E&E REDAC Subcommittee

Supersonic Civil Aircraft Research

17 March 2020

15:45

Content Development Leads:

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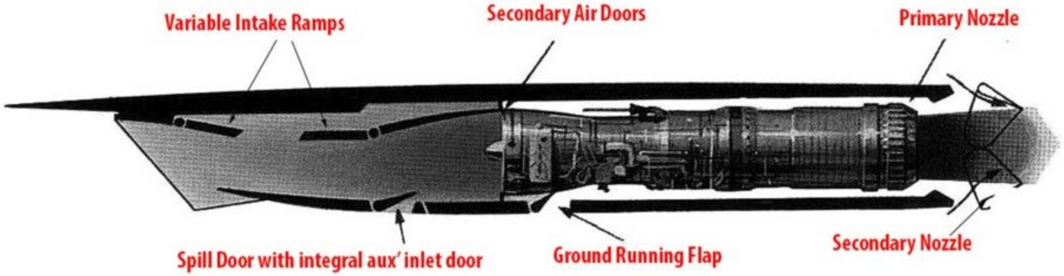
Issue: Re-Emergence of Civil Supersonics

- **Concorde retired in 2003.**
- **Today U.S. manufacturers are developing civil supersonic airplanes.**
  - Aerion (w/ Boeing)
    - Business jet, Mach 1.6, 12-18 pax
  - Boom
    - Transport jet, Mach 2.2, up to 75 pax

- **Raises large policy questions**
    - Supersonic flight over land
    - Fit for purpose regulations: Technology, Environment, Ops

Relative Engine Attributes

Civil Supersonic Engine (Olympus 593)



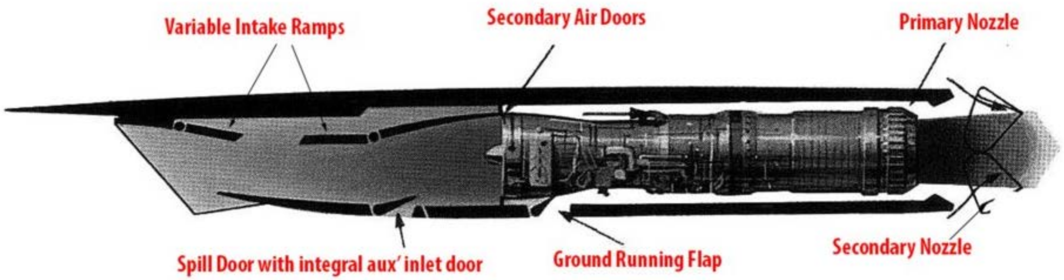
- Low BPR, work done by core
- Lower OPR
- Longer core
- Design Limit: Cruise

Subsonic Engine

- High BPR, work done by fan
- Higher OPR
- Shorter core
- Design Limit: Take Off + Top of Climb

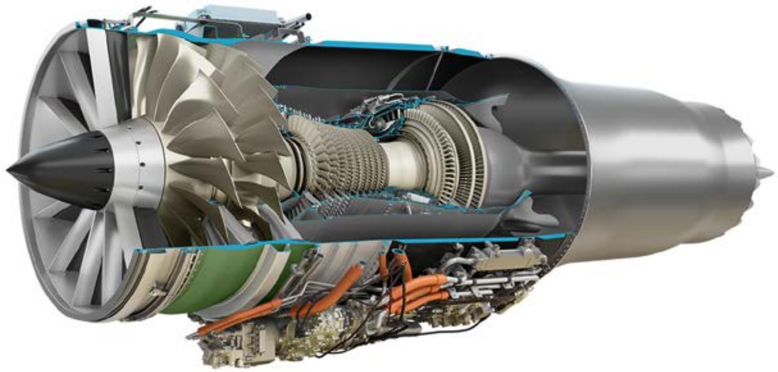
Supersonic Engine Modernization

Civil Supersonic Engine (Olympus 593)



- Low BPR, work done by core
- Uses afterburner
- Longer core
- Design Limit: Cruise

