An Overview of NASA's Commercial Supersonics Technology Project

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AIAA Aviation 2016
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Image: The Boeing Company

Commercial Supersonic Technology Project

Develop and Validate Tools, Technologies and Concepts to Overcome the Barriers to Practical Supersonic Commercial Aircraft

Focus FY 13-17

Development of tools and integrated concepts that will enable demonstration of overland supersonic flight with acceptable sonic boom

Scope

- Civil Supersonic Aircraft: business class to supersonic airliners
- Low Boom Flight Demonstration concept exploration & planning

Resources in FY16

- ~ $32 M (includes labor cost)
- ~ 92 FTE
- Additional funds from budget augmentation

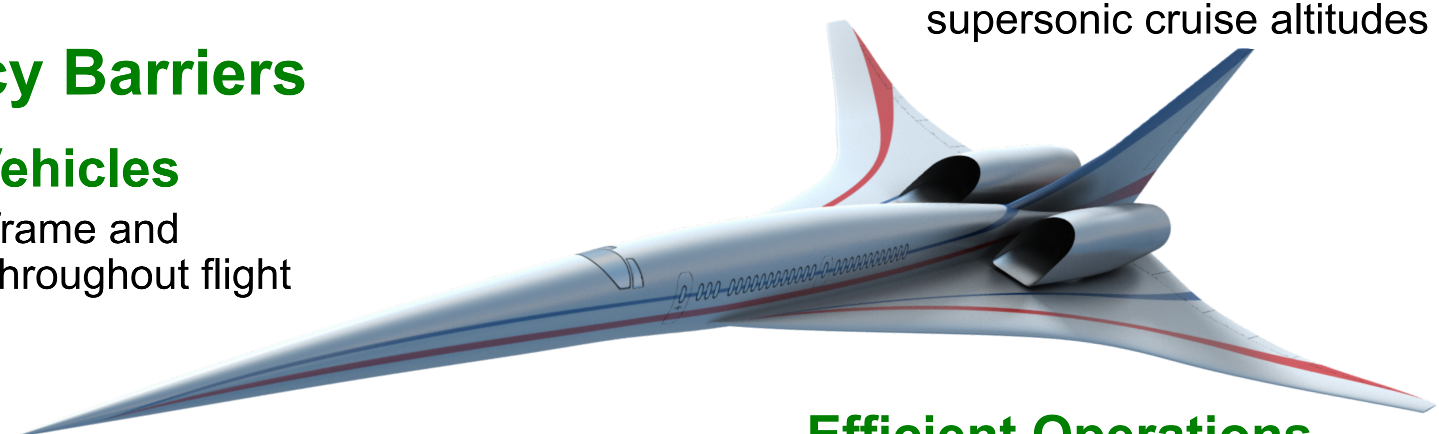
Barriers to Practical Supersonic Commercial Aircraft

Environmental Barriers

Sonic Boom
- Design for low noise sonic boom
- Understand Community Response

Airport Noise
- Noise levels not louder than subsonic aircraft at appropriate airports

High Altitude Emissions
- No or minimal long term impact at supersonic cruise altitudes



Efficiency Barriers

Efficient Vehicles
- Efficient airframe and propulsion throughout flight envelope

Light Weight, Durable Vehicles
- Low airframe and propulsion weight in a slender flexible vehicle operating at supersonic cruise temperatures

Efficient Operations
- Airspace-Vehicle interaction for full utilization of high speed

Solutions to Barriers Drives Selection of Research Themes

CST Project Research Themes

CST Project Builds on the Success of Supersonics / High Speed Projects FY 08-14

Research Themes Focus on Low Boom Flight Demonstration Readiness, Potential Next Tech Challenges

Integrated Design Solutions

Successful low boom design driven by highly integrated airframe/propulsion systems

Airport Community Noise

Airport noise to not exceed subsonic aircraft is a challenge, especially for new Chapter 14 requirement

Sonic Boom Community Response

Annoyance metrics & data collection methodology are key to providing database to enable rule change

High Altitude Emissions

Supersonic flight altitudes & engine operating conditions challenge emission reduction technology

Cruise Efficiency

Fuel consumption at supersonic speed has a large effect on operating economics

Aeroservoelasticity

Long slender airframes, thin wings and large engines create unique ASE challenges

Flight Systems

Unique systems required in low boom design & supersonic aircraft operations

Light Weight, Durable Engines/Airframes

(Research Content in other ARMD Programs & Projects)

Linkage to the NASA Strategic Thrust 2 Roadmap

NASA strategy supports each of the three Community Outcomes (2015-2025, 2025-2035, 2035+)

COMMUNITY OUTCOMES

2015	2025	2035
Supersonic Overland Certification Standard Based on Acceptable Sonic Boom Noise	Introduction of Affordable, Low-boom, Low-noise, and Low-emission Supersonic Transports	Increased Mission Utility and Commercial Market Growth of Supersonic Transport fleet

NASA Strategy

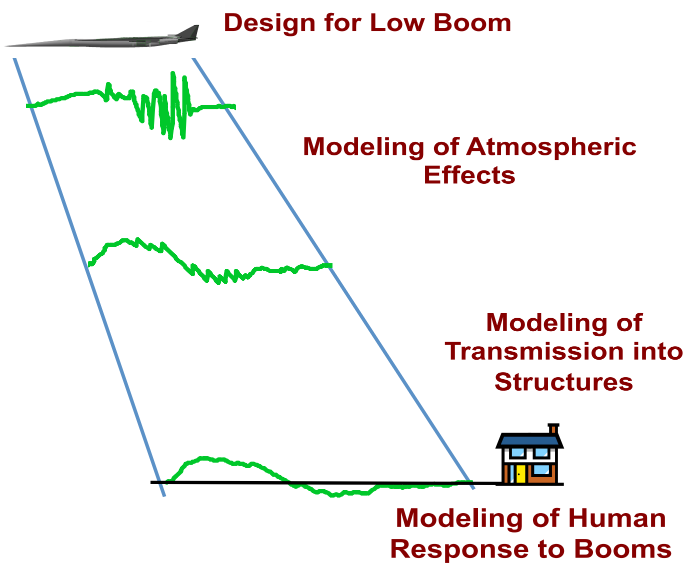
- **Focus investment on the development of low boom design, flight validation and community response**
- **Focus on key technologies that ensure that supersonic aircraft will be environmental good neighbors and meet standards similar to latest subsonic aircraft**
- **Focus on capabilities and technologies that enable airline compatible operating economics for supersonic aircraft**

