Toward a Community Noise Assessment of Single-Aisle Aircraft with Hybrid-Electric Propulsion

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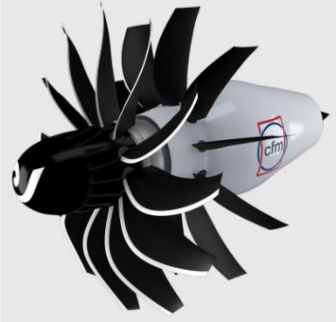
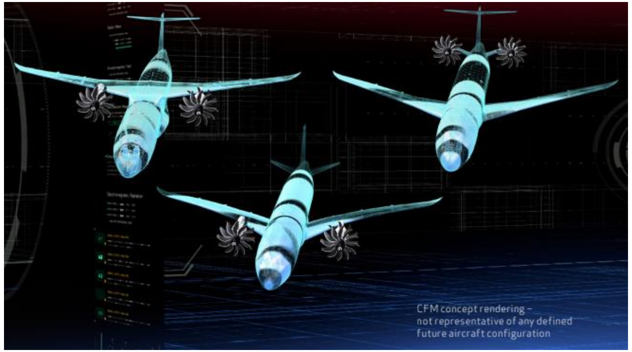
Outline

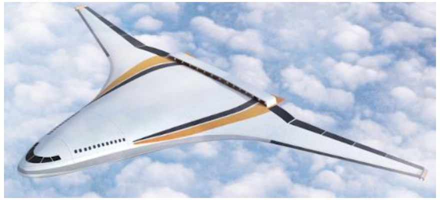
- **Background**
- **Development of surrogate turbofan engine**
  - Direct drive
  - Geared drive
    - Hybrid-electric
- **Development of surrogate airframe**
- **Acoustic assessment**
- **Anticipated challenges**
- **Concluding remarks**

Background

- **Motivation**
  - Advanced propulsion and airframe concepts are being matured that could yield substantial reductions in fuel consumption and emissions to foster sustainable aviation
  - A need exists for an accurate, complementary but separate, physics-based acoustic assessment of these novel aircraft configurations







- **Goal**
  - To conduct a high-fidelity, simulation-based, acoustic evaluation of an aircraft equipped with hybrid-electric engines

Background

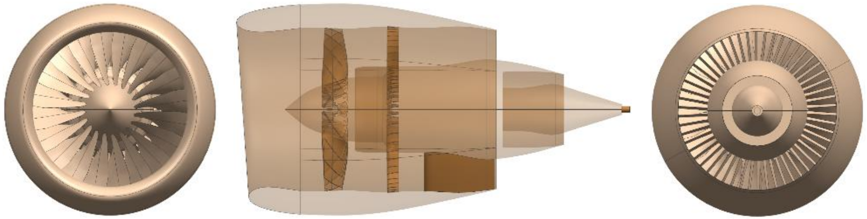
- **Total Aircraft Noise with Electrified Propulsion (TANEP)**
  - Sponsored by Electrified Powertrain Flight Demonstrator project
  - Task started during Spring of 2021
  - All simulations conducted with Dassault Systèmes PowerFLOW
- **Small, enthusiastic team**
  - Part-time involvement for all members
- **Team members**
  - NASA: Mehdi Khorrami, Ed Envia, and Scott Brynildsen
  - Dassault Systèmes: Andre Ribeiro, Benedikt König, Ryan Ferris, and Davide Cerizza
  - AVEC, Inc: Patricio Ravetta

Development of Surrogate Turbofan Engine

- **Full-scale engine attributes**
  - Nonproprietary geometry
  - Address fan and core jet noise
  - Combustor noise not considered
  - Provides desired thrust, FPR, and BPR
- **Source Diagnostic Testbed (SDT)**
  - Starting point for baseline
  - Original model has no provision for core flow
- **Full-scale direct-drive engine**
  - Scaled-up SDT geometry
  - Reduced number of fan blades by two
  - Introduced core flow (jet)
  - Introduced inlet droop

