MITIGATING BLAST NOISE: EVALUATING WATER CURTAINS AND EXPANDED METALS

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1 INTRODUCTION

Impulsive noise is known to increase the risk of noise induced hearing loss at high intensities, and can cause annoyance for local communities at much lower levels [1]. The explosive testing at DNV Spadeadam has the potential for negative impacts on operatives and visitors on site, as well as on the surrounding local community. Some tests have been known to cause noise complaints in the surrounding villages of the site, the closest being Gilsland Spa, approximately 5 km away. The closest residence to the site is much closer, approximately 2 km from the site boundary.

Outdoor noise propagation is varies with factors such as topography, meteorological conditions, ground impedance, atmospheric absorption, and turbulence [2]. Blast wave propagation introduces further complexity, with highly non-linear relationships governing its behaviour in the near field. Advanced source characterisation techniques are commonly used to identify the characteristics of blast noise sources [3]. The uncertainty introduced by the accumulation of these factors causes noise propagation prediction models to be largely inaccurate. Therefore, to effectively mitigate the impact on surrounding communities, it is pertinent to attenuate noise levels at the source.

The aim of this project is to develop an effective, blast noise mitigation method that is feasible for use with industrial blast sources. This paper details the laboratory testing of two blast noise mitigation methods: water curtains, and expanded metals, and discusses the merits of each.

2 LITERATURE REVIEW

2.1 Water Curtains

Water-based acoustic suppression is not a novel concept, with roots tracing back to its utilization in the NASA Space Shuttle Program as early as 1981. This approach was employed to reduce the pressure levels generated during the ignition period of a rocket launch, effectively reducing noise levels by 3-5dB within the frequency ranges of interest [4]. The fundamental principle underlying the efficacy of water-based mitigation lies in the ability of water molecules to absorb and dissipate acoustic energy. Consequently, it finds particular relevance in scenarios involving open-field and large-scale applications.

Recently, Zhang, Li, Wang, Zhu, and Cao [5] have undertaken experiments to determine the effectiveness of water curtains of various thicknesses as mitigation against shocks of various Mach numbers. The paper demonstrated that a reduction in overpressures was achieved when introducing the water curtain barrier. It showed that the thicker the curtain, the more percentage reduction in overpressure, however with higher Mach number shocks, less percentage reduction in overpressure was observed.

Investigations using a vertical shock tube, with unbroken water sheets parallel to the shock propagation have been undertaken [6]. For assessing the contribution of the water sheets, experiments were undertaken several times, once when the shock exits the shock tube directly into the ambient air, once when it propagates between two rigid plates introduced at the shock tube exit and, once with the rigid plates replaced by water sheets. Schlieren imaging showed that at the shock-water interface, reflections and absorption occurred, reducing the shock to a compression wave with significantly lower overpressures. The primary form of reductions in these experiments was shown to be energy from the shocks being reflected off of the surface of the water.

2.2 Expanded Metals

Recent research has underscored the potential of combining water curtains with perforated metal grids for blast noise mitigation, with findings indicating that the addition of a water layer over one grid enhances its mitigation [7]. However, the experiments primarily focused on utilizing various combinations of metal grids for blast mitigation, lacking comprehensive investigations into the effect of water flow rate or flow type (laminar/spray) on noise attenuation. Further studies are imperative to optimize water curtains for blast noise applications.

The interaction between water-based mitigation methods and other blast noise control strategies, such as the use of metamaterials, hold great potential for synergistic noise reduction effects. However, the intricacies of this interplay and the most effective implementation strategies necessitate further research.

3 METHODOLOGY

3.1 Experimental Setup

This investigation uses a shock tube and ¼ inch pressure transducers to gather pressure data, from which insertion losses from the mitigation types can be gathered. The shock tube provides an easily repeatable, versatile, and safe way to conduct high intensity acoustic measurements. At one end of the shock tube is the rupture chamber, a section separated from the remaining length of the tube by a thin mylar membrane. The rupture chamber is pressurised with an air compressor to the point where the mylar membrane ruptures allowing a shock wave to propagate through the tube. The intensity of the shock is controlled by varying thickness of mylar used. Each use requires the use of only one disposable element, the mylar, making the setup highly cost-effective in comparison with methods that use explosive charges. This assessment uses 20μm and 40μm mylar, helping to determine the effect of different strength blasts on the experimental mitigation.

Measurements were taken using type 113B28 ¼" PCB High Frequency ICP piezoelectric transducers, these are suitable for measurement as they can measure pressures up to 345kPa and have response times in the micro-seconds. These pressure sensors are water-resistant and cost-effective, holding superiority over traditional ¼" microphones. All transducers were calibrated with a B&K type 4230 calibrator before measurement.

