Nonlinear sonic boom distortion due to propagation through atmospheric turbulence

Trevor Stout and Victor Sparrow

Objective

Quantify the statistical nature of supersonic signature distortions due to turbulence
Amplitude and loudness of a sonic boom can be greatly increased or decreased when atmospheric turbulence either focuses or defocuses the wave

Method

Distortions are modelled numerically by solving the nonlinear KZK propagation equation
Turbulence is random, so many simulations are necessary to generate good statistics
The numerical solution will be evaluated against supersonic flyover measurements

Background

Currently, supersonic flight over civil airspace is prohibited
This study hopes to eliminate uncertainties in the design process for future "low-boom" aircraft

Hypothesis

It is expected that metric distributions will increase in width with increasing boundary layer height and increasing turbulence strength
Metric distributions are expected to be narrower in all cases for low-boom signatures

The KZK Equation

\[
\frac{\partial p}{\partial z} = \frac{c_0^2}{2} \int_{-\infty}^{\tau} \nabla^2 p \, dt + \frac{\delta}{2} \frac{\partial^2 p}{\partial t^2} + \frac{\beta p}{2} \frac{\partial p}{\partial t} + \frac{c_1^2}{2} \frac{\partial p}{\partial t} + \frac{u_z}{c_0} \frac{\partial p}{\partial t} - \frac{1}{c_0} \left( \frac{\partial p}{\partial t} \right) + \sum_{v} \frac{c_v^2}{2} \int_{-\infty}^{\tau} \frac{\partial^2 p}{\partial t^2} e^{-i(v\tau)} \, dt
\]

Diffraction Thermoviscous Absorption Nonlinearity Scalar Turbulence Vector Turbulence Molecular Relaxation

Atmospheric Turbulence

Solar heating and wind shear cause relatively small temperature and wind fluctuations
The planetary boundary layer can be 2 km or more in height
Turbulence is both scalar and vector in nature
Scalar: temperature fluctuations change the local sound speed
Vector: fluctuations in wind convect the sound
The length scale of turbulent eddies increases with increasing height
Simulated fields are generated with the Random Fourier Modes method.

Preliminary Results

The simulation has been run on NASA's supercomputing cluster Pleiades
Results appear realistic, but the code is not yet evaluated against physical measurements
Once the code is evaluated, more simulations will gauge the effect of turbulence in a wide range of atmospheric conditions

Measurement

The NASA-led research team measured sonic booms at the ground, on a motor glider above the boundary layer, and recorded atmospheric turbulence simultaneously
To test the code, the signature recorded on the motor glider will be propagated through simulated turbulence and results compared with the ground measurements

Motor glider measures the signature before any turbulence

Turbulent Planetary Boundary Layer

Turbulence randomly causes spiking (shown here) and rounding of the signature

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Acoustic Signature

Nearfield pressure of the typical supersonic aircraft coalesces into an "N-wave"

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