Acoustics • Shock • Vibration • Signal Processing **February 2003 Newsletter**

Gia'sou

We are saddened by the tragic loss of the seven astronauts. These brave men and women gave their lives in the pursuit of scientific and medical research.

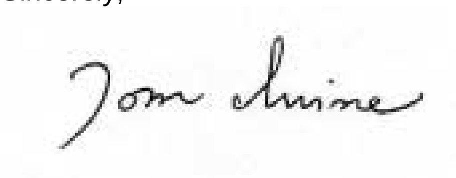
The astronauts performed this research in the shuttle's Spacehab microgravity lab.

In one experiment, the astronauts studied the effect of hormone therapy on bone cells, for the purpose of preventing osteoporosis. The astronauts also studied the development of prostate cancer cells in weightlessness, using a small rotating device called a "bioreactor."

May we always remember their service to mankind.

The precise cause of the shuttle's failure during re-entry is still under investigation. This month's newsletter presents some infrasound data from the shuttle's sonic boom signature that may provide clues. The data is courtesy of Southern Methodist University.

Sincerely,



Tom Irvine
Email: tomirvine@aol.com

Feature Articles

Vibrationdata Announces

Shock & Vibration Response Spectra & Software Training Course

Course Benefits

This training will benefit engineers who must analyze test data, derive test specifications, and design isolation systems, with respect to shock and vibration environments.

Engineers in the aerospace, automotive, medical, petroleum, and semiconductor industries can apply the course materials to solve real-world vibration problems.

Course Description

- The course includes PowerPoint slide presentations as well as hands-on software training
- Each student will receive a licensed copy of MIT's EasyPlot software
- Each student will receive software programs which perform the following calculations:

  Power Spectral Density (PSD), Fast Fourier Transforms (FFT), Shock Response Spectrum (SRS), and digital filtering

- Students will receive data samples so that they can practice using the software programs
- Students are also welcome to bring their own data samples

Dates for 2003 Courses

February 5-7

March 11-13

May 7-9

July 9-11

Location

Dynamic Labs
1720 W. Parkside Lane
Phoenix, Arizona 85027

Students may also arrange for onsite training.

For Further Information Please Contact

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Space Shuttle Columbia Infrasound By Tom Irvine

Rick Husband

William McCool

Kalpana Chawla

David Brown

Mike Anderson

Laurel Clark

Ilan Ramon

Figure 1. The Space Shuttle Columbia at Liftoff and the Seven Astronauts

Figure 2. Shuttle Columbia Debris Trail

Introduction

The space shuttle Columbia was launched on January 16, 2003, for the STS-107 space research mission. The shuttle re-entered the atmosphere on February 1, for the planned landing at Kennedy Space Center.

During this descent, the shuttle passed over the coast of California at 8:15 a.m. EST. The shuttle began its roll reversal maneuver at this time, while traveling at a speed of Mach 20.9 and an altitude of 224,390 ft.

Sensors showed an unusual temperature rise in the left wheel well and in adjacent areas.

Over a five minute period, Columbia's left side increased 60 degrees F while the right side increased only 15 degrees F during the same time.

Additional sensors indicated an increase in drag on the Columbia's left side shortly before 8:58 a.m. EST, while the orbiter was over New Mexico. The flight control systems automatically compensated for this effect.

Next, the tire pressure sensor for the left outboard wheel failed, causing an onboard alert that was acknowledged by the crew.

Communication with the crew and loss of data occurred shortly after, while Columbia was at a Mission Elapsed Time (MET) of 15 days 22 hours 20 minutes 22 seconds.

The vehicle broke up while traveling at 12,500 mph (Mach 18.3) at an altitude of 207,135 ft over East Central Texas resulting in the tragic loss of both the vehicle and the astronauts. The debris trail is shown in Figure 2.

Infrasonic sensors recorded the shuttle's sonic boom, followed by a series of explosions.

Infrasound Measurements

Universities and government agencies have set up infrasound monitoring stations throughout the world. These sensors measure low-frequency sound below 20 Hz, which is the lower frequency limit for human hearing.

