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Enhancing Experimental and Numerical Data Validation through Acoustic Noise Signal Demodulation for Estimating Drone Propeller Rotational Speed

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Abstract. *This study addresses a novel approach for estimating the rotational speed of small-scale propellers, typically found in drones, through the analysis of their acoustic noise signal. Accurately determining the instantaneous rotational speed of propellers in anechoic wind-tunnels poses significant challenges due to inherent experimental rotational speed fluctuations. These fluctuations can distort harmonic peaks levels, or deteriorate the process of applying comparable techniques when validating constant rotational speed numerical simulations with experimental data. This can be overcome by the knowledge of the propeller instantaneous rotational speed, allowing the signal to be resampled, correcting it to a constant rotational speed. Measured tachometer data is often not available nor reliable, as the use of external devices is not always feasible due to space constraints, costs, and sensitivity to adverse environmental conditions. An alternative approach is to directly estimate the propeller rotational speed from the measured acoustic signal, which is the focus of this study. The proposed methodology is based on the signal demodulation, which is a tacholess method that calculates the Hilbert Transform of the acoustic signal to obtain the frequency and phase related to the shaft rotation. To evaluate the technique, a synthetic propeller noise data are generated with a previous established rotational speed fluctuation, allowing a characteristic error for the algorithm predicted instantaneous rotation to be obtained. Secondly, the process is repeated for a real propeller noise signal, and the results are compared with the actual rotational speed measurement obtained with the tachometer. Finally, the obtained instantaneous rotation is employed to resample the experimental signal, allowing it to be suitable for validating numerical simulated signals. The spectra obtained from both signals are then compared, and the signal components are evaluated using a Time Synchronous Averaging (TSA) analysis. Preliminary results indicate the consistency and feasibility of the technique.*

Keywords: *Propeller noise, frequency estimation,signal processing, aerodynamic noise.*

1. INTRODUCTION

In the ever-evolving realm of drone technology, the precise estimation of propeller rotational speed stands as a pivotal challenge. The need of knowing this information provides further analysis, such as dynamic control, precise noise sources identifications with decomposition techniques and failure prediction. Small-scale propellers, typically found in drones, necessitate accurate measurement techniques amidst the backdrop of inherent experimental fluctuations. Traditional methods, reliant on tachometer data, often falter due to practical constraints and environmental sensitivities, prompting a quest for alternative methodologies.

For this matter, Bonnardot *et al.* (2005) proposed a tacholess technique of estimating the instantaneous rotation of a shaft with limited frequency fluctuations. The method is based on the phase demodulation and utilizes the Hilbert Transform, a matematical instrument to obtain the imaginary part of the analytic signal, which corresponds to the phase of the signal. The main achievement of this technique is that extincts the need of a tachometer, the instant rotation can calculated based on the shaft vibration data.

This work is organized as follows: Section 2 presents the methodology of the phase demodulation technique, describing in details the physics behind the numerical calculation. Section 3 describes some setups of both numerical and experimental data and Section 4 compares the results with the tachometer real information, as well as evaluates the components of the resampled signal with Time Synchronous Averaging (TSA) techiniques. Finally, Section 5 concludes the consistency of the demodulation method.

2. TEXT FORMAT

The manuscripts should be written in English, typed in A4 size pages, using font Times New Roman, size 10, except for the title, authors affiliation, abstract and keywords, for which particular formatting instructions are indicated above. Single space between lines is to be used throughout the text.

The text block that contains the title, the authors' names and affiliation, the abstract and the keywords must be indented 0.1 cm from the left margin and marked by a leftmost black line border of width 2 1/4 pt.

The first page must have a top margin of 3 cm and all the other margins (left, right and bottom) must have 2 cm. All the other pages must be set with all margins equal to 2 cm.

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All the symbols and notation must be defined in the text. Physical quantities must be expressed in the SI (metric) units. Mathematical symbols appearing in the text must be typed in italic style.

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Acceptable references include journal articles (MLA, 2004), numbered papers, dissertations and theses (Cavalini Junior, 2013; Coelho, 2017), published conference proceedings, preprints from conferences, books (McConnell and Varoto, 2008) and submitted articles (if the journal is identified).

