Acoustics • Shock • Vibration • Signal Processing **May 2002 Newsletter**

Bom Dia

This month's newsletter features articles on acoustic reverberant chambers and on bolide fireballs.

Engineers use reverberant chambers to subject spacecraft to high intensity acoustic noise. The goal is to represent the environments during liftoff and transonic flight. The spacecraft solar panels, antennas, and other components must be designed to withstand these environments.

The second article discusses a class of exploding meteorites called bolides. These fireballs are a source of naturally occurring sound and vibration. The sonic boom produced by bolides has in some cases been severe enough to shatter windows.

Once again, I invite readers to submit articles, letters, advertisement, and other items of interest for publication in this newsletter.

Thank you for your support.

Sincerely,

Tom Irvine
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Acoustic Reverberant Chambers By Tom Irvine

Figure 1-1. Data Relay Test Satellite inside Acoustic Chamber at Tsukuba Space Center, Japan

Introduction

Satellites are typically subjected to acoustic tests in reverberant chambers prior to launch. An example is shown in Figure 1-1. The purpose of the test is to subject the satellite to high intensity acoustic noise in order to verify that it can withstand the maximum expected flight environments.

Flight Environments

Consider the launch and powered flight of a rocket vehicle. A tremendous amount of noise is generated in the exhaust plume flowing from the nozzle, or nozzles, as the vehicle lifts off. This is due to the turbulent mixing of the exhaust gas with the ambient atmosphere. Note that the exhaust gas velocity may be as high as 10,000 feet/sec (3000 meters/sec), which is nearly nine times greater than the speed of sound.

Some of this acoustic energy reflects off of the ground and propagates into the vehicle's nosecone. In addition, structure-borne vibration propagates from the solid motor, or liquid engine, to the nosecone fairing.

Furthermore, turbulent boundary layers and aerodynamic shock waves form on the vehicle's external skin as it approaches and surpasses the speed of sound. The vehicle then encounters its maximum dynamic pressure condition, at which point the most severe aerodynamic buffeting usually occurs.

A portion of the acoustical and vibration energy from these events propagates to the nosecone fairing. Some of this energy is then radiated as sound pressure into the internal volume where the satellite is enclosed, as shown in Figure 1-2. The arrows in this figure represent the acoustic pressure field, inside and outside of the fairing.

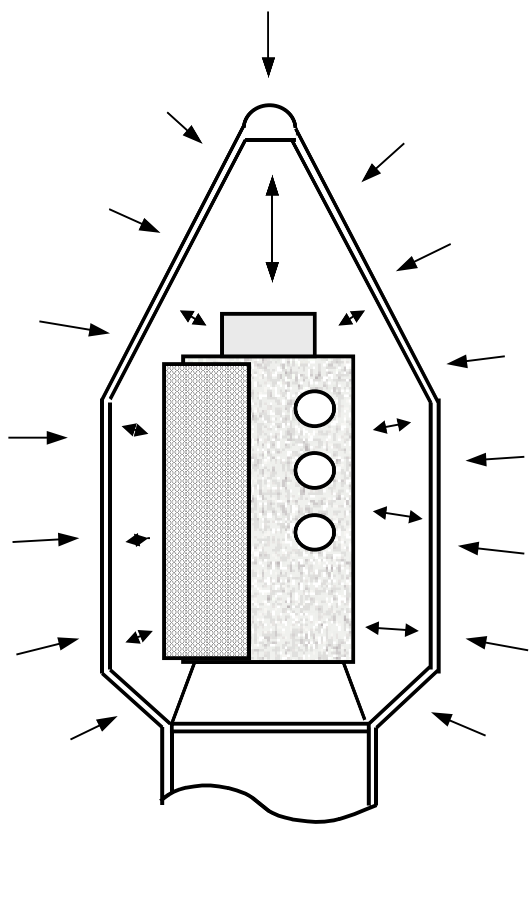

Figure 1-2. Satellite Enclosed Inside Nosecone Fairing

Note that the sound pressure level on the outer fairing walls may reach 160 dB. The fairing walls must be designed to attenuate this sound energy as the energy propagates into the enclosed volume. The walls inside the fairing may be lined with acoustics blankets to provide additional attenuation.

