LAUNCH VEHICLE LIFTOFF ACOUSTICS
SCALED FROM GROUND TO AIR-LAUNCH
RevisionA

By Tom Irvine
Email: tomirvine@aol.com

September 4, 2009

This is a work in progress.

Introduction

Consider a rocket vehicle launched from a ground stool or rail. Acoustic and vibration measurements are made on the vehicle for the liftoff event.

Now consider that a similar rocket vehicle is to be carried inside a military cargo aircraft and then ejected from aircraft. The rocket vehicle descends for some duration via parachutes. The parachutes are then released, and the first stage motor then ignites.

The task is to estimate the liftoff sound and vibration levels for the air-launched vehicle from the ground launch data.

There are several key variables in this calculation:

1. The exhaust flow angle relative to the vehicle
2. The directivity factor
3. Radiation volume
4. Ambient air density

Note that the air-launched vehicle radiates sound into a sphere.

The ground launched vehicle radiates sound into a rough hemisphere

Example

A study is made using an example.[1] Consider a rocket vehicle with a Castor 4B first stage motor. The station of interest is the Castor 4B aft skirt. The results and assumptions for the ground and air launched cases are given in Appendices A and B respectively. The analysis is carried out using the method in Reference 1.

The sound pressure levels for the two cases are shown in Figure 1. The difference between the two levels is shown in Figure 2.

[1] Additional examples will be included in future revisions of this analysis.

Rule-of-thumb

The following is a conservative rule-of-thumb:

> The liftoff acoustic level for an air-launched vehicle can be set to the corresponding level for a ground launch vehicle minus 15 dB for frequencies above 100 Hz.

This rule is conservative per the difference curve in Figure 1. The true difference may be up to 30 dB above 2000 Hz.

The rule is also conservative because the ambient air density for the air-launched case will be lower than that for the ground launched case. This difference was not included in the example.

Further note that the rule does not account for direct, structural-borne vibration effects. This effect would tend to reduce the difference for a vibration analysis.

Thus, the conservatism in the rule-of-thumb is warranted.

References

1. Rocket Vehicle Liftoff Acoustics and Skin Vibration Acoustic Loads Generated by the Propulsion System, NASA SP-8072, Monograph N71-33195, 1971.
2. T. Irvine, Sound Intensity Rev C, Vibrationdata, 2004.

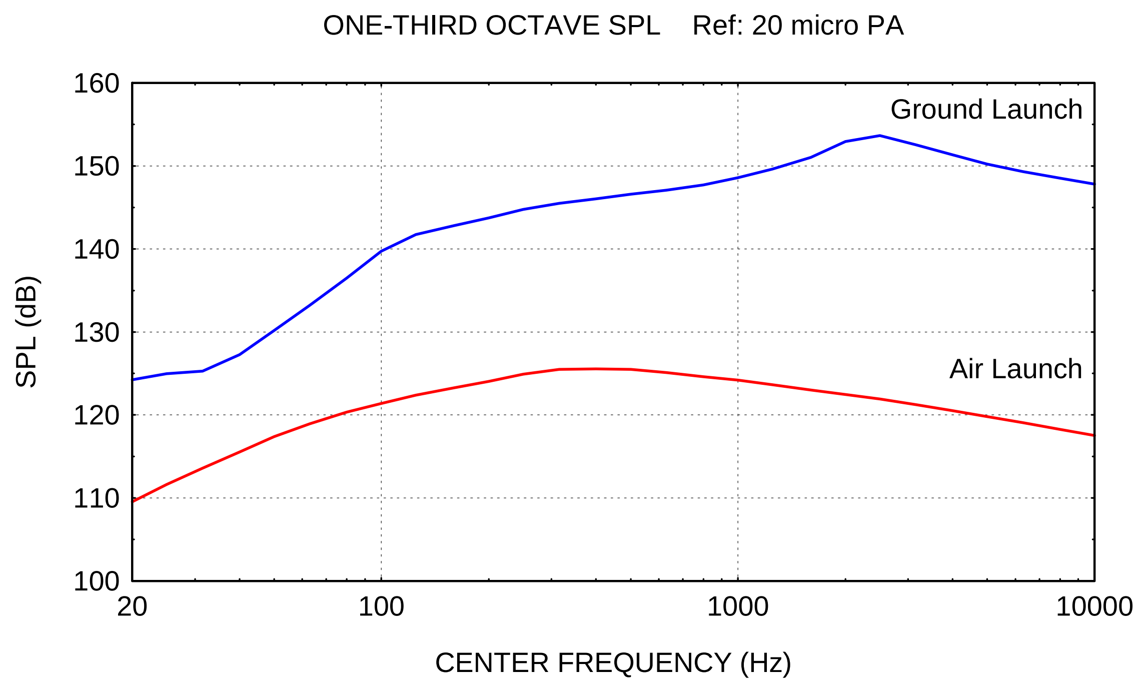

Figure 1.

