Assessing the Impact of Meteorological Effects on Military Jet Aircraft Noise

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A senior thesis submitted to the faculty of
Brigham Young University
in partial fulfillment of the requirements for the degree of

Bachelor of Science

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ABSTRACT

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ANSI/ASA standard S12.75 (2012) provides guidance on allowable meteorological conditions for acoustical measurements of installed high-performance jet engines. This paper investigates meteorological effects on acoustic data acquisition by analyzing recent measurements of a T-7A-installed GE F404 engine. During this measurement, the aircraft was run up six times at engine powers from idle to full afterburner, with test conditions following those prescribed by S12.75. However, far-field spectra show variability between runs, despite relatively uniform test conditions. Measurements of the vertical temperature gradient show a correlation between the gradient and spectral characteristics. This analysis suggests that local temperature profiles must be considered more carefully in future full-scale measurements.

Keywords: Jet Noise, Afterburner, ANSI/ASA Standards

ACKNOWLEDGMENTS

I would like to acknowledge the Office of Naval Research for funding this research. It would not have been possible without their support.

Dr. Kent Gee has been right there to give invaluable support and guidance for me throughout the process of this research. I am grateful for his tremendous help and for giving me the motivation I needed to get through this project.

I extend my appreciation to an outstanding team that mentored me throughout the experiment: Matthew Christian, Logan Mathews, Tyce Olaveson, Kristi Epps, and Mark Anderson. In particular, I want to acknowledge Matthew for his exceptional mentorship, which significantly contributed to my growth and the success of this endeavor.

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Chapter 1

Introduction

The motivations for the T-7A measurement, examine standards for military jet measurements, and understand the discrepancies that were seen during this measurement.

1.1 Motivation

High-performance military jet aircraft are known for generating and propagating significant levels of noise into the surrounding environment. Close proximity to these aircraft can have adverse effects on one's hearing, raising particular concerns for the Navy. Those at the highest risk of hearing loss are individuals who work close to high-performance afterburning aircraft, such as the ground crews on aircraft carriers. Despite the provision of hearing protection, it often proves insufficient to address the high-intensity noise produced by these jets. This has prompted the Navy to explore solutions to reduce noise levels and ensure the well-being of those who maintain and operate these aircraft. [1].

The primary motivation behind conducting tests of the T-7A aircraft is to gain an understanding of the noise generated by jet aircraft. These tests provide data for future research and development of models for new aircraft, potentially leading to quieter planes [2]. The ability to model and predict noise propagation from this aircraft is crucial in providing essential data to improve these military jets.

1.2 The Measurement/Aircraft

The T-7A, developed by Boeing, is the latest training aircraft and is capable of afterburner—a capability that amplifies thrust by increasing combustion within the engine. Typically, this afterburner is engaged during takeoff and supersonic flight, producing fast exhaust gases from the jet engine, causing shock waves and turbulent mixing of ambient air. The turbulent mixing generates noise that propagates away from the aircraft [3]. As full afterburning capable aircraft is widespread among most military jet aircraft, the T-7A offers a unique opportunity to investigate the noise characteristics of military jets with afterburner capabilities. The data gained from these tests can provide valuable information in the modeling and design of future aircraft. Fig. 1.1 demonstrates the T-7A's full afterburner capabilities.

During the measurement of the T-7A, the aircraft underwent six increments of thrust, transitioning from idle to full afterburner or run-up. The multiple run-ups serve to ensure greater consistency and precision in the measurements. It also enables the examination of various thrust levels generated by the aircraft.

1.3 Standards

Measurements for military aircraft adhere to standards to maintain consistency from one measurement to another. These standards cover a range of requirements including meteorological conditions, microphone placement, and data analysis. Ground-based measurement standards for military aircraft are given by the ANSI/ASA S12.75 standard. It states that acquiring "Accurate, reliable, and repeatable noise measures from standardized noise measurement techniques will help

Figure 1.1 Full Afterburner of the T-7A during the run-up. Due to the high temperature and speed of the emitting gases, they remain together farther downstream.

ensure confidence in the data used in the modeling and prediction of noise impacts" [4]. These techniques were followed during the T-7A measurement.

This thesis specifically focuses on two sets of standards: meteorological standards and specific thrust output for these measurements. The meteorological standards encompass standard include wind speed, temperature, pressure, and humidity. The thrust specifications are used for normalizing each run-up and ensuring equitable data for each run-up. While most of these standards keep the measurement within a certain range of tolerance, good for data analysis, recent data collection shows a discrepancy that appears to be correlated to weather.

During the analysis of the acoustical data obtained from the measurement, the T-7A test exhibited variations from run to run. Specifically, these variations were evident between the first two runs and the last four runs. As the run-ups progressed, changes occurred that had a direct impact on the collected data. To find the reason behind these data discrepancies the standards were reviewed to ensure confidence in the setup. Reaffirming that the standards were upheld prompted an insight that the existing standards might not sufficiently account for all the necessary measurements. Of the measurement parameters, meteorological data displayed noticeable variations in recorded values. The identification of this source of error is both compelling and has the potential to refine the standards for future measurements.

