Acoustics • Shock • Vibration • Signal Processing **January 2006 Newsletter**

Greetings

Sound has been used as a tool in warfare throughout recorded history.

Seven priests each blowing a ram’s horn brought down the walls of Jericho under the leadership of Joshua, according to a Bible story. The priests were accompanied by a chorus of shouting Israelites.

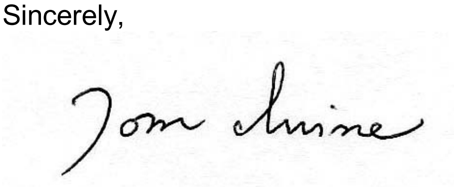
Greeks, Romans, and Celts used an assortment of horns, drums, and bagpipes to rally their troops, as well as to strike fear in the enemy.

During World War II, the Stuka dive bomber used sirens for psychological effects. A Stuka siren recording is analyzed in the first article of this newsletter.

Additional articles discuss the sound and vibration of the C130J aircraft, a model rocket, and a tubular enclosure built around an elevated railway.

I wish everyone a Happy New Year!

Sincerely,



Tom Irvine
Email: tomirvine@aol.com

Feature Articles

Stuka Dive Bomber Siren by Tom Irvine

Figure 1. Junkers JU-87 Stuka Die Cast Model

Introduction

The JU-87 Stuka was a tactical precision dive bomber. It was the airborne component of the German Blitzkrieg (lightning war) in World War II.

Stuka is an abbreviation for Sturzkampfflugzeuge which is the German word for “dive bomber.”

The Stuka’s main advantage was its bombing accuracy. In addition, the aircraft had a fixed landing gear with front wheel covers, which allowed the Stuka squadrons to land and take off from undeveloped front line "airfields."

The aircraft was slow and lacked armor, however. It was thus an easy target for enemy fighters and anti-aircraft batteries.

Sirens

The air rushing over the Stuka’s body made a screaming noise when the dive brakes were extended.

The noise was greatly enhanced in later B-series models by small propeller-driven sirens. One siren was mounted on each landing gear.

The purpose of the sirens was to terrorize civilians and enemy troops, including anti-aircraft gunners. The sirens were a very effective psychological warfare tool.

George Lucas's Star Wars movie series exploited the legend of the Stuka, with Darth Vader's Imperial TIE fighters shrieking through space, although sound cannot propagate in the vacuum of space.

Spectral Analysis

A time history of Stuka siren is shown in Figure 2. The background of this particular recording in unknown, but it is one of several available at numerous websites. The amplitude scale is uncalibrated.

The corresponding Fourier transform is shown in Figure 3. There is a cluster of peaks from 270 to 450 Hz. Most of the peaks are probably due to aerodynamic interaction with the air brakes.

The apparent fundamental frequency of the siren is 447 Hz with integer harmonics at 874, 1321 and 1788 Hz.

The 447 Hz frequency is nearly the same as the musical note “A above middle C.”

The whistle frequency depends on the aircraft speed, air density, and trajectory. A Doppler shift occurs depending on these factors as well as the relative position between the aircraft and observer.