The resulting sound pressure inside the fairing may be 145 dB.

The purpose of the acoustic reverberant test is to simulate the maximum expected acoustic environment including an appropriate safety margin.

Potential Failure Modes

Satellites usually have numerous components that are sensitive to sound and vibration. Solar panels are a particular concern, because they typically have a large surface area relative to their volume. Fatigue cracks can thus form and propagate in the panels under harsh environments. A similar concern exists for high-gain, dish antennae.

In addition, the following failure modes may occur

- Failure of micro-electronic component lead wires
- Shattering of crystal oscillators
- Chafing of wires
- Cracking of printed circuit boards
- Malfunction or failure of waveguides or Klystron tubes
- Vibration of optical elements
- Failure of joints in structures made from composite materials

MIL-STD-1540C Test Level

Acoustic test levels are typically represented in terms of a one-third octave power spectrum.

The acoustic acceptance test level from MIL-STD-1540C is shown in Figure 1-3 and in Table 1-1. The overall level is 138 dB. The minimum test duration is 1 minute.

Additional Test Levels

Consider the Delta II 7920 and 7925 vehicles as configured with a 2.4 m (8 ft) payload fairing and with 3.8 cm (1.5 in) blanket.

The overall acceptance test level is 145 dB for spacecraft mounted inside the payload fairing of either of these vehicles, per Reference 1-1.

This reference also gives acoustic test levels for other launch vehicles.

