Noise Radiation from Circular Rods at Low-Moderate Reynolds Number

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Abstract

The well-known dominant sources of airframe noise are associated with unsteadiness of separated and/or vortical flow regions around the high-lift system (flaps, slats) and the aircraft undercarriage (landing gear). Current practical landing gear noise prediction models are individual component - based, which means that the various components are divided into groups according to the frequency range, in which they predominantly radiate noise. Since the far-field noise spectra are approximately Strouhal - based, the emitted frequency is assumed to be directly related to their size: the large elements are responsible for the low frequency region of the spectra, and the small components for the high frequency region. On the basis of such understanding of the noise generation mechanism, the special configurations that lead to considerable noise suppression were proposed. One element of these configurations are rods with different shape and cross section. In this work the situation when circular rods are in area of laminar-turbulent flow were analysed. The measurements were carried out for single circular rod with different diameters to study the noise effect depended on Reynolds number. Far field noise for broad range of Reynolds numbers was also examined depending on distance from the source of noise.

Keywords: aeroacoustical noise, circular rod, low Reynolds number

1. Introduction

The noise radiating from the outer parts of an aircraft is the dominant airframe noise source. Plenty of numerical and experimental studies are being conducted to identify the noise generated from these elements [1, 2]. Many components of a landing gear of aircraft (struts, cables, axles and wheels) can be modelled by rods of various lengths and cross-sections. Characteristic noise is radiated from single and multiple rods configurations. The subcritical, critical, and turbulent states of flow are of most interest in aspect of aircraft noise because of the Reynolds number range it encompasses. For circular rod the Reynolds number is based on the rod diameter and the free-stream velocity of the uniform flow (especially when Re > 10^5) [3, 4]. But so far, it is not known at which value of Re the fully turbulent state of flow starts [5, 6].

The noise generated by a circular rod in a uniform or turbulent flow has been studied through [7, 8]. Vortex shedding noise from single cylindrical rods were studied. Far field noise, surface pressure fluctuations and span-wise correlation lengths over a broad range of Reynolds numbers (2 x 10^4 to 5.5 x 10^5) were examined [7].The Aeolian tones from a single rod at very high Reynolds (namely 2.5 x 10^5 to 2 x 10^6) were related to the decrease and increase of the tone's amplitude in the super- and post-critical regimes to surface pressure fluctuation characteristics [9, 10]. The effect of free-stream turbulence on the vortex shedding noise from a single rod has also been studied and more broadband nature of the vortex shedding noise in the presence of free-stream turbulence was identified.

In these experimental studies acoustic and aerodynamic measurements were performed on a single circular rod with different diameters to study the effect of low-Reynolds number on the radiated noise. The test matrix included rods of diameter – 8 mm, 10 mm and 16 mm and low Re numbers were studied. Obtained flow physics and acoustics properties have been analysed to understand the effects of aerodynamically noise of circular rods. The present studies can be also referenced to the flow in ventilation system (elements like grills, diffusers, slats), because in these system the low Reynolds numbers are often used and velocity does not exceed 5 m/s.

2. Experimental method

The measurements were performed on the specially constructed test stand with the outlet to the anechoic room at the Institute of Power Energy in Lodz – Figure 1. Airflow was induced by a fan mounted on the inlet of the stand and regulated by the power inverter. The anechoic test chamber is cubic, approximately 350 m^3 in volume and has got walls that are acoustically treated with foam wedges providing a reflection free environment.

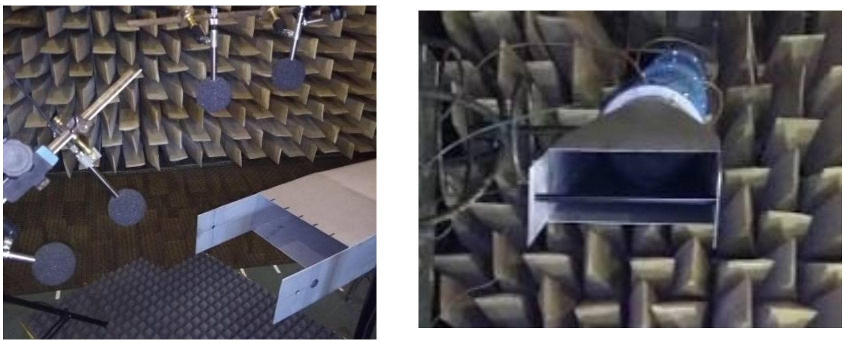

Figure 1. The construction of test stand with outflow to anechoic room and microphones

