EXPERIMENTAL AND NUMERICAL INVESTIGATION OF NEAR-FIELD ROTOR AEROACOUSTICS

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Abstract

This work presents comparisons between experimental and numerical estimates of near-field rotor aeroacoustics in hover. The experiments took place at the Kazan National Research Technical University named after A. N. Tupolev (Kazan Aviation Institute). A set of rotor blades with NACA-0012 aerofoil sections was used to obtain the sound pressure distribution using a linear array of microphones. It is shown that CFD and experimental results are in good agreement suggesting that the obtained test data can be useful as a validation case for development of CFD tools.

1. INTRODUCTION

In recent years, the noise reduction of helicopters has become a priority due to new, stricter certification requirements for civil helicopters, operating in densely populated areas. Obtaining reliable experimental data of rotor aeroacoustics is a challenging task due to the high cost of experimental facilities, and the need for wind tunnels with high operational costs. In recent years, attention has been shifting towards numerical simulation, where experimental data is needed to validate the obtained numerical results [1-3].

This work aims to obtain experimental data in near-field, suitable for validation of CFD computations. To this end, a set of blades of a rectangular planform were manufactured using the NACA-0012 aerofoil. A linear microphone array was placed next to the Mach-scaled rotor model, and hence the measurements were dominated primarily by thickness noise, which is dictated mainly by the angular speed of the rotor and blade thickness. The thickness noise is the dominant component on the rotor plane, especially in hover [4].

The broadband noise sources are related to turbulence and are caused by the interaction between blades and turbulence; self noise of the boundary layer of the blade [5, 6], and turbulence behind its sharp trailing edge. The mechanisms of rotor broadband noise generation are described in [7].

An advantage of the current dataset is that near-field acoustic pressure is made available to allow direct comparisons with CFD computations.

CFD computations were obtained using the HMB code of Glasgow University and were based on

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RANS approach with the k-ω turbulence model. The numerical results were then compared to the experimental results as sound pressure level (SPL) in the time domain. Previous studies for a different set of blades showed good agreement of experimental data with CFD computations [2, 3].

2. EXPERIMENTAL SETUP AND CONDITIONS

2.1. Wind Tunnel

Experiments were conducted in the acoustic chamber of T-1K wind tunnel of the Kazan National Technical University named after A.N. Tupolev. The acoustic chamber consists of retractable side walls, which contain Helmholz resonators to minimize low frequency noise in the test section, and melamine pyramid-shaped foam material to absorb high-frequency noise, emanating from rotors, operating at high tip speeds. The acoustic chamber is shown in Figure 1.

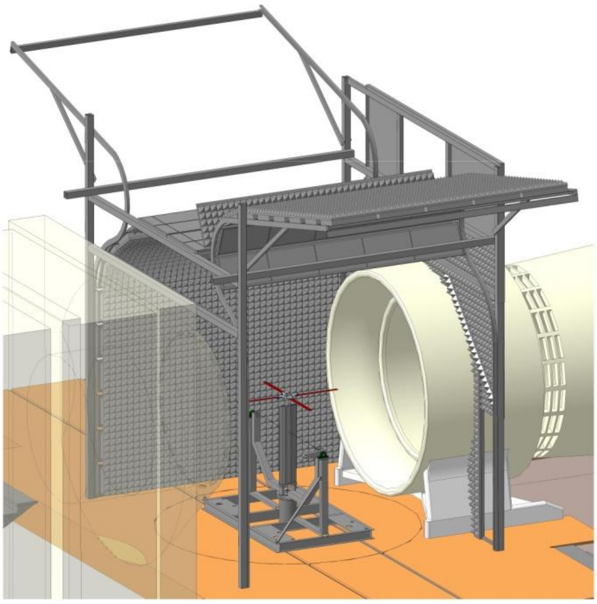

Figure 1. 3D model of the acoustic chamber of T-1K wind tunnel at KNRTU-KAI.

2.2. Rotor Rig

All experiments were performed in hover. The rotor rig was operated at 900 rpm, corresponding to tip Mach number of 0.22. The rotor radius was R=0.8 m. The collective pitch angle was set to 8°. The rotor blades with a rectangular planform had a constant cord with a symmetrical NACA-0012 aerofoil, and no twist along their span.

