DISCOVER-AQ: a unique acoustic propagation verification and validation data set

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In 2013, the National Aeronautics and Space Administration conducted a month-long flight test for the "Deriving Information on Surface conditions from Column and Vertically Resolved Observations Relevant to Air Quality" research effort in Houston, Texas. The goal of this flight test was to simultaneously collect pollution data from satellite-, aircraft- and ground-based emissions monitoring systems, which can then be compared and correlated, as well as detailed atmospheric, meteorological and aircraft position data. An opportunity arose to provide supplemental acoustic measurements during this flight test that could then be coupled with corresponding aircraft performance, aircraft position and meteorological data. Up to this point, there has been a significant need for high quality aircraft acoustic validation data sets that include detailed acoustic, meteorology, aircraft position and performance data representing a range of acoustic propagation geometries and meteorological conditions. Following these measurements, a comprehensive data set has been developed, in order to investigate, validate and improve the aircraft acoustic and performance modeling capabilities used in the Federal Aviation Administration's Aviation Environmental Design Tool and other aircraft acoustic research efforts. This paper

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provides descriptions of the acoustic measurements, example validation data, and potential uses of the validation data.

1 INTRODUCTION

The National Aeronautics and Space Administration (NASA) has been conducting a series of flight tests that assess the improved ability of satellites to monitor air quality, to more accurately determine the sources of pollutants in the air and to more closely determine the fluctuations in air quality, through the evaluation of pollution data collected simultaneously from satellite-, aircraft- and ground-based air quality monitoring systems. This multi-year research effort is known as "Deriving Information on Surface conditions from Column and Vertically Resolved Observations Relevant to Air Quality" (DISCOVER-AQ)[1]. Detailed air quality, atmospheric, meteorological and aircraft tracking data were collected during the course of these flight tests.

The Federal Aviation Administration's Office of Environment and Energy's (FAA AEE) Aviation Environmental Design Tool (AEDT) is FAA's next generation environmental noise, air quality and fuel burn modeling tool[2]. There has long been a need to develop a high quality aircraft acoustic data for the purpose of validating the accuracy of AEDT and other tools, including potential new modeling capabilities[3].

An opportunity arose to develop such a validation database by undertaking supplemental acoustic measurements during the third NASA DISCOVER-AQ flight test in September 2013 in the vicinity of Houston, Texas. The John A. Volpe National Transportation Systems Center (Volpe), in support of FAA AEE, was tasked with measuring in situ acoustic level data from the flight tests that could then be coupled with corresponding aircraft performance and position, as well as meteorological data. The resulting data set may be used to investigate, validate and improve the aircraft acoustic propagation modeling methods in AEDT and other FAA research efforts.

This paper documents the acoustic measurements that supplemented the September 2013 NASA DISCOVER-AQ flight tests and presents exemplar validation data developed from those measurements.

2 SCOPE

The scope of the DISCOVER-AQ acoustic research included the measurement of acoustic data at several ground-based measurement systems from the two aircraft performing controlled flight operations as part of the DISCOVER-AQ flight tests. Acoustic measurements were made at a variety of distances and elevation angles relative to the nominal aircraft flight paths, in order to measure noise data reflective of a wide range of aircraft operational parameters, orientations and propagation distances. Supplemental meteorological data were collected at each acoustic measurement site, and this data set, measured by the Volpe team, was then coupled with corresponding aircraft performance and position, as well as meteorological data measured by NASA and collaborating research organizations. These data were data processed and a final validation data set was accumulated.

3 MEASUREMENT OVERVIEW

NASA's DISCOVER-AQ research effort consists of four, month-long flight tests where pollution data are simultaneously collected by satellite, two aircraft flying fixed flight patterns around a study area, and multiple group monitoring stations scattered across the study area. These air quality measurements were supplemented by aircraft performance data, and detailed meteorological data collected aboard the aircraft, from weather balloons, and from various ground-based meteorological measurement systems. The flight tests that included the supplemental acoustic measurements took place from September 4, 2013 through September 28, 2013 in the vicinity of Houston, TX. These flight tests resulted in 10 individual flight days, eight of which were supplemented by acoustic and meteorological measurements.