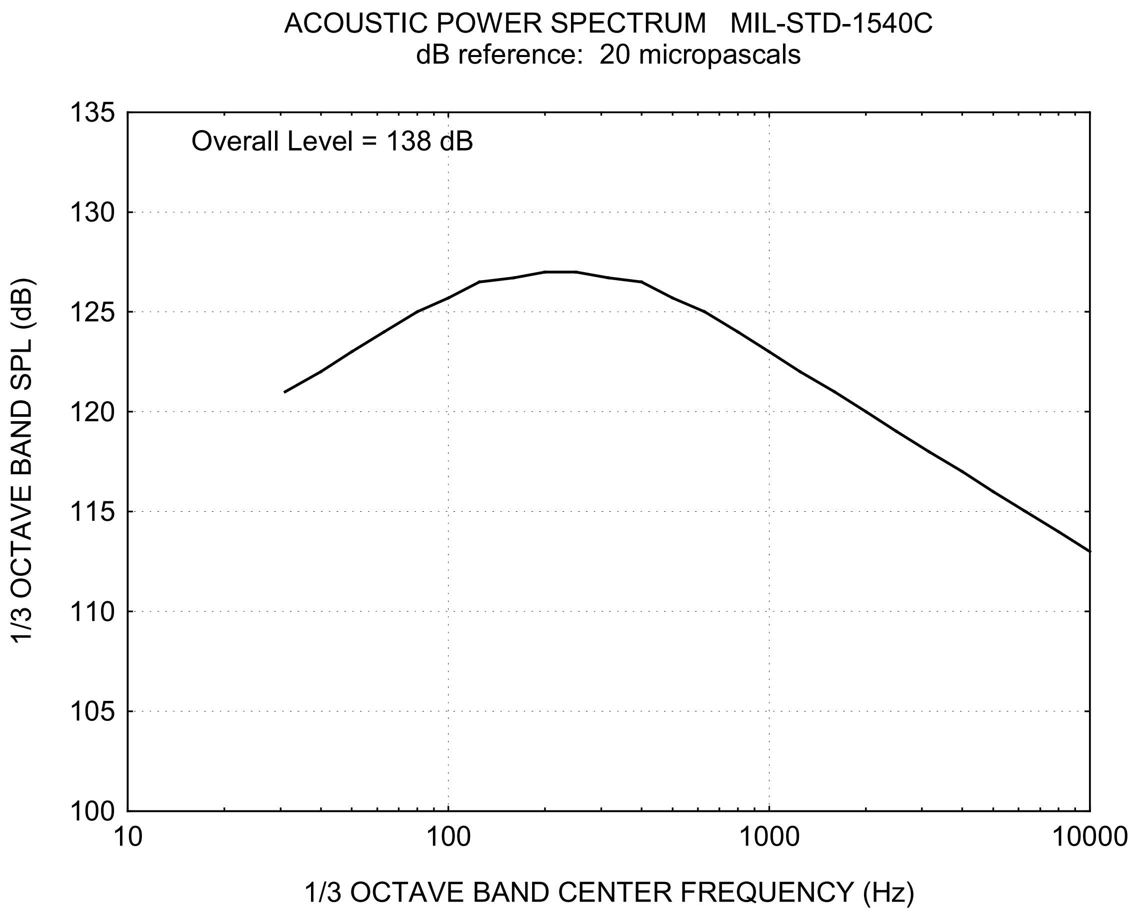

Figure 1-3.

Table 1-1. Coordinates for MIL-STD-1540C Acoustic Power Spectrum

1/3 Octave Center Frequency (Hz)	Sound Pressure Level (dB)
31	121
40	122
50	123
63	124
80	125
100	125.7
125	126.5
160	126.7
200	127
250	127
315	126.7
400	126.5
500	125.7

1/3 Octave Center Frequency (Hz)	Sound Pressure Level (dB)
630	125
800	124
1000	123
1250	122
1600	121
2000	120
2500	119
3150	118
4000	117
5000	116
6300	115
8000	114
10000	113

Evolved Expendable Launch Vehicle

The U.S. Air Force is funding the development of new launch vehicles, as part of the Evolved Expendable Launch Vehicle (EELV) program.

The specified maximum acoustic levels at the EELV payload location are given in Table 1-2, as taken from Reference 1-2.

Table 1-2. EELV Payload Maximum Acoustic Levels

Payload Class	Overall SPL (dB)
Medium	140.4
Intermediate with 4 meter diameter fairing	141.6
Intermediate or Heavy with 5 meter diameter fairing	142.7

Acoustic Test Methods

Acoustic tests are conducted with a closed-loop narrow-band control system. The control system outputs a signal to a power amplifier. The amplified signal is then applied to an array of transducers that modulate nitrogen gas through horns to produce high intensity acoustic energy inside the chamber.

Microphones are used to measure the acoustic pressure inside the chamber. The microphones are calibrated for random incidence noise.

The microphone signals are sent to the control computer, via the feedback loop.

The control computer then compares the measured results to the specification. The control computer then adjusts its output signal accordingly.

In addition, accelerometers may be placed on the test item to measure the item’s vibration response to the acoustical noise.

Chamber Design

Acoustic reverberant chambers should be as large as possible, per the guidelines in Reference 1-3. Large chambers perform much better at lower frequencies than small ones. The sound fields in large chambers are more uniform over space and frequency.

Furthermore, the sound pressure field in large chambers is less perturbed by the presence of the test item. The test item size should be less than 10% of the chamber volume to avoid excessive perturbation of the sound field.

The chamber should be designed to produce an overall sound pressure level of 160 dB, which is equivalent to 41.76 psf rms. This level is necessary because the chamber may be used to test systems that are directly exposed to external rocket and aerodynamic flow noise.

In addition, the chamber walls must be thick enough to withstand acoustic fatigue. The required wall thickness might thus be 2 feet (61 cm), for example.

The walls are typically made from reinforced concrete, with several coats of hard epoxy paint.

Nitrogen Gas

Chambers are typically filled with nitrogen prior to the test. There are two reasons for this. First, a pure nitrogen environment reduces the possibility of contamination during the test. Second, nitrogen conducts sound more efficiently than air.

This introduces a safety hazard, however, since a person would suffocate in a pure nitrogen environment. Thus a safety interlock system is required to control access to the chamber.

Acoustic Power

A typical power requirement for a large chamber is 180 acoustic kilowatts, per Reference 1-3.

Horns

The chamber requires exponential horns. It should have one or more of each of the following:

- 25 Hz cutoff horn
- 35 Hz cutoff horn
- 50 Hz cutoff horn
- 80 Hz cutoff horn
- 160 Hz cutoff horn

Each frequency is the low cutoff frequencies, or the minimum frequency at which the horn will transmit sound.