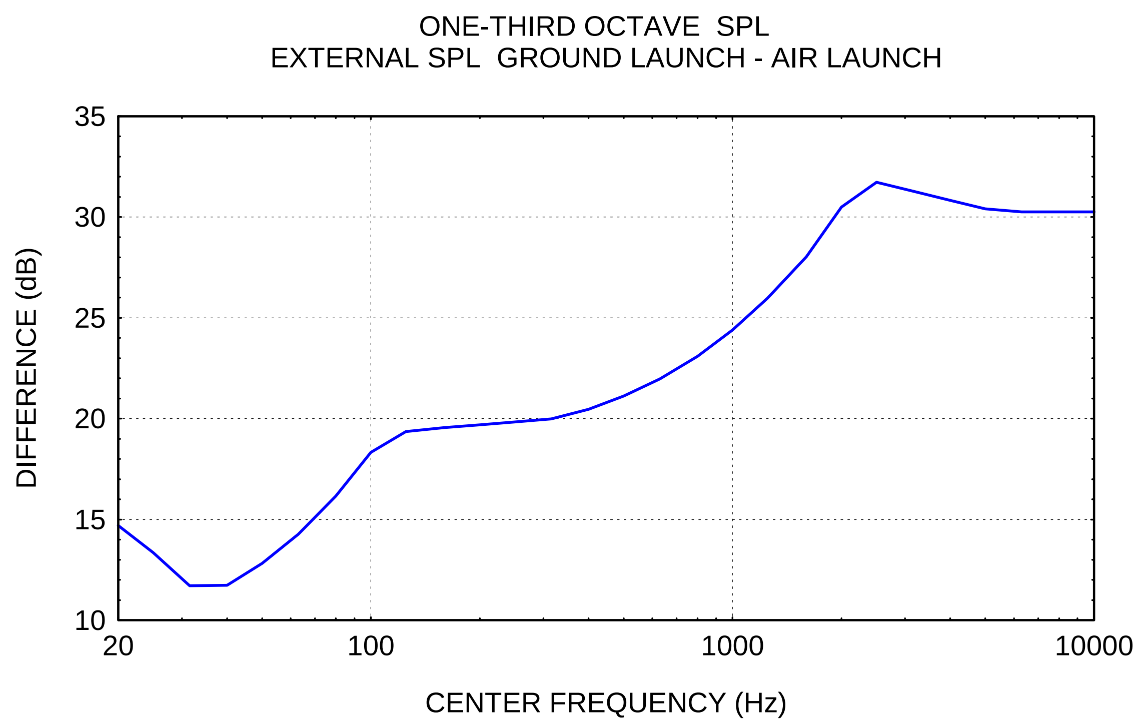

Figure 2.

APPENDIX A

Ground Launch

```
 liftoff.cpp, ver 6.3, May 13, 2009

  By Tom Irvine   Email: tomirvine@aol.com

References:

1. Rocket Vehicle Liftoff Acoustics and Skin Vibration
   Acoustic Loads Generated by the Propulsion System.
   NASA SP-8072, Monograph N71-33195, 1971.

2. Wilby & Wilby, Prediction of External Acoustic Field
   on Taurus During Liftoff, AARC No. 121, 1991.

Castor 4B

Thrust = 1.12e+005 lbf
       = 4.9818e+005 N

Exhaust exit velocity =     8475 ft/sec
                      =     2583 m/sec

Speed of sound =     1120 ft/sec
               =    341.4 m/sec

Acoustic Efficiency =    0.010 decimal
                    =    1.000 percent

Nozzle Diameter =  37.500 in
                =   0.952 m

Number of nozzles = 1

 Sound radiation into hemisphere (flat ground plane).

 Wilby correction factor for surface reflections: applied.

deflected, 90 deg flat plate, conical diffuser, or wedge


x1 =     120.00 inches  (distance from nozzle exit plane to ground)
   =       3.05 meters
   =       3.20 nozzle exit diameters

angle from deflected flow to ground =          5.0 deg

Peak Instantaneous Mechanical Power = 9.492e+008 ft-lbf/sec
                                    = 1.287e+009 Watts


overall acoustic power WOA =    4.75e+006 ft-lbf/sec
```