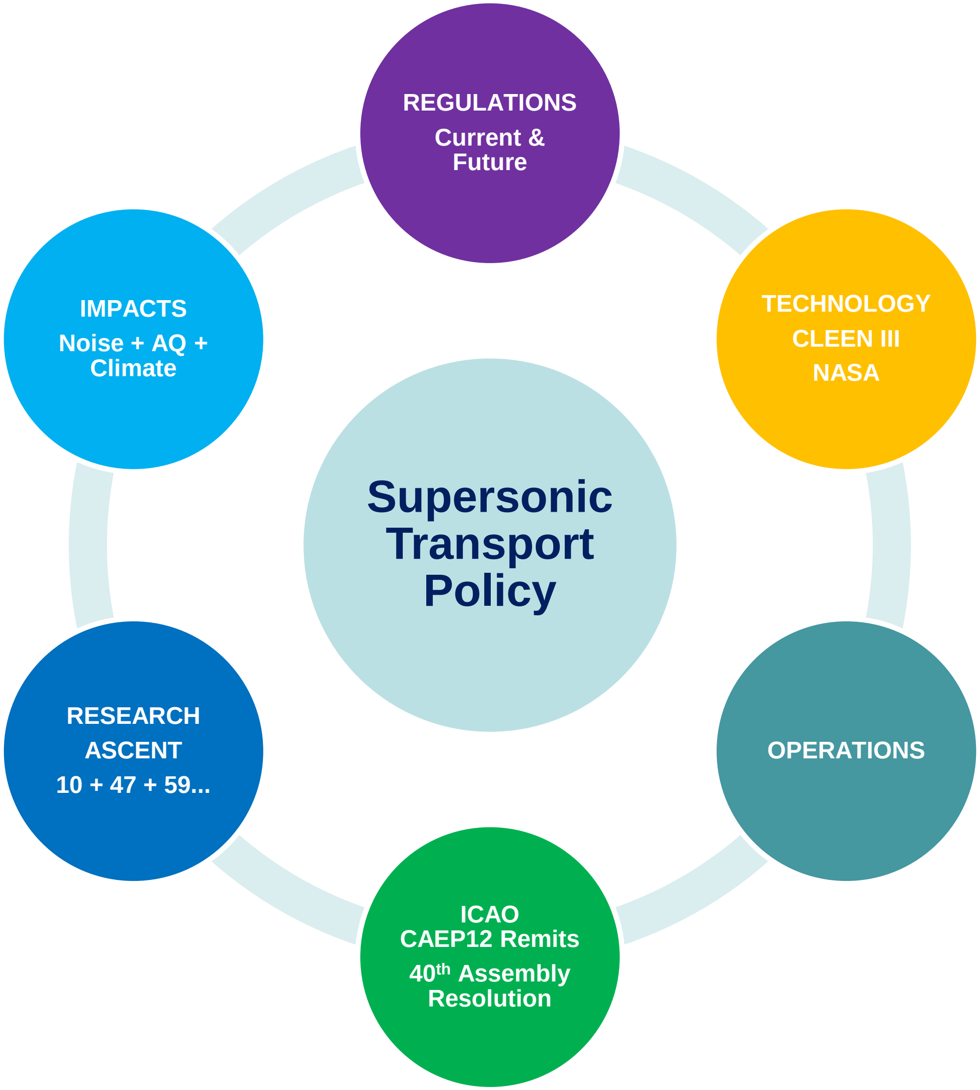
Modern Supersonic Engine



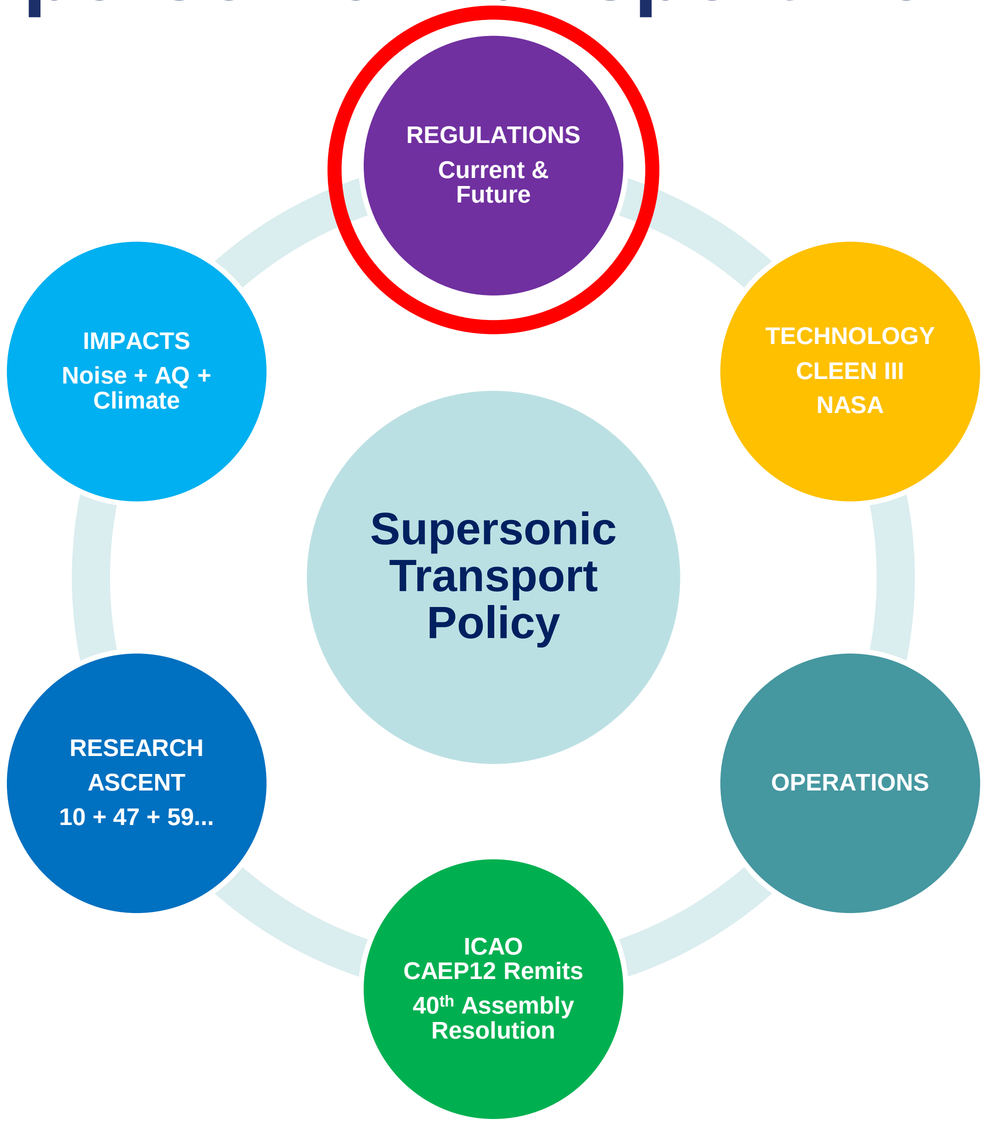
- Medium BPR, more work done by fan
- No afterburner
- Shorter core, twin shaft + twin fan
- Design Limit: Supersonic + Subsonic cruise
- Constructed from lighter, stronger materials

GE Affinity™ Supersonic turbofan https://www.geaviation.com/bga/engines/ge-affinity

Supersonic Transport Policy



Supersonic Transport Policy



Supersonic Aircraft Emissions – Current Standards

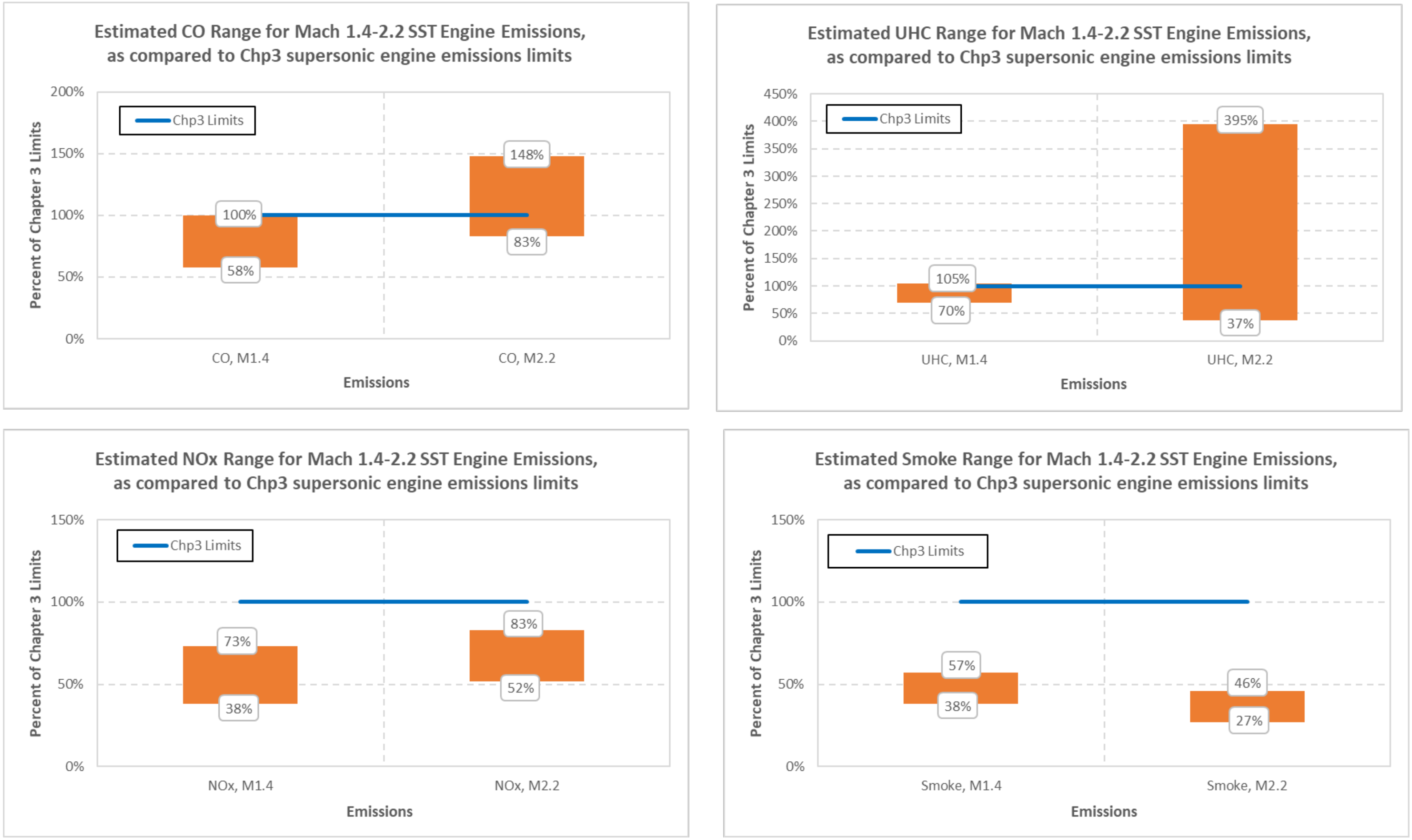
14 CFR Part 34 (FAA/DOT) & 40 CFR Part 87 (EPA)

