Status of Noise Research Aimed at Subsonic Transport Technology Solutions

By Amr Ali (Pratt & Whitney), Jose Alonso (Collins Aerospace), Micael Carmo (Embraer), Dominique Collin (Safran), Carlos Grandi (Embraer), Mark Huising (Bombardier), Nicholas Humphreys (Rolls-Royce), Yuri Khaletski (CIAM), Victor Kopiev (TsAGI), Pierre Lempereur (Airbus), Muni Majjigi (GE Aviation), Duane McCormick (UTRC), Eric Nesbitt (Boeing), Tsutomu Oishi (IHI), Jeffrey Peters (Rolls-Royce), Scott Piercy (Boeing)

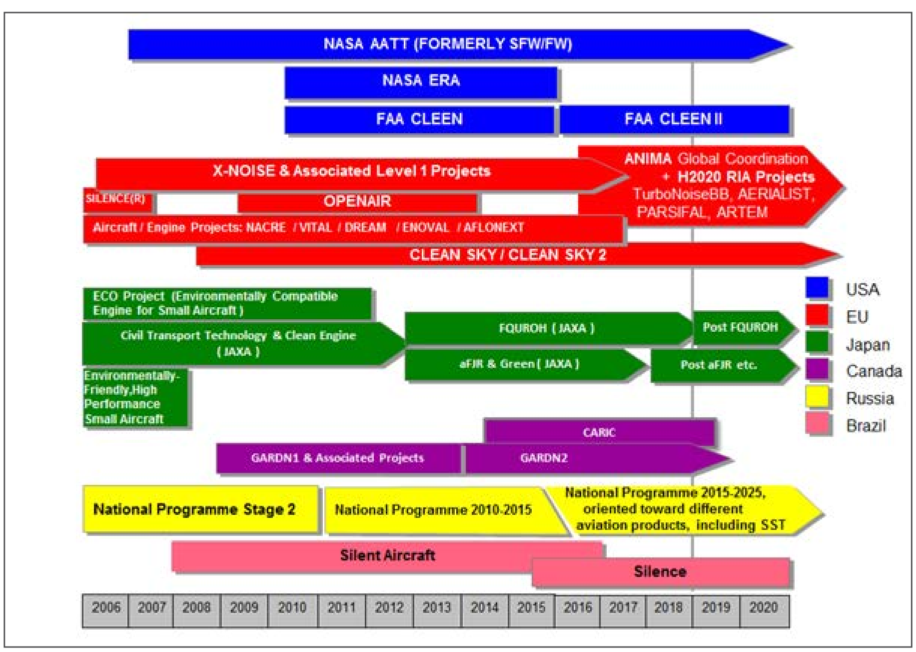
INTRODUCTION

The task of monitoring noise technology research programs has been underway since the CAEP/6 cycle (2006). This has provided an opportunity to develop a broader view of the status of joint Government / Industry efforts in implementing research initiatives. As such, this article provides an overview of the ongoing research projects on noise technology worldwide.

The global situation of noise technology research initiatives as of December 2018, is summarized in Figure 1. It covers a 15-year period (2006-2020), and provides an evolutionary perspective, indicative of the worldwide commitment to continuously support the technology side of ICAO's Balanced Approach.

Summaries of each research initiative represented in Figure 1 are provided in the following sections of this chapter.

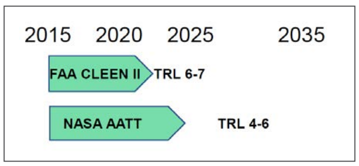
FIGURE 1: Committed major national / regional initiatives as of end 2018



US NOISE TECHNOLOGY RESEARCH PROGRAMS

Aircraft noise research efforts in the United States have two major funding sources: the National Aeronautics and Space Administration (NASA), and the Federal Aviation Administration (FAA). For both entities, noise reduction concepts must meet multidisciplinary criteria and should have minimal impact on aircraft weight and performance.

FIGURE 2: Timeline for US aircraft noise reduction research



NASA's Advanced Air Transport Technology (AATT) project has numerous technical challenges related to noise reduction. Its objective is to demonstrate Technological Readiness Level (TLR) 4-6, looking toward mature technology solutions in the 2035 – 2045 timeframe. The noise reduction technical objectives target 22-32dB (below Stage 4) in the near-term (2015-2025), 32-42dB in the mid-term (2025-2035) and 42-52dB in the far term beyond 2035. Of the $90M of funding in 2018, $11.7M was focused on noise reduction and involved 37 researchers. For 2019, $11.2M in funding and 35 researchers were allocated for noise research. Solicitations for NASA Research Opportunities in Aeronautics continue on an annual basis.

