	Engineering Analysis (EA) Record		Date:	Feb. 15, 2012
NASA John C. Stennis Space Center	Title: A Brief Historical Survey of Rocket Testing Induced Acoustic Environments at NASA SSC		Prepared By: D. Allgood	
			Group: NASA-SSC EA33	
			EA Number: EA-00294	

Overview

A survey was conducted of all the various rocket test programs that have been performed since the establishment of NASA Stennis Space Center. The relevant information from each of these programs were compiled and used to quantify the theoretical noise source levels using the NASA approved methodology for computing "acoustic loads generated by a propulsion system" (NASA SP-8072). This methodology, which is outlined in Reference 1, has been verified as a reliable means of determining the noise source characteristics of rocket engines. This information is being provided to establish reference environments for new government/business residents to ascertain whether or not their activities will generate acoustic environments that are more "encroaching" in the NASA Fee Area.

In this report, the designation of <u>sound power</u> level refers to the acoustic power of the rocket engine at the engine itself. This is in contrast to the <u>sound pressure</u> level associated with the propagation of the acoustic energy in the surrounding air. The first part of the survey documents the "at source" sound power levels and their dominant frequency bands for the range of engines tested at Stennis. The second part of the survey discusses how the acoustic energy levels will propagate non-uniformly from the test stands. To demonstrate this, representative acoustic sound pressure mappings in the NASA Stennis Fee Area were computed for typical engine tests on the B-1 and E-1 test stands.

Characterization of Noise Sources from Rocket Testing

The overall sound power level of a rocket engine is a measure of the total acoustic power being generated by the rocket exhaust. Figure 1 shows that the overall sound power levels (in units of decibels, dB) vary logarithmically with the thrust of the rocket engine. In reality, the governing parameter is the mechanical energy of the rocket exhaust plume as defined by the thrust of the rocket times its exit velocity. However, since rocket thrust is a value that has more "physical" meaning to the reader, it was chosen as the correlating parameter without substantial loss in the logarithmic fit. Figure 1 also shows that this logarithmic variation of sound power with rocket thrust is independent of oxidizer and fuel combinations being used, e.g. liquid-oxygen (LOX) and liquid hydrogen (LH2) versus hydrogen peroxide (H2O2) and kerosene (JP-8). The logarithmic function for estimating the acoustic power level for a particular rocket engine has been given in Figure 1.

Figure 1 also shows that the largest sound power levels ever experienced at NASA Stennis was approximately 204dB, which corresponded to the Saturn S-IC stage on the B-2 test stand. This particular rocket stage contained 5 F-1 LOX/RP-1 engines, which generated a cumulative thrust of 7.5 million pounds of thrust. However, most of our test programs in recent years are for engines with much lower thrust levels. Typically, they are on the order of 100,000 to 650,000 pounds of thrust (units of lbf) or on the lower end of the spectra, e.g. 1000 lbf. Therefore, normally, the acoustic power levels being generated are less than 195 dB.

Acoustic spectra generated by rocket exhaust plumes are characteristically broadband in their distributions. A representative rocket engine sound power spectra is depicted in Figure 2.   Generally, rocket engine spectra indicate that there is some mid-frequency (10-100 Hertz) band containing most of the energy, a very slow roll-off at low frequencies (<10 Hertz), and a rapid roll off at high frequencies (>10,000 Hertz). This data signifies that most of the acoustic energy being emitted from a rocket engine test will be concentrated in the low to mid frequency ranges, which may have the potential to damage structures or harm personnel in the immediate vicinity of the test stand. Thus, there is a tangible need to predict the acoustic fields from these tests and ensure all the necessary safety precautions are implemented.

Figure 3 shows a rough indication of how the dominant peak in the broadband spectrum changes with thrust level of the engine. There is significant scatter in this data as the thrust is not the optimum correlating factor as was discussed previously, but the figure does provide the reader with an approximate indication of the variability in the dominant acoustic frequency.   In addition, the corresponding upper and lower frequency ranges at which the overall sound power has dropped by 5 dB have been plotted.   The primary purpose of Figure 3 is to demonstrate

