MIT GAS TURBINE LABORATORY

MIT LABORATORY FOR AVIATION AND THE ENVIRONMENT

Aviation Noise & Emissions Symposium 2019
Jacksonville, FL | March 3-5, 2019

Noise and Emissions Characteristics of Commercial Supersonic Aircraft Propulsion System

Prashanth Prakash, Laurens Voet, Jayant Sabnis, Raymond Speth, Choon Tan

Concorde At 50: Faster Than A Speeding Bullet

Feb 28, 2019

Guy Norris | *Aviation Week & Space Technology*

COMMENTS 0

First Flight Crew

Concorde 001 Landing

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

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

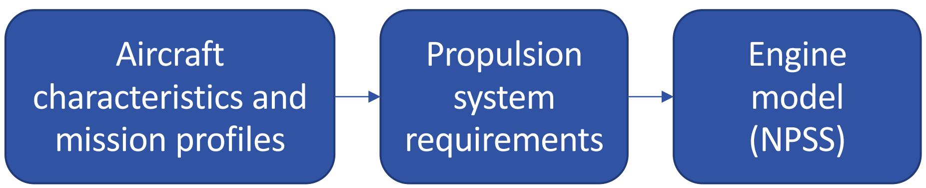
How are we going to approach this?

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

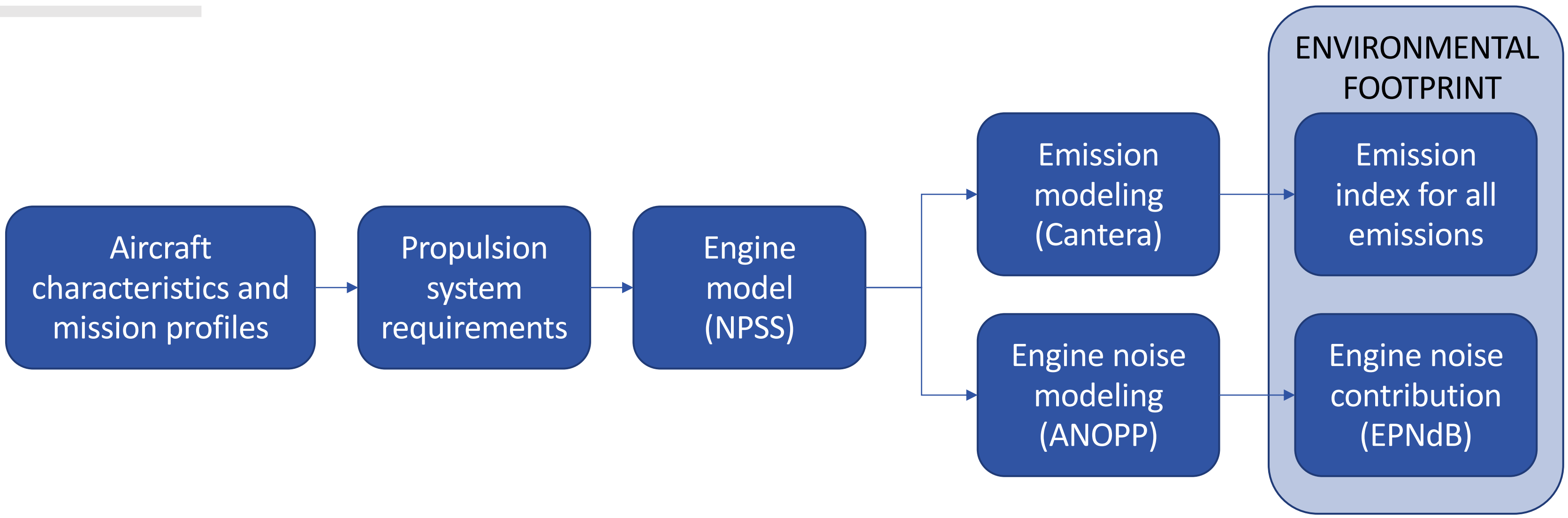
How are we going to approach this?

