In this study we use FlareSIM Version 5.2, an industrial flare simulation tool, to investigate noise emission from vertical flares and multipoint ground flares of 100 MMscfd and 175 MMscfd design capacities. The following aspects are addressed:

- Variation of flare sound power with flaring rate,
- Sound pressure level in the near-field of the flares, and
- Measures for achieving flare noise attenuation.

1. Flare Design Details and Environmental Conditions

The flares are sized based on datasheets and other specifications contained in Arrow Energy's EFI 103816. Relevant design details of the vertical flares and multipoint ground flares (MPGF's) are tabulated below.

Table 1 – Design Details of Vertical Flares

Flare Code	VF-100	VF-175
Design Capacity	100 MMscfd	175 MMscfd
Flare Gas Compositions	As per EFI 103816	As per EFI 103816
Flare Tip Diameter	DN500	DN650
Overall Flare Height	21m	40m
Sterile Radius	60m	60m
Radiation at Sterile Boundary	4.73 kW/m2	4.73 kW/m2
Location of 1.58 kW/m2 Radiation	161m from stack	208 from stack

Table 2 – Design Details of Multipoint Ground Flares (MPGF's)

Flare Code	MPGF-100	MPGF-175
Design Capacity	100 MMscfd	175 MMscfd
Flare Gas Compositions	As per EFI 103816	As per EFI 103816
Wind Fence Dimensions: L x W x H	50m x 50m x 14m	61m x 53m x 14m
Total Number of Burners	26	46
Number of Burner Stages	3	3
Burner Staging Design	Stage 1: 3 burners Stage 2: 9 burners Stage 3: 14 burners	Stage 1: 5 burners Stage 2: 15 burners Stage 3: 26 burners

Flare noise emission is simulated based on the following environmental conditions:

- Temperature = 13°C
- Humidity = 86%
- Pasquil-Gifford-Turner (PGT) Atmospheric Stability Class = F
- Wind speed = 2 m/s (from source to receptor)
- Terrain type = Rural (open grassland)

2. Flare Sound Power

Sound Power of the Vertical Flares

For the flares considered, flare sound power is directly related to total heat release of the flare gas and is independent of flare tip diameter. This is because flare noises are predominantly due to flare gas combustion, and contribution of jet noise is negligibly small. Therefore, as far as flare sound power is concerned, we do not need to differentiate between flare tip size, i.e., DN500 or DN650.

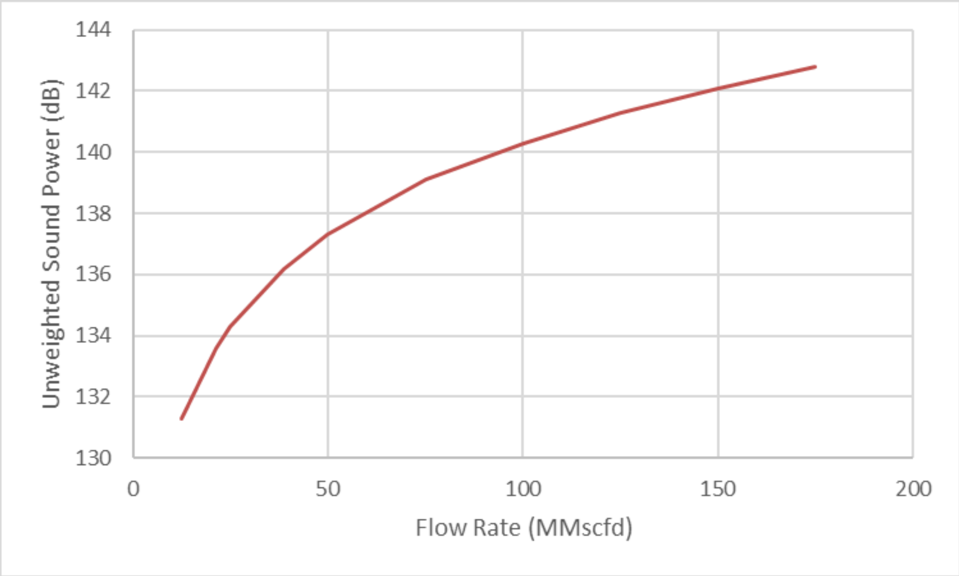

Fig. 1: Variation of Flare Sound Power with Flaring Rate

Variation of flare sound power with flaring rate is shown in Fig. 1. We have found that as flaring rate is reduced from 175 MMscfd to 12.5 MMscfd, the flare sound power decreases from 142.8 dB to 131.3 dB.

