ASCENT Project 47

Clean-sheet supersonic engine design and performance

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Objective

- Assessing the environmental performance of clean-sheet and derivative engines for supersonic transport (SST)
- Evaluating the suitability of LTO emission certification standards for supersonic transport using variable noise reduction systems (VNRS)

Project Benefits

- Development of roadmap for technology development to mitigate of the environmental signature of supersonic transport engines.

Research Approach

- Identify the operating requirements for SST propulsion systems
- Develop framework for tracing the fuel burn, noise and emissions of engines for SST to their design parameters.
- Quantify and compare fuel burn, noise and emissions characteristics of clean-sheet and derivative engines

Major Accomplishments (to date)

- Presented our work at SciTech 2021 Conference
- Co-submitted a working paper to WG3 with Georgia Tech on impacts of VNRS on emissions from supersonic aircraft

Future Work / Schedule

- Modeling of soot emissions

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Motivation and approach

- What are the noise and emissions characteristics of clean-sheet and derivative engines designed for future civil supersonic transport aircraft?
- What propulsion system requirements can be met using donor cores?
- What are the effects of using VNRS on LTO emissions for SST engines?

Derivative

Supersonic derivative engines **using existing cores** without any modifications

Turbomachinery & cooling flows sized by the donor engine cycle → design space constraints

Clean-sheet

Engine cycle & turbomachinery components are **purpose-designed**

Turbine cooling flows are sized to meet material temperature limits

Method

1. Identify propulsion system requirements
2. Explore design space using engine cycle models
3. Quantify fuel burn, noise and emissions characteristics
4. Compare clean-sheet to repurposed engine core

VNRS

Variable noise reduction systems (VNRS) are going to be used by 2nd generation SST during noise certification:

- Programmed thrust cut-back (PTCB)
- Programmed high-lift devices (PHLD)

Operational strategies to reduce noise will affect engine operation and therefore take-off and climb-out emissions.

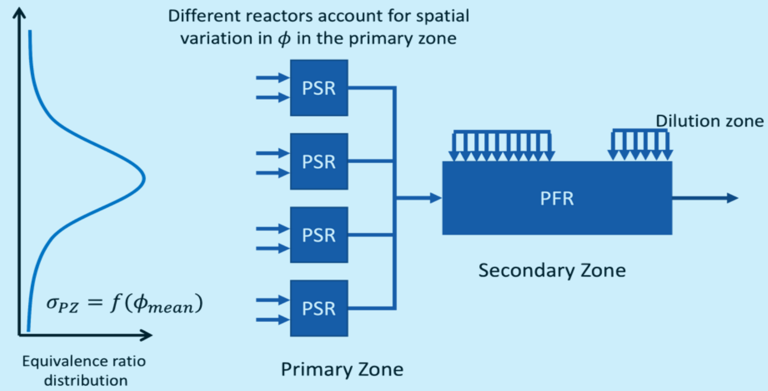
Method

1. Model representative take-off trajectories for SST conforming with certification standards
2. Quantify noise and emissions integrated over take-off trajectory
3. Compare trajectories w/ and w/o VNRS

Methods – Emissions and Noise

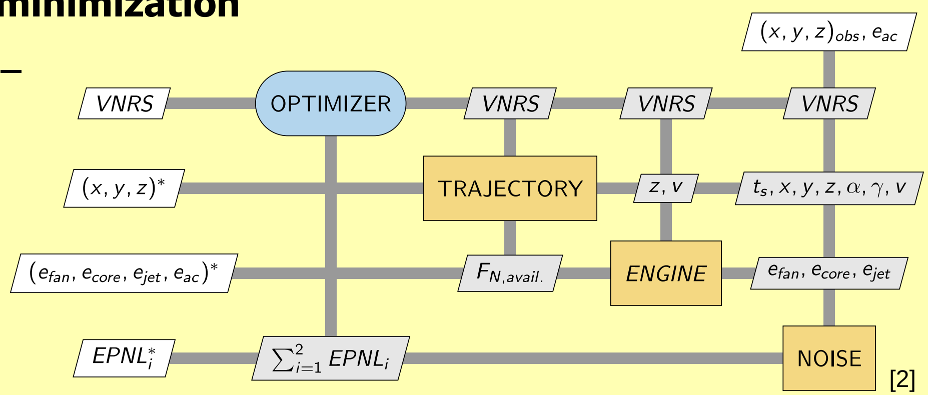
Combustor emissions model

- Incorporates chemical kinetics + combustor design + engine cycle parameters beyond the P_3T_3 method [1].
- P_3T_3 methods adequate for RQL combustor NO_x emissions since T_3 is a good indicator of peak temperature and therefore NO_x production
- Soot and CO are not only dependent on P_3, T_3 but also depend on other parameters such as AFR and T_4
- **Future work**: Modeling soot formation using two-equation methods in chemical reactor network model



