An Overview of Canadian CAEWG Noise Research

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ABSTRACT

In October 2006, members of the Canadian aerospace industry, academics and government institutions formed the Canadian Aviation Environmental Working Group to develop a research program for Canada in the face of worldwide environmental concerns in the civil aviation sector. Using environmental life-cycle design principles, the program seeks to mature technologies and configurations that can be applied within 3-5 years to meet the competing demands of lower noise and lower emissions required of the next generation of engines and aircraft. Although industry-led, the research program will rely on collaborations with Canadian universities and research institutions. Within the field of aircraft noise, the program will include the development, improvement and validation of aero-acoustic prediction and design tools as well as optimisation methods applied to airframe/engine configurations. We have recently applied for federal funding to be established as a Business-led Network of Centres of Excellence and, if successful, will leverage that funding through other Canadian provincial funding programs as well as international collaborations.

1.0 INTRODUCTION

This paper presents the development of the Canadian Aviation Environmental Working Group (CAEWG), which focuses on improving the environmental performance of Canadian civil aviation products. It describes efforts of the Group to become established as a Canadian federally funded Business-Led Network of Centres of Excellence (BL-NCE) and the associated proposed Noise Source Reduction projects.

2.0 CANADIAN AVIATION ENVIRONMENTAL WORKING GROUP

2.1 Global Challenges

To accommodate the increase in commercial air traffic that is anticipated over the next 20 years and to address concerns regarding the impact of aviation on the environment, large-scale research programs have been established in Europe and the United States to mitigate the environmental impact of the growth in air traffic. Given the importance of these two markets, every aviation manufacturer has to be mindful of the impacts of these programs and plan accordingly.

2.1.1 ACARE Goals

In Europe, the Advisory Council For Aeronautics Research in Europe (ACARE) has set out the following goals by the year 2020 relative to 2000 [1]:

- reduce CO_2 by 50% per passenger kilometre,
- reduce average perceived noise levels by one half,
- reduce NO_x emissions by 80% and
- minimize industrial impact during manufacture, maintenance, overhaul, repair and disposal.

The European Commission Seventh Framework Programme for Research and Technological Development has budgeted approximately €1.5B for 2007-2013 to fund research in aeronautics and air transport, with one of the highest priority items being environmental improvements [2].

2.1.2 NextGen Goals and CLEEN Technology Program

In the United States, within the Next Generation Air Transportation System, or "NextGen," program, work has been undertaken to prepare for the three-fold increase in air traffic that is anticipated by 2025. One objective of NextGen is to satisfy this growth in demand while reducing significant environmental impacts. As part of NextGen, the Federal Aviation Authority (FAA) is seeking to fund a research consortium for the development, maturation and certification of Continuous Lower Energy, Emissions and Noise (CLEEN) engine and airframe technology [3].

The CLEEN Technology Program seeks to advance technologies from TRL 3-4 through 6-7, resulting in certifiable aircraft technologies that reduce

- fuel burn by 33% relative to current technology,
- landing and take-off cycle (LTO) nitrogen oxide emissions by 60% relative to the International Civil Aviation Organization (ICAO) standard adopted in 2004 and
- noise levels by 32 EPNdB cumulative relative to Stage 4.

The CLEEN program will also strive to demonstrate alternative, particularly renewable, fuels for aviation.

The FAA is requesting approximately US$123M for 2009 through 2014 to support the CLEEN program. These funds would be available to match cash or in-kind contributions by the program participants.

2.2 Canadian Challenges

With more than 80% of its products exported, the Canadian aerospace industry is of course very aware of the current and possible future environmental standards set by its major foreign markets, the largest of which are Europe and the USA. Moreover, as a signatory to the Convention on International Civil Aviation (ICAO), Canada would adopt any new requirements that are incorporated into the ICAO Standards and Recommended Practices, and this would have a direct bearing on the Type Certification of future Canadian aviation products.

