ANALYSIS OF THE JET ENGINE NOISE EMISSIONS AT THE INLET AIR TO THE COMPRESSOR AND NOZZLE EXHAUST OUTLET

Abdulgader A. G. Abdulrahem

Department of Mechanical and Industrial Engineering,
Faculty of Engineering, University of Tripoli
Email: a.abdulrahem@uot.edu.ly

الملخص

تحليل الضوضاء المنبعثة من المحركات النفاثة أمراً مهماً، وذلك لما لها من أهمية لمعرفة خصائص الضوضاء المنبعثة من تردد وشدت مستوى الضوضاء وطورها التي تساعد في تصميم تقنيات مخمدات لمستوى الضوضاء في هذا النوع من المحركات، ومن بين المخمدات المستخدمة هي تقنية (Herschel and Quincke (HQ. في هذه الورقة تم قياس لحظيا الاشارتين الصوتيتين في موضعين مختلفين لمحرك نفاث معملي تدريبي صغير وذلك باستخدام نظام الميكروفون، الأول عند مدخل الهواء الداخل للضاغط بينما الآخر عند مخرج العادم لفوهة المحرك عند سرعات مختلفة لمحور الضاغط. أيضا وفي نفس موضع نظام الميكروفون تم قياس مستوى الضوضاء باستخدام جهاز قياس مستوى الضوضاء بالديسبل. تم تجميع وتحليل الاشارتين باستخدام تقنية تجميع بيانات متقدمة حيث تصل سرعتها إلى 1.25 Msample/sec، مع استخدام برنامج لاب فيو في تحليل الاشارتين وحساب مدى الارتباط بين الاشارتين والتحليل الطيفي لهما. أظهرت النتائج أن مستوى الضوضاء عند خروج العادم من الفوهة أكبر من مستوى الضوضاء عند مدخل الهواء للضاغط، وأن مستوى الضوضاء عند مخرج الفوهة يتناسب طرديًا مع سرعة دوران الضاغط. بينما عند مدخل الضاغط له سلوك متغير، عند السرعات المنخفضة كان مستوى الضوضاء منخفضًا نسبيًا، عند زيادة سرعة الضاغط بدأ مستوى شدة الضوضاء في تزايد إلى سرعة معينة إلى أن وصل الى أقصى مستوى للضوضاء. عند الزيادة أكثر في سرعة الضاغط بدأ مستوى الضوضاء في الانخفاض ليأخذ شكل المنحنى الكامل شكل القبة، ويرجع ذلك لحدوث الرنين الصوتي للضوضاء، وغالباً ما يكون نتيجة لعملية الاحتراق التي تتبع الضاغط، والتي تعتبر من بين المشاكل التي تحدث في الاحتراق المستمر للمحركات الحرارية، نتيجة للتفاعل بين التذبذب في الحرارة المنبعثة والضغط المتذبذب داخل غرفة الاحتراق. هذه الظاهرة تسمى بعدم الاستقرار الحراري الصوتي. علاوة على ذلك، أظهرت النتائج أن التردد السائد للإشارة المنبعثة من فوهة النفث للمحرك أكبر بكثير من التردد عند مدخل الهواء للضاغط، حيث يصل إلى حوالي 20 ضعف، هذا طبيعي نتيجة السرعة العالية للتدفق النفاث عند مخرج الفوهة. بالإضافة إلى ذلك، يمكن أن تكون البيانات المجمعة مفيدة في تطوير مخططات النمذجة التي توفر إمكانات تنبؤ كافية بحدوث عدم استقرار الاحتراق أو لفهم تفاعلات الموجات الصوتية واللهب، وأيضا تطوير تقنية مخمدات الضوضاء للمحركات النفاثة.

ABSTRACT

The analysis of the noise emitted by jet engines is important, because of its importance to know the characteristics of the noise emitted such as; frequency and sound pressure level and its signal phase, which helps in the design of dampers for the noise level in these type of engines, and among the dampers used is Herschel and Quincke (HQ) technology. In this paper, two acoustic signals were measured instantaneously in two different locations of a small laboratory training jet engine using a microphone system. the first microphone at the inlet of the compressor air, while the other at the exhaust outlet of the engine nozzle. Also, in the same position as the microphone system, the noise level was measured using a decibel noise level meter. The two signals were collected and