The rods were supported by two vertical side plates that were mounted to the short sides of the nozzle. The diameter of the cylindrical rods was 8 mm, 10 mm and 16 mm. The measurements of noise were made by using analyzer SVAN 958. The four microphones (M1, M2, M3, M4) were located at a distance of 500 – 600 mm above the rods, with the distance between microphones presented on Figure 2. The microphones were calibrated before commencing the acoustic test. Microphones were used to measure noise in the flow filed. When a microphone is located within an airflow field, it is recommended as best practice that a windscreen or nose-cone accessory should be used when taking acoustic measurements. In head-on laminar flow, the nose-cone accessory is the best choice. In all turbulent flow and parallel orientation laminar flow, the windscreen accessory is the best choice [11]. In these studies the microphones were located parallel orientation to flow streamline and were used in turbulent flow, so windscreens were placed on these microphones. In this studies, due to the large number of data, the results obtained only from microphone M1 were interpret.

The measurements were taken at range of flow velocities between 0.02 m/s and 17 m/s (for studied rods range of Reynolds numbers was between Re = 12 ÷ 18000). The velocity distribution in outlet of the stand test was measured by using a wing anemometer connected with a HD 2103.2 instrument. Mean velocities were calculated by using the logarithmic Chebyshev method. Additional, detailed flow measurements at several points behind the rods have been performed using thermo anemometer measurement technique. For thermoanemometer the points of measurement were logged at locations *z*-axis = (-30 mm; -10 mm; 0 mm; 10 mm; 30 mm) and *x*-axis = (10 mm and 30 mm), relative to the surface of mounted rods.

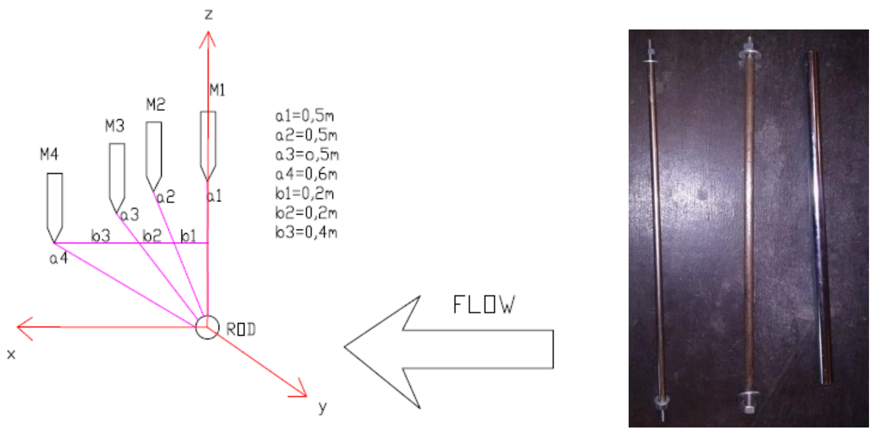

Figure 2. Localization of microphones above the rods (on the left) and rods used in these studies (on the right)

3. Aeroacoustical results

Aerodynamic and acoustic parameters of airfoil or other objects (e.g. circular or square rods) in low Reynolds number are important for learning its physical nature. Most of the flying animals (insects, birds), fly at Reynolds number of 10^3 - 10^5, due to their low speed and small length scales and they have got varied physiology which accommodates to those low velocities. Current trend of "inspiration on nature" to improve the aerodynamics of flight and reduce flight's noise parameters requires knowledge in this aspect. But very important is knowing the aerodynamical and acoustic parameters for simple objects like rods with different cross section, or flat or bend plate, which might be used for studying more complicated structures.

The first step in this study was determination of the distance between the rods and microphones. The preliminary studies allowed determining the maximum velocity in the outlet of constructed research stand at 17 m/s. Dependence between of the observed peak for rod with diameter of 10 mm (315 Hz at flow velocity 17 m/s) on the 1/3 octave sound pressure level spectrum (SPL), determined as the difference between the SPL spectrum of studied rod and background of the research stand, is presented at the Figure 4. The results show the measurements acquired with microphone M1 (Figure 2), for an observer located at a 90° elevation angle. The value of studied SPL difference increases with distance, and due to stable position of microphones as a studied farness from the rods, the 500 mm was chosen.

