Why on Some Days Aircraft Noise is Louder

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Outline / Agenda

- Fundamentals of sound
- Human perception of sound
- Propagation of Sound

Assumption: The change in aircraft noise levels is not related to the operating configuration of the Airport
  - Aircraft departures and arrivals sound different
Fundamentals of Sound

What is Sound?

- Small and rapid changes in air pressure
  - Small compared to changes due to altitude or weather
  - Audible when pressure fluctuations occur between 20 times and 20,000 times per second

- Characteristics of sound that we can quantify
  - Speed
  - Frequency/Wavelength
  - Magnitude
What is Sound? Schematic

Energy transferred through the air as variations in air pressure

Source (Tuning Fork)

Energy of Motion

Path

Receiver

Variations in air pressure cause ear drum to vibrate

High pressure

low pressure
What is Sound?

- Speed of sound (in air)
  - 770 mph (344 m/s)
  - 5 seconds per mile or 0.2 miles per second
  - Example: Counting the number of seconds between lightning and the associated thunder determines the distance of the lightning

- Frequency
  - The number of pressure variations per second
  - Rumble of distant thunder is low frequency
  - A whistle is high frequency

- Wavelength
  - High frequency sounds have short wavelengths
  - Low frequency sounds have long wavelengths

- Magnitude
  - Convert from average pressure (in Pascal) as compared to atmospheric pressure to a decibel scale

$$L_p = 10 \log \left[ \frac{(p_{RMS})^2}{(p_0)^2} \right]$$

Decibels = 10 Log["Energy"]
Fundamentals of Sound

Decibels

- Why decibels instead of sound pressure?
  - Compress the huge range of values:
    - We can hear sound pressures over a huge range
    - The decibel compresses this to a smaller range: 0 to 140 dB (threshold of hearing to threshold of pain)
  - Decibel scale is logarithmic, like the Richter scale used for earthquakes
  - Sound “levels” are always expressed in decibels
- Match with our ear/brain system:
  - Decibels relate better to how we hear
  - Increases in the same sound:
    - 1 dB is barely detectable
    - 10 dB sounds twice as loud
Decibel “rules of thumb”

- Smallest detectable change **in the same sound:**
  - 1 dB in a laboratory (A/B comparison test)
  - 3 dB in a community setting

- 3 dB change: Two times the sound energy

- 10 dB change:
  - Ten times the sound energy
  - Twice as loud, subjectively, for the same sound
Human Perception of Sound

- Perceived Loudness
  - Determined by several complex factors
    - Frequency content
      - Human ear is not equally sensitive at all frequencies
        - Most sensitive between (2 and 5 kHz)
        - Most sensitive in the range of speech
    - Sound Level amplitudes
      - The difference in sensitivity to different frequencies is more pronounced at low sound levels than at high sound levels
    - Duration
      - Short duration sounds - Impulse sound (< 1 sec.)
        - Ear is less sensitive perceiving the loudness
Human Perception of Sound
The Ear

- Three main parts
  - Outer ear (pinna and auditory canal)
  - Middle ear (three small bones - set of levers)
  - Inner ear (semi-circular canals and cochlea)
- The outer ear collects the airborne sound waves
- The sound waves vibrate the eardrum
- The eardrum is the interface with the middle ear
- The bones transfer the vibration to the inner ear
- The fluid in the cochlea is disturbed, which distorts the basilar membrane whose upper surface are thousands of very sensitive hair cells
- The hair cells transforms the distortions as nerve impulses which are transmitted to the brain
Propagation of Sound
Geometric Spreading of Sound

- Sound propagation of a point source can be compared to ripples on a pond when a rock is thrown into it.
- The ripples spread out uniformly in all directions, decreasing in amplitude as they move further away from the rock.

- When no obstacles and no reflectors (free field), sound pressure level decreases by 6 dB when distance doubles.
Propagation of Sound
Meteorological Effects: Atmospheric Absorption

- Sound energy is converted to heat by “molecular absorption”
  - Mostly higher frequencies over long distances
  - Depends on temperature, humidity and air pressure
  - Tabulated by frequency for different atmospheric conditions
Propagation of Sound
Meteorological effects: Refraction

- Sound paths are bent (curved) up or down
  - Only important when aircraft are on or near the ground (elevation angle less than 30 degrees, or so)
  - Upwind and/or during a sunny day (temperature lapse)
    - Upward refraction produces a sound “shadow” (10-to-20 dB at large distances)
    - This sound shadow “comes and goes” as the wind changes
  - Downwind and/or evening and night after a sunny day (temperature inversion)
    - Downward refraction causes sound to bend up and over obstructions (so is louder)
Propagation of Sound
Meteorological effects: Fog, rain

- Sound often “carries” well on days of fog or light rain, because:
  - Very little upward refraction (sound shadow):
    - Low winds, no sun
  - And so no sound “shadows”
Sound propagation over ground is affected by the reflective and absorptive properties of the ground: Soft or hard ground (water is reflective/hard)

- Only important when aircraft are on or near the ground (elevation angle less than 30 degrees, or so)
- Soft ground can significantly attenuate – depends on distance
- Hard ground (including water) can increase sound levels
Propagation of Sound Barrier effects

- Obstacles can attenuate and/or reflect sound
  - Buildings, walls, hills, thick forests

- Barriers are effective when they:
  - Block line of sight between source and receiver
  - Are made of dense materials with no gaps
  - Are close to source or receiver

- Barriers are not effective for airborne sound sources

- Barriers effectiveness can be reduced by winds/temperature inversions
Questions?