Low Sonic Boom Noise

Atmospheric Reference Day Standard for En-Route Noise Standard Development for Supersonic Aircraft

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Introduction

The International Civil Aviation Organization (ICAO) Working Group 1 (WG1) – Noise Technical recently developed a new supporting atmospheric technical standard that was agreed to by the ICAO Committee on Aviation for Environmental Protection (CAEP). This atmospheric standard serves to prescribe reference atmospheric conditions that anchor a level playing field for applicants of en-route noise certification for future supersonic (low boom) aircraft.

Since 2004 as part of the CAEP/7 cycle, the WG1 Supersonic Task Group (SSTG) has been responsible for monitoring various aspects of Super Sonic Transport (SST) projects including: assessing their prospects for operation, monitoring research to characterize, quantify and measure sonic boom signatures and their acceptability, and developing noise certification standards for supersonic aircraft. After numerous sonic boom predictive noise analyses were performed with global atmospheric data and several reference day options, a technical recommendation was formulated that proposed the use of the Manual of the ICAO Standard Atmosphere (Doc 7488, 3rd Edition) for temperature and pressure, paired with the selection of ISO 5878 with extension humidity model. Unanimously WG1 and eventually the CAEP agreed and accepted it for establishing a Reference Day standard for en-route, sonic boom certification, as a potential key component in the development of future noise standards for supersonic aircraft.

A Fundamental Element of the En-Route Noise Standard Development for Supersonic Aircraft

ICAO noise certification standards prescribe essential and relevant reference conditions that are imperative for uniform and fair noise characterization of a product. Such traditional noise standards have defined that reference conditions consist of reference flight trajectories, reference measurement points and a reference day atmosphere. Along with systematically establishing associated test tolerances and defining adjustment procedures that account for test day conditions, aircraft noise can be measured and adjusted to common reference conditions to establish accurate noise certification levels.

Following these procedures offers a comparison of aircraft certification noise levels for a category of type design from different designer/manufacturers. This guarantees a level playing field between applicants and the possibility to rank aircraft according to their intrinsic performance.

1 The authors would like to acknowledge William Doebler and Sriram Rallabhandi of NASA for setting up the various standard atmosphere profiles and conducting the sonic boom predictions with those atmospheres.

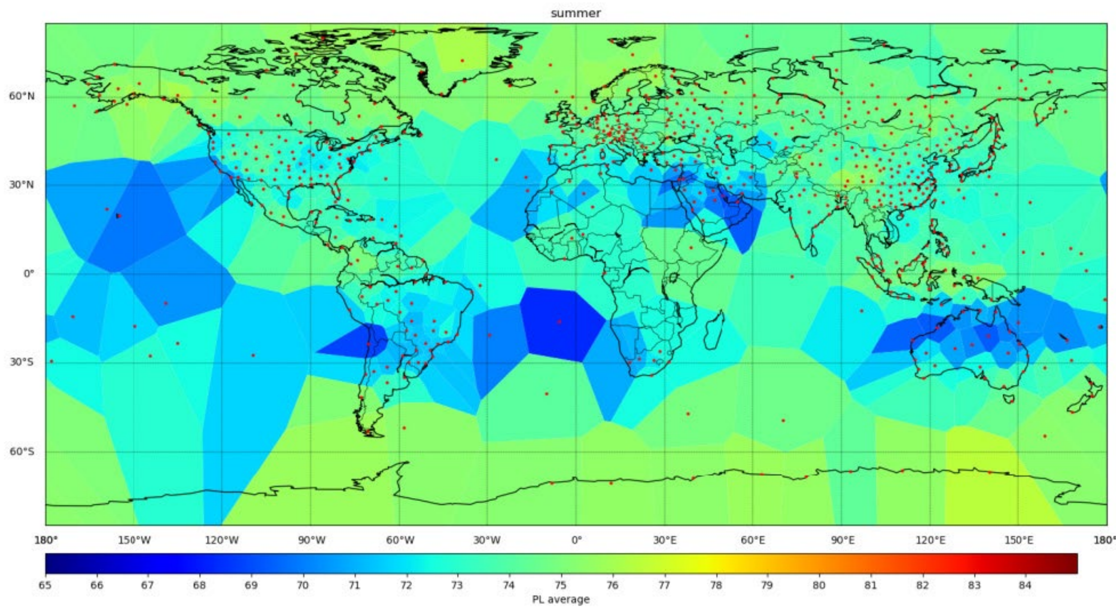

FIGURE 1 : Mean PL noise metric values at various locations (red dots) in summer 2017, flying east – ERA5 database.

For a supersonic aircraft, a reference day atmosphere has important application when propagating the sonic boom noise levels generated in the near-field of the aircraft through the atmosphere towards the ground using sonic boom propagation prediction codes. It could also be used to either compute an acoustical adjustment factor for far-field measurements made in a Test Day atmosphere, to recreate the far-field noise levels in the Reference Day conditions, or to directly predict the sonic boom noise levels in the Reference Day condition (using a measurement-validated, proven code).