- Applicable to all aircraft gas turbine engines designed to operate at supersonic flight speeds
- Regulated exhaust emissions are:
  - **Hydrocarbons (HC)** = $140\ (0.92)^{rPR}$ g/kN rO; For engines manufactured on or after January 1, 1984
  - **Smoke Number SN** = $83.6\ (rO)^{-0.274}$ not to exceed a maximum of SN = 50; For engines with rO ≥ 26.7 kN (6,000 lb) manufactured on or after January 1, 1984
  - **Nitrogen Oxides (NOx)** = 36 + 2.42 (rPR) g/kN; For engines manufactured on and after July 18, 2012 and all rO with afterburning applied
  - **Carbon Monoxide (CO)** = $4{,}550\ (rPR)^{-1.03}$ g/kN; For engines manufactured on and after July 18, 2012 and all rO with afterburning applied
  - where rPR is rated pressure ratio, and rO is rated thrust output in kilonewtons (kN)

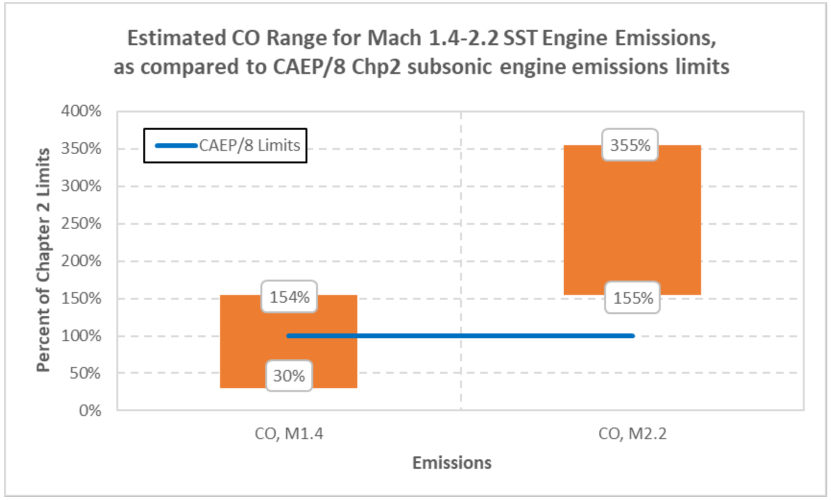
Current Supersonic Transport (SST) Operating Mode and Time in Mode (TIM) LTO Cycle

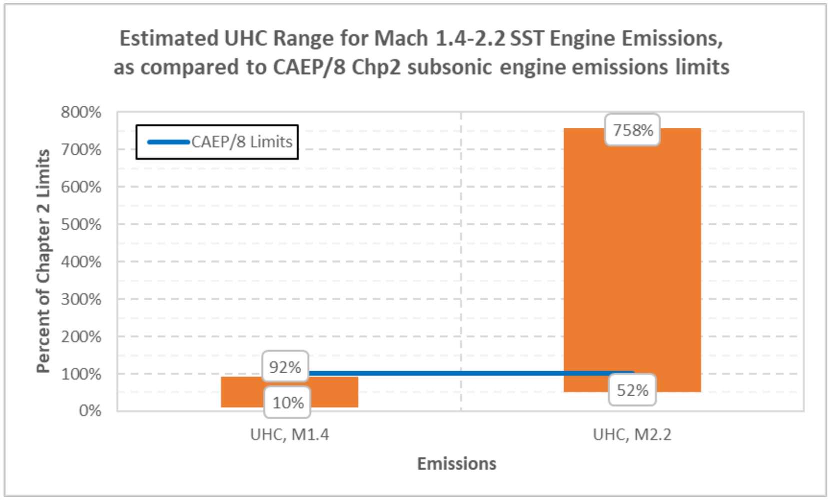
Operating Mode	Engine Power	Time in Mode
Takeoff	100%	1.2 minutes
Climb	65%	2.0 minutes
Descent	15%	1.2 minutes
Approach	34%	2.3 minutes
Taxi/ground idle	5.8%	26 minutes