that the dominant acoustic energy can be contained in a band of frequencies ranging from 1 Hz all the way to 1000 Hz depending on the size and thrust of the engine.
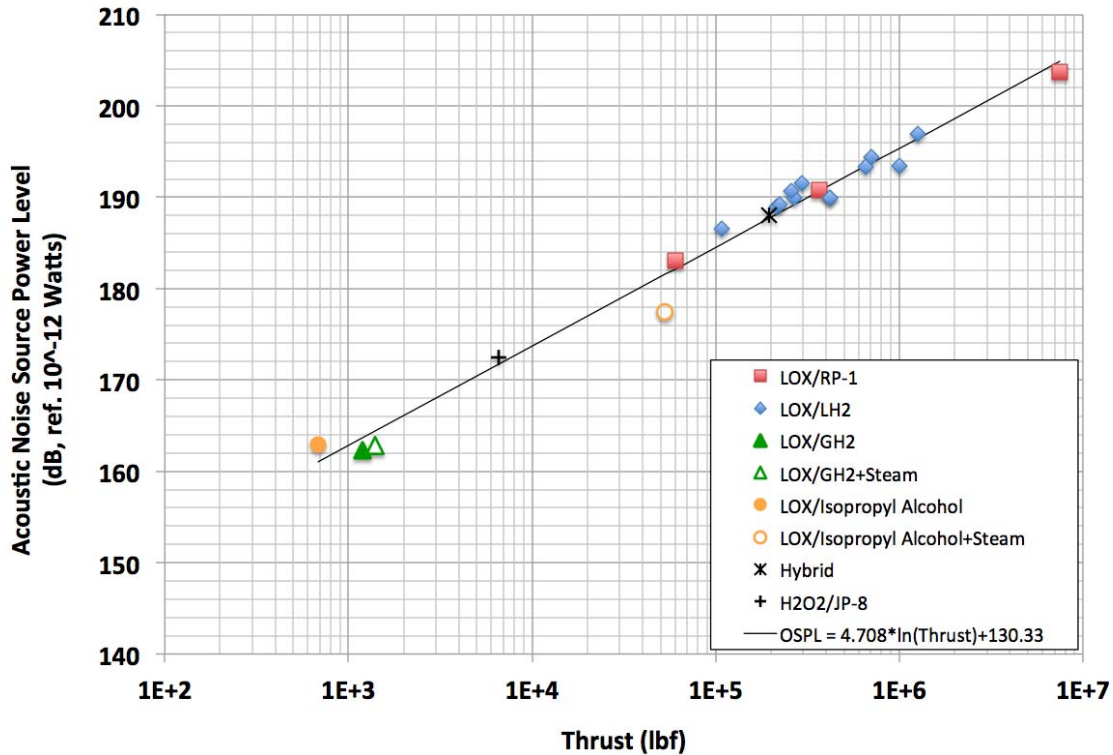

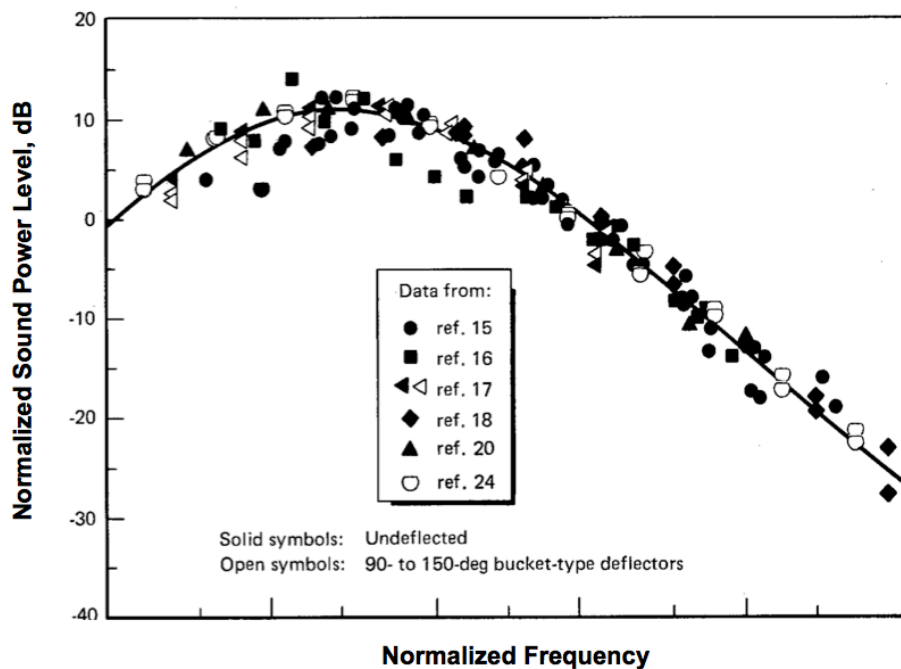**Figure 1: Acoustic Power Levels Generated by Rocket Testing**