Octave bands of flare sound power for various flaring rates of interest are presented in Appendix 1.

Sound Power of the Multipoint Ground Flares (MPGF's)

In MPGF's, flare gas is combusted in multiple burners rather than a single flare tip. Taking MPGF-175 for example, forty-six (46) burners are used and the burners are arranged in three stages. When the MPGF-175 flare is operated at its design capacity, gas flow through each of its 46 burners will be approximately 3.8 MMscfd.

Table 3 – Sound Power of a Single Burner Operated at 3.8 MMscfd Flaring Rate

Hz	31.25	62.5	125	250	500	1000	2000	4000	8000	16000
dB	116.4	121.4	120.4	118.5	114.1	112.3	107.7	103.5	100.9	97.7

Total Sound Power: 126.18 dB

Table 3 shows sound power of a single burner operated at 3.8 MMscfd flaring rate. Calculation shows that combining the sound power of 46 burners each flaring at 3.8 MMscfd gives 143 dB, which is approximately the same sound power of a single vertical flare operated at 175 MMscfd flaring rate (referring to Appendix 1).

Similarly, we note that total sound power of the MPGF-100 flaring at its design capacity with 26 burners approximately equals that of a single vertical flare operated at 100 MMscfd flaring rate.

The above results suggest that, for a given flaring rate, we expect the same total sound power whether the gas is flared in a MPGF or in a vertical flare.

3. Sound Pressure Level in the Near-Field of the Flares

Vertical Flares

Fig. 2 shows sound pressure level in the near-field of flare VP-100 operated at 21.2 MMscfd flaring rate. We note the following variations:

- 86.7 dBA at flare base,
- 78.7 dBA at 50 m,
- 73.8 dBA at 100 m,
- 71.3 dBA at 150 m, and
- 69.9 dBA at 200 m.

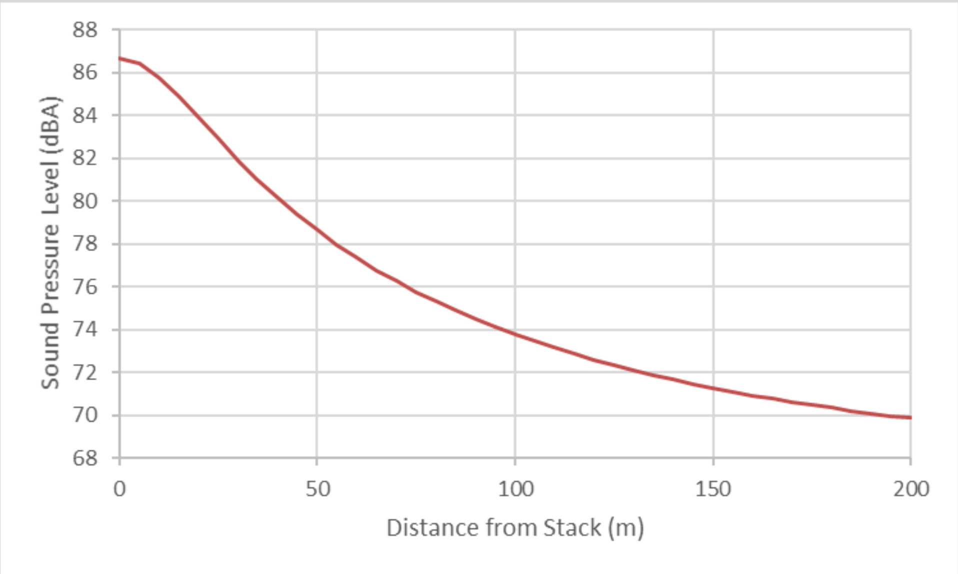

Fig. 2: Flare Sound Pressure Level near Vertical Flare of 100 MMscfd Design Capacity. Flaring Rate: 21.2 MMscfd

In Fig. 3 we present sound pressure results in the near-field of flare VP-175 operated at 38.6 MMscfd flaring rate. The following sound pressure variations are noted:

- 83.7 dBA at flare base,
- 79.7 dBA at 50 m,
- 75.5 dBA at 100 m,
- 72.9 dBA at 150 m, and
- 71.2 dBA at 200 m.