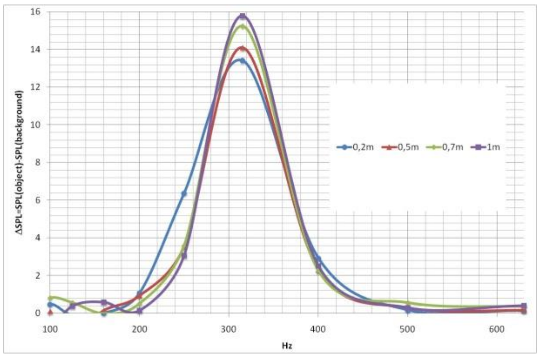

Figure 3. Dependence between the observed peak on the 1/3 octave sound pressure level spectrum (SPL), determined as the difference between the SPL spectrum of the studied rod with 10 mm diameter and background of the research stand

Acoustic measurements were performed on a simple single rod configurations to determine the 1/3 octave spectrum of the sound pressure level (SPL). This analysis will aid in the interpretation of the results and might be ground for future studies when this shape of rods will be used in more complex arrangements. The free stream flow was uniform, and the surface of the rods was smooth. The 1/3 SPL spectrums were measure for empty research stand and research stand with rods. The difference between these two 1/3 SPL spectrum was important in these studies. The spectrums for each of studied rods was only evaluated for frequencies and velocities where the level difference of these two measurements is above 2 dB. As is seen from Figure 4 and Table 1 the maximum peak at low range of frequencies is observed for studied rods. This peak move to higher frequencies along with increase the velocity of flow. For example, there is maximum at 125 Hz at 6.5 m/s for rod with diameter 8 mm, but when the velocity increase to 15.8 m/s the maximum peak move to 315 Hz.

Table 1. Differential SPL values of characteristic peaks the 1/3 octave spectrums depending on frequency and velocity of air flow (microphone M1)

m/s	rod with 8 mm diameter						rod with10 mm diameter						rod with16 mm diameter				
	Hz						Hz						Hz				
	100	125	160	200	250	315	100	125	160	200	250	315	80	100	125	160	200
4.8	1.99						2.22						5.19				
6.5		3.48						3.04						8.51			
8.2			6.47						6.46					9.56			
9.8				6.79						5.55					11.2		
11.4				5.94						5.57						13.61	
12.9					9.61						7.7					13.53	
14.4						10.5						10.65					12.24
15.8						13.78						14.09					13.09

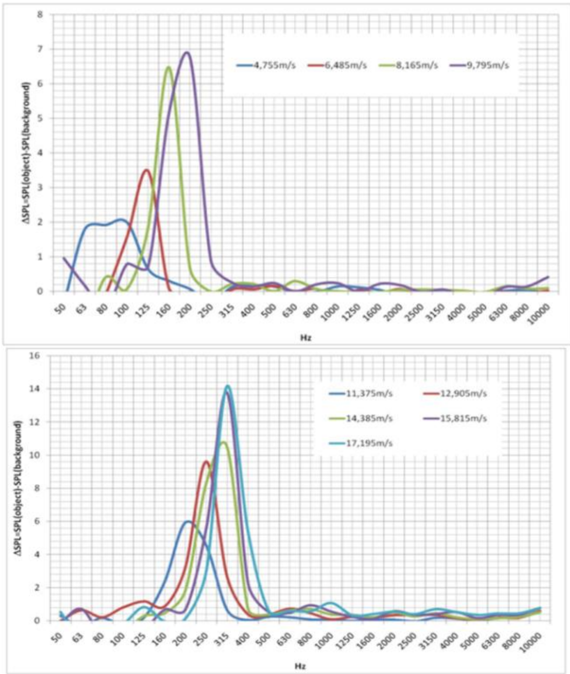

Figure 4. Differential 1/3 SPL spectrum between the SPL spectrum of studied rods with 8 mm diameter and background of the research stand dependent on velocity

If diameter of rod increases twice (from 8 mm to 16 mm), the maximum peak at the same velocity moves to lower frequency. For example, at velocity of 15.8 m/s, there is maximum peak at 315 Hz for the rod with diameter 8 mm, but at 200 Hz for rod with diameter 16 mm.