Framework for take-off noise assessment and minimization

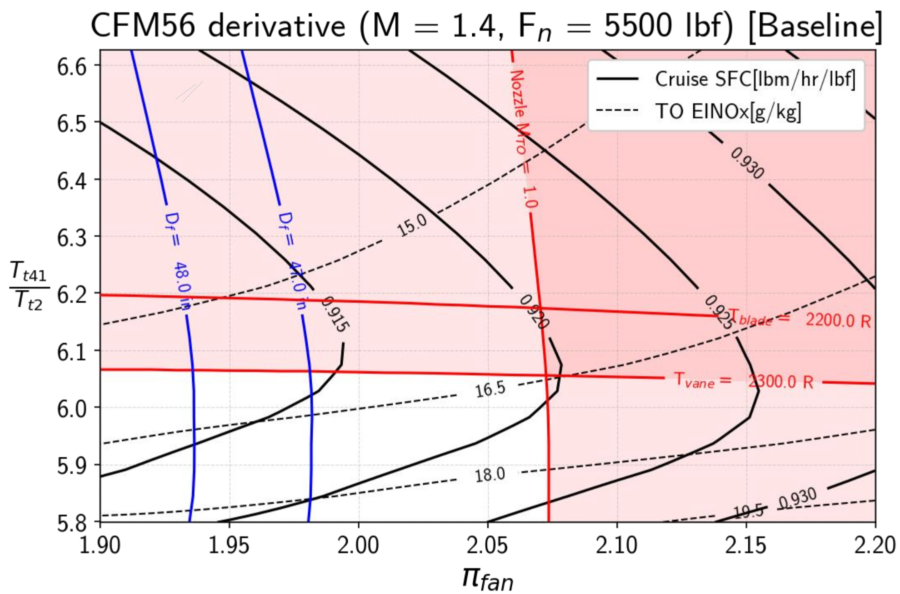
- *Take-off trajectory model*: ground roll – rotation – initial climb – VNRS – cutback
- *Engine model:* NPSS model of derivative or clean-sheet engine
- *Noise model*: semi-empirical noise model including fan, core, jet and aircraft noise sources
- **Future work**: Include emissions in optimization

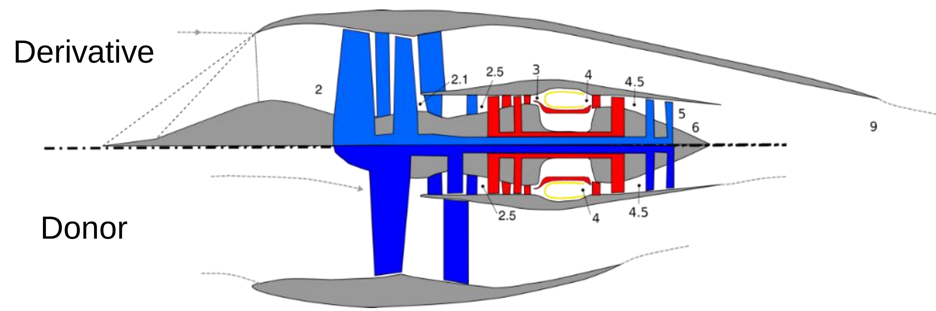


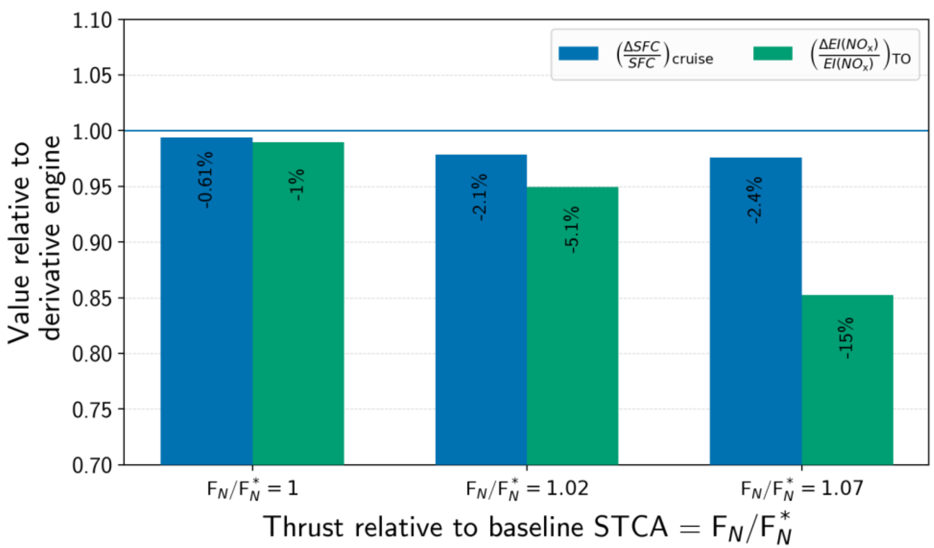
[2]

[1] DuBois, D. and Paynter, G.C., 2006. " Fuel Flow Method2" for Estimating Aircraft Emissions. *SAE Transactions*, pp.1-14.
[2] Lambe, A.B. and Martins, J.R., 2012. Extensions to the design structure matrix for the description of multidisciplinary design, analysis, and optimization processes. *Structural and Multidisciplinary Optimization*, *46*(2), pp.273-284.