Figure 2: Normalized Acoustic Power Spectra for Rocket Engines with 350 to 7,000,000 Pounds of Thrust (Reference 1)

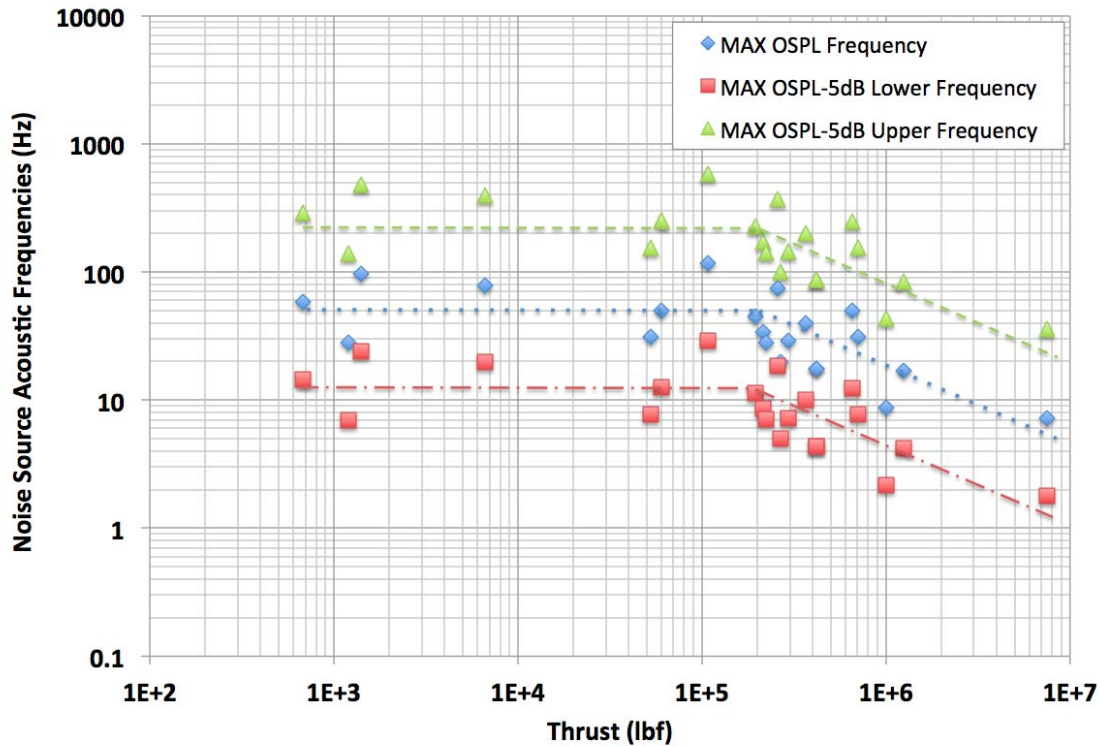|	Engineering Analysis (EA) Record		Date:	Feb. 15, 2012
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Figure 3: Primary Acoustic Frequencies Generated by Rocket Testing

Propagation of Noise Levels to the NASA Stennis Fee Area

Once the sound power level spectra have been determined, the propagation of that acoustic power as overall sound pressure levels (OSPL) can be determined using the methods outline in NASA SP-8072 (Reference 1). However, the propagation of this energy is not uniform due to the high speed and temperature of exhaust plume refracting the sound. Figure 4 depicts the directivity of the sound for various rocket engine types. At NASA Stennis Space Center, we test "standard chemical rocket" engines and stages and as such the dominant directivity for the sound will be in the 40-60 degree directivity angle where 0 degrees is in the direction of the exhaust plume. In reality, there will be changes in the overall sound pressure level directivity angle due to engine type and whether the rocket exhaust plume is fired horizontally or vertically on a deflector.

The NASA Stennis Space Center's A1/A2 and B test complexes are oriented such the rocket engines exhaust predominantly towards the North, while the E1 test stand faces towards the South. Thus, the acoustic field generated in the Stennis Fee Area is dependent on which test stand is being used. Figures 5a and 5b give example predictions for acoustic mappings in the Fee Area during recent rocket test programs on the B-1 and E-1 test stands respectively. The B-1 acoustic mapping corresponds to an engine thrust level of the order of 650,000 lbf, while the E-1 acoustic mapping is for a 400,000 lbf class engine.