Experimental results are presented in terms of relative radius $\bar{r} = r/R$, where r is a horizontal distance from the rotor's axis of rotation; and $\bar{y} = y/R$, where y is the vertical distance of a microphone from the rotor plane.

2.3. Data Acquisition and Analysis

For the recordings, DMX RTA-M microphones with Panasonic WM-61A cartridges were used. A 24-bit NI-PXI 4496 ADC sampled the signals at a rate of 48 kHz.

Experimental data was obtained using a linear array of 9 microphones. The placement of the linear array relative to the rotor is shown in Figure 2. The array was positioned vertically at a distance of $\bar{r} = 1.23$ away from the rotor axis of rotation. Earlier work showed that positioning microphones in this manner has little effect on the flow field of the rotor [3].

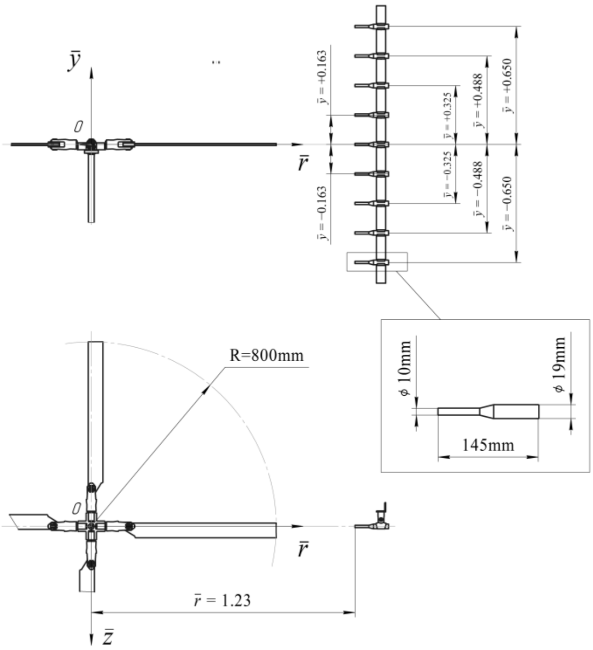

Figure 2. Placement of microphones relative to the rotor.

Due to the periodicity of the microphone signal with respect to the angular position of the blade, phase-averaging was used, calculated as follows:

(1) $$p_{avg} = \frac{1}{N}\sum_{i=1}^{N} p_{ij}.$$

Here i is the period of the passing blade, and j is a pressure reading p_{ij} along the period i. The phase averaged confidence intervals σ_j were calculated over 60 periods as the root mean square deviation:

(2) $$\sigma_j = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(p_{avg} - p_{ij}\right)^2}.$$

Compared to the results, presented in the earlier work for a different set of blades [3], the experimental data for each microphone position is analyzed over a larger number of periods ($i = 60$), which could contribute to a wider range of confidence intervals of the experimental data, obtained in this work.

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2.4. Some Acoustic Characteristics of the Anechoic Chamber

A preliminary study has been performed to investigate noise reflections inside the anechoic chamber.

For this purpose, the Maximal Length Sequence (MLS) [8] method was used. It requires a noise source with volumetric velocity measuring, which is based on a given noise signal with its autocorrelation function close to a delta-function.

Figure 3 shows the schematic of the experimental setup.

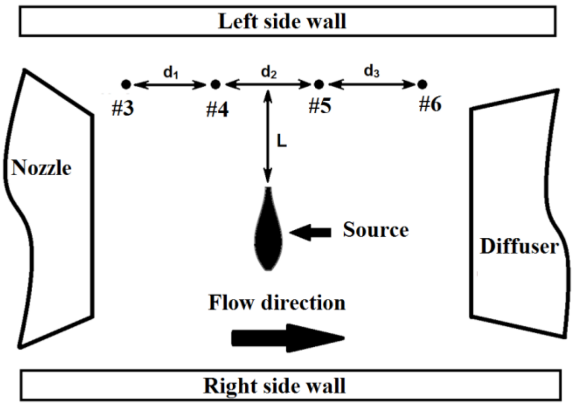

Figure 3. Schematic of the reflection experiment

Figure 4 shows measurement results of the reflection study for microphone #6. Here, the reflection peaks are shown as a function of distance from the microphone. The impulse at 2,5 m corresponds to reflections from side walls, and peaks at 4,5 m correspond to reflections from the floor. It can be seen that the noise reflections are 6-6.5 times lower than the initial impulse for both cases.