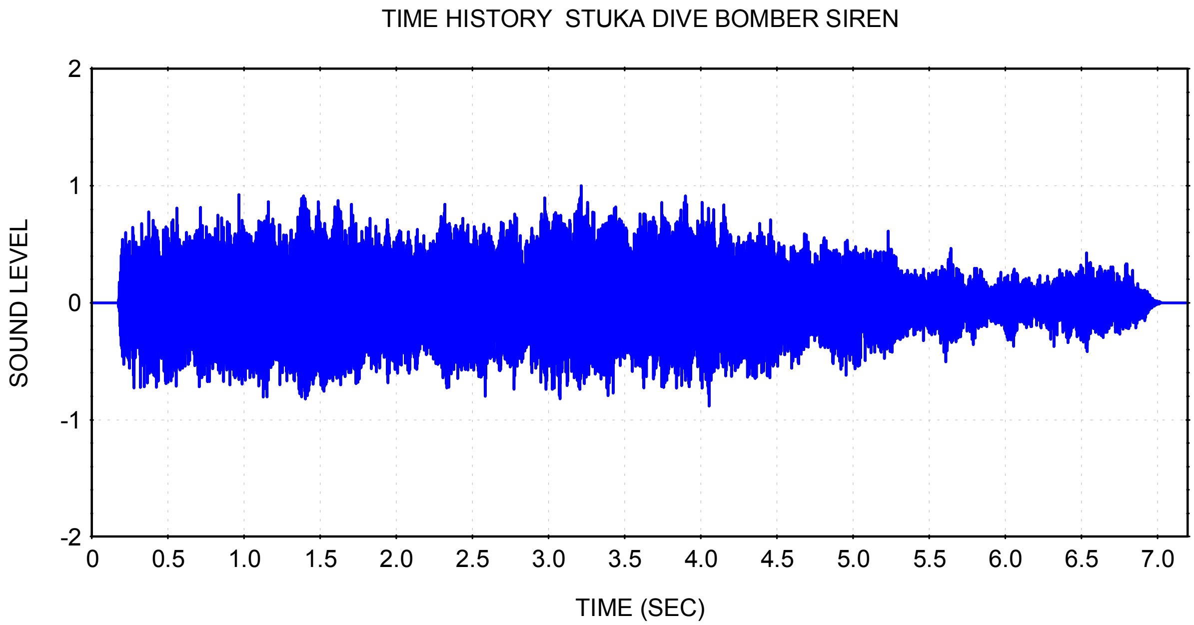


Figure 2.

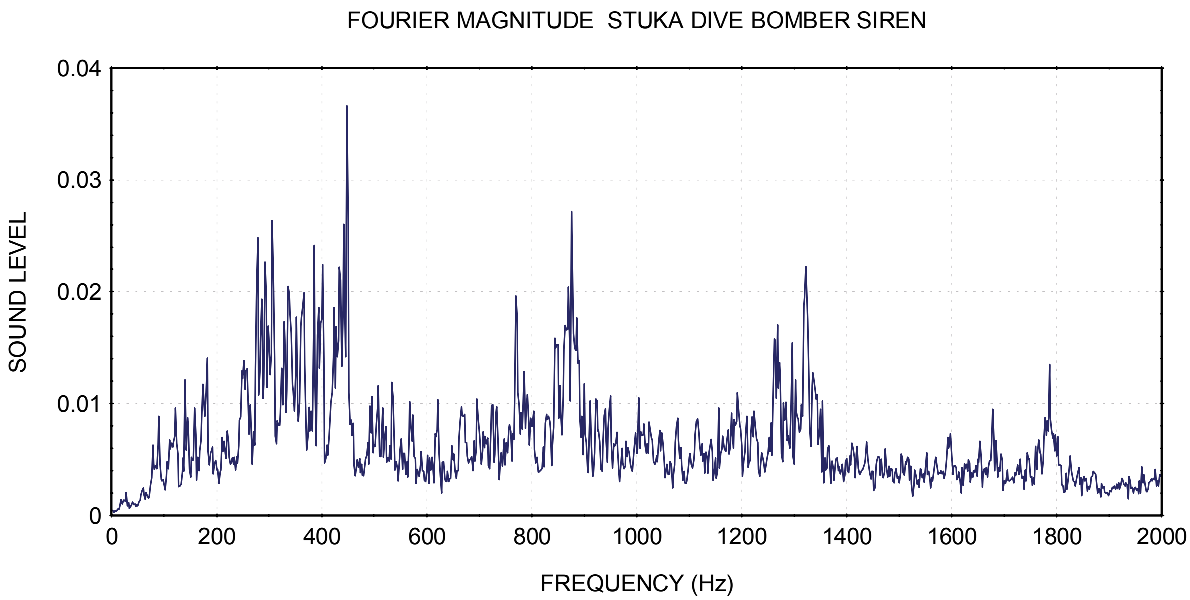


Figure 3.

Lockheed C130J Hercules Vibration by Tom Irvine

Introduction

The C-130J is a tactical and multi-role transport aircraft. It is manufactured by Lockheed Martin Aeronautical Systems in Marietta, Georgia.