Detailed results of sound pressure levels for VP-100 and VP-175 flares over a wide range of flaring rates are presented in Appendix 2 and Appendix 3.

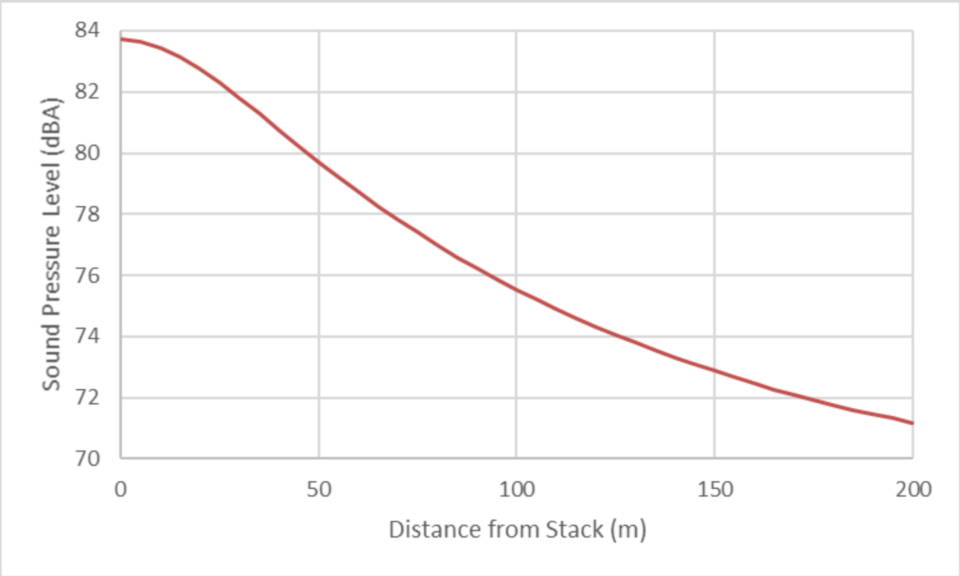

Fig. 3: Flare Sound Pressure Level near Vertical Flare of 175 MMscfd Design Capacity. Flaring Rate: 38.6 MMscfd

<u>Multipoint Ground Flares (MPGF's)</u>

We have looked at the following cases for sound pressure level in the near-field of the MPGF's:

- MPGF-100 flaring at 21.2 MMscfd, and
- MPGF-175 flaring at 38.6 MMscfd

In both cases, both of the Stage 1 and Stage 2 burners are operational.

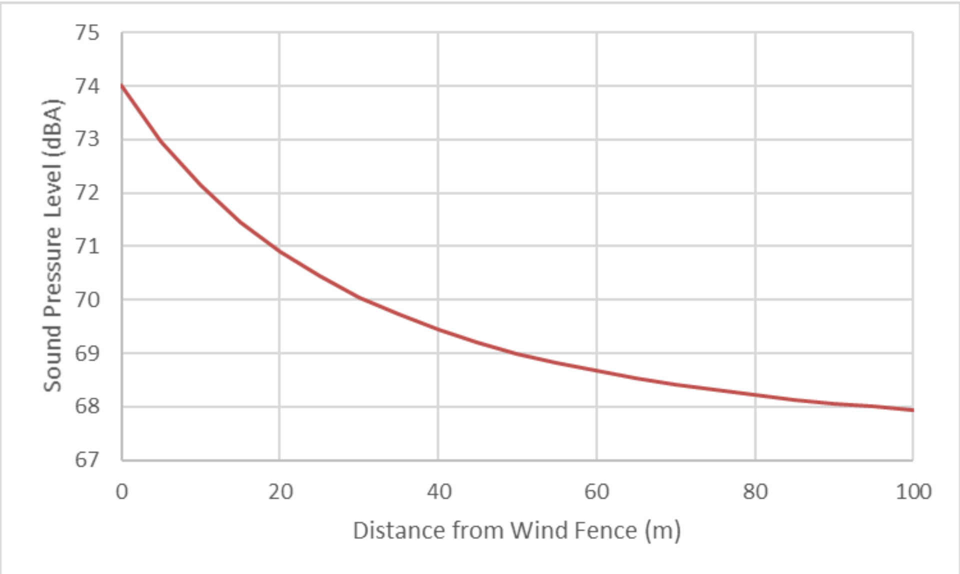

Fig. 4: Flare Sound Pressure Level near MPGF of 100 MMscfd Design Capacity. Flaring Rate: 21.2 MMscfd

