Assessment of Airframe Noise Reduction Technologies based on EPNL from Flight Tests

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The acoustic performance of various airframe noise reduction technologies – Adaptive Compliant Trailing Edge flap, main landing gear fairings, and gear cavity treatments – was determined, individually and in combination, using the Effective Perceived Noise Level metric. These noise measurements and calculations closely follow the Federal Aviation Administration aircraft noise certification standards, specifically for the approach noise measurement point. The flyover data correspond to pole-mounted, single-microphone measurements obtained during a series of flight tests, conducted under the NASA Flight Demonstrations and Capabilities project, that evaluated flap and landing gear noise reduction technologies. To minimize contributions from the propulsion system, the aircraft was flown along the approach path with engine thrust set at ground idle. Although contamination from engine, background, and secondary airframe noise sources partially masked the true performance of the tested technologies, the resulting acoustic data clearly showed substantial noise reductions relative to baseline levels. The acoustic benefits measured by the single microphones are consistent with previously reported trends in acoustic levels obtained from phased microphone array data.

Nomenclature and Acronyms

ACTE	=	Adaptive Compliant Trailing Edge
AFB	=	Air Force Base
AFRC	=	Armstrong Flight Research Center
ARMD	=	Aeronautics Research Mission Directorate
EPNL	=	Effective Perceived Noise Level
FAA	=	Federal Aviation Administration
IAS	=	Indicated air speed
ICAO	=	International Civil Aviation Organization
MLG	=	Main landing gear
NR	=	Noise reduction
SCRAT	=	SubsoniC Research Aircraft Testbed
SNR	=	Signal-to-noise ratio
SPL	=	Sound pressure level
TAS	=	True air speed

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I. Introduction

A drastic reduction in the airframe component of aircraft noise during approach and landing is necessary if NASA's long-term vision of confining the noise from civil aviation operations to within airport boundaries is to be realized. Aircraft with smaller noise footprints are key enablers for continuing growth in air travel [1, 2]. The major sources of airframe noise are deployed wing high-lift devices (e.g., slats and flaps) and the aircraft undercarriage [3]. The NASA Aeronautics Research Mission Directorate (ARMD) is vigorously pursuing the development and maturation of efficient concepts that provide substantial airframe noise mitigation without negatively affecting aircraft aerodynamic performance.

NASA evaluated the aeroacoustic performance of several airframe noise reduction (NR) technologies installed on a Gulfstream-III (G-III) aircraft during the Acoustic Research Measurements (ARM) test flights, conducted between 2016 and 2018. The first campaign (ARM-I, 2016) evaluated the Adaptive Compliant Trailing Edge (ACTE) concept to reduce the noise produced by the wing flaps [4, 5]. The second test (ARM-II, 2017) targeted main landing gear (MLG) and gear cavity NR treatments in combination with the ACTE technology. For the third flight test (ARM-III, 2018), the ACTE flaps were removed and the original Fowler flaps were reinstalled on the G-III aircraft to obtain baseline flap and landing gear data, and to assess the noise reduction capability of the landing gear technologies when conventional flaps are used.

Extensive acoustic measurements were acquired during the ARM tests with a NASA-developed phased microphone array comprised of 185 sensors [6] and three pole-mounted single microphones. Processed phased array data from the ARM-I and ARM-II tests, presented in Ref. [4], demonstrated that significant reductions in acoustic energy for sources associated with the flaps and main landing gear were obtained when the ACTE concept and gear treatments were installed. The effectiveness of the NR technologies was observed over a wide range of forward directivity angles [4]. Although the NASA flight tests were not conducted for noise certification purposes, it was desired to quantify the acoustic benefits of the ACTE flap and MLG NR technologies in terms of the Effective Perceived Noise Level (EPNL), the metric for annoyance to aircraft flyover noise defined by the Federal Aviation Administration (FAA). Our motivation was three-fold. First, aircraft certification is of paramount importance to airframe manufacturers and any NR technology that demonstrates a substantial EPNL reduction will have a better chance for acceptance by the industry. Second, although an accurate assessment of component-level noise reduction is not possible with single-microphone data, such information can be used to corroborate global airframe noise reduction levels obtained from phased microphone array measurements. And third, to generate a set of vetted EPNL data that can be used for comparison with the full-scale simulations conducted in support of the ARM flight tests.

The information contained in this paper is organized into five sections. Section II describes the test aircraft, evaluated NR technologies, test site, and ground instrumentation. An overview of test procedures and data processing, including calculation of EPNL, is provided in Section III. An assessment of data repeatability in terms of EPNL confidence intervals opens Section IV, followed by EPNL evaluations of NR technology for flaps and MLG. Significant findings of the investigation are summarized in Section V.

II. Test Aircraft and Test Site

All ARM flights were conducted with two Gulfstream G-III aircraft based at the NASA Armstrong Flight Research Center (AFRC). The primary G-III used during the ARM-I (2016) and ARM-II (2017) tests was the SubsoniC Research Aircraft Testbed (SCRAT), also known by its tail number as "804" (see Fig. 1a) [5]. The heavily instrumented 804 allows in-flight recording of aircraft parameters such as global position, angle of attack (AOA), and true airspeed (TAS). The second aircraft, also known by its tail number as "808" (Fig. 1b), was a stock G-III that served as the initial baseline configuration. For the ARM-III test (2018), the ACTE flaps were removed from 804 and the original Fowler flaps were reinstalled. This conversion allowed 804 to serve both as the baseline, unmodified testbed and as a vehicle for evaluating the acoustic performance of the MLG and cavity noise reduction technologies in conjunction with conventional (Fowler) flaps. Detailed information for the 804 and 808 testbeds is provided in Ref. [5]. Both ARM-I and ARM-II flight tests were conducted on the Rogers dry lakebed at the Edwards Air Force Base (AFB) in southern California. During these tests, the microphone array and certification microphones were deployed at the North end of runway 18L. This location provided ample flat terrain for the disposition of various elements of the ground operations and data collection hardware. To avoid possible delays/cancellations caused by rainy spring weather, the microphone array and certification microphones were deployed on the overrun section of an inactive runway at Edwards AFB during ARM-III. The new deployment site was relatively close to the lakebed site used during ARM-I and ARM-II. However, as will be shown later, background noise (BN) levels were higher than those at the lakebed due to closer proximity to a nearby highway. Furthermore, depending on traffic and meteorological conditions, background noise levels varied significantly during any given day.

a) NASA 804 (SCRAT) b) NASA 808

Fig. 1 Gulfstream G-III aircraft with ACTE flaps (left image) and Fowler flaps (right image).

A. Noise Reduction Technologies

The evaluated noise reduction technologies were the ACTE flap, MLG fairings, and two gear cavity treatments. A full description of these technologies can be found in Refs. [4, 5]. The ACTE concept, as applied to the 804 aircraft, is depicted in Fig. 2. The G-III MLG with and without acoustic treatment is shown in Fig. 3. The fairings comprised a porous knee fairing covering the front post, plus an assortment of smaller fairings that are collectively referred to as upper fairings. The two cavity treatments consisted of a stretchable mesh and a concept that combines chevrons at the leading edge with an acoustic foam treatment on the downstream side of the cavity. A close-up view of the two concepts, as installed on the 804 aircraft, is shown in Fig. 4.

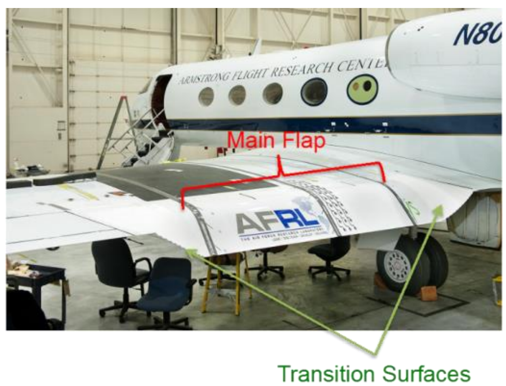
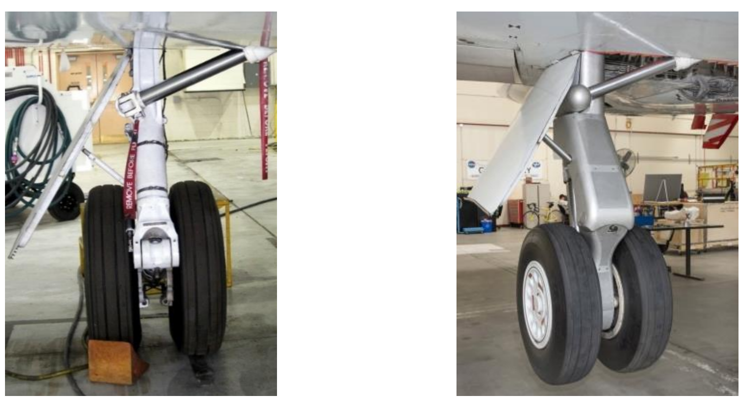


Fig. 2 NASA 804 (SCRAT) G-III aircraft with ACTE flaps (from Refs. [4, 5]).



a) Baseline b) Fairings installed

Fig. 3 Gulfstream G-III main landing gear. Baseline gear is shown in its compressed, on the ground state; the faired gear is depicted in its stretched, in-flight state (from Refs. [4, 5]).

a) Stretchable mesh　　　　b) Chevrons and acoustic foam

Fig. 4 Flight-tested main gear cavity treatments as installed on 804 aircraft (from Refs. [4, 5]).

B. Microphone Locations

The instrumentation used to obtain data for EPNL calculation consisted of pole-mounted B&K4939 ¼" free-field microphones. Two certification microphones aligned with the flight path and one sideline microphone were used for the analyses presented in this paper. Their nominal locations relative to the phased array during the ARM-III test are shown in Fig. 5. The two flyover microphones are spaced 200 m apart along the flight path, 100 m upstream and downstream of the center of the array. To evaluate acoustic behavior away from the flight path, a microphone was installed 100 m starboard of the array center.

