a strong influence on the boundary layer transition, and so on the noise production. The roughness of the surface is implied in the transition of the boundary layer (underlying the common idea of roughness trips to force the transition) [4]. Moreover, a laminar boundary layer is typically associated to the production of a tonal trailing-edge noise, while a turbulent boundary layer is associated with broadband trailing-edge noise [5,6,7]. This aspect is studied, but usually with roughness elements added on an otherwise smoother surface [8]. In this work, the general roughness on the surface of a propeller made using different 3D printing techniques will be assessed. Then, in the following experiments, the noise emission and the forces exerted on the propeller will be measured and studied.

2. EXPERIMENTAL SETUP

2.1 Propellers

The rotor shape used in this work is the one referred to as the DLR 13x7 in previous work by Rossignol et al. [9,10]. With this shape, two propellers have been produced with two different 3D printing techniques. The first one is made on an industrial Stratasys machine with a mix of VeroWhite Plus and TangoBlack+. The second one is entirely made from PLA on a Ultimaker machine, using fused filament fabrication. The two propellers will be named VeroWhite propeller and PLA propeller respectively in the following and are shown in Figure 1.

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Figure 1. Photograph of the VeroWhite propeller (top) and the PLA propeller (bottom). The red lines show the position of the rugosity measurements discussed in part 3.

The difference in roughness heights between both propellers can be noticed with a simple examination by touch (or even a visual one): the PLA propeller is notably rougher than the VeroWhite one.

The tip Reynolds numbers and tip Mach numbers for some usual rotation speeds are shown in Table 1.

Rotations per minute	Tip Mach number	Tip Reynolds number
4000	0.20	44300
6000	0.31	66500
8000	0.41	88700

Table 1. Typical values for the tip Mach and Reynolds numbers on the DLR 13x7 propeller.

2.2 Engine and instrumentation

The engine used is a brushless DC-servomotor, a Faulhaber 3274G024BP4. Its no-load speed is up to 8820 rpm.

A thrust and torque sensor is mounted under the engine in order to measure the lift and drag of the propeller in rotation. The sensor is an ATI FT-MINI40.

The calibrated 7-axis robotic arm used for the precise positioning of the microphone is a Franka Emika Panda and is presented in Figure 2. It is programmed to operate automatically, which allows us to measure acoustic pressure over a 3D grid of positions effortlessly.

The whole system is mounted in the anechoic chamber in UME, ENSTA Paris.

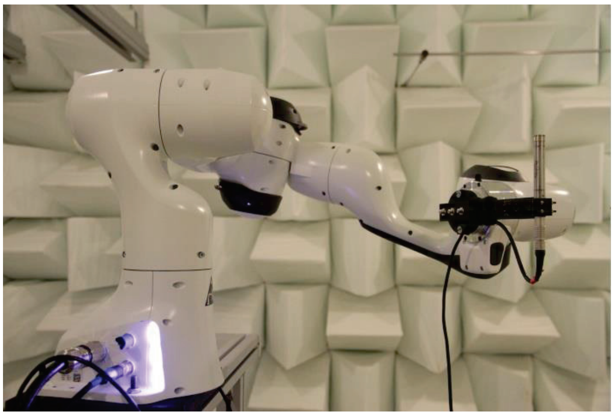

Figure 2. Photograph of the 7-axis Franka Emika Panda robotic arm, holding a microphone in the anechoic chamber.

2.3 Roughness measuring system

The roughness level on the propellers is assessed using a Someco RTP80-TL90, which is a modular unit able to perform either skidded or skidless measurements. In this work, the skidless measurements are preferred, in order to better represent the surface profiles.

3. RESULTS AND DISCUSSION

The robotic measurement campaign is still in progress and this article only reports the analysis of the roughness level.

The same method is applied on both propellers: at a radial position $r = 100$ mm ($r/r_{tip} = 0.61$), a measurement is done on the upper surface of the propeller, in the direction of the chord (from the leading edge to the trailing edge, see the red lines on Figure 1). The sensor travels 5 mm in order to get a profile, but the first and last 0.5 millimeters are not kept, because the velocity of the probe is changing in these areas (so the profile is plotted on 4 mm). The profiles obtained with the measurements are then filtered to separate the large shape variations from the roughness of the surface, and the roughness profiles are obtained. These profiles are shown in Figures 3 and 4.

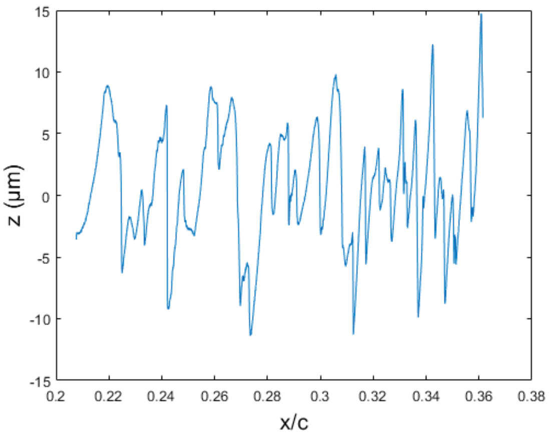

Figure 3. Roughness profile on the VeroWhite propeller, at r = 100 mm (chord c(r) = 26 mm).

The roughness on the VeroWhite propeller is stochastic, with no discernable pattern. The value for the average of the difference with the mean (“Ra”) is 3.80 µm. On the contrary, the roughness on the PLA propeller is mainly periodic, and is clearly due to the fused filament fabrication. In our sample, the period for the oscillations is 0.6 mm, and the Ra is 13.85 µm. As it was expected, the roughness levels are higher on the PLA propeller, and they are markedly higher, as the value for Ra is more than 3 times larger.

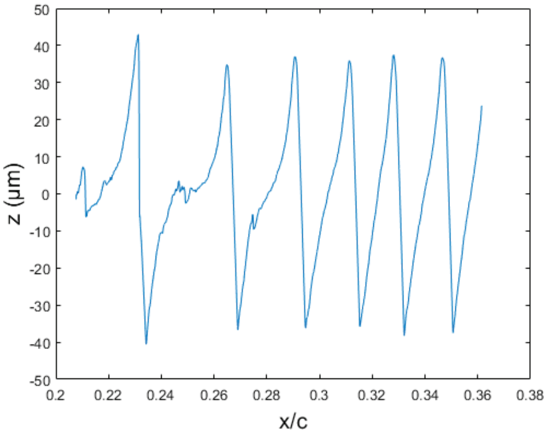

Figure 4. Roughness profile on the PLA propeller, at r = 100 mm (chord c(r) = 26 mm).

4. PERSPECTIVES

The first measurements allow us to emphasize the differences in roughness level for two different 3D-printed propellers. Differences in roughness have been seen to be significant, but their influence on the boundary layer transition and ultimately on the noise production still needs to be assessed. The acoustic and aerodynamic force measurements will be presented at the conference.

5. ACKNOWLEDGEMENTS

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