3.1 Test Aircraft and Expected Flight Tracks

Two aircraft were flown for the DISCOVER-AQ flight tests: the Lockheed P-3B Orion and the Beechcraft King Air B200. Both of these aircraft were owned and operated by NASA. During the Houston flight tests, the P-3B flew dynamic flight tracks that included level flight around 4,572 m (15,000 ft) above ground level (AGL), level flight at 305 m (1,000 ft), level flight at 500 ft, upward spirals from 305 m (1,000 ft) or 152 m (500 ft) to 4,572 m (15,000 ft), and downward spirals from 4,572 m (15,000 ft) to 305 m (1,000 ft) or 152 m (500 ft). Simultaneously, the King Air flew control flight tracks that included level flight around 6,096 m (20,000 ft) AGL. The nominal aircraft flight tracks are displayed in Fig. 1.

For each DISCOVER-AQ flight test day, the two aircraft were scheduled to fly fixed patterns over the measurement area, originating at Ellington Field (KEFD). With the P-3 completing three passes and the King Air completing four daily passes, there was the possibility of measuring noise from up to 18 P-3 and 24 King Air overflights at each measurement location (or up to 135 P-3 overflights including 66 spirals and 180 King Air overflights).

P-3B events will be focused on in this paper. Data for both aircraft, along with a full description of the acoustic measurements, are presented in the FAA/Volpe report "DISCOVER-AQ Acoustics: Measurement and Data Report."

3.2 Measurement Locations

The suitability of measurement sites in the Houston metro-area was dependent on the test aircraft flight plan, as well as several other factors, including local ambient noise environment, proximity to highways and other air traffic not associated with DISCOVER-AQ land accessibility during the study period, and site security for measurement system deployment. With the King Air flying at 6,096 m (20,000 ft) and over half of the P-3B operations were at or above 4,572 m (15,000 ft) AGL altitude, the measurement sites were required to have low ambient noise levels, in order to reduce noise masking of the test aircraft. Acoustic and meteorological data were collected at eight measurement locations. These measurement sites are described in Table 1 and Fig. 1.

Table 1 – Measurement Site Locations

Measurement Site	Estimated Horizontal Distance to P-3B (m)	Estimated Horizontal Distance to King Air (m)	Latitude (deg)	Longitude (deg)	Estimated P-3B Altitude (ft)
NB-1	762	6,096	30.277533	-95.484000	1,000
NP-1	2,286	9,754	30.223933	-95.495383	1,000
NP-2	0	6,706	30.273200	-95.476367	1,000
NP-10	2,926	10,485	30.222083	-95.489783	1,000
NP-11	3,627	10,912	30.217633	-95.485417	1,000
NP-12	3,536	11,217	30.221567	-95.483517	1,000
SP-1	762	396	29.544517	-94.779250	15,000 to 500
SP-2	3,048	853	29.527333	-94.766100	500

