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Toward Establishing a Realistic Benchmark for Airframe Noise Research: Issues and Challenges

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Abstract

The availability of realistic benchmark configurations is essential to enable the validation of current Computational Aeroacoustic (CAA) methodologies and to further the development of new ideas and concepts that will foster the technologies of the next generation of CAA tools. The selection of a real-world configuration, the subsequent design and fabrication of an appropriate model for testing, and the acquisition of the necessarily comprehensive aeroacoustic data base are critical steps that demand great care and attention. In this paper, a brief account of the nose landing-gear configuration, being proposed jointly by NASA and the Gulfstream Aerospace Company as an airframe noise benchmark, is provided. The underlying thought processes and the resulting building block steps that were taken during the development of this benchmark case are given. Resolution of critical, yet conflicting issues is discussed – the desire to maintain geometric fidelity versus model modifications required to accommodate instrumentation; balancing model scale size versus Reynolds number effects; and time, cost, and facility availability versus important parameters like surface finish and installation effects. The decisions taken during the experimental phase of a study can significantly affect the ability of a CAA calculation to reproduce the prevalent flow conditions and associated measurements. For the nose landing gear, the most critical of such issues are highlighted and the compromises made to resolve them are discussed. The results of these compromises will be summarized by examining the positive attributes and shortcomings of this particular benchmark case.

Airframe noise; Benchmark configuration; Nose landing gear; CAA validation

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1. INTRODUCTION

High fidelity simulations and accurate predictions of airframe noise pose some of the most difficult problems facing today's computational aeroacousticians. As one of the more prominent airframe noise sources, landing gear provide the greatest challenge due to their extreme geometric complexity which involves the presence of numerous

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bluff bodies of differing shapes and spatial scales. As such, landing gear noise spectra are very broad in nature making the simulations very resource intensive. Nevertheless, advances in computational aeroacoustic (CAA) methodologies and tools, in conjunction with the increase in computational power, have paved the way for a direct assault on the prediction of noise sources and radiated sound from landing gear. The simulated geometries are no longer the simplified versions of the last ten years [1-5], but rather involve realistic fully-dressed gear (dressing refers to the smaller structural features of a gear such as hydraulic and electrical lines, lighting fixtures, etc.) with most of the finer details taken into account [6-8] – landing gear geometries that only a few years ago were deemed computationally intractable are now within the realm of CAA simulations. What has been seriously lacking within the airframe noise community is the availability of realistic benchmark geometries and the associated comprehensive aeroacoustic database that would allow the CAA simulations to be validated in a systematic manner. As a government research institution working with both industry and academia, NASA is uniquely positioned to help identify candidate geometries, design and fabricate fully instrumented models, and support acquisition of the data sets that are critical for the validation of CAA methodologies. Although on paper this process seems to be fairly straight forward, in reality, it is often fraught with many challenges and decisions that often require compromises in order to resolve conflicting requirements.

To be an enduring airframe noise benchmark, the selected configuration must possess several key attributes. Foremost is that the geometry has to be realistic enough to be of relevance to industry and yet remain sufficiently simple to be of interest to the wider aeroacoustic research community; such a geometry would not only highlight the shortcomings of current CAA methodologies, but it would also entice development of more capable CAA tools. Besides having the proper geometric shape and details, a benchmark airframe configuration must also be a vehicle for addressing the effects of Reynolds number, geometric fidelity, and installation, critical issues that are encountered in full scale applications. These effects represent some of the most daunting challenges when it comes to reconciling/extrapolating ground based model scale experiments to full-scale flight test measurements; to the author's knowledge, they have not been addressed in a systematic manner previously.

A brief account of the nose landing-gear configuration, being proposed jointly by NASA and the Gulfstream Aerospace Company as an airframe noise benchmark, is provided in this paper. It is not being championed as the ideal configuration, nor is it guaranteed to be devoid of shortcomings; however, it does represent a good starting point and a leap forward in what is currently available. This particular example is used to highlight some of the critical issues encountered during the developmental stages of such benchmark problems. The underlying thought processes and building block steps that were followed to arrive at a reasonable outcome are the main focus of this paper.