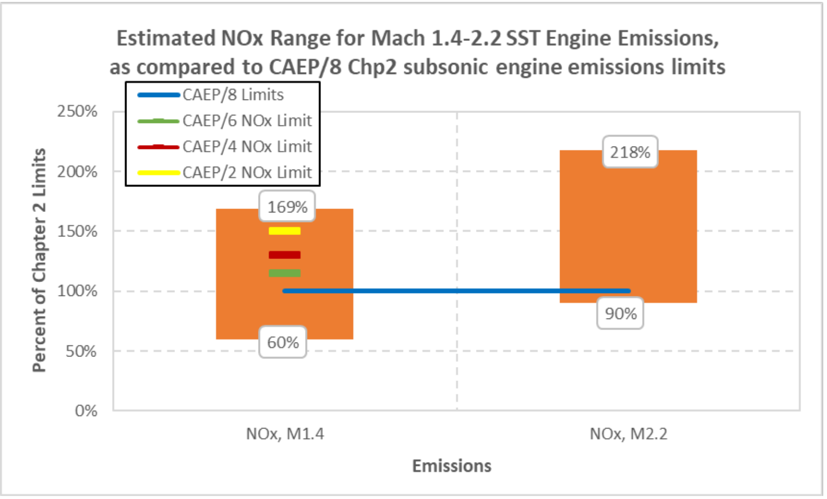
Supersonic Engine Emissions Standards

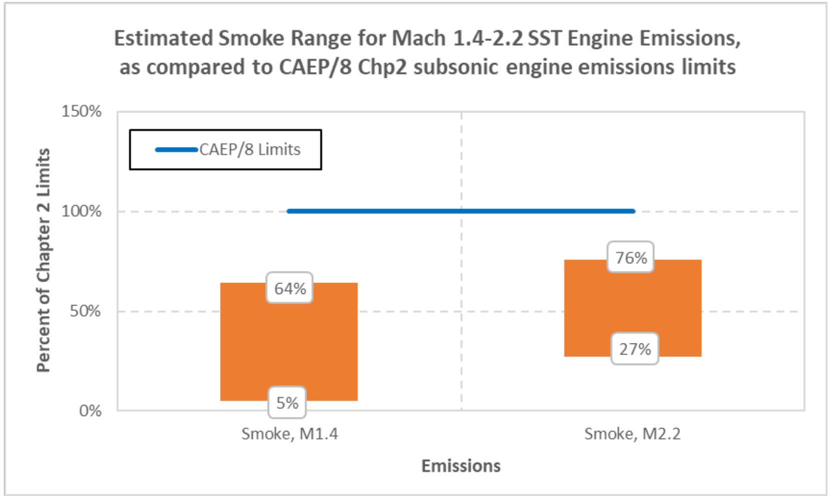


Subsonic Engine Emissions Standards









Rulemaking: Update Part 91

NPRM: Special Flight Authorizations for Supersonic Aircraft

- Current regulations prohibit overland supersonic civil flights in the United States, but include a procedure to request authorization for these flights for the purposes of test and development of new aircraft.
- NPRM issued on June 28, 2019 and comment period closed August 27, 2019
- FAA is in the process of responding to comments.

Rulemaking: Update Part 36

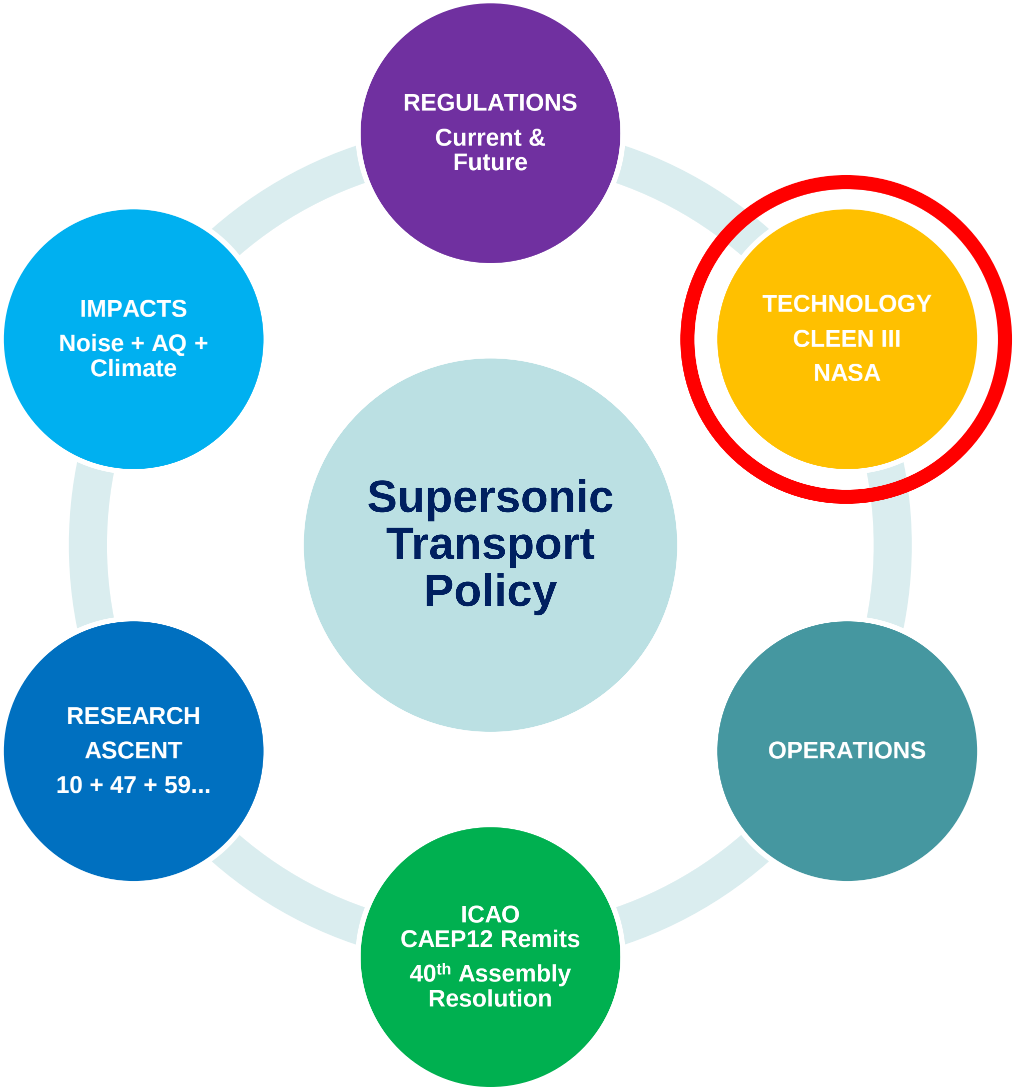
NPRM: Landing and Takeoff Noise Certification Supersonic Airplanes.

- Currently no regulations exist for the LTO noise certification of civil supersonic airplanes in the United States.
- NPRM to be published in Spring 2020
- FAA is in the rulemaking process

ICAO and US Guidance

Subject	Noise	Emissions
ICAO Annex 16 Standards and Recommended Practices (SARPS) - Volume I: LTO Noise SST (amend) - Volume II: Emissions SST (new) - *Volume III: En Route Sonic Boom Noise (TC proposed new)*	- Develop Environmental Technical Manual (ETM) for Volume I	- Update Environmental Technical Manual (ETM) for Volume II
Title 14 Code of Federal Regulations (CFR) - Part 36: Noise - Part 34: Emissions	- Update Advisory Circular 36-4D	- Update Advisory Circular 34-1C
FAA Offices and Others	- Briefings and Workshops with Aircraft Certification (AIR) Offices - Potential Public Outreach	- Briefings and Workshops with AIR Offices

