Noise and Emissions Characteristics of Commercial Supersonic Aircraft Propulsion System

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Concorde At 50: Faster Than A Speeding Bullet

Guy Norris | Aviation Week & Space Technology

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First Flight Crew

Concorde 001 Landing

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Introduction

Increasing interest in Civil Supersonic Transport
• The first test flight of the Concorde was 50 years ago last Saturday!
• Scope for environmental performance improvement is much higher

Challenges posed by the civil SSTs:
• Operating conditions of these aircraft are significantly different
  • Different operating condition
  • Different operating environment
• Propulsion system built around of-the-shelf engine (even 50 years ago)
  • No clean-sheet engine development programs

Question: What is the Noise and Emissions characteristic of civil SST aircraft?
Contents

1. Project description
2. Why are we doing this?
3. What is the impact of this project?
4. How are we going to approach this?
5. Where are we now?
Project description

**RESEARCH QUESTION:**
How do the aircraft operating conditions and the engine technology affect the environmental footprint of commercial supersonic transport aircraft?

- Identify mission profiles and operating requirements for propulsion system
- Build cycle deck to explore the design space: engine model
- Analyze fuel burn, noise and emission profiles: design & optimization
- Reduced-order modeling
Why are we interested in this?

- Understand the environmental impact of the unique operating conditions of supersonic aircraft
  - Altitude – increased environmental sensitivity
  - Cruise Mach number – elevated stagnation temperature
  - Operation at high thrust level – sustained duration elevated combustor temperature
  - *New noise challenges due to high jet velocity*

- Understand the challenges of supersonic aircraft engine technology and their environmental footprint
What will this project achieve?

- Develop a rational basis for environmental regulations of SST
  - Supersonic regulations based on the Concorde
  - Lack of sufficient understanding to set meaningful regulations

- Identify what new technologies are needed to mitigate the environmental impact of supersonic aircraft engines
How are we going to approach this?

1. Develop a model to assess the noise and emissions footprint of supersonic transport aircraft
How are we going to approach this?

Aircraft characteristics and mission profiles
How are we going to approach this?

- Aircraft characteristics and mission profiles
- Propulsion system requirements
- Engine model (NPSS)
How are we going to approach this?

Aircraft characteristics and mission profiles → Propulsion system requirements → Engine model (NPSS) → Emission modeling (Cantera) → Engine noise modeling (ANOPP) → Engine noise contribution (EPN dB) → ENVIRONMENTAL FOOTPRINT (Emission index for all emissions)
How are we going to approach this?

- Aircraft characteristics and mission profiles
- Propulsion system requirements
- Engine model (NPSS)
- Emission modeling (Cantera)
- Engine noise modeling (ANOPP)
- Engine noise contribution (EPNdB)
- Reduced order modeling

**ENVIRONMENTAL FOOTPRINT**
- Emission index for all emissions
Workflow

FLIGHT INPUTS
- Ambient & Flying Conditions
- Thrust level

ENGINE CONFIGURATION INPUTS
- Engine model (.mdl) file

COMBUSTOR INPUTS
- Combustor model
- Fuel composition model

ENGINE CONFIGURATION OUTPUTS
- Engine parameters: $P_{3}, T_{3}, m_f, f$

OUTPUTS
- Emission index for all emissions
- Engine noise contribution (EPNdB)

NPSS Run

Post-processing

ANOPP

Post-processing

CANTERA
How are we going to approach this?

1. Develop a model to assess the noise and emissions footprint of supersonic transport aircraft

2. Compute sensitivities of environmental footprint to engine technology and aircraft operating parameters

3. Identify key technological innovations and improvements to mitigate environmental impacts of commercial SST’s
Where are we now?

Developing tools for analysis

- Mission analysis tool
- Engine cycle model using NPSS
- Engine combustor using Cantera
Engine modeling
NPSS
Development of the Engine Model

Start by looking at the thermodynamic cycle:
- Intercoolers?
- Reheat?
- Variable cycle for different phases?
- Tandem fan design

Estimate engine size, flow-path areas, TSFC by using the thrust required
Estimate efficiencies from mean-line design

Compressor maps/ turbine maps

Off-design analysis

Noise model

- Noise
- Emissions
- Fuel burn

\[ \frac{F_n}{m_a} \]

\[ \frac{A_i}{F_{n,req}} \]

\[ A_{i, \text{TSFC}_{des}} \]
Emissions modeling
Cantera
Combustor emissions

Combustor emissions impacted by physics as well as chemistry
- Combustor flow physics
  - Fuel atomization, vaporization and mixing could be altered
- Combustion chemistry
  - Reaction rates and time scales could be altered

Combustor flow physics
- Model via distribution of local equivalence ratio

Combustion chemistry
- Model with Cantera
Combustor modeling

![Diagram of a combustor with zones labeled]

- PRIMARY ZONE
- SECONDARY ZONE
Primary zone modeling

Fig. 1 Chemical reactor network for aircraft gas turbine and associated input parameters.
Summary
Summary

Flight speed and altitude for SST’s affect their thermodynamic cycle and hence the noise/emissions performance of the propulsion system

• Combustor pressure and temperature will be different due to changes in ambient conditions as well as flight speed
• Use of existing engine and/or core will not necessarily preserve their noise/emissions performance

The higher jet velocity necessary for high speed flight will present new noise challenges

A first-principles based approach has been initiated to provide rational basis for regulations as well as identifying new technologies valuable to improve the environmental footprint of the next generation SSTs

• Approach uses existing industry standard modules for modeling engine performance, combustion chemistry and noise assessment to provide system level assessment
Questions