Rationale for CST Technical Challenges

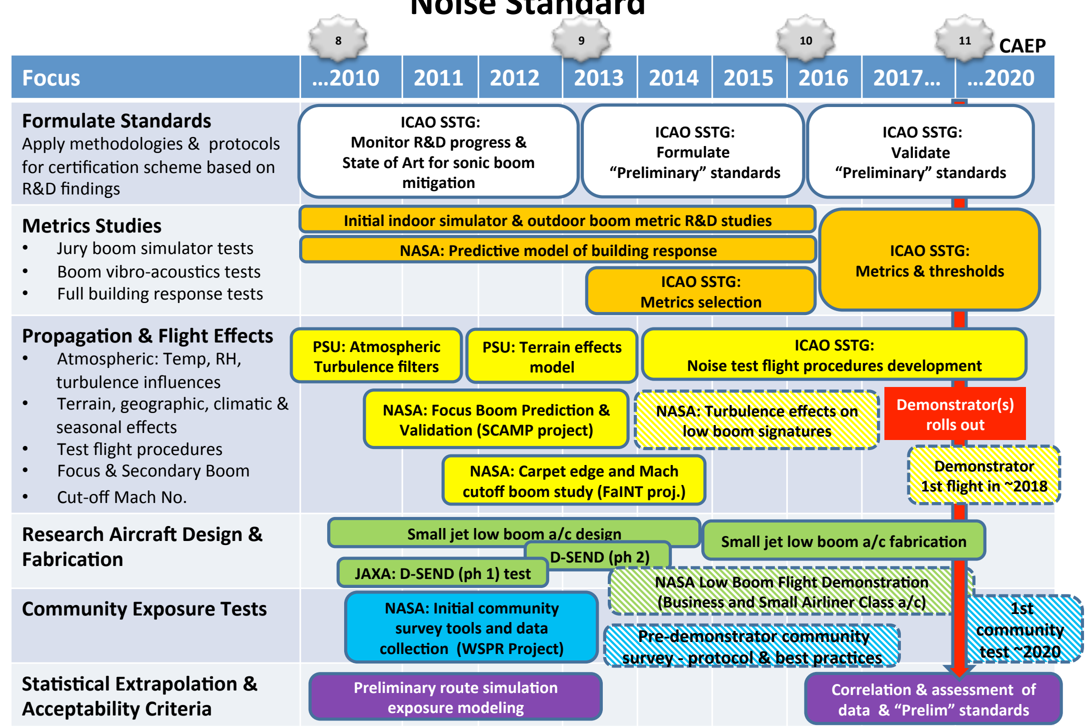
Overland Supersonic Flight

- Most significant barrier to opening new markets for supersonic civil aircraft
  - US: No flight at Mach > 1.0
  - ICAO: No sonic boom disturbance
- ICAO & FAA: rule change driven by improved technology, industry interest
- NASA has leadership, clear role in technology & science
  - Design for low boom
  - Understand community response to exposure
  - Scientific data to support a noise based rule

Sonic Boom Technical Challenge Elements



ICAO/FAA Notional Roadmap for Sonic Boom Noise Standard



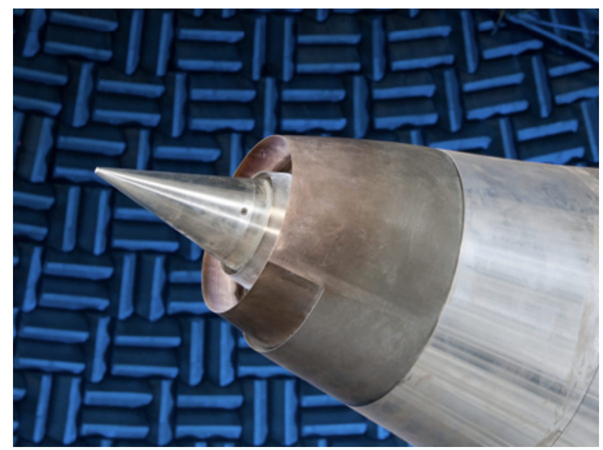
May 2013 version

Rationale for CST Technical Challenges (cont.)