Supersonic Transport Policy



CLEEN III Supersonic Technology

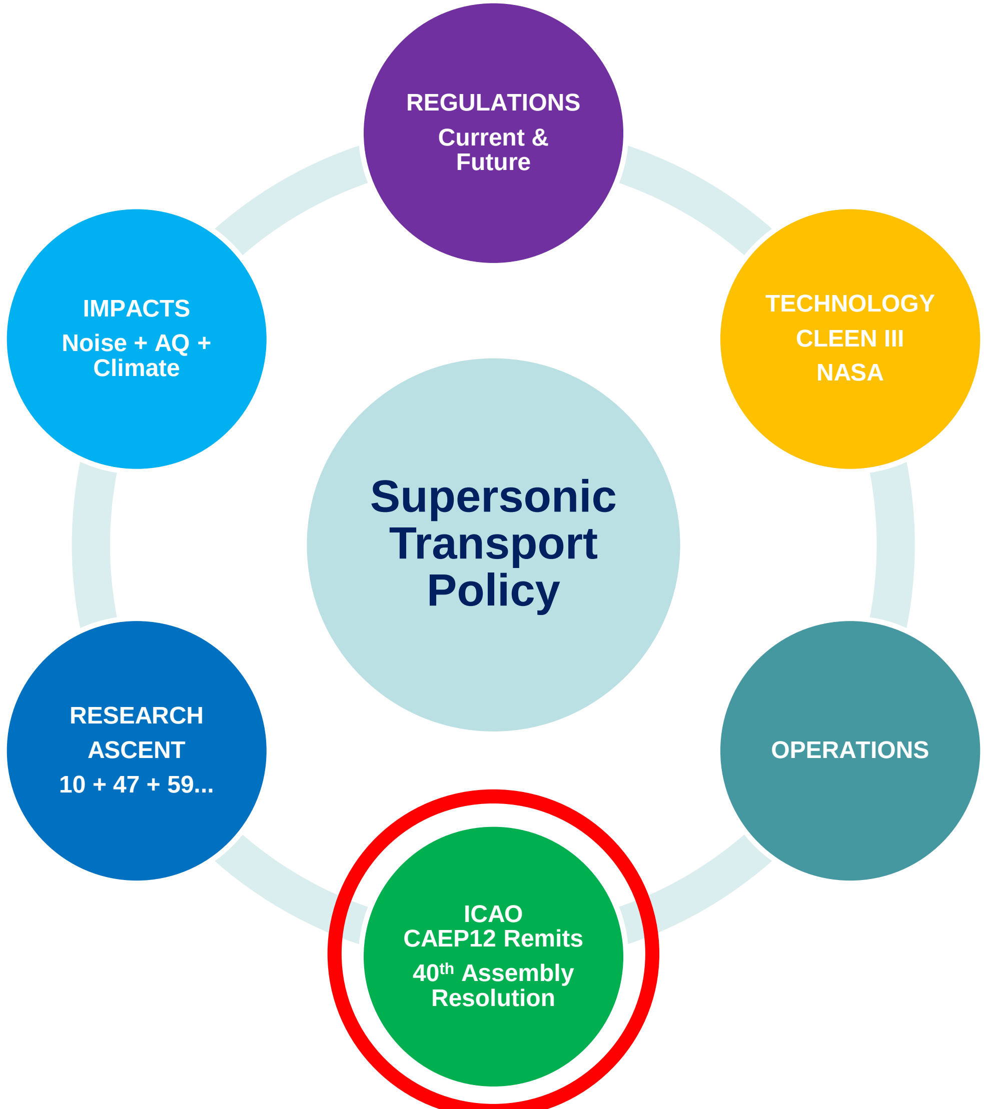
- Tier 4 Goal: Certifiable aircraft technology that reduces noise levels during the landing and takeoff cycle (LTO) for civil supersonic airplanes or reduces landing and takeoff cycle (LTO) nitrogen oxide emissions for civil supersonic airplanes
- Market Survey feedback:
  – Not all companies supportive of inclusion in CLEEN
  – Focus should be on certification challenges (LTO noise), collecting noise/emissions data
  – Potential Technology Areas: multi-stage fan source noise reduction, high-speed jet noise reduction, variable nozzles, high-speed liners, FMS/FADEC integration
- Supersonic Technical Trade Studies

Supersonic Transport Policy

Operations

- ATC/Navigation for SST was first published in ICAO Circular 126 for basics.
- Pan Ops operability supports subsonic aircraft but uncertain of applicability for SST.
- More discussions needed…

Supersonic Transport Policy



Status: ICAO Supersonic Aircraft

40th Assembly Resolution

- *Reaffirmed* the importance (ICAO) attaches to ensuring that no unacceptable situation for the public is created by sonic boom from supersonic aircraft
- *Recognized* the need for an exploratory study to provide better understanding of airport noise impacts resulting from the introduction of supersonic aircraft

Exploratory Study for Supersonic Aircraft

- ➲ Groups to define supersonic aircraft and data to model noise and emissions
- ✓ WG1 to recommend landing takeoff cycle (LTO) noise certification procedures
- ➲ FESG to develop multiple supersonic aircraft demand scenarios
- ➲ MDG to model LTO noise and full flight fuel burn and emissions
- ➲ Groups to consider supersonic aircraft data uncertainty
- ➲ Groups to consider trades, including noise and full-flight fuel burn