Each horn is driven by a transducer. The transducer modulates large volumes of nitrogen gas through the horns to produce high-intensity acoustic energy.

Exhaust Attenuator

Furthermore, an exhaust system is mounted n the chamber. The chamber exhaust gas is passed through an attenuator in order to prevent the direct transmission of high intensity noise to areas outside the test chamber.

Sound Field Uniformity

The sound field must be uniform and diffuse, preferably with at least 20 modes per octave band.

The modal density $\Delta N / \Delta f$ for an acoustic volume is

$$\Delta N / \Delta f \approx 4\pi f^2 V \Big/ C^3 \qquad (1\text{-}1)$$

where

f is the frequency in Hertz
V is the volume
C is the speed of sound in the gas

The modal density increases in proportion to the frequency squared. Thus modal density is mainly a concern at the lowest test frequency.

As an example, consider that the lowest test frequency is 30 Hz. A one-octave band centered at this frequency would extend from 21 Hz to 42 Hz. The volume of the chamber should have a modal density of approximately 1 mode/Hz at 30 Hz to meet the goal of 20 modes per octave.

The required chamber volume is 125,000 cubic feet per equation (1-1).

Test Item Location

In practice, the sound pressure at the walls and corners will be excessive. Thus, the test item should be located away from the walls, by at least 20 inches (0.5 meters).

On the other hand, the test item should not be mounted at the chamber center since this is a nodal location for numerous modes.

Furthermore, the item should be mounted so that none of its large flat faces is parallel with the chamber walls. Otherwise standing waves would from between the test item and the walls.

Another concern is that the test item should be mounted away from the mouths of the noise input horns, to avoid the impact of the gas jets emanating from the horns.

Shaker Table

A shaker table may be mounted in the chamber floor. The shaker table is used to apply a base excitation to the test item. The shaker vibration may be applied to the test item during the acoustic test, or at a separate time.

Test Facilities

There are numerous acoustic reverberant chamber facilities throughout the world. A partial listing is given in Table 1-3.

Table 1-3. Acoustic Reverberant Chamber Facilities

Name	Location	Volume (cubic feet)	Volume (cubic meters)	Overall Sound Pressure Level (dB)
Johnson Space Center, Chamber 1	Houston, Texas	138,000	3098	166
Large European Acoustic Facility (LEAF)	Noordwijk, The Netherlands	57,400	1625	155
Tsukuba Space Center	Tsukuba, Japan	56,503	1600	151
ISVR Large Reverberant Chamber	Southampton, UK	12,290	348	147
Marshall Space Flight Center, ED Acoustic Test Facility	Huntsville, Alabama	5000	142	164

References

1-1. General Environmental Verification Specification for STS & ELV Payloads, Subsystems, and Components, NASA Goddard Space Flight Center, 1996.

1-2. Evolved Expendable Launch Vehicle Standard Interface Specification, Version 6.0, September 2000.

1-3. F. Singerland, Acoustic Design of Large Reverberant Chambers, Journal of the IES, September/October 1990.

Bolides by Tom Irvine

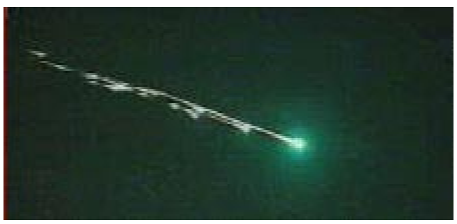

Figure 2-1. Bolide over Peekskill, NY, 1992

Introduction

A bolide is a rocky meteorite or icy comet fragment that explodes into a fireball as it descends through the Earth's atmosphere. An example is shown in Figure 2-1.

The flash of light is accompanied by a blasting noise. Most of the sound energy is infrasonic, with a frequency spectrum below human hearing range. In addition, a bolide may produce audible noise.

The size of the fireball may vary greatly. A bolide may be as small as a golf ball. On the other hand, a bolide may be large with a diameter of 100 feet (30.5 meters) or more. Furthermore, the bolide may explode in the upper atmosphere, near the Earth's surface, or at some intermediate altitude.

Bolides may occur during periodic meteor showers, such as the Leonid, or as single, random events.

A bolide may appear as white, yellow, or any color of the visible light spectrum.