TABLE 1: NASA AATT technology objectives

TECHNOLOGY BENEFITS	TECHNOLOGY GENERATIONS (Technology Readiness Level = 5-6)		
	Near Term 2015-2025	Mid Term 2025-2035	Far Term beyond 2035
Noise (cum below Stage 4)	22 - 32 dB	32 - 42 dB	42 - 52 dB
LTO NOx Emissions (below CAEP 6)	70 - 75%	80%	> 80%
Cruise NOx Emissions (rel. to 2005 best in class)	65 - 70%	80%	> 80%
Aircraft Fuel/Energy Consumption (rel. to 2005 best in class)	40 - 50%	50 - 60%	60 - 80%

Technologies currently being researched under AATT are: low-noise high-lift devices to reduce airframe noise on approach, multi-degree-of-freedom low-drag liners on purpose-built research turbofan engines (DART) including full-scale flight tests, novel fan case-liners for short intakes, and system studies on novel aircraft designs.

The FAA CLEEN II program looks at more mature noise reduction technologies to demonstrate TRL 6-7. The objectives of CLEEN II include demonstrating certifiable technologies to meet the environmental targets of 32dB below Stage 4 by 2020. While CLEEN II will be ending in 2020, CLEEN III plans to pick up with new projects solicitations expected in 2019. CLEEN II funded $18.9M for research in 2018, and $6.7M is planned in 2019. Key participants for noise reduction studies were Boeing/Aurora, GE, and Collins (formerly UTAS).

TABLE 2: FAA CLEEN technology objectives

Goal Area	CLEEN I Goals (2010-2015)	CLEEN II Goals (2015-2020)
Noise (cumulative below Stage 4)	-32 decibels (dB)	-32 decibels (dB)
LTO NO_X Emissions (Below CAEP/6)	-60 percent	-75 percent (-70 percent re: CAEP/8)
Aircraft Fuel Burn	-33 percent	-40 percent

In July and August of 2018, Boeing completed the Quiet Technology Demonstrator 3 (QTD3) flight test under the NASA AATT program to demonstrate and increase the TRL of the low-drag Multi-Degree Of Freedom (MDOF) acoustic lining in the inlet. Introduction of the low-drag lining technology led to a 3.4 EPNdB cumulative benefit on measured inlet noise when compared with a standard production liner (see Figures 3 and 4, and Table 3).

FIGURE 3: Low-Drag Lining technology progression

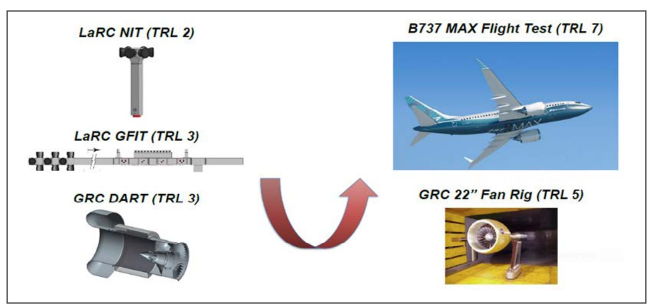


FIGURE 4: Hardware tested and noise measurements taken

TABLE 3: Inlet measured component noise reduction

Condition	Approach	Cutback	Takeoff	Cumulative
Benefit (re Production Liner)	0.6 EPNdB	1.5 EPNdB	1.3 EPNdB	**3.4 EPNdB**

Under FAA's CLEEN I, GE Aviation completed open rotor wind tunnel tests which demonstrated 15 EPNdB cumulative reduction relative to Chapter 4 and a 26 per cent fuel burn reduction relative to engines with BPR of ~5-6. Under FAA's CLEEN II, GEis developing two noise technologies:

- Liners employing new manufacturing and analytical techniques to provide 2 EPNdB cumulative noise reduction relative to single degree of freedom liners. Another objective of this technology is not to impact fuel burn.
- Three-dimensional aero-acoustic design of fan-OGV to reduce fan-OGV interaction noise to provide ~1 EPNdB cumulative noise reduction. GE plans to test such designs in a sub-scale rig.