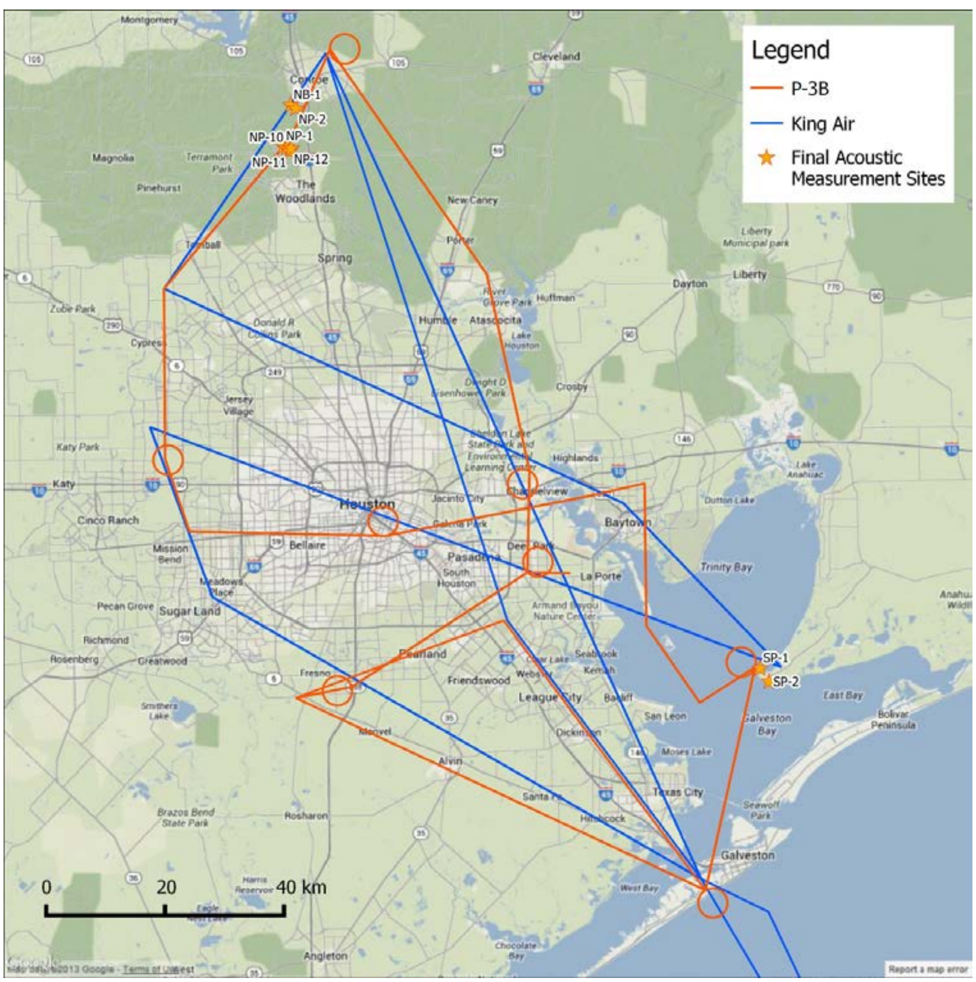

Fig. 1 – DISCOVER-AQ planned flight tracks and acoustic measurement sites.

3.3 Measurement Data Format

The following data were measured by Volpe at the eight acoustic measurement sites during the flight tests:

1. 0.5 second time history acoustic data, including:
   a. A-weighted sound pressure level with slow response (L_{AS});
   b. Un-weighted sound pressure level with slow response (L_{ZS});
   c. Un-weighted, one-third octave-band sound pressure levels;
2. Overall acoustic metrics, including:
   a. A-weighted, equivalent sound pressure level with slow response over the measurement time period (L_{Aeq});
   b. A-weighted, exceedance levels (L_N: e.g., L_{90});
3. 0.5 second time history meteorological data, including:
   a. Wind speed (mph);
   b. Wind direction (degrees);
   c. Average temperature (˚F);
   d. Average relative humidity (% RH);
4. 0.5 second time history device diagnostic data, including:
   a. External power (VDC); and
   b. Internal temperature (˚F).

The measurement systems had a GPS receiver, which calibrates the device with UTC time stamp and position information including latitude, longitude and altitude.

The following relevant, detailed meteorological data were also collected by NASA with weather balloons as well as onboard the P-3B during the flight test:

1. Position;
2. Pressure (hPa and millibars);
3. Temperature (˚C);
4. Relative humidity (% RH);
5. Altitude (m above MSL); and
6. Wind Speed (m/s).

The sample rate for these data was 10 seconds for the weather balloons and 1 second for the P-3B. The King Air did not collect meteorological data during this flight test.

During the DISCOVER-AQ flight tests, both the King Air and the P-3B collected information about aircraft position and performance. While GPS latitude, longitude and altitude were collected for each aircraft, not all aircraft performance data were collected automatically. In these instances, the NASA King Air flight team noted their power settings and speeds during the flight tests. These pilot logs were deemed to provide sufficient performance data for this data set, since the aircraft were flown in a consistent manner each day.

4 MEASURED DATA AND DATA PROCESSING

Following the September 2013 measurements, the following data were accumulated and synchronized: aircraft tracking and performance, measurement site locations, aircraft-based meteorological, balloon meteorological, on-ground meteorological and acoustic measurements. These data were archived in a structured query language (SQL) database for further processing and to better facilitate data analysis.

Hundreds of hours of acoustic data were collected at each measurement location during the DISCOVER-AQ flight test. However, only a small fraction of that time coincided to P-3B or King Air events flying near the acoustic measurement systems; out of that small sub set of events, even fewer occurred during times without other acoustic interference and under acceptable meteorological and operational conditions. These data were further processed to identify flight test aircraft overflights, evaluate data quality and determine the final data to be used for aircraft acoustic model validation.