2. CONFIGURATION SELECTION

The impetus for creating a benchmark arose from the NASA-Gulfstream partnership effort on airframe noise research. This ongoing partnership consists of targeted studies of some of the major airframe noise sources using a combination of flight tests, model-scale experiments in ground facilities, and high-fidelity computational simulations. The main purpose of the joint effort is to generate a high-fidelity aerodynamic and acoustic database to guide the development of the tools and technologies necessary to predict and reduce airframe noise.

The first critical step involved the decision of whether to develop the benchmark around a main landing gear or nose gear geometry. The NASA-Gulfstream airframe noise (AFN) flight test [9] conducted in 2006 provided the needed guidance. The flight test was executed using a Gulfstream G550 aircraft on approach to landing. The test matrix, ranging from cruise to landing configurations, was designed to provide an acoustic characterization of both the full aircraft and individual airframe components. Noise sources were isolated by selectively deploying components (flaps, main landing gear, nose gear, spoilers, etc.) and altering the airspeed, glide path, and engine settings.

Figure 1 displays a test configuration with the nose gear isolated. The resulting beamform maps from the microphone array clearly show that for low to moderate frequencies, the noise associated with the nose gear is 4-5 dB higher than the surrounding noise levels. Using the AFN flight test results, the nose landing gear was deemed to be better suited (as compared to the main gear) as a benchmark configuration for the following reasons. First, the proximity of the main gear to a wing with deployed flaps meant that installation effects were extremely significant for this component – the circulation produced by the high-lift wing imposes a highly three dimensional, non-uniform flow for the main gear during approach that would be hard to duplicate in model-scale tests without the inclusion of the wing geometry. Second, addition of the wing to a main gear in order to recreate a realistic flow field would have produced a benchmark configuration that is too complex to be of interest for an initial study. Third, given that the wing geometry was, and still is, proprietary to Gulfstream, its inclusion in a model problem for the main landing gear would have prevented dissemination of the overall configuration, thus defeating the purpose of the benchmark.

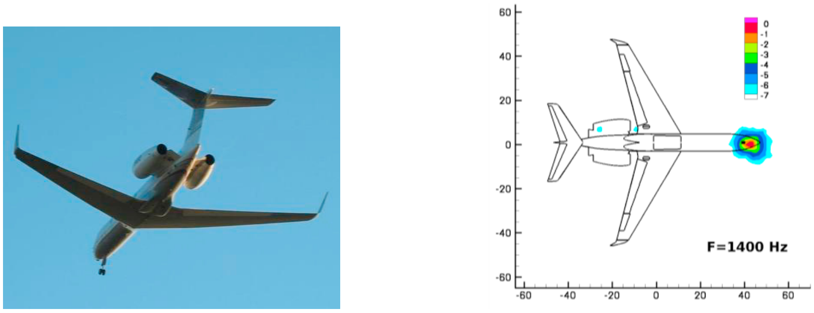


Fig. 1 Isolated nose landing gear configuration during AFN flight test and a sample noise source localization map.

In contrast to the main gear, the installation effects for the nose gear are relatively benign and mainly arise from the internal structure of the gear cavity and the influence of the fuselage on the approach flow field. Thus, the nose gear model should possess a detailed cavity plus a segment of the underside of the aircraft fuselage. The full nose landing gear geometry is intended for use in direct comparisons of model-scale results to the measurements obtained from the AFN flight tests and/or other planned future full scale tests. To arrive at a simpler configuration that would be suitable for an airframe noise benchmark, the (subscale) wind tunnel model of the nose gear was developed in a modular form. That is, provisions were made to partially remove some of the gear dressing to simplify the configuration and make it amenable for a progressive increase in complexity.

3. MODEL DEVELOPEMENT

Once the nose gear had been selected as the more appropriate benchmark configuration, attention was focused on the strategy to develop a suitable model. The most critical issues faced during this stage are briefly described below.

3.1 Model Size Selection

The size of the model relative to the full scale article is one of those rare parameters that globally affect every aspect of the model development. Thus, the choice had to be made with great care. The selection process focused on how to arrive at an option that would best resolve some of the competing, and at times conflicting, requirements. These requirements include, but are not limited to, a) Reynolds number effects, b) geometric fidelity effects, c) installation effects and model structural integrity, d) model instrumentation, e) model cost, and f) ability to acquire measurements in multiple facilities. To satisfy the first four requirements (items a-d), one option would have been to build a full-scale model. However, because of the last two requirements (items e-f) and for many additional reasons not listed, this was an impractical choice. After carefully considering the ramifications of each requirement, a decision was made to build the nose gear model as a ¼-scale high-fidelity replica of a Gulfstream G550 nose landing gear, including part of the lower fuselage section (Fig. 2a). To duplicate the angle-of-attack effect during flight, inherent in the model design is an inclination angle of 3 degrees relative to the streamwise (x) axis. The nose gear geometry chosen for benchmarking purposes is a “partially-dressed” version of the fully-dressed gear, whereby the hydraulic and electrical lines, lighting cluster, and the steering assembly were removed and the gear cavity was closed (taped over) as shown in Fig. 2b.