1.4 Weather

Variations in weather conditions provided insights into possible factors contributing to the observed variations during the measurement. Meteorological conditions have a significant influence on the propagation and dispersion of sound in the atmosphere [5] [6]. Temperature and humidity directly affect the speed of sound in the medium, altering how sound travels. The circulation of wind over surfaces can generate noise which can potentially impede the acquisition of data for the aircraft. The changing weather conditions can be considered a variable in our analysis, causing discrepancies and can complicate the comparison of different runs. If these weather anomalies continue, data collected above the threshold established by the ASA/ANSI standards may not yield viable results [7].

In the T-7A setup, three weather stations were used at varying heights above the ground. These stations collected meteorological data both before and during the measurement, capturing readings on parameters such as wind speed, wind direction, temperature, humidity, and pressure. While the test experienced only minor meteorological changes, significant variations were observed in the far-field spectral array. Though not specified by the standards, a temperature gradient manifested in the vertical direction over time. This gradient appears to align with the trends in the spectral graphs produced by the gathered data.

Chapter 2

Methods

This section goes over the setup of the measurement and the equipment deployed for data collection. Microphone arcs and weather stations were used to collect the data from the T-7A jet aircraft.

2.1 Run-up

On August 18th, 2019, at Holloman Air Force Base in New Mexico, acoustical data was collected from a T-7A military jet. Equipped with a General Electric F404-103 afterburn-capable turbofan engine, this aircraft was used to acquire acoustic data to enhance modeling and potentially revise standards for future measurements. The data collection involved microphone arrays positioned around the aircraft. The engine underwent a series of six run-ups, each lasting 30 seconds. A run-up consisted of engine conditions from idle to full afterburner. The specific conditions monitored included 82% N2 (50% thrust), 88% N2 (75% thrust), full military power (MIL), and afterburner (AB). The focus of this paper is on the full military power and full afterburner conditions, given that similar shifts were observed in the spectral graphs of the other conditions.

Figure 2.1 The T-7A from the side view and the 38 m (125 ft) arc around the aircraft.

2.2 Setup

A coordinate system was created to reference the positioning of the microphones. The measurement's origin was situated beneath the aircraft's nozzle exit. The aircraft was aligned such that the positive x-direction extended outward from the engine's nozzle, while the positive y-direction aligned with the positioning of the measurement equipment, as depicted in Fig. 2.2. Microphones were then placed around a Microphone Array Reference Point (MARP), located at a distance of 4.0 m (13 ft) from the nozzle exit. The test featured over 200 microphones distributed across the entire array. For the purposes of this paper, only the microphones on the 38 m (125 ft) arc, 76 m (250 ft) arc, and 152.4 m (500 ft) arc will be used for analysis.

The microphones on the 38 m arc covered a range from 30° to 160° at 10° increments. Likewise, the microphones on the 76 m arc spanned from 30° to 160°, with one microphone placed at every 10° increment. This arc also has additional microphones with 5° spacing from 30° to 60° and from 110° and 160°. The microphone at 130° on the 76 m arc was excluded from the analysis due to hardware failure. The microphones on the 152.4 m arc were placed between 40° and 160° with varying distances, unlike the 38 m and 76 m arcs. Refer to Fig. 2.2 to see the exact spacing.

2.3 Equipment

Different types of microphones were employed for each arc to optimize data collection. The 38m arc consisted of 14 1/4" GRAS 40BD-NAH microphones, while the 76m and 152.4m arcs were equipped with 22 1/4" GRAS 46BD microphones. The microphones on the 38 m and 76 m arc microphones were connected to a National Instruments PXIe-1062 chassis using a 4496 card, and the 152.4 m arc used a cDAQ-9174 chassis with a NI 9250 card for data acquisition [8].

Meteorological data was gathered using Vaisala WXT520 weather stations [9]. Three such stations were strategically positioned 50 meters from the aircraft, each at a different height above