The crew consists of two pilots and a loadmaster.

This aircraft seats 128 troops, or 74 paratroops, or 74 stretchers and two medical crew attendants. It can also carry cargo pallets.

It is powered by four Allison AE2100D3 turboprops. Each has 4,590 shaft horsepower, driving six blade variable pitch propellers.

The C-130J speed is 625 km/hr (390 mph) during normal operations.

Vibration Zone

Passengers in the C-130J have reported annoying and fatigue-inducing vibration levels. The passengers are thus exposed to “Whole-Body Vibration.”

The vibration is particularly prominent in the cargo compartment near the propeller plane. The vibration levels diminish forward and aft of the propeller plane. Furthermore, the vibration levels at the centerline passenger seats tend to be

lower than the levels near the sidewalls.

The vibration appears to be primarily due to direct transmission of sidewall vibration to the seat via the seat's attachment hardware.

A High Vibration Zone (HVZ) has thus been identified as the outer port and starboard passenger seats located near tie-down positions 6 through 17.

Vibration Frequencies

There are two vibration frequencies of concern. The C130J propeller shaft speed is 17 Hz. The blade passing frequency is 102 Hz, which is equal to number of blades times the shaft speed.

These frequencies are transposed down to 16 Hz and 100 Hz, respectively, when the vibration is considered in terms of standard one-third octave bands.

16 Hz Effects

Studies reported in Reference 1 show that the C130J vibration levels in the 16 Hz depend on the propeller balancing, altitude, speed, maneuver, flap position, etc.

The highest measured amplitude for the 16 Hz band was 9.44 m/sec^2 rms in the vertical or Z-axis.

The equivalent "weighted Wk" value per Reference 2 is 7.26 m/sec^2 rms. This level is within "Health Guidance Caution Zone" for a duration of 3 hours or more, per Reference 2, Annex B, Figure B-1.

Vibration in the 16 Hz band has a number of potential consequences for passengers. Appreciable vibration may be transmitted up a passenger's spine at this frequency, causing backaches.

Additional symptoms in this frequency band include:

- Headaches
- Eye strain
- Fatigue
- Digestive problems
- Suppression of some reflex responses
- Attention lapses
- Degraded short-term memory

These problems may hinder the performance of troops, including paratroopers, who are being flown to the battlefield for high-risk military operations.

Another concern is the effect of vibration on sick and wounded soldiers who are being evacuated on the C130J.

100 Hz Effects

There is little information on the effects of whole body vibration above 80 Hz, however.

One study showed that nausea, giddiness, and tingling could occur at 100 Hz. The amplitude needed to provoke these symptoms would be greater than that on a C130J, however.

Furthermore, the lower jaw-skull area has a natural frequency between 100 and 200 Hz.

Conclusion

The severity of the whole-body vibration in the C130J high vibration zone depends on the exposure duration, as well as the vibration amplitude. Reference 1 summarizes some studies in this regard, although further research is needed.

Potential mitigations steps include:

- Dynamic propeller balancing
- Optimizing synchrophase angles
- Adjustment of seating materials and seating attachment design
- Application of vibration-reducing materials in the fuselage

References

1. Hopcroft & Skinner, C130J Human Vibration, DSTO-TR-1756, Australian Government Department of Defense, 2005.

2. ISO 2631-1:1997 Mechanical Vibration and Shock Evaluation of Human Exposure to Whole-body Vibration

Model Rocket Liftoff Acoustics By Tom Irvine

Figure 1. Vibrationdata/Estes Silver Comet

Introduction

Rockets have been around for hundreds of years. The Chinese used rockets as a battlefield weapon in 1232 CE. These rockets were described as "arrows of flying fire."

The British fired rockets against Ft. McHenry in the War of 1812, inspiring Francis Scott Key to write "The Star Spangled Banner" with its lyrics about "The rockets' red glare."

The movie “October Sky” in 1999 gave the true story of Homer Hickam, a coal miner's son who was inspired by the first Sputnik launch to take up rocketry as a serious hobby.