The certification microphones were calibrated twice per day using a pistonphone. All microphones were sampled simultaneously with the array at 76.8 kHz for 40 seconds during an aircraft flyover. In 2016 and 2017, all microphones were installed over the same surface (compacted dirt) of the dry lakebed. However, in 2018, flyover microphones were installed on an asphalt runway, while the sideline microphone was placed on a relatively flat region of the surroundings consisting of a moderately noncompacted dirt surface with short desert vegetation, as shown in Fig. 5.

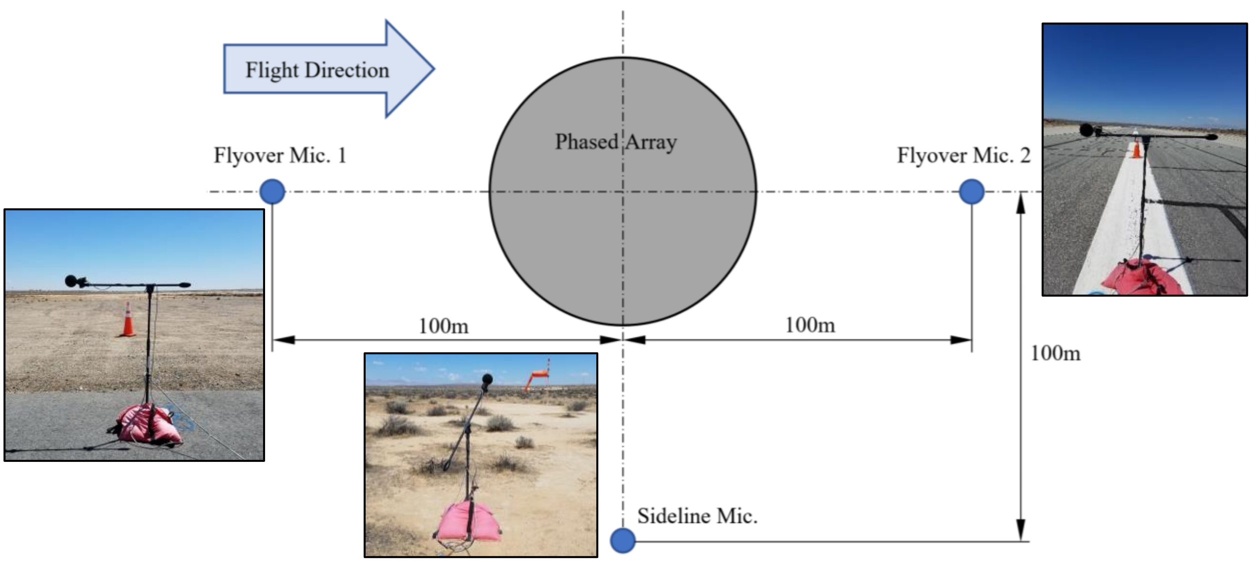


Fig. 5 Schematic with nominal locations of certification microphones relative to the phased array, and pictures of pole-mounted microphones with wind screens installed.

III. Test Procedure and Measurements

An overview of the overall test procedure and supporting measurements is provided in this section. The pole-mounted, single microphone data presented in this paper were obtained simultaneously with the array measurements of Ref. [4]. Thus, the former measurements were subjected to the same operational, atmospheric, and local conditions as the latter. Sections A and B below, mostly taken from Ref. [4], are included here for completeness. Additional information on the flight and ground operations in support of the airframe noise test campaign is provided in Ref. [5].

A. Flight Pattern and Local Climate Conditions

The tests were performed by flying the aircraft in a "racetrack" pattern, closely resembling the approach path for a typical landing as the airplane passed over the microphone array. Typical pass completion time was approximately 5 minutes. All passes were executed with the aircraft engines operating at "ground-idle" to minimize contamination of the acoustic measurements by propulsion noise. Therefore, the glide slope depended on the aircraft configuration and conditions for each pass, i.e., flap and gear setting, speed, angle-of-attack, and weight.

During flyover operations, the target altitude as the aircraft passed over the array center was 350 ft (106.7 m), with allowed vertical deviations of ±50 ft (15.2 m). This is slightly lower than the 394 ft (120 m) recommended for certification. However, as will be explained in the next section, all EPNL results were calculated for a reference altitude of 120 m. The allowable lateral deviation from the array center was ±35 ft (10.7 m). The airspeed tolerance was set at ±5 kts of the indicated airspeed (IAS). To determine velocity scaling, acoustic measurements for most configurations of interest were obtained at 140, 150, and 165 kts with the middle value representing the speed at which the majority of the measurements were taken. To ensure that the data were statistically meaningful, multiple passes during each flight and multiple flights on different days were executed for most aircraft configurations. For these tests, and for a few select configurations, data collection spanned multiple years. As a result, pass-to-pass, day-to-day, and year-to-year variations in the measured noise signature and the resulting uncertainties can be evaluated and assessed.

Most flight operations were conducted early in the morning, around sunrise, when atmospheric turbulence was generally low and thermal effects (temperature inversions) ranged from mild to moderate, e.g., 15°F (8.3°C) over 400 ft (122 m). Measurements of local meteorological conditions served two important purposes: firstly, to provide a real-time assessment of the local weather prior to, and during, aircraft flight operations to ensure that prevailing conditions were within acceptable limits (see Fig. 6 and Table 1); and secondly, to facilitate the application of necessary post-flight corrections to the acoustic data. A layered approach to implementing weather corrections was adopted to provide accurate estimates of atmospheric absorption. In this approach, the measured temperature, relative humidity, and pressure profiles were divided into 25 ft-high layers up to 500 ft. For each layer, an average value for each variable was computed and used to correct the acoustic measurements for attenuation effects. A detailed account of the weather measurement operation, sensors used to collect data, and the procedure for applying appropriate corrections to the acoustic array data is provided in Ref. [8]. The use of layered meteorological conditions for EPNL calculation is explained in detail in Ref. [7].

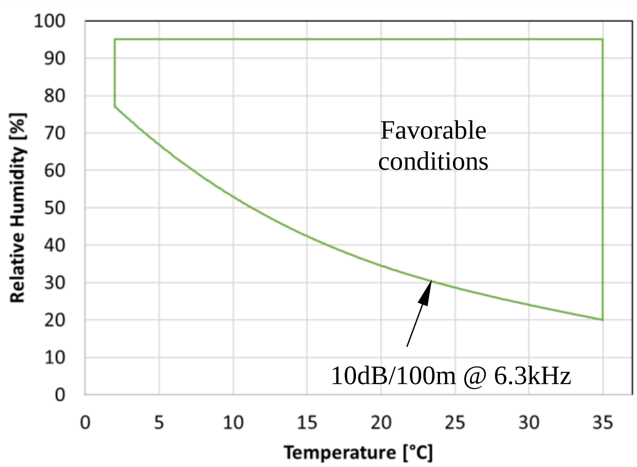


Fig. 6 Temperature and relative humidity combinations favorable to acoustic measurements (from Ref. [7]). Lower boundary defined by atmospheric conditions rendering an attenuation of 10dB/100m at 6.3 kHz.

Table 1. Wind restrictions.

Maximum wind speed	< 13 knots
Average wind speed	< 10 knots
Maximum crosswind	< 9 knots
Average cross wind	< 6 knots

B. Effective Perceived Noise Level Calculation

The advent of commercial aircraft powered by jet engines in the late 1950s prompted a swift and vigorous reaction from communities affected by the noise emanating from these powerplants. Within a few years, local authorities had sponsored the development of sophisticated metrics that could objectively represent subjective human responses to complex aircraft noise. The perceived noise level (PNL) – a single-number rating of the "noisiness" of broadband sound that could account for the vast differences in annoyance produced by exposure to propeller versus jet aircraft noise – resulted from this effort [9, 10]. Corrections to the PNL of a signal to include the effect of narrowband (tonal) noise produced the tone-corrected perceived noise level (PNLT).

In the late 1960s, the Federal Aviation Administration (FAA) was granted congressional authority to define the processes that would lead to the certification of aircraft for noise. The basic element in the regulation criteria is the Effective Perceived Noise Level (EPNL), which is, in essence, instantaneous PNLT corrected for the duration of an aircraft flyover [11, 12]. Thus, EPNL is based on the level, frequency distribution, and time variation of measured sound pressure. In general, the calculation method is applied to a continuous sequence of 0.5-second intervals throughout the period of the flyover and consists of the following main steps [7]:

1) Based on the actual aircraft position and velocity as a function of time, define a straight-line average flight path and determine its descriptors (i.e., average ground speed, average descent angle, time at overhead, lateral offset).
2) Determine the sound propagation distance and acoustic emission angle for each time interval/spectrum.
3) Adjust aircraft noise levels (at each time interval) to account for background noise, as described in the next section.
4) Define the reference flight path (i.e., reference altitude, reference ground speed, reference descent angle).
5) Calculate the reference spectrum, SPL_R, for each time interval considering altitude, glide slope, and test day atmospheric conditions. This includes adjustments to account for differences between the actual and reference flight path, and differences in sound attenuation between the test and reference atmospheric conditions (77°F/25°C, and a relative humidity of 70%).
6) Calculate effective time duration, δ_{tR}, for each SPL_R.
7) Calculate the reference perceived noise level, PNL_R, for each SPL_R and each of the 24 one-third octave bands with center frequencies from 50 Hz to 10 kHz.
8) Compute tone correction factors, C_R, for each SPL_R.
9) Obtain the tone-corrected reference perceived noise level: $PNLT_R = PNL_R + C_R$.
10) Compute the band-sharing adjustment by averaging all tone correction factors within 1 second of the maximum $PNLT_R$.
11) Apply the band-sharing adjustment to the maximum $PNLT_R$ and determine the first (K_{FR}) and last (K_{LR}) location within 10 dB of that value (other considerations also apply, see Ref. [7] for more details).
12) Compute the integrated reference-condition $EPNL_R$ by summing $PNLT_R$ energy between the limits K_{FR} and K_{LR}:

$$EPNL_R = 10\log\left[\frac{1}{t_o}\sum_{K_{FR}}^{K_{LR}} 10^{0.1 PNLT_R(k)}\delta t_R(k)\right], \text{ where } t_o = 10 \text{ seconds.}$$

