Project 059C Modeling Supersonic Jet Noise Reduction with Global Resolvent Modes

University of Illinois Urbana-Champaign

Project Lead Investigator

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University Participants

University of Illinois Urbana-Champaign (UIUC)

- PIs: Dr. Daniel J. Bodony, Dr. Tim Colonius
- FAA Award Number: 13-C-AJFE-UI-031
- Period of Performance: June 5, 2020 to June 4, 2021
- Tasks:
    1. Establish industry-relevant low bypass ratio (BPR) engine parameters and acoustic assessment workflow with cost-share partner.
    2. Automated Reynolds-averaged Navier–Stokes equations (RANS) predictions of jet exhaust.
    3. Resolvent mode computation—primary and sensitivity.
    4. Python resolvent mode interpolation tool.
    5. Python optimization tool for jet noise reduction (JNR)

Project Funding Level

FAA provided $199,956 in funding. Proposed cost match with GE Aviation (POC: Dr. Robert Babbitt) is no longer in force. Negotiations with Boom (POC: Dr. Joe Salamone) are in progress.

Investigation Team

- Dr. Daniel Bodony, UIUC, PI
- Mr. Omar Gutierrez, UIUC, MS student
- Dr. Tim Colonius, California Institute of Technology (Caltech), Co-PI
- Mr. Ethan Pickering, Caltech, PhD student
- Mr. Liam Heidt, Caltech, PhD student

Project Overview

This ASCENT project will leverage recent research in global resolvent mode-based descriptions of jet turbulence and associated noise to develop an efficient, physics-based tool for estimating the impact of jet noise reduction (JNR) strategies on the takeoff noise of civil supersonic transports. The software tool will quickly identify promising JNR technologies as well as more precisely evaluate the noise impact of parametric variation of a specific JNR approach. The tool will be compatible with the fleet-scale evaluation codes GREAT (Georgia Institute of Technology) and FLEET (Purdue University) developed in ASCENT Project 10 and integrated into the ASCENT Project 47 "clean sheet" evaluation tool targeting civil supersonic transport.

The proposed research will create a multi-fidelity JNR tool that can operate in two modes: one mode for specific engine estimates, and one mode for fleet-scale estimates:

1. *JNR evaluation for an engine* mode: Using the RANS-provided mean flow for a specific engine, the global resolvent description of wavepackets and their sensitivity to mean flow variations will be computed. The solutions will provide estimates of the low-frequency radiated noise while the sensitivity derivatives will estimate how the noise changes due to changes in the engine design, thus enabling JNR optimization.
2. *Fleet-level estimation* mode: The resolvent modes and their sensitivity derivatives for existing JNR strategies (e.g., chevrons, internal mixers) will be pre-computed for canonical jet exhaust profiles and flow conditions, compressed, and stored within an efficient data layout that can be quickly evaluated within FLEET, GREAT, and/or NASA's Aircraft Noise Prediction Program (ANOPP).

The original proposal outlined six tasks that were to be conducted. The project tasks have been modified in response to changes in the ASCENT Project 59 objectives as well as changes to our cost share partner. In particular, ASCENT Project 59 now includes a Georgia Tech Research Institute- (GTRI-) provided extensible dual stream, internally mixed nozzle that is to be studied computationally and whose noise is to be measured for validation. Further, our GE Aviation cost share partner has been removed due to personnel changes at GE Aviation coupled with pandemic financial impact.

Task 1 – Establish Industry-Relevant Low-BPR Engine Parameters and Acoustic Assessment Workflow with Cost-share Partner

University of Illinois at Urbana-Champaign

Objectives

Work with our cost share partner, identify the anticipated range of characteristics of the low-BPR engines being considered for business-class civil supersonic transport. These parameters include, but are not limited to diameter, BPR, mass flow rate, core and fan stream pressure ratios, core stream temperature ratio, thrust, nozzle configuration, plug designs, chevron designs, internal mixer designs, and afterburner design.

Research Approach

Conduct face-to-face meetings and document exchanges to obtain industry-relevant low-BPR engine parameters and acoustic assessment workflows.

Milestones

1. Find new cost share partner candidate.
2. Establish an NDA to initiate discussions.
3. Exchange low-BPR engine parameters and acoustic assessment workflow.

Major Accomplishments

Milestone 1 has been completed with the help of Donald Scata (FAA). An initial discussion was held October 28, 2020, between UIUC (Bodony) and Boom Supersonics (Rachel Devine, Joe Salamone, Lourdes Maurice) to connect and establish the overall goals of the ASCENT 59 Project. Milestone 2 Is in progress; UIUC is currently working with Boom (Devine) to agree to an NDA to initiate technical discussions with intent to formally agree on a cost-sharing arrangement.

Publications

None

Outreach Efforts

None

Awards

None

Student Involvement
None

Plans for Next Period
Finalize NDA between UIUC and Boom and exchange JNR-relevant information, including low-BPR engine parameters and Boom-internal acoustic assessment workflows.

Task 2 – Automated RANS Predictions of Jet Exhaust
University of Illinois at Urbana-Champaign

Objectives
Develop and verify an automated toolchain for using RANS methods for predicting the jet exhaust plume from candidate near-sonic multi-stream jet nozzles.