= 6.43e+006 Watts

Subtract 3 dB for: deflected, 90 deg flat plate, conical diffuser, or wedge

overall acoustic power level LW = 185 dB
Ref = 1.0e-12 Watts

Station Diameter = 50 in
= 1.27 m

Station = 0 inches
= 0 meters

Zero dB reference: 20 micro Pa

f(Hz)	Strouhal	Lwb[i]	source[m]	x[m]	r[m]	theta(deg)	beta(deg)	DI(dB)	delta(dB)	spl(dB)
20.0	0.0074	166.5	30.66	30.67	30.67	85.0	90.0	-7.86	3.32	124.3
25.0	0.0092	168.1	29.91	29.91	29.91	85.0	90.0	-9.08	3.44	125.0
31.5	0.0116	169.6	29.06	28.38	28.33	86.4	88.6	-10.88	3.62	125.3
40.0	0.0147	171.0	28.13	27.62	27.58	86.0	89.0	-10.75	3.85	127.3
50.0	0.0184	172.3	27.19	27.05	27.04	85.3	89.7	-9.53	4.10	130.2
63.0	0.0232	173.2	26.14	26.10	26.09	85.1	89.9	-8.07	4.39	133.2
80.0	0.0295	174.0	24.99	24.96	24.95	85.1	89.9	-6.21	4.70	136.5
100.0	0.0369	174.3	23.84	23.81	23.81	85.1	89.9	-4.01	4.98	139.7
125.0	0.0461	174.6	22.62	22.67	22.67	85.0	90.0	-2.98	5.22	141.7
160.0	0.0590	174.7	21.20	21.15	21.14	85.1	89.9	-2.85	5.44	142.8
200.0	0.0737	174.7	19.84	19.81	19.81	85.1	89.9	-2.63	5.60	143.8
250.0	0.0922	174.7	18.41	18.48	18.48	85.0	90.0	-2.37	5.71	144.7
315.0	0.1162	174.3	16.87	16.76	16.75	85.4	89.6	-2.14	5.80	145.5
400.0	0.1475	173.6	15.22	15.24	15.24	85.0	90.0	-1.80	5.87	146.0
500.0	0.1844	173.0	13.63	13.53	13.52	85.4	89.6	-1.68	5.91	146.6
630.0	0.2323	172.0	11.94	12.00	12.00	85.0	90.0	-1.28	5.94	147.1
800.0	0.2950	170.8	10.17	10.10	10.09	85.4	89.6	-0.99	5.96	147.7
1000.0	0.3687	169.7	8.51	8.57	8.57	85.0	90.0	-0.44	5.97	148.6
1250.0	0.4609	168.6	6.87	6.86	6.86	85.1	89.9	-0.28	6.00	149.6
1600.0	0.5900	167.5	5.13	5.14	5.14	85.0	90.0	-0.25	6.00	151.0
2000.0	0.7375	166.5	3.66	3.62	3.62	85.7	89.3	-0.42	6.00	153.0
2500.0	0.9218	165.6	2.36	3.05	3.05	85.0	90.0	-0.25	6.00	153.7
3150.0	1.1615	164.5	1.26	3.05	3.05	85.0	90.0	-0.25	6.00	152.5
4000.0	1.4749	163.3	0.48	3.05	3.05	85.0	90.0	-0.25	6.00	151.3
5000.0	1.8437	162.2	0.11	3.05	3.05	85.0	90.0	-0.25	6.00	150.2
6300.0	2.3230	161.2	0.10	3.05	3.05	85.0	90.0	-0.25	6.00	149.3
8000.0	2.9499	160.5	0.10	3.05	3.05	85.0	90.0	-0.25	6.00	148.5
10000.0	3.6873	159.7	0.10	3.05	3.05	85.0	90.0	-0.25	6.00	147.8