The steps described above were followed for each aircraft pass. The reference flight conditions include an altitude of 394 ft (120 m), a 3° descent slope, and a speed of 150 kts. As explained in Section III-A, the target aircraft altitude (350 ft, 106.7 m) was prescribed over the center of the array. Therefore, the altitude over each flyover microphone depended on the flight path, e.g., the glide slope for a given flap and gear configuration. For flyover microphone 1, the altitude deviation from the 120 m reference was smaller than the stipulated ±30 m for most passes. However, depending on the flight slope, a "low" pass might be outside this range for flyover microphone 2. Furthermore, for high descent angles, the aircraft level-off altitude/location (without an increase in thrust from ground idle) might have caused the flight path to deviate from a straight line. These are potential causes for EPNL differences between the two flyover microphones. Deviations from the recommended altitude prompted a concern that jet noise corrections would have to be considered. However, further analysis showed that such corrections are negligible for the ground-idle engine condition used during the test. Since the sideline microphone was aligned with the center of the microphone phased array, deviations from the reference altitude were not an issue. Also, although all passes were adjusted according to the standard to a reference descent slope of 3°, the slope for configurations with high drag (flap 39°, gear down) reached values over 8°. This is a wider range than the recommended 3°±0.5° for aircraft certification. The impact of these flight path variations relative to the reference conditions was not fully studied. However, sample calculations for the configurations with Fowler flaps deflected 20°, gear down and with ACTE flaps deflected 25°, gear down showed variations of less than 0.1 EPNdB when using the actual flight slope or a reference descent slope of 3°. This finding was corroborated by flight test phased array results presented in Ref. [13], which clearly demonstrate that farfield noise spectra are very weakly dependent on aircraft glide slope and angle-of-attack.

The International Civil Aviation Organization (ICAO) standard [7] requires that testing be conducted when atmospheric conditions render attenuations less than 12 dB/100m (or 14 dB/100m, depending on the accuracy of the temperature measurements) for the one-third octave band centered at 8 kHz. Sample atmospheric attenuation levels per 100m are shown in Fig. 7 for different arbitrary conditions deemed good, marginal and bad. The reference condition from the standard is shown in black. As can be seen, even on days considered "good" (in green), these corrections can easily reach 50 dB at high frequencies (e.g., 10 dB/100m at 8kHz for a representative 10 dB-down distance of ~500m). For bad days (in red), atmospheric attenuation causes the corrected bands to dominate the EPNL calculation, rendering invalid and/or unusable EPNL values. However, for marginal days, and considering that the goal was not to certify the aircraft, it is possible to obtain a representative EPNL by relaxing the limit on the number of masked and/or reconstructed bands. This was made possible by implementing an automated algorithm[5] that determines "discontinuities" at high frequencies (caused by a combination of excessive attenuation corrections and relative background noise levels), in particular for aircraft locations far from the microphone. The PNLT curves for all passes were also individually inspected to ensure that the 10 dB-down period did not contain any anomalies related to excessive atmospheric attenuation, background noise or other test conditions.

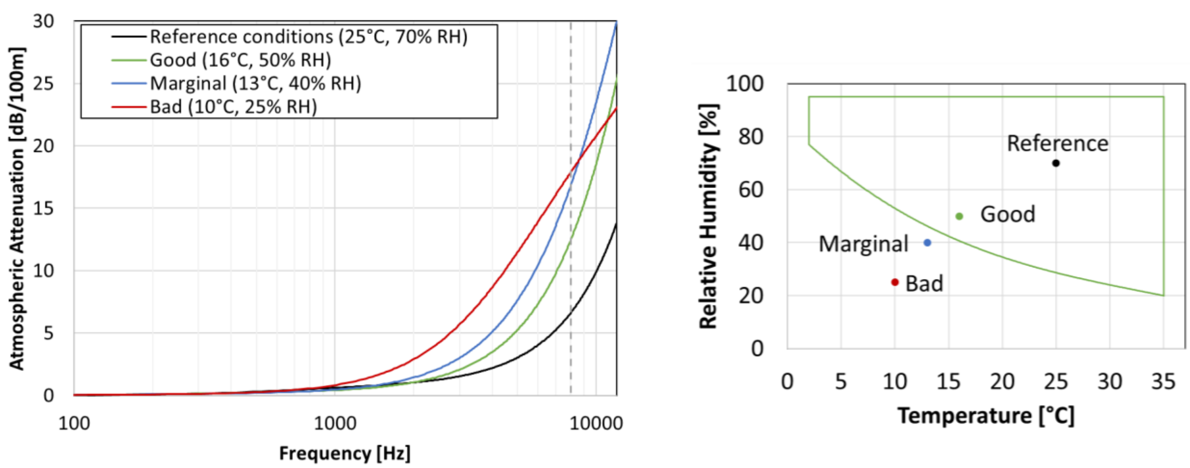


Fig. 7 Atmospheric attenuation per 100 m as a function of frequency for different atmospheric conditions (denoted as reference, good, marginal, and bad. Based on recommended test conditions from Ref. [7]).

The EPNLs for all passes in a given configuration were arithmetically averaged and the uncertainty in the mean value was computed using the t-distribution for two-sided 90% confidence bounds, as specified in Ref. [7]. Since the confidence interval depends on the number of data points and the standard deviation within that sample, large uncertainties are possible for configurations that have less than 4 valid EPNL measurements and/or that show a large variation between passes. As recommended in Ref. [7], passes with speeds more than ±5 kts (±9 km/h) from the target 150 kts (277.8 km/h) were ignored. Indicated air speed (IAS) was used for passes where true air speed (TAS) was not available, e.g., for 808 aircraft flights. Ground speed, although recommended in Ref. [7] for noise certification, was not used during the ARM tests because their main objective was to measure airframe noise, not to certify the aircraft. The use of IAS allowed the pilots to maintain the required aircraft settings. This resulted in relatively small variations in airframe noise levels, as measured with the phased microphone array [4,13].

Outlier passes (those more than 2 EPNdB from the mean value) were also removed from the set used to obtain the average EPNL for a given configuration and its confidence interval. The EPNL reduction reported in this paper is simply the difference between the mean EPNL values for the configurations being compared. The confidence interval of the EPNL reduction for a given pair of configurations was computed as the Euclidean norm of the uncertainties for each of them. Therefore, if one of the configurations being compared showed a large standard deviation or was computed using a relatively low number of passes, the uncertainty in the noise reduction would also be large.

[5] This algorithm was required to avoid manual inspection of the spectra at each time step for more than 3,300 data sets (over 1,100 passes for each of the three certification microphones).

C. Background Noise at the Test Sites

The procedure for background noise subtraction specified in Ref. [7], including the determination of masked bands, was implemented. This procedure consists of the following main steps:

1) Spectra for each 0.5-second interval are compared to a masking criterion equal to the background noise plus 3dB.
   a. Levels below this criterion are considered "masked."
   b. Levels above this criterion are background subtracted.
2) Masked levels are then "reconstructed" using various interpolation and extrapolation procedures that depend on their frequency and proximity to unmasked bands. If masked levels cannot be reconstructed, then they remain masked.
3) A spectrum is flagged as invalid based on the number of masked or reconstructed bands. This procedure becomes increasingly restrictive within 1 second of the maximum PNLT.
4) The entire EPNL calculation is flagged as invalid if an invalid spectrum occurs within the 10 dB-down period.

