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Sonic Boom Environment Under a Supersonic Military Operating Area

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A measurement program was conducted to record the sonic boom environment under a busy supersonic air combat maneuver training (ACM) arena. Simultaneous with sonic boom measurements, a complete record was made of supersonic activity. The measurements provided validation of the predicted elliptical pattern of C-weighted day-night average sound level (L_{Cdn}) contours and demonstration of the nature of ACM sonic boom, which often includes non-N-wave signatures. Correlation of measured booms with flight activity data provided a quantitative model for prediction of L_{Cdn} contours for other similar airspaces.

I. Introduction

ENVIRONMENTAL assessment of sonic booms generated by supersonic air combat maneuver (ACM) training requires prediction of the C-weighted day-night average sound level (L_{Cdn}). Initial efforts to compute L_{Cdn} contours[1] were based on analysis of tracking data from an air combat maneuver instrumentation (ACMI) system, combined with simplified calculations[2] of carpet booms (i.e., booms from steady level flight) for average supersonic conditions. The resultant model showed that supersonic activity occurs in an elliptical maneuver area centered between setup points used by pilots before engagement, and that L_{Cdn} contours are elliptical and aligned with the maneuver ellipse. Field validation of predictions for a new supersonic military operating area (MOA) confirmed the elliptical pattern, but measured L_{Cdn} values were at least 10 dB below predictions.[3] The difference was thought to be due to the difference between carpet sonic boom footprints and the more complex footprints (described in Sec. III.B, below) which actually result from the supersonic phases of air combat maneuvers. The data collected and reported in Ref. 3 were, however, too sparse to draw general conclusions. Accordingly, a project was undertaken to measure sonic booms in a busy supersonic airspace.

A 6 month sonic boom measurement program was conducted in the Lava/Mesa airspace at the White Sands Missile Range, New Mexico. This airspace is used for ACM training, primarily by F-15 aircraft from Holloman AFB. Thirty five sonic boom monitors were deployed. During the measurement period, all flight activity data for the airspace was reviewed and correlated with measured booms. A sample of ACMI tracking data was obtained for detailed analysis of particular events and to develop an understanding of how and when supersonic events occurred. Section II contains a description of the measurement program.

Following completion of the measurements, statistical analyses were made of sonic booms identified with ACM activity. These analyses included development of models for the long-term L_{Cdn}, frequency of occurrence of booms at various locations in the airspace, and the probability distribution of boom amplitudes at a given location. The nature of sonic booms occurring in the airspace was also examined in order to resolve the differences between measurements and earlier predictions. These results are presented in Sec. III. Application of these results to other airspaces is presented in Sec. IV.

II. Measurement Program

Figure 1 shows the Lava/Mesa airspace which was the subject of this study. It lies over the north end of the White Sands