Blast waves are characterized by their sharp increase to a high pressure at the shock front. Because of this, it is crucial to use fast response and high sampling rate instrumentation. Measurements have been undertaken using a Dewesoft SIRUSi-CD4 data logger, sampling at 200kHz. Ensuring a high resolution in the time domain allows for accurate identification of wave parameters that can be used to calculate metrics such as shock front rise time.

Figure 1 shows the two experimental setups for the shock tube adopted for this assessment. A Fourier analysis of a produced shock revealed that 97% of the energy content lies at frequencies less than 1kHz. Meaning that the highest frequency of interest has a wavelength of 343mm, around 6 times the tube diameter (57mm). This is considered large in comparison with the tube diameter, and as such, pulses in the tube can be approximated as planar.

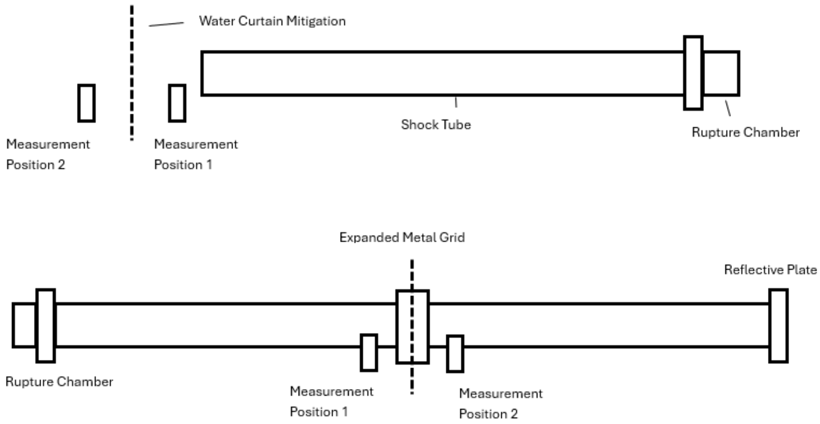

Figure 1: Experimental shock tube setup.

In the case where a closed system shock tube setup is impractical, such as testing the hypothesis that water barrier insertion loss is proportional to mass per unit area, an open-ended shock tube setup has been employed. Measurement positions 1 and 2 were positioned 50mm and 150mm from the tube exit, respectively. The mitigation was positioned at 100mm from the tube exit. When the blast wave reaches the open end of the tube, it spreads hemi-spherically from the tube exit. A portion of the wave energy is reflected back down the shock tube due to the impedance mismatch of the ambient air and air within the tube.

MATLAB code has been developed to take a Fast Fourier Transform (FFT) of the measurement data. The frequency response for an 20μm open end shock tube has been produced in Figure 2.

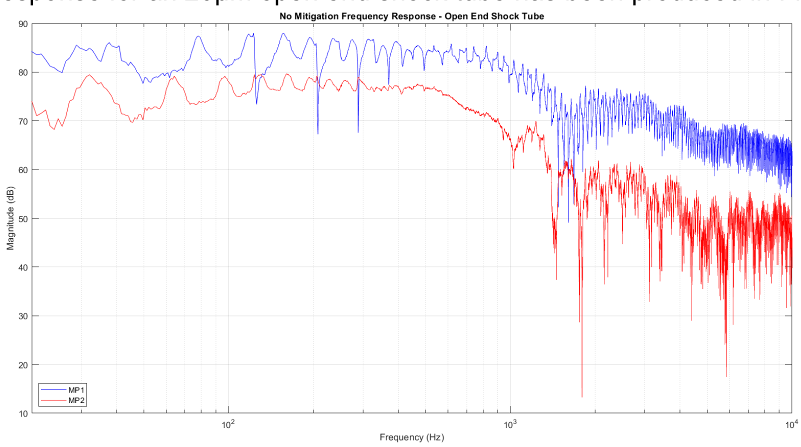

Figure 2: Shock tube Frequency Response – Open End Shock Tube

The pressure response shows that the main energy content lies below 1kHz and that the magnitude at MP2 is less than that of MP1. It is also shown that the high frequency content at MP2 is also much more variable, indicating more noise within the signal.

The frequency response for an 20μm closed shock tube has been produced in Figure 3.