a) Fully-dressed cavity open b) Partially-dressed cavity closed

Fig. 2 High-fidelity ¼-scale model of Gulfstream G550 nose landing gear. Only the partially-dressed cavity-closed configuration (b) is being advocated as a benchmark case.

3.1.1 Reynolds Number Effects

Given that a landing gear is a collection of many bluff bodies of differing shapes and disparate scales, Reynolds number (*Re*) effects come from two aspects of the model. The obvious one is its subscale nature; the second, its surface finish. We will talk about the former issue in this subsection and leave the surface finish discussion to section 3.2.

Many of the nose gear subcomponents are of cylindrical shape with the most notable pieces being the shock strut (piston), main strut, wheel axles, drag links, wheels, and hydraulic lines. The close proximity of most components to each other implies that those structures buried in the wake of upstream pieces experience a flow that is fully turbulent in most instances. Therefore, of critical importance is the state of the flow field generated by those upstream components that face the undisturbed flow. What determines the state of the wake emanating from the upstream components is the *Re* based on the local length scale, which in turn characterizes the state of the boundary layer adjacent to the solid surfaces, the nature of separation and its location from the bluff body, and the subsequent development of the detached shear layer in the wake.

In a typical nose landing gear design, the primary component facing the undisturbed incoming flow is the main strut, including the piston. Except for the largest of civil transports, the full-scale main-strut diameter on nose gears ranges from 0.1m for a regional jet to about 0.15m for a Boeing 737 class of aircraft. Assuming an approach speed of 75 m/sec (equivalent to a Mach number, M, of 0.22) for a landing aircraft and standard atmospheric conditions, the corresponding *Re* (based on strut diameter) at full scale falls between 5.0×10^5 and 7.5×10^5. This *Re* range implies that the nose gear strut on many aircraft may experience a critical flow regime precisely within the narrow range where the drag crisis occurs [10]. Thus, the strut flow field for any subscale model will surely be subcritical. Given the sensitivities of the critical flow regime to a variety of parameters, and the many difficulties in simulating such flows, it is not easy to reliably duplicate the full-scale flow field using model scale experiments.

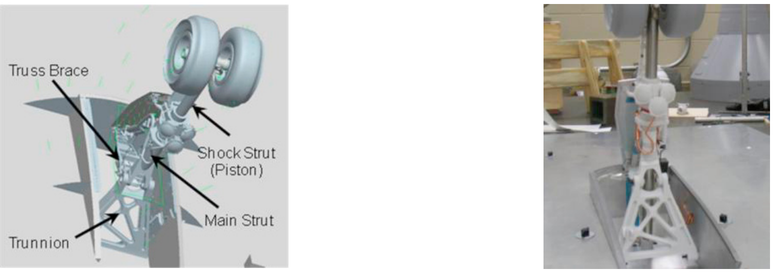
3.1.2 Geometric Fidelity Effects

A reasonable geometric fidelity to the flight test article is a direct consequence of the chosen scale for the model. Invariably, the ability to faithfully replicate the finer details of the full scale gear is diminished rather quickly as the scale of the model is reduced. The prevailing view within the airframe noise community attributes the high-frequency content of gear generated broadband noise to the smaller scale structural features that are often bundled under the name of “gear dressing” [11]. To replicate a good portion of the high-frequency gear noise, the aim was to build a high-fidelity model that would reproduce some of the finer details (structures) of the G550 nose gear. Inevitably, due to the subscale size of the model and a host of other fabrication and cost reasons, finer features of the gear below a certain length scale have to be eliminated. For the current ¼-scale nose gear model, that threshold value was set at about 0.3 cm (i.e., 1.2 cm or 0.5 inches when translated to full scale). It must be emphasized that the threshold was not applied evenly to every component or subcomponent of the nose gear. On several occasions, depending on the shape and location of the feature, structures smaller than 0.3 cm were maintained. The decision of which sub-threshold features were eliminated and which ones were kept was a judgment call. The correctness of this judgment will be evaluated when a limited comparison with the results from the AFN flight test is attempted.

