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Effects of Meteorological Variability on Sonic Boom Propagation from Hypersonic Aircraft

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A numerical study of primary sonic boom propagation from a hypersonic Mach 6 cruise aircraft is performed, including the effects of nonlinearity, atmospheric absorption and dispersion, and atmospheric stratification. A second-order split-step algorithm alternating between the time domain for nonlinearity and the frequency domain for absorption allows for a faster convergence of results than conventional first-order algorithms. Daily variability of meteorological parameters is used to investigate the variability of sonic boom shock overpressure, rise time, and carpet width over the span of a year. Two locations are chosen based on their difference in climates, especially humidity, and two flight directions are considered. It is found that sonic boom rise time is especially susceptible to variability in humidity, whereas shock overpressure and carpet width are most sensitive to winds. A statistical analysis and comparison between hypersonic and supersonic aircraft configurations reveal that all sonic boom characteristics are highly dependent on the aircraft and flight conditions, so that generalizations of statistics cannot be made.

I. Introduction

AIRCRAFT flying at supersonic speeds cause the formation of shock waves that travel through the atmosphere to the ground [1]. The resultant sonic booms have characteristics that depend on the aircraft source and the atmosphere. The aircraft size, shape, speed, and flight altitude all affect the sonic boom signature.

Meteorological parameters along the wave propagation path (such as temperature, humidity, and wind) determine the nonlinear distortion, absorption, and refraction that the shock wave experiences. Variability in these meteorological parameters with location and time therefore causes appreciable variation in sonic boom characteristics.

Meteorological effects on aircraft sonic boom propagation were investigated in the 1960s, and a review from that era by Garrick and Maglieri [2] noted the complexity of atmospheric effects and presented a statistical approach to analyzing variations in measured sonic booms. Numerical modeling of sonic boom propagation was also developed by Hayes et al. [3] for a horizontally stratified atmosphere that accounted for a moving heterogeneous medium. Research in this area was continued with the implementation of atmospheric absorption and dispersion in several algorithms [4] that have demonstrated the large influence of humidity on sonic boom rise times.

Neither comprehensive measurements nor numerical predictions of the variability of sonic booms from a hypersonic aircraft have been performed to date. Although many measurements of sonic booms from supersonic aircraft are available [1,5–7], they do not assess seasonal variability nor differences due to geographical location. In addition, it is not possible to extend these results to the higher altitudes and pressure levels associated with hypersonic cruise flight. Several numerical predictions of sonic boom variability from realistic aircraft have been performed [8–11], although all have been simulated for lower Mach numbers than what is being considered in the present study.

This paper investigates the sonic boom ground impact for an aircraft flying at Mach 6 cruise at a 28 km altitude. Sonic boom impact is estimated in terms of the peak overpressure at the vertical of the flight track, the front shock rise time, and the lateral extent of the geometrical carpet. The first two parameters provide an estimation of the loudest boom likely to induce maximum annoyance, and the third parameter estimates the lateral impact of the boom during the cruise phase. As a sonic boom propagates over long distances, it is strongly affected by the atmosphere and thus is dependent on meteorology and geographical location. The impact is quantified statistically, based on numerical simulations using an extensive meteorological database.

A numerical study of primary sonic boom propagation from the Mach 6 aircraft is performed, including the effects of nonlinearity, absorption and dispersion, and stratification. Tests of accurate numerical parameters for varying strengths of nonlinearity and absorption are performed to determine the most efficient alternatives. An extended absorption model is adopted that accounts for changes in the atmosphere up to the high flight altitude required by Mach 6 operation. The effects of meteorological variability on sonic boom propagation are investigated by considering the climate at two different geographical locations over the course of a year at a 6 h resolution. Vertical gradients of meteorological parameters at a coastal area with high ground humidity are juxtaposed with those for a desert region. Key sonic boom parameters are compared with predictions for other aircraft configurations at Mach 1.6 and with a previous study for a Mach 2 aircraft [9].

Section II presents the meteorological data. In the following Sec. III, an extended absorption model is presented to take into account the high flight altitudes (about 30 km) for the Mach 6 case. Modifications to include high-altitude sound absorption in the sonic boom code are briefly presented. A brief explanation of the theory behind the sonic boom algorithm is outlined in Sec. IV, and Sec. V presents the specific parameters used in the simulations. Sonic boom predictions at the ground level are synthesized and compared with other cases and previous studies in Sec. VI.

II. Meteorological Data

Meteorological data are obtained from the European Centre for Medium-Range Weather Forecasts (ECMWF) 40-year European reanalysis (ERA-40) database [12]. Two locations are chosen based on their differences in climates, especially humidity, because atmospheric absorption was highly dependent on this parameter. The

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