My own “Silver Comet” rocket is shown in Figure 1. The purpose of this article is to give a brief analysis of the rocket’s acoustic signature.

Motor

The motor is an Estes D12-5. The propellant is a black powder compound. The thrust-time curve is given in Figure 2.

Note that the following values are approximate.

Thrust Duration = 1.6 seconds

Maximum Total Impulse = 20 Newton-sec

Propellant Weight = 25 g

Exhaust Velocity = 800 meters/sec

Mechanical Power = 9600 Watts

Total mass at liftoff = 0.23 kg

Peak Thrust = 30 Newtons

Average Thrust = 12 Newtons

Acceleration is equal to force divided by mass. The peak acceleration is thus 13 G. The average acceleration is 4.4 G.

Note that 1 G = 9.8 m/sec^2.

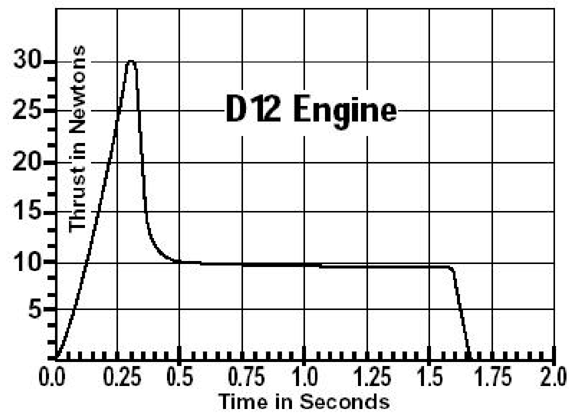


Figure 2. Thrust-Time Curve

Acoustic Analysis

The sound source is the propellant combustion as well as turbulent mixing of gases in the exhaust plume.

The sound generated during the brief burn duration was recorded by a tape recorder on the ground adjacent to the launch stand. The recorder’s built-in microphone was used. The microphone’s amplitude scale factor is uncalibrated. The purpose of measurement was to assess the frequency content of noise and the relative amplitude in each band. An absolute dB level was not calculated, however, since the zero dB reference was arbitrary. The reference was nevertheless uniform for each band.

The recorded data was played back into a computer sound card. The resulting time history is shown in Figure 3. The corresponding sound pressure level is given in Figure 4. The two plots reveal that the signal is transient white noise.