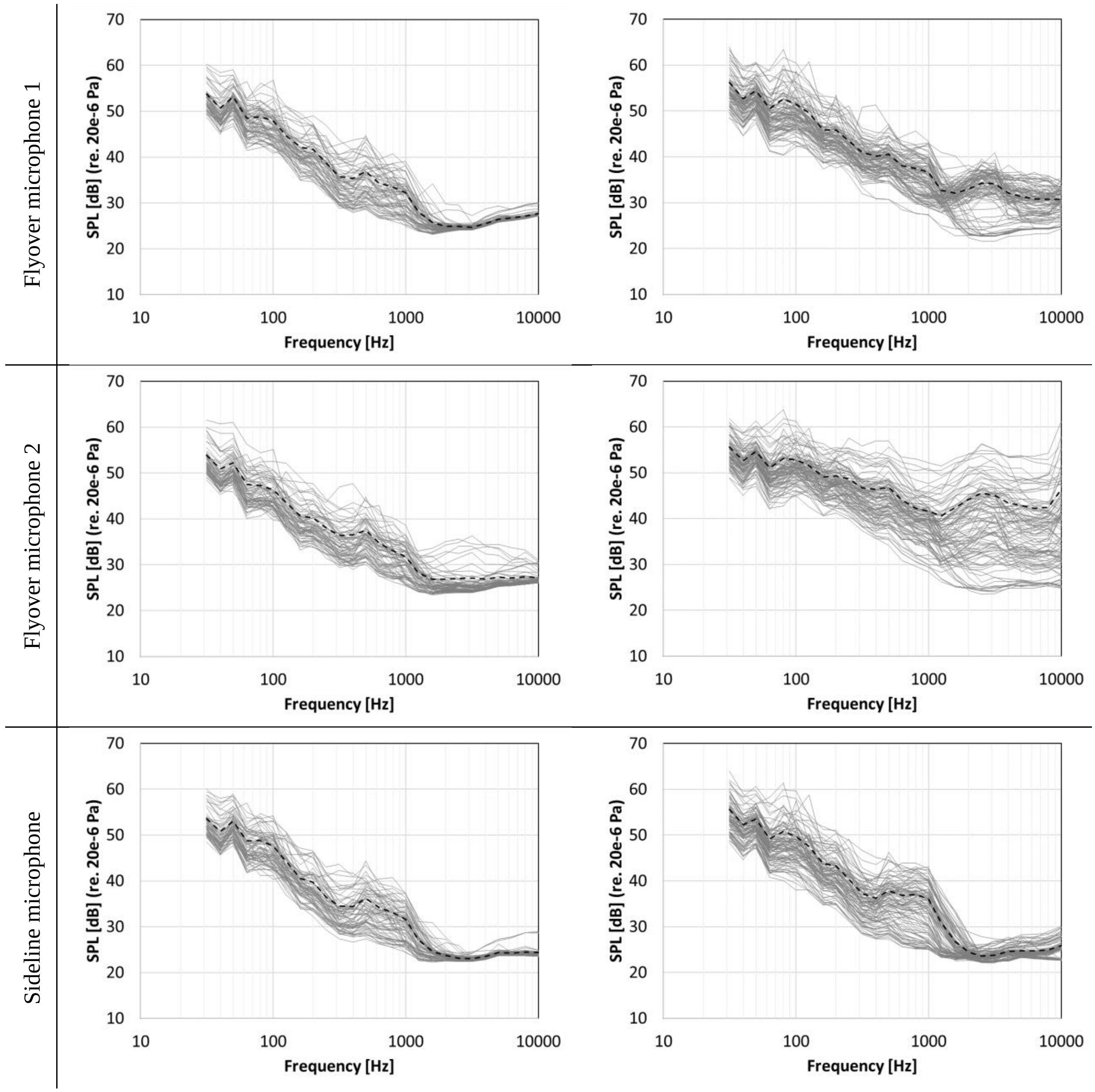
The frequency content and amplitude of background noise (BN) at the test site play a key role in the quality of the measured airframe noise signatures by setting the signal-to-noise ratio (SNR) during data acquisition and hence affecting the number of masked levels for a particular data set. Therefore, the subtraction procedure requires accurate measurements of the BN within a relatively short period of time from the actual aircraft pass. Given the short time between array flyover passes and the fact that EPNL measurements were not the top priority of the tests, a relatively small amount of BN data was collected (mostly during flap angle or gear up/down configuration changes) when compared to a typical noise certification test. Furthermore, the BN acquisition process was changed from year to year, becoming a higher priority after the 2016 ARM-I test. During the ARM-II and ARM-III tests, BN was measured several times during the course of any given flight day. Background noise spectra[6] in one-third octave bands for each certification microphone, measured over several flight days in 2017 and 2018, are shown in Fig. 8. The dashed black line represents the energy average of all spectra shown in a given plot. Note that BN is highest at frequencies below 1 kHz due to traffic noise from a nearby highway; at higher frequencies, the background noise for ARM-II (2017) plateaus for most data sets because the noise floor of the system (microphones, amplifiers, filters, and data acquisition system) was reached. The spectra also clearly show that closer proximity to the highway significantly affected BN during ARM-III (2018), both in terms of absolute levels and variability. In general, a good SNR was maintained for sound waves with frequencies less than 5 to 6 kHz. However, for aircraft locations far away from the array center, reductions in SNR can affect the EPNL calculation. This effect is accentuated when atmospheric attenuation is applied to days with "marginal" or "bad" atmospheric conditions. Note that the differences in relative levels and variability among microphones observed during ARM-II could be partially attributed to their cardioid response since they were installed at grazing incidence relative to the flight path, with flyover microphone 1 and 2 pointing in opposite directions and the sideline microphone pointing in the same direction as flyover microphone 1. The unusually higher levels and the much wider spread in BN acquired by microphone 2 during ARM-III could be partially attributed to noise pollution from the generators powering the data acquisition system, since their location and arrangement were different than those for the previous flight test campaigns.

Based on a detailed analysis of the BN data for each year, we decided to use different approaches to minimize the impact of variations in BN levels throughout the day while also simplifying analysis of the data (1,100+ aircraft passes) for each microphone. The BN data observed during the ARM-II test were the most consistent. As such, the energy average of same-day background noise levels were used for BN subtraction. Consistent day-to-day BN measurements were not made during ARM-I, and during ARM-III the BN levels were higher and less consistent throughout the flights than those observed at the lakebed. Therefore, a different approach was developed to obtain usable background noise spectra for those tests. The approach consisted of using the first 1.6 seconds of data of each aircraft pass (typically 20 seconds elapsed before the aircraft reached the array center, translating into a distance of about 1,500 m) plus 1 dB as the background noise spectra for the pass. This choice was based on the fact that noise levels when the aircraft is far from the array center are similar to the actual BN levels, especially at mid to high frequencies where aircraft noise is significantly affected by atmospheric attenuation. An advantage of this approach is that the effects of background level variations are mitigated because the BN spectra are measured as close as possible (in time) to the aircraft pass. The EPNL for ARM-II data was computed using this new approach and compared to the results obtained with same-day average BN data. In general, levels were found to be within 0.2 EPNdB. However, in many instances, we observed that this approach could affect the validity of the results by masking low frequencies that are only slightly affected by atmospheric attenuation when the aircraft approaches. Regardless, we decided that the approach could be reliably

[6] Very few clearly outlying spectra, such as those indicating another aircraft or a train in the area, were removed.

applied to ARM-I and ARM-III data to obtain representative BN levels, in particular at mid to high frequencies, and therefore, improve the number of passes with a representative EPNL.

We also found that poor weather conditions and an excess of low frequency masked bands caused many EPNLs to be flagged as invalid, but otherwise agree with other runs of the same configuration. EPNLs flagged as invalid due to excess masked bins were still used, provided that their PNLT distributions were not obviously affected by those masked bands and that their values did not deviate more than 2 EPNdB from the mean for a given configuration.



a) Lakebed, ARM-II (2017)   b) Inactive runway, ARM-III (2018)

Fig. 8 Background noise spectra at the test sites (in one-third octave bands) measured multiple times a day for all flight days. Dashed black line represents the energy average of all measurements in a figure.

IV. Results and Discussion

As mentioned in Section III-A, measurements were obtained for target indicated air speeds (IAS) of 140, 150, and 165 kts, with multiple passes at each speed, to determine velocity scaling and other dependencies of the measured airframe noise. The majority of passes, however, were conducted at a nominal IAS of 150 knots that is close to, and representative of, typical aircraft landing speeds. Therefore, this section only includes analyses for passes in the range between 145 and 155 kts, consistent with the reference speed of 150 kts used in EPNL calculations and the deviation of ±5 kts recommended in Ref. [7]. However, as explained before, IAS (or TAS if available) was matched instead of the ground speed. The only exception was the 804 configuration with Fowler flaps deflected 39° measured during ARM-III (2018), where the speed restriction was relaxed (TAS ranging from ~148 to ~158 kts, with a mean of ~155 kts) to obtain a larger number of passes and therefore a better EPNL estimate. The EPNL variations presented here were obtained by subtracting the arithmetic average of all valid EPNLs for the given flap deflection/gear combinations of the first configuration indicated in each caption from the corresponding arithmetic average of all valid EPNL values for the second configuration. For example, the EPNL variations in Table 2 were obtained by subtracting the 808 baseline measured during ARM-I (2016) from the 808 baseline measured during ARM-II (2017).

Recall that confidence levels on the EPNL reduction between two configurations are computed as the Euclidean norm of the uncertainties for each configuration. In general, differences in EPNL with a confidence interval larger than ~ ±1.5 dB should not be considered accurate. This can occur, for instance, when at least one of the configurations has either less than four valid data points and/or a standard deviation over ~0.75 dB. Note that confidence levels greater than 1 dB are conservatively marked in red to alert the reader about a potential inaccuracy.

A. Comparison of Baselines and Year-to-Year Repeatability

Evaluation of the acoustic performance of applied NR technologies requires a consistent set of baseline data. Thus, the main goals of the analyses in this section are: 1) to quantify year-to-year repeatability of the acquired data, and 2) to determine whether 808 and 804 in their baseline configurations produce comparable acoustic signatures. The year-to-year repeatability will allow us to determine if 804 ACTE data measured during ARM-I (2016) or ARM-II (2017) can be compared directly to data for 804 with Fowler flaps obtained during ARM-III (2018). A comparison between 808 and 804 baselines, both measured during ARM-III, would help us determine if the 808 baseline data measured during ARM-II can be used to assess the noise reduction characteristics of 804 with ACTE flaps measured during the same test. This would permit a direct comparison under the same test conditions in terms of test site, setup, and background noise levels.

The first set of results analyzed corresponds to the 808 baseline from 2016 and 2017. Table 2 shows a comparison with gear retracted for different flap deflections, while Table 3 shows the corresponding results with the landing gears deployed. Very good year-to-year repeatability is observed for the conditions presented in the tables, with differences generally less than 1 dB and relatively narrow confidence intervals. Note that most of the differences are negative, indicating that the EPNL levels from 2016 are slightly higher than those from 2017. Unfortunately, not enough measurements were obtained during the 2016 test for the configuration with Fowler flaps deflected 39° to provide a better confidence interval.

Table 2. EPNL variations and confidence intervals [dB] between 2016 and 2017 808 baseline with different flap angles for gear up condition.