Aircraft characteristics and mission profiles

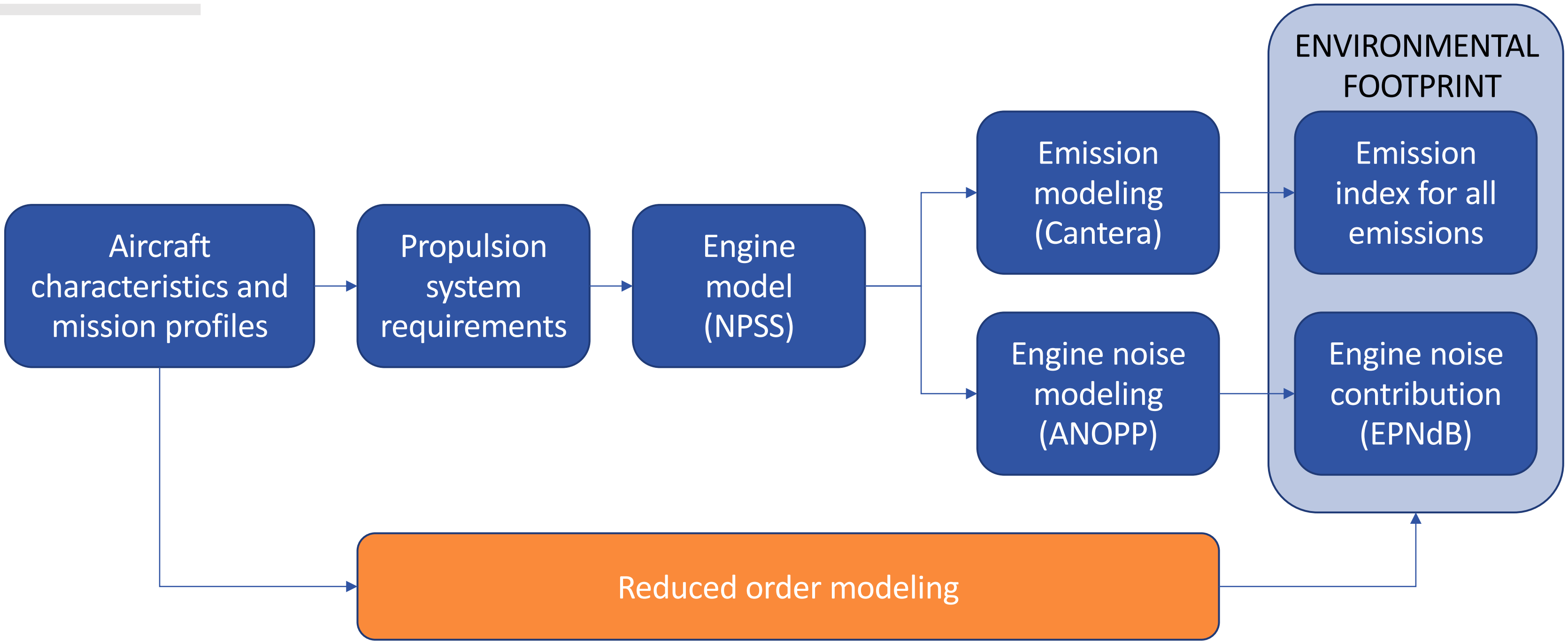
How are we going to approach this?