Airport Community Noise

- Arguably second most significant barrier to supersonic civil aircraft
  - Existing ICAO and FAA certification requirements
    - Initial guidelines for supersonic aircraft already in place
    - Subsonic rules regularly reviewed and updated to increase stringency
  - Stringent local limits
- Low noise propulsion solutions for low boom aircraft are technically very challenging
  - Balance of takeoff performance, noise and cruise efficiency
  - Jet noise is primary source, but inlet-fan can be a significant contributor
- Opportunity to build on success of N+2 Study investment


Image: Lockheed Martin



Research Theme Selection Rationale

- Activities in Research Themes address High Speed unique elements of barriers to High Speed Flight
- Selection Criteria included:
  - Integration / Interaction with tech challenge research at systems level
  - Next set of High Speed tech challenges
  - Potential impact on readiness for low boom demonstration

High Altitude Emissions

- Supersonic flight altitudes and engine operating conditions challenge emission reduction technology

Cruise Efficiency

- Fuel consumption at supersonic speed has a large effect on operating economics

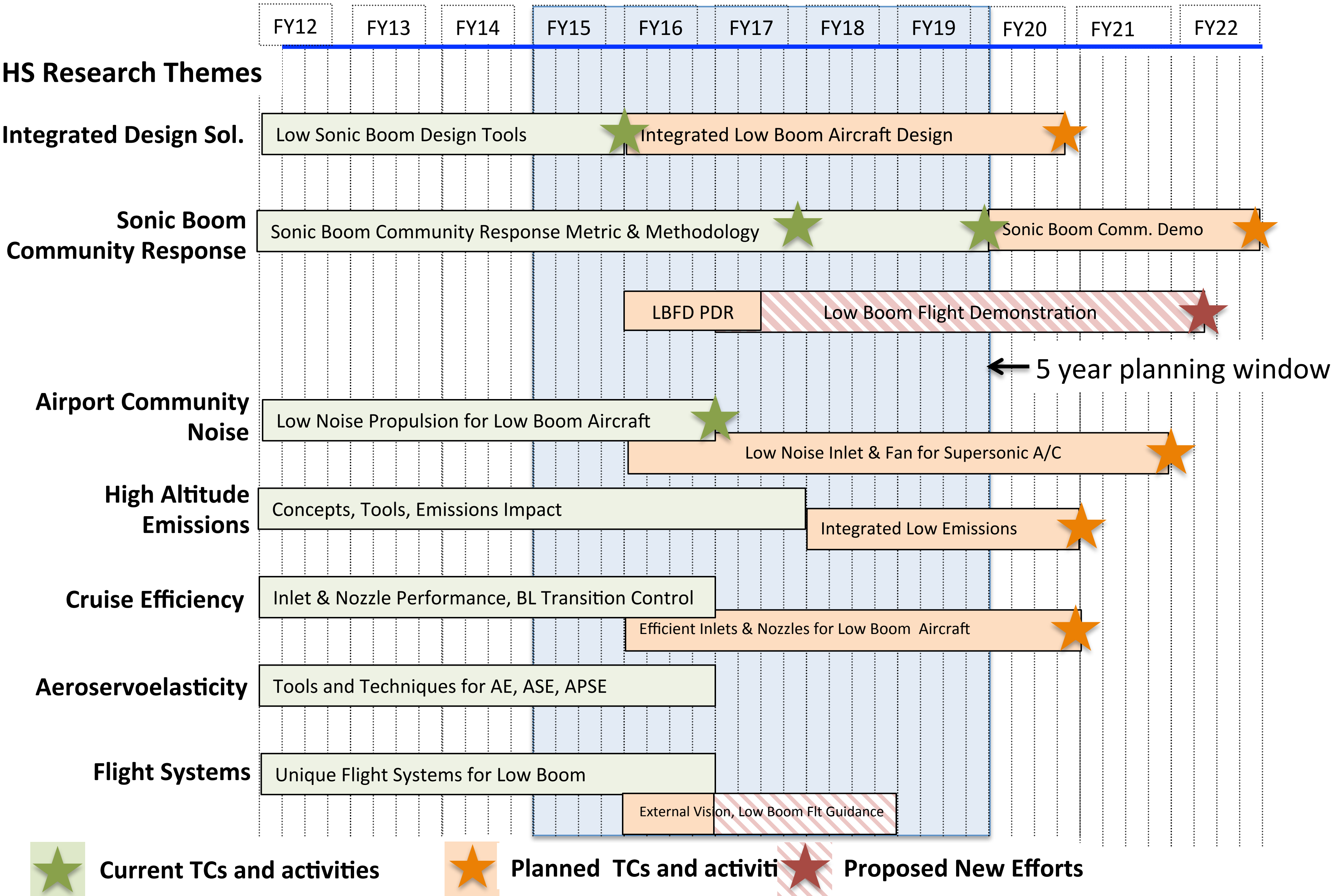
Aeroservoelasticity

- Long slender airframes, thin wings and large engines create unique ASE challenges

Flight Systems

- Unique systems required in low boom design & supersonic aircraft operations

Technical Challenges Evolution : FY 15-16



CST Project Structure for FY 16

PROJECT LEVEL

Note: Project/Center liaison is a function (not a Project position) performed by SPM or other TBD

Project Manager:	Peter Coen (LaRC)
Deputy Project Manager:	Clayton Meyers (GRC)
Project Engineer:	Lou Povinelli (GRC)
Associate PM for Flight:	Tom Jones (AFRC)
ARC Center Liaison:	Don Durston

Systems Analysis

<u>Business unit</u>

Lead Analyst: Mary Neuzil (GRC)

Center Analysts: Angela Williams (LaRC)
Glenda Almeida(AFRC)
Kim Washington (ARC)

Scheduler: Leslie Letzinger (LaRC)

SUB-PROJECT

Overland Supersonic Flight

SPM: Brett Pauer (AFRC)

Tech POCs: Alexandra Loubeau (LaRC), Dan Banks (AFRC)

- Sonic Boom Community Response Tech Challenge
- Flight Systems Research Theme

Integrated Supersonic Aircraft Technology

SPM: Dave Hahne (LaRC)

Tech POCs: Lori Ozoroski (LaRC), Jon Seidel (GRC), Linda Bangert (LaRC), Walt Silva (LaRC)

- Integrated Low Boom Design Tools Tech Challenge
- Cruise Efficiency Research Theme
- Aeroservoelasticity Research Theme

Environmental Impact of Supersonic Aircraft

SPM: Steve Sinacore (GRC)