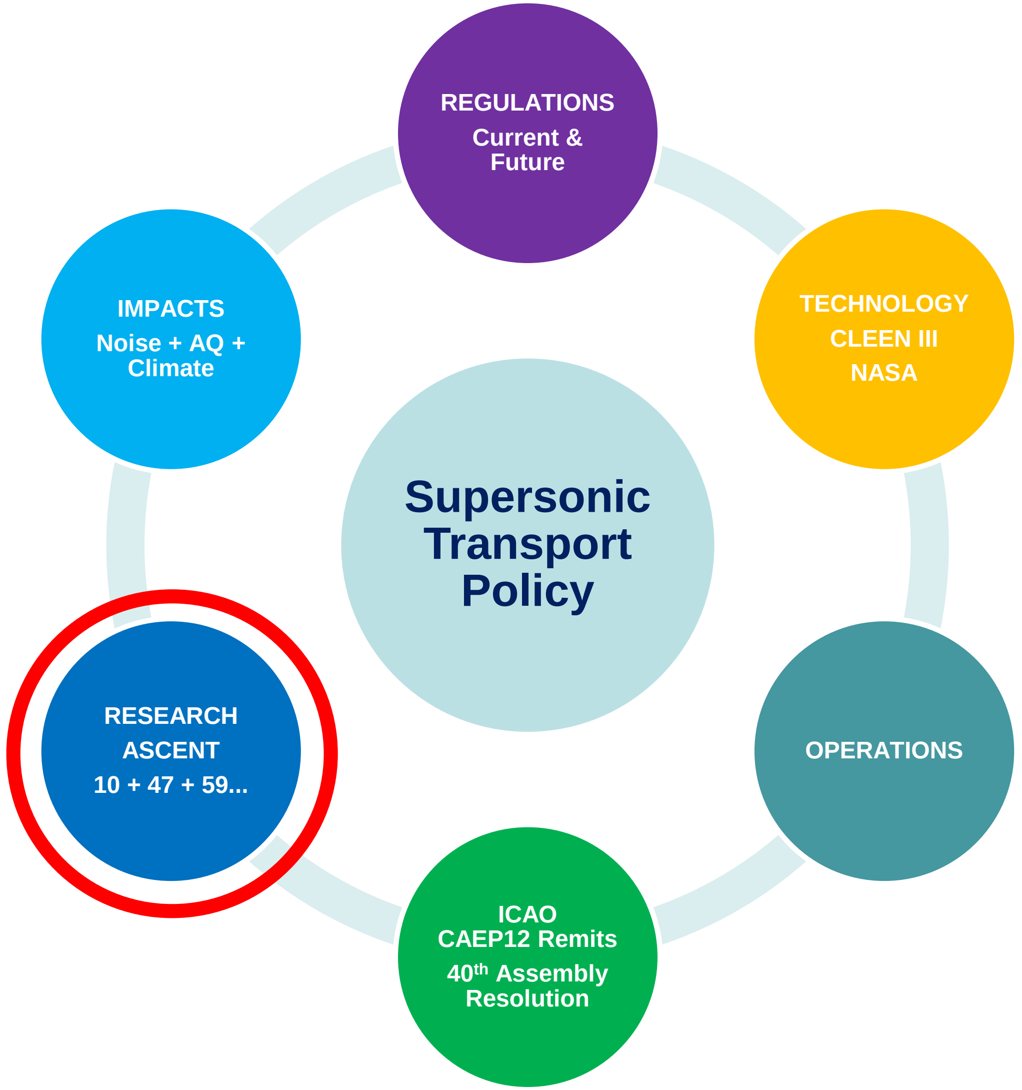
➲ plan to be developed

➲ work has begun in the US

Other ICAO Committee on Aviation Environmental Protection (CAEP) Remits

- Monitor SST research and development for noise and engine emissions consequences
- Continue work toward SST noise standards and recommended practices (SARPs)
- Assess consequences for engine-based certification standards
- Assess potential for an aeroplane CO_2 emissions certification standard

Supersonic Transport Policy



ASCENT 10 – Aircraft Technology and Modeling Assessment

Goal: Model and assess environmental impacts (fuel burn, emissions, noise) of supersonic transport (SST) aircraft in the fleet.

Drivers:

- Recent developments in technology has made SST viable, necessitating further detailed study.
- Regulation: Domestic (FAA, EPA) and international (ICAO) regulatory bodies want to be prepared to facilitate SST inclusion in the fleet.

Approach:

Georgia Tech and Purdue Univ. are carrying out:

- Fleet assumptions and demand assessment
- Fleet Analysis
- AEDT Vehicle Definition
- EDS Vehicle Modeling
- Assess Interdependencies due to Technologies
- Coordinate with other SST projects that develop Clean Sheet Supersonic engine designs.

So far:

The teams have completed analysis of two aircraft designs and will continue with others, much larger aircraft.

Next Steps:

- Refine SST demand scenarios
- Use actual designs in impact analyses
- Provide regulatory support.

ASCENT 47: Supersonic Engine Designs

PRIMARY OBJECTIVE & DRIVER:

What are the noise and emissions characteristics of ***clean-sheet vs. derivative engines*** that are designed for future civil supersonic (SST) transport aircraft?

The answer to this question will help ***bound the capabilities of new technologies*** and subsequently ***inform new and revised supersonic noise and emissions regulations***.

APPROACH

Identify operating requirements for SST propulsion systems → Build SST engine cycle model to explore the design space → Quantify fuel burn, noise and emission characteristics → Compare clean-sheet design to a repurposed engine core

Outcomes Since Spring'19:

- Students completed a 3 month internship at Aerion Supersonic company
- Established modelling framework using the CFM56-5B/7B engines, which will be used to model derivative SST engines.
- Completed reactor network based gas turbine combustor model for estimating NO_X

Next Steps:

- Extend combustor model for other emission (e.g. carbon monoxide)
- Build noise model to quantify engine noise
- Model derivative engine with inputs from collaborators
- Model clean-sheet engine for a given mission and airframe

ASCENT 59 - SST Jet Noise Models & Experiments

GOAL: Improved Jet Noise Prediction Methods with Reduced Uncertainty

A#59: Jet Noise Modeling

•Varied modeling approaches

- Low fidelity (Illinois)
- Moderate fidelity (PSU / GT)
- Higher fidelity (Stanford)

A#59-E: Jet Noise Measurements

Parametric examination of key variables (cycle, mixer, and nozzle) and their influence on jet noise

Performed by Georgia Tech (GT)

- Open engine / cycle info for jet noise modeling and experimental validation
- Developed based on ASCENT analysis of CAEP NASA STCA vehicles with industry insights on key engine details

NASA STCA

(Supersonic Technology Concept Airplane for ICAO CAEP)

A#10: Aircraft Technology Modeling & Assessment [GT/Purdue]

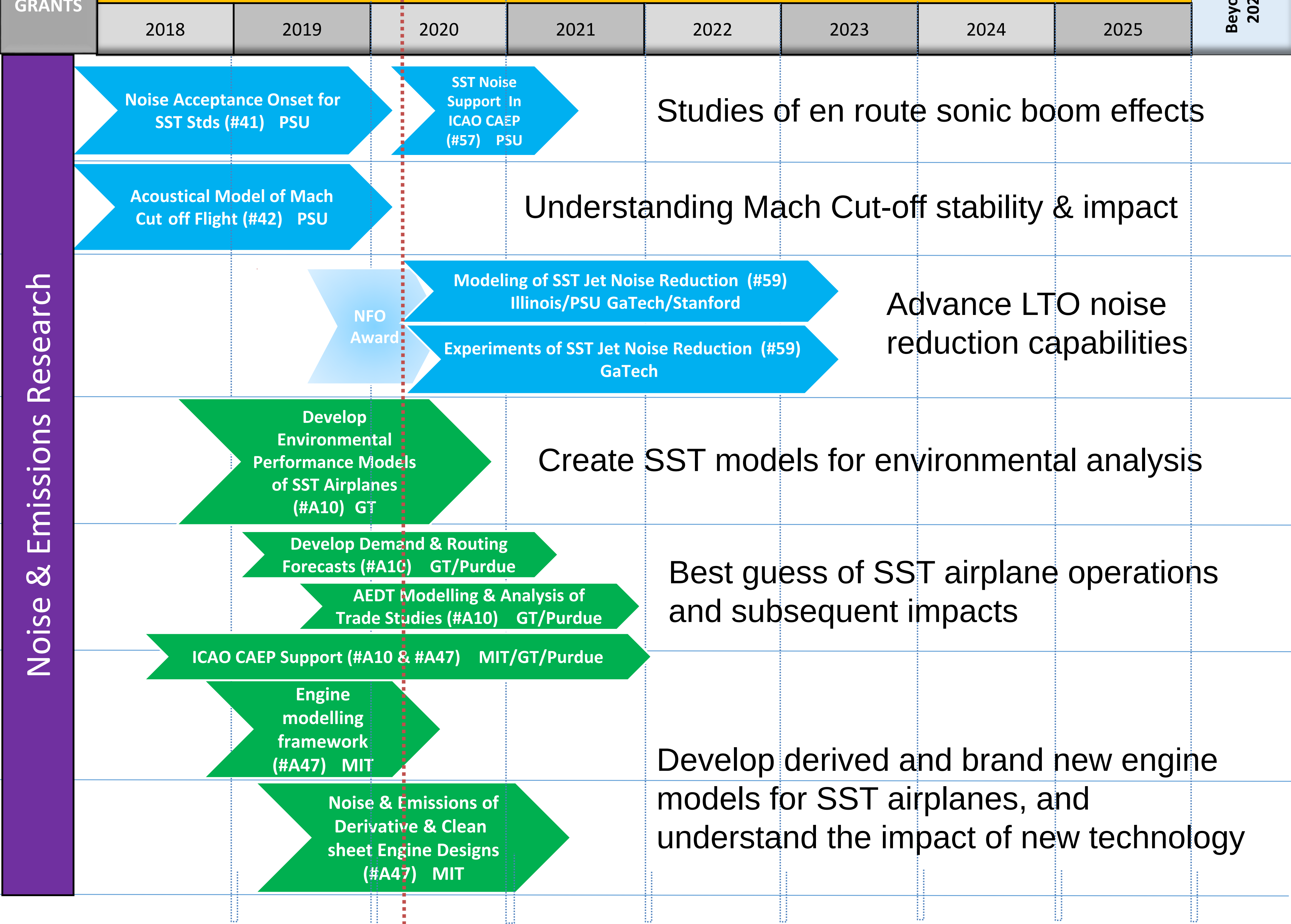
A#47: Clean Sheet Supersonic Aircraft Engine Design and Performance [MIT]