SDT Model				
Fan blades	**Fan blade diameter**	**Stator vanes**	**Core flow**	**Inlet droop**
22	22 inches	54	No	None

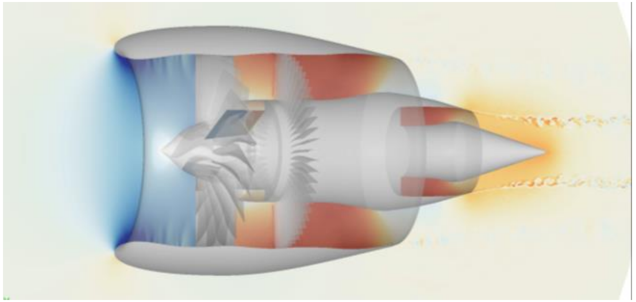
Front view Side view Rear view

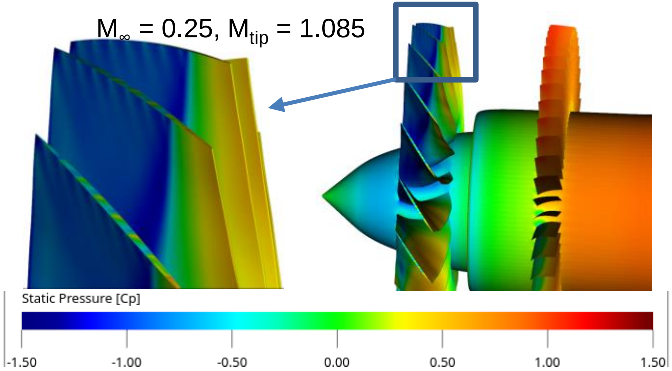


Full-scale direct-drive turbofan				
Fan blades	**Fan blade diameter**	**Stator vanes**	**Core flow**	**Inlet droop**
20	78 inches	54	Yes	4°

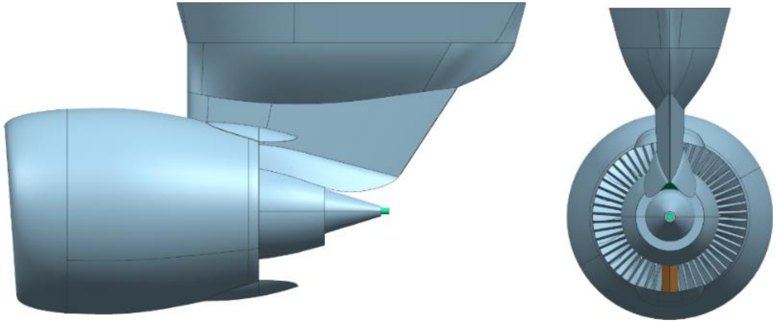
Development of Surrogate Turbofan Engine

- **Full-scale direct-drive engine (continued)**
  - Preliminary high-fidelity simulations for engine fine-tuning
    - Eliminate flow separation at core inlet
    - Ensure proper fan loading and blade tip conditions
      - Supersonic tip region, shocks at/near tip





- **Further Development**
  - Added realistic engine pylon



Direct-drive engine conditions				
Core exhaust Temp	**Total thrust**	**Core exhaust thrust**	**BPR**	**FPR**
850K	24.9k lbf	2.6k lbf	11.3	1.44
955K	26.0k lbf	4.1k lbf	11.3	1.44

Development of Surrogate Turbofan Engine

❑ Full-scale geared-drive engine

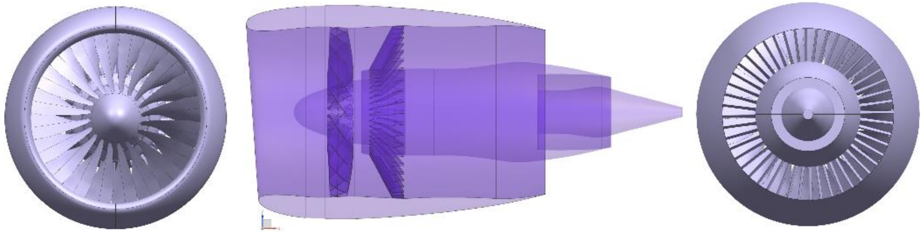
- Direct-drive engine as starting geometry
- Increased fan blade diameter
- Reduced number of stators by six
- Shortened rotor-stator distance
- Added stator sweep

