Subjective Study on Attributes Related to Mach-cutoff Sonic Booms

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Alleviating Annoyance

Flight has an unfortunate speed limit due to sonic booms. If supersonic flight were possible without causing sonic booms, this speed limit would not exist. Flying at supersonic speeds could lead to faster travel and significant economic benefits.

One possible method of increasing this speed limit is flying at Mach cutoff. This does not eliminate the formation of a sonic boom but mitigates the sound that arrives at the ground. Unfortunately, there is still a sound heard at the ground when flying at Mach cutoff. No studies have evaluated perception of or reaction to these Mach-cutoff ground signatures.

This preliminary vocabulary study will assess how the general public describes Mach-cutoff ground signatures, identify what the prominent features of Mach cutoff are, and prepare for a future study assessing public reaction to Mach cutoff sounds.

Concerning Cutoff

Mach cutoff refers to a set of flight conditions for which the atmosphere refracts the direct sound of a sonic boom away from the ground. This is achieved due to the temperature gradient in the lower atmosphere. The higher speed of sound closer to the ground (due to the higher temperature) refracts sound away from the ground.

The horizontal line below which the direct sound does not travel is known as the caustic. Above the caustic, the sonic boom is a traditional N-wave. Below the caustic, the sound is evanescent, causing decay and distortion.

These sounds can vary greatly and do not sound like traditional sonic booms. As no perceptual studies have been done before, perception and common description of Mach cutoff are unknown. Past researchers have compared Mach-cutoff sounds to waving sheet metal or thunder.

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Developing Descriptors

This study uses an individual vocabulary profiling method to develop an overall list of attributes that factor into Mach-cutoff stimuli. In this method, participants first develop their own list of attributes. The researcher then helps each subject refine their list to include 3-5 attributes that best describe the whole stimulus set.

Once the individual has their final list, the participant rates each stimulus based on their attributes. These ratings are done on a per-stimulus basis to allow for statistical comparison across all stimuli. Previous individual vocabulary profiling techniques have used multiple-comparison techniques. Since this study uses a larger number of stimuli than previous studies, they cannot be rated side-by-side on one interface.

Analyzing Attributes

With the many and varied lists that may be generated, statistical analysis is necessary to elicit a common set of attributes that explain the characteristics of these signals.

Principal component analysis will be used to identify the set of factors that explains the most variance. Depending on how much variance is explained by each factor, 3 to 5 factors will be rotated in the factor space using Varimax rotation. This technique will help improve the researchers’ ability to interpret this set of factors.

Definitions of the attributes provided by the subjects will be used to assist the researchers in assigning a single label to each cluster group. Then, these groups will be correlated with results from the factor analysis for practical interpretation of each factor.

Selecting Stimuli

The Mach-cutoff ground signatures were selected from NASA’s Far-field Investigation of No-boom Thresholds (FaINT) dataset recorded in 2012. These recordings were taken near Edwards Air Force Base across a 60-microphone array stretching 1 mile long. 36 fly overs were recorded, yielding 2160 recordings.

From these recordings, 24 stimuli were selected from the overall set using a k-means clustering analysis. After listening to several samples, these stimuli were determined to be representative of the whole set of recordings.

Reproducing Rumble

The stimuli for this experiment are characterized by strong, low-frequency components. Much of this energy is below the audible range. However, these sounds can still be felt, if not heard. Thus, care has been taken in considering our reproduction setup.

Reproduction will take place in the Auralization and Reproduction of Acoustic Sound-fields (AURAS) facility. This facility uses 30 loudspeakers spherically distributed around a listener to recreate 3D sound fields. For this study, two subwoofers have been added to generate the low-frequency portions of the stimuli.

References