Tech POCs: James Bridges (GRC), Clarence Chang (GRC), Ray Castner (GRC)

- Low Noise Propulsion Tech Challenge
- High Altitude Emissions Research Theme
- Low Noise Inlet/Fan Tech Challenge
- Efficient Inlets & Nozzles Tech Challenge

Low Boom Flight Demonstration

SPM: Dave Richwine(LaRC)

Planning Team: All Centers

- Low Boom Flight Demonstration

Research Theme:
Integrated Design Solutions for Revolutionary High Speed Aircraft

Technical Challenge:
Low Sonic Boom Design Tools

Low Boom Design Tools Technical Challenge

Description: **Tools and technologies** enabling the design of supersonic aircraft that **reduce sonic boom noise to 80 PLdB** validated as **ready for applica[illegible]n in a flight demonstrator**

Deliverables: 1) Integrated higher fidelity tools for prediction & **design o[illegible] [illegible]oom**
2) Include **inlet and nozzle flow field effects**
3) Focus boom, **full (cruise) flight profile and [illegible] [illegible]s**

COMPLETED!!!

Tools

- Advancements in mesh adaptation, refi[illegible] [illegible]n, & automation
- New and improved low boom de[illegible] [illegible]ools and approaches
- Adjoint equation based te[illegible] [illegible]pact many aspect of the development
- Powered inlet and [illegible] [illegible]ons for accurate simulation of propulsion flow

Design

- Multi-f[illegible] [illegible]rated into improved fidelity conceptual design
- [illegible] [illegible]ertainty considerations
- [illegible]d for small airliner and flight demonstrator configurations

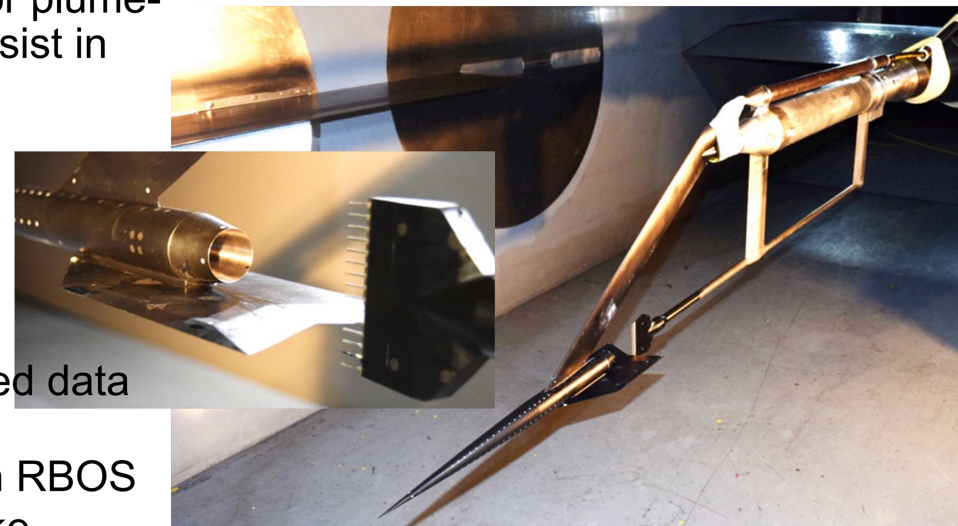
Valida[illegible]

- Ne[illegible] linear rail pressure measurement hardware
- Improved data collection techniques improve speed and reduce uncertainty in measurements
- Validation tests and CFD comparisons completed for full configuration, inlet and nozzle flow

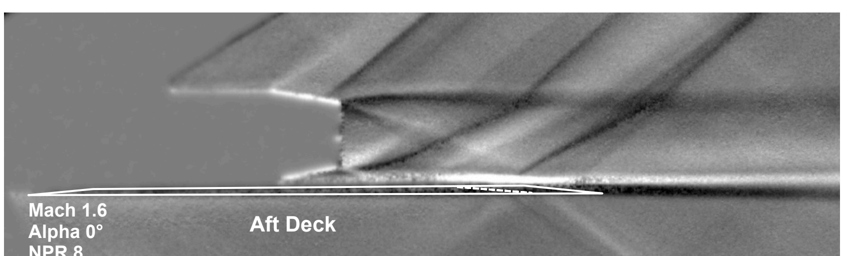
FY16 Plume/Shock Interaction Test

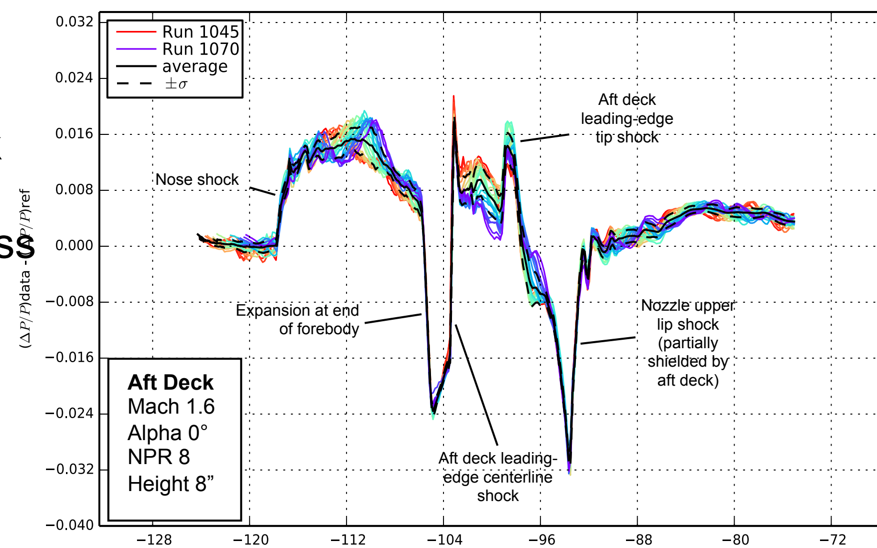
Objective:
- Acquire improved quality experimental data for plume-shock interaction for CFD validation and to assist in the design of future low-boom aircraft

Approach:
- Test larger scale models in large test section (ARC 9x7 SWT)
- Multiple configurations representing several wing, tail and nozzle arrangements
- Utilize wall mounted pressure rail and improved data collection techniques
- Plume/shock interaction flow field imaged with RBOS
- Measure plume profiles with total pressure rake downstream of nozzle



Significance:
- High-quality data from all three measurement techniques give useful insights into plume/shock interactions for multiple configurations
- Industry partner test participation and data access





What's next in Integrated Design Development?