Microphone	Fowler flap 0°, gear up	Fowler flap 20°, gear up	Fowler flap 39°, gear up
Flyover 1	-1.16 ± 0.40	-0.26 ± 0.39	-0.26 ± 0.39
Sideline	-1.26 ± 0.88	-0.29 ± 0.53	-0.29 ± 0.53

Table 3. EPNL variations and confidence intervals [dB] between 2016 and 2017 808 baseline with different flap angles for gear down condition.

Microphone	Fowler flap 20°, gear down	Fowler flap 39°, gear down
Flyover 1	-0.15 ± 0.62	-0.45 ± 0.58
Sideline	0.50 ± 0.71	-0.04 ± 1.13

Comparisons between 808 baseline from 2018 and 2017 are presented in Table 4 for configurations with landing gear down. In this table, positive values indicate that 2018 EPNLs were lower than those measured in 2017. Although the magnitudes of these year-to-year differences are generally within 1 EPNdB, as are those of the differences presented in Table 3, some confidence intervals are slightly larger due to the very limited number of valid EPNLs available. As mentioned in section III.C, the large number of invalid EPNL values for 2018 is a consequence of the increased background noise levels at the test site during ARM-III, in particular at the Flyover 2 microphone position.

Table 4. EPNL variations and confidence intervals [dB] between 2018 and 2017 808 baseline with different flap angles for gear down condition.

Microphone	Fowler flap 20°, gear down	Fowler flap 39°, gear down
Flyover 1	0.87 ± 0.74	0.55 ± 0.52
Flyover 2	-0.11 ± 0.53	-0.73 ± 0.54
Sideline	1.89 ± 0.71	1.17 ± 0.55

Table 5 shows repeatability results for configurations with ACTE flaps deflected 25° measured during ARM-I (2016) and ARM-II (2017), both with gear up and down. Note that these values have slightly higher differences in mean EPNL than those shown before, particularly for the gear up configuration. Also observe from Table 5 that, as was the case for the Fowler flap configurations, 2016 data are higher. This behavior is potentially a consequence of the lack of accurate BN data for 2016 and the workaround implemented to obtain them. Nevertheless, considering that the data were taken a year apart, these results are considered satisfactory for the intended purpose of supplementing the noise reduction results obtained with the phased microphone array measurements.

Table 5. EPNL variations and confidence intervals [dB] between 2016 and 2017 ACTE flap 25° configuration.

Microphone	ACTE flap 25° Gear up	ACTE flap 25° Gear down
Flyover 1	-1.93 ± 0.69	-1.14 ± 0.46
Sideline	-1.59 ± 0.76	-0.52 ± 0.50

Since the ARM-II (2017) test provided the best overall conditions to measure EPNL accurately, we wanted to determine if the 804 and 808 baselines rendered similar acoustic information during the ARM-III (2018) test. If that were the case, the 808 baseline from 2017 could be compared directly to the ACTE 804 data acquired during the same year. Unfortunately, only a few 808 flights were performed during the 2018 test. This is evidenced in the slightly larger confidence intervals for the Fowler flap 20° gear up and gear down configurations presented in Table 6. In these results, positive EPNL differences indicate that the 804 baseline was quieter than the 808 baseline, while negative values indicate the opposite. Gear down configurations at both flap deflections show EPNL differences of less than ~0.7 EPNdB. Larger differences are observed for gear up configurations, with the 804 being quieter than the 808 baseline by up to about1 EPNdB.

Table 6. EPNL variations and confidence intervals [dB] between 804 (2018) and 808 (2018) baselines.

Microphone	Fowler flap 20°, gear up	Fowler flap 20°, gear down	Fowler flap 39°, gear up	Fowler flap 39°, gear down
Flyover 1	0.59 ± 0.55	-0.34 ± 0.82	-0.19 ± 0.92	-0.06 ± 0.42
Flyover 2	0.18 ± 0.53	-0.29 ± 0.64	-0.32 ± 0.86	-0.02 ± 0.46
Sideline	1.03 ± 0.52	-0.63 ± 0.74	-0.57 ± 1.14	0.22 ± 0.44

To provide additional information on the “interchangeability” of baselines, we wanted to assess the differences in EPNL between the 804 baseline measured in 2018 and the 808 baseline measured in 2017. The results for gear up and down configurations at different flap deflection angles are presented in Table 7. Since, in general, a larger number of data points were available, narrower confidence intervals were obtained for most configurations. As a result of higher background noise levels during ARM-III (2018), the EPNL variations for flyover microphone 2 are not consistent with those of flyover microphone 1, for both gear up and down configurations.

Because of insufficient background noise measurements obtained during the ARM-I (2016) test and the ensuing lack of insight on its character, we decided to exclude the acoustic data acquired in 2016 from further consideration. As the data presented in this section amply demonstrate, the change in test site location from 2017 to 2018 and the noticeably higher background noise (with wider spreads) encountered during the ARM-III (2018) deployment complicate the choice of an appropriate data set to represent G-III baseline configurations. After careful and extensive cross examination of the 2017 and 2018 data, we determined that the best quality and most consistent noise reduction values (in terms of PNLT curves and EPNL) were achieved when the collected acoustic data for configurations with NR technologies were compared to reference baseline information acquired during the same year. As a result, we will evaluate the acoustic performance of the ACTE technology without and with MLG fairings and cavity treatments measured during the ARM-II (2017) flight test with baseline 808 aircraft data gathered in 2017. Similarly, the NR performance of the MLG fairings plus cavity treatments installed on the Fowler flap-equipped 804 that were tested during the 2018 ARM-III test will be determined relative to the 2018 804 baseline data.

Table 7. EPNL variations and confidence intervals [dB] between 804 (2018) and 808 (2017) baselines.

Microphone	Fowler flap 10°, gear up	Fowler flap 20°, gear up	Fowler flap 39°, gear up	Fowler flap 20°, gear down	Fowler flap 39°, gear down
Flyover 1	0.14 ± 0.75	1.09 ± 0.39	0.12 ± 0.83	0.53 ± 0.72	0.49 ± 0.57
Flyover 2	-1.75 ± 0.52	-0.38 ± 0.40	-1.34 ± 0.40	-0.40 ± 0.58	-0.74 ± 0.59
Sideline	0.15 ± 0.68	1.95 ± 0.53	0.15 ± 1.05	1.26 ± 0.51	1.39 ± 0.61

B. Evaluation of ACTE Flap Technology

The ARM-II test (2017) evaluated the aeroacoustic performance of the ACTE technology, both individually and in combination with MLG fairings and cavity treatments. The ACTE flaps were set at 25° for the duration of the test. At this deflection, the aerodynamic performance (lift) of the ACTE flaps is more or less equivalent to that of Fowler flaps deflected 20° and represents a typical approach configuration.

Since the main goal of the study was to determine the acoustic performance of the installed technologies, the EPNL differences presented from here on were obtained by subtracting the EPNL of the treated configuration of interest from the EPNL of the baseline/reference configuration it is being compared to. Thus, positive and negative values signify noise reduction and noise increase, respectively. The EPNL differentials and confidence intervals for each configuration consist of data points corresponding to Flyover 1, Flyover 2, and sideline microphones. The arrangement and order of appearance of these three values in each plot is indicated in Fig. 9 and will remain the same for all subsequent figures.

Fig. 9 shows the difference in noise levels between configurations with ACTE flaps deflected 25° and the 808 aircraft at four Fowler flap deflection angles for the gear up condition. Notice that the confidence intervals are relatively small, indicating that the values are consistent. The results in Fig. 9 show that EPNLs for the ACTE flaps deflected 25°, while slightly lower, are comparable to those obtained for configurations with Fowler flaps deflected 0° (cruise) and 10°. The EPNL reductions relative to the configuration with Fowler flaps deflected 20° are on the order of 2 EPNdB. A larger noise reduction of about 4 EPNdB was attained relative to Fowler flaps deflected 39°, as expected, since Fowler flap noise is prominent for G-III aircraft in landing configuration. The reduction in levels relative to Fowler flaps deflected 20° and 39° corroborate the reduction trends observed in integrated farfield spectra obtained from phased array measurements [4].

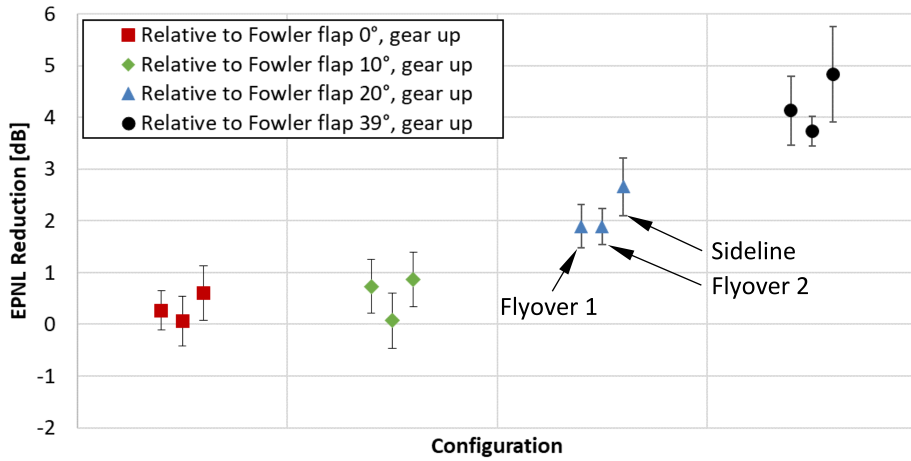


Fig. 9 EPNL reduction and confidence intervals for configurations with ACTE flaps deflected 25° (2017) relative to 808 Fowler flap (2017), gear up.