Sources of infrasound include:

- avalanches
- auroras
- tornados
- severe storms
- volcanoes
- earthquakes
- meteorites (bolides)
- ocean waves (microbaroms)
- explosions

One obvious purpose of these sensors is to detect explosions produced by clandestine weapons testing.

Note that infrasonic waves can travel vast distances through the Earth's atmosphere. Low-frequency waves travel hundreds of miles, while higher-pitched waves are absorbed by the atmosphere.

Furthermore, data from multiple stations can be used to pinpoint the location of the source.

Seismic sensors can also detect many of the same sources as infrasound sensors. Each type covers a similar frequency domain. Infrasound research is thus sometimes referred to as "air seismology."

Shuttle Columbia's Infrasound

Infrasound sensors recorded the sonic boom produce during the shuttle's re-entry into the atmosphere on February 1.

Southern Methodist University seismologists Gene Herrin and Petru Negraru analyzed the resulting infrasound signals from the TXAR and NVAR arrays.

The TXAR array is located in Fajitas, Texas. The NVAR array is in Mina, Nevada.

N-Wave, Recorded over Nevada

The image in Figure 3 shows the sound pressure wave, called the N-wave, which is commonly known as a sonic boom. This record was taken as the shuttle Columbia passed over the array at Mina, Nevada.

Compare the Columbia data in Figure 3 with the sound pressure N wave in Figure 4. The N-wave in Figure 4 recorded on February 21, 1997 as the shuttle Discovery passed over the TXAR array, during the STS-82 mission.

There appears to be some unexplained high frequency content in the Columbia's signal in Figure 3, as contrasted with the comparatively clean N signature of the Discovery record in Figure 4.

Columbia's unusual infrasound signature may be a clue to understanding the disaster.

Explosion, Recorded over Texas

The shuttle Columbia suffered a series of catastrophic explosions over Texas. The explosions may have begun over New Mexico, however.

The resulting infrasonic data from the explosions is shown in Figure 5. The N-wave is noticeably absent. The record is composed instead of a series of pulses, over a period of about six minutes. These pulses are characteristic of explosions.

Note that the sound waves took several minutes to travel from the shuttle to the TXAR ground station.