To find the dependences between velocities, frequencies and observed peaks for studied rods, the colour-maps of differential 1/3 SPL were done. Sound field propagation depends on many factors like distance, air density, temperature, humidity, terrain, wind direction, etc. In addition to these simple factors there are issues relating to tonality of the noise source and also octave spreading. Additionally, noise is effected by refraction and reflection, so frequently does not travel in a straight line. The perception of noise is highly subjective and non-linear, and it must still be interpreted to have any meaning. In this context the pragmatic approach to noise calculation is needed. In this work the differential 1/3 SPL, determined as the difference between the 1/3 SPL spectrum of studied rod and background of the research stand, for studied rods is examined, what eliminates other phenomena, which could influence on 1/3 SPL spectrum. The 2 - D colour-maps were done by using bi-cubic interpolation depending on the obtained parameters for studied rods. The bi-cubic interpolation can archieve good performance for smooth regions because it assumes smoothness of obtained data. For each rods, the differential 1/3 SPL colour-maps were done for the range of frequency 63 – 400 Hz (Figure 5).

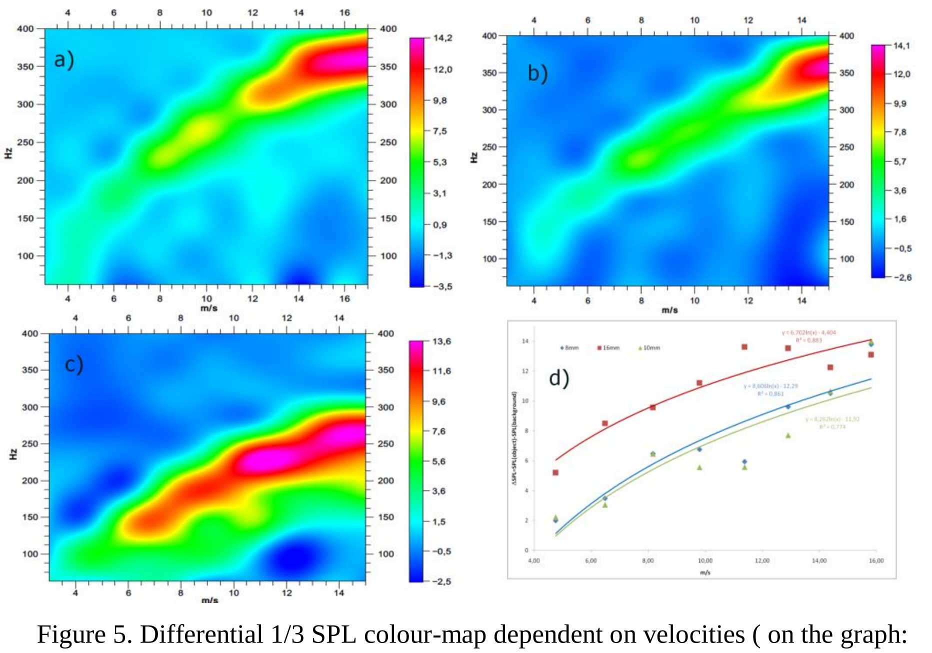

Figure 5. Differential 1/3 SPL colour-map dependent on velocities (on the graph: a) for 8 mm rod (microphone M1); b) for 10 mm rod (microphone M1); c) for 16 mm rod (microphone M1); d) linear-log models for values of differential 1/3 SPL for observed peaks of rods dependent on velocities

As seen from these colour-maps, the maximum peak (from microphone M1) is moving along the curve could be described by the linear-log model, what is seen on the Figure 5, graph d). Logarithmic functions are very helpful when working with phenomena that have a very wide range of values, because they allow you to keep the actually obtained values in a smaller range. Logarithmically transforming variables in a regression model is a very common way to handle situations where a non - linear relationship exists between the variables and such situation we often have got in acoustic measurements. However exact interpolation and get the better adjustment of data by these functions require more measurements, what will be continued.

The velocities of flow at several points behind the rods have been evaluated using thermo anemometer measurement technique. The points of measurement were chosen at locations *z* = (-30 mm; -10 mm; 0 mm; 10 mm; 30 mm) – perpendicular to stream flow and *x* = 10mm and 30mm (according to flow stream), relative to the surface of mounted rods. In the Figure 6, the mean velocities of flow in chosen points behind the 10 mm rod and 16 mm rod are presented.

