

Data Spectral Content Analysis Laboratory Report

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1 Introduction

The study of noise from jet engines falls under aero acoustics, which deals with sound generated by fluid motion and its interaction with solid boundaries. According to Bose (2013), much of the acoustic emission from aero-engines originates from turbulent jets and shear layers, which can be described using monopole, dipole, and quadrupole source models and analyzed through spectral methods.

These models help identify the dominant frequency components responsible for the overall noise generation. The frequency of the acoustic signal corresponds to the rate at which fluctuating aerodynamic forces act on air particles or, in the case of turbo machinery, the blade passage frequency f_{BP} — a key feature of dipole-type noise sources (Huang, 2013). Its relationship with the rotational speed (RPM) of the rotor vanes is given as follows:

$$RPM = 4\pi \cdot \frac{f_{\text{bp}}}{60v} \quad (1)$$

where v is the number of rotor vanes which is 7 for this lab experiment.

The objective of this laboratory experiment is to analyze the sound pressure level (SPL) data obtained from an educational turbojet, identify the predominant noise sources, and evaluate the relationship between engine throttle setting and acoustic output. It is expected that increasing the throttle (and thus thrust) raises the rotational speed of the compressor vanes, leading to higher-frequency and higher-intensity noise due to enhanced aerodynamic loading and jet turbulence.

2 Methodology

2.1 Experimental Setup

The experiment carried out records the SPL waves of the Amt Olympus HP turbojet engine at different throttle percentages using a Rion NL-53-EX Class 1 microphone with calibrator and a high-performance data acquisition system

The microphone picks up SPL waves in the form of voltage output signals against time and feeds that data to the system. The relationship between the microphone transducer voltage output v and the sound pressure p is given as:

$$p = \frac{v}{S} \quad (2)$$

where S is the microphone sensitivity [VPa^{-1}]. This value can be determined after using the appropriate data analysis techniques on the calibration data (see Figure 2) and the formula given below:

$$SPL = 20 \log_{10} \left(\frac{p}{p_{\text{ref}}} \right) \quad (3)$$

where p_{ref} is the reference sound pressure equivalent to 0 dB.

The data obtained appeared as shown in Table 1. The data acquisition system sampled $2 \times N$ samples, where N is the number of samples recorded and $N = f_s T$. Here, T is the sampling duration and f_s is the sampling frequency, both of which were set on the front panel of the data acquisition system. Each test data file is formatted as a $2 \times N$ array, as shown in Table 2.

2.2 Data Analysis

In this lab experiment, the representation of the microphone signal was initially shown as the amplitudes of the signal versus the sampling time instances. However, the signal frequency content was more useful than

the digital signal samples. The representation of the digital signal in terms of its frequency components, also known as the signal spectrum, needed to be developed (Tan, 2013). This allowed a better interpretation of the data. To achieve this, the signal amplitudes were converted from the time domain to the frequency domain using the signal processing algorithm Discrete Fourier Transform (DFT) and the sample time instances were converted to sample frequencies. These steps were implemented and more are shown in the MATLAB Calibration Code (PDF). Upon completing the above steps the Calibration signal spectrum was obtained as shown in Figure 3. The Calibration code was then adapted to analyse the turbo jet noise signals at different throttle percentages. However for the output to be relevant the noise signals had to be converted to Sound pressure levels using the Microphone sensitivity S . From this the Sound pressure spectrum contents were derived.

3 Results

Sound pressure spectrum content at 0%, 30%, 50% and 70% throttle was obtained. These plots illustrate the effect of increasing throttle percentage on the spectral characteristics of the sound pressure level. They can be viewed in Figure 4. The blade passage frequency was identified to be the peak frequencies of the Sound pressure spectrum for the different thrust levels. Using these frequencies the (RPM) was found. A relationship was established between the thrust level and the rotational speed of the compressor vanes using the values given in Table 3

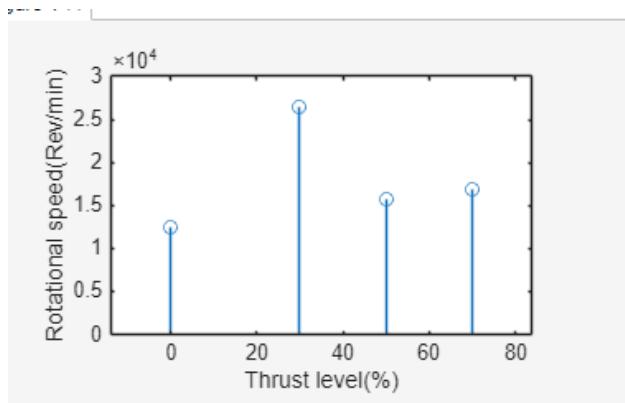


Figure 1: plot of Rotational speed against Throttle percentages

4 Discussion

From Figure 1 we were able to deduce that there is a linear relationship between the f_{BP} and thrust level. The reason why there is an unusual spike of frequency at 30% is because for percentages 50% and 70% the microphone was not calibrated to record frequencies higher than 20,000(Hz). So in reality what the peak frequencies at those percentages are in fact the harmonics of the fundamental frequency of the latter test cases. Aside from this, the data gathered was for informative purposes and qualitative in nature.