analysed using advanced data collection technology, with a speed of up to 1.25 Msample/sec, with the Lab View program used to analyze the two signals and calculate the correlation between the two signals and their spectral analysis. The results showed that the noise level at the exit of the exhaust from the nozzle is greater than the noise level at the air inlet of the compressor, and that the noise level at the outlet of the nozzle is directly proportional to the rotational speed of the compressor. While at the entrance of the compressor has a variable behaviour, at low speeds, the noise level was relatively low, when the compressor speed increased, the sound pressure level began to increase to a certain speed until it reached the maximum noise level.
When the compressor speed increases further, the noise level begins to decrease to take the shape of the dome, this is due to the occurrence of acoustic resonance of the noise, and it is often a result of the combustion process that follows the compressor, which is among the problems that occur in the continuous combustion of heat engines, as a result of the reaction between the fluctuation in the heat released and the fluctuating pressure inside the combustion chamber. This phenomenon is called thermo-acoustic instability. Moreover, the results showed that the dominant frequency of the signal emitted from the jetting nozzle of the engine is much greater than the frequency at the air inlet of the compressor, reaching about 20 times, which is normal due to the high velocity of the jet flow at the outlet of the nozzle. In addition, the collected data can be useful in developing modelling schemes that provide sufficient prediction capabilities for the occurrence of combustion instability or for understanding the interactions of sound waves and flames, as well as in developing noise dampening technology for jet engines.

KEYWORDS: Cross-Correlation; Jet Engine; Power Spectrum; Sound Level.

INTRODUCTION

The noise emitted from heat engines is one of the most important environmental pollutants, which is no less harmful than other pollutants such as chemical, nuclear and others. Among these heat engines are jet engines, which are the highest in noise level, reaching 130 dB. Also, the noise not only has a negative impact on the environment, but also has a very strong negative impact on the performance of the engine itself, as the noise inside the combustion chambers of continuous combustion has a direct effect on the occurrence of flame instability. Which causes large vibrations in the combustion chamber, which leads to its complete destruction. Therefore, the characteristics of the emitted noise must be known to avoid this problem. This phenomenon is called the thermo-acoustic of combustion instability. Many researches have been done on studying the sources of noise in jet engines and their negative impact on the environment and engine performance. In this research, the noise correlation between the signals dynamics of the noise emanating from the air compressor at the entrance of the jet engine and the exhaust noise at the nozzle exit of the jet engine at a different turbo-fan speed of the jet engine will be studied.

Engine noise reduction has increasingly become an important topic of research. As such, many studies are addressing the topic from different angles. For example, there are studies concerned with the reduction of noise emitting from turbojet engines, where the results of measurements are presented followed by a performance analysis [1]. Other studies focus on aircraft noise reduction, processing and prediction [2-6]. It is contended that the field of aircraft noise prediction has not reached a sufficient level of maturity yet [2]. However, there are serious attempts to treat jet noise reduction in which autocorrelation and modelling of jet engines were presented [7,8]. Nevertheless, some researchers considered combustion noise is contributing more to overall noise [3]. This of course is based on analyses using different methods such processing methods for measuring combustion noise [9,10].

Moreover, direct and indirect combustion noise were analyzed by W. Tao et. al (2016) [11], they identified a new indirect noise-source contribution arising from mixture in homogeneities. This is of course beside previously known contributions from direct combustion noise originating from unsteady combustion, and indirect combustion noise resulting from the interaction of flow-field perturbations with mean-flow variations in turbine stages and nozzles [11,12]. Ways to reduce noise emission have also been the focus of many researchers. A significant study conducted by Jeffrey Miles on core noise from turbofan engines has managed to reduce noise by a modelling method to separate correlated and uncorrelated sources through using multiple microphone and acoustic [13]. Also, Azimi et. al. (2011) [14] presented a discussion of the supersonic jet noise sources and a review of the main passive technologies employed for the reduction of supersonic jet noise.

Similarly, empirical methodologies have been utilized to predict the noise for turbojet engines for a newly designed turbojet engine [15,16]. One source of turbofan engine combustion noise is attributed to an unsteady combustion process, which produces unsteady pressures that propagate through the turbine to the far field. This is known as “direct” combustion noise mechanism [17]. Although researchers have been interested in studying jet engines recently, the study of jet engines noise has been in this field for decades, as the diagnosis of noise sources on a jet engine has been studied using correlation and coherence techniques [18]. However, there are still different areas worth studying and investigating. The present paper proposes a study of the acoustic spectra analysis and cross-correlation of jet engine at two different locations, one at inlet air to the jet engine, and the other at the outlet of jet exhaust gas of the jet engine.

EXPERIMENTAL SETUP

The current experiments are designed to analyse the noise emissions from jet engine at the intake air to compressor and at the exit of the jet engine nozzle. The overview of the experimental set up is shown in Figure (1). This test rig consists of a The ET 796 trainer Gas turbine jet engine, a data acquisition system, an acoustic microphone system, and a sound pressure level meter. The trainer includes a complete gas turbine system with the following sub-systems: Model gas turbine consisting of compressor (1 to 2), combustion chamber (2 to 3), turbine and jet nozzle (3 to 4) and thrust force measurement system. The jet engine model also consists of measurement and control instrumentation with temperature, flow rate, speed and pressure measuring points and associated displays. This also includes safety elements such as temperature and speed limiters. All parts of the system are arranged on a table frame [19].