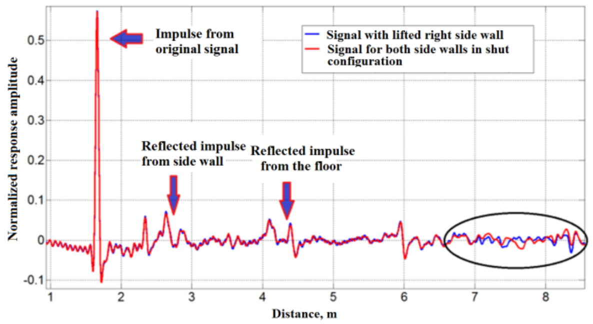

Figure 4. Reflection study results for microphone 6.

3. COMPUTATIONAL SETTINGS

CFD simulations based on RANS solutions with the k-ω turbulence model and were performed using the HMB code [9]. Due to the periodicity of the flow around a rotor operating in hover mode, the computational domain was set up only for one blade, as shown in Figure 1. A multiblock grid was built using ICEM Hexa^{TM}. The grid contained 4.4 million points and 172 blocks. The mesh was put together based on experience from previous studies, and was designed to give a high resolution flow field with good accuracy [10]. The wake topology from CFD simulations is shown in Figure 6. The ground proximity of the experimental setup was not taken into account during CFD simulations, due to the expected small influence on the results.

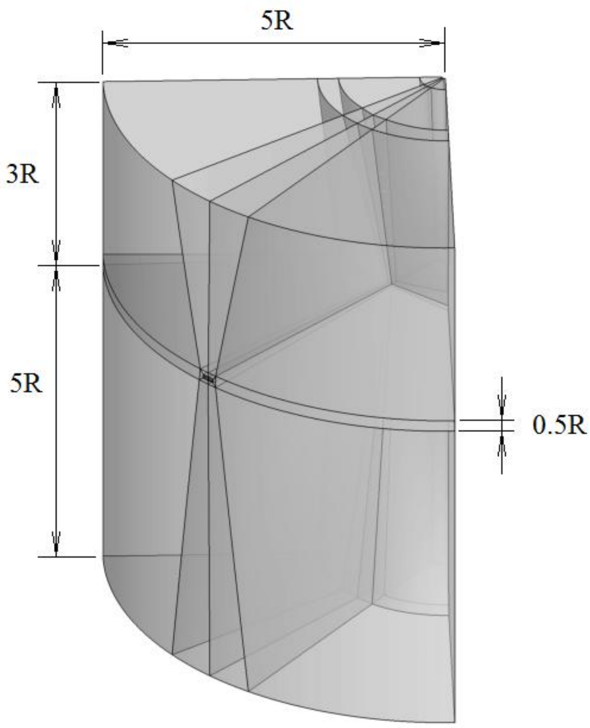

Figure 5. Computational domain.

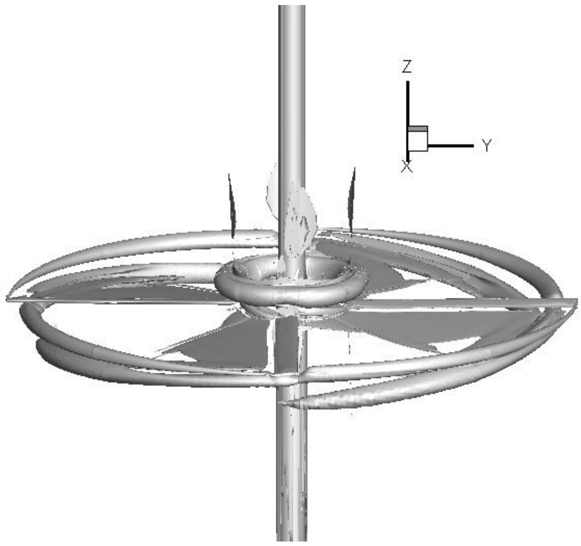

Figure 6. Wake topology obtained from CFD simulations.