❑ Preliminary high-fidelity simulations

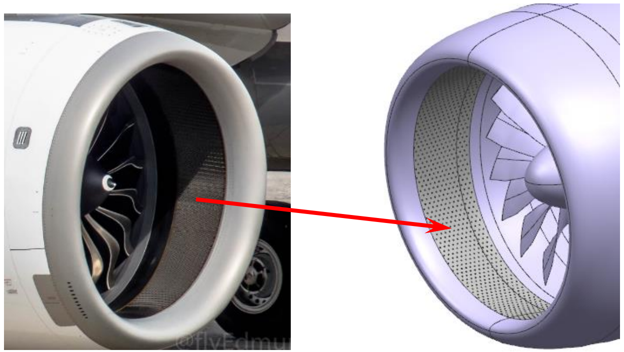
- Will commence soon
- Evaluate and fine-tune engine conditions
- Will include liner geometry in nacelle walls

Target geared-drive engine conditions				
Core exhaust Temp	**Total thrust**	**Core exhaust thrust**	**BPR**	**FPR**
800K–900K	26k–27k lbf	??	12.0 –12.3	1.3 –1.35

Front view Side view Rear view

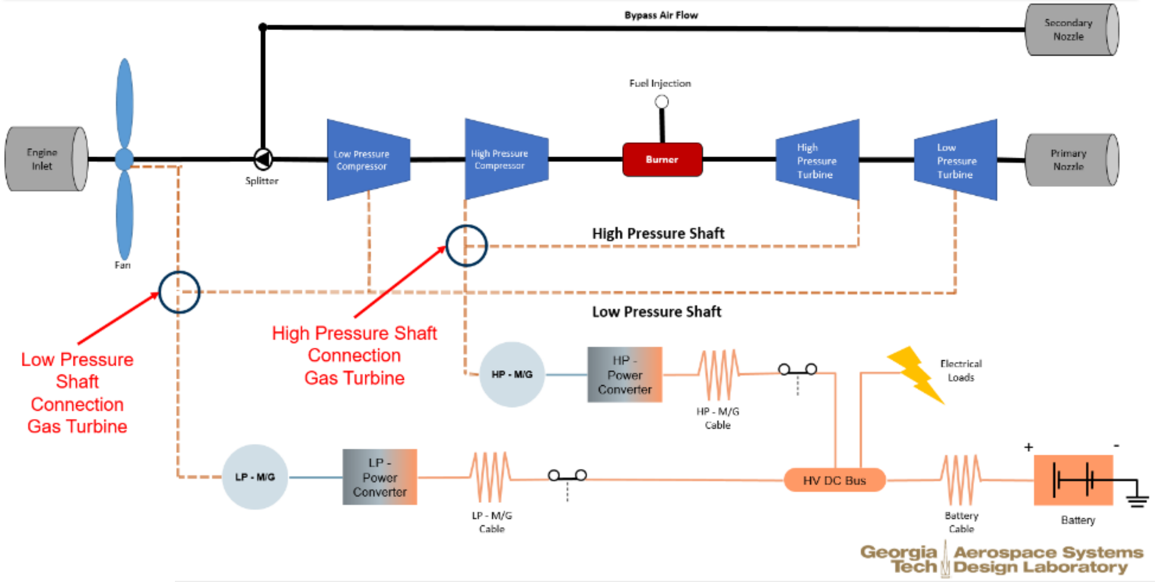


Full-scale geared-drive turbofan					
Fan blades	**Fan blade diameter**	**Stator vanes**	**Stator sweep**	**Core flow**	**Inlet droop**
20	81 inches	48	28°	yes	4°