Under CLEEN I, Pratt & Whitney developed and demonstrated an ultra-high bypass ratio Geared TurbofanTM (GTF) engine, and associated advanced technologies.

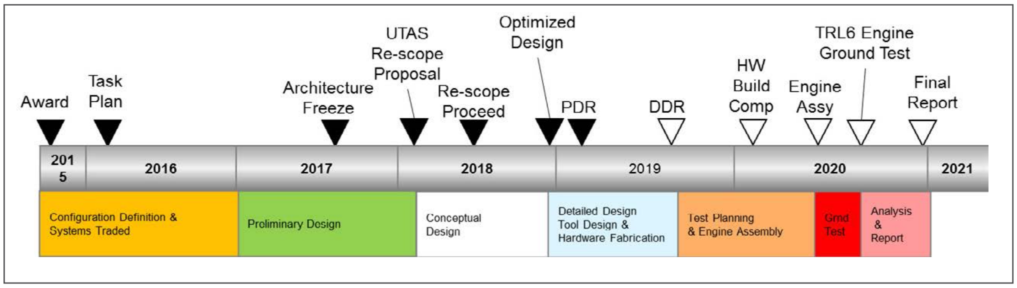
In 2017, Pratt & Whitney completed an ultra-high bypass engine test campaign, demonstrating aerodynamic performance, mechanical, and acoustic characteristics of advanced fan system technologies. GTF engine technologies contributed to a 20 dB aircraft noise reduction and a 20 per cent fuel burn reduction because of increased engine efficiency. This advancement builds on the completion of 275 hours of fan rig testing of the technology in 2014 and 2015. A key element in the technology maturation is the development and application of highly-integrated Computational Fluid Dynamics (CFD) tools developed by United Technologies, which provide accurate predictions and design guidance.

Under NASA funding, United Technologies Research Center (UTRC) is developing a first-of-its-kind database of detailed unsteady measurements characterizing noise sources of advanced (N+3) low-emissions aero-combustors. This data enables improvements to reduced-order models for use in system level noise assessments. In the longer term, it will address the validation needs of high fidelity prediction methods suited for detailed multi-disciplinary acoustics and emissions combustor design.

Under CLEEN II, the efforts of Collins Aerospace are aimed at maximizing efficiency of 2025 high-bypass ratio propulsion systems, by conducting a nacelle technology demonstrator that incorporates an aerodynamically and acoustically optimized fan duct architecture (Figure 5). The ground demonstrator, which will be tested on a Pratt & Whitney engine, simulates a clean fan duct with maximized acoustic area, low drag surfaces, and zoned acoustic liners. The overall package targets 2.0 EPNdB community noise benefit. Manufacturing efforts are currently underway to support a full-scale acoustic test in 2020. The overall project schedule is summarized in Figure 6.

FIGURE 5: Collins Aerospace CLEEN II technologies

FIGURE 6: Collins Aerospace CLEEN II schedule



EU NOISE TECHNOLOGY RESEARCH PROGRAMS

A full assessment of the situation relative to the ACARE 2020 noise target (-10 dB/ operation relative to 2000) was performed in 2015. Conclusions were that the European aircraft noise research effort was to be considered on-track to meet its objective, albeit requiring maintaining significant support in the few years remaining before 2020. In parallel, the 2012 ACARE Strategic Research and Innovation Agenda (SRIA) had already established noise targets for the longer term, and laid out key directions for post-2025 technology solutions.

A number of projects have then addressed both aspects, involving major manufacturers (Airbus, Rolls-Royce, Safran, MTU, GKN, Leonardo) and leading research establishments (DLR, Onera, NLR, CIRA) among others. The whole effort is further described below and summarized in Figure 7.