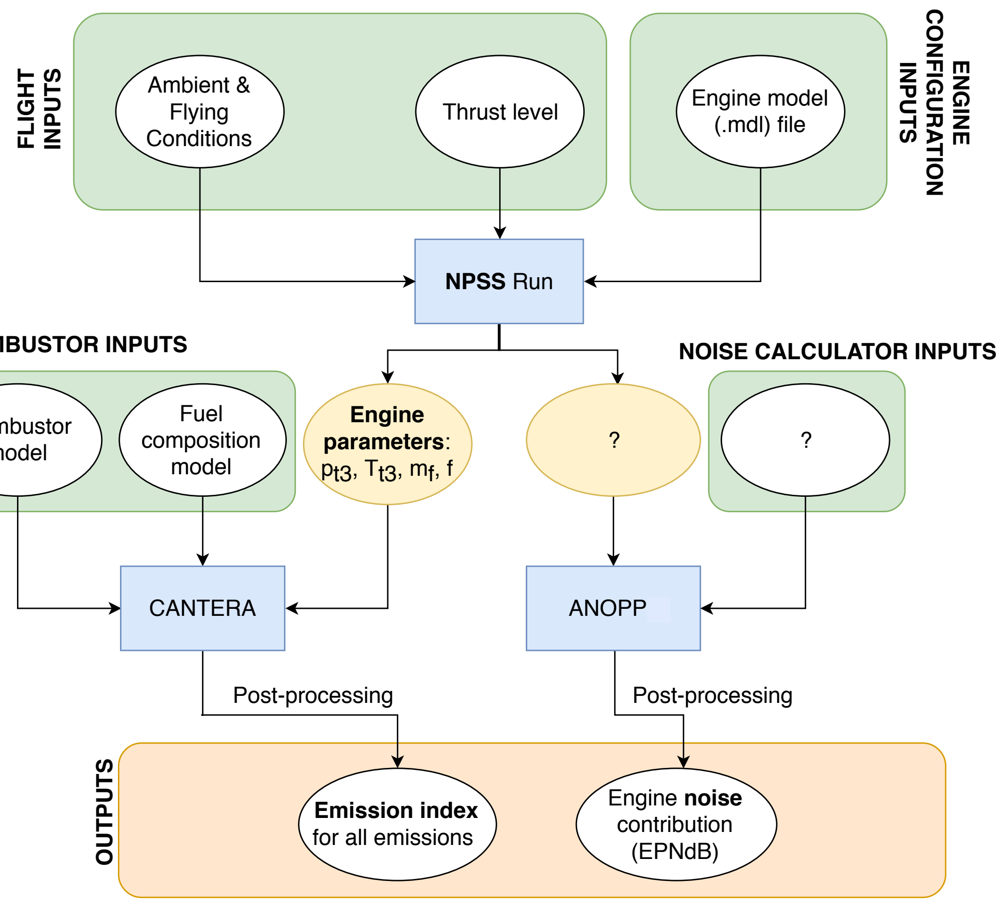
How are we going to approach this?



How are we going to approach this?



Workflow


FLIGHT INPUTS
Ambient & Flying Conditions
Thrust level
Engine model (.mdl) file
ENGINE CONFIGURATION INPUTS
NPSS Run
COMBUSTOR INPUTS
Combustor model
Fuel composition model
Engine parameters: p_{t3}, T_{t3}, m_f, f
?
NOISE CALCULATOR INPUTS
?
CANTERA
ANOPP
Post-processing
Post-processing
OUTPUTS
Emission index for all emissions
Engine noise contribution (EPNdB)

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

Compressor maps/ turbine maps

Thermodynamic cycle design $\xrightarrow{\frac{F_n}{\dot{m}_a}}$ Size engine for design point $\xrightarrow{A_i,\ \mathrm{TSFC}_{des}}$ Off-design analysis

$\overbrace{\frac{T_{t4}}{T_{t2}} \quad \mathrm{OPR} \quad \mathrm{FPR}}$

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

$\overbrace{F_{n,req}}$

Estimate engine **size**, **flow-path areas**, **TSFC** by using the thrust required