Research Approach
Achieving JNR will require changes to engine cycle and nozzle geometries. A Python-based software infrastructure that takes parametrically defined CAD-based descriptions of nozzle geometries, automatically generates meshes and boundary conditions for the nozzle internal flow path and the external nozzle plume, initiates an open-source RANS solver, and curates the data is to be developed.

Milestones
1. Initial development of end-to-end Python infrastructure.
2. Verification of RANS solutions.

Major Accomplishments
Milestone 1 has been completed using Python bindings for Gmsh, a 3D finite element mesh generator, to generate the mesh and boundary conditions for the SU2 open-source RANS solver. Challenges with the axisymmetric version of SU2 are being evaluated using a locally modified compressible OpenFOAM variant fitted with RANS models tuned for hot jet plumes. Milestone 2 is in progress and dependent on the outcome of the SU2-OpenFOAM selection.

Publications
None

Outreach Efforts
None

Awards
Omar Gutierrez is a UIUC Grainger College of Engineering MERGE Fellowship recipient.

Student Involvement
Omar Gutierrez is responsible for developing the entirety of the Python tool described previously.

Plans for Next Period
Complete the SU2-OpenFOAM selection and complete Milestone 2. Review and revise, as necessary, the Python tool to integrate into the Python-based interpolator and optimizer of Task 3 and Task 4.

Task 3 – Resolvent Mode Computation—Primary and Sensitivity

Caltech (lead) and University of Illinois at Urbana-Champaign

Objectives

Develop and verify a resolvent mode computation tool suitable for evaluating the JNR potential of candidate near-sonic multi-stream jet nozzles.

Research Approach

Achieving JNR will require changes to engine cycle and nozzle geometries. Estimation of the JNR potential of candidate cycles and geometries will use resolvent mode descriptions of the coherent, wavepacket-associated jet noise of the loudest sound sources. We term as "primary" the resolvent calculations that provide the input-gain-output modes of the resolvent operator $(i\omega - A)^{-1}$ and as "sensitivity" the changes in those modes due to changes in the jet nozzle geometry and engine cycle. The resolvent operator requires knowledge of the linearized Navier-Stokes operator A generated for each nozzle and its exhaust plume and a global mode computational infrastructure. Sensitivity of the resolvent input-gain-output modes requires knowledge of the change in A, say δA, that result from changes in the nozzle design and/or engine cycle.

Milestones

1. Primary resolvent mode computation capability.
2. Resolvent mode training data and fitting.
3. Resolvent mode sensitivity computation capability.

Major Accomplishments

Milestone 1 has been completed and tested on single-stream sub- and supersonic jets. Milestone 2 is in progress for the low-BPR, near-sonic jets anticipated for the supersonic aircraft of interest to ASCENT Project 59.

Publications

None

Outreach Efforts

None

Awards

None

Student Involvement

Ethan Pickering is responsible for the primary resolvent mode computation and the preliminary training data and fitting tasks. Liam Heidt is a new student who is learning from Ethan and will assume leadership of the global mode computation and its data-driven alignment.

Plans for Next Period

Complete Milestone 2 using to-be-acquired GTRI acoustic data and high-fidelity LES data from the Stanford University ASCENT Project 59 team. Initiate Milestone 3 by collaborating with UIUC on the sensitivity derivation and implementation.

Task 4 – Python Resolvent Mode interpolation Tool

University of Illinois at Urbana-Champaign (lead) and Caltech

Objectives

Develop and verify a Python-based interpolation tool computing resolvent input-gain-output modes at nozzle geometry and/or engine cycles for which RANS data are not available but are near to previously known input-gain-output modes from nearby nozzle geometries and/or engine cycles.

Research Approach

Using gradient-enhanced interpolation methods, develop a response surface-based interpolation approach for estimating resolvent input-gain-output modes for estimating the radiated noise from an engine geometry / engine cycle for which previously computed RANS data, linearized operators, and resolvent data are not available.

Milestones

1. Identify candidate interpolation methods and down select.
2. Develop Python tool to implement interpolation method.
3. Verify Python tool.

Major Accomplishments

Work on this Task has not yet begun.

Publications

None

Outreach Efforts

None

Awards

None

Student Involvement

None

Plans for Next Period

Begin Task 4.

Task 5 – Python Optimization Tool for JNR

University of Illinois at Urbana-Champaign (lead) and Caltech

Objectives

Develop and verify a Python-based optimization tool that searches the optimization space of engine geometry/cycle to identify design choices that improve JNR.

Research Approach

Using gradient-informed optimization methods, develop an optimization approach for estimating JNR potential from a class of candidate engine geometries/cycles using resolvent mode predictions of the jet noise based on linearized operators described by RANS predictions of the jet exhaust plume.

Milestone(s)

1. Identify candidate optimization methods and down select.
2. Develop Python tool to implement optimization method.
3. Verify Python tool.

Major Accomplishments

Work on this Task has not yet begun.

Publications

None

Outreach Efforts
None

Awards
None

Student Involvement
None

Plans for Next Period
Begin Task 5.