The specific values of temperature, pressure, and humidity as functions of altitude are absolutely critical for the accurate prediction of noise, particularly considering the long distances that sonic boom noises propagate, due to absorption and refraction of sound waves through the atmosphere which are controlled by the former parameters. Hence, WG1 carefully considered these profiles of the global atmosphere.

What Do Global Atmospheric Data Show?

Extensive analyses were performed during the CAEP/11 and CAEP/12 cycles to identify the most appropriate Reference Day Atmosphere. Technical discussions were held between many WG1 participants, including individuals from Europe, Asia, and North America. Worldwide meteorological conditions were considered.

Sonic boom levels have been predicted in different meteorological conditions, using existing models and real measurement meteorological data. Specifically, the analyses employed the worldwide ERA5 reanalysis database from the European Centre for Medium-Range Weather Forecasts and the Integrated Global Radiosonde Archive (IGRA) from the U.S. National Oceanic and Atmospheric Administration. An example of predictions in the PL (Perceived Level) noise metric are shown in Figure 1 for various locations around the world. These predictions were made available to WG1 courtesy of the RUMBLE consortium (rumble-project.eu).

While a "Conservative" Reference Day atmosphere was initially proposed with the objective of obtaining sonic boom levels on the upper range with an existing standard atmosphere, it was finally agreed that an "Average" atmosphere would be more appropriate considering that it would allow to minimize differences between Test Day conditions and Reference Day conditions. Therefore, any bias in the sonic boom predictions performed in Test Day conditions or in Reference Day conditions would also be minimized as well as a potential discrepancy between measurements and predictions both done in the Test Day conditions. To illustrate, Figure 2 shows the average PL values for a selection of possible aircraft certification test sites and the PL value for one definition of the standard atmosphere (ICAO 7488/3 with ISO9613 Annex C humidity model).

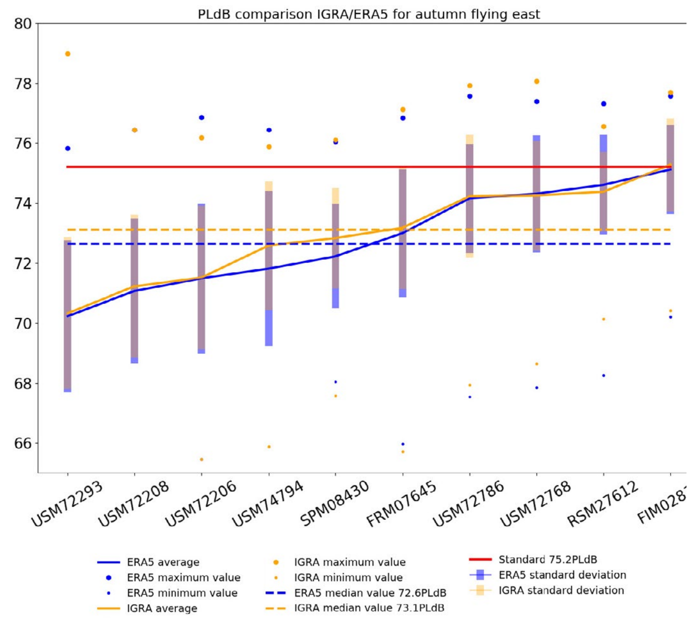

FIGURE 2: Subset of 10 aircraft certification test sites and their associated average, maximum, and minimum PL noise metric values compared to one definition of the standard atmosphere (ICAO 7488/3 with ISO9613 Annex C humidity model).

Why This Atmospheric Reference Day Standard?

Sonic boom levels obtained with different atmospheric models were compared to those obtained with the measured atmospheres dataset for the 6 ICAO down-selected noise metrics (ASEL, BSEL, DSEL, ESEL, PL and ISBAP). From the original 666 sites, ten potential noise certification sites for supersonic aircraft noise certification testing were considered in the analysis.

The ICAO 7488/3 standard atmosphere for temperature and pressure, with zero wind, was selected and paired with six different humidity models for the analysis. Three constant relative humidity profiles were considered, along with humidity models from three different standards, see Figure 3.

A modelling study was conducted to calculate the undertrack sonic boom from a low-boom demonstration concept aeroplane using each candidate reference day atmosphere. These results were compared to the worldwide dataset and the subset of 10 certification sites for all seasons and headings considered. The summary of all comparisons in Figure 4 shows that the mean difference values depend on the metric, but the same trends appear for each metric.