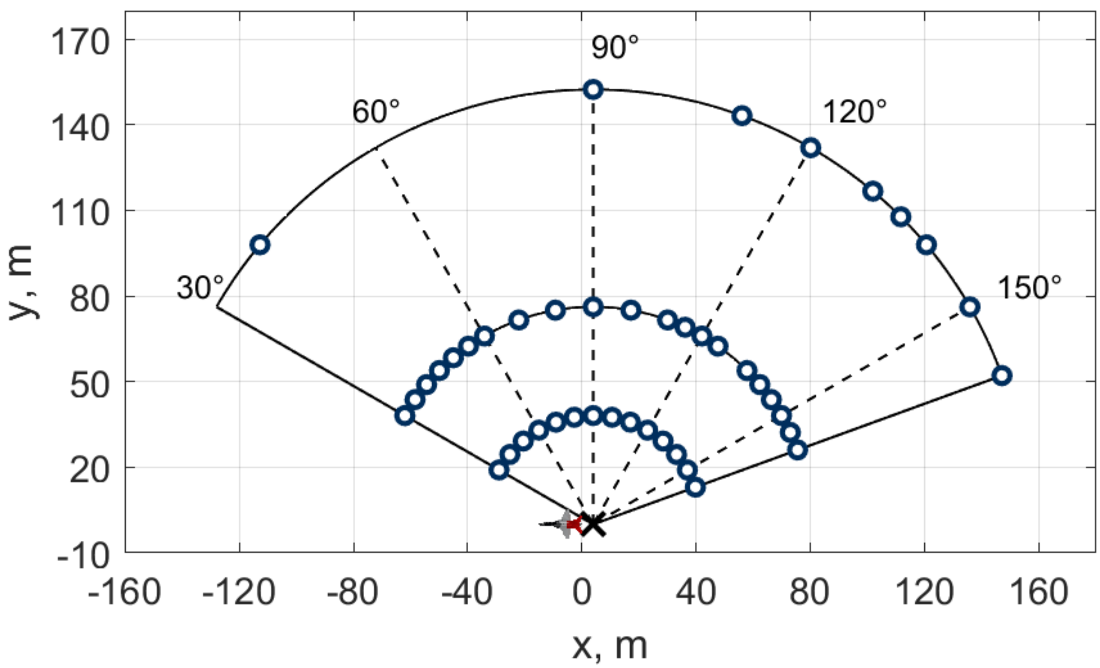

Figure 2.2 Representation of the microphones and their positions on the 38 m (125 ft), 76 m (250 ft), and 152.4 m (500 ft) arcs.

the ground. Station 1 was situated at 0.64 m (2.1 ft), station 2 at 1.5 m (5 ft), and station 3 at 6.1 m (20 ft) above the ground (AGL). This arrangement provides comprehensive coverage of the weather conditions in close proximity to the aircraft during the measurement. The placement of weather stations followed the ANSI 5.3.2.2 standard [4], ensuring compliance. These stations continuously recorded meteorological parameters, including temperature, wind speed, wind direction, and humidity. Data was recorded every second. No pressure data was collected from station 3 due to a malfunction in the pressure gauge, rendering it non-functional.

2.4 Data

Data was acquired by the individual equipment and saved as .bin files on a hard drive. These data files can be extracted and analyzed using Matlab programs. A significant portion of the data is organized into Excel files for individual examination. Each microphone has its own dedicated channel, ensuring individual data storage during the measurement process. Further details regarding data acquisition and this measurement can be found in Leete et al [10].

Chapter 3

Results

Runs one and two exhibit disparities when compared to the final four runs, particularly in the context of spectral analysis. This chapter looks at the understanding and possible causes of these discrepancies.

3.1 Spectral Analysis

The far-field measurements reveal significant discrepancies between the first two runs and the subsequent four runs in this measurement. Across consecutive runs, observable frequency nulls and peaks are evident which are attributed to ground reflections—noise bouncing off the ground and returning to the microphone, amplifying the overall noise level. [2]. The shifts in these nulls or low points in Power Spectral Density (PSD), representing the division of sound power into its frequency components, indicate a variation from the expected consistency throughout the runs. Run data should remain constant unless there is a variation in the parameters. Fig. 3.1 illustrates significant shifts in the nulls between the first two runs and the last four. Since neither the microphones nor the setup changed during this measurement, they are not contributing factors to the observed discrepancies in the frequency spectra.