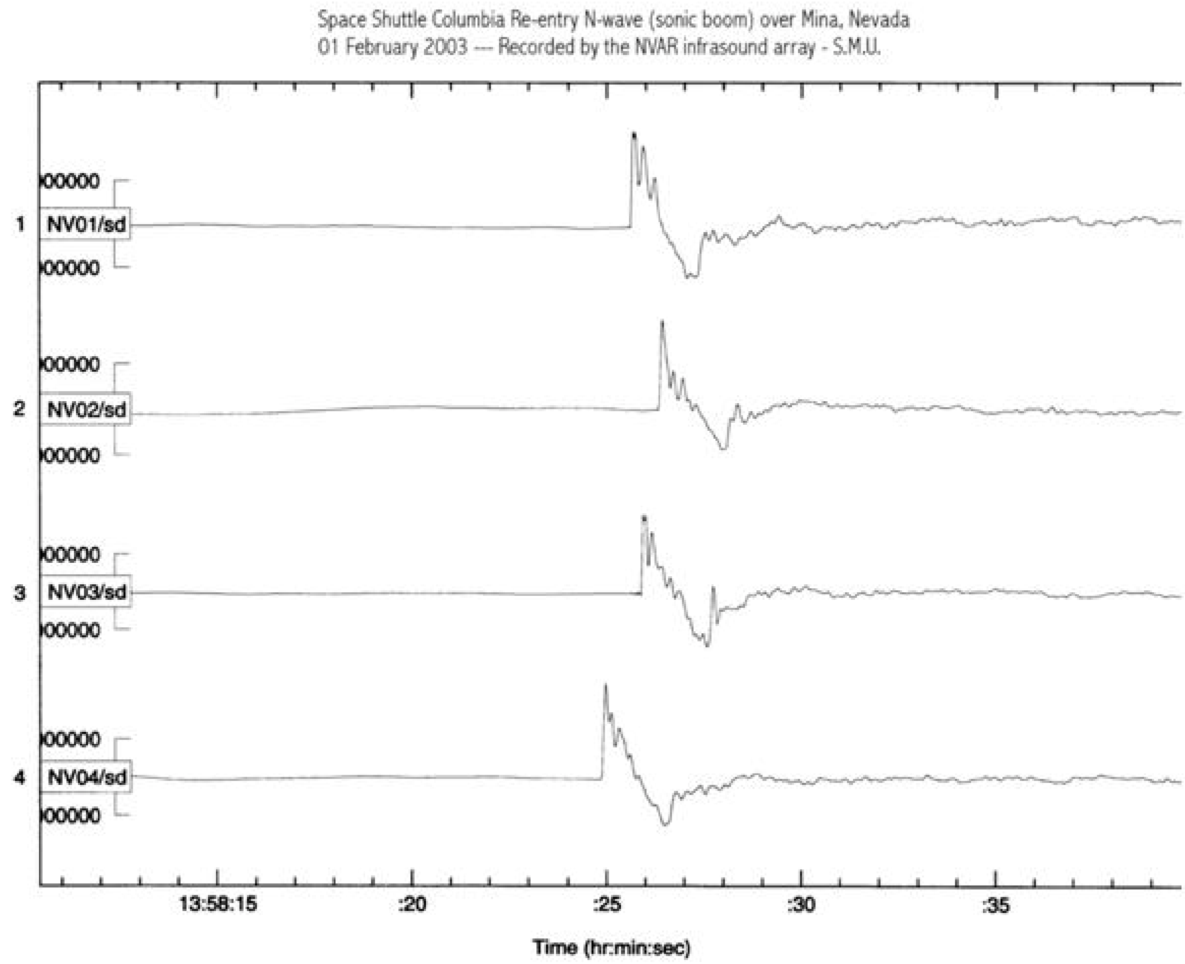


Figure 3. Shuttle Columbia, STS-107 Mission, Sonic Boom during Re-entry, Nevada Station