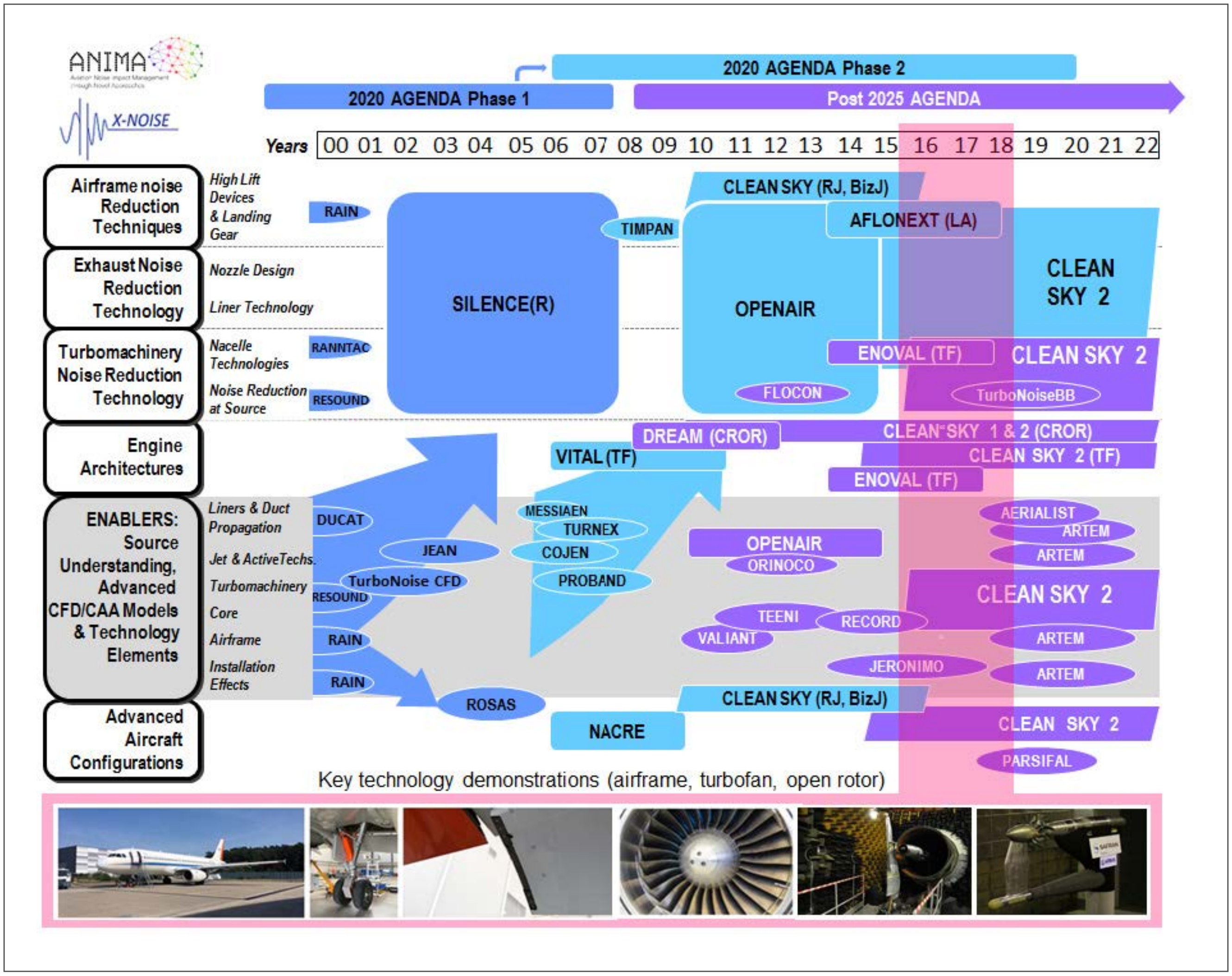
On the aircraft side, the project AFLONEXT (Active Flow, Loads & Noise control on next generation wing) successfully advanced maturation of airframe noise reduction technologies through flight testing a series of flap and main landing gear solutions in 2018. On the engine side, JERONIMO (Jet noise of high bypass ratio engine: Installation, advanced modelling and mitigation) completed its experimental assessment of “under the wing” installation effects on jet noise generated by UHBR engines. ENOVAL (Engine Module Validators) addressed similar engine designs from the fan noise perspective, supporting low noise rotor and stator configurations, associated with advances on active liner concepts. In this area, TurboNoiseBB (Validation of improved Turbomachinery Noise prediction models and development of novel design methods for fan stages with reduced BroadBand noise) has now taken over, supporting the validation of improved turbomachinery noise prediction models and the utilization of novel design methods for fan stages with reduced broadband noise, while CLEAN SKY 2 is involved in further maturation of engine acoustic liners.