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2.1 Section titles and subtitles

The section titles and subtitles must be aligned at left, typed with Times New Roman, size 10, bold style font. They must be numbered using Arabic numerals separated by points. No more than 3 sublevels should be used. One single line must be included above and bellow each section title/subtitle.

2.2 Mathematical equations

The mathematical equations must be indented by 0.5 cm from the left margin. They must be typed using Times New Roman, italic, size 10 pt. font. Arabic numerals must be used as equation numbers, enclosed between parentheses, right-aligned, as shown in the examples below. Equations should be referred to either as "Eq. (1)" in the middle of a phrase or as "Equation (1)" in the beginning of a sentence. Matrix and vector quantities can be indicated either by brackets and braces, as in Eq. (1), or in bold style, as in Eq. (2). Symbols used in the equations must be defined immediately before or after their first appearance.

One single line must be included above and below each equation.

$$[M]\{\ddot{x}\} + [C]\{\dot{x}(t)\} + [K]\{x(t)\} = f(t) \tag{1}$$

$$\mathbf{M}\ddot{\mathbf{x}}(t) + \mathbf{C}\dot{\mathbf{x}}(t) + \mathbf{K}\mathbf{x}(t) = \mathbf{f}(t) \tag{2}$$

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Figures and tables should be placed in the text as close as possible to the point they are first mentioned and must be numbered consecutively in arabic numerals. Figures must be referred to either as "Fig. 1" in the middle of a phrase or as "Figure 1" in the beginning of a sentence. The figures themselves as well as their captions must be centered in the breadth-wise direction. The captions of the figures should not be longer than 3 lines.

The legend for the data symbols as well as the labels for each curve should be included into the figure. Lettering should be large enough for ease reading. All units must be expressed in the S.I. (metric) system.

One blank line must be left before and after each figure.

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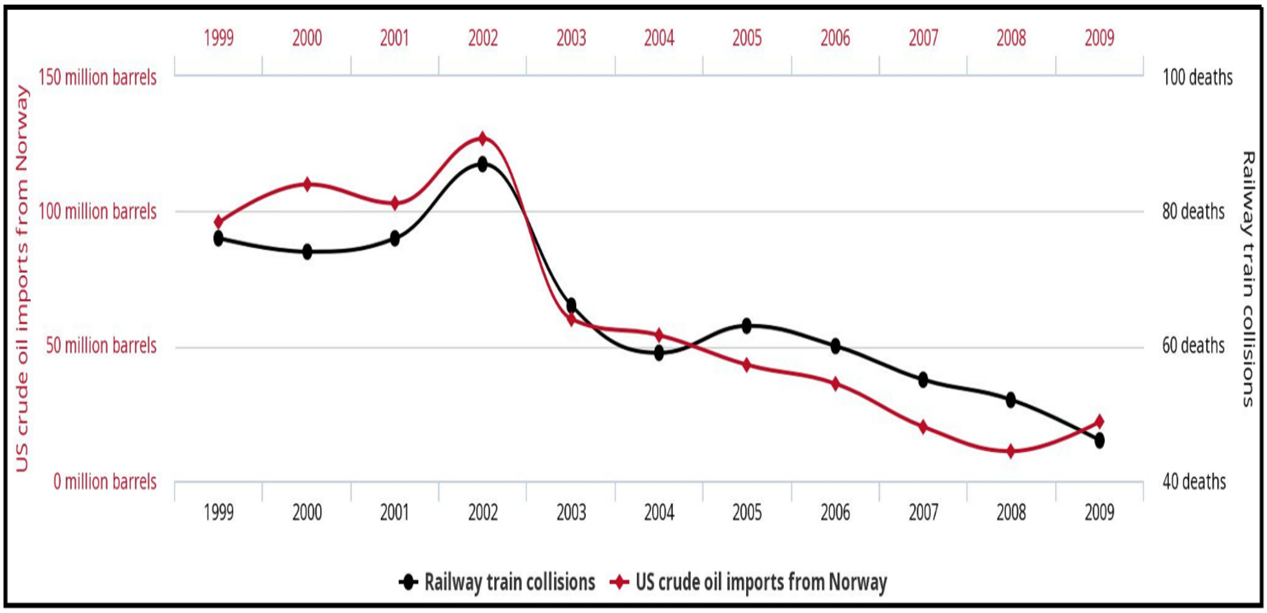