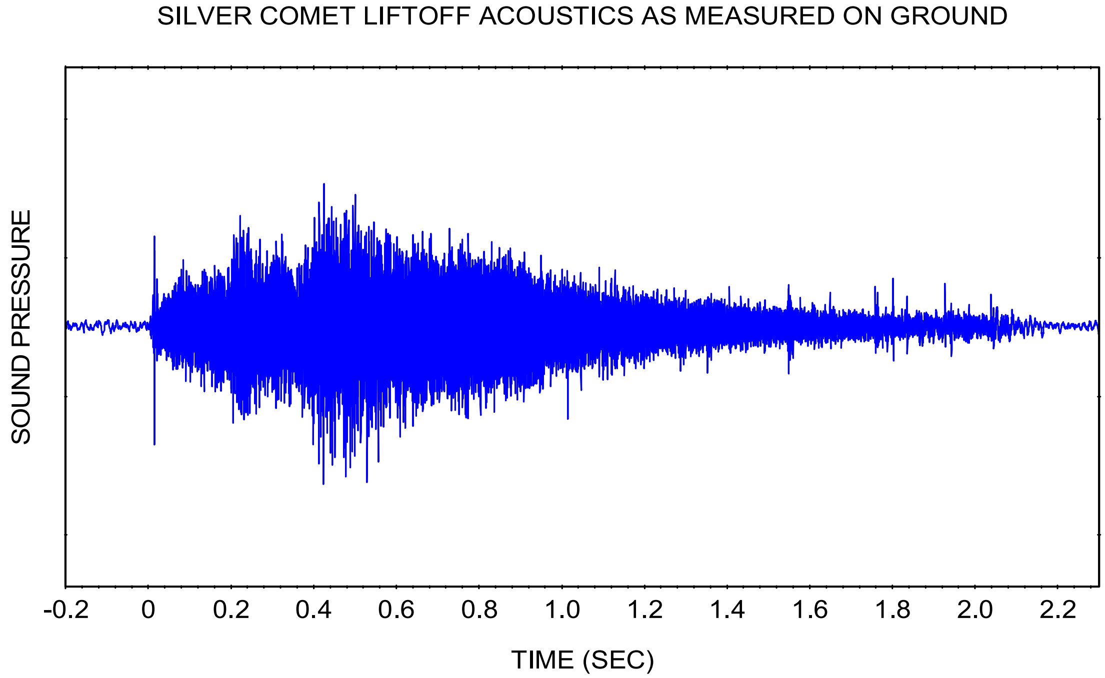


Figure 3.

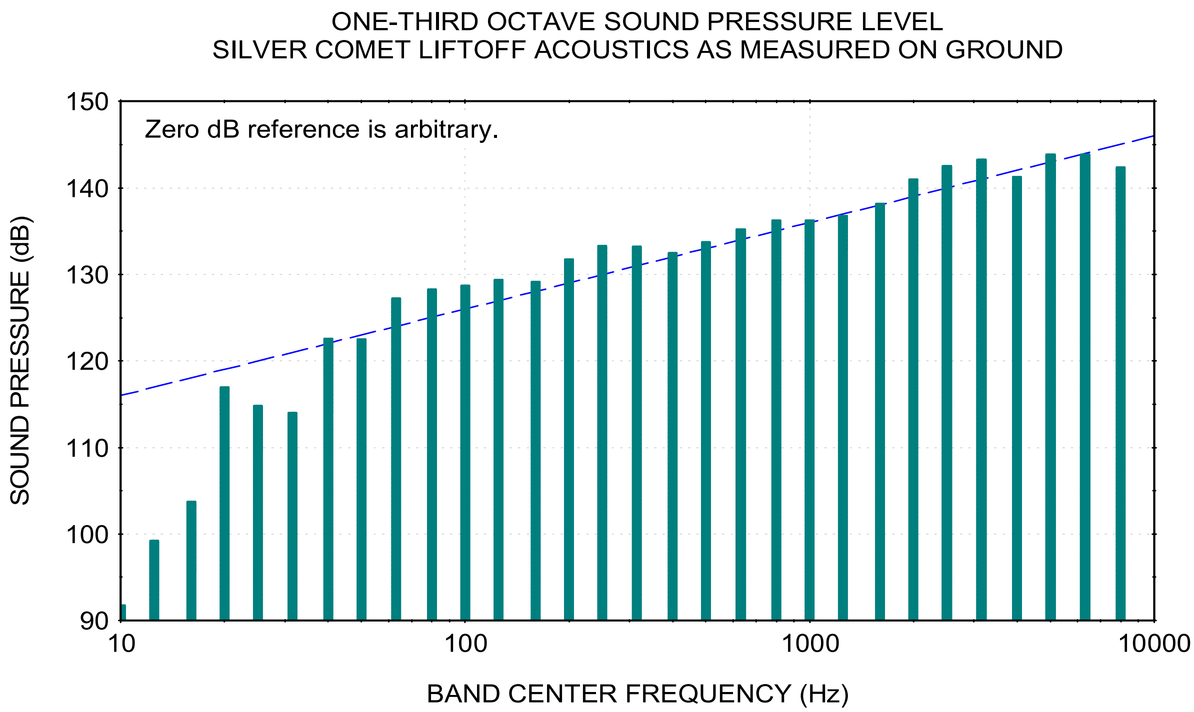
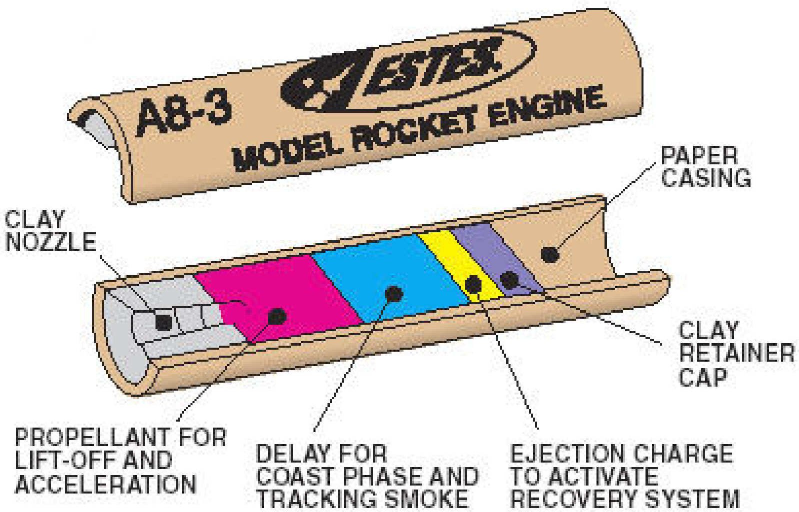
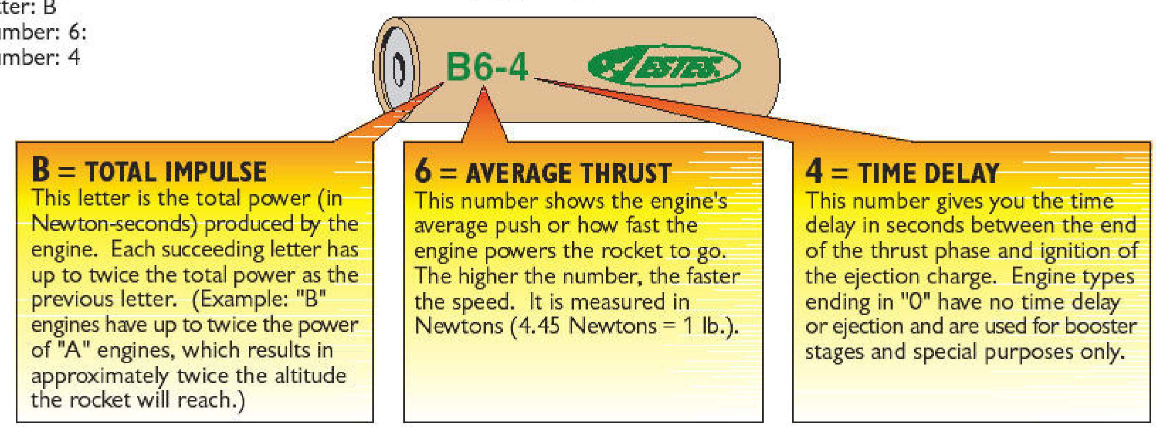