4.1 Determination of Acoustic Events based on Aircraft Distance from the Measurement Site

An event in the DISCOVER AQ validation data is defined as a level flyover or a spiral maneuver from the test aircraft that is audible at a measurement location. A first pass at determining at what distance an aircraft might be audible, given an anticipated ambient level of 45-50 dB(A), was established by modeling the P-3B in the FAA's Integrated Noise Model (INM)[4] using the P-3C as a proxy aircraft. INM predicted that at a lower power setting of 50%, the P-3C SEL level would drop down to 50 dB at approximately 15 km (approximately 50,000 ft). Therefore, a 15 km threshold was established. Given this criterion, a total of 324 unique events were captured during the DISCOVER-AQ acoustic measurements.

4.2 Acoustic Data Evaluation

Once the unique acoustic events were identified, each event underwent a series of checks to determine data quality and to assure that measurements were collected under acceptable conditions. These data quality checks consisted of a calibration check and a check against meteorological limits.

Each usable event was made subject to a quality check to assure that the deviation in sensitivity between pre- and post-measurement calibrations performed on acoustics instrumentation was less than or equal to 1 dB. If the event had a calibration shift less than 1 dB, all of the sound pressure level values for that event were adjusted by the average difference between the pre- and post-measurement calibration levels. If this calibration criterion was not met, the event was deemed invalid and not used for analysis.

Meteorological conditions were checked for each event to insure that they were within the limitations set forth by Federal Aviation Regulations, Part 36, Noise Standards (FAR Part 36)[5] for temperature and wind speed, as well as instrumentation limits specified by the equipment manufacturers. Meteorological limits are listed in Table 2. For this data quality assessment, the meteorological conditions were checked against data collected by Volpe's on-ground meteorological system. If less than 30% of an event occurred outside the meteorological limits, that event was flagged within the DISCOVER AQ database as a valid event. If this meteorological criterion was not met, the event was deemed invalid.

Table 2 – Meteorological Limits for Acoustic Events

Meteorological Parameter	DISCOVER-AQ Data Quality Limit
Temperature	36 °F to 95 °F
Wind Speed	Less than 12 m/s
Relative Humidity	5% to 85%

After calibration and meteorological checks, the events were also compared against the pilot log for each aircraft and observer log for each measurement site. Events with non-standard performance characteristics or audible acoustic interference were removed from this analysis. Following these checks, 205 of 324 unique events were deemed valid.

4.3 Acoustic Data Quality

For each valid event, the acoustic time history data were inspected. A-weighted sound pressure level (L_{AS}) versus time were plotted for each event, alongside aircraft position relative to the measurement site versus time, to aid in the identification of events and check for any data synchronization issues. As an aid for identifying aircraft events in the acoustic data, aircraft position was shifted by an offset based on the speed of sound and the sound propagation distance, so the aircraft position data would line up in time with the acoustic data at the measurement system. For most events, the aircraft operated at relatively high altitudes in the airspace around a metropolitan area, with the potential for acoustic interference due to high ambient noise- this scenario sometimes resulted in low signal to noise ratios. In order to insure that a level flyover or spiral maneuver was adequately captured by the acoustic measurement systems and not masked by other noise, an event threshold level of greater than 10 dB above the ambient noise levels was established. Events were categorized according to the criteria in Table 3.

Table 3 – Acoustic Event Categories

Aircraft	Category	Physical Description
P-3B	1	Level flyovers with >10 dB rise and fall in L_{ASmx}
P-3B	2	Spirals with 3 to 6 peaks in L_{ASmx} >10 dB rise and fall
King Air	3	Level flyovers with >10 dB rise and fall in L_{ASmx}

If an event occurred where the test aircraft was within 15 km of the measurement site and met the other data quality criteria, the data were then visually inspected, and the unique aircraft event was categorized as a "good" event. A total of 95 good events were identified: 29 P-3B level flyover events (Category 1), 50 P-3B spiral events (Category 2) and 16 King Air level flyover events (Category 3).