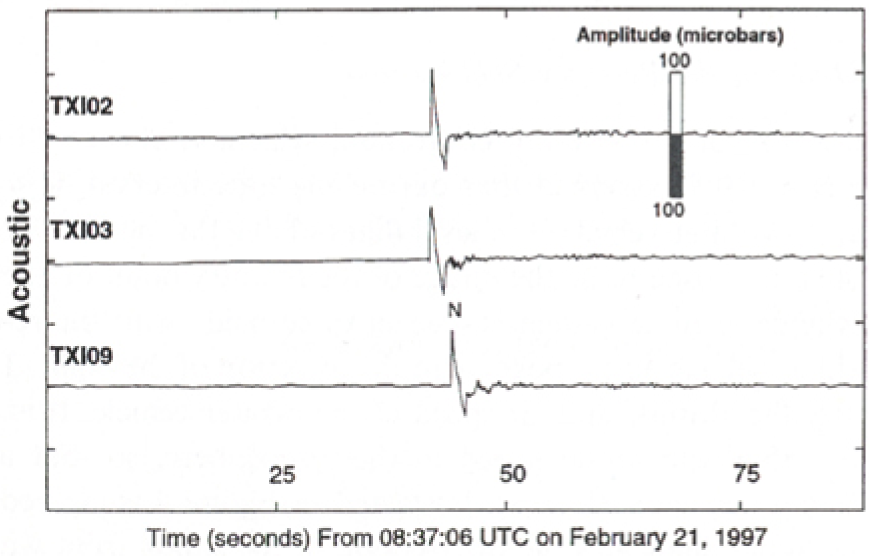
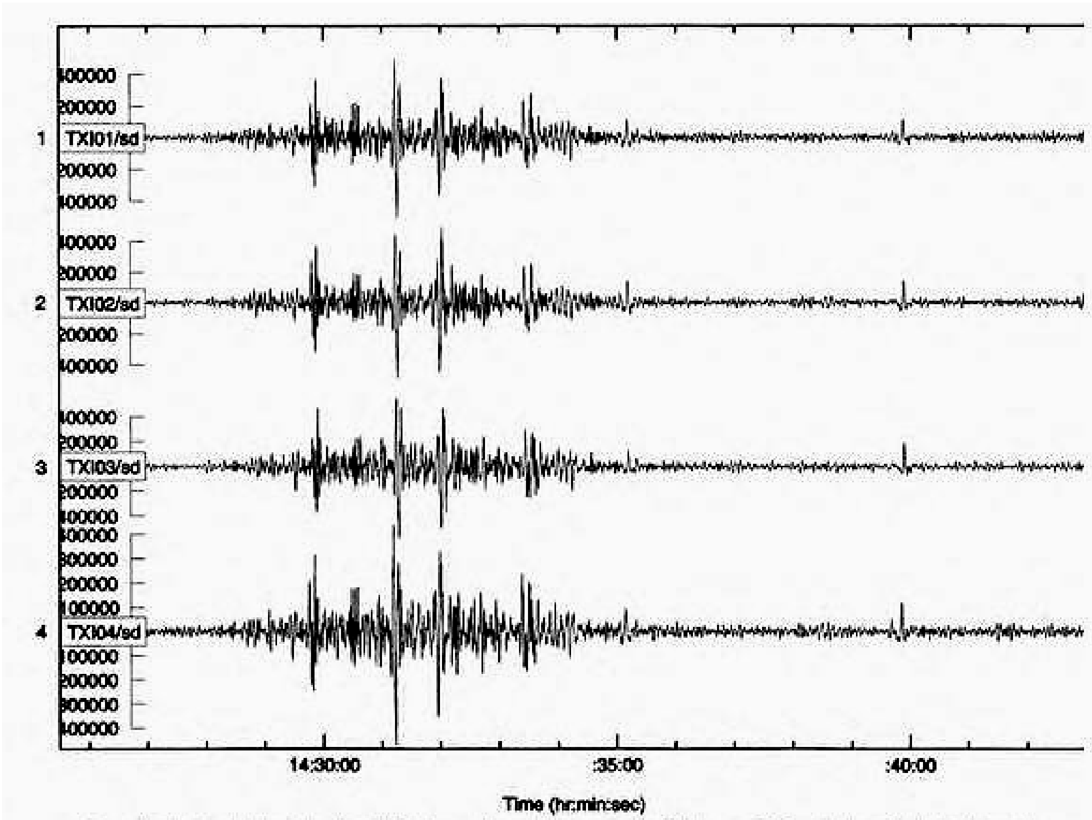


Figure 4. Shuttle Discovery, STS-81 Mission, Sonic Boom during Re-entry



Space Shuttle Columbia Explosion, fromTXAR infrasound array in Lajitas, Texas, 01 February 2003 — Southern Methodist University

Figure 5. Shuttle Columbia, STS-107 Mission, Explosions during Re-entry, Texas Station

Witness Accounts

Jay Lawson is an astronomer in Sparks, Nevada. He said that he saw a big flash at 5:54:34 PST. Mission Control lost contact with the shuttle at 5:59:32 Pacific time.

Minutes after the shuttle flew over, Lawson said he heard what he thought was a sonic boom that also was reported by several other northern Nevada residents.

Keith Johnson is the associate director of Fleischmann Planetarium in Reno, Nevada. Johnson, who also heard the sound, said a sonic boom from a shuttle was not unusual, even one that was 43 miles above the earth.

“Even in very thin atmosphere, a sonic boom occurs,” he said.

Furthermore, numerous residents of Texas reported hearing a reverberating, rumbling sound as the Columbia broke up above them and debris began to rain down on the landscape. "Very scary," said ham radio operator Ralston Gober, of Corsicana, Texas. "It shook the heck out of my house and shack!"

Charles Hutchison of Nacogdoches, Texas, reported that his mobile home shook shortly after 9 a.m. CST, knocking some items from the shelves. A friend of Hutchison called from 20 miles away to say he, too, had heard a boom, "an incredible exploding sound," Hutchison said. "My friend told me it sent ripples over his pond."

Mary Ann Page, of Keithville, Louisiana, thought it was an explosion. "It shook stuff in my kitchen," she said. "It was tremendous noise. I thought a house had exploded.... We ran outside, but didn't see anything. There was a beautiful clear sky. We could hear the rumble go on for several minutes."