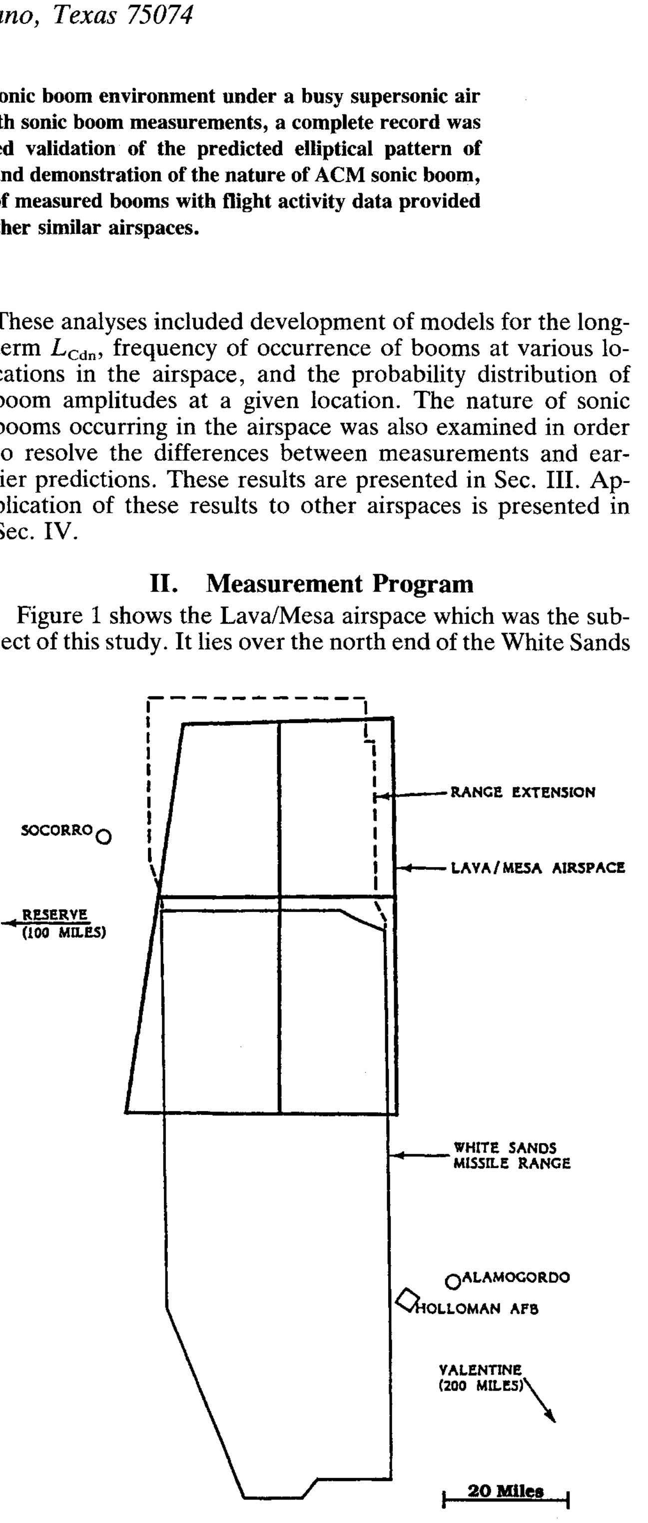

Fig. 1 White Sands missile range and Lava/Mesa airspace.

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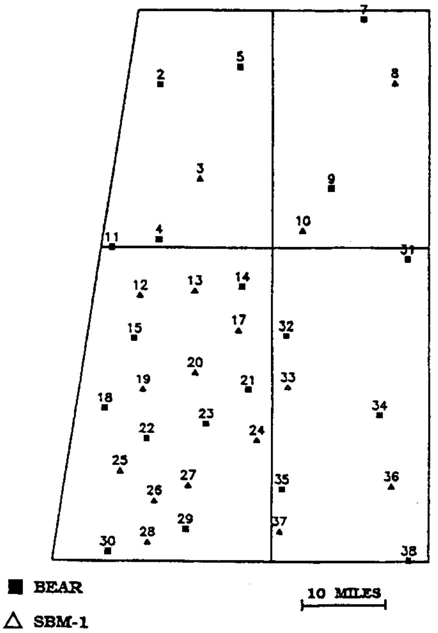

Fig. 2 Measurement sites in Lava/Mesa airspace.

Missile Range and range extension, and has an area of about 2,600 square miles. Due to mountains in the southeast quadrant of the airspace, ACM tends to use all of the western half and most of the northeast quadrant. The nominal ACM capacity is 600 sorties per month.

Thirty-eight automatic sonic boom monitors were available. These consisted of 21 "BEAR" monitors,[4] which captured complete sonic boom waveforms, and 17 "SBM-1" monitors,[5] which captured peak overpressure and C-weighted sound exposure level. Using ACMI data from about 200 sorties to develop an expected boom pattern, a basic site plan was designed using the method of D-optimality.[6] This design placed monitors on the axes and the corners, and required about half the instruments. The remaining were located in the southwest quadrant, where they were spaced about 5 miles apart. BEAR and SBM-1 units were alternated, so that the full-signature BEARs formed a primary array and the SBM-1s provided supplemental data between BEARs. Allowing for equipment maintenance, approximately 35 sites were operated for 6 months. Figure 2 shows the locations of these sites.

Simultaneous with the monitoring, all operations schedule and airspace clearance data were collected so that measured sonic booms could be correlated with specific events. A sample of air combat maneuver instrumentation (ACMI) tracking data was also collected. Available weather data were collected. All analyses were, however, performed using range standard atmospheric conditions.[7]

III. Results

A. Measured Sonic Booms

During the 6-month measurement period, 4,600 ACM sorties were flown, 72% of which were F-15s. A total of 591 sonic boom events were recorded (2,246 individual boom recordings; each sonic boom was detected by an average of just under four monitors), of which 506 were associated with ACM training. There was 0.11 sonic boom per sortie. For those missions for which ACMI tracking data were obtained, sonic boom ray tracing calculations agreed well with the measured boom occurrences.