4.4 Meteorological Data Processing and Profile Development

Meteorological data for the DISCOVER-AQ acoustic data set were collected from 3 sources; Volpe on-ground instrumentation, P-3B on-board measurement systems, and weather balloons. Temperature, wind speed, atmospheric pressure, and humidity were utilized from all sources in order to fully define the atmospheric conditions over the acoustic propagation path during each acoustic event.

In order to determine the most suitable data source for each event, meteorological data from all 3 sources were correlated to events based on date, time and measurement site. An exploratory analysis of the meteorological data showed the following:

- Temperature changes were largely dependent on altitude and could be described with a lapse-rate type equation. Smaller increases in temperature near ground were observed over the course of the day.

- Relative humidity changes were somewhat dependent on altitude and time-of-day with minimal dependence on location, and could not be accurately described with simple regressions or lapse rate equations.
- Wind speed had no observed dependencies on altitude or time-of-day, and could not be accurately described with regression equations.
- Atmospheric pressure changes were dependent on altitude, and could be described with a lapse-rate equation.

Because both relative humidity and wind speed cannot be easily described with simple equations, it was deemed appropriate to summarize these data as layered atmospheric profiles, stratified in 0.5 km (1,640 ft) layers.

For the purpose of building the most complete weather profile for all events, P-3B on-board meteorological data were generalized as “aircraft” meteorological data and applied to P-3B and King Air events. Altitude bin 0 was associated with altitudes between 0 and 1.5 m (5 ft) and assigned meteorological averages from ground data. Between altitude bins 1 and 11 (ranging from 1.5 m (5 ft) to 5,500 m (18,040 ft)), where aircraft data were available, temperature and humidity averages were assigned to a record from aircraft data and are substituted with balloon data wherever aircraft data were absent. Wind speed was taken from balloon data for all altitude bins because on-aircraft wind speed records were deemed unreliable due to the variability in the maneuvers executed by the P-3B. For records with altitude bins between 12 and 19 (ranging from 5,500 m (18,040 ft) to 9,500 m (31,160 ft)), all meteorological data were sourced from the weather balloon. This process is presented in Fig. 2.