Lastly, the duration of the noise can affect the overall perceived "nuisance" to the surrounding community, and if sufficient acoustic levels are propagated to areas occupied by personnel, acoustic hearing protection might need to be implemented. However, due to the nature of rocket engine testing, the tests are relatively short (1 second to 10 minutes) such that long-term exposure is not very common and hearing protection is generally only required around the immediate vicinity of the test stand.
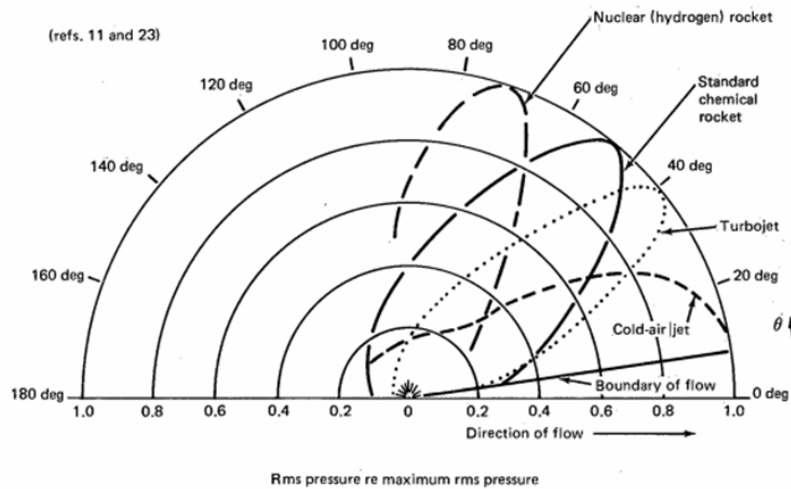

Figure 4: Directional Characteristics of Overall Sound Pressure Levels Generated by Rocket Testing. (Reference 1)

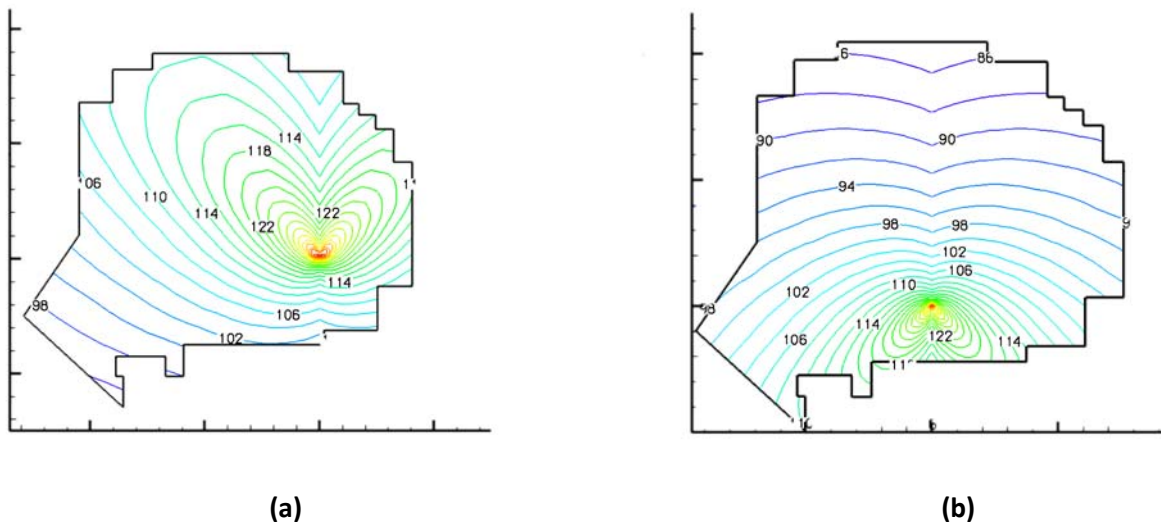**(a)**   **(b)**

**Figure 5: Example Overall Sound Pressure Level Acoustic Propagations in the NASA Stennis Fee Area
(a) B-Complex for 700,000 lbf class engine and (b) E-Complex for a 400,000 lbf class engine**

References

[1] Eldred, K.M., " Acoustic Loads Generated by the Propulsion System", NASA SP-8072, 1971.