Figure 3 shows the primary measurement result of this study, contours of L_{Cdn}. These results are consistent with the measurements reported in Ref. 3, which were substantially below predictions in Ref. 1. Figure 4 shows the cumulative probability distribution of peak overpressures, and Fig. 5 shows the distribution of C-weighted sound exposure level (CSEL) for

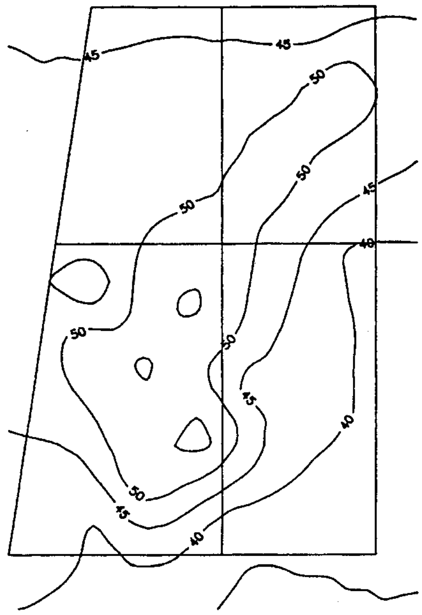

Fig. 3 Measured ACM L_{Cdn} in Lava/Mesa airspace.

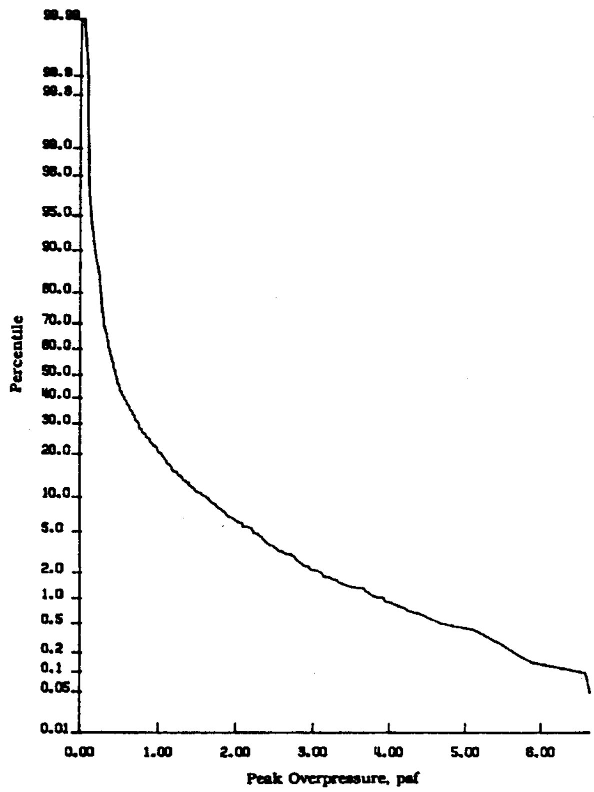

Fig. 4 Cumulative distribution of peak overpressures.

all recorded booms (CSEL and L_{Cdn} are computed from sonic boom signatures by the procedures defined in Ref. 8). The CSEL distribution is normal, similar to—but broader than—the log-normal overpressure distribution typical of sonic boom variability due to atmospheric effects. Near the center of the airspace, the average overpressure was about 1 psf, and there was about 0.5 boom per day. Ninety-nine percent of all sonic booms were below 4 psf, and none exceeded 7 psf.

The model in Ref. 1, based on carpet booms, predicts that near the center of the ellipse there would be two to three booms per day, with an average overpressure of 4 psf, and L_{Cdn} of 67 dB. The substantially lower measured results must be due to differences in aircraft operation and/or inadequacy of the carpet boom analysis.