The acoustic performance of the ACTE flaps with landing gear deployed is plotted in Fig. 10. Relatively small confidence intervals were attained for the differential EPNL values displayed. The landing gear and Fowler flap systems are the major airframe sources on G-III aircraft [4]. This fact is clearly reflected in Fig. 10, where gear deployment significantly masks the performance of the ACTE flaps and substantially lowers the magnitude of the noise reduction, relative to the values for the gear up cases (Fig. 9). With the gear down, ACTE flaps deflected 25° yield 0.85 EPNdB and 1.36 EPNdB reductions relative to Fowler flaps deflected 20° and 39°, respectively. These values represent approximately 40% of the reduction levels measured for the gear up condition.

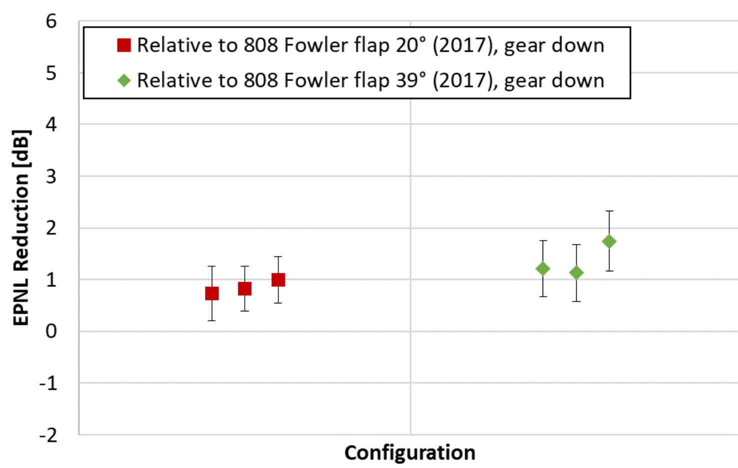


Fig. 10 EPNL reduction and confidence interval for configurations with ACTE flaps deflected 25° (2017) relative to 808 Fowler flap (2017), gear down.

C. Evaluation of MLG and Cavity NR Technologies

The ARM-II and ARM-III flight tests were focused on the aeroacoustic evaluation of NR technologies for the main landing gear and cavity. The main gear fairings plus the cavity treatments were tested on the 804 aircraft equipped with ACTE flaps during ARM-II (2017) and with conventional Fowler flaps during ARM-III (2018). The maximum possible noise reduction achievable from any individual or combined landing gear treatment is that associated with retracted gear. Thus, differences in EPNL values between gear up and gear down configurations help establish the ideal upper bound on gear noise reduction for the G-III aircraft. Note, however, that no treatments were applied to the nose landing gear, which is a dominant source at several frequencies [13].

The reduction in EPNL with gear retraction is shown in Fig. 11 for the configuration with ACTE flaps deployed 25°. Note from the figure that the absence of both MLG and NLG subtracts approximately 4 EPNdB from the EPNL values. This significant change in noise levels made the configuration with ACTE flaps set at 25° with gear down an ideal setting for evaluating the unmasked performance of various gear treatments.

The differences in EPNL between gear up and gear down conditions for G-III aircraft equipped with Fowler flaps are shown in Fig. 12. Results from the ARM-II (2017) and ARM-III (2018) tests for flap deflection angles of 20° and 39° are presented. Note that 2017 results are based on data collected for 808 and 2018 results are based on data acquired for the 804 aircraft. Overall, the results reveal that both aircraft produce consistent trends with relatively small confidence intervals. Nevertheless, differences of about 0.5 EPNdB exist between 808 and 804 aircraft data. As noted previously, such discrepancies are directly attributed to the differences in background noise and other issues that arose from the change in test sites between 2017 and 2018. Observe also from Fig. 12 that, for both aircraft with flaps deflected 20°, nearly 3 EPNdB are gained with MLG/NLG retraction. Thus, this flap deflection angle is an ideal configuration for measuring the performance of various MLG treatments. The realizable benefit is significantly reduced when the deflection angle is increased to 39° due to a substantial increase in flap noise.

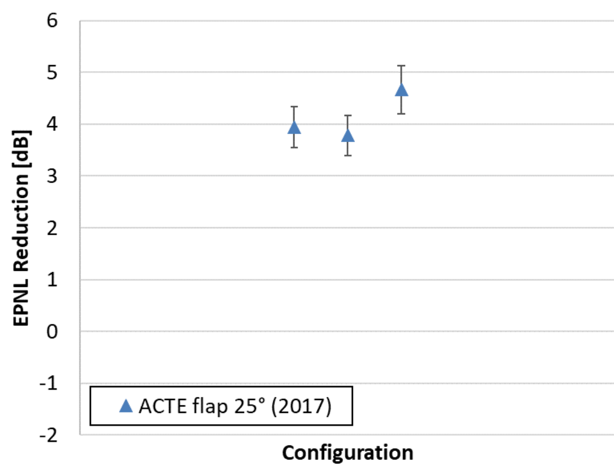


Fig. 11 EPNL reduction and confidence interval for ACTE flaps deflected 25°, gear up relative to gear down.

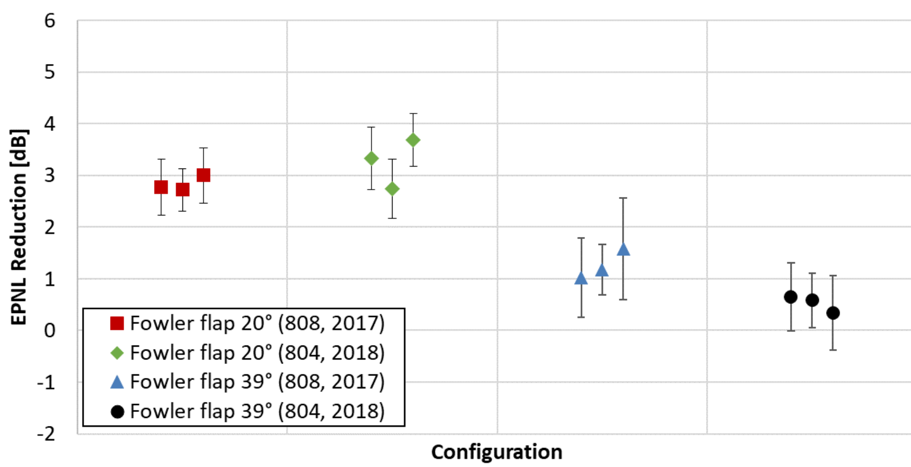


Fig. 12 EPNL reduction and confidence interval for Fowler flaps, gear up relative to gear down.

1. Evaluation of MLG and Cavity NR Technologies with ACTE Flaps

With flap noise nearly eliminated, the ACTE-equipped G-III (804) aircraft provided an ideal platform for evaluating the noise reduction capability of the MLG fairings and cavity treatments. The resulting combinations of applied flap and gear technologies were among the quietest configurations tested; thus, they provided the maximum EPNL reductions achievable with these devices for the G-III aircraft.

Fig. 13 depicts the decrements in EPNL obtained for configurations with ACTE flaps deflected 25° (ACTE 25°) equipped with various MLG noise abatement treatments relative to ACTE 25° with gear down, all based on measurements conducted in 2017. Notice that due to the large number of EPNL results available (about 15-20 for most combinations, except for the fairings plus mesh with only 6), very narrow confidence intervals, typically less than 0.4 dB, were obtained for all configurations and microphones. The maximum EPNL reduction of about 2.2 EPNdB was obtained with the fairings, chevrons and foam installed, which is approximately 0.3–0.4 EPNdB higher than that for the fairings only configuration. The fairings and mesh combination was found to be the least effective, producing slightly less noise reduction than the fairings only configuration. This trend was unexpected. The integrated farfield spectra obtained from phased array measurements showed that the combination of fairings plus mesh produced slightly more noise reduction than the fairings only because of partial mitigation of cavity noise at frequencies below 400 Hz [4]. Accordingly, we anticipated its performance to fall somewhere between the fairings only and fairings plus chevrons and foam configurations. We must point out, however, that array results of Ref. [4] also hinted to a small noise increase at frequencies above 3,500 Hz at overhead and forward directivity angles caused by mesh (self-generated) noise. Therefore, we attribute the lack of mesh performance (in terms of EPNL reduction) for the fairings plus mesh configuration partly to the low number of available passes and partly to possible self-noise.

Also plotted in Fig. 13 are the values for the gear up configuration (shown with black circle symbols) representing the upper bound on maximum possible noise reduction. Comparison of treated gear results to the gear up values indicates that a substantial EPNL reduction was obtained, even though the nose gear, which is a dominant source over a large frequency range, was not acoustically treated during the ARM tests. The significance of this reduction is illustrated with Fig. 14, which depicts sample acoustic maps at two frequencies for ACTE 25° with and without MLG NR technologies (fairings, chevrons and foam) for overhead radiation, taken from Ref. [4]. The maps clearly show that 1) a substantial reduction in the strength of the MLG sources was obtained when the treatments were installed; 2) the nose gear is a prominent noise source, equivalent to either MLG; and 3) residual engine noise, which adversely affects single-microphone measurements, is present.