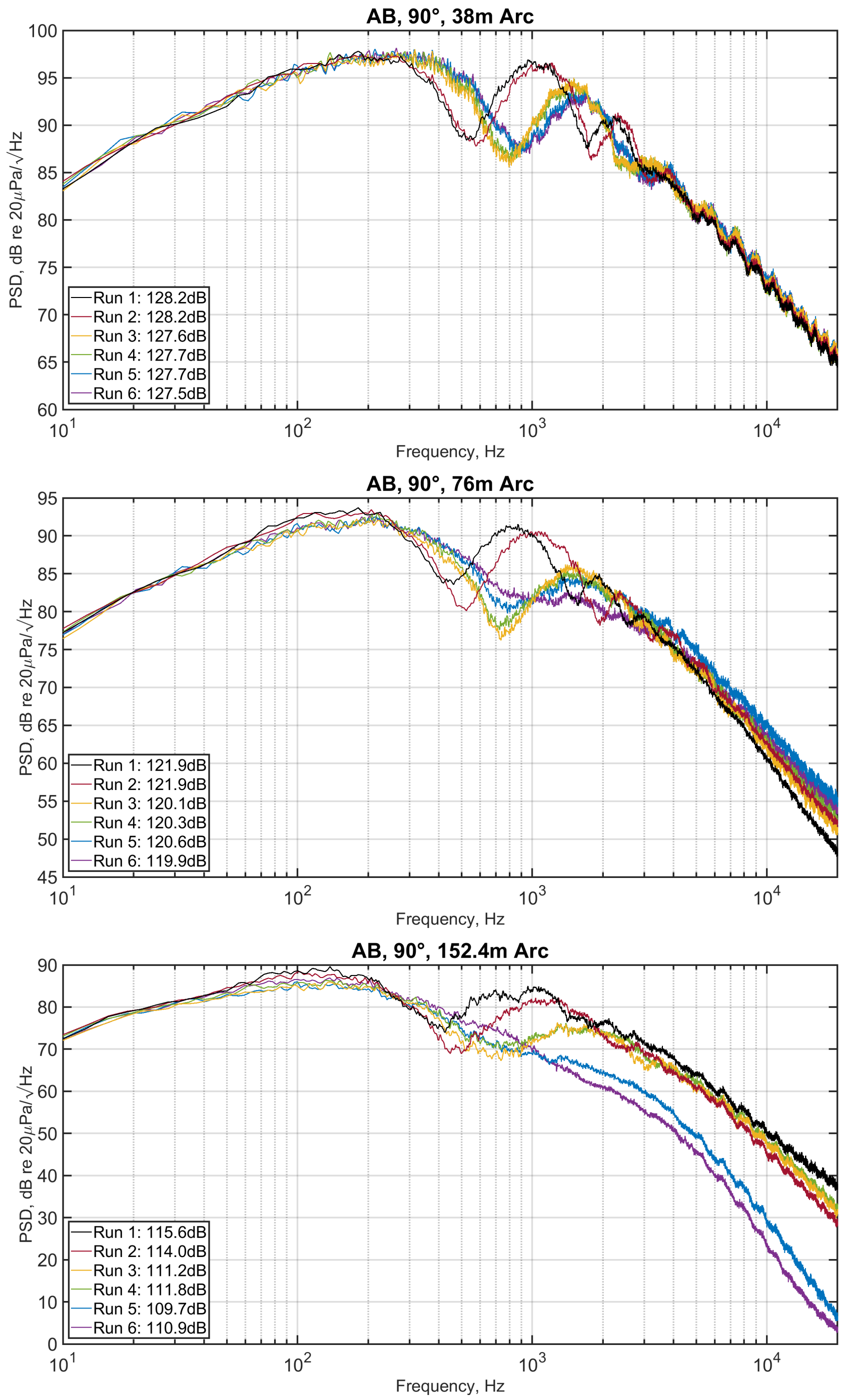

Figure 3.1 A graphical representation of frequency and the Power Sound Density (PSD), showing the division of sound power into its frequency components on a logarithmic scale. Run 1 and run 2 (represented by the red and black lines) have frequency peaks at the same frequency whereas the last four runs have nulls. These graphs serve as a comparative analysis at 90° for each arc during afterburner operation. The number in the legend corresponds to the overall sound pressure level (OASPL) for each respective run.