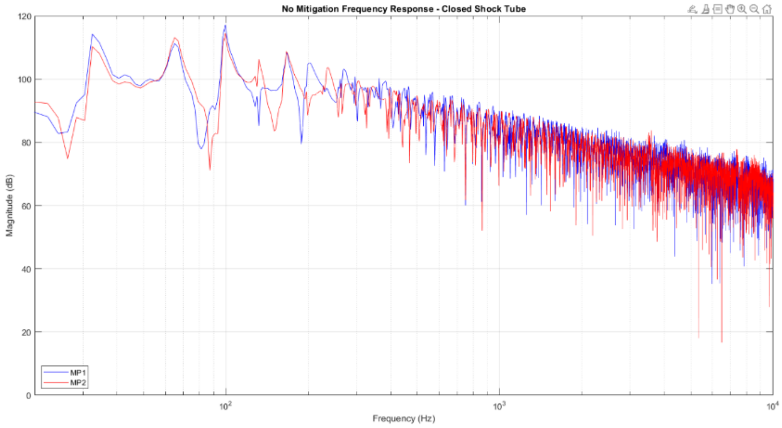

Figure 3: Shock tube frequency response – closed shock tube

The frequency content is very almost identical between measurement positions, with the majority lying below 1kHz. Additionally, the magnitude of the blast is much higher within the closed shock tube environment. Upon frequency analysis of the mitigation tests, it is determined that there are no significant differences between measurement positions.

3.2 Water Curtains

The water curtain was created using a plastic spillway water feature and a water pump with a maximum flow rate of approximately 3000 litres per hour. The flow rate was controlled by reducing the area of the intake valve. To determine different flow rates, a stopwatch was used to measure the time it took for the water curtain to fill a 1.25 Litre measuring jug.

Table 1: Water curtain flow rates used in experimental testing

Flow Type	Flow Rate (litres per second)
Low	0.18
Medium	0.24
High	0.32

For both 20μm and 40μm mylar measurements, 5 No. tests were taken with no mitigation to determine the average attenuation between measurement positions, a further 5 No. tests were undertaken for each flow rate (0.18lps, 0.24lps, and 0.32lps) to determine the insertion loss of the water barrier. Figure 4 shows the water barrier measurement setup.

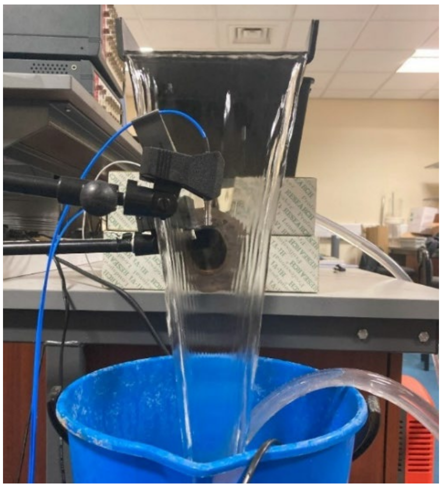

Figure 4: Experimental Water Barrier setup.

3.3 Expanded Metal Grids

The closed shock tube setup was used to test expanded metal samples. The mitigation was clamped into the shock tube between measurement positions 1 and 2. The distance between measurement position 1 and the mitigation is 150mm, followed by measurement position 2, located 100mm after the mitigation.

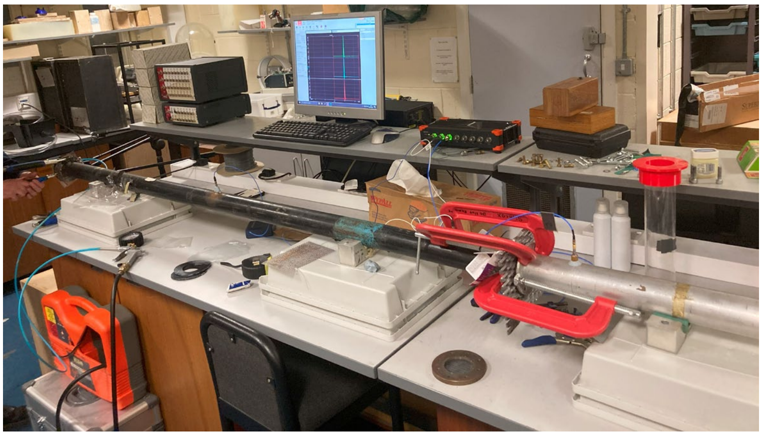

Figure 5: Experimental Expanded Metals setup.

Four no. expanded metal sheets have been tested. The manufacturer details of each metal sheet have been reproduced in Table 2, and images are shown in Figure 6.

Table 2: Expanded Metals Dimensions

Metal ID	Strand (mm) (Width x Thickness)	Aperture (mm) (Length x Height)	Weight (kg/m2)	Open Area (%)
226F	0.79x0.60	3.81x2.03	2.10	56
0794F	1.70x1.00	14.22x4.83	3.30	57
1583F	1.91x0.90	35.05x12.56	1.60	76
1576	4.75x3.00	-*	-*	44
*Raised profile so unapplicable for comparison.				