Canada's aerospace industry, with roots going back to the beginning of aviation, has established itself as the fourth largest in the world [4]. In keeping with this leadership role, it is reasonable to expect that

Canada should be proactive on aviation environmental issues. This is indeed the case with regard to the strong participation by Canada in the ICAO Committee on Aviation Environmental Protection; however, so far, perhaps due to its relatively small economy, Canada has had no publicly funded research and development programs on aviation source noise and emissions reduction comparable to those in the EU and the US. The advent of a more integrated North American economy with NAFTA has not helped in this regard, either. Whereas European countries can participate in the EU research programs, there has been no similar development in North America. Even though Transport Canada has joined the FAA and NASA to fund the Partnership for Aviation Noise and Emissions Reduction (PARTNER), source noise and emissions reduction is not included directly in the PARTNER work program [5]. In North America, funding for this type of work is only being planned through the US CLEEN program. So, in the face of the mounting pressure to improve the environmental performance of its products, the Canadian aerospace industry has had to be proactive and develop a research program of its own.

2.3 Industry Response

In order to develop a program that would enable the Canadian aerospace industry to remain environmentally and commercially competitive in the global marketplace, members of the industry, led by Benny Pang of Bombardier Aerospace (BA) and Gaetan Girard of Pratt & Whitney Canada (P&WC), formed the Canadian Aviation Environmental Working Group in October 2006. CAEWG comprises well-respected experts in the field of aviation environmental protection and since its formation has built a vision and strategy for the future. Membership in CAEWG is open to Canadian industry and researchers based on technical competence, interest and the ability to contribute. CAEWG comprises a network of large, medium and small enterprises, governmental institutions and academia, and its membership reflects a broad geographical distribution within Canada. Currently, CAEWG includes the following organizations:

Industry:

> Aercoustics Engineering Limited, Bell Helicopter Textron Canada Limited, Bodycote Testing Group, Bombardier Aerospace, CMC Electronics, Goodrich Corporation, Messier-Dowty Inc., Pratt &Whitney Canada

Academia:

> University of British Columbia, Concordia University, École Polytechnique, École de Technologie Superieure, Université Laval, McGill University, Ryerson University, Université de Sherbrooke, University of Toronto, University of Waterloo

Government/Not-For-Profit:

> Consortium for Research and Innovation in Aerospace in Quebec, Greater Toronto Airports Authority, Industry Canada, National Research Council, Ontario Centres of Excellence, Transport Canada

The current co-chairs of CAEWG are Benny Pang (Noise) and Sam Sampath of P&WC (Emissions).

CAEWG has been meeting semi-annually since its inception. It has developed a research program to mature technologies and configurations that can be applied to meet the competing demands of lower noise and lower emissions required of the next generation of engines and aircraft.

2.4 CAEWG Research Program

The CAEWG research program will evaluate the following items:

- new technologies and systems
- unconventional and more specialized aircraft configurations
- new architectures applicable to turbofan, turboprop and turboshaft gas turbine engines
- incremental changes to current configurations
- alternative operational capabilities
- elimination/replacement of chromium-, lead- and/or cadmium-based coating, plating and paint
- high altitude engine emissions
- sensible combinations of the above mentioned items
- product end of life

Future aircraft configurations will reduce noise through a combination of low noise components (such as landing gear and high-lift devices), noise shielding, better engine integration, and operational procedures, such as noise abatement, steep climb-out and approach capabilities.

Next-generation engines will reduce noise through the application of advanced aero-acoustic design principles for better optimisation of fan and exhaust components. Lower engine noise will be achieved by reducing or eliminating noise sources through better design and by more efficient attenuation of remaining emitted noise through novel acoustic treatments.

Most of the current aircraft emissions data available is confined to sea level through 3000 ft. A better understanding of engine emissions at higher altitudes will result in better predictive methods to study the real impact of Green House Gas (GHG) emissions from aviation sources and their impact on global warming.

CO_2 level (fuel burn) reductions will be achieved at the aircraft configuration level through improved aerodynamics, weight reductions and operational improvements. Further reductions in CO_2 can be achieved through the use of more efficient power plants, and more efficient flight paths and operations.

NO_x reductions, resulting in improved local air quality, can be achieved through the use of advanced power-plant design features such as next-generation combustors.

In addition to reducing aircraft noise and emissions, life-cycle design considerations will minimize environmental impact during the build, maintenance and disposal of the next generation of aircraft and engines. Better choice of materials, manufacturing processes and maintenance procedures will help reduce hazardous wastes and reduce energy consumption throughout the production of the whole aircraft and engines.