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4. RESULTS AND DISCUSSION

Comparison of CFD with experimental results for the SPL distribution, obtained from the linear array, is shown in Figure 7. Here, SPL values are presented in terms of peak-to-peak decibel values of the signal.
The acoustic noise peaks in the vicinity of the rotor plane, reaching its highest slightly above the rotor blade. It should be noted that the CFD models had no blade coning angle. However, the rotor rig model had a finite coning angle due to the flap hinge of the rotor head. It can be seen from Figure 7 that SPL peaks at $\bar{y} = 0.163$ for both CFD and the experiment, which indicates that it cannot be solely attributed to the coning angle.
It can also be seen that the CFD simulations agree well with the experimental data. A noticeable difference of 7 dB can be seen between experiments and CFD at $\bar{y} = -0.65$, which happens due to the very low values of peak-to-peak pressure amplitudes in that region. Figure 8 shows this clearly.

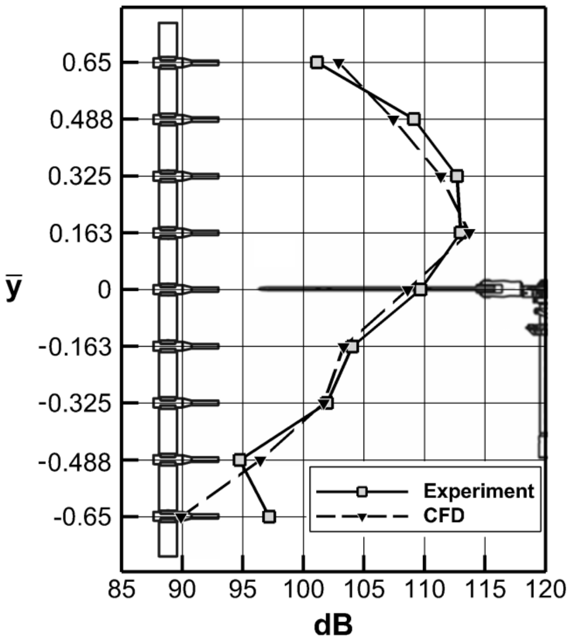

Figure 7. Acoustic pressure distribution of the linear array, located at a distance $\bar{r} = 1.23$.

Figure 8 shows comparisons of CFD and experimental results for the acoustic pressure distributions in the time domain. Statistically analyzed experimental data is presented along with their confidence intervals, as mentioned in Section 2.3. Results of CFD simulations are denoted by long dash lines. It can be seen that CFD and experimental data are in good agreement, and most of the time, pressure distributions obtained from CFD, lie within the phase averaged confidence intervals. However, a noticeable difference of the signal can be observed after the pressure peaks for microphone positions $\bar{y} = 0$, $\bar{y} = 0.163$ and $\bar{y} = 0.325$, where CFD has lower pressure levels compared to the experiment. It should be stated that these microphone locations correspond to highest peaks of the SPL in Figure 7.
Experimental SPLs also show somehow larger values compared to CFD below the rotor plane, at microphone positions $\bar{y} = -0.163$ and $\bar{y} = -0.325$, although the overall signal amplitude tends to be smaller below the rotor plane.
The slightly higher CFD estimates at $\bar{y} = 0.163$ ahead of the blade are similar to results obtained for a different set of blades [3].

6. CONCLUSIONS

Experimental results and CFD simulations for near-field rotor acoustics were presented and compared. A set of blades with a rectangular planform and NACA-0012 aerofoil have been used, and data was gathered using a linear array of microphones.
The agreement between simulations and experiments is, overall, very good, suggesting that this data set can be used as a first step in the validation of CFD codes for near-field acoustic predictions. This study is expected to move towards measurements of different blade shapes and also cover rotors in forward flight.

7. NOTATION

r	Horizontal distance from the rotor's axis of rotation.
$\bar{r}$	Relative distance, scaled to the rotor radius ($\bar{r} = r/R$).
y	Vertical distance from the rotor plane. y is positive in the upstream direction.
$\bar{y}$	Relative vertical distnace, scaled to the radius R ($\bar{y} = y/R$ m).
R	Rotor radius ($R = 0.8$ m).
SPL	Sound pressure level.