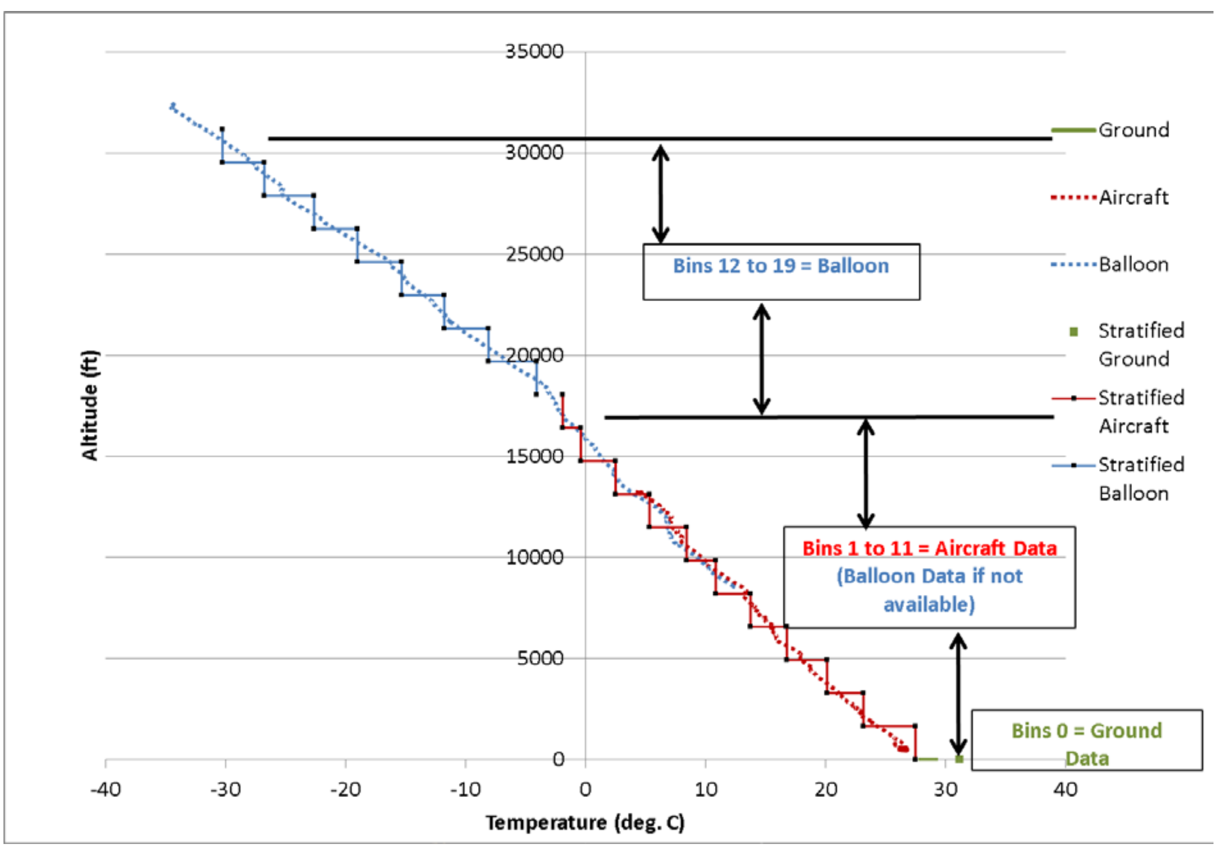

Fig. 2 – DISCOVER-AQ meteorological profile development binning criteria.

4.5 Aircraft Performance Data Processing

As noted previously, aircraft performance data were not automatically collected by the aircraft data collection systems and had to be manually logged by the pilots. Aircraft event specific data were used to model aircraft performance, when available. Because the operational conditions of both aircraft were relatively consistent for the duration of the flight test, and aircraft operational data were only collected at a few, select points during each flight day, average performance data for each aircraft were computed (see Table 4) and used when event specific data were not available.

Table 4 – Average P-3B Performance Data

		Altitude (ft)	Airspeed (KIAS)	Power Setting (SHP)
Overall	Average	6,731.7	201.7	1,648.7
	Stdev	6,097.7	9.2	394.0
Low Altitude	Average	821.2	199.6	1,429.2
	Stdev	272.4	9.9	312.3
High Altitude	Average	12,642.3	203.9	1,868.1
	Stdev	1,764.4	8.0	344.9

5 EXAMPLE VALIDATION DATA

The DISCOVER-AQ acoustic validation data set includes 95 aircraft events. Event # 102 is included in this paper as an example. This is a P-3B spiral, category 2 event, occurring at site SP-1. It includes five LAS peaks, as defined in Table 14, as the aircraft spiraled downwards from an altitude of approximately 13,000 ft to 600 ft. The sound level, position, altitude, and slant distance from the measurement site at each acoustic peak, are presented in Table 6.

Table 6 – L_{AS} Peaks in Category 2 Event 102 at Site SP-1

Event Peaks	1	2	3	4	5
GPS Midpoint Time (s)	51884	52075	52255	52441	52636
Maximum LAS (dB)	60.1	55.3	59.3	62.7	70.1
Distance from Site (km)	3.86	2.90	2.21	1.47	1.35
Altitude (ft)	13,061	9,057	5,555	2,326	535

The following data are presented for Event 102 in Fig. 3 through Fig. 5: L_{AS} versus time; aircraft position relative to the acoustic measurement site versus time (time shifted as described previously); un-weighted SPL for the one-third octave-band including the blade pass frequency of the aircraft versus time; temperature profile; humidity profile; wind speed profile; and barometric pressure profile.