- New TC: Integrated Low Boom Aircraft Design
- Return focus to N+2 small airliner configuration
- New Capabilities
  - Non-cruise conditions
  - Improved trim robustness
  - Structural considerations
  - Low-Boom integration of propulsion OMLs considering efficiency & takeoff acoustics
  - Design under uncertainty
- Integrate results from Low Boom Demonstrator development and flight activities

Technical Challenge 1.2
Integrated Low Boom Aircraft Design

THRUST 2: Innovation in Commercial Supersonic Aircraft	OUTCOME: Introduction of Affordable, Low-boom, Low-noise, and Low-emission Supersonic Transports	AAVP/CST

Need:
- Low-boom shaping has been proven successful at the design cruise Mach; but off-design conditions, coupled with cruise efficiency, especially trim, still challenge low-boom commercial aircraft operability.

Goal/Objective:
- Off-design boom characterization (impact of climb rate, acceleration, transonic focusing, etc.)
- Low-boom design impacts from pitch trim, PAI, aeroelastics and takeoff lift requirements.
- Low-Boom integration of propulsion OMLs considering efficiency & takeoff acoustics.

Deliverables & Impact

Deliverables:
- Tools & processes for multi-objective shape opt. with PAI & commercial operability considerations
- N+2 designs demonstrating extended tools & processes for low-boom design & off-design opt.

Impact to Outcome:
- Overcome efficiency barriers that inhibit the ability to introduce affordable supersonic transportation

Benefit to Community: Enables low-boom supersonic aircraft design with commercial operability & mission/market adaptability.

Technical Approach
- Extend shape-optimization tools to include multi-objective off-design & full-carpet characteristics
- Include propulsion integration & OML impacts from inlet and nozzle design in overall vehicle shape-optimization
- Refine tools & create processes for rapid PAI grid generation & adjoint based MDO
- Validate tools & design approaches via scaled ground & flight tests
- Develop & validate UQ tools for certification prediction

Partnerships, Workforce & Facilities

Potential Partners:
- LM, Boeing, Aerion, Gulfstream, various universities

NASA Workforce:
LaRC
GRC
ARC
AFRC

Facilities:
LaRC, ARC 9x7, GRC 8x6, 1x1

Research Theme:
Understand and Measure
Sonic Boom Community Response

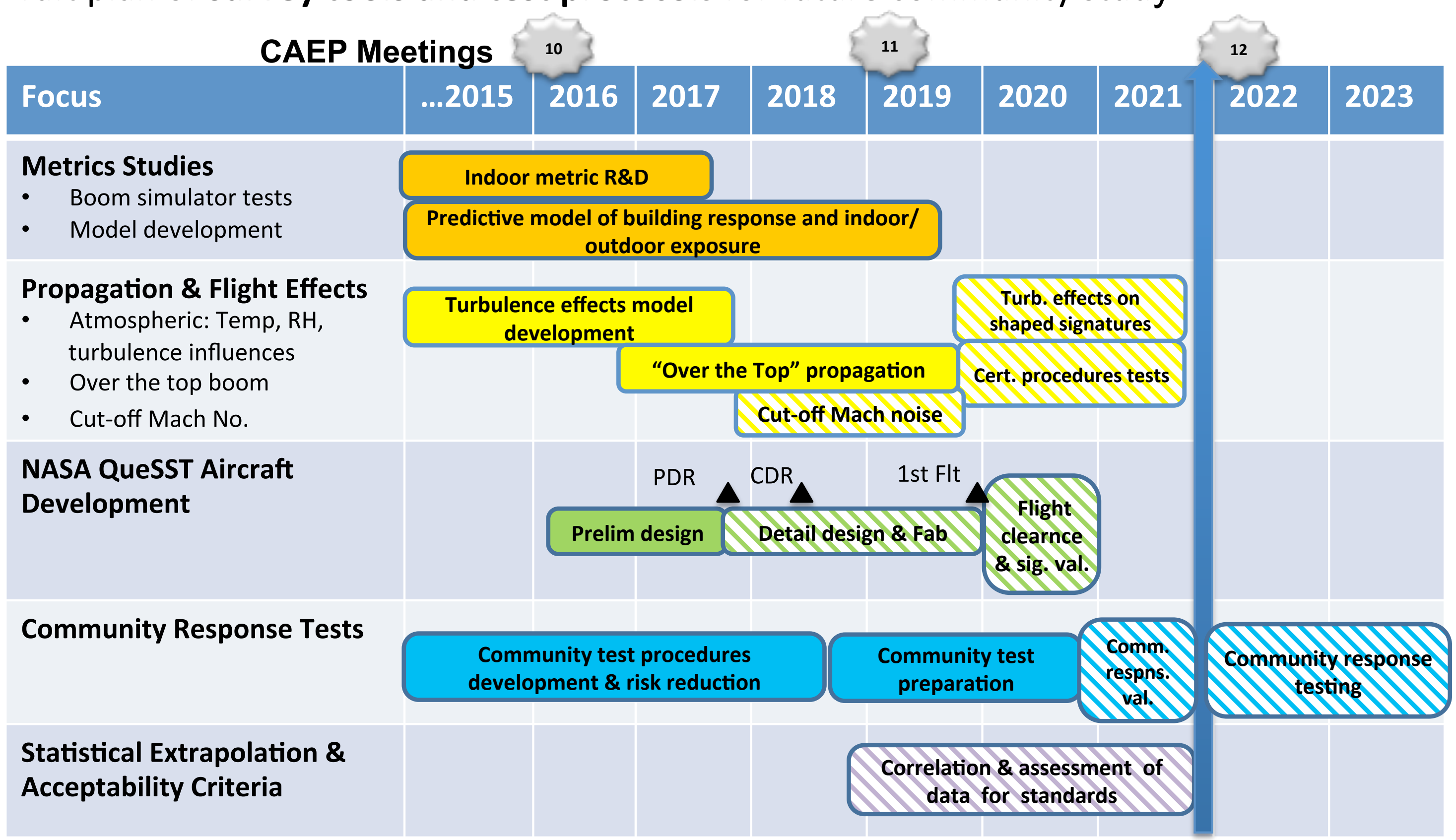
Technical Challenge: Community Response Metrics and Methodology