Project Advisory Panel:

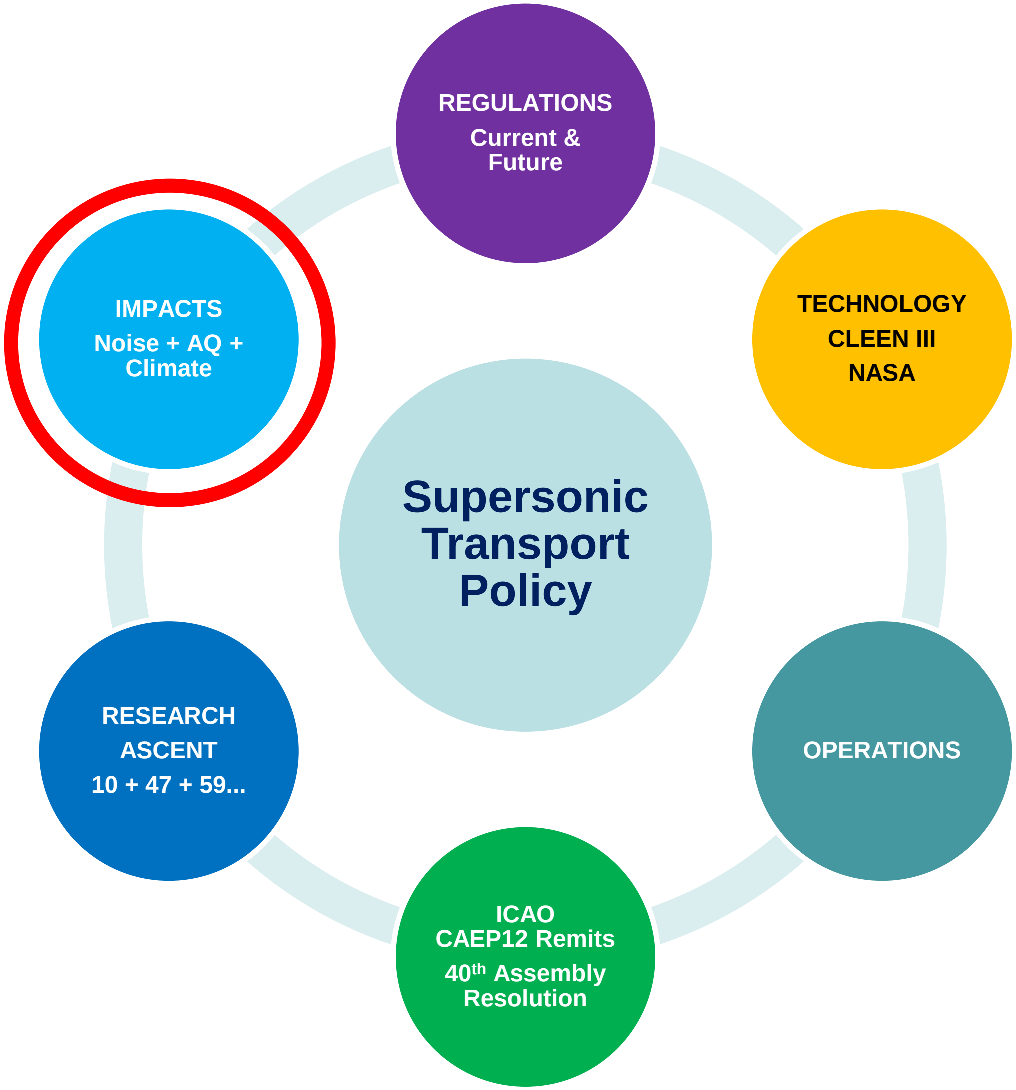
FAA, NASA, DOD (TBC)

Industry: Aerion, GE, Gulfstream

ASCENT Supersonics Research Timelines



Supersonic Transport Policy



SST Environmental Impacts

EMISSIONS [ASCENT #22 and #58]

- Climate Impacts due CO_2, NOx, Water Vapor and Particulate Matter Emissions

  - SST climate impacts mainly from the NASA High Speed Civil Transport (HSCT) Project of 1990s, in which results depend strongly on assumptions: fleet mix, operations and emission rates of pollutants.

- Air Quality Impacts due to NOx and Particulate Matter Emissions

  - SST AQ impacts are not addressed – health impacts due to increased exposure to UV radiation quantified

NOISE: [ASCENT #41, #57]

- LTO Noise Impact due low BPR engines and greater than Mach 1 airplane flight capabilities, for day to day operations around airports.