Fig. 4 shows sound pressure level in the near-field of flare MPGF-100 at 21.2 MMscfd flaring rate. We note the following sound pressure variations:

- 74.0 dBA at the wind fence,
- 69.0 dBA at 50 m outside the wind fence, and
- 67.9 dBA at 100 m outside the wind fence.

Sound pressure results in the near-field of flare MPGF-175 at 38.6 MMscfd flaring rate are shown in Fig. 5. The following sound pressure levels are noted:

- 74.6 dBA at the wind fence,
- 69.7 dBA at 50 m outside the wind fence, and
- 68.4 dBA at 100 m outside the wind fence.

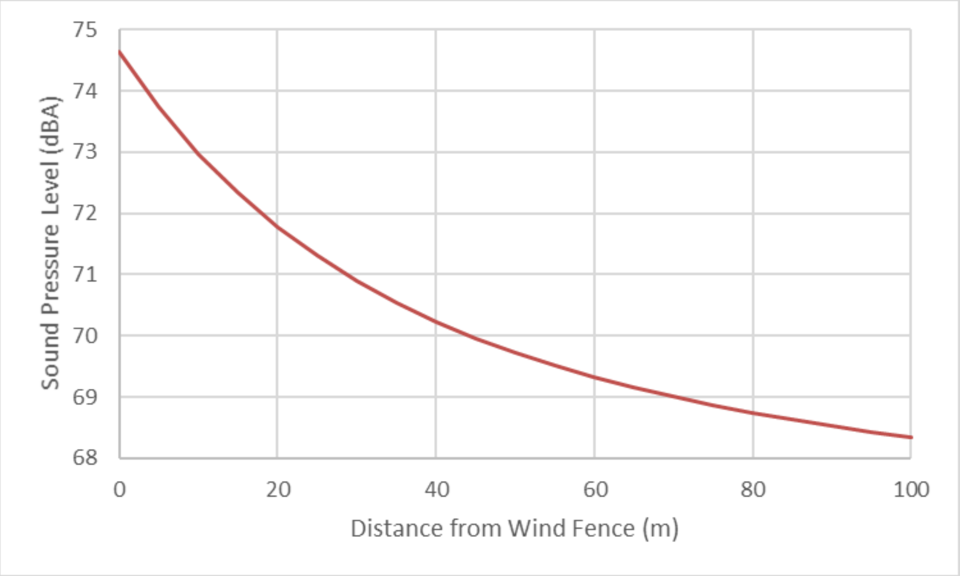

Fig. 5: Flare Sound Pressure Level near MPGF of 175 MMscfd Design Capacity.
Flaring Rate: 38.6 MMscfd

4. Discussion on Measures for Achieving Flare Noise Attenuation

<u>Vertical Flares</u>

We address the following question in this section: Can we reduce SPL by over-sizing the vertical flares, such as increasing flare tip diameter and flare height?

(a) Over-sizing of flare through use of a larger flare tip

In Fig. 6 and Fig. 7 we compare predicted flare sound power at 100 MMscfd flaring rate using DN500 and DN1050 flare tips. We note that while jet noise decreases from 111.5 dB for a DN500 tip to 62.9 dB for a DN1050 tip, the total sound power remains 140.3 dB in both cases. Reasons for this are:

1) Combustion noises are the same for the flare tips of different size, and
2) Compared to combustion noise, jet noise contributes little towards the total flare noise.

Therefore, increasing flare tip diameter will not help to reduce flare noise.