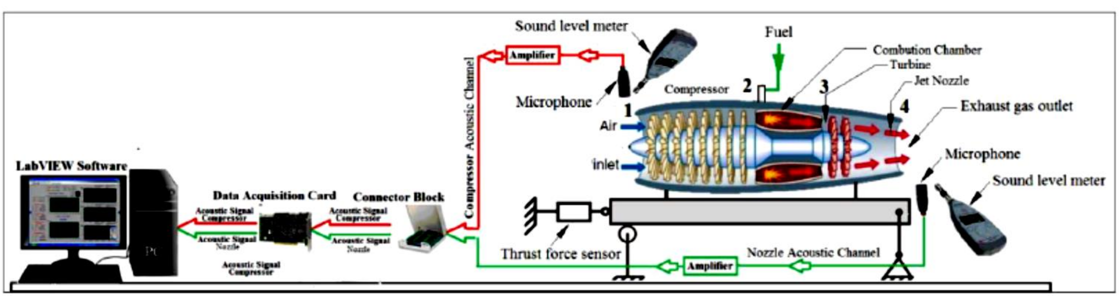

Figure 1: The overview of the experimental set up.

A data acquisition system was used to record the two acoustic pressure signals simultaneously. Two acoustic microphones were installed to measure the acoustic pressure dynamic: The first microphone at inlet air (compressor air inlet) and other at the nozzle exit (Exhaust gas outlet) at distance 10 cm away from both edge of inlet and outlet of the gas turbine jet engine. To measure the sound pressure level in dB, two sound level meter had been used at the same position of microphones. National Instrument DAQ card (model PCI-MIO-16E-1) and LabVIEW 7 software had been applied for data acquisition, monitoring and analyses.

RESULTS AND DISCUSSIONS

The noise emitted by jet engines is one of the strongest environmental pollution emissions. Its sources are usually when the air enters the compressor and the exhaust exits from the jet nozzle at high speed and at high temperatures of the gases. Another source of noise in a jet engine is the combustion process in the combustion chamber. In this paper, the acoustic signal was measured and analysed using the microphone system of a training jet engine of the type ET 796, where two microphones were placed: The first near the air inlet of the compressor at a distance of 10 cm, and the second at a distance of 10 cm from the outlet of the exhaust gases at the jet nozzle. The microphone system is connected to a data acquisition with a high sampling rate with speed of up to 1.25Msample/s. After recording the two signals using the two microphone systems and converting the analogue acoustic signal into a digital signal simultaneously with a data collection system, the signals analysed using Lab. VIEW. The experimental investigation was analysed in terms of power spectrum and cross-correlation between the two signals at the air inlet of the compressor and the exhaust gases exit from the jetting nozzle at different speeds of the axial compressor of the jet engine. Also, simultaneously with the recording of the two acoustic signals, the noise level was measured using a sound level meter device in dB at the inlet and outlet of the jet engine.

Figures (2 to 8) show the time series and power spectrum at different compressor speed of 45100, 52400, 60600, 70400, 80800, 91900, and 101700 rpm respectively. From the results, the spectral analysis shows the noise emitted from the air inlet of the jet engine that the dominant frequency ranges between 200-500 Hz, which is much lower than the dominant frequency at the outlet of the jet engine, which ranges from 4500 to about 10100 Hz at compressor speeds from 45000 to 101000 rpm.

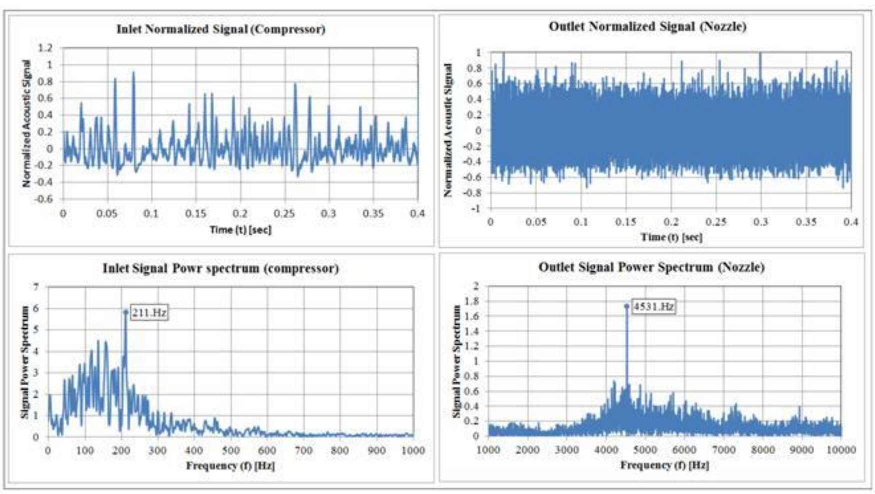

Figure 2: Time history of the acoustic signals, and power spectrum at compressor speed of 45100 rpm