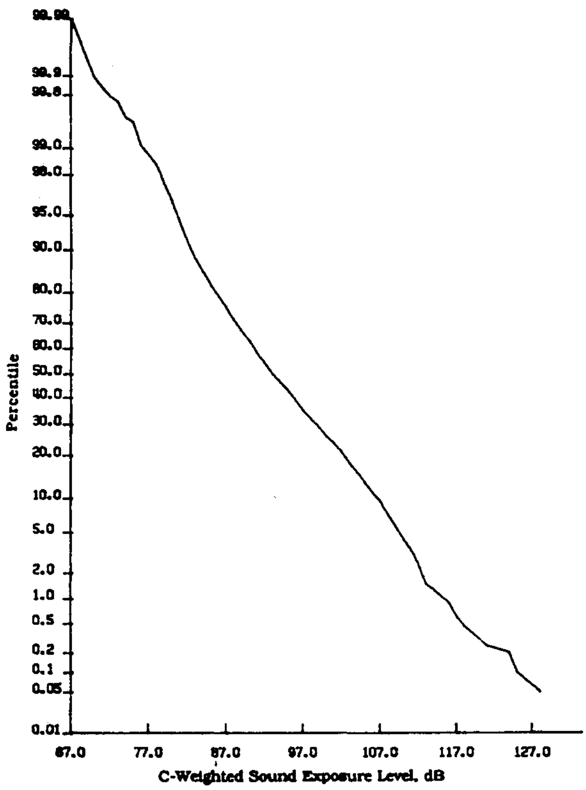

Fig. 5 Cumulative probability distribution of C-weighted sound exposure levels.

Analysis of ACMI data showed that aircraft were supersonic about 8% of the time while in the MOA. The statistical patterns of Mach number, altitude, etc., for supersonic flight were consistent with statistical analysis of ACMI data for other airspaces.[1,9] Analysis of complete tracking data (subsonic as well as supersonic) showed that supersonic events occur randomly within the full area used for all air combat training maneuvers. The maneuver area was found to be an ellipse approximately 35 by 60 miles, aligned with setup points 30–50 miles apart. This pattern is consistent with analysis of ACMI data from other airspaces.[9] The difference between predictions and measurements must, therefore, be due to the nature of ACM sonic booms vs carpet booms.

B. Nature of ACM Sonic Booms

A characteristic of supersonic ACM operations is that supersonic events are brief, and Mach number rarely exceeds 1.1. The combination of these low supersonic Mach numbers, a minimum altitude of 5000 ft above the ground, and atmospheric refraction, results in many booms not reaching the ground. The following description pertains to those booms which do reach the ground. Much of the ground footprint of this type of brief event is dominated by the characteristics of the focal zone associated with the acceleration to supersonic speed; the focal zone forms the initial boundary of the footprint. A carpet boom is never established because deceleration begins nearly as soon as acceleration ends: steady supersonic flight is rarely sustained.

Sonic booms are generally typified by N-wave signatures. At a focus, boom signatures have an amplified U-wave shape. Focal zones form a boundary delimiting a nominal carpet boom area. Near a focus, various combinations of N- and U-waves can occur, with U-waves decaying away from the focus. On the "shadow" side of the focal zone, sine-like "evanescent" waves are expected, diminishing rapidly away from the boundary. Sonic boom signatures recorded by the BEAR monitors included significant numbers of U-waves, N-U combinations, and evanescent waves. When a boom event was recorded at several monitors, there would typically be at least one nominal N-wave, but there would invariably also be some non-N focus and near-focus types of signatures. Figure 6 is a fairly common signature recording, a combination N-U. This clearly demonstrated that sonic booms in ACM areas have complex focal zone footprints and cannot be characterized by the simple carpet booms associated with steady sustained supersonic flight. As discussed in detail in Refs. 3 and 10, a focal zone footprint is substantially smaller than would be estimated from carpet boom analysis. The deceleration phase of a transient supersonic event has boom amplitude substantially lower than a carpet boom. These factors account for the order-of-magnitude difference between Ref. 1 and the current results.

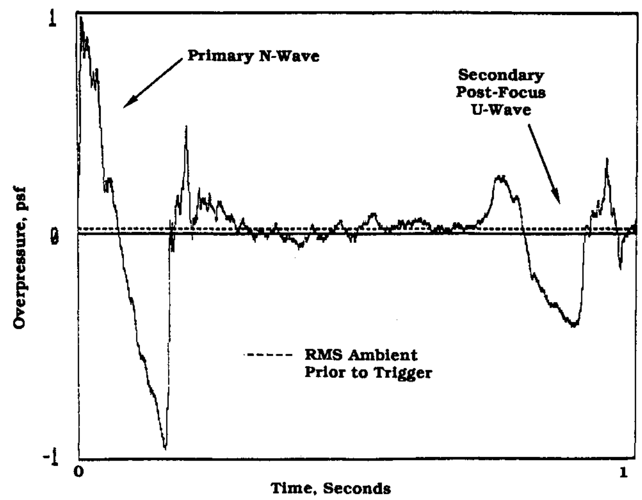

Fig. 6 Example sonic boom signature recorded by a BEAR.