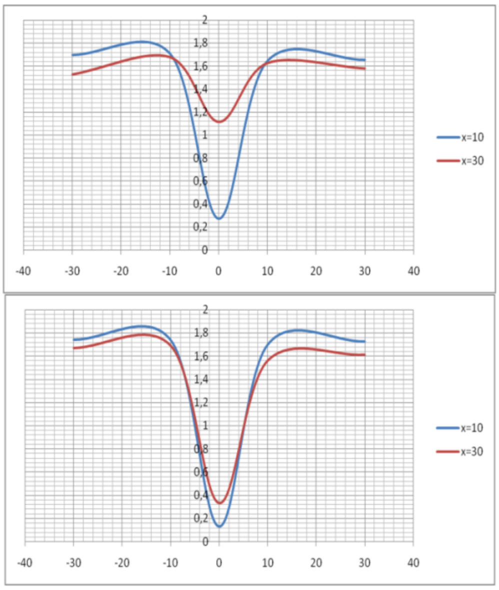

Figure 6. The mean velocities of flow behind the 10 mm rod (on the top) and 16 mm rod (on the bottom) in z and *x* axis at 1.2 m/s

The points of measurement were chosen at locations axis *z* = (-30 mm; -10 mm; 0 mm; 10 mm; 30 mm) – perpendicular to stream flow and axis *x* = 10 mm and 30 mm - according to flow stream, relative to the surface of mounted rods. At the Figure 6 the velocities of flow in chosen points behind the 10 mm rod and 16 mm rod are presented. Results show a similar velocity distribution along the *x*-axis. It can be seen that the minimum of the velocity profile behind the 10 mm rod is at 0.27, and behind the 16 mm rod is at 0.12, at the distance of *x* = 10 mm. The velocity profile at distance of *x* = 30 mm increases for 10 mm rod to 1.1 but a little for 16 mm rod to 0.33.

Figure 6 shows a different shape of the wake for the 16 mm rod as for the 10 mm rod. This means that the width of the wake behind the rods is predicted correctly.

4. Conclusions

Experiments have been performed to investigate the flow around a circular rods with different diameter into uniform air stream. The vortex shedding frequencies and flow velocity were measured for Reynolds numbers between 12 and 18000, but the range Re above 3000 was emphasized. The sound pressure level as a 1/3 octave spectrum and position of the dominant noise is highly dependent on the velocity. For studied rods, the maximum peaks at low frequencies are observed (from 100 Hz to 315 Hz). Maximum peaks move to higher frequencies along with the increase of the velocity of flow. Finally, the aerodynamic parameters, as a flow velocity around cylinder, were performed. The velocity profile behind the rods is predicted correctly according to literature data.

References

1. M. G. Smith, L. C. Chow, *Validation of a prediction model for aerodynamic noise from aircraft landing gear"*, AIAA paper 2002 – 2581.
2. W. Dobrzynski, H. Buchholz, *Full scale noise testing on airbus landing gears in the German-Dutch Wind Tunnel"*, AIAA paper 97-1597.
3. M. M. Zdravkovich, *Flow around circular cylinder, Volume 1*, Oxford University Press, 1997.
4. M. M. Zdravkovich, *Flow around circular cylinder, Volume 2*,Oxford University Press, 2003.
5. O. Inoue, N. Hatakeyama, *Sound generation by a two-dimensional circular cylinder in a uniform flow,* Journal of Fluid Mechanics, **471** (2002) 285 – 314.
6. S. J. Park, C. W. Lee, *Flow structure around a finite circular cylinder embedded in various atmospheric boundary layers*, Fluid Dynamics Research, **30**(3) (2002) 197 – 215.
7. R. H. Schlinker, M. R. Fink, R. K. Amiet, *Vortex noise from non-rotating cylinders and airfoils,* AIAA paper 76 – 81.
8. H. Fujita, H. Suzuki, A. Sagawa, T. Takaishi, *The Aeolian tone characteristics of a circular cylinder in high Reynolds number flow*, AIAA paper 99 – 1849.
9. W. A. Olsen, *Noise generated by impingement of turbulent flow on airfoils of varied chord, cylinders, and other flow obstructions*, AIAA paper, 76 – 504.
10. M. R. Davis, N. H. Pan, *Noise generated by the interaction of turbulent jets with circular cylinders*, Journal of Sound and Vibration, **135**(3) (1989) 427 – 442.
11. A. R. Barnard, *Flow Induced Noise Reduction Techniques for Microphones,* Sound & Vibration, October (2014) 3 – 12.
12. L. McCormack, S. Delikaris-Manias, V. Pulkki, *Parametric acoustic camera for real-time sound capture, analysis and tracking*, Proceedings of the 20th International Conference on Digital Audio Effects (DAFx-17), Edinburgh, UK, September (2017) 5 – 9.