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# Effect Of Various Deflectors On Acoustic Load Distribution During Rocket Vehicle Launch

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## Abstract

*Generally, during the lift-off operation of the space launch vehicle, there will be a high turbulence mixing and shock waves produced inside and exit of the engine nozzle. Due to this effect, there will be heavy pressure fluctuations in the downstream of the engine nozzle. The shocks formed in the nozzle with the continuity of pressure fluctuations create various noise levels. The noise level varies from near field, transition region and far field. The sound pressure level varies from different locations along the nozzle exit plane. The rendering sound power doesn't carry to the structural members in launch vehicle. If sound power is more, there will be a heavy damage to the payload structure affecting the satellite. In order to reduce the sound power, deflectors were used. The deflectors are of various types which are used to reduce the overall acoustic efficiency and sound power level. The acoustic efficiency increases with increase in acoustic power. In this project, various deflectors were designed and Empirical analysis ere done. The various deflectors corresponding to single nozzle parameters are selected for lift-off operation and acoustic load is certainly reduced in various noise fields.*

## 1. Introduction

Rocket motors generate tremendous acoustic energy at liftoff. Turbulent mixing of the hot exhaust gas with the surrounding air is the dominant acoustic source. The exhaust gas may also have aerodynamic shock waves, which further add to the noise. Combustion instability and rough burning may also contribute to the noise. Consider a rocket vehicle which has a payload enclosed in a nosecone fairing. The acoustic energy propagates to the payload fairing. The energy is then transmitted through the fairing wall to the enclosed air volume. The payload may be sensitive to the transmitted acoustic excitation, especially if the payload has solar panels or delicate instruments. The deflector is used in the exit of the rocket nozzle to reduce the acoustic excitation. There are various deflectors used to reduce the acoustic power along the nozzle exit plane.

In this paper, the deflectors of various shapes and sizes are considered. The empirical analysis is done in various noise fields for various deflectors. The best deflector is choosing for engine producing high thrust and velocity reducing the overall acoustic pressure level and acoustic efficiency.

## 2. Prediction of Acoustic loads by Empirical Analysis (Near field Noise):

The prediction of acoustic loads required for design account for the following factors,

1. Exhaust flow properties
2. Configuration variables
3. Vehicle parameters
4. **Atmospheric parameters**

### 2.1. Acoustic load Parameters:

To the extent required for design, the predicted acoustic loads shall be given as a function of position and time in terms of

- Overall sound- pressure level
- Frequency spectrum
- Spatial correlation

### 2.2. Steps involved in Source Allocation Method for empirical analysis:

The recommended methods for predicting acoustic loads are the source allocation methods based on allocating the noise generation sources along the exhaust stream. The following summarizes the detailed steps for prediction of the overall sound pressure level spectrum at a point P on the vehicle. The source allocation method uses the technique of assigning each frequency band a unique source location along the flow axis as follows:

1. Determine the flow axis relative to the vehicle and the stand. (distance x, along the flow axis is measured from the nozzle)
2. Estimate the overall acoustic power from Eldred Method:

$$W_{OA} = 0.005\, nF\, U_e$$

Where,
$W_{OA}$ = Overall acoustic power, W
$F$ = thrust of engine, N
$U_e$ = Fully expanded exit velocity, m/sec
$n$ = No. of Nozzles

3. The exit diameter is considered as

$$d_e = \sqrt{n} d_{ie}$$

4. Calculate the overall sound power level, from:

$$L_w = 10 \log W_{OA} + 120\, dB\, (re\, 10^{-12}\, watts)$$

5. Convert the normalized spectrum to a conventional acoustic bandwidth( i.e., the power spectrum per Hz, per 1/3 octave or per octave as desired) from:

$$L_{w,b} = 10 \log \left[\frac{W(f)}{W_{OA}} \frac{U_e}{d_e}\right] + L_w - 10 \log \frac{U_e}{d_e} + 10 \log \Delta f_b$$

Where,
$L_{w,b}$ = sound power level in the band centered on frequency b, dB ( re $10^{-12}$ watts)
$\Delta f_b$ = bandwidth of the frequency band, Hz