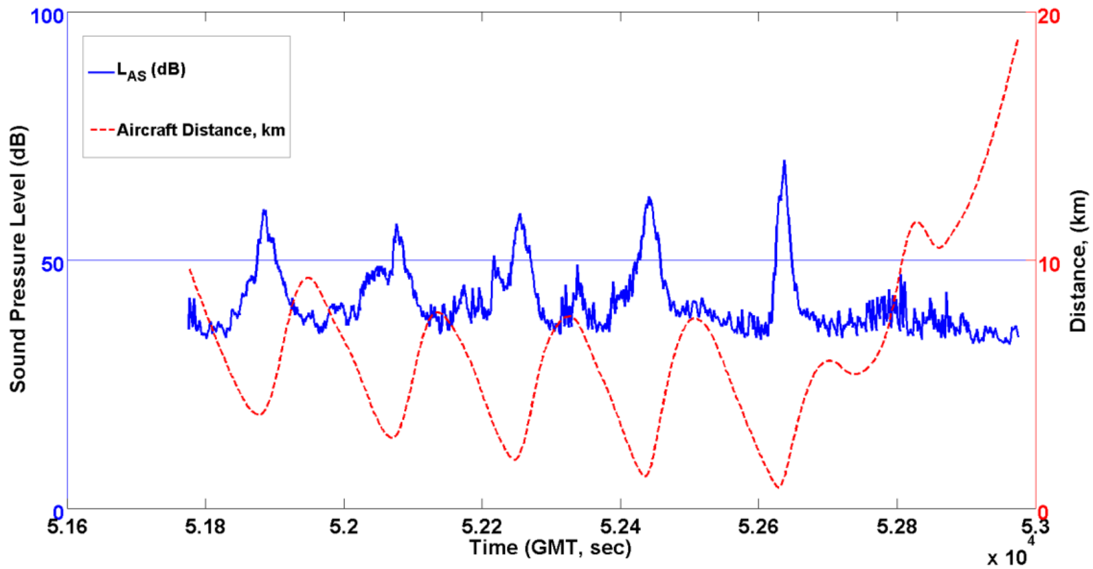

Fig. 3 – DISCOVER-AQ L_{AS} Sound Pressure Level during Event 102 with Aircraft Distance from Site SP-1.

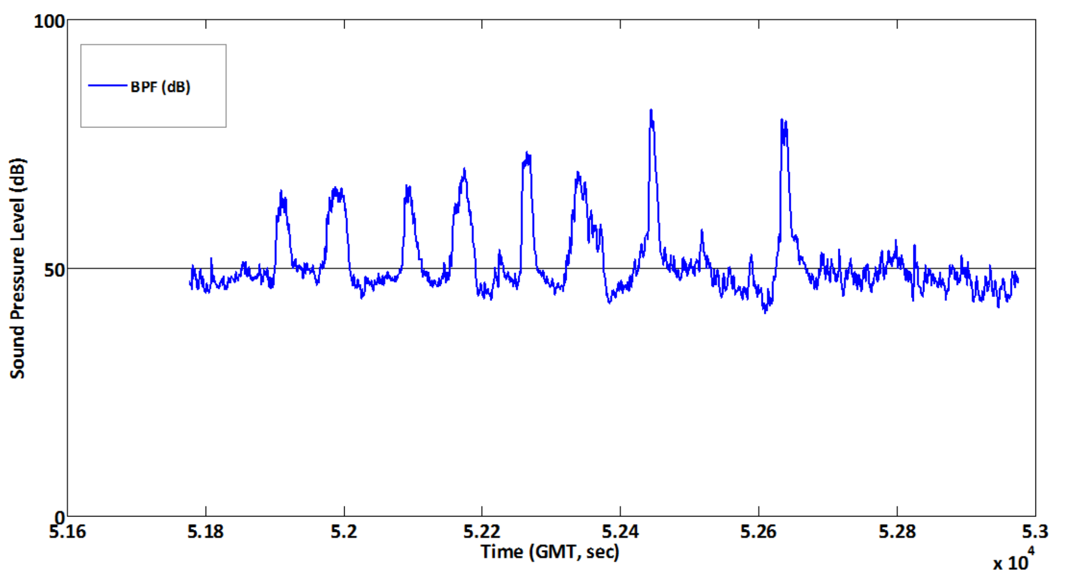

Fig. 4 – DISCOVER-AQ Sound Pressure Level at Blade Pass Frequency of 66.7 Hz (captured in the 63 Hz band) over Time for Event 102 at Site SP-1.