Detection

Infrasonic sensors can detect the blast noise from a bolide. Seismic sensors can also detect a bolide if the blast overpressure is strong enough to shake the ground.

Furthermore, satellite optical sensors can detect some bolides.

Bolides can be located using triangulation and ray tracing if multiple stations record the blast effects.

Note that seismic and infrasonic stations and optical satellites serve other purposes besides the measurement of natural events. For example, scientists in the department of defense use the data to determine whether any nations are carrying out secret nuclear weapons tests.

Meteor Crater, Arizona

Figure 2-2. Meteor Crater

Some 35 to 50 thousand years ago a huge boulder crashed into a desert plateau in what is now Arizona. It left behind a bowl-shaped hole 4,000 feet (1.2 km) wide and 570 feet (174 meters) deep, as shown in Figure 2-2.

Scientists have concluded that the object was a nickel-iron meteor 100 feet in diameter and weighing 60,000 tons, traveling at speed of almost 45,000 miles an hour.

Some meteorite fragments have been recovered, but perhaps 85 percent of the nickel-iron mass vaporized into gas. The gas was swept away by winds reaching speed of perhaps 2000 miles per hour.

Tunguska, Siberia 1908

A tremendous explosion occurred over a remote region of Siberia called Tunguska, on June 30, 1908. Reindeer herders 80 km from the explosion were knocked unconscious. The explosion was described as deafening at a distance of 500 km from the impact location. In addition, seismic waves were recorded 1000 km away.

Figure 2-3. Tunguska Forrest

The Tunguska bolide knocked down trees over a very large area, as shown in Figure 2-3. The trees were blown down in a circular pattern, with a center. However, there was no discernible crater. The present theory for the explosion is that it was fragment of a comet, about 50 meters in diameter that exploded in the atmosphere just above the Earth's surface.

El Paso 1997

Some residents of El Paso, Texas saw a fireball accompanied by sonic booms on Thursday, October 9, 1997. The cause of these events was a meteorite that entered the atmosphere over west Texas and southern New Mexico.

A meteor appeared at 12:47 p.m. as a streak about as bright as the surface of a setting sun, said Robert Simpson, a spokesman for McDonald Observatory, as reported in Reference 2-1.

"It was like a chunk of the sun had fallen off and was heading toward the Earth. It was not a piece of the sun. If anything, it might be golf-ball size at best or larger," said Mr. Simpson, who saw the meteor from his home near Fort Davis, 175 miles southeast of El Paso.

He said the reports given by people throughout El Paso - a flashing light, an explosive blast and a smoke trail - were all consistent with the appearance of a daytime meteor, also known as a fireball or bolide.

Fire and police agencies in El Paso County and southern New Mexico were flooded with reports of an explosion that shook homes and a burst of smoke that many feared had been an airplane exploding or a midair collision.

Some saw a flash of light. Others heard only a shuddering boom or what sounded like debris raining down on their roofs, though there was nothing to be found on the ground.

The noise was heard from Anthony, Texas, along the New Mexico state line, to Horizon City, in far east El Paso County.

"It shook the whole damn neighborhood," said Tom Tyra, a Horizon City resident, as reported in Reference 2-1.

At least four different infrasound arrivals from this event were processed at the ten-element seismic array (TXAR) near Lajitas, Texas, as documented in Reference 2-2. The events are listed in Table 2-1. The initial event produced an oscillating pressure response as shown in Figure 2-4. Later events had more of an impulse response as shown by the example in Figure 2-5.

Infrasound Arrivals (UTC)[1]	Backazimuth	Phase Velocity (m/sec)	Notes:
19:06:13.6	321.6	348	Small SNR
19:07:54.175	321.0	358	
19:11:38.650	323.9	369	Impulsive
19:11:35	321.8	359	

Table 2-1.

