NASA Facts

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Space Shuttles and Sonic Booms

One of the most distinctive features associated with the return of space shuttles from orbital missions are the twin sonic booms that herald their supersonic arrival back into the atmosphere.

Like all other vehicles traveling faster than the speed of sound, the orbiters produce shock waves as they pass through the atmosphere. On the ground, these shock waves are heard much like sharp thunderclaps.

Most people expected to hear a sonic boom when the orbiter Columbia soared back into the atmosphere for the first space shuttle landing April 14, l981, at NASA's Dryden Flight Research Center, Edwards, Calif. Single booms were heard when the Mercury, Gemini, and Apollo spacecraft reentered the atmosphere. The double sonic booms are now distinctive signatures of each space shuttle landing.

The Cause

Sonic booms are created by air pressure. Much like a boat pushes up a bow wave as it travels through the water, an aircraft or aerospace vehicle pushes air molecules aside in such a way they are compressed to the point where shock waves are formed.

These shock waves form two cones, at the nose as well as at the tail of the vehicle. The shock waves move outward and rearward in all directions and usually extend to the ground. As the shock cones spread across the landscape along the flight path, they create a continuous sonic boom along the full width of the cone's base. The sharp release of pressure, after the buildup by the shock wave, is heard as the sonic boom.

The nose and tail shock waves are usually of similar strength. The time interval between the nose and tail shock waves is primarily dependent on the size of the aircraft and its altitude. Most people on the ground cannot distinguish between the two and they are usually heard as a single sonic boom. As the time interval increases, two booms are heard. A small fighter-type aircraft about 50 feet long will generate nose and tail shock waves of less than a tenth of a second (0.1 sec). The ear usually detects these as a single sonic boom.

The interval between nose and tail shock waves on the space shuttles, which are 122 feet long, is about one-half of a second (0.50 sec), making the double boom very distinguishable.

General Factors Associated With Sonic Booms

There are several factors that can influence sonic booms -- weight, size, and shape of the aircraft or vehicle, plus its altitude, attitude and flight path, and weather or atmospheric conditions.

A larger and heavier aircraft must displace more air and create more lift to sustain flight, compared with small, light aircraft. Therefore, they will create stronger and louder sonic booms than smaller, lighter aircraft. The larger and heavier the aircraft, the stronger the shock waves will be.

Altitude determines the distance shock waves travel before reaching the ground, and this has the most significant effect on intensity. As the shock cone gets wider, as it moves outward and downward, its strength is reduced. Generally, the higher the aircraft, the greater the distance the shock wave must travel, reducing the intensity of the sonic boom. Of all the factors influencing sonic booms, increasing altitude is the most effective method of reducing sonic boom intensity.

The width of the boom “carpet” beneath the aircraft is about one mile for each 1000 feet of altitude. An aircraft, for example, flying supersonic at 50,000 feet can produce a sonic boom cone about 50 miles wide. The sonic boom, however, will not be uniform. Maximum intensity is directly beneath the aircraft, and decreases as the lateral distance from the flight path increases until it ceases to exist because the shock waves refract away from the ground. The lateral spreading of the sonic boom depends only upon altitude, speed, and the atmosphere -- and is independent of the vehicle's shape, size, and weight.

The ratio of aircraft length to maximum cross sectional area also influences the intensity of the sonic boom. The longer and more slender the aircraft, the weaker the shock waves. The fatter and more blunt the vehicle, the stronger the shock wave can be.

Increasing speeds above Mach 1.3 results in only small changes in shock wave strength.

The direction of travel and strength of shock waves are influenced by wind, speed, and direction, and by air temperature and pressure. At speeds slightly greater than Mach 1, their effect can be significant, but their influence is small at speeds greater than Mach 1.3. Distortions in the shape of the sonic boom signatures can also be influenced by local air turbulence near the ground. This, too, will cause variations in the overpressure levels.

Aircraft maneuvering can cause distortions in shock wave patterns. Some maneuvers -- pushovers, acceleration, and “S” turns -- can amplify the intensity of the shock wave. Hills, valleys, and other terrain features can create multiple reflections of the shock waves and affect intensity.

Overpressure

Sonic booms are measured in pounds per square foot of overpressure. This is the amount of the increase over the normal atmospheric pressure which surrounds us (2,116 psf/14.7 psi).

At one pound overpressure, no damage to structures would be expected.

Overpressures of 1 to 2 pounds are produced by supersonic aircraft flying at normal operating altitudes. Some public reaction could be expected between 1.5 and 2 pounds.

Rare minor damage may occur with 2 to 5 pounds overpressure.

As overpressure increases, the likelihood of structural damage and stronger public reaction also increases. Tests, however, have shown that structures in good condition have been undamaged by overpressures of up to 11 pounds.

Sonic booms produced by aircraft flying supersonic at altitudes of less than 100 feet, creating between 20 and 144 pounds overpressure, have been experienced by humans without injury.

Damage to eardrums can be expected when overpressures reach 720 pounds. Overpressures of 2160 pounds would have to be generated to produce lung damage.

Sonic Boom Footprints

Overpressures recorded on the ground during the landing of the orbiter Discovery on mission STS-26 Oct. 3, 1988, revealed that the intensity was 1.06 pounds in the Santa Barbara area as Discovery crossed the coastline at a speed of Mach 4.37 at an altitude of 115,400 feet. Intensity rose to 1.15 pounds in the Santa Clarita Valley area, 45 miles southwest of Edwards, as the vehicle's speed and altitude reduced. At Edwards, when Discovery was about 60,000 feet overhead just minutes before the landing the overpressure was 1.25 pounds. The highest reading during the landing approach over Southern California was 1.75 pounds in the areas of Palmdale and Lancaster 20 to 30 miles southwest of Edwards.

Typical overpressure of other aircraft types are:

- SR-71: 0.9 pounds, speed of Mach 3, 80,000 feet
- Concorde SST: 1.94 pounds, speed of Mach 2, 52,000 feet
- F-104: 0.8 pounds, speed of Mach 1.93, 48,000 feet

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