With regard to the longer term agenda, while a general novel aircraft architectures effort is further supported in CLEAN SKY 2 and PARSIFAL (Prandtlplane Architecture for the Sustainable Improvement of Future Airplanes), the project ARTEM (Aircraft Noise Reduction Technologies and related Environmental Impact) has initiated a wide approach investigating new “generation 3” noise reduction technologies and installation effects relevant to the use of UHBR turbofans and distributed propulsion configurations (DEP) on such aircraft concepts. This effort is complemented by AERIALIST (AdvancEd aicRaft-noIse-AlLeviation devIceS using meTamaterials), a project specifically addressing the use of meta-materials applied to the reduction of engine and airframe noise emission.

Concerning Open Rotors engine designs, further wind tunnel experiments carried out under CLEAN SKY 2 have helped to consolidate the assessment of noise levels expressed in the previous report, while a full-scale engine demonstrator ran to confirm the high interest in such a propulsion concept. When placed in perspective with the best expectations resulting from the original 1987 flight-test assessments conducted on such a concept, this represents a typical 20dB noise reduction on a cumulative margin basis, a spectacular achievement for the European research effort that was initiated in 2008.

At last, in response to the expressed need for a strongly coordinated and integrated approach, taking over the legacy of the X-NOISE coordination action, the ANIMA (Aviation Noise

FIGURE 7: European noise projects roadmap and key technology demonstrations



Impact Management through novel Approaches) project team has now been tasked to: support the global coordination of EU research activities, establish a common strategic research roadmap for aviation noise reduction through the involvement of a pan-European network of experts and project leaders, and address international collaboration opportunities.

JAPANESE NOISE TECHNOLOGY RESEARCH PROGRAMS

A couple of projects in Japan have addressed both aircraft and engine noise reduction. Both JAXA's FQUROH (Flight Demonstration of Quiet Technology to Reduce Noise from High-lift Configurations), aFJR and Green projects are discussed below.

JAXA's FQUROH project is aimed at establishing technologies for airframe noise reduction. Noise reduction concepts for flap side – edges and main landing gear were applied to JAXA's experimental aircraft "Hisho" which is a modified version of a Cessna Citation Sovereign. The project name "FQUROH" is derived from the word for "owl" in Japanese. The 2nd flight test campaign was conducted in 2017 to validate the CFD/CAA-based noise reduction designs, and successfully showed flap and MLG noise reductions of 3 to 4 dB[A].

JAXA's aFJR (advanced Fan Jet Research) project is aimed at developing a light-weight acoustic liner panel made from resin. The aFJR project was a collaboration between JAXA and IHI. A fan rig test in an acoustic facility confirmed noise reduction similar to what was achieved with a conventional

Al-based liner panel in 2017.The Green engine program involved noise reduction technologies including a "notched nozzle". JAXA and IHI have demonstrated acoustic and aerodynamic performances of the notched nozzle. A microjet nozzle was also studied through international cooperation.

The FQUROH project is going to finish in 2019, and the FQUROH+ project will be continued. The aFJR project and Green programs completed in 2018, however new research programs are to be continued. For example, demonstration of aFJR acoustic panel with a full-scale engine has been planned, also acoustic R&D nacelle, nozzle, etc., with rig and subscale engine has been started.