It is also noticeable from the results, at different speeds, that the spectral analysis at the air intake of the engine shows many sub-frequencies and has a high amplitude close to the amplitude of the dominant frequency of this signal. While at the exit of the exhaust from the jetting, the spectral analysis shows only one frequency with a large amplitude and there are no other frequencies in all of the results. From the spectral analysis, the acoustic signal at the engine outlet from the jetting is also characterized by its high frequencies. It is noted that these frequencies have a strong relationship with the rotating speed of the compressor, approximately that the speed is ten times the frequency of the acoustic signal.

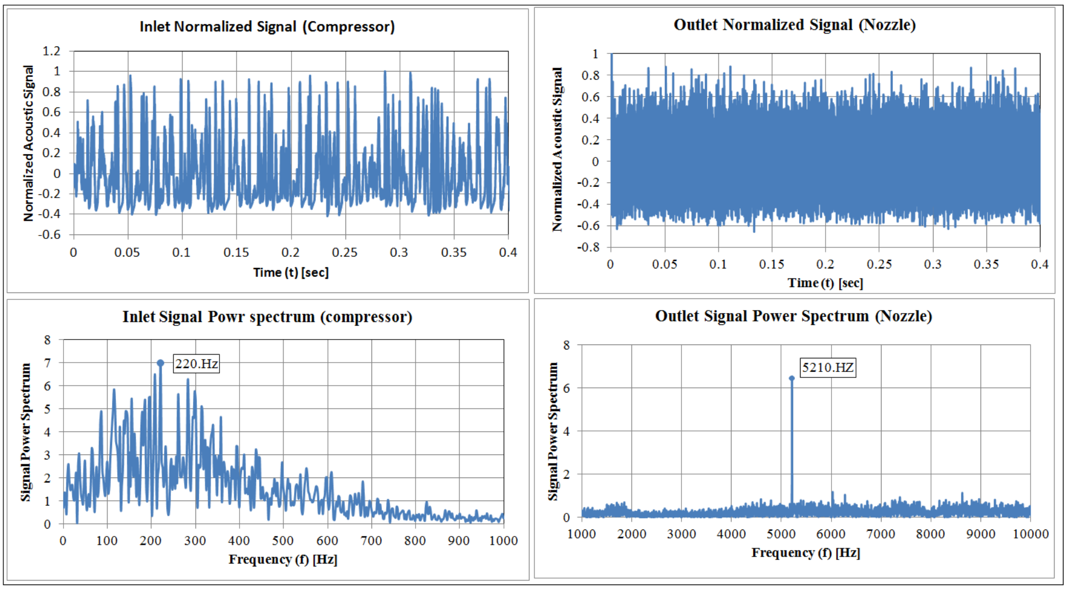

Figure 3: Time history of the acoustic signals, and power spectrum at compressor speed of 52400 rpm

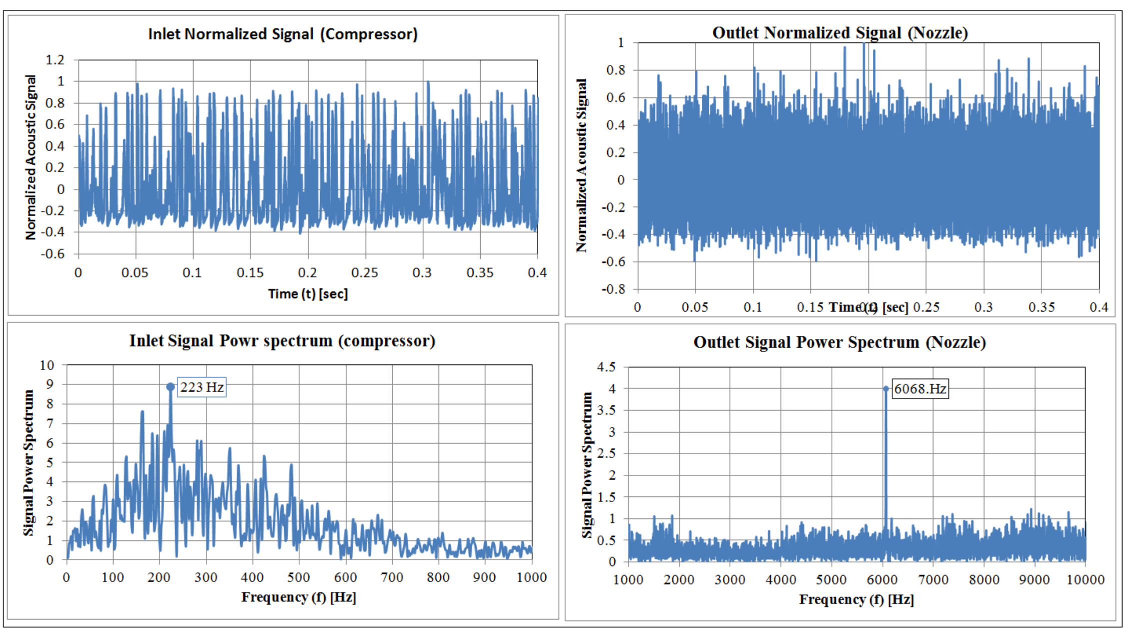

Figure 4: Time history of the acoustic signals, and power spectrum at compressor speed of 60600 rpm

