

ACOUSTIC LOADS ON A SOUNDING ROCKET LIFT-OFF

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Abstract. *During take off operation launchers and its payloads are submitted to strong acoustic loads generated by boosters. Typical values of the OSPL (overall sound pressure level) achieved are within the 140-160 dB range. Although it is difficult to predict precisely the sound pressure level fluctuations, and so measurements should be performed in order to acquire a better knowledge of the acoustic loads, some techniques can help the design team to estimate these loads along the vehicle during early steps of satellite or payload conception. By this way the real need for payload protection can be evaluated and strategies to reduce the acoustic energy inside the fairing can be considered. A combination of empirical relations derived from experimental data and mathematical modeling was used by NASA researchers to create a routine which can predict approximately the acoustic loads rockets during lift-off . However, simple acoustic theory can also be used. In this work we use both techniques to estimate the acoustic loads on the SARA vehicle, a payload specially designed to carry zero gravity experiments in a sub-orbital flight, during its lift-off. The results are analyzed and compared to those produced for rockets of similar size.*

Keywords*: acoustics, rockets*

1. INTRODUCTION

In moments like the lift off, during transonic flight and when submitted to a maximum dynamic pressure, a launching rocket and its payload are submitted to strong acoustic loads. When a re-entrance procedure is part of the mission it must be considered also in the acoustic loads analysis since thermo-acoustic excitations will be present. In a flight without re-entrance the most critical acoustic loads occurs during the lift-off. These loads could affect the payload and other rocket internal equipment (Stavrinidis, C. et al 2001). The knowledge of payload dynamic acoustic behavior is of great importance in order to define the intensity levels for qualification tests and to design an acoustic protection system. The prediction of the acoustic loads is probably the most difficult part of this task.

The high intensity noise generated by the high velocity exhaust gases are reflected by the ground and the launching facilities generating a diffuse acoustic excitation which strikes the launcher structure, as can be seen in Fig. (1) extracted from Carneiro (2006). For re-entrance missions Lange (1996) gives values of SPL (sound pressure levels) smaller than the ones generated during the lift-off. However, in the same reference it is pointed out that the acoustic qualification tests should be performed in a high temperature environment.

The vibro - acoustic behavior of space subsystems when submitted to dynamic loads plays an important role during preliminary design stages. It must be taken into account that in the higher stages, where delicate control equipments and the payload are placed, the acoustic excitations are dominant. The system's response to an acoustic field can be calculated (Miranda, 1995) but a precise description of the acoustic load generated by the launching vehicle remains a difficult task. Therefore, field measurements and dynamic tests in acoustic reverberant chambers are strongly recommended.

In this work preliminary calculations of the acoustic loads generated by a VS-40 rocket during lift-off are presented. The sound pressure levels applied to the payload (a SARA sub-orbital vehicle) are evaluated using a simple acoustic model which considers a single acoustic source (Gerges, 1992) and a more sophisticated model which includes a source-distribution technique along the exhaust stream (NASA, 1971; Irvine, 2002). The results are also compared with the ones obtained for a similar vehicle by Lange (1996).

2. THE SARA PROJECT

The SARA vehicle is a recoverable small satellite (150 Kg of total mass) designed to carry up to 25 Kg of payload, typically small scientific equipment, in a Low Earth Orbit (LEO) up to 300Km. After some days in orbit it can be redirected to Earth and recovered to be used other times. It is expected that SARA strongly reduce the costs for zero gravity experiments.

In order to analyze the SARA's behavior during the flight, a geometrically identical vehicle is being developed, the SARA sub – orbital vehicle. It should make a sub - orbital flight in a VS-40 sounding rocket, use parachutes to reduce its re-entrance velocity and finally be rescued in the sea (Moraes Júnior et al, 2002).