6. Allocate the acoustic sources along the exhaust flow centre line. The location of a single source for each frequency band, either 1/3 octave or octave band, is determined by arranging a source of strength given by the acoustic power spectrum at points given by the solid line curve of fig.
7. Calculate the sound pressure level in the band centered on any frequrency, b, and at any point,P, on the vehicle from:

$$SPL_{b,p} = L_{w,b} - 10 \log r^2 - 11 + DI\,(b, \theta)$$

Where,
$SPL_{b,p}$ = sound pressure level at position p, in the band centered on frequency b, dB ( re $2 \times 10^{-5}$ N/m$^2$)
$r$ = length of the radius line from the assumed position of the frequency source to the point on the vehicle,m
ɵ = angle between the flow centerline and r
$DI\,(b, \theta)$= directivity at the angle ɵ for the band centered on frequency b, dB

8. Calculate the overall sound pressure level at any point p, on the vehicle by logarithmic summation of $SPL_{b,p}$ over the entire spectrum from:

$$SPL_{OA,p} = 10 \log \sum_{All\ b} \left[antilog\, \frac{SPL_{b,p}}{10}\right] dB$$

## 3. Variation of position of various deflectors:

### 3.1. 45 deg Flat plate deflector:

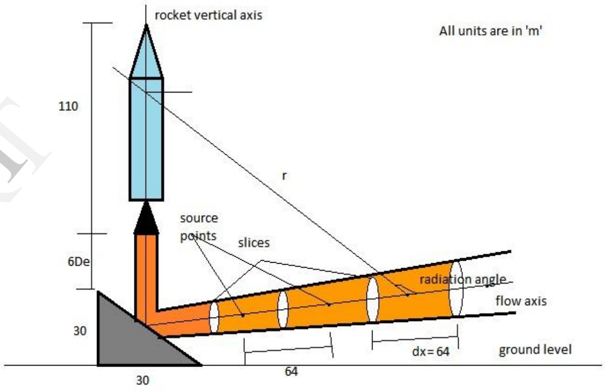

**Fig 3.1.1 45 deg flat plate**

Here the plate is kept with the distance of 6De with 5 slices and 5 source points.

### 3.2. 45 deg curved plate deflector:

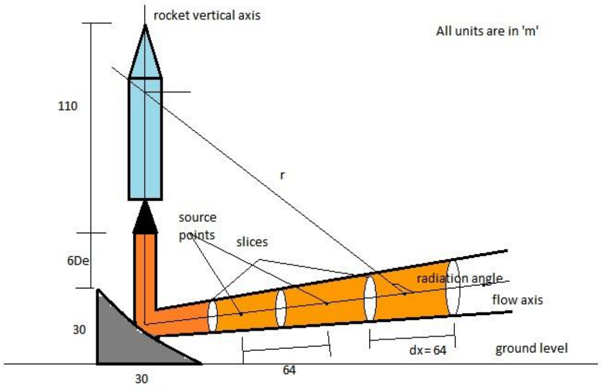

**Fig 3.2.1 45 deg curved plate**

Here the plate is distanced to the length of 4De with the slices of 5 numbers and 5 source points having angle of radiations in obtuse.

### 3.3. 90 deg bucket blast deflector:

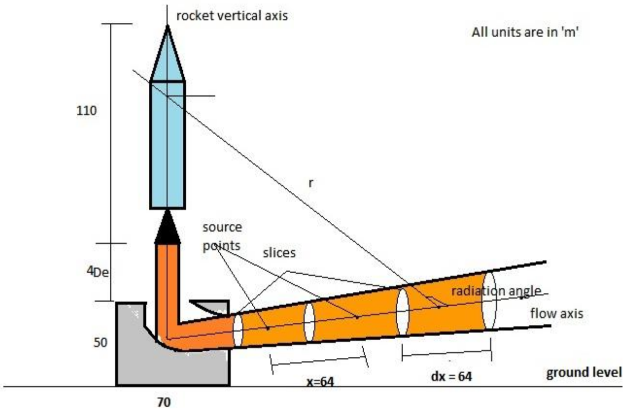

Fig 3.3.1 90 deg bucket type

Here the bucket is placed at a distance of 4De with 5 slices and 5 source points.