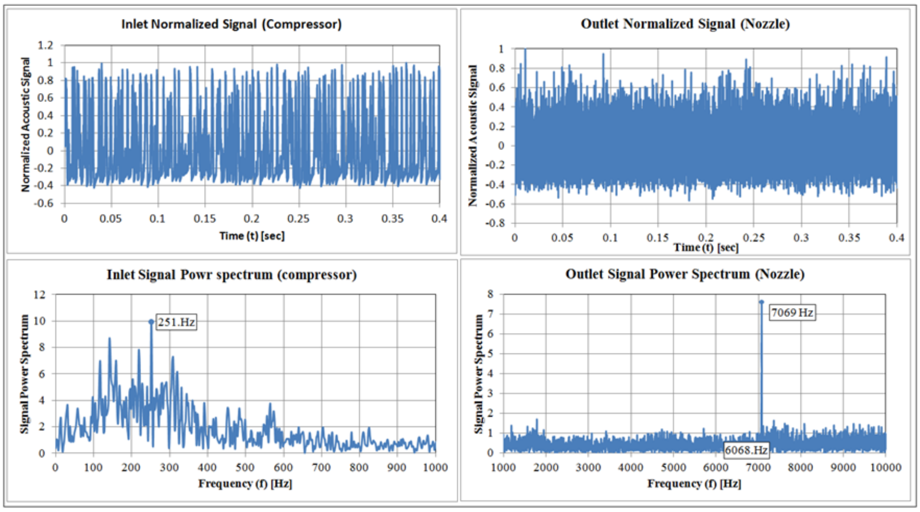

Figure 5: Time history of the acoustic signals, and power spectrum at compressor speed of 70400 rpm

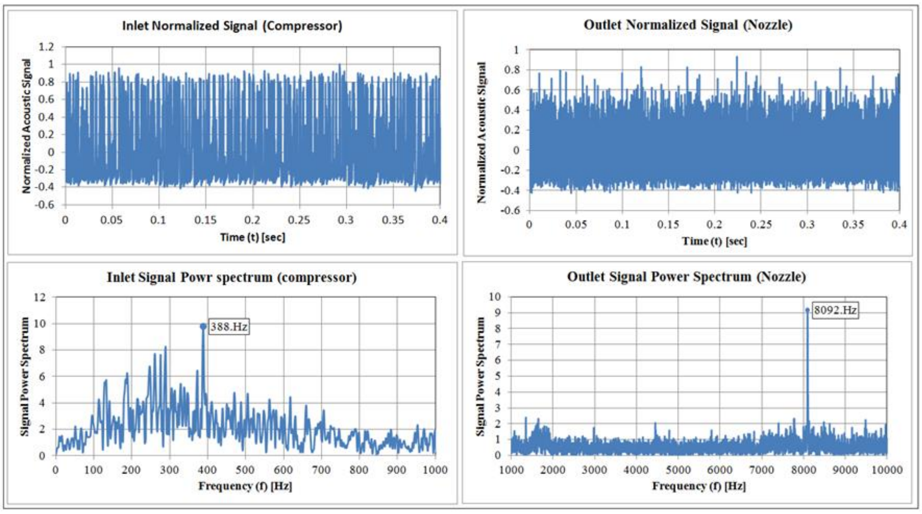

Figure 6: Time history of the acoustic signals, and power spectrum at compressor speed of 80800 rpm