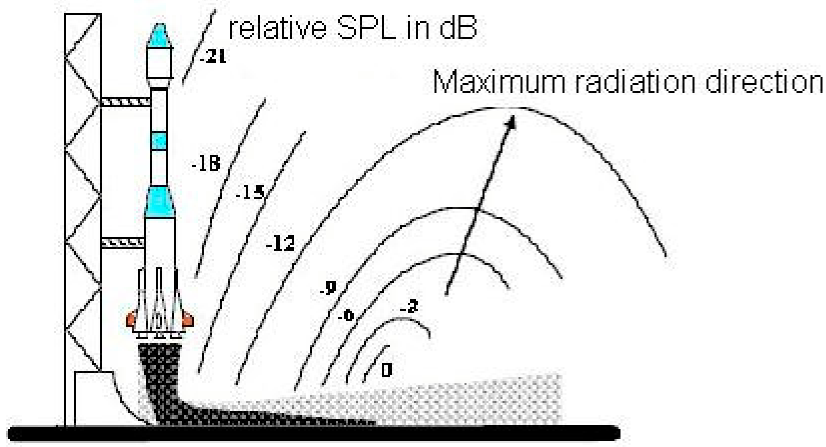

Figure 1 – Acoustic noise generation during lift-off

3. THE VS-40 SOUNDING ROCKET

The VS-40 sounding rocket was developed to test the VLS (Satellite Launching Vehicle) 4^{th} stage in vacuum conditions and to perform other experiments for the VLS project. It can carry payloads up to 500 Kg in trajectories with apogee of 650 Km. It is a single stage solid propelled rocket with a total mass of 6235 Kg. It has 6.25 m of length and 1.0 m of diameter. The VS-40 can be observed in Figure 2.

Figure 2 – The VS-40 Rocket

4. SINGLE ACOUSTIC SOURCE CALCULATIONS

The sound power emitted by a mechanical system can be estimated as a fraction of its mechanical power. For rockets this fraction can be assumed to be 0.5% (NASA, 1971). Once the sound power level is calculated the irradiated sound pressure level can be evaluated, in a first approximation.

Given the exhaust gases velocity (2296.8 m/s) and the average thrust at sea level (228 kN) one can calculate the rocket engine mechanical power (Wmec) and the acoustic power (Wac) corresponding to 0.5% of the mechanical power:

$$Wmec = Fv = 228.000x2.296{,}8 = 523{,}7\ MW \qquad (1)$$

$$Wac = 0{,}005x523.700.000 = 2{,}62\ MW \qquad (2)$$

At the sea level the thrust values will be 13% smaller than the ones given in Fig. 1.

The sound power level (NWL) can be calculated using Eq. (3) below:

$$NWL(dB) = 10\log\frac{W(Watt)}{Wref} = 10\log\frac{2{,}62^6}{10^{-12}} = 184\ dB \tag{3}$$

Where: Wref (reference) $=10^{-12}$ Watts

The overall sound pressure level (OSPL) is obtained considering the point where the exhaust gases are reflected as half - sphere sound source (directivity factor equal to 1) irradiating sound in a free field. The overall sound pressure must be first calculated in the nozzle exit plane, considering the divergent radius r=0.35 m and assuming the divergent a half-spherical sound source with one direction. Equation (4) gives the overall sound pressure level generated by the rocket engine in the nozzle exit plane.

$$OSPL(dB) = NWL(dB) - 20\log r - 8 = 184 - 20\log 0{,}35 - 8 = 176{,}45\ dB \tag{4}$$

In these calculations a free field behavior was assumed and so the sound pressure level decays 6 dB when the distance is doubled. Therefore the attenuation of the overall sound pressure level must be considered for the higher parts of the rocket. The nozzle exit plane is placed 5.3 m upper the ground in the lift-off. Assuming a free field behavior one can estimate a decay of 9 dB to the ground, which gives a overall sound pressure level reflected on the ground of 167.45 dB. This value must be considered the initial overall sound pressure level in which the proportional attenuations must be applied in order to obtain overall sound pressure levels along the launcher height. Table 1 displays the overall sound pressure level values calculated for many positions in the launcher. The heights were measured from the ground considering the launcher placed vertically (0^o inclination).

Table 1: Overall sound pressure level (OSPL) in different launcher positions

Height [m]	NPS OSPL [dB]	Comments
0 - 1	167,45	On the ground (point of reflexion)
3	161,45	3 meters from the ground
7	155,45	7 meters from the ground
10	152,45	10 meters from the ground (launcher's fairing height)
14	149,45	14 meters from the ground

5. VIKING LAUNCHER ACOUSTIC LOADS

Lange (1996) has presented the dynamic loads for a payload carried by the Viking launcher (a launcher with some propulsion characteristics similar to the VS-40). The spectral distribution of the sound pressure levels evaluated for the lift-off, the re-entrance, the values considered for qualification tests and its overall sound pressure levels are displayed in Tab. (2).

Table 2: SPL during lift-off , re-entrance, qualification levels and OSPL values

Frequency [Hz]	Lift-off SPL [dB]	Re-entrance SPL [dB]	Qualification tests SPL [dB]
31,5	126,5	120,5	151,5
62,5	132,5	125,5	153,5
125	137,5	129,5	154,5
250	141,5	134,5	154,5
500	136,5	137,5	156,5
1000	130,5	139,5	155,5
2000	126,5	139,5	154,5
OSPL	144,5	144,4	163,0

6. NUMERICAL SIMULATION USING MULTIPLE ACOUSTIC SOURCES

Computational routines for calculation of sound pressure levels generated by launchers during its lift-off were presented by Margasahayam and Caimi (1999) and Irvine (2002). The former routine was based on NASA (1971) and was used in this work. It uses a source distribution technique allocating the sources along the deflected exhaust stream. The radiated field from each source is summed and the acoustic load in the required points is calculated. Some rocket design parameters like exhaust gases velocity, distance from the nozzle to the ground, the way the jet is reflected by the ground among others are the input data. The sound pressure level spectrum in any position on the launcher can then be calculated.