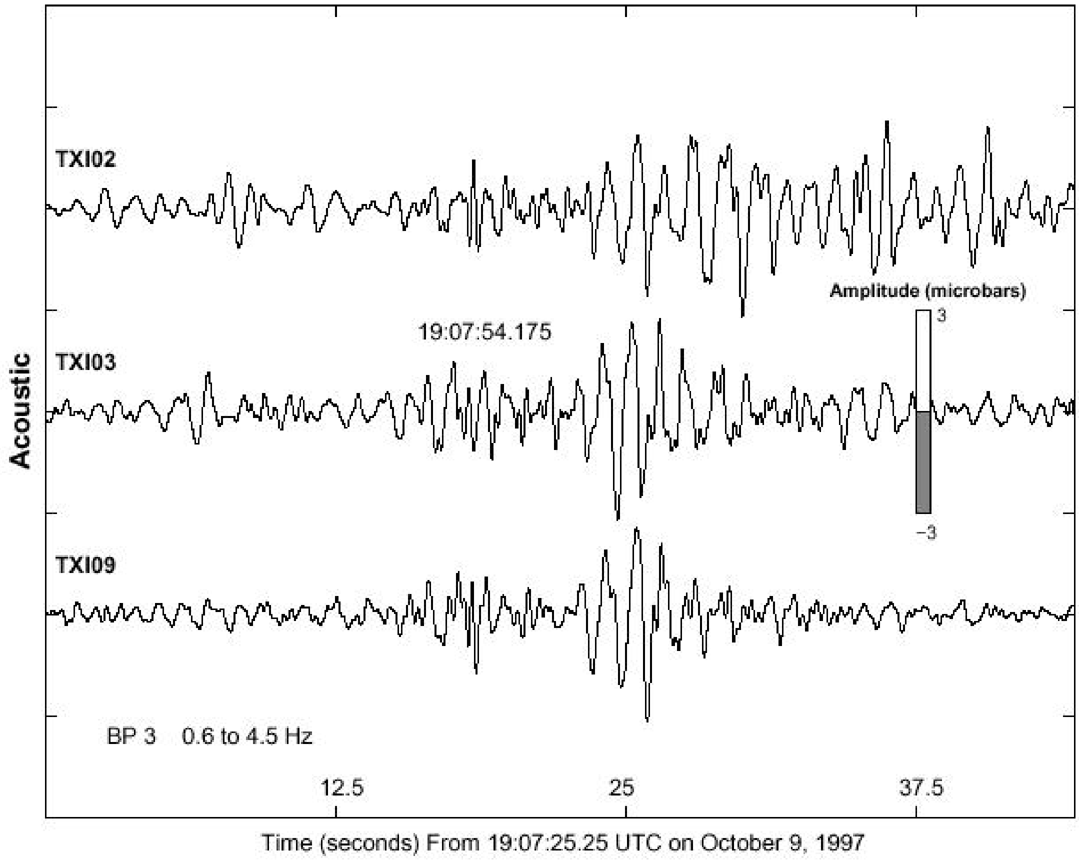

Figure 2-4. Infrasound arrival (19:07:54.175) from the October 9, 1997 El Paso Meteor as recorded on the TXAR acoustic array.