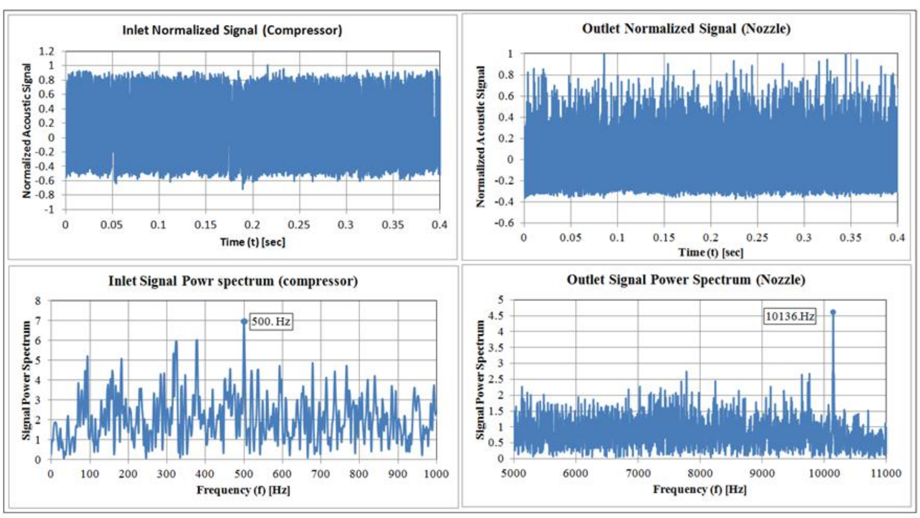

Figure 7: Time history of the acoustic signals, and power spectrum at compressor speed of 91900 rpm

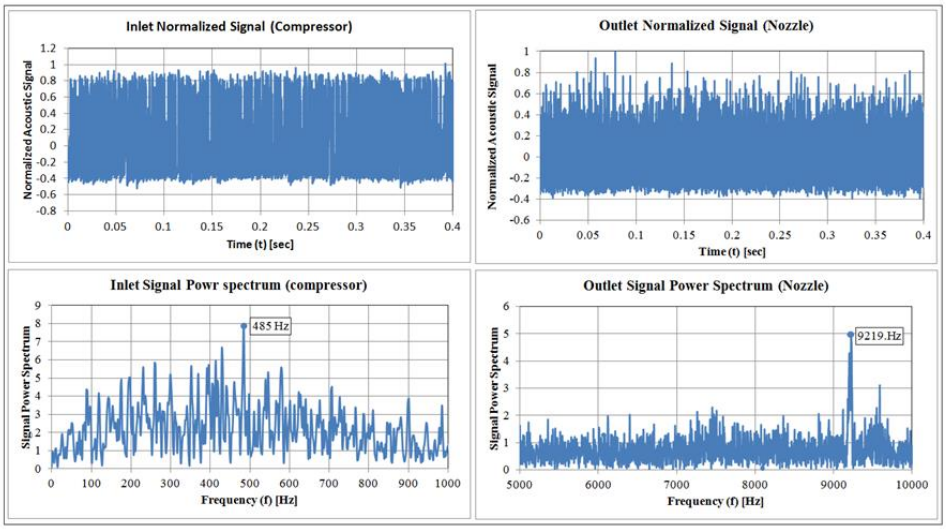

Figure 8: Time history of the acoustic signals, and power spectrum at compressor speed of 101700 rpm

Figure (9) shows a family of cross-correlation curves of the acoustic signals at different compressor speed are presented. From the figure, it can be seen that the cross-correlation curves of the acoustic signals do not vary for all speeds; their trends are not strong correlation. In all speeds the cross-correlation curves do not drop to zero, which means that the signals have no weak correlation for all speeds. From results at 45100 rpm the cross-correlation is weaker than the cross-correlation at 52400 rpm, where the strongest correlation was at the speed of 52400 rpm. The correlation began to decrease gradually as the compressor speed increased.