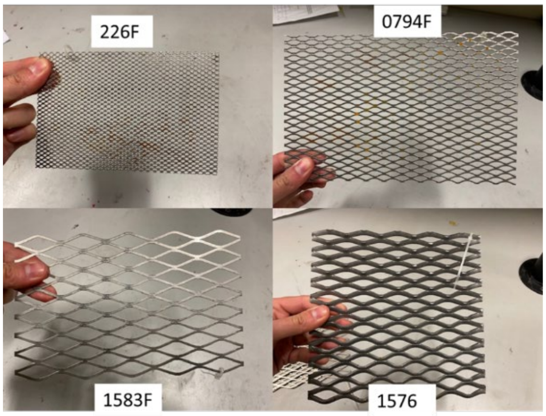

Figure 6: Expanded Metals.

4 RESULTS AND ANALYSIS

4.1 Water Curtains

A time pressure trace of a water curtain trial is shown in Figure 7. Measurement position 1 is shown in the top trace (blue) and measurement position 2 is shown in the bottom trace (red).

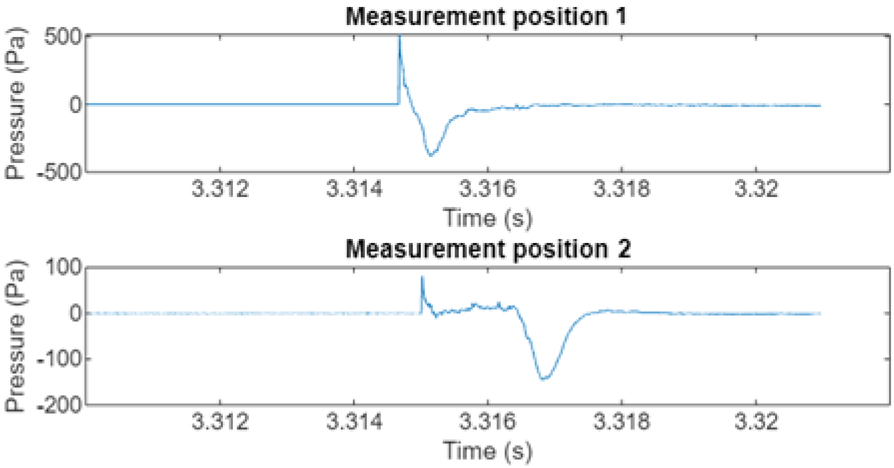

Figure 7: Time pressure trace of water curtain trial, MP1 and MP2

Measurement position 1 exhibits a pressure trace almost identical to those without the water curtain present, with the exception that in the negative phase a reflection off of the water curtain is seen. During measurements it was noted that measurement position 2 would often show a large increase or decrease in pressure following the blast, this was determined to be caused by water droplets attaching to the diaphragm of the transducers. The trace shows a large decrease in pressure when the water curtain is present, more than that of hemispherical spreading alone. Insertion losses for each water curtain trial are shown in Table 3.

Table 3: Measured Insertion Loss for Three Water Curtain Flow Rates

Water curtain flow rate (litres per second)	Insertion loss with 40µm membrane (dB)	Insertion loss with 20µm membrane (dB)
0.18	6.3	11.3
0.24	11.6	12.4
0.32	11.4	15.0

All measurements show a significant reduction in sound pressure level attributed to the water curtain, with the lowest and highest measured insertion loss being 6.3 and 15.0 dB, respectively. The results show a general increase in insertion loss with water curtain flow rate.

4.2 Expanded Metal Grids

The pressure time trace for a 20µm trial with 1576 type expanded metal is shown in Figure 8.