FIGURE 8: Overall views of research outcomes from the FQUROH project

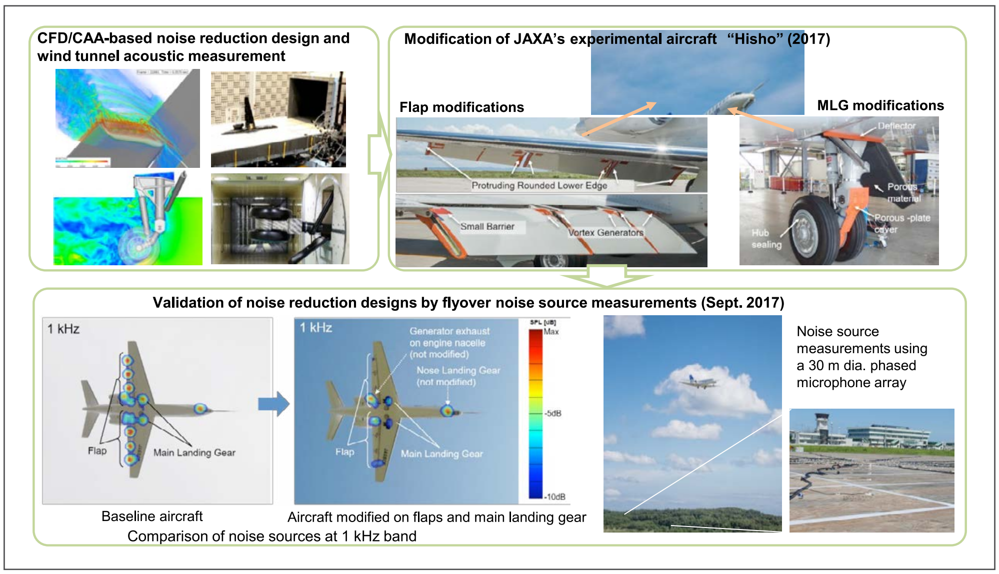
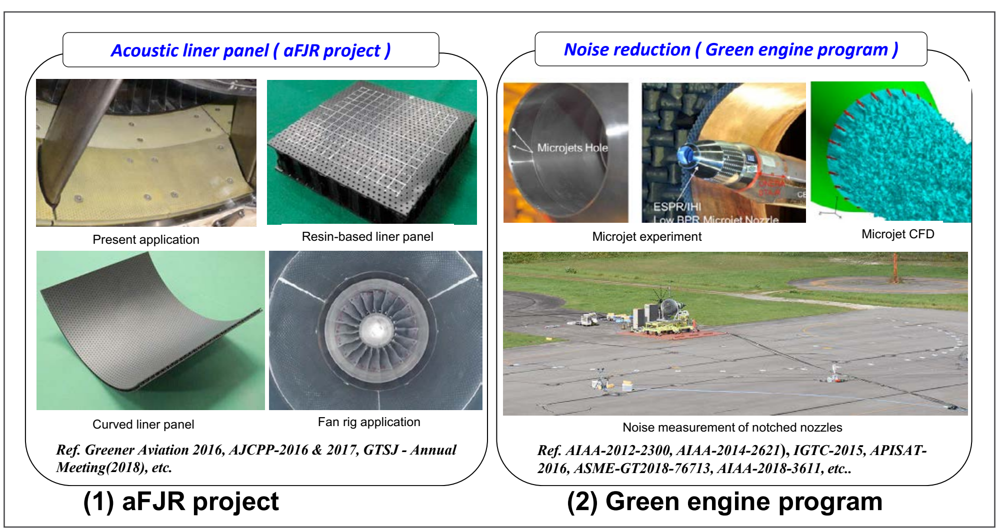


FIGURE 9: Overall views of research outcomes from aFJR project and Green engine program



CANADIAN NOISE TECHNOLOGY RESEARCH PROGRAMS

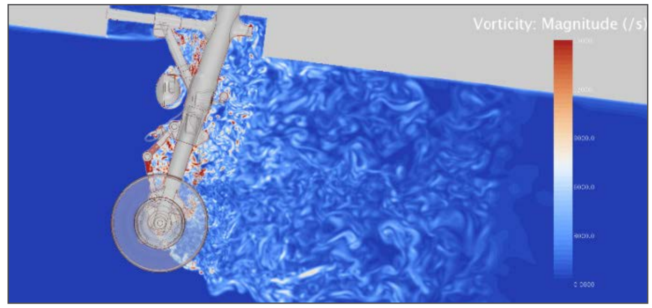
The Canadian Green Aviation Research and Development Network (GARDN) has funded three noise source reduction projects since 2014.

Airframe Noise Reduction for Business and Commercial Aircraft

This project sought to improve noise modeling and to develop noise reduction techniques to reduce exterior noise of new aircraft designs. Partners included: Bombardier, Héroux-Devtek, University of Toronto, and the National Research Council of Canada (NRC).

- Phase array technology: Advanced algorithms to enhance sound source localization, particularly low frequency methods.
- Airframe noise prediction and reduction: Improved computational methods to predict noise from high-lift devices as well as nose and main landing gears. Numerical predictions were validated by high-quality on-surface and far-field measurements.