### 3.4. 150 deg bucket blast deflector:

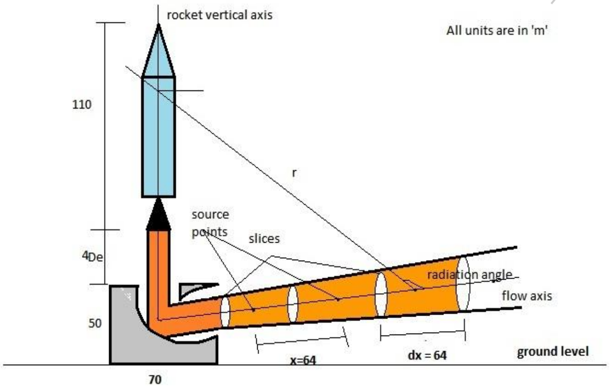

Fig 3.4.1 150 deg bucket type

Here the bucket is placed at a distance of 4De with 5 source points and 5 slices of same distance as x from the deflector plate.

### 3.5. Normal flat plate deflector:

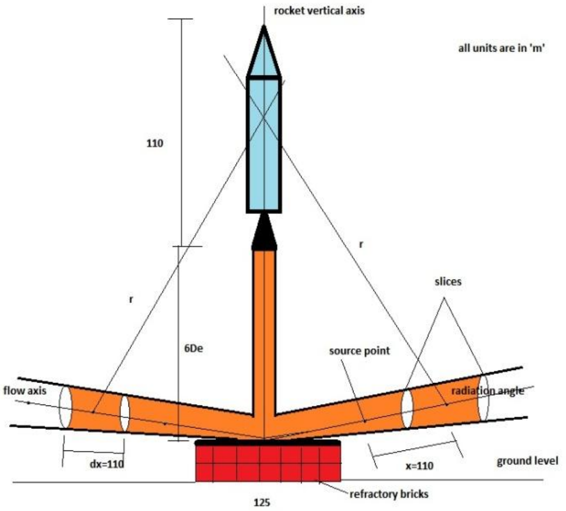

Fig 3.5.1 normal flat plate

Here the flat plate normal to the flow axis is kept at a distance of 6 De from the nozzle exit. Since it has two axial unsymmetrical flow we took only 2 source points and 2 slices on each sides.

### 3.6. Normal conical flat plate deflector:

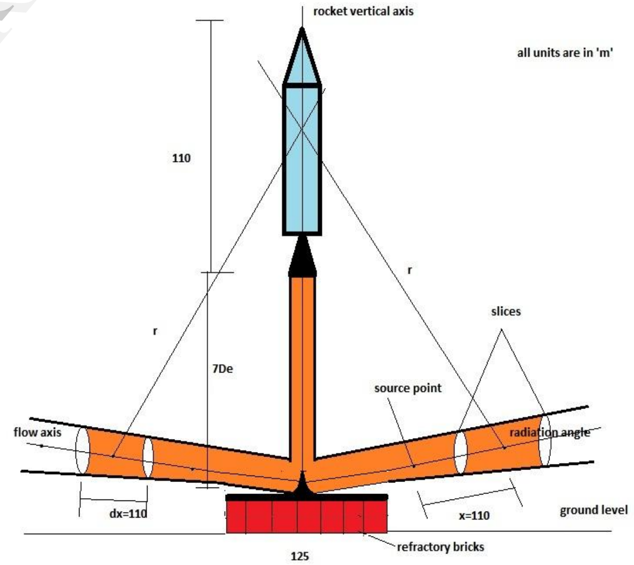

Fig 3.6.1 normal conical flat plate

Here the conical flat plate is kept at the distance of 7De in order to separate the flow linearly and in symmetrical and hence easy to calculate and manipulate them and having 2 source points on each sides.