Using the S-40 rocket engine data as input we calculate the sound pressure level in many positions on the launcher structure. A region of special interest is the launcher fairing and upper parts since it contains the payload and the electronic control equipment both sensitive to acoustic loads. Figure (3) presents 8 points in the launcher's structure where the sound pressure level was calculated. The points' coordinates are displayed in Tab. (1).

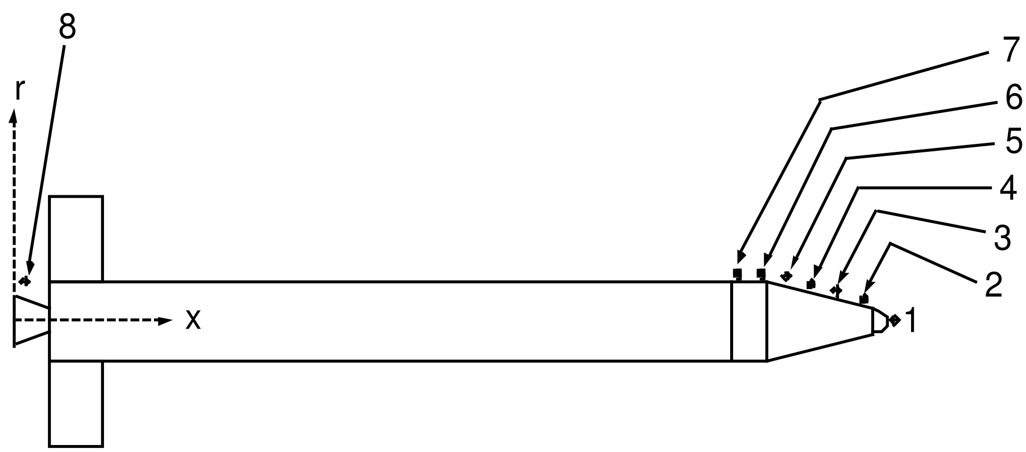

Figure 3 – Points on the VS-40 launcher for the calculation of sound pressure levels

Table 1 – Points 1 to 8 coordinates

Point	x [mm]	r [mm]
1	6076,3	5
2	5466	351,79
3	5230	396,50
4	5000	441,21
5	4770	485,92
6	4540	508,50
7	4420	508,50
8	100	503,50

The spectral distribution of sound pressure level in the points 1 to 7 is displayed in Fig. (4). The same results for point 8 are shown separately in Fig. (5) due to its higher magnitude. It can be noticed that the closer to the nozzle (the acoustic noise source), the higher the sound pressure level.

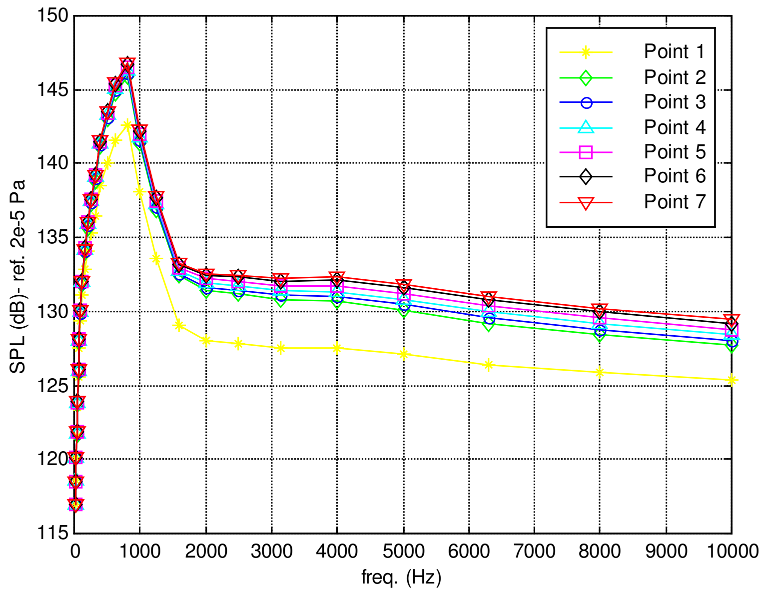

Figure 4- Sound pressure level spectrum in points 1 to 7 (launcher fairing)