8. ACKNOWLEDGEMENTS

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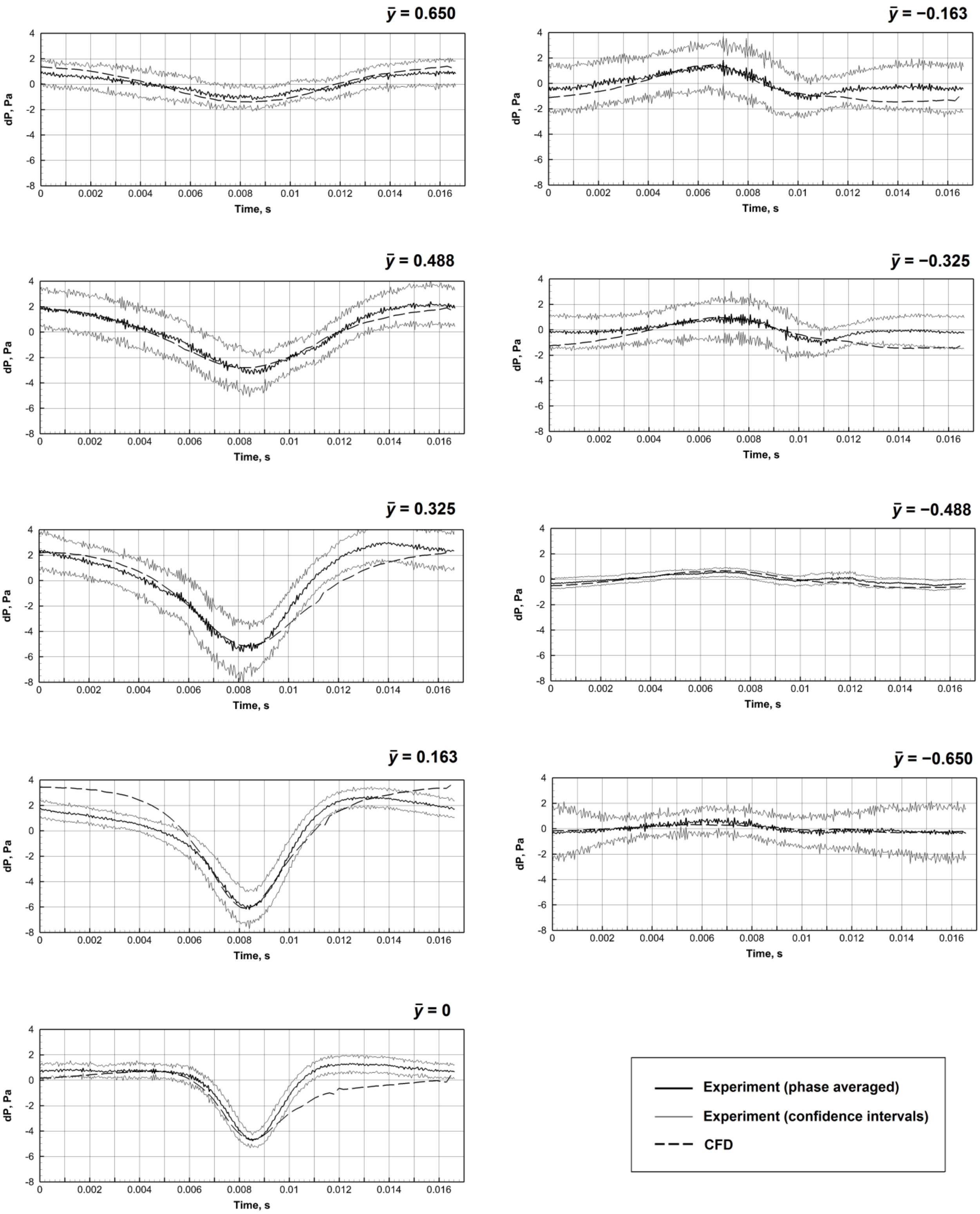

Figure 8. Comparison of experimental data with CFD results for different vertical distances $\bar{y}$ of the microphones.

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