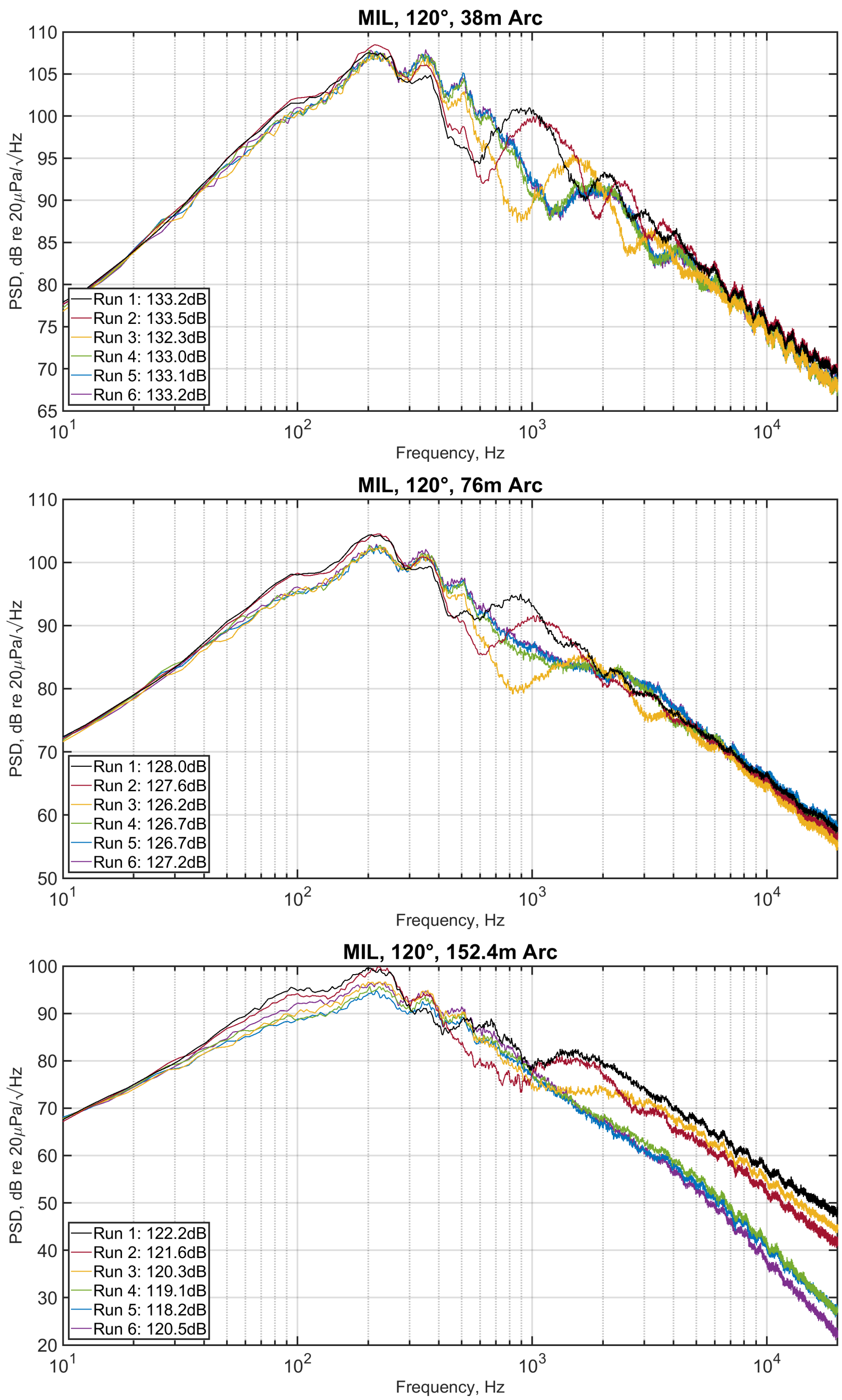

Figure 3.2 In contrast to the last set of graphs, these depict a comparison of runs at 120° for the three arcs at military power (MIL)

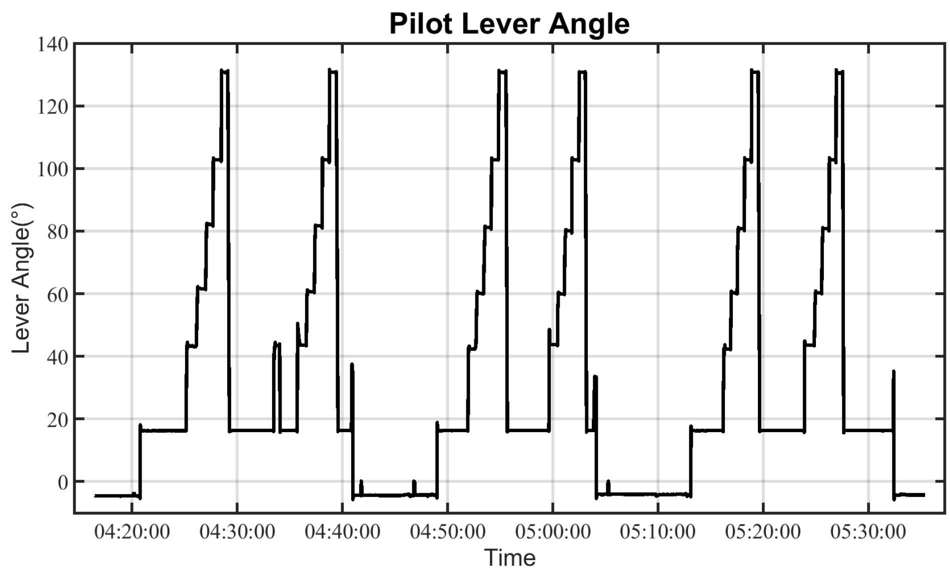

Figure 3.3 Pilot lever angle during the measurement. Each step during the six runs indicates the next engine condition lasting about 30 seconds.

The identified discrepancies were consistently observed across all locations along the 38 m, 76 m, and 152.4 m arcs, encompassing different engine conditions (MIL and AB) as seen in Figures 3.1 and 3.2. Note that both the microphone setup and the overall configuration remained constant throughout the measurement. The factors contributing to these variations are likely associated with either the plane or changes in weather conditions.

3.2 Engine parameters

The aircraft's thrust during each run, which was manually adjusted by the pilots, ranged from idle to full afterburner. These manual adjustments using the pilot lever introduced a potential source of error in the measurement. For accurate data, each engine condition should ideally generate a consistent level of noise and thrust. The provided engine data in Fig. 3.3 is determined by the pilot lever angle during each run-up, directly correlating with the thrust produced by the aircraft.

As depicted in Fig. 3.3, there is little to no change in the pilot lever angle between runs,

	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6
Average Wind Speed (Knots)	2.40	1.79	2.12	2.89	2.88	3.39
Average Wind Direction	139°	11°	19°	321°	346°	11°

Table 3.1 The average Wind speed and wind direction of all three weather stations. The change is minimal between each station.

especially nothing that would distinguish runs one and two from the others. The lack of significant differences indicates that the discrepancies observed are not attributed to variations in thrust. This graphic also illustrates the interval of each engine condition and the corresponding times for each run. Understanding the time of day during this measurement can provide useful context for analyzing other data, such as meteorological conditions.

3.3 Weather conditions

The weather stations collected comprehensive environmental data during the test. The initial variable explored was wind direction and velocity, with the ANSI standard specifying, "The surface wind conditions (5 feet AGL) shall not exceed 8 knots maximum with 5-knot maximum cross-wind" [4]. Throughout the test duration, the wind direction was variable. As shown in Table 3.1, wind speed remained well below 5 knots, and wind direction varied from run 1 to 6. This data and the wind's variability do not appear to correlate with the observed spectral results. Despite runs 2 and 6 sharing the same average wind angle, their lack of influence on each other suggests that further investigation with additional stations in the far field is necessary for future work.