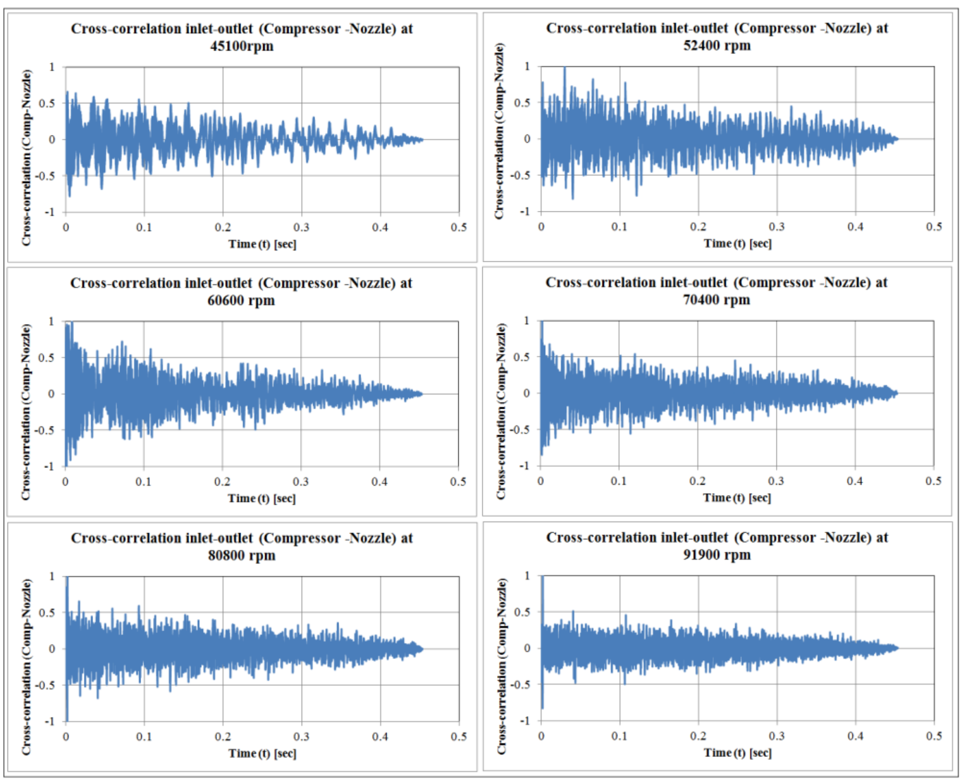

Figure 9: Cross-correlations inlet to outlet of the acoustic signals at different speed of compressor

In this paper, the noise level was measured by using a sound pressure level (SPL) meter for each of the air inlet (compressor) of the jet engine and at the exhaust outlet (Nozzle) of the jet engine, as it was connected to the system for measuring the two acoustical signals using the microphone system. Figure (10) shows the noise level when the motor is running at different compressor shaft speeds. From the Figure, the results show that the noise level at the exhaust exit from the jet engine nozzle is much greater than the noise level at the air inlet of the jet engine compressor. This is due to the speed of the exhaust gases flowing from the jet engine nozzle. It is noted that the noise level produced by the exhaust nozzle increases with the speed of rotation of the compressor. However, when the air enters the compressor, the noise level increases to a certain extent. In this papers, the maximum noise level at the speed was about 80,000 rpm, and the noise level was 110 dB, then the noise level began to decrease. This is likely to occur resonance at this frequency, which is 388 Hz, and is often the result of the combustion process in the combustion chamber immediately following the compressor.

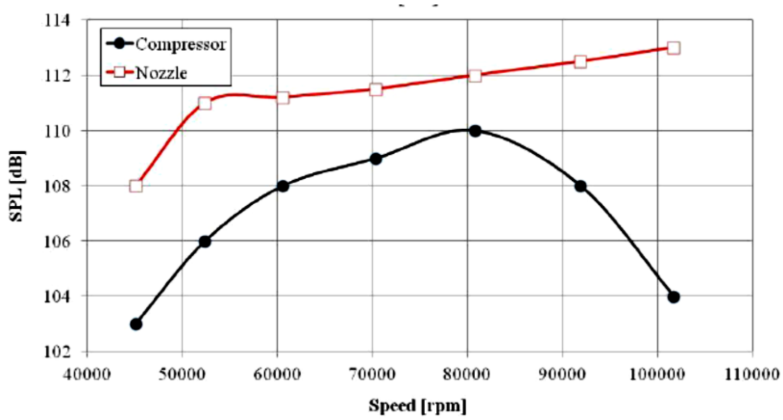

Figure 10: sound pressure level as a function of axial compressor speed

Figure (11) shows dominant frequency at different axial compressor speed. It is very clear that at the outlet of the jet engine the acoustic signal has very high frequencies of up to 10,000 Hz at the speed of about 100,000 rpm. Compared to the air entered the compressor at the same speed, the frequency was about 500 Hz. Each of the frequencies increases with the increase in the rotational speed of the compressor. However, is noticeable from the Figure that the frequency at the outlet of the jet engine increased linearly, while at the entry of air into the compressor, the increase was non-linear, in the form of S shape.

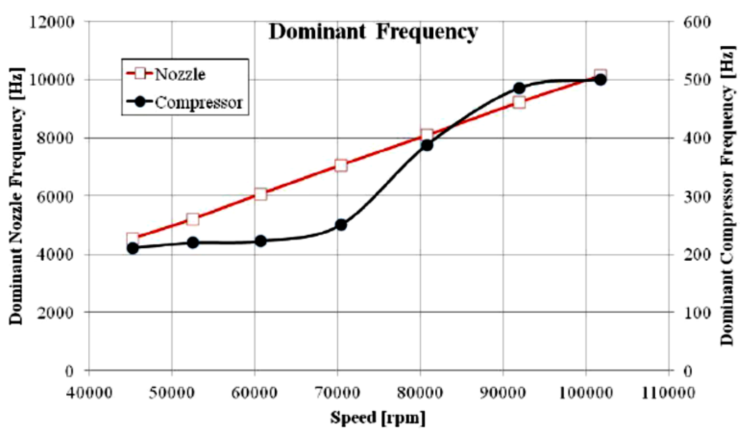

Figure 11: Dominant frequency as a function of axial compressor speed.