Development of Surrogate Turbofan Engine

- **Full-scale hybrid-electric engine**
  - Parallel-hybrid architecture
    - To be finalized soon
  - 1-MW class electric system
  - Start from geared-drive engine
  - Boost during climb
  - Reduction in core size
  - Most fuel-efficient climb profile
- **Preliminary high-fidelity simulations**
  - Iterate on engine conditions

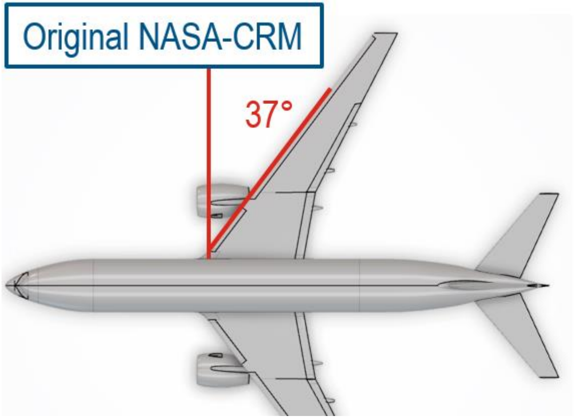


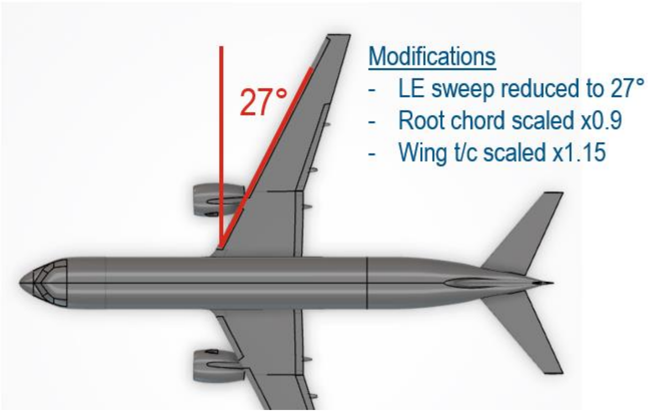
Target hybrid-electric engine conditions				
Core exhaust Temp	**Total thrust**	**Core exhaust thrust**	**BPR**	**FPR**
800K–900K	26k–27k lbf	??	??	1.3 –1.35

Full-scale hybrid-electric turbofan					
Fan blades	**Fan blade diameter**	**Stator vanes**	**Stator sweep**	**Core flow**	**Inlet droop**
20	??	48	28°	yes	4°

Development of Surrogate Airframe

- **Full-scale airframe attributes**
  - Representative of single-aisle, 150-160 passengers
  - Nonproprietary geometry
  - Address all prominent airframe noise sources
- **NASA Common Research Model (CRM)**
  - Starting point for airframe
  - Representative of twin-aisle, long range, large aircraft (M_{cruise} = 0.85)