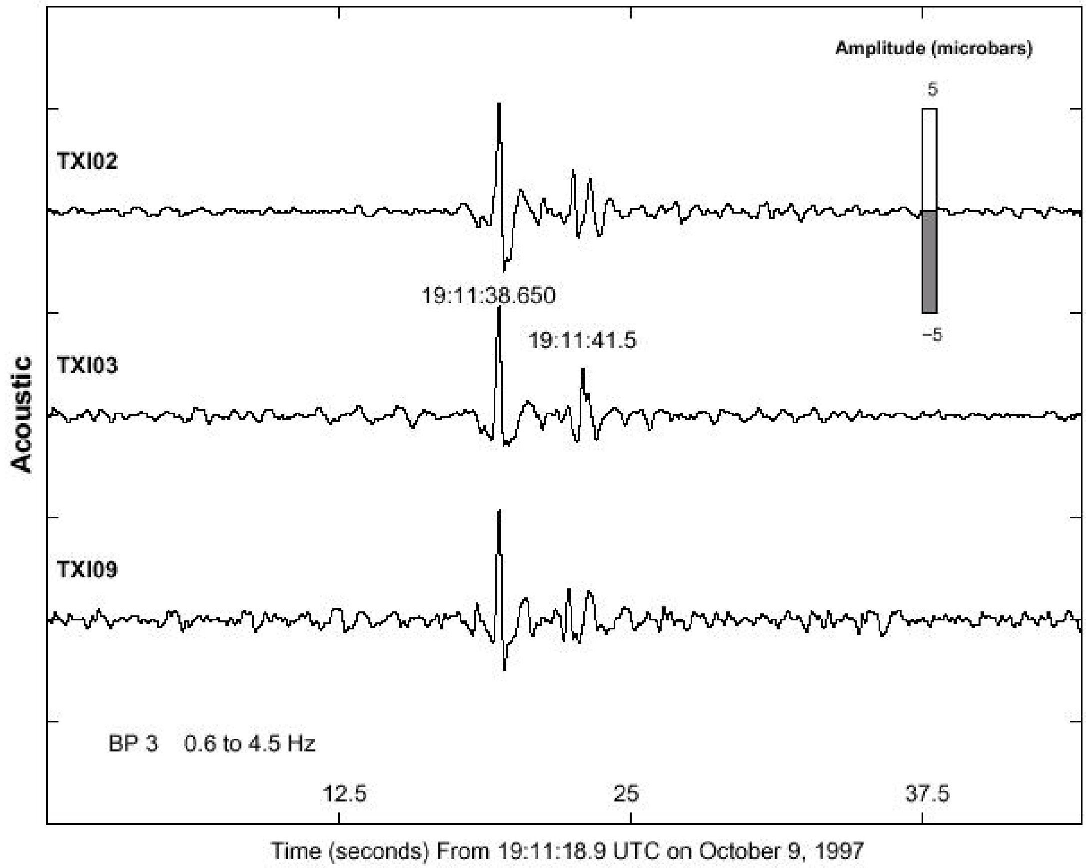

Figure 2-5. Infrasound arrivals (19:11:38.650 and 19:11:41.5) from the October 9, 1997 El Paso Meteor as recorded on the TXAR acoustic array.

Pennsylvania, 2001

A fireball event occurred over the state of Pennsylvania in the early evening of July 23, 2001.

Witnesses reported that it had an orange or yellow color, and that is lasted about 2 to 5 seconds. Some also reported a loud series of sonic booms from the fireball, shaking houses and cars.

Hundreds of eyewitness reports collected by the American Meteor Society establish that the fireball was moving on an east-west trajectory that carried it directly over the state of Pennsylvania.

Bill Cooke, a member of the Space Environments team at the Marshall Space Flight Center, analyzed the bolide data. He reported that "It was traveling perhaps 15 km/s (34,000 mph) or faster when it exploded in the atmosphere with the force of about 3 kilotons of TNT." Cooke also said that it probably measured between 1 and 2 meters across and weighed 30 or so metric tons.

"The pressure wave from the airburst shattered some windows in towns west of Williamsport," Cooke continued. "Breaking glass requires an overpressure of about 5 millibars (10.5 psf), which means that those homes were within 100 km of the explosion."

Overpressure

Bolides have the potential to produce must greater sonic booms than aircraft and space vehicles, as shown in Table 2-2.

Table 2-2.
Overpressure Measured at the Ground

Overpressure (psf)	Source
0.8	F-104 at Mach 1.93 and 48,000 feet
0.9	SR-71 at Mach 3 and 80,000 feet
1.25	Space Shuttle at Mach 1.5 and 60,000 feet during landing approach
1.94	Concorde SST at Mach 2 and 52,000 feet
2.0	SR-71 at Mach 1.3 and 31,000 feet
10.5	Bolide over Williamsport, Pennslyvania, July 23, 2001

Bolides on Other Planets

This article has focused on bolides exploding the Earth's atmosphere.

Bolides may occur on other planets. As an example, the series of Shoemaker-Levy 9 comets that impacted Jupiter in 1994 produced spectacular bolide explosions that were recorded by the orbiting Hubbell Space Telescope, as well as by the ground-based Keck Telescope in Hawaii.

References

2-1. The Dallas Morning News, October 10, 1997, Friday, Home Final Edition.

2-2. Jessie Bonner, Paul Golden, and Eugene Herrin; Infrasound Recordings of Bolides and Explosions.