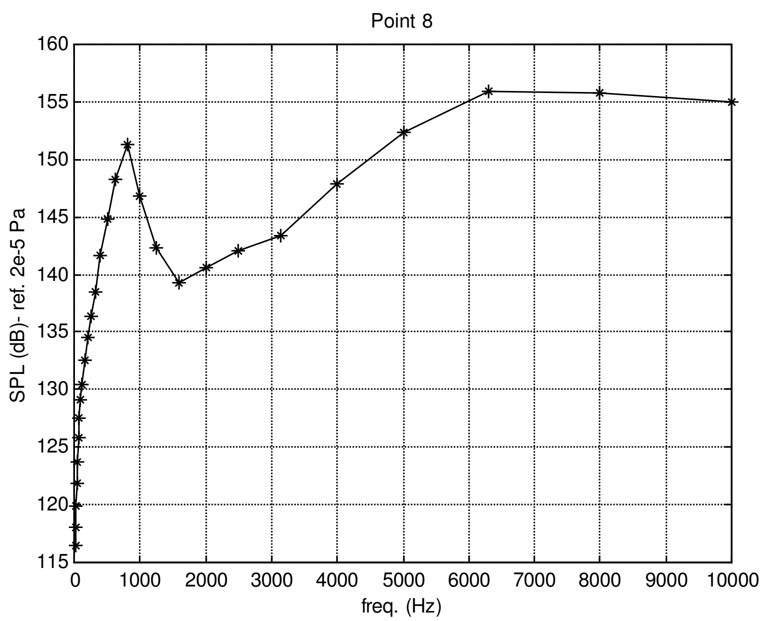

Figure 5 – Sound pressure level spectrum in point 8 (near to the nozzle)

The overall sound pressure levels in each one of the 8 points is calculated by Eq.(5) (Gerges, 1992):

$$OSPL = 10\log(10^{SPL1/10} + 10^{SPL2/10} + ... + 10^{SPLn/10}) \tag{5}$$

Where n is the sound pressure level for the corresponding third of octave.

Table (2) displays the overall sound pressure levels in each point shown in Fig. (2).

Table 2 – Overall sound pressure levels (OSPL) in points 1 to 8

Point	OSPL [dB]
1	149,00
2	151,88
3	152,05
4	152,22
5	152,39
6	152,52
7	152,60
8	162,32

The higher sound pressure level near the payload occurs in point 7. The sound pressure level and the acoustic pressure are related by Eq. (6):

$$SPL = 20\log(\frac{P}{P_{ref}}) \tag{6}$$

where $P_{ref} = 20x10^{-6} \quad Pa$

Table (3) presents the sound pressure level and the acoustic pressure calculated for this point in a frequency band from 20 to 10,000 Hz.

Table 3 – Sound pressure level and acoustic pressure in point 7

Frequency [Hz]	Sound pressure level [dB]	Acoustic pressure [Pa]
20,00	116,90	14,00
25,00	118,50	16,83
31,50	120,10	20,23
40,00	121,90	24,89
50,00	123,90	31,34
63,00	126,10	40,37
80,00	128,10	50,82
100,00	130,10	63,98
125,00	132,00	79,62
160,00	134,20	102,57
200,00	136,00	126,19
250,00	137,60	151,72
315,00	139,20	182,40
400,00	141,60	240,45
500,00	143,50	299,25
630,00	145,50	376,73
800,00	146,80	437,55
1000,00	142,30	260,63
1250,00	137,80	155,25
1600,00	133,30	92,48
2000,00	132,60	85,32
2500,00	132,50	84,34
3150,00	132,20	81,48
4000,00	132,30	82,42
5000,00	131,80	77,81
6300,00	131,00	70,96
8000,00	130,20	64,72
10000,00	129,50	59,71

7. CONCLUSIONS

In Tab. (4) one can compare the overall sound pressure levels generated during the lift – off calculated for point 4 (on the fairing) and point 8 (near the nozzle) using both methods (single acoustic source and multiple acoustic source located along the exhaust stream). The results for the Viking launcher, a rocket with similar characteristics, are also displayed for comparison. A difference of 5 dB is observed in the results calculated for the nozzle region but a good correlation was obtained for the fairing. The overall sound pressure values for the Viking launcher fairing are 8 dB smaller, probably due to the fact that its spectral distribution was analyzed up to 2000 Hz while the VS-40 spectrum was analyzed up to 10000Hz.

The results obtained in this work are just preliminary estimations to be used in the initial design steps of the SARA sub-orbital vehicle (Pirk and Souto, 2006) and should be validated with acoustic measurements performed during launching operations whenever possible.

Table 4: OSPL calculated

Method	OSPL (nozzle) [dB]	OSPL (coifa) [dB]
Acoustics theory	167,45	152,45
Viking launcher data	---	144,5
Numerical Simulation	162,32	152,22*

8. ACKNOWLEDGEMENTS

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10. RESPONSIBILITY NOTICE