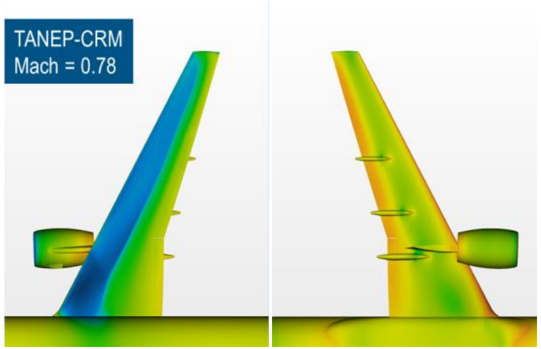




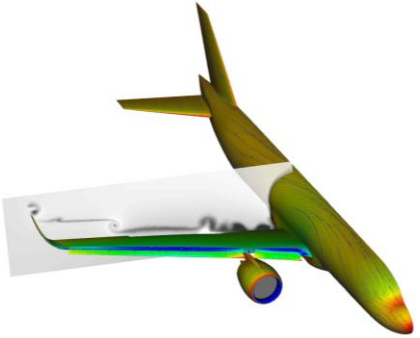
Development of Surrogate Airframe

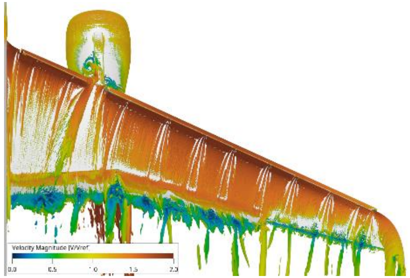
- **Initial airframe simulations**
  - Ensure acceptable cruise performance
  - Tailor and fine-tune high-lift components
  - Evaluate effects of slat and flap brackets

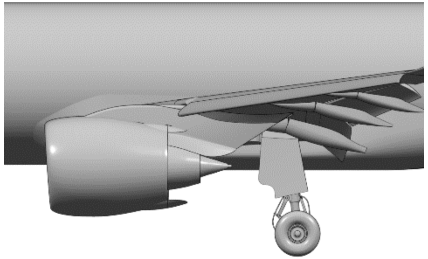
- **Propulsion-airframe integration**
  - Direct-drive engine mated with airframe
  - Simulations to fine-tune wing-pylon juncture are ongoing