The research program as described above is a high-level framework and CAEWG requires specific projects in order to make progress towards its goals and objectives. Such projects are contingent on the availability of funding and the development of partnerships across companies and institutions. CAEWG is currently seeking funding through the Canadian BL-NCE program and has accordingly defined numerous projects involving 13 organizations and 50 researchers.

3.0 BUSINESS-LED NETWORKS OF CENTRES OF EXCELLENCE

The BL-NCE initiative has been developed by the Networks of Centres of Excellence (NCE) of Canada [6], which is a joint program of three Canadian granting agencies: the Natural Sciences and Engineering Research Council of Canada (NSERC), the Social Sciences and Humanities Research Council of Canada (SSHRC), and the Canadian Institutes of Health Research and Industry Canada (CIHR). The BL-NCE program is overseen by a Steering Committee comprised of the presidents of NSERC, SSHRC and CIHR, the Deputy Minister of Industry Canada and, as an observer, the President of the Canada Foundation for Innovation.

The goal of the BL-NCE Program is to fund large-scale collaborative networks to support private sector innovation in order to deliver potential economic, social and/or environmental benefits. The intention is to increase private sector investments in research in Canada, support the training of skilled researchers, and optimise the timeline between research and commercialisation. $46M total is available for 2009 through 2012 to fund up to five new BL-NCEs. Funding would match the cash or in-kind contributions by industry.

While there is no restriction on the Canadian industrial sector that can apply for a Network, the research undertaken by the proposed Networks must be in one or more of the five priority research areas, namely:

- Environmental science and technologies;
- Natural resources and energy;
- Health and related life sciences and technologies;
- Information and communications technologies; and
- Management, business or finance.

In order to qualify,

- The application must be submitted by not-for-profit consortia (must be incorporated at time of funding) that represent the interests of private sector enterprises with substantial R&D operations in Canada or potential to benefit from R&D (ideally comprising a mix of SME and large companies, and research providers and research-users).
- The Canadian private sector represented by the above must have a clear vision of their sector/cluster's shared needs over the next 5-10 years, the major R&D and commercialisation challenges and barriers to that vision, and present a comprehensive plan that shows how the proposed network will address these challenges and barriers to ultimately enhance their innovativeness and competitiveness.
- Significant investment and strong support for the proposed initiative by the private sector partners.
- A well described and managed collaborative research program involving the most suitable expert researchers from academia, government and/or the private sector.
- A cohesive plan that clearly describes the path for the commercialisation of the research results generated from the BL-NCE.
- The research undertaken must be in the priority areas listed above.

4.0 THE CAEWG-RC BL-NCE

The CAEWG felt that the group met all of the qualifying criteria. Consequently, a research plan was developed and a Letter of Intent (LOI) to become established as a BL-NCE – tentatively called the "CAEWG Research Consortium" (CAEWG-RC) – in the category of Environmental Science and Technologies was sent on January 30, 2008.

The CAEWG-RC LOI was successful and the CAEWG was invited to submit a Full Application. The Full Application required the development of a management plan along with fully budgeted, detailed projects outlining research partnerships, paths to market and sharing of intellectual property.

The Full Application was submitted on August 19, 2008. An Expert Panel reviewed the application with representations by members of the proposed CAEWG-RC on September 12, 2008. The Expert Panel will inform a Private Sector Advisory Board (PSAB), which will then assess the economic and commercial benefits and opportunities of the application and provide advice and funding recommendations to the NCE Steering Committee. The NCE Steering Committee will make the final funding decision in November, with funding released in early 2009.

4.1 Network and Projects

For the BL-NCE research plan, the CAEWG has defined nine projects involving 50 researchers, five companies and seven universities. The projects cover environmentally focused advanced design of aircraft, life-cycle materials of concern, noise source reduction, emissions source reduction and operational improvements, including the measurement and modelling of altitude-level emissions leading to improved air traffic management practices and the development of advanced aircraft flight management systems for optimised continuous descent arrivals. Each project has an industry lead with participation by other industrial and/or university partners.

4.2 Proposed Noise Source Reduction Projects

Of the nine projects proposed for the CAEWG-RC, three pertain to noise source reduction. Due to the proprietary nature of the research, only limited information can be disseminated herein on each project. Upon completion of the project milestones and subject to agreements by the partners, results will be presented in the appropriate forums.