## 4. Calculation for the overall sound pressure level:

The first 4 steps is common to all and it is calculated as the following ways:

1. Determine the flow axis relative to the vehicle and the stand. (distance x, along the flow axis is measured from the nozzle)

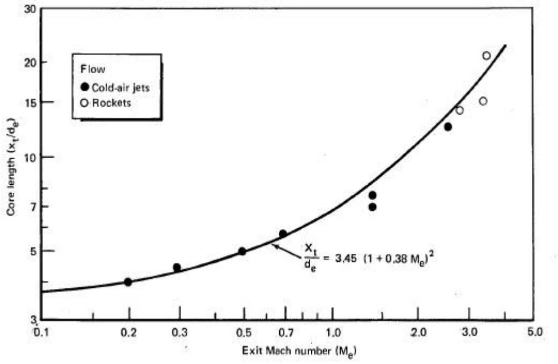

Fig 4.1. determine the distance x=384 m

2. Estimate the overall acoustic power from Eldred Method:

$$W_{OA} = 0.005\, nF\, U_e$$
$$W_{OA} = 0.005 \times\ 5 \times 3.42e7 \times 2600.75$$
$$W_{OA} = 4.42e11\ w$$

Where,

$W_{OA}$ = Overall acoustic power, W
$F$ = thrust of engine, N
$U_e$ = Fully expanded exit velocity, m/sec
$n$ = No. of Nozzles

3. The exit diameter is considered as

$$d_e = \sqrt{n} d_{ie}$$
$$d_e = \sqrt{53.7}$$
$$d_e = 8.3\ m$$

4. Calculate the overall sound power level, from:

$$L_w = \ 10 \log 4.42e11 + \ 120\ dB\ (re\ 10^{-12}\ watts)$$
$$L_w = 236\ dB$$

## 4.1. Overall SPL for 45 deg flat plate:

Step 5 continues in this session.

5. Convert the normalized spectrum to a conventional acoustic bandwidth( i.e., the power spectrum per Hz, per 1/3 octave or per octave as desired)

| $f_b$ | $-10\log\Delta$ | $W(f)$ | $10log\left[\frac{W(}{W}\right.$ | -10 $\log\frac{U_e}{d_e}$ | $L_{w,b}$ |
|---|---|---|---|---|---|
| 200 | 1.66 | 4.88 | -36 | 7.45 | 142 |
| 315 | 1.86 | 3.10 | -38 | 7.45 | 140 |
| 800 | 2.26 | 1.22 | -42 | 7.45 | 135 |
| 1000 | 2.36 | 0.97 | -43 | 7.45 | 134 |
| 2000 | 2.66 | 0.48 | -46 | 7.45 | 131 |
| 4000 | 2.96 | 0.24 | -49 | 7.45 | 127 |
| 5000 | 3.06 | 0.19 | -50 | 7.45 | 126 |
| 8000 | 3.26 | 0.12 | -52 | 7.45 | 124 |
| 10000 | 3.36 | 0.09 | -53 | 7.45 | 123 |

**Table 4.1.1 sound power level calculation of various band centered frequency.**

$$L_{w,b} = 10\log\left[\frac{W(f)}{W_{OA}}\frac{U_e}{d_e}\right] + \ L_w - \ 10\log\frac{U_e}{d_e} + 10\log\Delta f_b$$

Where,

$L_{w,b}$ = sound power level in the band centered on frequency b, dB ( re $10^{-12}$ watts)
$\Delta f_b$ = bandwidth of the frequency band, Hz

6. Allocate the acoustic sources along the exhaust flow centre line. The location of a single source for each frequency band, either 1/3 octave or octave band, is determined by arranging a source of strength given by the acoustic power spectrum at points given by the solid line curve of fig.