The atmospheric pressure was monitored throughout the measurement period, with Station 3, positioned at 20 ft in the z-direction, failing to collect this data. Despite the absence of data from Station 3, the information obtained from Stations 1 and 2 is sufficient to demonstrate a minimal change in pressure. Throughout the measurements, a variation of 0.01 in-Hg was recorded, as

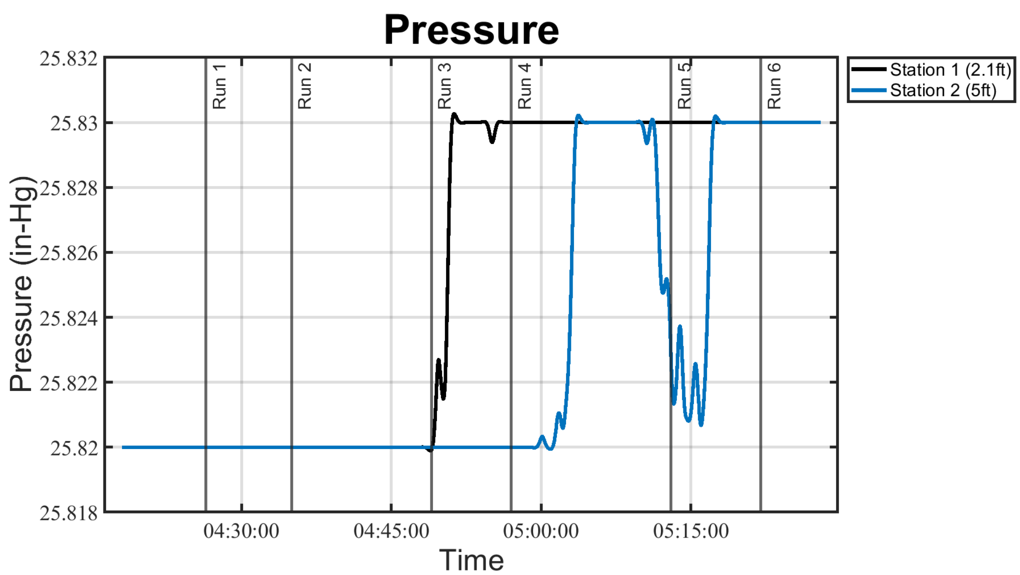

Figure 3.4 Barometric pressure over time in inches of Mercury. There is a minimal change in pressure over time.

depicted in Fig. 3.4. According to the standards, the barometric pressure is to be recorded without specific limitations [4]. The insignificant change in pressure is unlikely to have any notable impact on the sound propagation from run to run.

The analysis of humidity reveals a notable variation between the first two runs, while the last four runs exhibit similar humidity levels. The standard specifies that "relative humidity is greater than 20 percent" [4], and as shown in Fig. 3.5, the humidity remains above this threshold throughout the measurement. Additionally, a direct correlation between temperature and humidity is observed.

The temperature gradient, especially noticeable in the initial runs, shows a significant separation between stations 1 and 2 from station 3. Air temperature influences the density of air, impacting how noise travels through the medium. Over time, the temperature at each station gradually converges. The changing temperature gradient is correlated with the observed frequency nulls and peaks. As depicted in Fig. 3.6, during runs 1 and 2, there is a temperature separation of about 4°F. Subsequent run-ups demonstrate a reduction in temperature differences, eventually reaching a convergence within a degree for the last two run-ups.

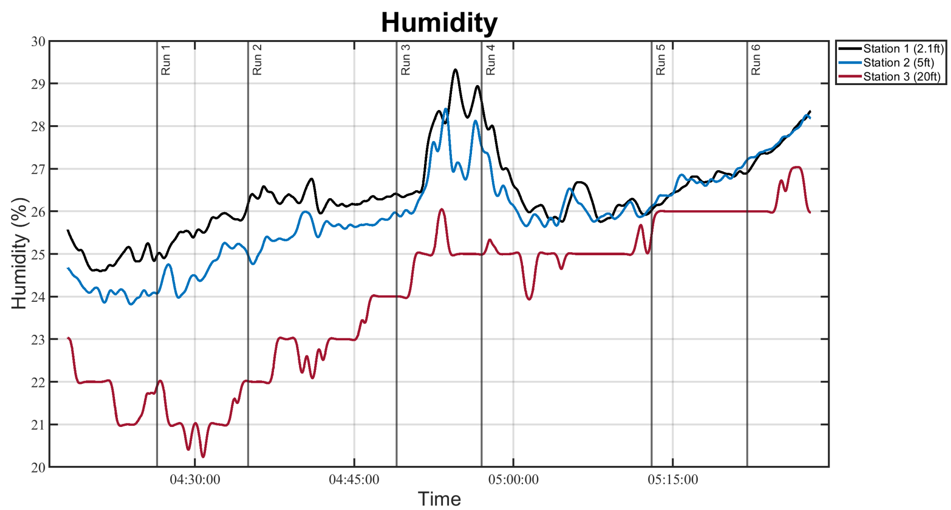

Figure 3.5 Humidity over time in percent humidity. The separation between the first two stations and the third shows that there was a change that occurred. Humidity is directly correlated to temperature and a similar occurrence is seen there as well.