  -SST Noise Impacts relies on NASA/OEM STCA modeling

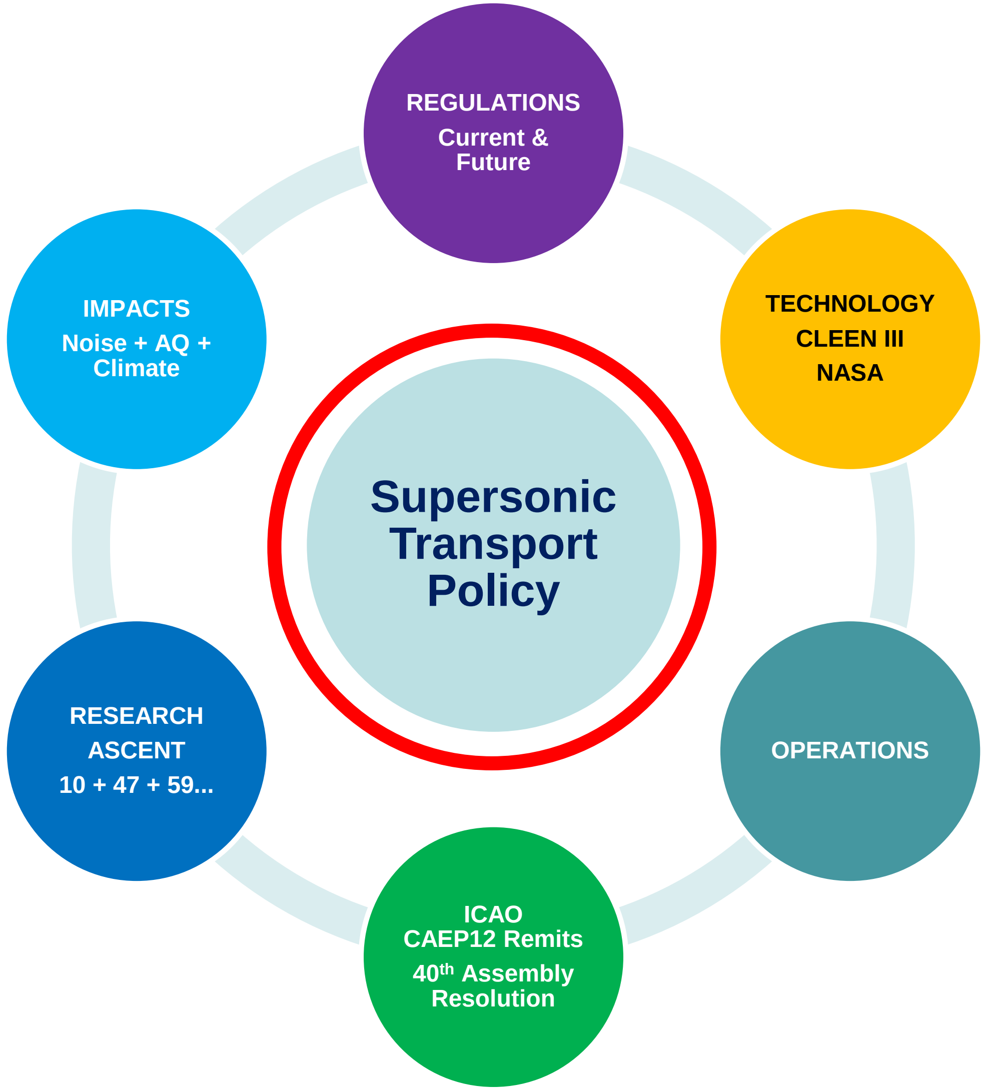
- Sonic Boom Impacts due to coalesces of shockwaves propagated to ground - focus booms, “N” waves, and secondary booms.

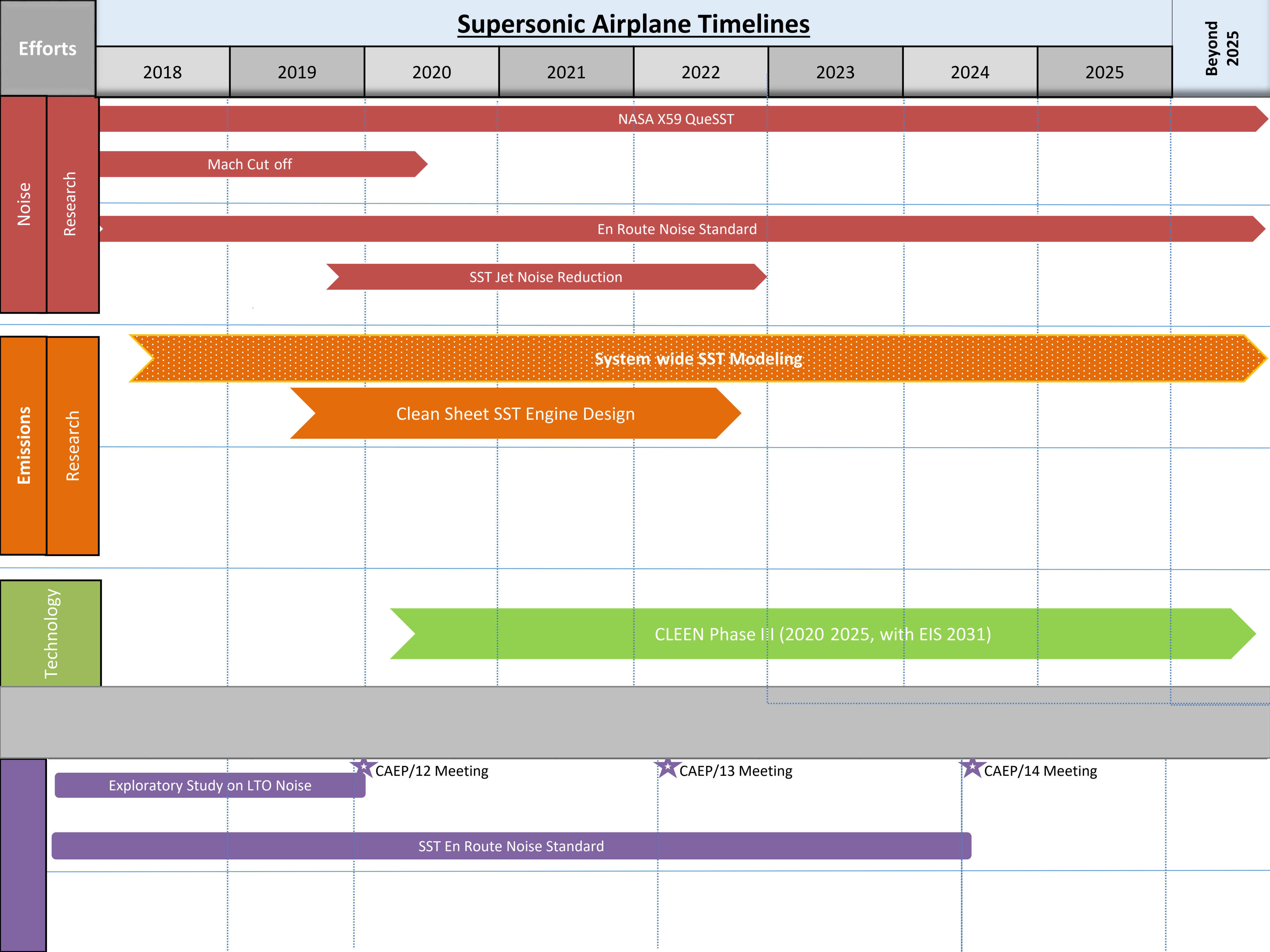
  - Secondary boom under study for abatement conditions and modeling.

ICAO CAEP Impacts Science Group (ISG)

- ISG will prepare a report summarizing existing scientific knowledge on the impact of supersonic aircraft on climate, air quality and noise for CAEP/12. A report on the impacts of supersonic aircraft noise and sonic boom was finalized at CAEP/11.

Supersonic Transport Policy





Supersonic Airplane Timelines
Efforts
2018
2019
2020
2021
2022
2023
2024
2025
Beyond 2025
Noise
Research
NASA X59 QueSST
Mach Cut off
En Route Noise Standard
SST Jet Noise Reduction
Emissions
Research
System wide SST Modeling
Clean Sheet SST Engine Design
Technology
CLEEN Phase III (2020 2025, with EIS 2031)
CAEP/12 Meeting
CAEP/13 Meeting
CAEP/14 Meeting
Exploratory Study on LTO Noise
SST En Route Noise Standard