overall SPL = 162 dB ref 20 micro Pa

pressure in air = 0.3776 psi rms
= 2602 Pa rms

APPENDIX B

AIR LAUNCH

```
 liftoff.cpp, ver 6.3, May 13, 2009

  By Tom Irvine   Email: tomirvine@aol.com


References:

1. Rocket Vehicle Liftoff Acoustics and Skin Vibration
   Acoustic Loads Generated by the Propulsion System.
   NASA SP-8072, Monograph N71-33195, 1971.

2. Wilby & Wilby, Prediction of External Acoustic Field
   on Taurus During Liftoff, AARC No. 121, 1991.

Castor 4B

Thrust = 1.12e+005 lbf
       = 4.9818e+005 N

Exhaust exit velocity =     8475 ft/sec
                      =     2583 m/sec

Speed of sound =     1120 ft/sec
               =    341.4 m/sec

Acoustic Efficiency =    0.010 decimal
                    =    1.000 percent

Nozzle Diameter =  37.500 in
                =   0.952 m

Number of nozzles = 1

 Sound radiation into sphere (free space).


 Wilby correction factor for surface reflections: applied.


single nozzle, undeflected (Smith & Brown)


Peak Instantaneous Mechanical Power = 9.492e+008 ft-lbf/sec
                                    = 1.287e+009 Watts


overall acoustic power WOA =    4.75e+006 ft-lbf/sec
                           =    6.43e+006 Watts
```

```
overall acoustic power level LW =          188 dB
Ref = 1.0e-12 Watts


Station Diameter =      50 in
                 =    1.27 m

Station =            0 inches
        =            0 meters
```

Zero dB reference: 20 micro Pa

f(Hz)	Strouhal	Lwb[i]	source[m]	x[m]	r[m]	theta(deg)	beta(deg)	DI(dB)	delta(dB)	spl(dB)
20.0	0.0074	169.5	55.32	0.00	55.32	180.0	180.0	-17.12	3.00	109.6
25.0	0.0092	171.1	52.67	0.00	52.67	180.0	180.0	-17.08	3.00	111.6
31.5	0.0116	172.6	50.07	0.00	50.07	180.0	180.0	-17.02	3.00	113.6
40.0	0.0147	174.0	47.52	0.00	47.52	180.0	180.0	-16.92	3.00	115.5
50.0	0.0184	175.3	45.25	0.00	45.25	180.0	180.0	-16.78	3.00	117.4
63.0	0.0232	176.2	43.01	0.00	43.01	180.0	180.0	-16.61	3.00	118.9
80.0	0.0295	177.0	40.82	0.00	40.82	180.0	180.0	-16.38	3.00	120.4
100.0	0.0369	177.3	38.87	0.00	38.87	180.0	180.0	-16.11	3.00	121.4
125.0	0.0461	177.6	37.01	0.00	37.01	180.0	180.0	-15.86	3.00	122.4
160.0	0.0590	177.7	35.06	0.00	35.06	180.0	180.0	-15.55	3.00	123.3
200.0	0.0737	177.7	33.39	0.00	33.39	180.0	180.0	-15.21	3.00	124.0
250.0	0.0922	177.7	31.79	0.00	31.79	180.0	180.0	-14.77	3.00	124.9
315.0	0.1162	177.3	30.22	0.00	30.22	180.0	180.0	-14.21	3.00	125.5
400.0	0.1475	176.6	28.68	0.00	28.68	180.0	180.0	-13.92	3.00	125.5
500.0	0.1844	176.0	27.31	0.00	27.31	180.0	180.0	-13.78	3.00	125.5
630.0	0.2323	175.0	25.96	0.00	25.96	180.0	180.0	-13.61	3.00	125.1
800.0	0.2950	173.8	24.64	0.00	24.64	180.0	180.0	-13.38	3.00	124.6
1000.0	0.3687	172.7	23.46	0.00	23.46	180.0	180.0	-13.11	3.00	124.2
1250.0	0.4609	171.6	22.34	0.00	22.34	180.0	180.0	-13.00	3.00	123.6
1600.0	0.5900	170.5	21.16	0.00	21.16	180.0	180.0	-13.00	3.00	123.0
2000.0	0.7375	169.5	20.15	0.00	20.15	180.0	180.0	-13.00	3.00	122.5
2500.0	0.9218	168.6	19.19	0.00	19.19	180.0	180.0	-13.00	3.00	121.9
3150.0	1.1615	167.5	18.24	0.00	18.24	180.0	180.0	-13.00	3.00	121.3
4000.0	1.4749	166.3	17.31	0.00	17.31	180.0	180.0	-13.00	3.00	120.5
5000.0	1.8437	165.2	16.48	0.00	16.48	180.0	180.0	-13.00	3.00	119.8
6300.0	2.3230	164.2	16.19	0.00	16.19	180.0	180.0	-13.00	3.00	119.1
8000.0	2.9499	163.5	16.19	0.00	16.19	180.0	180.0	-13.00	3.00	118.3
10000.0	3.6873	162.7	16.19	0.00	16.19	180.0	180.0	-13.00	3.00	117.5

overall SPL = 137 dB ref 20 micro Pa

pressure in air = 0.0198 psi rms
= 136.4 Pa rms