Project Description	Industry Leader	Participants	
		Industry	University
Airframe Noise Reduction	Bombardier Aerospace	Messier-Dowty, Aercoustics	Waterloo
Forced Mixer and Nozzle Noise Reduction	Pratt & Whitney Canada		McGill
Noise Reduction for Transonic Fans	Pratt & Whitney Canada		Sherbrooke

Table 1: Noise Source Reduction Projects of the CAEWG-RC

4.2.1 Airframe Noise Reduction

The next generation of aircraft engines will be significantly quieter than current engines, so airframe noise will become a more significant contributor to total aircraft noise and, on approach, may be the dominant noise source. In order to meet anticipated increasingly stringent noise certification limits, future aircraft will need to take innovative approaches to reduce airframe noise. The major contributors to airframe noise are the landing gear and the high-lift system (flaps and slats).

Bombardier Aerospace (BA) is the industrial lead for this project. Messier-Dowty (M-D) will provide a production-representative landing gear from the Global Express aircraft and will participate in discussions on manufacturability. Aercoustics Engineering Limited will restore the anechoic wind tunnel at the University of Toronto Institute for Aerospace Studies (UTIAS). A Ph.D. student from the University of Waterloo will work with Bombardier Aerospace on aspects of the high-lift system design.

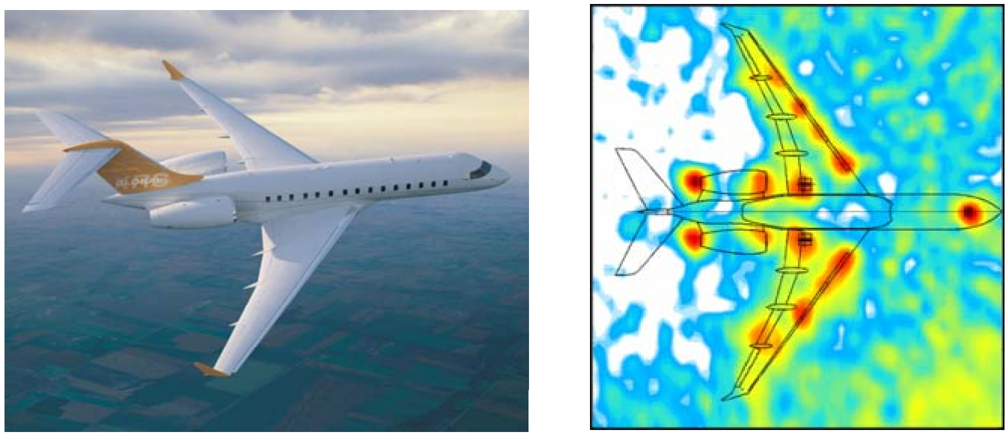

Figure 1: Bombardier phased-array microphone measurement of a Global Express aircraft

Landing Gear Noise Reduction

Due to the lack of aerodynamic refinement, landing gears are often the noisiest airframe component but, conversely, are the most amenable to noise reduction measures.

It is proposed to test a full-scale landing gear with all its fittings and representation of the wheel well and door wind tunnel to analyze the contributions of individual components and to provide a baseline for smaller-scale tests looking at noise reduction measures. The tests would be done at the ONERA CEPRA19 wind tunnel and would include selective removal of the individual gear components. This would provide the basis for a semi-empirical landing gear noise prediction method. Microphone phased arrays and surface mounted dynamic pressure probes would also be used to understand the flows around the model. In parallel a computational aero-acoustics (CAA) modeling exercise would be undertaken to validate a more sophisticated, but longer term, approach to landing gear noise prediction.

In order to establish and validate scaling effects as a precursor to testing noise reduction measures, parallel wind-tunnel tests of smaller scale, higher fidelity models would be done at the National Research Council (NRC) in Ottawa.

A final set of landing gear tests will be done in a suitable NRC wind tunnel, depending on the scale chosen.

High-Lift System Noise Reduction

The relative contribution of the high-lift system to the total airframe noise is dependent on component size and complexity. The design of any high-lift system seeks to achieve the maximum lift at approach and maximum lift-to-drag ratio at take-off. Any noise reduction devices must have minimum effect on these aerodynamic parameters as well as integrating properly with the mechanical functioning of the flaps and slats. Despite extensive research conducted on flap and slat noise in Europe and the US over the last ten years, no clearly superior noise reduction method has emerged.