Environmental performance of clean-sheet vs derivative SST engines







Derivative engine design space

- Two design variables: π_{fan} and T_{t41}/T_{t2} in derivative engine
- Core temperature limits (HPT and HPC) are determined by the donor core materials and cooling flows
- π_{HPC} is *only* an independent variable in clean-sheet engine (constrained by donor core characteristics in the derivative engine)

Fuel burn and emission comparison between clean-sheet and derivative engine for STCA [3]

- Performance of a clean-sheet engine relative to a derivative engine increases as the thrust requirement of the propulsion system, F_N, deviates from that of the STCA, F_N^*.

[3] Berton, J.J., Huff, D.L., Geiselhart, K. and Seidel, J., 2020. Supersonic Technology Concept Aeroplanes for Environmental Studies. In *AIAA Scitech 2020 Forum* (p. 0263).

Impacts of VNRS on climb-out emissions of SST engines

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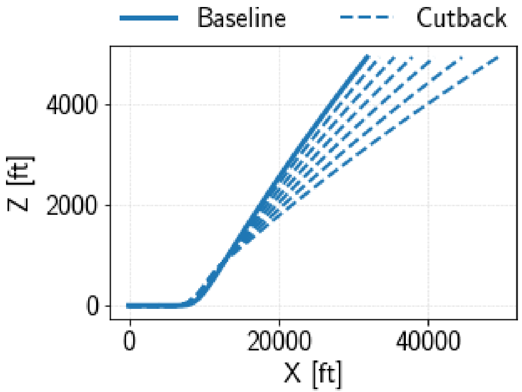
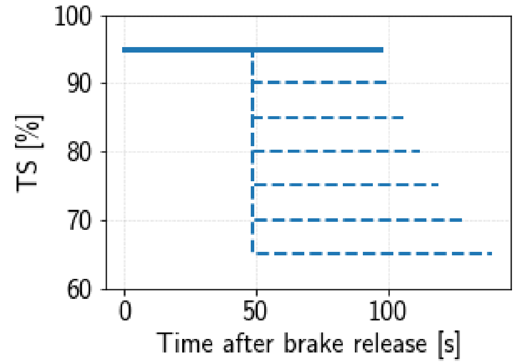


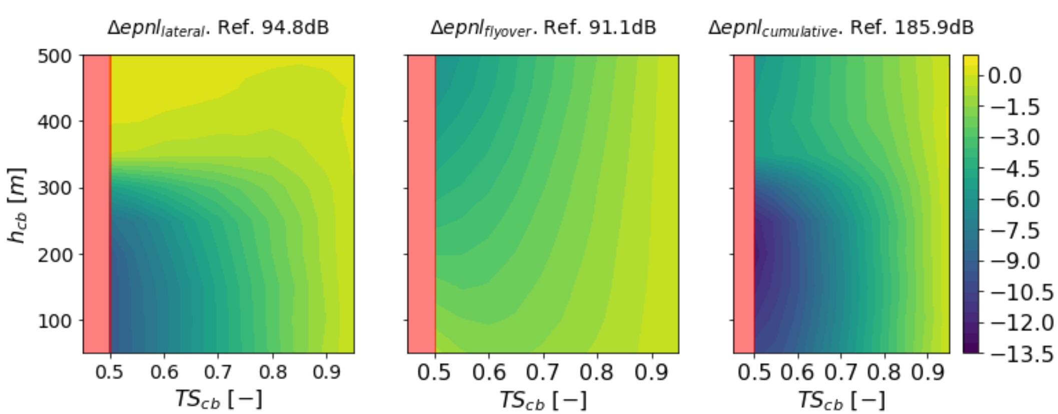


Single cutback take-off maneuver

- Varied cutback thrust-setting, TS_{cb}, and cutback altitude, h_{cb}.
- Analysis for NASA STCA (Mach 1.4, 8 passenger business jet)

Noise signature design space for single-cutback take-off maneuver

- Identified trade-off between lateral and flyover noise reduction using single-cutback
- **Future work**: extend to continuous thrust-setting schedule, TS(t)



Instantaneous effect of VNRS on emissions

- Compared instantaneous EI(NO_x) of certification standards and VNRS trajectories
- Both thrust-setting and time for climb-out (until 3000 ft) are affected by VNRS