IV. Application to Other Airspaces

The data collected in this study were cast in a form that could be applied to environmental assessment of other airspaces with similar types of operations. Contours were fitted to the measured average L_{Cdn} and number of events, n, at each site. It was found that these contours could be represented by a two-dimensional Gaussian distribution, with elliptical contour shape. The formulae defining these quantities are[11]

$$L_{Cdn} = 25 + 10 \log_{10} N + 10 \log_{10} \exp\{-\tfrac{1}{2}[(x/11.1 \text{ mi})^2 + (y/18.9 \text{ mi})^2]\} \quad (1)$$

$$n = 0.0012\, N \exp\{-\tfrac{1}{2}[(x/13.0 \text{ mi})^2 + (y/21.4 \text{ mi})^2]\} \quad (2)$$

where x and y are coordinates along the minor and major axes of the ellipse, and N is the number of ACM sorties per month. Figure 7 shows the Gaussian fit to L_{Cdn} for the Lava/Mesa sortie rate.

Care should be exercised when applying Eqs. (1) and (2) to other airspaces. They are based on data collected from ACM training operations dominated by F-15 aircraft from an operational fighter wing. Without additional data, they cannot be assumed to be directly applicable to other aircraft types or to units at other levels of training. It is, however, fully expected that the patterns established here are universal, and that only the amplitude and axis dimensions would vary with circumstances.

The results of these measurements were projected to planned supersonic operations at the Reserve, New Mexico, and Valentine, Texas, MOAs. These areas will be used by the same operational units that use Lava/Mesa, so that Eqs. (1) and (2) are fully applicable. The result of this prediction is that, at full capacity of 300 ACM sorties per month in each MOA, L_{Cdn} will be below 50 dB at all locations. Near the center of

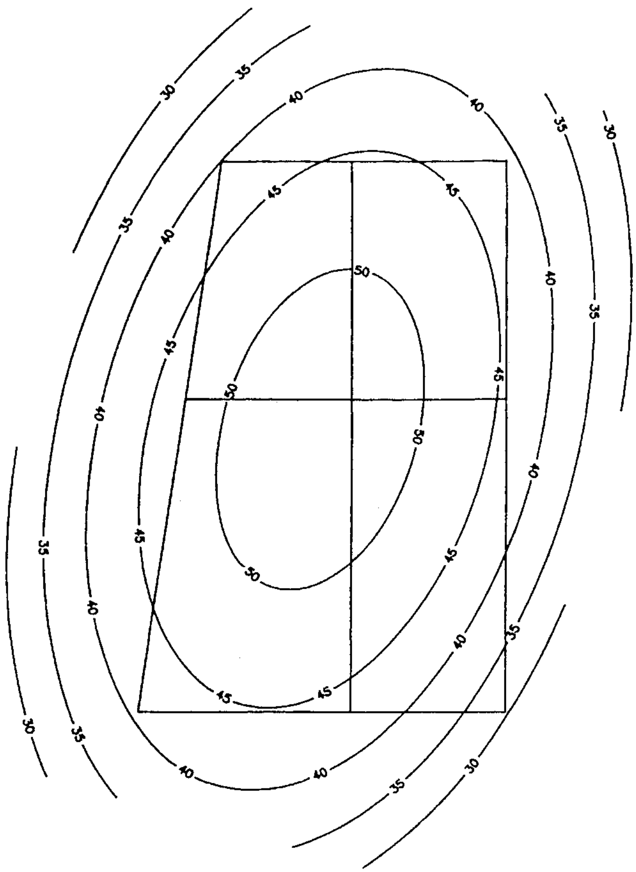

Fig. 7 Gaussian fit to measured ACM L_{Cdn}.

the supersonic area at Reserve, a sonic boom would be heard an average of once every 3 days. At valentine, where supersonic operations will be divided among two areas, a sonic boom would be heard about once a week. If potential impact is estimated based on the annoyance relationship presented in Ref. 12, these planned operations will have little or no adverse effect.

Acknowledgments

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