Flap Noise

Recent successful work by BA, using a commercial CAA code (STAR) to predict flap-edge noise, has provided insight into the flap noise generation mechanism. Using these results, it is hoped to apply various methods for flap noise reduction. Selection of candidate designs for wind tunnel testing would be done by running CAA simulations ahead of time.

Initial testing of flap treatments will be done with Aercoustics Engineering Ltd. in the UTIAS anechoic wind tunnel using a simple, semi-span rectangular wing. The best treatments will then be tested on a wing with a semi-span flap in the NRC 2m x 3m wind tunnel. The NRC tests will include phased-array acoustical measurements, aerodynamic force coefficient measurement and wing and flap pressure distributions.

Slat Noise

The unsteady shear layer shed from the slat lower cusp generates slat noise. Broadband noise is generated mainly from the lower surface of the slat, close to the slat trailing edge, where the shear layer impacts the surface. It is proposed to look at various treatments to reduce the strength of the shear layer. CAA modeling would be used to obtain an understanding of the physics of slat flows and, if possible, to develop models of the treatments chosen.

The slat testing will be done at NRC in the 2m x 3m wind tunnel using a full span and semi-span slat fitted to the leading edge of the semi-span flap model.

Systems Integration

The final funding year (2012) would include an examination of the feasibility and overall effectiveness of introducing the best noise reduction measures of the landing gear, flaps and slats into production. Systems integration and effects on aircraft performance would be included in the assessment.

4.2.2 Forced Mixer and Nozzle Noise Reduction

In the design of a new engine, the choice of the cycle point (mainly defined by the choice of fan diameter, bypass ratio and nozzle area) determines, in most of the cases, the relative importance of jet noise versus the rest of the engine components. For engines with relatively low bypass ratio, the take-off condition is dominated by jet noise. Over the past number of years, small engine manufacturers have spent only limited effort on jet noise mainly because noise has not been a major concern for small jet aircraft. However, more recently, emphasis has been put on the necessity to reduce the environmental footprint of all aircraft, which includes noise emissions especially around airports.

The industrial lead for this project is Pratt & Whitney Canada (P&WC), with participation by McGill University.

For long-cowl engine installations, it is generally beneficial to enhance the mixing of the cold and hot streams to increase thrust. This can be done by a series of lobes installed at the back of the engine that forces the cold air from the bypass towards the centre of the engine and vice-versa for the hot air from the turbine exit. The design point for performance optimisation is typically a cruise condition at high altitude. Therefore, the low altitude Take-off and Approach conditions, where the aircraft has the biggest influence on community noise, do not benefit from this design point of the mixer. Furthermore, the guidelines to design a well performing forced mixer are relatively well understood, but little is known regarding the rules a designer should follow to minimize noise whilst maintaining the mixer thrust enhancement.