Snapping Shrimp Acoustics By Tom Irvine

Figure 1. The Snapping or Pistol Shrimp

Introduction

The ocean environment is filled with sounds from surface waves, seismic waves, rain, ships, whales, and dolphins. Furthermore, the ocean is a very efficient conductor of sound. The speed of sound in seawater is about 4.5 times greater than in air.

A surprising source of underwater sound is a finger-sized shrimp, called the snapping shrimp. These shrimp are so numerous in shallow waters that their collective sound output interferes with sonar, as used by the military and by scientists.

Snapper Claw

A snapping shrimp has one normal claw and one large snapper claw that can be up to half its body size. The snapper claw stays cocked open until a closer muscle contracts, causing the claw to close with lightening speed. This action generates a high intensity sound pulse.

The shrimp uses this pulse to stun its prey, defend its territory, and communicate with other shrimp. The prey includes small crabs, worms, goby fish, or other shrimp.

Scientists originally thought that the snapping itself directly generate the pulse. Biologist Barbara Schmitz, Professor Detlef Lohse and other researchers have found that the process is more complex, however.

Cavitation

As the snap occurs, a tooth-shaped plunger moves into a niche in the other half of the claw. This motion shoots a jet of water out of the niche. The jet velocity is approximately 30 meters/sec.

The pressure within the water jet decreases as the liquid moves at a high speed.

This phenomenon, known as Bernoulli's principle, occurs in a wide variety of environments, from rivers to liquids flowing through pipes.

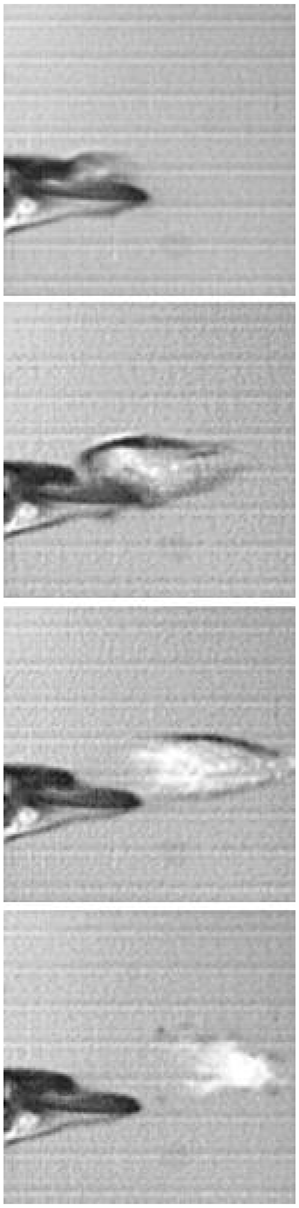


Figure 2. Laboratory Study of Bubbles Generated by a Snapping Shrimp's Claw

(Images courtesy of *Nature*).

The decreasing pressure vaporizes the water. Tiny air bubbles thus form and expand in the fast-moving water jet.

The jet slows down after traveling some distance. The water pressure thus increases, causing the bubbles to collapse. The vapor in the bubbles returns to a liquid state. The imploding bubbles generate a high intensity sound pulse. The popping sound is similar to a pistol shot.

In addition, the collapsing bubble may emit light, in a process called sonoluminescence.

The time between the claw closure and the collapse of the bubble is 700 microseconds. A microsecond is one-millionth of a second.

A sequence of images of this action is shown in Figure 2, obtained through high-speed photography. The images show the bubble generation, although it is not accompanied by sonoluminescence.

The process of bubble generation and collapse is called cavitation. Note that cavitation is primarily known for damaging ship propellers and pumps, because the energy released from the tiny implosions pits and weakens metal surfaces.

The British Royal Navy asked physicist Lord Rayleigh to solve the problem of ship propeller cavitation in 1916. Lord Rayleigh was unable to solve the problem, but he derived a mathematical description of the bubbles' growth and collapse.

<u>Acoustic Parameters</u>

The cavitation from the snapping shrimp generates a spectrum with a low-frequency peak between 2 and 5 kHz and energy extending out to 200 kHz.

The pressure amplitude at the source can approach 200 dB, referenced to 1 micro Pascal.