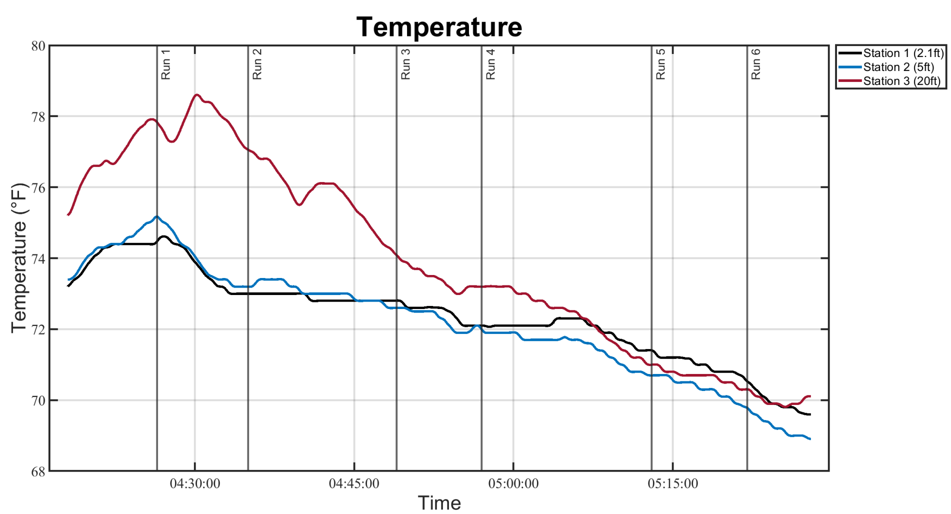

Figure 3.6 Temperature changes over time, with vertical lines indicating the start time of the runs. Runs 1 and 2 exhibit a significant temperature separation, while the subsequent runs show a smaller temperature difference.

3.4 Temperature Gradient

This temperature gradient poses an issue as the standards lack specifications regarding restrictions on temperature gradients and how to address this concern. The evidence indicates a correlation between the changing gradient over time. The taller weather station, with a higher temperature profile, contributes to the observed change in sound measurements.

The reason behind the observed temperature gradient remains unclear, but the measurement occurred near sunrise, suggesting a potential meteorological phenomenon such as an inversion of warm air over cooler air. Based on the data gathered inversions can significantly impact the propagation of sound and, in this case, appear to have influenced the T-7a measurement. The existence of such meteorological phenomena underscores the need for further investigation into their effects on overall sound propagation, particularly in environments where measurements will be taken.

3.5 Revision of Standards

The data collected during the test reveals that the temperature gradient can result in notable variations in sound propagation, influencing the presence of frequency nulls and peaks across different runs. There arises a compelling need to reassess and potentially update the standards guiding military jet noise measurements to account for a temperature gradient to enhance the accuracy and consistency of future measurements.