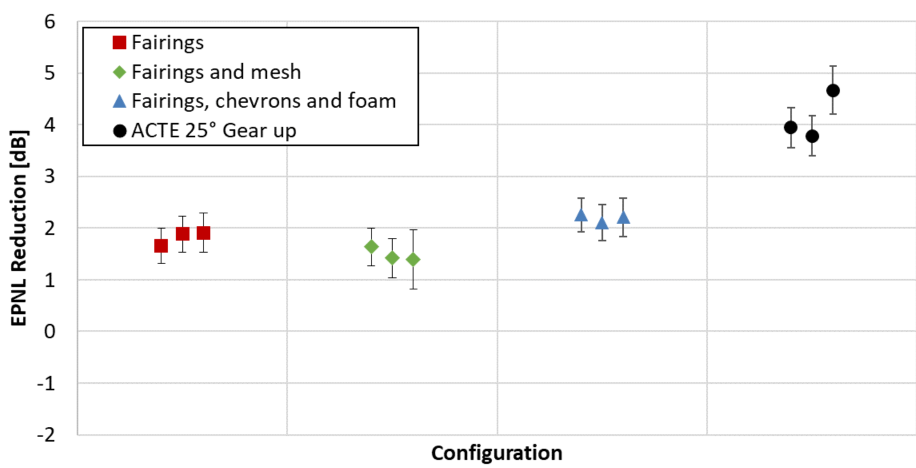
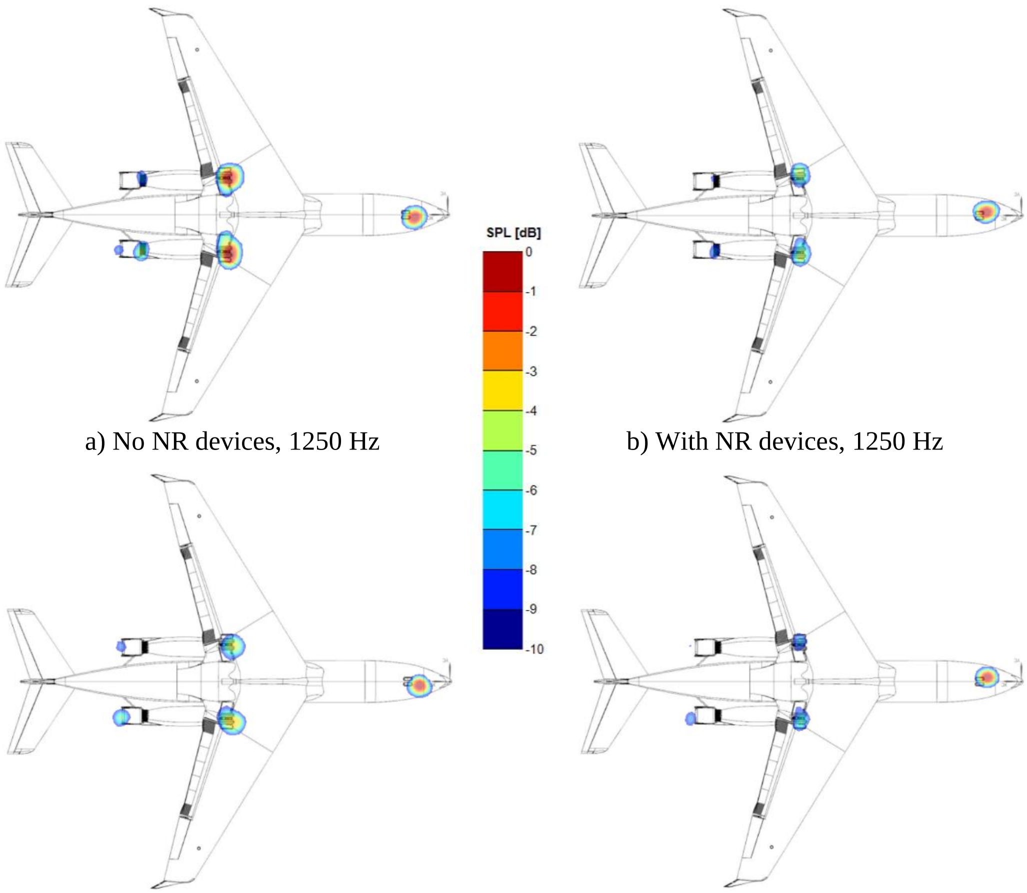


Fig. 13 EPNL reduction and confidence interval for ACTE 25° with different MLG NR devices relative to ACTE 25° with baseline gear. EPNL reduction for ACTE 25° gear up also shown.



a) No NR devices, 1250 Hz b) With NR devices, 1250 Hz

c) No NR devices, 4000 Hz d) With NR devices, 4000 Hz

Fig. 14 Sample acoustic maps for ACTE 25° without (left column) and with (right column) NR technologies (fairings, chevrons and foam). Peak levels set to same absolute values on both maps (from Ref. [4]).

Of great interest is quantification of the noise reduction potential of the ACTE technology with MLG treatments relative to the 808 baseline measurements acquired during the same year. Comparisons of configurations with ACTE flaps and various gear treatments with Fowler flaps deflected 20° and 39° are presented in Fig. 15 and Fig. 16, respectively. For a Fowler flap deflection of 20° (Fig. 15), maximum reduction was obtained for the configuration with gear fairings plus cavity chevrons and foam, which lowered the EPNL by about 3 EPNdB. This reduction is approximately 0.3–0.6 EPNdB larger than that obtained with gear fairings only. As was observed in Fig. 13, the combination of gear fairings plus cavity mesh had the lowest performance, achieving reductions that were slightly lower than those for configurations with fairings alone. Except for slightly larger reductions, similar trends are observed for configurations with Fowler flaps deflected 39° (Fig. 16). At this flap deflection, the combination of ACTE flaps with gear fairings plus cavity chevrons and foam yields a noise reduction of approximately 3.5 EPNdB. Overall, the results show significant reductions ranging from 2.55 EPNdB to 3.95 EPNdB. Direct comparison of the values plotted in Fig. 15 and Fig. 16 reveal that increasing flap deflection from 20° to 39° increases the noise reduction benefits for all configurations by almost the same amount. The extra noise reduction falls within the narrow range of 0.3–0.6 EPNdB.

Taken from Ref. [4], sample overhead acoustic maps comparing the 808 Fowler flap 39° gear down configuration to ACTE 25° with MLG fairings, chevrons and foam are shown in Fig. 17 for a frequency of 1,250 Hz. The maps highlight the effectiveness of the flap and MLG NR technologies installed. Observe from these maps that, at this frequency, the nose landing gear is a dominant source on par with the main landing gear and the sources residing at both inboard and outboard flap tips. Very similar results were noted in the beamform maps at several other frequencies and directivity angles. Obviously, lower aircraft noise signatures could have been achieved had similarly effective treatments been applied to the nose landing gear.

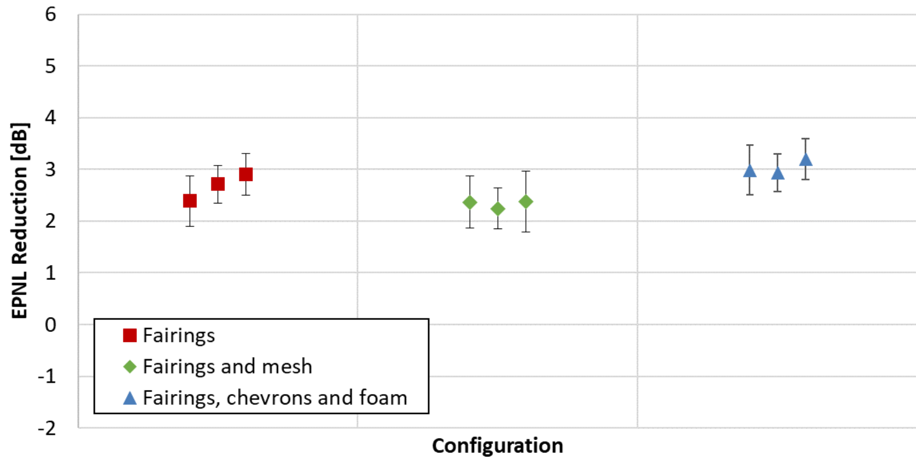


Fig. 15 EPNL reduction and confidence interval for ACTE 25° with NR devices (2017) relative to 808 Fowler flap 20° with baseline gear (2017).

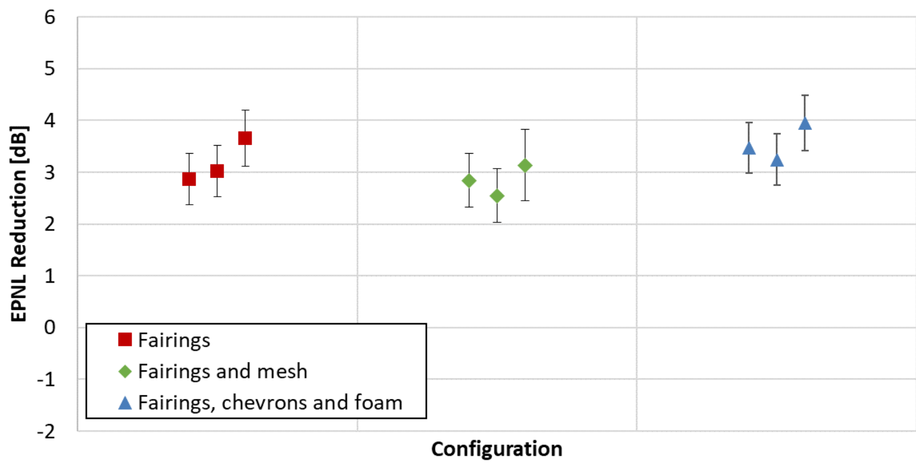
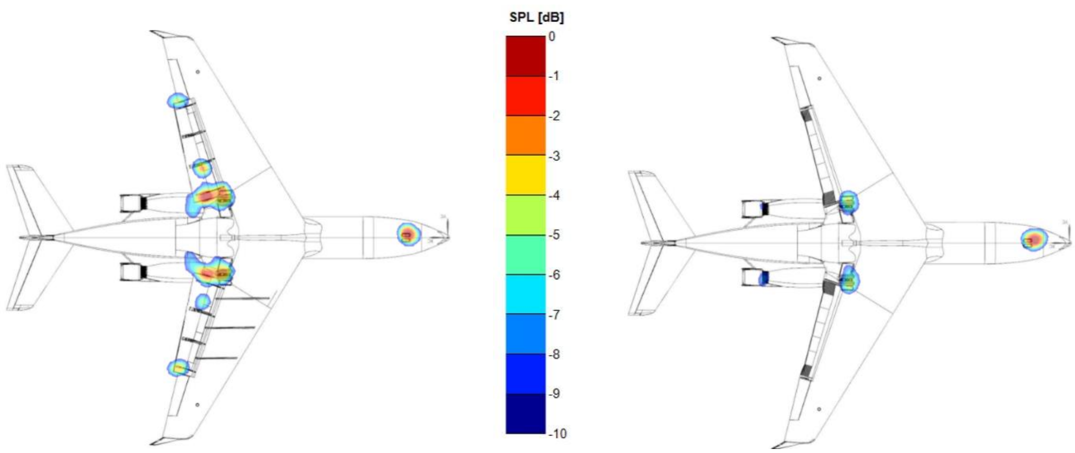


Fig. 16 EPNL reduction and confidence interval for ACTE 25° with NR devices (2017) relative to 808 Fowler flap 39° with baseline gear (2017).



a) 808, flaps 39°, gear deployed   b) 804, ACTE flaps 25°, MLG fairings, cavity chevrons and foam

Fig. 17 Comparison of acoustic maps between 808 and 804 aircraft depicting noise reduction performance of installed technologies at 1,250 Hz. Peak levels set to same values on both maps (from Ref. [4]).