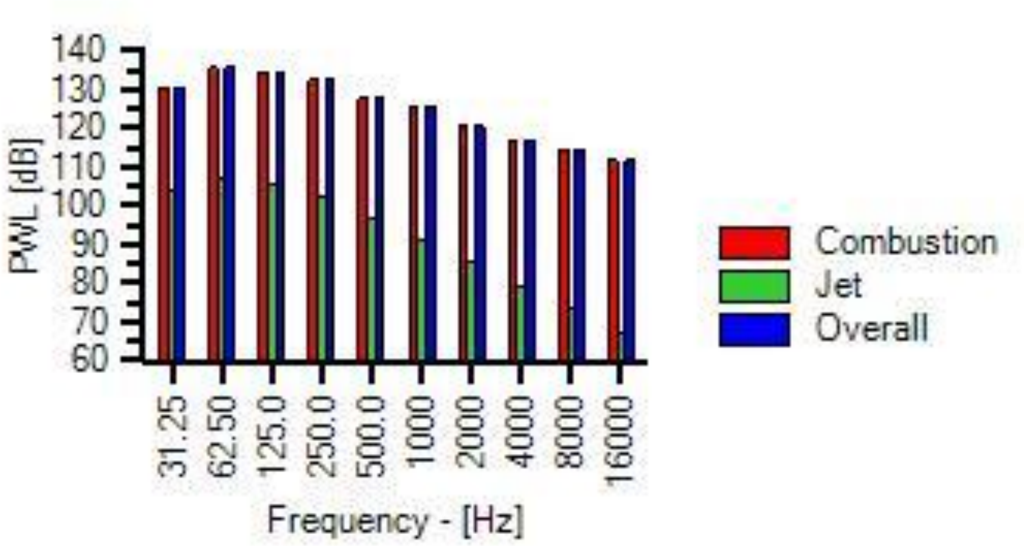

Fig 6: Sound Power of DN500 Tip Flaring at 100 MMscfd
Total Jet Noise: 111.5 dB
Total Combustion Noise: 140.3 dB
Total Noise: 140.3 dB

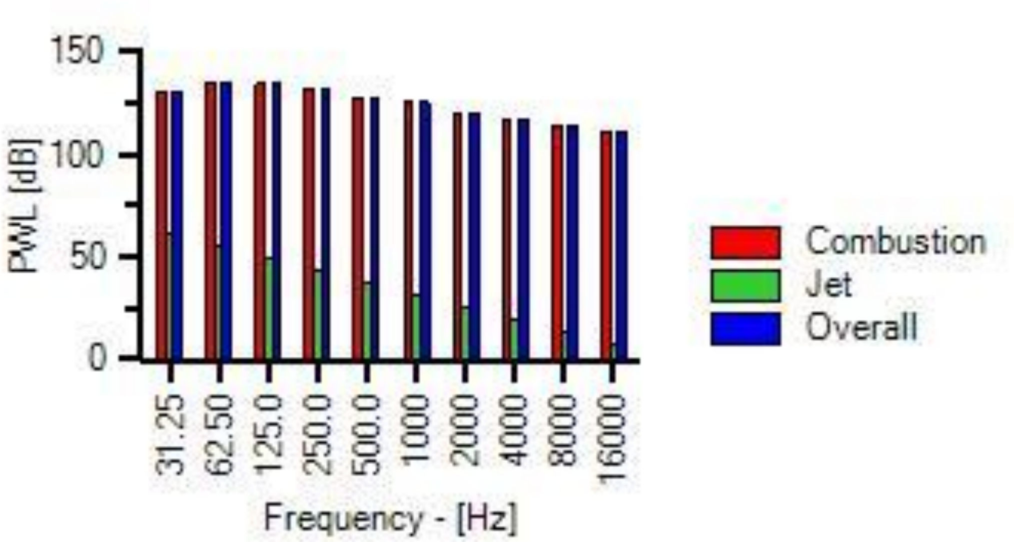

Fig 7: Sound Power of DN1050 Tip Flaring at 100 MMscfd
Total Jet Noise: 62.9
Total Combustion Noise: 140.3
Total Noise: 140.3 dB

(b) Over-sizing of flare through use of a larger flare height

A comparison of sound pressure level at 100 MMscfd flaring rate for two different flare heights is shown in Fig. 8. We note the following changes in sound pressure level caused by increase in flare height from 21m to 42m:

- 6 dBA reduction at flare base (from 93.4 dBA to 87.4 dBA),
- 1.6 dBA reduction at 50 m (from 85.1 dBA to 83.5 dBA),
- 0.5 dBA reduction at 100 m (from 79.7 dBA to 79.2 dBA),
- 0.2 dBA reduction at 150 m (from 76.4 dBA to 76.2 dBA), and
- 0.1 dBA reduction at 100 m (from 74.2 dBA to 74.1 dBA).