CONCLUSION

The study in this paper focused on the laboratory analysis of the spectral and extent of the correlation (cross-correlation) of the two signals recorded at the air inlet and at the exhaust gas outlet of a ET 796 trainer gas turbine jet engine in order to know the relationship between the two signals such as the frequency, sound pressure level, and the cross-correlation of the acoustic signals between them at different axis speeds of the jet engine compressor. The main conclusions of this paper can be summarized as follows: i- the noise level at the exhaust outlet of the jetting is greater than at the air inlet of the compressor; ii- the frequency at the exhaust outlet of the jetting is much greater than the frequency at the air inlet of the jet engine, where the frequency ratio between the inlet to the outlet is about 1:20; iii- the cross-correlation between the two signals at the input and the output was relatively strong at all the different speeds. The results also showed that the cross-correlation decreased slightly at speeds close to 80000 rpm. This is likely to occur due to the acoustic resonance of the combustion process in the jet engine combustion chamber. It is also noted in the results that the relationship of the predominant frequency of the noise resulting from the exhaust exiting from the jetting was a linearly proportional relationship with the axial speed of the compressor. While at the air inlet for the jet engine, the relationship increased by increasing the speed, producing S-shaped curve, as the speed increased strongly from 70000rpm to 90000rpm.

REFERENCES

[1] Grigore Cican, Marius Deaconu and Daniel-Eugeniu Crunteanu. 2021. Impact of Using Chevrons Nozzle on the Acoustics and Performances of a Micro Turbojet Engine. Applied science.

[2] Antonio Filippone. 2014. Aircraft Noise Prediction. The University of Manchester.

[3] Pa´ul Rodr´ıguez Garc´ıa. 2016. Aircraft Turbine Combustion Noise Processing. University of Southampton.

[4] Mojtaba Sadeghian, Mofid Gorji Bandpy. 2020. Technologies for Aircraft Noise Reduction: A Review. J Aeronaut Aerospace Eng, Vol. 9 Iss. 1 No: 219.

[5] Yukino Sakai. 2022. Aircraft Engine Audio Signal Analysis in Assisting Maintenance Inspections. Journal of Physics. 10.1088/1742-6596/2218/1/012002.

[6] Shashikant R. More. 2011. Aircraft Noise Characteristics and Metrics. PARTNER-COE-2011-004.

[7] Blaine M. Harker, Kent L. Gee, Tracianne B. Neilsen, and Alan T. Wall. 2013. On autocorrelation analysis of jet noise. Acoustical Society of America. 43.28. Ra, 43.50.Nm.

[8] Guillaume A. Brès1 and Sanjiva K. Lele. 2019. Modelling of jet noise: a perspective from large-eddy simulations. Stanford University. royalsocietypublishing.org/journal/rsta.

[9] Anthony Hart. 2020. Development of Processing Methods for Measuring Combustion Noise in Turbofan Jet Engines. University of Southampton. School of Engineering.

[10] Ann P. Dowling, Yasser Mahmoudi. 2014. Combustion noise. Science Direct. Cambridge CB2 1PZ.

[11] W. Tao, Marek Mazur, M. Huet, Franck Richecoeur. 2016. Indirect Combustion Noise Contributions in a Gas Turbine Model Combustor with a Choked Nozzle. Combustion Science and Technology. hal-01312563.

[12] Matthias Ihme. 2017. Combustion and Engine-Core Noise. Annual Reviews. 10.1146/annurev-fluid-122414-034542.

[13] Jeffrey Hilton Miles. 2006. Procedure for Separating Noise Sources in Measurements of Turbofan Engine Core Noise. NASA/TM. 2006-214352.

[14] Mohammadreza Azimi and Fathollah Ommi. 2014. Supersonic Jet Noise: Main Sources and Reduction Methodologies. Journal of Engineering Science and Technology Review 7 (2) (2014) 95 – 98.

[15] João Roberto Barbosa and Daniel Jonas Dezan. 2013. Turbojet Engine Noise Prediction Utilizing Empirical Methods. research gate. DOI: 10.1115/GT2013-95274.

[16] João Roberto Barbosa and Daniel Jonas Dezan. 2013. Single-Stream Jet Noise Prediction Using Empirical Methodology for a Newly Designed Turbojet Engine. research gate. DOI: 10.1115/GT2013-95199.

[17] Jeffrey Hilton Miles. 2008. Spectral Separation of the Turbofan Engine Coherent Combustion Noise Component. NASA/TM—2008-215157.

[18] Allen Karchmer and Meyer Reshotko. 1976. Core Noise Source Diagnostics On A Turbofan Engine Using Correlation And Coherence Techniques. NASA TM X-73535.

[19] Dipl.-Ing. (FH) Peter Mittasch "Experiment Instructions of Gas Turbine Jet Engine Catalogue ET 796" G.U.N.T. Gerätebau, Barsbüttel, Germany, Version 0.3. 2017.