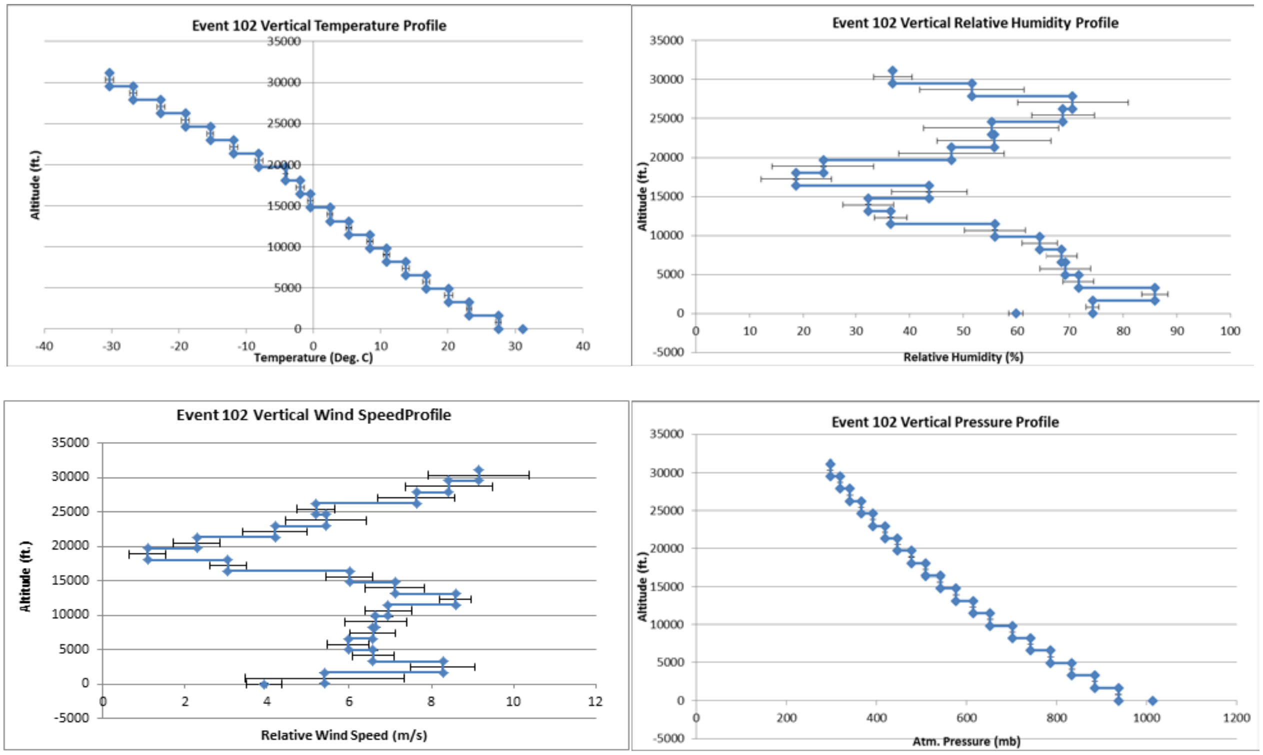

Fig. 5 – DISCOVER-AQ Meteorological Profiles for Event 102 at Site SP-1: (clockwise from top left) Temperature, Relative Humidity, Wind Speed and Atmospheric Pressure.

6 VALIDATION RECOMMENDATIONS AND CONCLUSIONS

The DISCOVER-AQ Acoustics data set is a high quality, fully documented database of acoustic, meteorological, tracking and observational data for use in the validation of aircraft noise modeling methodologies. The altitude dependent data set is ideally suited for the evaluation of aircraft acoustic propagation algorithms, especially those that account for vertically-changing atmospheric effects. FAA AEE plans to utilize the DISCOVER-AQ acoustic data set for additional validation of AEDT and other acoustic research capabilities. This can most effectively be done through detailed modeling of single-event noise.

In order to validate propagation algorithms, the aircraft acoustic source data must also be known. For the purpose of this paper, source data for the test aircraft can be modeling using proxy aircraft currently available in AEDT and INM. The P-3C Orion can be used to model the P-3B, and the Cessna 441 Conquest II can be used to model the King Air.

For a given event, aircraft source data are defined, and the aircraft position data are imported into the noise model to define a ground track. The aircraft altitude, speed and performance data can then be used to define the profile along that ground track. The atmospheric profile data can be used to define the atmosphere in the study, either as a layered atmosphere or just with the ground meteorological data for a study with a homogeneous atmosphere. When using these inputs to define a single event, the measurement locations can then be modeled, and the modeled noise level results can be compared against the corresponding acoustic measurement data.

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