Sonic Boom Community Response Metric & Methodology Technical Challenge

Description: Validated field study methodology including indoor and outdoor noise metrics, survey tools and test protocols to support community studies with a demonstrator aircraft

Deliverables:
1) Validated models for **structural response & indoor acoustics** from sonic boom
2) Validated models of **human response** to sonic boom noise indoor & outdoors
3) Validated model of propagation and **atmospheric effects** for low noise sonic booms
4) Draft plan of **survey tools and test protocols** for future community study

NASA Supersonic Overland Flight Research Roadmap (under development)



Taking the Next Step…

Low-Boom Flight Demonstration Aircraft Preliminary Design task order awarded to Lockheed Martin. Announced by NASA Administrator Bolden on Feb. 29, 2016 as part of New Aviation Horizons Initiative.

Quiet SuperSonic Technology (QueSST) Aircraft

Pending budget decisions for FY17, the Preliminary Design effort will be followed by a full Design, Build and Test Project

Image: Lockheed Martin

Research Theme:
Minimize the Airport Community Noise Impact of High Speed Aircraft

Technical Challenge: Low Noise Propulsion for Low Boom Aircraft

Low Noise Propulsion for Low Boom Aircraft Technical Challenge

Description: Design tools and innovative concepts for integrated supersonic propulsion systems with noise levels of 10 EPNdB less than FAR 36 Stage 4 demonstrated in ground test

Deliverables:
1) Low-noise propulsion concepts compatible with low-boom, efficient cruise configurations
2) Integrated high-fidelity tools for prediction & design of propulsion systems
3) Scale-model simulated-flight assessments of airport-community noise and validation of acoustic prediction tools

CST Research Theme Highlights

2015 Research Theme Highlights
Aeroelastic & Control Effects on Sonic Boom

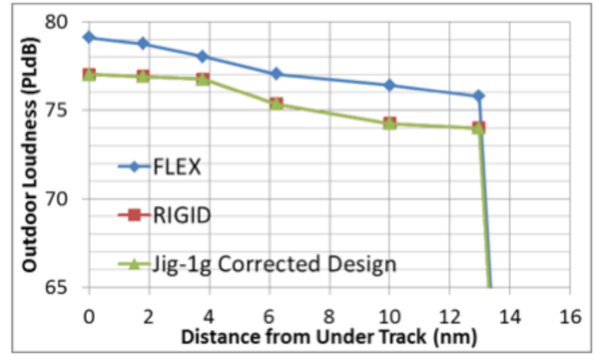
Objective: Understand and mitigate the effects of static and dynamic shape change on the sonic boom ground signature

Approach:

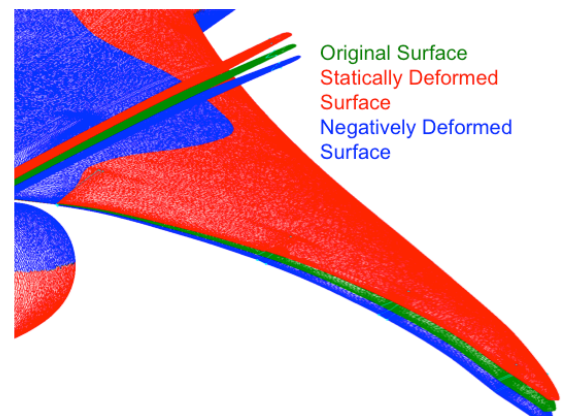
- **Static:** Assume linearity of CFD loads and FEM deflections, generate deflected shape under load, create “negative” of these deflections to simulate unloaded or “jig” shape
- **Dynamic:** Use 6-DOF simulation in assumed turbulence to determine aircraft state, use mean state and worst case states in sonic boom analysis

Significance:

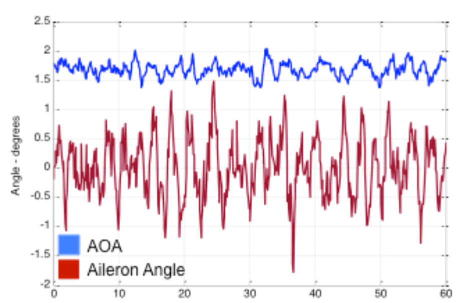
- Design process modifications can correct for deflections in demonstrator scale aircraft
- Turbulence effects can be significant, but mitigated by low levels of turbulence at cruise altitude
- Impacts more significant in large aircraft
  - More flexible structure
  - Larger variations in load