The 0.3 cm threshold dimension can be used to arrive at a rough estimate of the affected frequency range. Using a freestream speed of 56.5 m/sec (the nominal speed at which the model was tested) and assuming that the dominant local flow fluctuations scale with the largest dimension (0.3 cm) of the omitted structures, the lowest model-scale frequencies affected by the loss of geometric fidelity are on the order of 19 kHz (or approximately 6 kHz in full scale based on 1/4th scale and an aircraft speed of 75 m/s). The 6 kHz frequency is certainly in the fringes of the upper frequency range of interest for airframe noise. Thus, the fully-dressed model should capture the low- to mid-frequency content of the radiated sound from the nose gear reasonably well.

3.1.3 Installation Effects

The installation effects on the model are of two distinct types. The first involves the alteration to the approach flow for the nose landing gear induced by the presence of the fuselage, and the gear-cavity flow interactions which are affected by the interior shape/structure of the gear cavity. The inclusion of a segment of the fuselage underside and a fairly accurate gear cavity as part of the nose gear configuration was intended to capture the prominent effects of these interactions. Recall that the benchmark configuration, which is a partially-dressed version of the full model, features a closed cavity; therefore, its effects are eliminated.



a) Full-scale geometry
b) ¼-scale model

Fig. 3 Difference between full-scale and model-scale nose gear geometries at junction of main strut, trunnion, and truss brace.

The second kind of installation effect results from some of the necessary modifications that are implemented on a subscale model in order to ensure the structural integrity/safety of the installed model during testing. For the nose gear model, extreme care was taken to ensure that the modifications a) are minimal, b) would not significantly alter the nose gear flow field, and c) would not become strong noise sources themselves. A clear example of this type of geometry alteration is displayed in Fig. 3. Figure 3a shows the termination of the full-scale main strut above the cavity opening at the juncture of the strut, trunnion, and truss brace. For the ¼-scale nose gear model, the necessary geometric fidelity of the trunnion and truss brace was maintained by fabricating these subcomponents from a polycarbonate material (hardened plastic) using rapid prototype manufacturing. Accordingly, they lacked the required strength to withstand the gear loads during wind tunnel testing. To maintain structural integrity of the model under loads, the most practical option was to extend the metallic shock piston all the way to the floor of the gear cavity where the model was anchored. Figure 3b shows the modified strut-trunnion juncture for the nose gear model. It is noted that the extension of the strut into the cavity only affects a very small region adjacent to the surface of the fuselage and the cavity opening. The flow speeds in this region were expected to be low; thus, flow alteration, and the resulting noise generation, would be minimal.

3.1.4 Model Instrumentation

To truly create an airframe noise benchmark that would assist in validating the ensuing CAA simulations, one must generate a comprehensive experimental dataset for the nose gear model. One important element of such a dataset is the acquisition of extensive steady and unsteady surface pressures. With surface instrumentation comes the need to accommodate a significant number of pressure tubes and wires that must be hidden inside the model. Often, failure to foresee the intricate balance between choosing a model size and the need to properly instrument the model can be disastrous. The small internal passages and openings of the nose gear model, and the fact that every surface probe on the wheels had to pass through the shock piston, exacerbated the problem.

As a clear example of some of the difficulties, Fig. 4a shows the juncture of the wheel axle and the shock piston components of the nose gear model. As a reference, the axle interior opening is roughly 1.27 cm in diameter and must accommodate approximately 18-20 1.0 mm pressure tubes coming from each wheel on either side of the axle. Note that at the axle-shock piston junction all 40 tubes must make a 90 degree turn in order to exit through the interior of the piston, which has an opening no larger than 1.56 cm. Figure 4b displays the fully dressed nose gear model with the bundle of tubes and wires exiting the main strut on the cavity floor. The example is provided to emphasize that the ¼-scale was chosen after carefully outlining an instrumentation plan and balancing that need with other model requirements. An easier and much cheaper option would have been to run a large number of the tubes and wires on the exterior surface of the model. However, given the high number of surface pressure ports and transducers that were required, that option would have produced a bulky, unrealistic configuration bearing little resemblance to the nose gear geometry of interest.

a) Internal passages b) Tubes routed inside strut c) Placement of exterior wires

Fig. 4 Internal routing of pressure tubes and external placement of transducer wires.