FIGURE 10: Landing Gear noise: Numerical Prediction

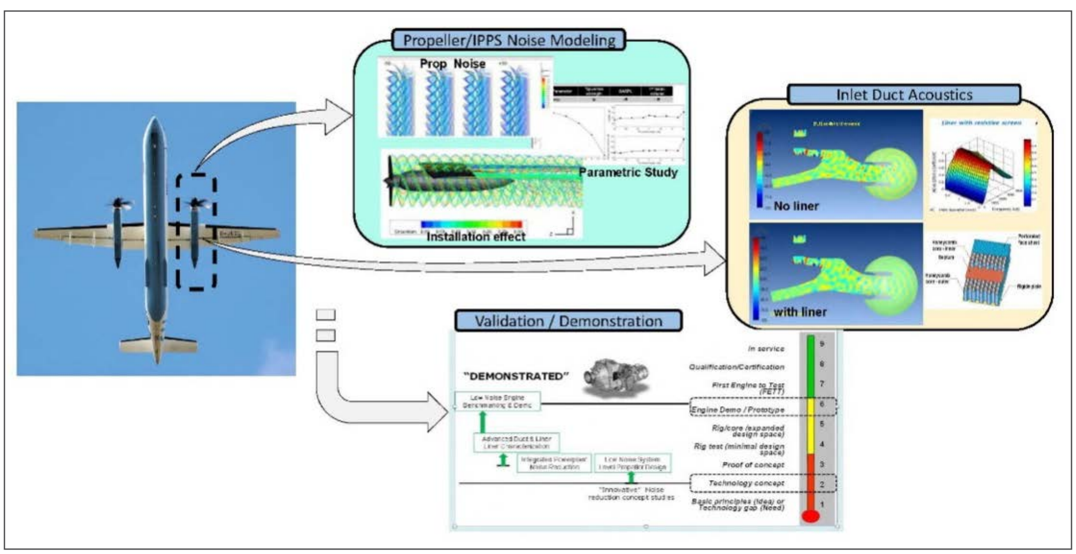


- Semi-empirical methods: The phased-array and computational aeroacoustic results were used to enhance traditional semi-empirical methods for the prediction of airframe noise.

Noise Reduction for Next Generation Regional Turboprop

The objective of this project is to leverage new technologies, to develop new design methodologies, and to enhance concepts in support of the development of low-noise large regional turboprop aircraft. Partners included Pratt & Whitney Canada, Mecanum Inc., Carleton University, and Université de Sherbrooke.

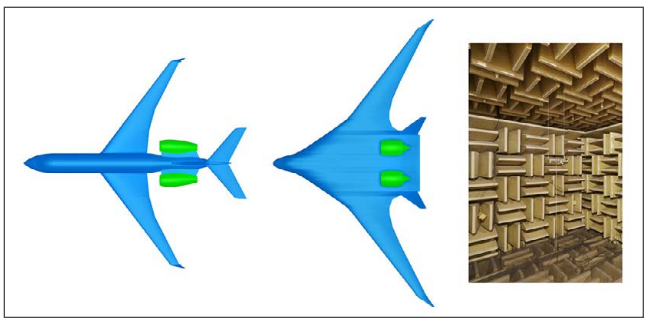
FIGURE 11: Noise measurements of innovative, environmentally friendly aircraft configuration



Noise Measurements of Innovative, Environmentally Friendly Aircraft Configuration

Bombardier, the NRC, and Mecanum Inc. conducted acoustic measurements using NRC's anechoic acoustic chamber facility and a point source developed by the Université de Sherbrooke. The project partners measured sound using a conventional aircraft model for experiment validation and tool calibration then conducted measurements using a novel aircraft configuration model. It is apparent that the novel configuration may have an advantage over the conventional configuration by using the wing, body, and tail to shield the engine noise from propagating to the ground.

FIGURE 12: Novel aircraft (centre) modeled by Bombardier using data found in: Bonet, J.T., "Boeing ERA N+2 Advanced Vehicle Concept Results", 50th AIAA Aerospace Sciences Meeting, 2012-01-11



RUSSIAN NOISE TECHNOLOGY RESEARCH PROGRAMS

The research on aviation noise in Russia addresses such topics as airframe noise, engine noise (including fan and jet noise), and interaction noise (primarily, jet-wing interaction noise).

Research on airframe noise includes: developing methods of noise reduction for landing gears based on small-scale experiment, large-scale tests of wing noise sources (slat, flap-side edges etc) and methods of their mitigation, and airframe noise localization of MS-21 in flight tests.