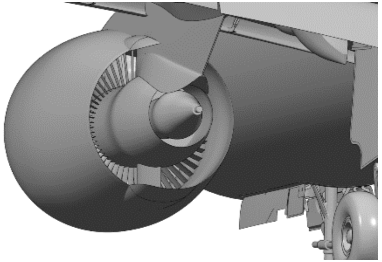


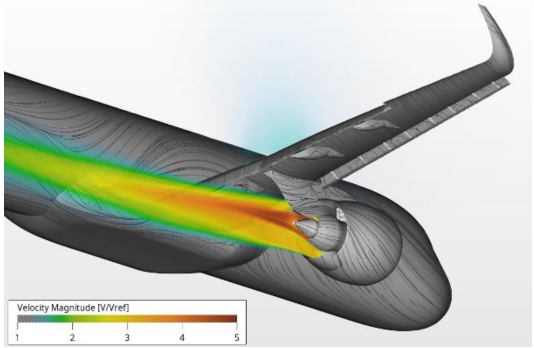
Surface pressure





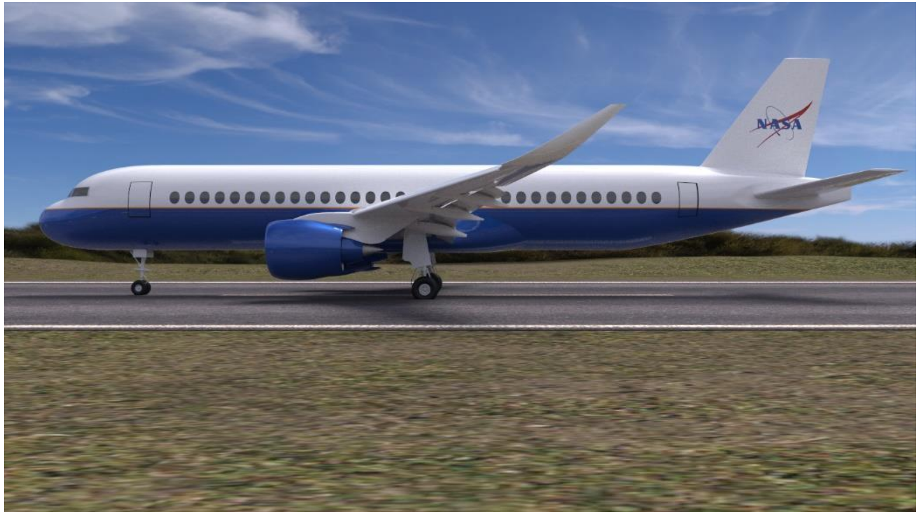






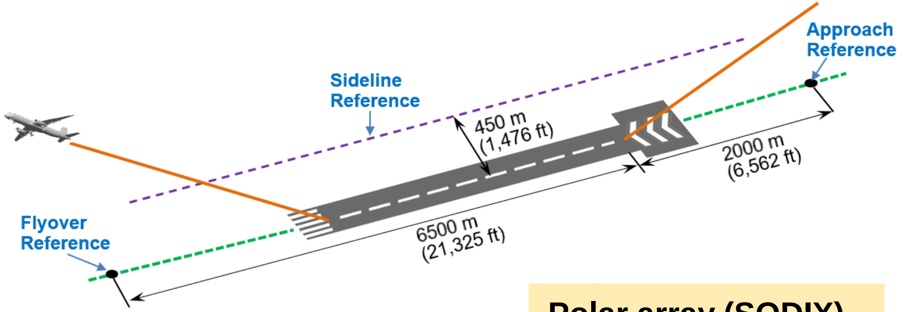
Surrogate Aircraft with Direct-Drive Engine

- **Full-scale, complete Aircraft**



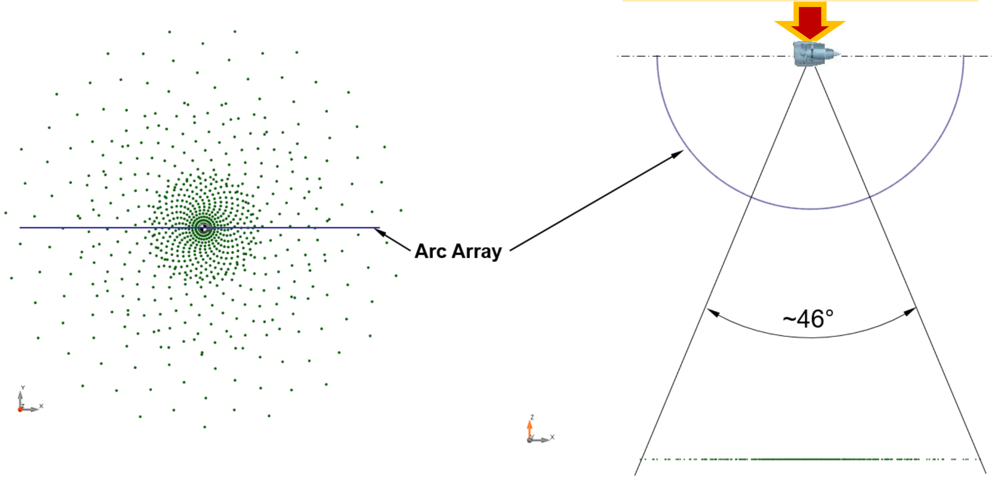
Acoustic Assessment

- **Approach**
  - Single-microphone certification points and standards (FAA, ICAO)
  - Focus on takeoff points
  - Area-based evaluation criteria



- **Diagnostic acoustic analysis**
  - Separate airframe from propulsion noise sources
  - Breakdown of engine sources and their directivity
  - Installation effects (e.g., jet-flap)