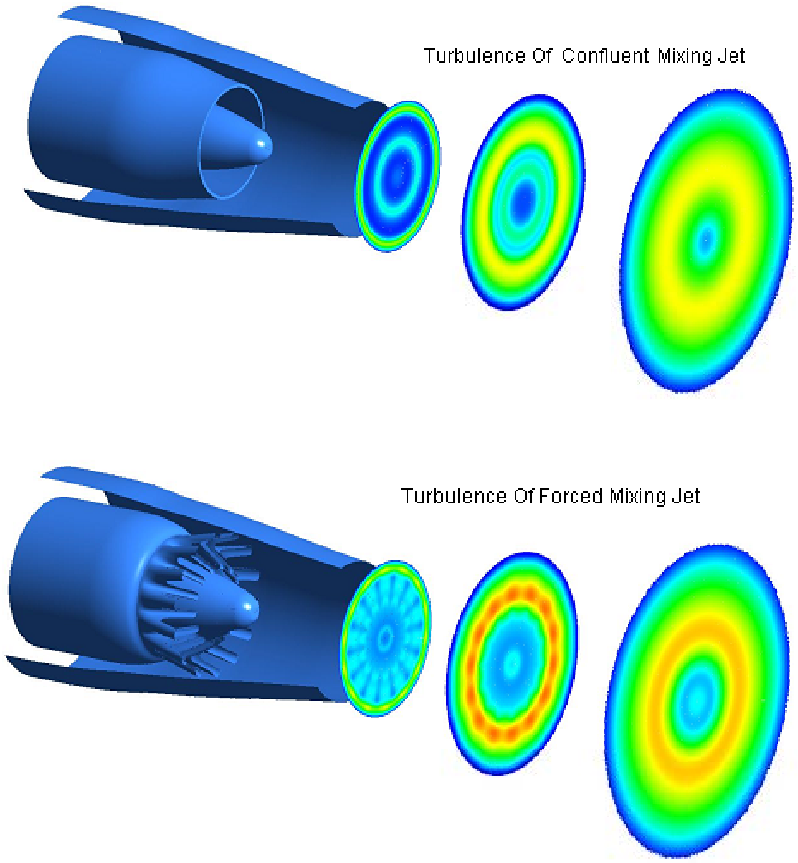

Figure 2: Turbulence with confluent and forced long-cowl jet mixing

The first step for this task will be to determine the dominant design features of the mixer; i.e., lobe count, penetration, length, cutback and location of mixing plane. A computational fluid dynamics (CFD) methodology will be finalized in order to extract the turbulence factor and any other pertinent parameters that would match actual test data. Once validated, the tool would be used to explore the mixer nozzle design space. The outcome of this analytical work will be various mixer designs that show potential noise reduction without compromising the thrust enhancement of the mixer nozzle.

These candidates will be tested in an anechoic wind tunnel to verify the far field noise spectra. An array of microphones will be used to acquire the noise spectra and determine the location of the two main noise generation sources: mixer noise and shear layer noise. Another objective of the wind tunnel testing will be to evaluate the effects of the aircraft speed on the propagation of the jet noise. Since jet noise is generated both inside and outside the engine, there is a possibility the jet flight effects are different for mixer noise.

The results of the wind tunnel tests will be used to validate the CFD methodology from the first phase of the program. After the proper analysis of the wind tunnel results, the most promising designs will be re-analysed and fine-tuned before going into full-scale testing on a PW307 engine. The tests will be done at the NORDAM outdoor test facilities where the noise spectra will be recorded by 32 microphones located on a 150-foot radius at 5° intervals. The data collected will be separated into individual source components to isolate the jet noise from the fan, turbine and core noise. The new data will then be incorporated into the P&WC noise database and be available for flight simulation. At this stage, the CFD methodology would be sufficiently validated to be applied to new products.

An extension of this project beyond 2012 would be to perform a series of flight tests with the final set of mixer designs tested at the outdoor facilities to validate the jet noise flight effects due to aircraft speed. For this exercise, the chosen aircraft would have the engines equipped with the same forced mixer. An array of microphones on the ground would be used to locate the jet noise source generation and the effect of the aircraft speed on the shielding and propagation of the jet noise.

For this project, Professor L. Mongeau and his team from McGill University would collaborate with P&WC specialists in Acoustics and Installation Aerodynamics to develop a CAA methodology based on the Lattice-Boltzmann Method (LBM). The focus of this study will be to use the LBM as an investigative tool for the far-field prediction of noise from turbulent subsonic jets. This tool will be used to rank the various mixer designs that will be tested in wind tunnel.

4.2.3 Noise Reduction for Transonic Fans

Fan noise sources remain a major contributor to total aircraft noise. Extensive acoustic treatments are usually required in the inlet and aft ducts for noise reduction, which affect IPPS weight, cost and performance.

The design of fans in current turbofan engines is challenging due to the high aerodynamic performance required. More stringent weight constraints imposed on new engine programs tend to favour a compact engine layout susceptible to high fan noise due to reduced spacing between rotating blades and fixed stator vanes and higher loading of the high tip Mach number transonic fan blade. Other new design features, such as a full-span stator, are also being applied, thus reducing the axial spacing even more.

The design of fans has significantly advanced in the last decade, for instance with the introduction of wide chord swept blades; however, the knowledge and tools for fan noise control have not followed suit. There is an immediate need for the development and characterization of design features, such as more advanced 3D shapes and the sweep/lean of vanes, to yield low noise fans.

P&WC is the industrial lead for this project with participation by Sherbrooke University. This project would demonstrate the noise reduction of a new low-noise fan design and characterize the effect on noise of introducing lean and sweep onto the stator just behind the fan trailing edge.