Despite our careful planning, the wiring for several surface mounted dynamic pressure transducers had to be placed on the exterior surface of the model. In those instances, in order to minimize the local flow alterations, every effort was made to run and locate the wires on the aft surface of the main strut where low speed wake (dead) flow zones are expected. Figure 4c shows the external placement of some of the transducer wires. It must be noted that the number of externally wired transducers was significantly lower on the partially-dressed cavity-closed (benchmark) configuration. This was due to the fact that most of these external transducers were installed on the components (e.g., lighting system, steering mechanism, etc.) that were part of the fully-dressed gear.

3.1.5 Measurements in Multiple Facilities

The process of gathering a high-quality dataset that can be used for benchmarking purposes involves the acquisition of a variety of data, including steady and unsteady surface pressures, off-surface mean flow and turbulent fluctuations, and far field acoustic measurements. The necessity and ability to conduct the tests in multiple wind tunnels arises from two critical and distinct needs. First, seldom can such an extensive dataset be gathered from measurements conducted in one facility. Second, entries in multiple tunnels are sought in order to determine and mitigate any facility dependencies of the data being acquired – the more facilities a model is tested in, the better defined the statistical uncertainties associated with the dataset become.

It has been emphasized in this section that much attention must be paid upfront in choosing the right scale for the model, as that decision determines where the model can be tested and the type of measurements that can be obtained. For example, it would have been possible to build a much larger G550 nose gear model than the current ¼-scale configuration. However, that action would have relegated the model to being tested in a particular facility only, probably one of the larger production tunnels at NASA. Because of limited tunnel availability and the high cost of each entry, testing in a large facility is not an efficient way of generating the extensive aeroacoustic database that is desired. For that purpose smaller, research oriented wind tunnels are more appropriate. A survey of available research tunnels in the United States where aerodynamics, acoustics, or both types of measurements could be performed within a reasonable budget pointed to an optimal model size approaching ¼-scale.

3.2 Surface Finish

Recall from section 3.1.1 that Reynolds number effects arise from the scale and surface finish of the model. To maintain a high geometric fidelity, many of the model components and subcomponents were mostly fabricated via a rapid prototyping procedure using a polycarbonate material, and on rare occasions were produced via metal casting. Typically, the surface roughness of such components is much higher than that of wind tunnel rated metallic parts produced from a regular machining process. Although no information could be found in the available literature on average values of surface roughness for objects made out of polycarbonate, expert machinists at the NASA Langley Research Center (LaRC) suggested a root mean square (rms) value ranging between 6 and 10 micrometers. This estimated roughness level is an order of magnitude higher than the surface finish of 0.8-1.0 micrometers associated with a typical machined piece suitable for low speed testing. The only subcomponent with a pre-specified smooth surface finish was the shock-strut (piston).

While smoothing and polishing the polycarbonate surfaces would have been an easy task, such an action, combined with the subscale size of the model, would have ensured a mostly laminar flow field adjacent to the solid surfaces, making comparisons with the full scale results more problematic. Thus, most of the model surfaces were kept rough. In our view, the extra roughness would accelerate the transition to a turbulent state, promoting a faster (premature) aging of the turbulent boundary layers adjacent to the solid walls. It was believed that such a premature aging would reproduce boundary layer characteristics similar to those encountered at full-scale Reynolds numbers. Obviously, this was a conjecture on our part, and its validity remains to be proven when direct comparison with full-scale results is attempted. More important, however, is the fact that the near wall boundary layers can be reasonably assumed to be turbulent, making the computational task of simulating the nose gear configuration a much easier and cost effective endeavor – hybrid approaches such as Detached Eddy Simulation (DES), which require the flow in the near wall regions to be fully turbulent, become viable tools.