Engine noise research comprises acoustical tests of single-rotor and counter-rotating fan models in CIAM C-3A test facility, and confirmation of their required mechanical and aerodynamic parameters in full-scale engine tests. Small-scale and large-scale acoustic liners with different geometrical parameters were manufactured and studied. Methods of impedance eduction were elaborated together with Onera and DLR (EU project ASPIRE, IFAR cooperation). Measurements of azimuthal acoustic modes in small-scale and full-scale engine inlets were carried out in three different configurations: in the model air inlet with incoming flow in AC-2 TsAGI, in the large-scale inlet without flow in the anechoic chamber of PNRPU in Perm, and at the open test rig OS-5 of "ODK-Aviadvigatel".

For jet noise reduction, active methods such as plasma actuators were studied. To enhance the physical understanding of jet noise sources, theoretical research and dedicated experiments were performed. Theoretical studies addressed large-scale sources, such as instability waves and vortex rings, and small-scale turbulence described by the correlation model. The vortex ring results were validated in large-scale experiments with vortex rings at Lavrentiev Institute of Hydrodynamics in Novosibirsk. For the first time, the azimuthal modes of a turbulent jet of an aviation engine were measured at OS-5 of "ODK-Aviadvigatel" and showed a significant agreement with the azimuthal mode measurements for small-scale jets in anechoic chamber AC-2 TsAGI.

Theoretical models of jet noise sources provided the input data for modelling jet noise shielding by the wing/fuselage, as well as jet-wing interaction. Jet noise shielding effects studied in AC-2 TsAGI for dual-stream nozzles with and without geometrical modifications (chevrons, corrugations, etc). Methods for reduction of jet-wing interaction noise were considered including different nozzle geometries and active methods such as plasma actuators.

BRAZILIAN NOISE TECHNOLOGY RESEARCH PROGRAMS

Brazilian Silent Aircraft Initiative – Aeronave Silenciosa (Fase I and Fase II - 2007 to 2015)

The objective of this initiative was to study and develop methodologies that will permit the estimate of aircraft noise generation and propagation through three main approaches: numerical simulation (CAA), analytical and semi-empirical models, and wind tunnel and flight tests.

Another objective was to bring together Brazilian specialists working on aerodynamics and acoustics, to start working cooperatively on aeroacoustics and community noise.

The main goals were to develop methodologies for prediction and measurements of jet noise, fan noise and airframe noise using wind tunnel and flight tests methodologies and tools for noise source identification.

The following Brazilian organizations were involved in this project: FINEP - Brazilian Innovation Agency, FAPESP - São Paulo Research Foundation, Embraer, USP–University of Sao Paulo, UFSC - Federal University of Santa Catarina, IAE - Brazilian Institute of Aeronautics and Space, UnB - University of Brasilia, and UFU - Federal University of Uberlandia.

SILENCE Project = Solutions for Integrating Low External Noise ConcEpts (2015 to 2018)

This initiative was designed to study and develop concepts and solutions for low external noise generation through: airframe wind tunnel testing, fan and jet rig tests, and numerical studies. A secondary objective was to improve the capabilities of Brazilian universities in providing accurate research on aeroacoustics through the use of state of the art experimental and computational techniques.

The main goals were to: develop airframe noise improvements through small scale wind tunnel tests, develop prediction and experimental methods for fan liner effects, and improve experimental and numerical capabilities on engine-airframe interaction and integration.

The following Brazilian organizations were involved in this project: FINEP - Brazilian Innovation Agency, Embraer, USP–University of Sao Paulo, UFSC - Federal University of Santa Catarina and ITA – Aeronautical Technological Institute.

FINAL REMARKS

The information presented in the foregoing article provides a useful perspective of the strong government and industry commitment that exists in numerous countries to address the technology aspects of ICAO's Balanced Approach.

In this context, the general trend for large research initiatives has been to address a global environmental agenda, with tradeoffs and interdependency aspects being considered in scientific and technical work programs. It is interesting to note that innovative approaches are investigating how an improved understanding of annoyance factors related to noise can influence noise technology development efforts. A number of such initiatives have recently emerged, broadening the scope of technology related research even further.

Finally, it should be noted that, beyond research goals, anticipated progress trends will remain dependent on several success factors such as the capability to ensure viable industrial applications for promising technology breakthroughs, as well as the commitment by governments and industry groups to maintain a steady funding support over a significant period of time.