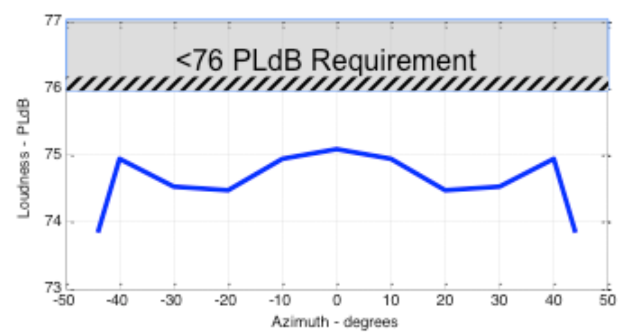


Static aeroelastic design for demo scale aircraft



“Jig” and deformed shape for N+2 scale aircraft





Aircraft state variation and integrated boom impact for flight through turbulence

2015 Research Theme Highlights
Advanced Techniques for In-flight Shock Imaging

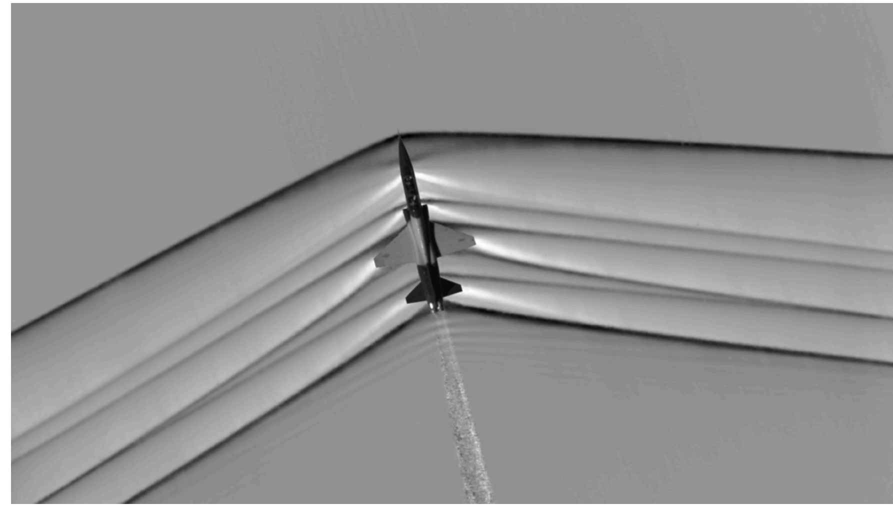
Objective: Develop techniques to accurately image the complete shock wave system in flight, both near and far field

Approach:

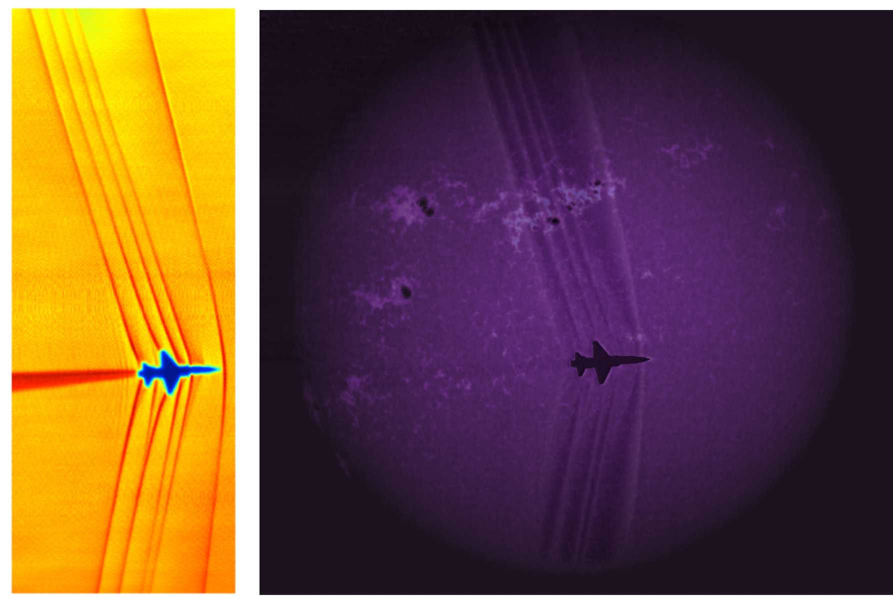
- Application of the Background Oriented Schlieren (BOS) techniques with advanced optics, high speed cameras and position tracking, Also focus on improved flight planning
- Air-Air techniques (AirBOS) use desert foliage as a background
- Ground based techniques use sun edge (GASPS) and Calcium K filtered sunspots (CaKEBOS)
- Use of publicly releasable configuration (USAF TPS T-38) has allowed innovation in broader image processing community

Significance:

- Shock images with unprecedented levels of detail have be capture for varying aircraft aspect
- Image processing techniques are rapidly improving, extraction of quantitative data may be possible