3.3 Benchmark Experiments

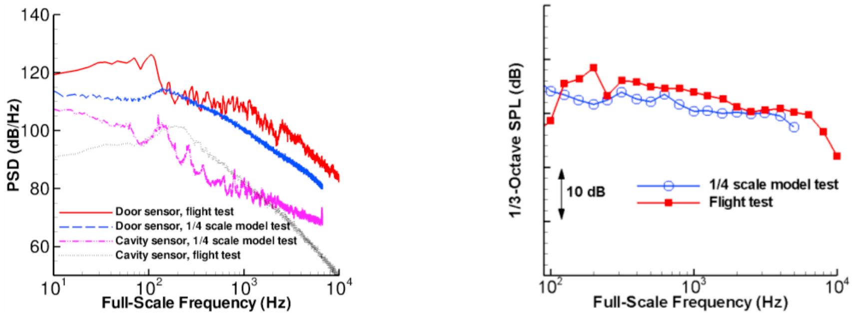
For airframe noise validation purposes, any benchmark dataset must go beyond documenting the mean flow state and include an extensive mapping of the perturbation field: surface pressure fluctuations, and off-surface Reynolds stress and turbulent kinetic energy fields. Moreover, to close the gap between test conditions and simulations, an accurate account of incoming flow and exit plane conditions such as boundary layer thickness on the tunnel walls, incoming flow free-stream turbulence levels, incoming flow uniformity and angularity, exit plane pressures, etc. is needed.

The aeroacoustic measurements for both the fully-dressed cavity-open and partially-dressed cavity-closed (the benchmark geometry) nose landing gear configurations were accomplished in multiple phases using two different wind tunnel configurations. Extensive aerodynamic measurements were obtained with the model installed in the closed-wall Basic Aerodynamic Research Tunnel (BART) at NASA LaRC [12]. The corresponding acoustic and limited aerodynamic measurements were acquired in the open-jet University of Florida Aeroacoustic Flow Facility (UFAFF) [13].

The aerodynamic measurements performed in BART were obtained at M = 0.12, 0.145, and 0.166. The data consisted of steady and unsteady surface pressures plus planar particle image velocimetry (PIV) for documenting the turbulent fluctuations field. Concurrent acoustic and surface pressure measurements (conducted in UFAFF) were obtained for M = 0.145, 0.166, and 0.189. Laser Doppler velocimetry (LDV) measurements of the regions that are hard to map using the PIV technique (i.e., between the shock-strut and torque arm, main strut and door, etc.) are ongoing at UFAFF as of this writing. In both tunnels, the boundary layer over the shock-strut was tripped to help achieve a turbulent flow separation. However, there were no direct measurements to verify whether this was achieved or not. The datasets were generated based on multiple entries in each facility to ensure data repeatability, determine statistical uncertainties, and extract measurement errors.

4. MEASURED DATA

A detailed account of the aerodynamic measurements conducted at BART, including data quality and repeatability, plus discussions of the post processed results for both fully-dressed and partially-dressed (benchmark) nose gear configurations were given by Neuhart et al. [12]. Similarly, the companion discussions of the acoustic measurements performed at the UFAFF were given by Zawodny et al. [13]. In this section, we show a comparison between flight test data and measurements for the fully dressed nose gear model in order to assess the validity of some of the critical decisions that were made during the model development stages. The comparison will be limited since surface pressures were measured at only three locations (the main gear strut, the nose gear door, and the nose gear cavity back wall) during the 2006 AFN flight test. Measurement of surface pressure fluctuations at more locations are planned for future flight tests.



a) Surface pressure fluctuations b) Far field noise

Fig. 5 Comparison of unsteady pressures and far field sound between flight-test and model-scale measurements

Power spectral density (PSD) plots of the surface pressure fluctuations are shown in Fig. 5a. It is noted that the flight sensors were mounted on top of the surface [9], as opposed to being flush mounted as in the model, which may cause minor alterations in the full-scale PSD. The model-scale data have been converted to correspond to the full-scale data using Strouhal scaling for the frequencies and dynamic-head scaling for the amplitudes. Focusing on the door pressures, notice that the pressure spectra obtained in flight and the model-scale measurements possess a similar character over most of the frequency range. The largest discrepancies between the two sets of data occur at low frequencies (below 100 Hz) where there is a sudden rise in the full-scale pressure levels. The underlying cause of this pressure rise is unknown. While installation effects may play a role, the gear cavity can be excluded due to the much lower pressure levels measured by the transducer mounted inside the cavity. Notice that both curves depicting the door pressures capture the roll-off at high frequencies with a similar slope. However, the roll-off from the model-scale test begins at much lower frequencies. This difference may be attributed to two distinct factors. One involves the low Reynolds number effects resulting from the subscale size of the model and the lower speed at which it was tested. The other factor is related to the lack of geometric fidelity for the extra fine details of the full landing gear, which in essence eliminates part, if not all, of the high-frequency content of the gear flow field. For the present case, it is very difficult to distinguish which factor is more important in reducing the high-frequency content of the model-scale data.