Estimate **efficiencies** from mean-line design

Noise model

Emissions model

- Noise
- Emissions
- Fuel burn

& $\frac{\partial J_i}{\partial x_j}$

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

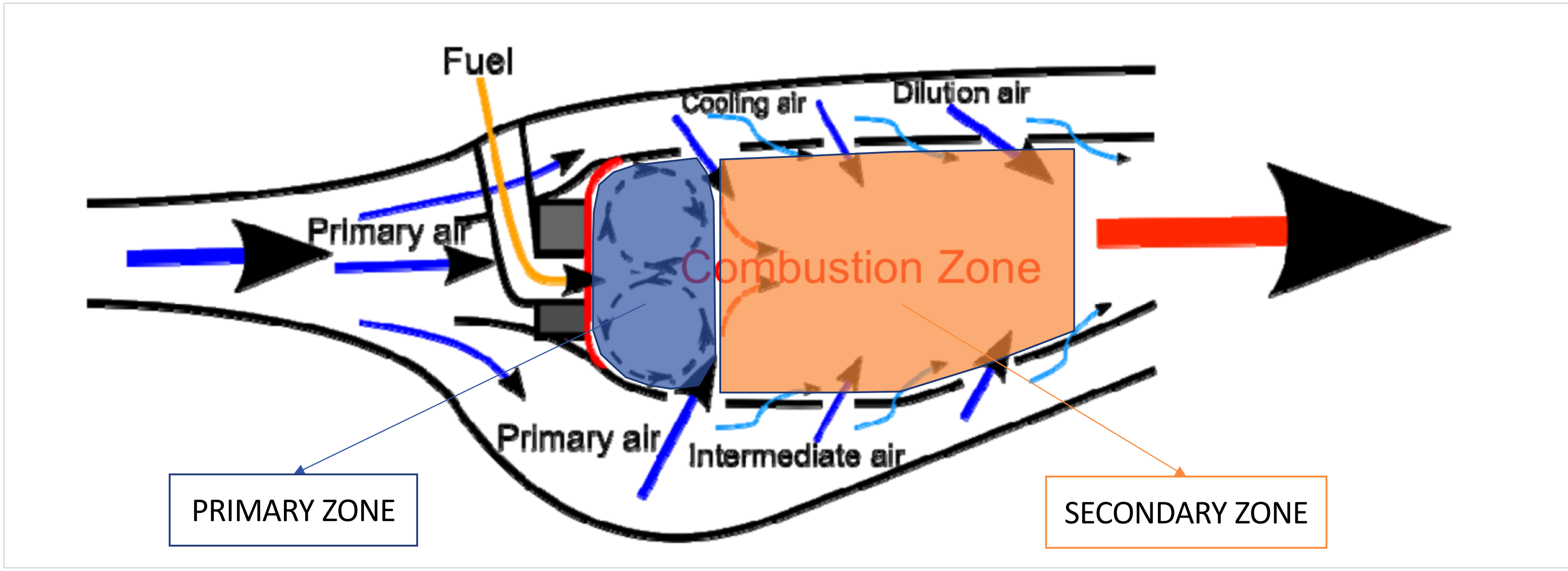
Combustor flow physics

- Model via distribution of local equivalence ratio

Combustion chemistry

- Model with Cantera

Combustor modeling



Primary zone modeling

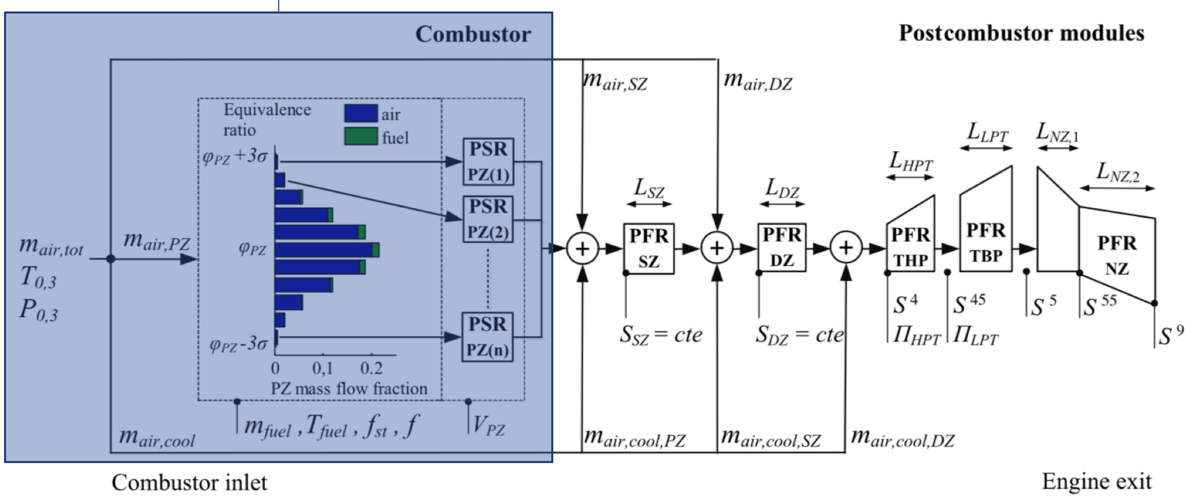
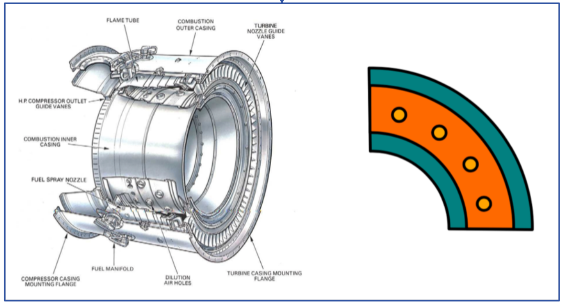


Fig. 1 Chemical reactor network for aircraft gas turbine and associated input parameters.



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