Processed image from the AirBOS Technique



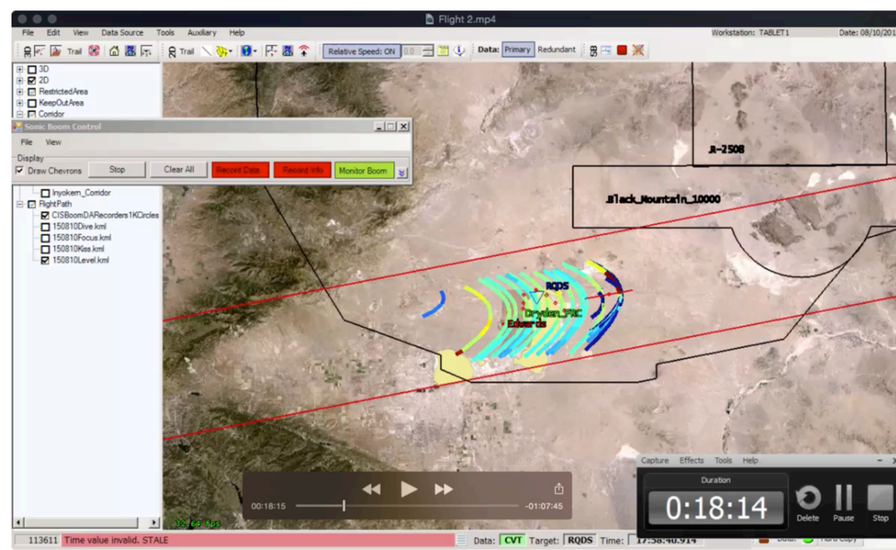
Processed images from the GASPS and CaKEBOS techniques

2015 Research Theme Highlights
Cockpit Display of Sonic Boom Ground Impact

Objective: Provide real time data on position and magnitude of sonic boom ground footprint to pilots for the purpose of controlling exposure

Approach:

- Compact, rapid version of acoustic propagation software coupled to terrain display demonstrated in AFRC control room
- Proof of concept uses tablet PC with real time data, preloaded weather in back seat of NASA F18 #846
- Performed a series of supersonic passes of a ground sensor array to validate integrated performance
- Parallel effort under way with NRA partners to study integration with commercial flight management software



Significance:

- Software/Hardware performed well in flight condition
- Slightly modified configuration to support upcoming turbulence research flights
- Integrated flight planning and management capability could be ready to support low boom community overflight research

CST Research Themes Technical Highlights

High Altitude Emissions

- Environmental Impact: Global Environmental Impact of Fleet of Supersonic Cruise Aircraft impact on the Stratosphere (MIT); yielding initial evaluation of ozone impact and water vapor
- N+2 Woodward LDI-2 9-point Recessed Injector tested and demonstrated a supersonic cruise NOx Emissions Level of ~8 EINOx
- Continued cooperative development and fuel injector testing with AATT and TTT projects

Cruise Efficiency

- Development of an Automated Supersonic Natural Laminar Flow (SSNLF) Design Method produced significant region of laminar flow on a large, highly-swept supersonic wing with net drag benefit
- Conducted initial Testing of Low-Boom Laminar Flow wing in quiet flow tunnel, investigating Laminar Flow control through distributed roughness and leading edge geometry variations
- Using CFD to design and analyze Streamline-Traced Inlet to reduce cowl wave drag by 50% as compared to an equivalent two-dimensional or axisymmetric spike inlet
- Propulsion Airframe Integration: analyzed several installed vs. isolated Streamline-Traced Inlet configurations accounting for pressure recovery loss due to installation

Aeroservoelasticity

- Langley patented Reduced-Order Modeling method has demonstrated excellent comparison with traditional full CFD solution based approach for both aeroelastic responses and flutter identification.
- A more accurate Atmospheric Turbulence model methodology developed under CST to enable AeroPropulsoServoElasticity (APSE) studies for supersonic vehicles under atmospheric turbulence conditions Models transferred to industry partners
- APSE Model Development, steady state results for the N+2 vehicle with propulsion system yields reasonable results. Comparison testing of unsteady sinusoidal responses from the propulsion system against the 1D model underway

Funded Research Partnerships (NRA)

Sonic Boom Effects Modeling	
The Influence of Turbulence on Shaped Sonic Booms	**Wyle Labs**
Waveforms and Sonic Boom Perception and Response Risk Reduction	**Applied Physical Sciences**
Risk Reduction for Future Community Testing with a Low-Boom Flight Demonstration Vehicle	**Fidell Associates**
Supersonic Flight Operational Efficiency	
Sonic Boom Display	**Rockwell Collins**
Pilot Interface for Mitigating Sonic Boom	**Honeywell**
Airport Noise	
Quiet Nozzle Concepts for Low Boom Aircraft	**University of California-Irvine**
Evaluation of Low Noise Integration Concepts and Propulsion Technologies for Future Supersonic Civil Transports	**General Electric Company**
High Altitude Emissions	
Global Environmental Impact of Supersonic Cruise Aircraft in the Stratosphere	**Massachusetts Institute of Technology**

New NRA topics in development, announcements pending FY17 budget decisions

Summary

- Successful transition to new ARMD/AAVP project structure
- Research themes and Technical Challenges are aligned with the ARMD SIP and supported by the community
- Low Boom Design Tools Technical Challenge Successfully Completed!!!
- Good progress on other Tech Challenges and Research Themes.
- Active transfer of knowledge and technology to community through partnerships and publications
- Low Boom Flight Demonstration Preliminary Design in progress
- Hold onto your seats! More details to follow today! More Excitement to follow this year!

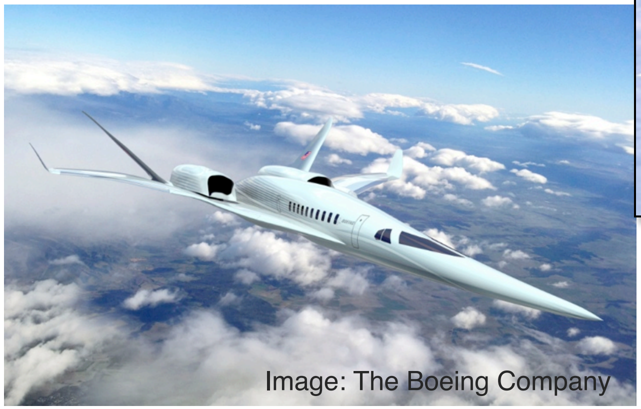


Image: The Boeing Company


Image: Lockheed Martin