Appendix A

Frequency Spectra

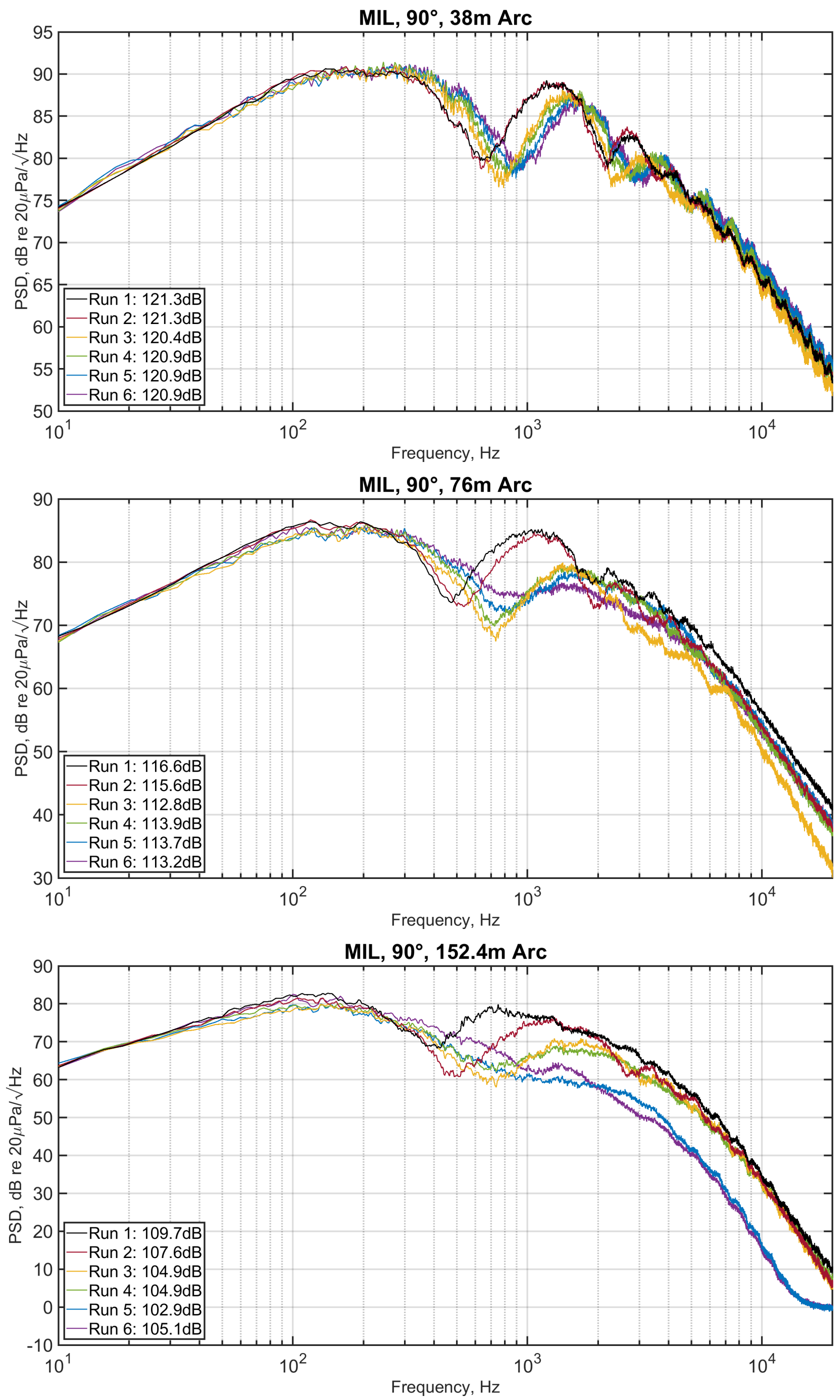

Figure A.1 Comparison of runs at 90° for the three arcs at military power (MIL)

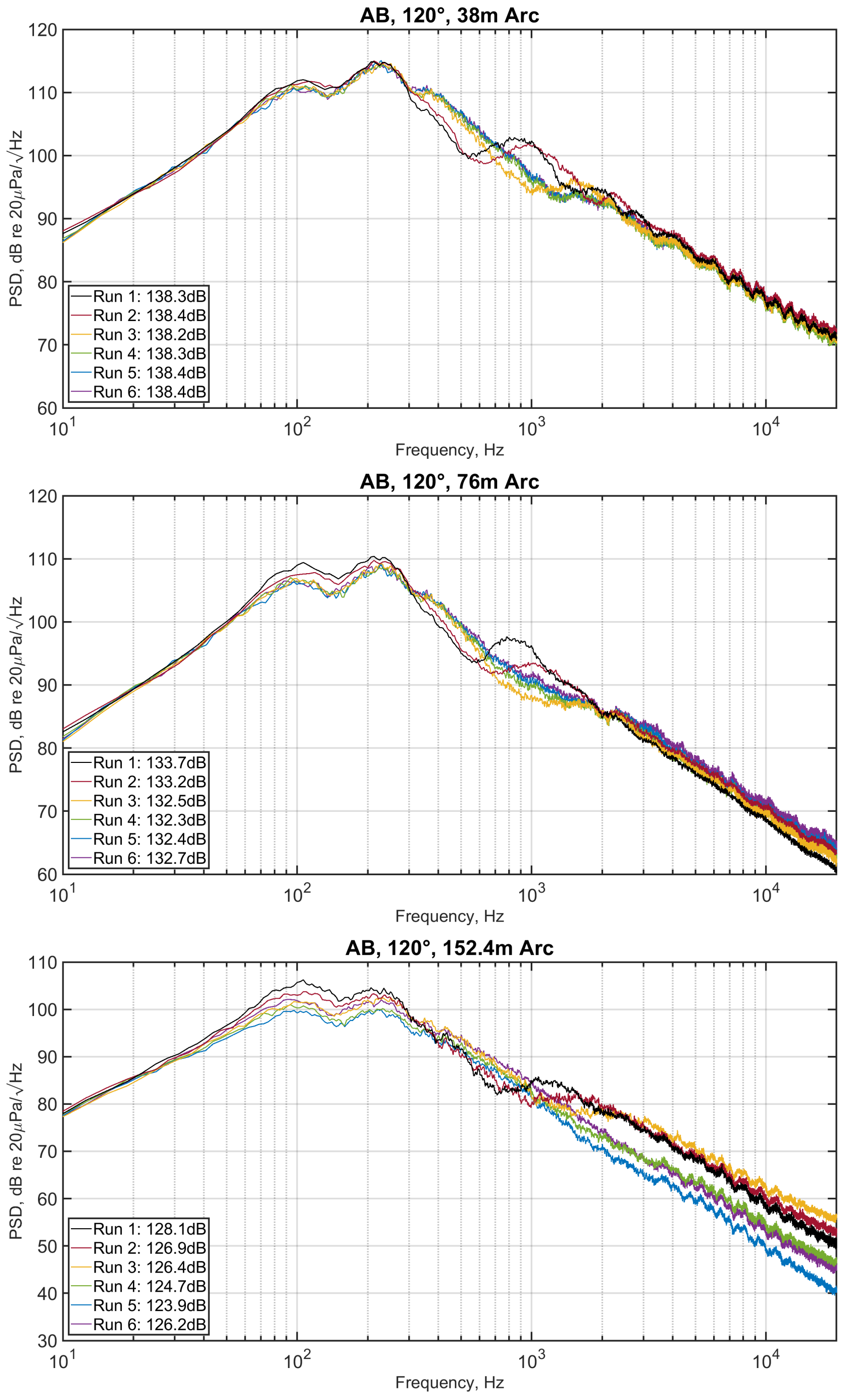

Figure A.2 Comparison of runs at 120° for the three arcs at afterburner (AB)

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