The above results indicate that noise reduction due to increasing flare height diminishes with increasing distance from the flare. This is because the impact of flare height on the distance between flare tip and receptor decreases as the receptor is further away from the flare.

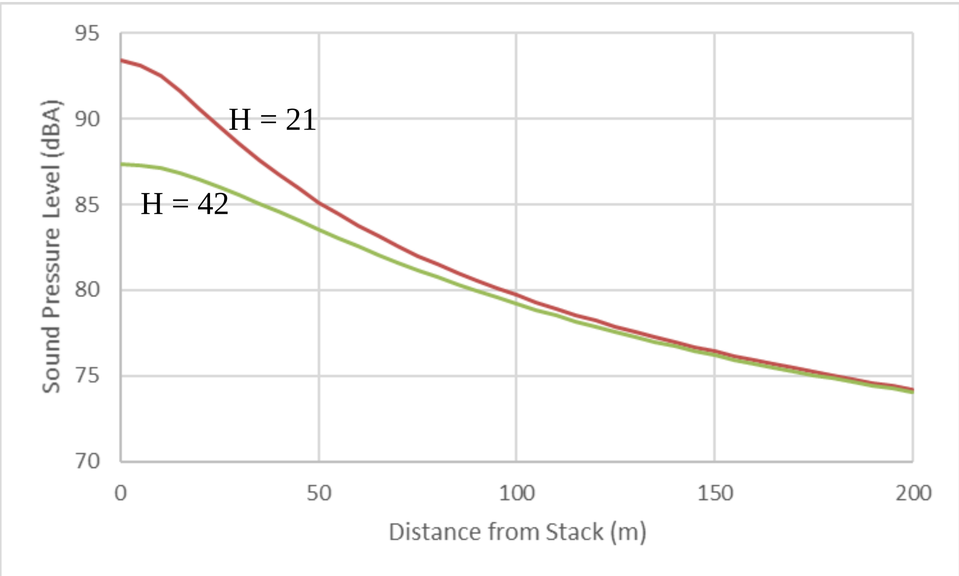

Fig 8: Effect of Flare Height on Sound Pressure Level. Gas Flow Rate: 100 MMscfd

Multipoint Ground Flares

In this section we discuss whether it is practical to reduce sound pressure level surrounding the MPGF's by changing (1) burner design, and (2) wind fence design. For ease of discussion, it is useful to note some main features of the MPGF's as shown in Appendix 4.

(1) Burner design

To reduce noise emission from flare burners, the burner design will need to incorporate mufflers / silencers close to the flame zone. Due to very large heat release and large flame volume, it is impractical to install such mufflers / silencers at the burner tips. So far, little progress has been achieved in flare noise attenuation by changing flare burner design.

Even for aeroplane engines where the heat release is significantly lower than the MPGF's, despite millions of dollars invested in the research and development of low-noise engines, noise problems near large airports remain a serious issue.

(2) Wind fence design

Wind fences for the MPGF's are always designed to maximize air in-flow to ensure high combustion efficiency and smokeless flaring. Therefore, modification to wind fence design must not cause restriction to the supply of combustion air.

It may be possible to reduce sound pressure level by (a) changing air passage angle and air passage length, and (2) using noise-absorbing materials surrounding the air passages at the wind fence. These changes will be rather expensive, and their effectiveness in flare noise attenuation has yet to be rigorously tested.

Horizontal Flares

(a) Horizontal flares with wind fence

Horizontal flares with wind fence can be considered as a simplified version of MPGF's. Noise performance of a horizontal flare with wind fence is expected to be not as good as a MPGF due to possibility of flame rising above the wind fence under unfavourable environmental conditions.

(b) Horizontal flares without wind fence

Horizontal flares without wind fence are similar to pit flares; their noise performance is expected to be similar to that of vertical flares. Since flare tip of a horizontal flare is closer to the ground, we expect sound pressure level in the near-field of a horizontal flare to be higher than that of a vertical flare.