7. Calculate the sound pressure level in the band centered on any frequrency, b, and at any point,P, on the vehicle from:

| $L_{w,b}$ | $-10\ logr^2$ | -11 | $DI\ (b, ɵ)$ | $SPL_{b,p}$ |
|---|---|---|---|---|
| 142 | 39.20 | -11 | 45.42 | 137 |
| 140 | 39.20 | -11 | 45.42 | 135 |
| 135 | 39.20 | -11 | 45.42 | 130 |
| 134 | 39.20 | -11 | 45.42 | 129 |
| 131 | 39.20 | -11 | 45.42 | 126 |
| 127 | 39.20 | -11 | 45.42 | 123 |
| 126 | 39.20 | -11 | 45.42 | 122 |
| 124 | 39.20 | -11 | 45.42 | 119 |
| 123 | 39.20 | -11 | 45.42 | 118 |

**Table 4.1.2 Sound Pressure level calculation for each band centred frequency.**

$$SPL_{b,p} = \ L_{w,b} - \ 10\log r^2 - \ 11 + DI\ (b, ɵ)$$

Where,

$SPL_{b,p}$ = sound pressure level at position p, in the band centered on frequency b, dB (re 2 × $10^{-5}$ N/$m^2$)
$r$ = length of the radius line from the assumed position of the frequency source to the point on the vehicle, m

ɵ = angle between the flow centerline and r
$DI\ (b, ɵ)$= directivity at the angle ɵ for the band centered on frequency b, dB

8. Calculate the overall sound pressure level at any point p, on the vehicle by logarithmic summation of $SPL_{b,p}$ over the entire spectrum from:

| Distance x 'm' | Total SPLb,p dB | $SPL_{OA,p}$ dB |
|---|---|---|
| 129 | 114 | 107 |
| 193 | 112 | |
| 257 | 106 | |
| 321 | 103 | |
| 384 | 101 | |

**Table 4.1.3 overall SPL calculation at any point p**

$$SPL_{OA,p} = 10\log \sum_{All\ b} \left[ antilog \frac{SPL_{b,p}}{10} \right] dB$$

### 4.2. 45 deg curved plate:

Follow the above steps same as all deflectors calculation and we get the overall sound pressure level at any point as.

| Distance x 'm' | Total SPLb,p dB | $SPL_{OA,p}$ dB |
|---|---|---|
| 129 | 115 | 110 |
| 193 | 110 | |
| 257 | 110 | |
| 321 | 104 | |
| 384 | 111 | |

**Table 4.2.1 Overall SPL at any point p**

### 4.3. 90 deg bucket:

| Distance x 'm' | Total SPLb,p dB | $SPL_{OA,p}$ dB |
|---|---|---|
| 129 | 120 | 117 |
| 193 | 119 | |
| 257 | 114 | |
| 321 | 112 | |
| 384 | 109 | |

**Table 4.3.1 Overall SPL at any point p**

### 4.4. 150 deg bucket:

| Distance x 'm' | Total SPLb,p dB | $SPL_{OA,p}$ dB |
|---|---|---|
| 129 | 125 | 125 |
| 193 | 121 | |
| 257 | 126 | |
| 321 | 124 | |
| 384 | 123 | |

**Table 4.4.1 Overall SPL at any point p**

### 4.5. Normal flat plate:

| Distance x 'm' | Total SPLb,p dB | $SPL_{OA,p}$ dB |
|---|---|---|
| 129 (left side) | 110 | 104 |
| 257 | 105 | |
| 384 | 101 | |
| 129(right side) | 111 | |
| 257 | 107 | |
| 384 | 104 | |

**Table 4.5.1 Overall SPL at any point p**

### 4.6. Normal conical flat plate:

| Distance x 'm' | Total SPLb,p dB | $SPL_{OA,p}$ dB |
|---|---|---|
| 129 (left side) | 109 | 101 |
| 257 | 105 | |
| 384 | 102 | |
| 129(right side) | 108 | |
| 257 | 101 | |
| 384 | 102 | |

**Table 4.6.1 Overall SPL at any point p**

## 5. Conclusion:

It is noted that the deflector plate which are not having the radiation shield plate covering them and which all are open will have the 6 to 20 dB of sound pressure level should be added due to the effect of reflection of sound from the surface. In order to avoid sound reflection points we enhance the bucket type to ensure good overall sound pressure level and creates less acoustic loading. The acoustic loading is also reduced by adding the water jet into the deflectors along with the jet stream will give the reduced acoustic pressure level and decreases the acoustic loading emissions.

## 6. References:

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