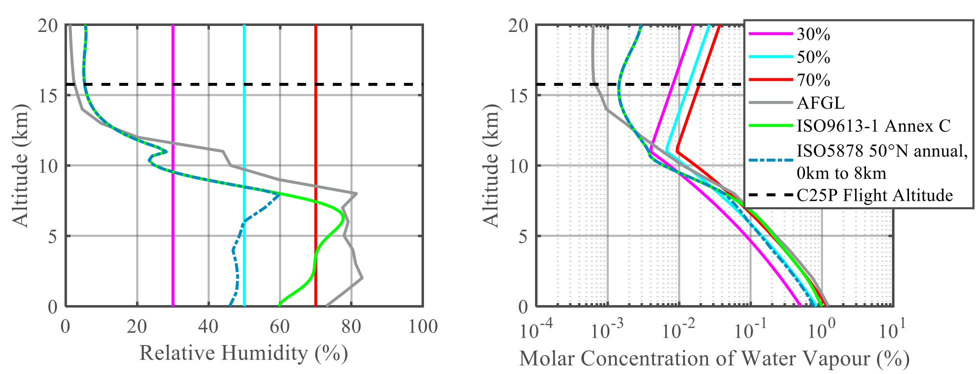

FIGURE 3 : Comparison of reference day humidity profiles. Relative humidity versus altitude is shown on the left and molar concentration of water vapour versus altitude is shown on the right. The dashed black line shows the flight altitude of NASA's C25P concept aircraft, used in some of the analyses.

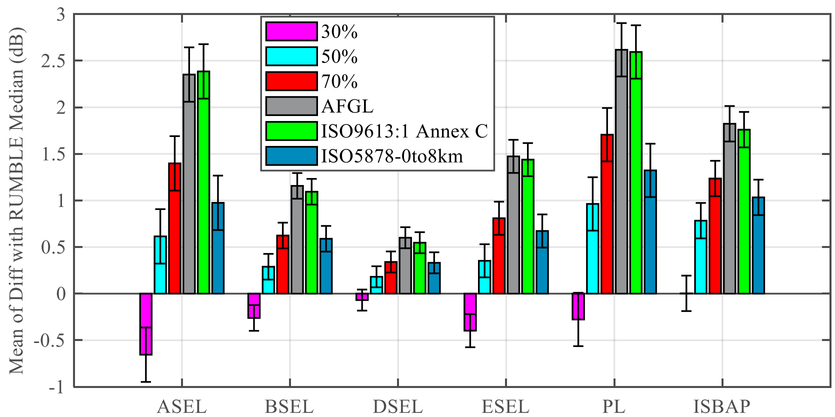

FIGURE 4 : Summary comparison of mean difference (and 90% confidence intervals) between candidate reference day option predictions and ERA5 subset medians for six noise metrics. All seasons, headings, and subset locations are included.

A mix of the ICAO 7488 standard atmosphere for temperature and pressure and the ISO 5878 (with ISO 9613-1 Annex C high-altitude extension above 8 km) standard atmosphere for humidity was selected by WG1 as providing small differences (<1.3±0.3 dB) with the median levels computed from the ERA5 meteorological database. This definition is preferred because the humidity is physically realizable at higher altitudes, while the constant relative humidity profiles, again see Figure 3, are not realistic.

The Next Three Years

In the next three years of the CAEP/13 cycle (2022-2025), the WG1 Supersonic Task Group will continue the development of a new Standards and Recommended Practices (SARP) for en-route low boom noise certification of supersonic aircraft. Following the successfully completed studies of atmospheric Reference Day standard and sonic boom metrics to-date, the supersonic work plan will focus on: scheme analysis/selection, data acquisition and instrumentation specification, and the definition of certification procedures for three flight conditions – design cruise, climb/acceleration (focus boom) and intermediate speed (off-design Mach numbers). Upon definition of the remaining SARP elements, the goal is to provide the preliminary SARP flight and test procedures to NASA to test with their X-59 demonstrator aircraft (and visa-versa, for resulting NASA X-59 data to be provided to SSTG to exercise/evaluate the effectiveness of the SARP) during its safety and performance validation, in addition to the acoustical validation periods.

For the CAEP/14 cycle (2025-2028), the remaining focus will hinge heavily on NASA research to establish data for defining a compatible human response of a low boom noise certification limit to complete the standard in support of WG1/SSTG.

In the meantime, WG1 will also continue to:

- Monitor and report on research to characterize, quantify and measure (including metric) climb and en-route noise from supersonic flight, including Mach cut-off conditions, and its community response while also assisting in promoting and defining such research.
- Gather data on which "other factors" need to be considered for SARPs development. These may include boom at "off design" Mach numbers, boom from accelerations and turns, secondary sonic booms, impacts on aquatic life, mammals and cruise ships, sleep and booms at night, rattle, effects on animals, and avalanches.
- Monitor, and report on, status of supersonic industry projects and OEM expectations of supersonic development.

The return of civil supersonic aircraft continues to become more apparent with recent news about the fabrication of demonstrators – Boom XB-1 and NASA X-59 airplanes. The major challenges will continue to be the reckoning of associated complex technologies and defining what constitutes a low boom supersonic airplane, with expected greater mission performance that achieves environmental protection sustainability.