The effectiveness of low-noise fan technology would be demonstrated on a fan noise test rig that would include acoustic measurements for a baseline fan/stator configuration with an engine nacelle inlet and acoustic treatment. The tests would be performed in an anechoic wind tunnel in which both the fan performance and its far field noise signature would be measured. The rig would be designed in such a way that the fan trailing edge / stator leading edge could be modified to study the fan / stator interaction. Also, the rig would allow changing the baseline straight stator for two different sweep angles, two different lean angles and one case with a combination of sweep and lean. The space on the outer diameter between the fan and stator would be designed to accommodate some acoustic treatment to verify if this area of the engine could be used to attenuate the fan noise efficiently.

The results of the wind tunnel testing would be used to adjust and calibrate the aerodynamic and acoustic models. From the resulting new models, an optimised fan/stator arrangement reducing noise and respecting fan performance and weight targets would be designed. This new arrangement could be tested in the wind tunnel to validate the new models.

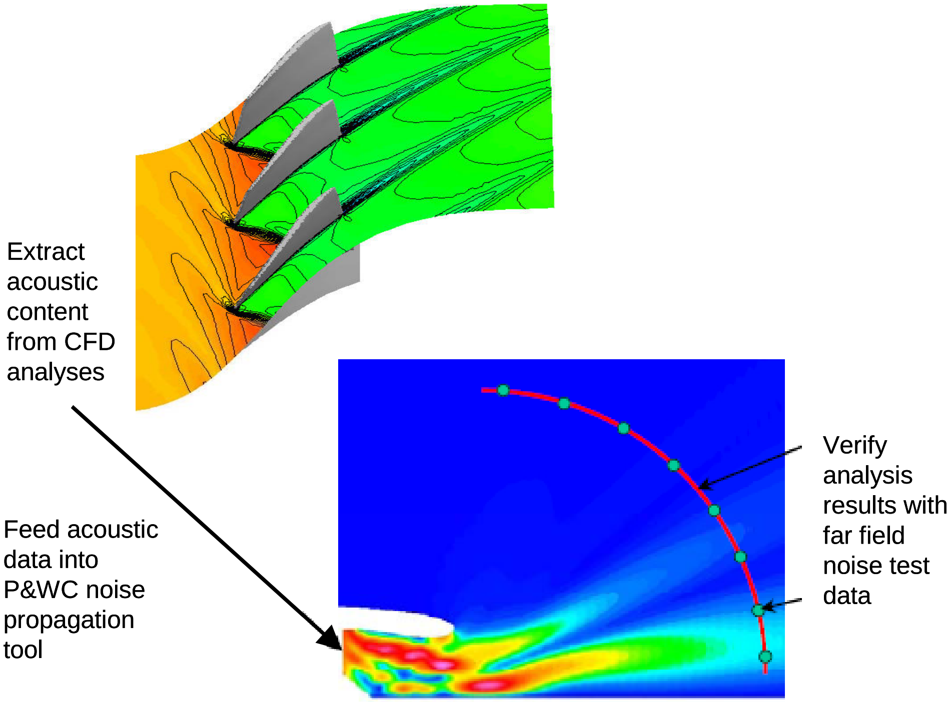

Figure 3: Calibration of P&WC fan noise acoustic models

For this project, Professor Noureddine Attala and his team from Sherbrooke University will closely work with P&WC Acoustics and Compressor Aerodynamics departments. The basic aerodynamic parameters of the fan-stator will be defined by P&WC to be consistent with the Best Practices of the company in term of performance and structural integrity whilst the aero-acoustic modelling will be defined by Sherbrooke. The selection of the tested fan-stator configurations will be chosen based on the outcome of the new model. Wind tunnel test results will calibrate and validate the model.

5.0 THE FUTURE

The CAEWG-RC BL-NCE application, should it be approved, would kick-start a Canadian collaborative network that would parallel, albeit on a smaller scale, the efforts being undertaken in Europe and the US. Although this program addresses the needs of the Canadian aerospace sector, it will also benefit all regions of the world as the technologies come to fruition. In the future, we intend to expand our network by seeking other partnerships, both domestic and international.

We are optimistic of our network's success, and will be changing our name from the provisional "Canadian Aviation Environmental Working Group" to the "Green Aviation Research and Development Network" (GARDN).

6.0 ACKNOWLEDGEMENTS

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