Measurements obtained inside the cavity indicate that the pressure levels there are at least one order of magnitude lower than the pressures on the door. In this regard, both flight and model tests reveal a consistent trend – the cavity is quiescent. For the PSD curve associated with the model test, the spikes between 90 Hz and 1000 Hz, and the elevated pressures at frequencies lower than 80 Hz, are caused by the tunnel fan tones and other related noise.

A comparison of far field sound pressure levels (SPL) is displayed in Fig. 5b. The model-scale frequencies have been converted to full-scale values using Strouhal scaling and the corresponding SPLs have been adjusted using a M^6 power law. In addition, 3 dB have been added to the pressure levels obtained with the UFAFF free field microphones to partially compensate for the ground reflection effects inherent in the standard certification (pole mounted microphone 1.2 m above ground) measurements of the flight test. This adjustment is quite conservative, based on the worst case scenario of ground reflections producing incoherent noise at all frequencies. This assumption is not fully correct. In reality, depending on the frequency of the reflected sound, the amplitude correction should fall somewhere between 3 dB and 6 dB. That is, at high frequencies, the correction is closer to 3 dB and at low frequencies, it approaches 6 dB.

Note from Fig. 5b that the noise spectrum produced by the ¼-scale model shows a good match with the flight test data both in terms of the shape and frequency content. For most of the frequencies, the model sound levels fall within 2 dB from the noise produced by the full-scale landing gear. As suspected, the difference in amplitudes is highest in the lower frequency range of the spectrum. Given the known difficulties inherent in flight test far field noise measurements and the various corrections applied to such data, the relatively close agreement displayed in Fig. 5b is very encouraging. This close agreement suggests that the surface pressure fluctuations produced by the nose gear model should be comparable (in an aggregate sense) to full scale pressures. Given the differences observed in the door pressures (Fig. 5a), this would imply that a) the discrepancies are unique to this sensor location, or b) the door is not a prominent noise source. Unfortunately, due to the limited availability of in-flight surface pressure measurements (door and cavity locations only), comparisons of pressures at other locations on the nose gear have to wait until a planned future flight test is conducted.

5. SUMMARY

Development of realistic CAA benchmarks targeting airframe noise research is a critical need that deserves urgent attention. To generate a set of benchmark cases that would remain viable for the foreseeable future, resolution of several competing and yet conflicting requirements and attributes is necessary.

An initial step towards fulfilling this need has been taken, resulting in a benchmark configuration that is based on a Gulfstream G550 aircraft nose landing gear. Although a high-fidelity replica of the nose gear geometry was developed, a somewhat reduced version of the configuration is being advocated at present as a benchmark case. A relatively detailed account of the thought processes and the subsequent steps taken to develop and establish the nose gear model as a benchmark case is given. It is shown that the task of selecting a configuration, fabricating a model, and acquiring high-quality measurements that are worthy of being designated a benchmark is an arduous, long journey that takes 3 to 4 years of hard work to accomplish. It is emphasized that the key decision during the developmental stages is the selection of the model scale, as this decision globally affects important issues such as: a) Reynolds number effects, b) model geometric fidelity, c) installation effects, d) model instrumentation and measurement strategy, e) model cost, f) testing in multiple facilities, and a host of other requirements. The most critical of these issues are discussed in detail, and in the process, it is shown how such requirements are coupled with the model size selection.

Although full resolution of the Reynolds number, geometric fidelity, and installation effects is yet to come, a limited comparison of the surface pressure fluctuations obtained during the AFN flight tests with those measured for the ¼ scale fully-dressed cavity-open nose gear model show that the model captures the overall character and relevant trends observed with the full-scale nose landing gear. Comparisons of the far field sound pressure levels are encouraging: both the shape and the frequency content of the sound spectrum are well duplicated by the model, and the noise amplitude falls within 2 dB of the flight test data for most frequencies of interest. Having established the validity of the fully-dressed gear model, the partially-dressed cavity-closed nose gear configuration should be a good benchmark, being realistic and yet simple enough to be of interest within the aeroacoustics community.

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