Polar array (SODIX)
- 361 mics (0.5° spacing)
- 150 ft (45.7 m) radius

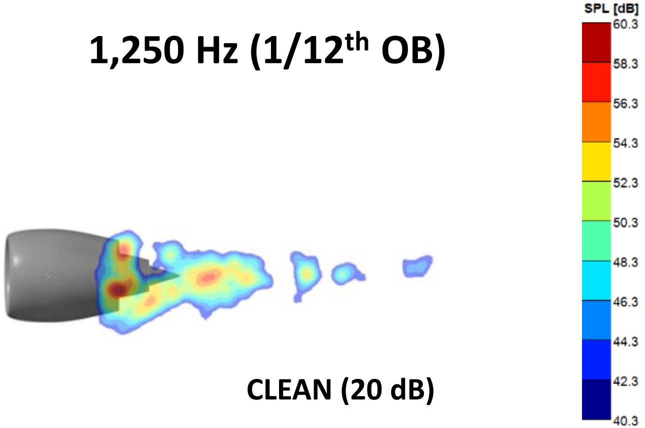


Phased array
- 800 mics
- ~ 331.4 ft (~101 m) diam.
- 394 ft (120 m) distance

Acoustic Assessment

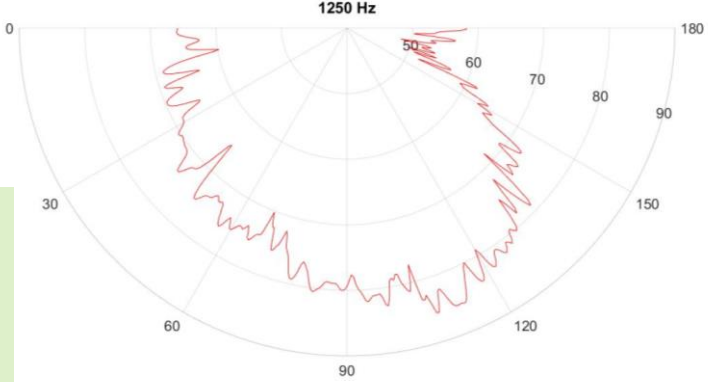
- **Isolated direct-drive engine**
  - Exploratory, coarse-resolution simulations
    - Ensure proper capture of engine sources and noise trends
  - Establish spatial resolution effects

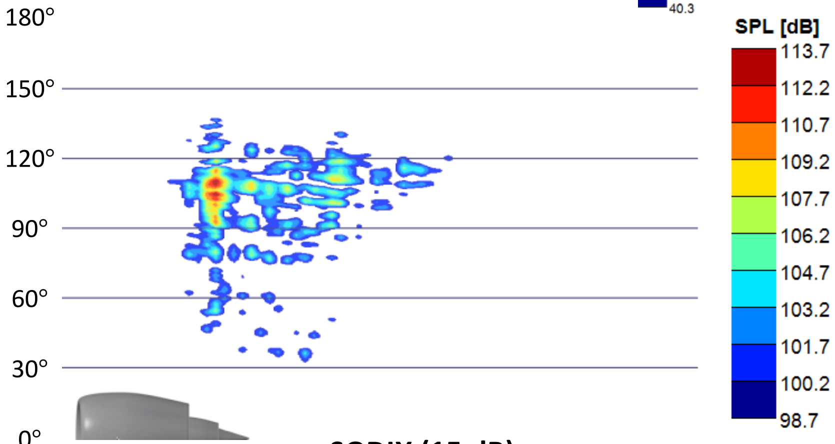
1,250 Hz (1/12th OB)



CLEAN (20 dB)

Sample directivity from single-microphone data





SODIX (15 dB)

Engine conditions
- M = 0.25
- Core jet temp = 850K
- RPM = 3557
- BPF ~ 1186 Hz
- Data length: 0.0949s

Anticipated Challenges

- **Hybrid-electric engine**
  - Noise signature of large electric motors
    - Tonal, broadband, or both
  - Core resizing and its implications for fan size and engine thrust
  - Determination of optimal climb path

- **Computational**
  - Balance between spatial resolution needs and simulation cost
  - Need to resolve an adequate portion of the far-field spectrum
  - Resolved spectrum to provide near-convergence of PNLT and EPNL values

Concluding Remarks

- An ambitious effort to predict total aircraft noise from high-fidelity simulations has commenced
- Simulation-based predictions target single-aisle, 150-160 pax aircraft equipped with geared turbofans (baseline) and hybrid-electric engines
- Good progress made in the development of realistic, full-scale, surrogate airframe and propulsion systems
- Acoustic assessment of a complete aircraft with direct-drive and geared-drive engines to begin shortly