5 Reference List

- Huang, J., & Zheng, L. (2013). *Noise analysis of the turbojet and turbofan engine tests*. Proceedings of the Institution of Mechanical Engineers, Part G: Journal of Aerospace Engineering, 228(13), 2414–2423. <https://doi.org/10.1177/0954410013518035>
- Tan, L., & Jiang, J. (2013). *Digital Signal Processing: Fundamentals and Applications*. Academic Press. <http://ci.nii.ac.jp/ncid/BB13248327>
- MATLAB Calibration Code (PDF)
- Bose T. Aerodynamic Noise: An Introduction for physicists and engineers [Internet]. 2012. Available from: <http://ci.nii.ac.jp/ncid/BB11402459>

6 Appendix

6.1 A

| Filename | Throttle (%) | Thrust [N] | Air Mass Flow Rate [kg/s] |
|-----------------|--------------|------------|---------------------------|
| calibration.dat | 0 | 10 | 0.12 |
| test0.dat | 30 | 71 | 0.30 |
| test50.dat | 50 | 123 | 0.38 |
| test70.dat | 70 | 164 | 0.415 |

Table 1: Turbojet test data.

| Channel | Data Description |
|---------|---------------------------------|
| 1 | Microphone signal amplitude [V] |
| 2 | Time from sample start [s] |

Table 2: Test data file structure.

| Thrust level(%) | Rotational speed (rev/min) |
|-----------------|----------------------------|
| 0 | 12467.52 |
| 30 | 26348.33 |
| 50 | 15628.38 |
| 70 | 16936.12 |

Table 3: Thrust level vs Blade Passage Frequency.

```

34 p_ref = 20e-6;           % reference pressure [Pa]
35 %at 1kHz The calibration source generates pure tone at a 94dB therefore
36 SPL_dB = 94;
37 p_calib = 10^(SPL_dB/20) * p_ref; % Calculate the calibration sound pressure
38 V_rms = rms(V_s);% root mean square of the Voltage signal values
39 S = V_rms/p_calib;%Microphone sensitivity
40 fprintf("the Microphone sensitivity of the microphone used is %. VPa^-1\n",S)
41

```

Figure 2: MATLAB calibration code snippet for microphone sensitivity. Full code available online via GitHub in the Reference List.

6.2 B

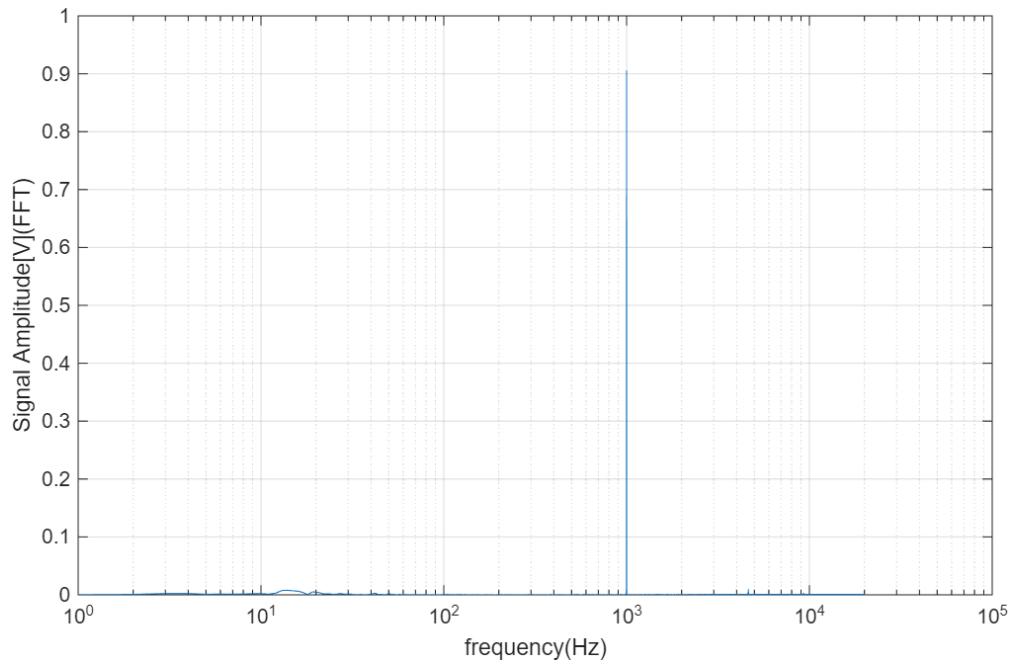


Figure 3: Calibration signal spectrum, peak at 1000(Hz)

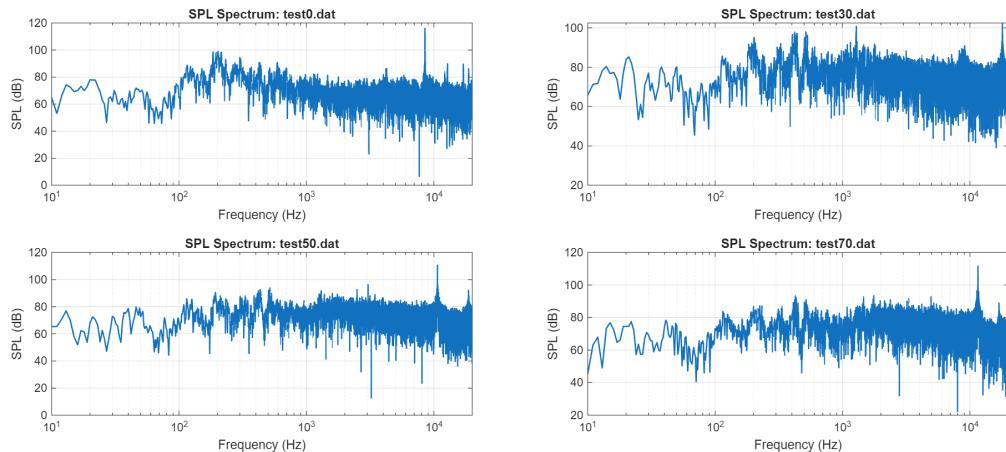


Figure 4: Sound pressure spectrum for all thrust level test case