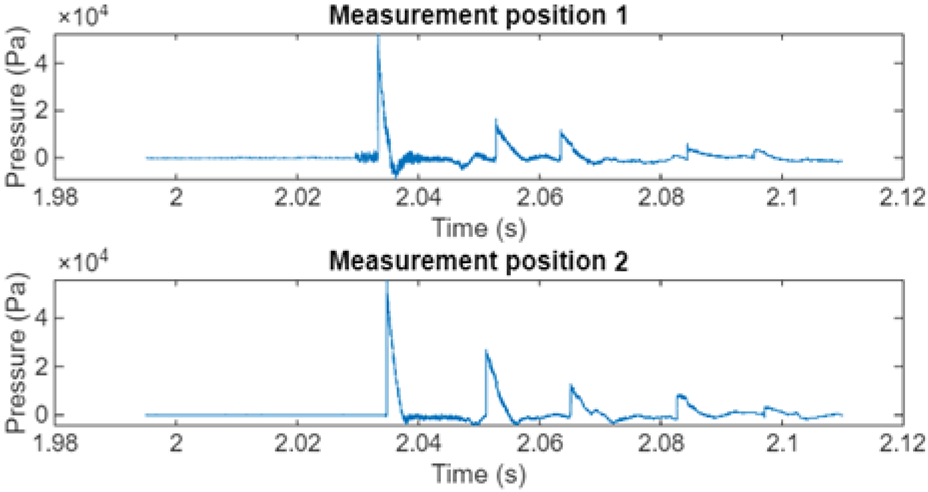

Figure 8: Time pressure trace of expanded metals, MP1 and MP2

The traces show the propagation of the shock from MP1 to MP2, and reflected shock from MP2 to MP1. Small reflections in the pressure trace from the expanded metals is also shown within the shock trace. The insertion loss attributed to different expanded metal types is shown in Table 4.

Table 4: Expanded metals insertion losses

Metal Grid ID	20µm Insertion Loss (dB)	40µm Insertion Loss (dB)
226F	1.6	1.4
0794F	0.9	0.9
1583F	0.6	0.7
1576	2.3	2.3

While the magnitude of insertion loss may not be significant, results indicate that metal grids can provide a repeatable reduction in blast pressure.

5 DISCUSSION

5.1 Water Curtains

The results of experimentation indicate that water curtains hold promise for reducing blast noise at source, with tests consistently showing an insertion loss in excess of 10dB with flow rates over 0.24 litres per second. For the 20µm mylar, there is a clear correlation between water flow rate and insertion loss, however, the 40µm mylar results are observed to have an apparent maximum in insertion loss indicated around 11.4 – 11.6 dB at higher water flow rates.

Results show that non-linear effects of higher-pressure blasts may produce smaller insertion losses when compared with lower intensity blasts. This is shown as the water curtains show lower insertion losses when comparing results from 40µm shocks than 20µm shocks.

The absolute error in these measurements, while within the uncertainty budget, was reasonably high, this could be due to inconsistencies in the water curtain formation or in mylar / chamber seal inconsistencies in the shock tube. This work is limited by a lack of varied incident blast overpressures, a more comprehensive dataset will be required to draw meaningful conclusions about the relationship between blast strength and insertion loss of a water curtain.

5.2 Expanded Metals

The grid-based mitigation consistently demonstrates a low absolute error in providing insertion loss, yielding comparable results irrespective of the incident blast overpressure or mylar thickness. The presence of apertures in the mitigation is theorized to mitigate the 'screening' effects typical of noise barriers, offering pathways for blast passage without hindrance. This is likely the driving factor behind the statistically significant decrease in insertion loss with increasing % open area. The insertion loss achieved by metal grids is considered negligible relative to the material costs involved, rendering their real-world application impractical and ineffective.

Overall, the water-based mitigation provides a much larger average insertion loss than that of the metal grids, regardless of flow rate. This efficacy, combined with the cost and availability considerations of water on site at DNV, positions water curtains as a viable method for real-world reduction of blast noise. This research is limited by the size of the experimental water curtain produced, in which the blast could refract around. In a real world scenario, it is assumed that complete coverage around the source would be required to mitigate noise in all directions. Similarly, developing methods to ensure repeatable laminar flows of known mass per unit area would be required to better predict the insertion loss of a water curtain. This work is also limited by a lack of varied incident blast overpressures, a more comprehensive dataset will be required to draw meaningful conclusions about the relationship between blast strength and insertion loss of a water curtain.

6 CONCLUSION

The efficacy of two novel blast noise mitigation methods, namely water curtains and metal grids have been assessed. Water curtains have demonstrated effectiveness in mitigating blast noise, with significant insertion losses observed. A correlation between flow rate and shock front time difference is observed although this lacks robust scientific underpinnings. An increase in water curtain flow rate, and so water curtain thickness shows an increase in insertion losses.

Expanded metal grids have been shown to provide repeatable insertion loss when mitigating blast noise, the insertion loss has been statistically proven to negatively correlate with percentage open area, eluding that metal grids provide attenuation by way of partial screening. Whilst expanded metal grids may offer advantages in durability over common noise barriers (noise passing through means less strain on the material) the intricacy of this relationship is not well understood. Additionally, the insertion losses do not seem significant when considering the costs of the materials, underscoring expanded metal grids as an inappropriate choice for real-world blast noise mitigation.

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