Figure 1. United States crude oil imports from Norway versus number of drivers killed in collision with railway train. Available from: http://tylervigen.com/spurious-correlations

Tables must be referred to either as “Tab. 1” in the middle of a phrase or as “Table 1” in the beginning of a sentence. The tables themselves as well as their titles must be centered in the breadth-wise direction. The titles of the tables should not be longer than 3 lines. The font style and size used in the tables must be similar (both in size and style) to those used in the text body. Units must be expressed in the S.I. (metric) system. Explanations, if any, should be given at the foot of the tables, not within the tables themselves.

One blank line must be left before and after each table.

The style of table borders is left free. An example is given in Tab. 1.

Table 1. Experimental results for flexural properties of CFRC-4HS and CFRC-TWILL composites. Span/depth ratio = 35:1. Average results of 7 specimens.

Composite Properties	CFRC-TWILL	CFRC-4HS
Flexural Strength (MPa)$^{(1)}$	209$\pm$ 10	180 $\pm$ 15
Flexural Modulus (GPa)$^{(1)}$	57.0 $\pm$ 2.8	18.0 $\pm$ 1.3
Mid-span deflection at the failure stress (mm)	2.15 $\pm$ 1.90	6.40 $\pm$ 0.25

$^{(1)}$ measured at 25^{o}C

3. ACKNOWLEDGEMENTS

This optional section must be placed before the list of references.

4. REFERENCES

The list of references must be introduced as a new section, located at the end of the paper. The first line of each reference must be aligned at left. All the other lines must be indented by 0.5 cm from the left margin. All references included in the reference list must have been mentioned in the text.

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Bonnardot, F., El Badaoui, M., Randall, R., Danière, J. and Guillet, F., 2005. “Use of the acceleration signal of a gearbox in order to perform angular resampling (with limited speed fluctuation)”. *Mechanical Systems and Signal Processing*, Vol. 19, No. 4, pp. 766–785. ISSN 0888-3270. doi:https://doi.org/10.1016/j.ymssp.2004.05.001. URL `https://www.sciencedirect.com/science/article/pii/S0888327004000664`.

Cavalini Junior, A.A., 2013. *Detecção e identificação de trincas transversais incipientes em eixos horizontais flexíveis de máquinas rotativas*. Ph.D. thesis, Universidade Federal de Uberlândia, Uberlândia, Brasil.

Cavalini Junior, A.A., Lara-Molina, F.A., Sales, T.P., Koroishi, E.H. and Steffen, V., 2015. "Uncertainty analysis of a flexible rotor supported by fluid film bearings". *Latin American Journal of Solids and Structures*, Vol. 12, pp. 1487–1504.

Coelho, F.R., 2017. *Geração de novas correlações da soma-ponderada-de-gases-cinza para H2O e CO2 em alta pressão*. Master's thesis, Universidade Federal do Rio Grande do Sul, Porto Alegre, Brasil.

McConnell, K.G. and Varoto, P.S., 2008. *Vibration Testing: Theory and Practice*. John Wiley & Sons, New Jersey, 2nd edition.

MLA, 2004. "How do I document sources from the web in my works-cited list?" Modern Language Association. 22 Feb. 2007 <http://www.mla.org>.

Santos, D.D., Furtado, G.M., Frey, S.L., Naccache, M.F. and de Souza Mendes, P.R., 2013a. "Flow of elasto-viscoplastic fluids inside a cavity". In *Proceedings of the 22nd International Congress of Mechanical Engineering - COBEM 2013*. Ribeirão Preto, Brazil.

Santos, D.D., Furtado, G.M., Frey, S.L., Naccache, M.F. and de Souza Mendes, P.R., 2013b. "Numerical investigation of elastic and viscous effects on inertial viscoplastic fluid flows". In *Proceedings of the 22nd International Congress of Mechanical Engineering - COBEM 2013*. Ribeirão Preto, Brazil.

5. RESPONSIBILITY NOTICE

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