2. Evaluation of MLG and Cavity NR Technologies with Fowler Flaps

Results for the 804 baseline with and without MLG noise reduction treatments are discussed in this section. The acoustic data for these results were acquired during ARM-III, in 2018, after reinstalling the Fowler flaps on the 804 aircraft. Since the nominal landing configuration during the test included Fowler flaps deflected 39° (Fowler 39°), the number of available passes for configurations with Fowler flaps deflected 20° (Fowler 20°) was not as large as some of the MLG NR configurations tested in 2017 with ACTE 25°. Therefore, slightly larger confidence intervals were observed for all Fowler 20° configurations. Nevertheless, most confidence intervals were smaller than 1 dB. Gear up results depicting the upper bound on achievable reductions are also shown for each flap deflection angle.

The acoustic performance of the gear treatments for Fowler 20° configurations is presented in Fig. 18. Note from the figure that, unlike the configurations with ACTE technology, the combination of MLG fairings, chevrons, and foam provided only a marginal increase in acoustic performance when compared to the fairings only configuration, yielding noise reductions of about 1.5 EPNdB. The gear fairings and cavity mesh combination again underperformed the other two configurations with fairings installed. Given the presence of an untreated NLG and residual engine noise, the magnitude of the reductions presented in Fig. 18 corroborate (albeit somewhat larger) reduction levels observed in the phased array measurements [13].

Fig. 19 shows the differences in EPNL values for Fowler 39° configurations. Due to the dominance of flap noise at this deflection, none of the configurations involving the gear fairings with or without cavity treatments produced noise reductions of any significance. The rather small reductions attained with gear retraction (black circle symbols) demonstrate the difficulties inherent in single-microphone measurements. Phased array results presented in Ref. [13] provide ample evidence of the noise benefits achieved with the tested MLG NR technologies. The difference lays in the fact that the integrated farfield spectra reported in Ref. [13] were obtained from integration of tailored regions within the beamform maps that exclude contributions from the NLG, engines, and other secondary sources present on the G-III aircraft. In contrast, EPNL values are extracted from single-microphone measurements and, thus, contain all elements of a noise signature.

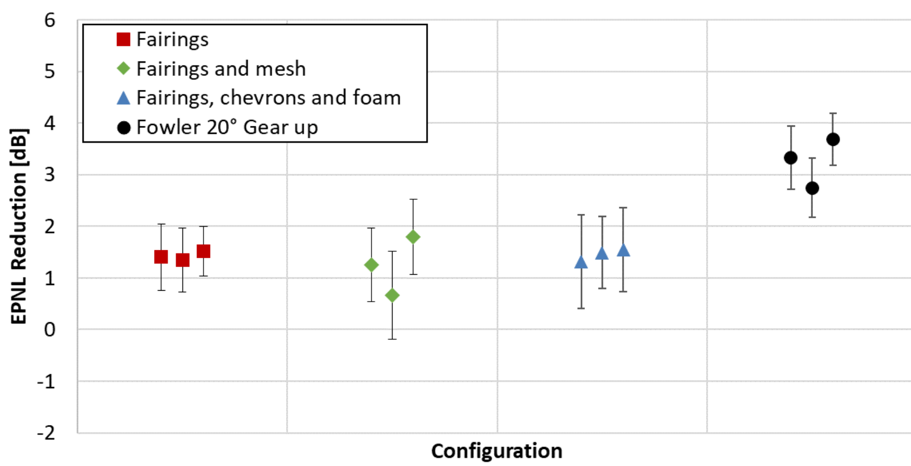


Fig. 18 EPNL reduction and confidence interval for 804 Fowler 20° with NR devices relative to 804 Fowler flap 20° with baseline gear. Reductions for 804 Fowler 20° gear up also shown.

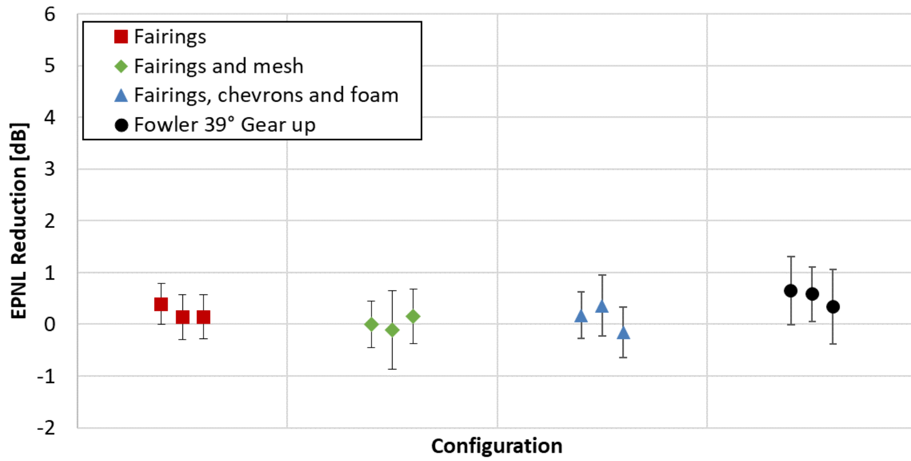


Fig. 19 EPNL reduction and confidence interval for 804 Fowler 39° with different NR devices relative to 804 Fowler flap 39° with baseline gear. Reductions for 804 Fowler 39° gear up also shown.

V. Summary

Flyover acoustic measurements were conducted for two Gulfstream G-III aircraft to measure the effectiveness of noise reduction technologies applied to the wing flaps and main landing gear (MLG). The technologies tested were the Adaptive Compliant Trailing Edge (ACTE); porous fairings applied to the MLG; and chevrons, mesh, and foam applied to the MLG cavity. Although the main goal of these tests was to evaluate airframe noise using a phased microphone array, valuable supplemental information was gathered using pole-mounted microphones with the secondary goal of establishing EPNLs according to established noise certification procedures. However, since the test sites were not chosen with noise certification in mind, background noise levels and atmospheric conditions were generally less than desirable for a noise certification test. The differences in environment and test setup that arose from the change in test locations between 2017 and 2018 made processing and analysis of the acquired acoustic data extremely challenging. After careful and extensive cross examination of ARM-II (2017) and ARM-III (2018) data, we determined that high quality and very consistent noise reduction values (in terms of PNLT curves and EPNL) can be produced when the collected acoustic data for configurations with noise abatement technologies were compared to reference baseline information acquired during the same year.

EPNL results revealed that ACTE flaps deflected 25° had noise levels similar to those of undeflected standard Fowler flaps (cruise configuration), effectively eliminating flap noise and corroborating previously published phased array results. For gear up configurations, EPNL reductions of approximately 2 EPNdB and 4 EPNdB were observed when comparing configurations with ACTE flaps deflected 25° to configurations with Fowler flaps deflected 20° and 39°, respectively.

The maximum achievable noise reduction for the tested MLG technologies was estimated by obtaining the EPNL reduction between gear up and gear down configurations. For ACTE flaps deflected 25°, gear retraction yielded an EPNL reduction of approximately 4 EPNdB, making this configuration an ideal platform for evaluating landing gear treatments. For a Fowler flap deflection of 20°, gear up baseline levels were found to be about 3 EPNdB quieter than gear down baseline levels for 804 measurements conducted in 2018, and about 2.75 EPNdB for 808 data acquired in 2017. At the higher flap deflection of 39°, both aircraft showed smaller reductions, ranging from approximately 0.5 to 1 EPNdB, caused by the prominence of flap noise at this deflection angle.

Regardless of flap system on the test aircraft, the combination of gear fairings plus cavity chevrons and foam produced the highest noise reduction of any gear treatment evaluated. When applied to the main gear of the configuration with ACTE flaps deflected 25°, this combination of treatments reduced the EPNL by about 2.2 EPNdB. When installed on the main gear of the configurations with Fowler flaps deflected 20°, the same set of treatments yielded a noise reduction of approximately 1.4 EPNdB. For configurations with Fowler flaps deflected 39°, the magnitude of the observed noise reduction was drastically reduced to less than about 0.25 EPNdB, a result of a much higher contribution of flap noise to the EPNL.

The combination of ACTE flap, MLG fairings, plus cavity chevrons and foam was determined to be the quietest configuration tested for the G-III aircraft. Direct comparison of EPNL values obtained for this configuration to those with Fowler flaps at 20° and 39° yielded substantial reductions approaching 3 EPNdB and 3.5 EPNdB, respectively.

Additional reductions could be obtained had we applied similar noise reduction treatments to the aircraft nose landing gear, which was found to be a dominant source over a wide frequency range.

Acknowledgments

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