Figure 4.

The green bars represent the sound pressure level. The blue dashed line has a slope of 3 dB/octave. The sound pressure level tends to follow the 3 dB/octave slope. This is indicative of white noise given the one-third octave format.



Each engine has a letter-number-number code. (e.g., B6-4)
Letter: B
Number: 6:
Number: 4



Further information about Estes motors is given at:

http://www.esteseducator.com/

IIT Tube Noise Attenuation by Tom Irvine

The Illinois Institute of Technology (IIT) is a university that places a high value on its campus architecture. IIT is located on Chicago's Near South Side. The campus was designed by Ludwig Mies van der Rohe, who helped define modernist architecture. He became head of IIT's architecture program in 1938.

Chicago Transit Authority's Green Line trains cross through the center of the IIT campus on an elevated track. The center portion of the campus was thus considered unsuitable for building due to the train noise.

Nevertheless, Dutch architect Rem Koolhaas was given the task of designing the McCormick Tribune Campus Center at this location. Koolhaas solved the noise problem by designing an enclosure for the train track.

The Exelon Tube is a cylindrical sheath that envelops 530 feet of the elevated train tracks. Reinforced concrete, clad in 4,800 square feet of corrugated stainless steel, muffles the train noise from an average of 120 decibels to less than 70 inside the building below. The sound attenuation of the tube has also been welcomed by the occupants of the nearby dormitories and classroom buildings.

“The elevated train has a huge impact on IIT's character,” said Koolhaas. “It demanded an innovative technological concept for the train enclosure for an institution devoted to technology.”