Simulation of Boundary Layer Ingestion Fan Noise for NOVA Aircraft Configuration

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TU-Delft/3DS Workshop on PowerFLOW Simulations of Aircraft Noise
14th September 2018, Delft

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Outline

- Background and motivation
- Numerical method
- Geometries and simulated cases
- Computational setup
- Numerical results
- Conclusions and future outlooks

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Background and motivation

- UHBR engines on next generation aircraft → Address increasingly stringent aviation regulations for pollution and noise impact
  - Enhanced propulsion efficiency and lower noise emissions
  - Integration challenges and special designs required
- Four different NOVA (Nextgen Onera Versatile Aircraft) aircraft geometries investigated at Onera with focus on engine integration options*

*Wiart et al., "Development of NOVA Aircraft Configurations for Large Engine Integration Studies", AIAA 2015-2254

Background and motivation

- Boundary Layer Ingestion (BLI) configuration benefits
  - Mass and drag penalty reduction
  - Jet and wake losses reduction

  → Potential fuel burn reduction
- Many implications have to be addressed before deriving the associated benefits: effects of inlet flow distortion on engine efficiency, operability, aeromechanics and aeroacoustics
- Research goals:
  - To perform the first CFD/CAA simulation of a full aircraft+BLI fan stage system
  - To address BLI installation effects on fan noise for a NOVA BLI-like configuration

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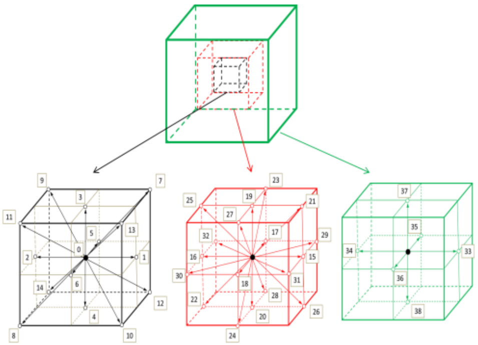
Numerical method



Hybrid D3Q39 Model
Ma_{max}~2.0

- SIMULIA PowerFLOW solver*:
  - Lattice-Boltzmann method for subsonic/supersonic flows
    - Solves the fully explicit, transient and compressible LBE
    - Sliding mesh (LRF) for rotating geometries
    - Hybrid solver: D3Q39 model inside LRF, D3Q19 model outside LRF
  - LBM-VLES turbulence model
    - Large-eddies are resolved (“coherent” statistically anisotropic eddies)
    - Small eddies (statistically universal) are modeled with an extended RNG k-ε model
    - Swirl term used to switch from modeled to resolved eddies
  - Extended turbulent wall model to account for favorable/adverse pressure gradients

*Nie et al., “A Lattice-Boltzmann/Finite-Difference Hybrid Simulation of Transonic Flow“, AIAA 2009-139
Gonzalez-Martino et al., “Fan Tonal and Broadband Noise Simulations at Transonic Operating Conditions Using Lattice-Boltzmann Methods“, AIAA 2018-3919
van der Velden et al., “Jet Noise Prediction: Validation and Physical Insight“, AIAA 2018-3617

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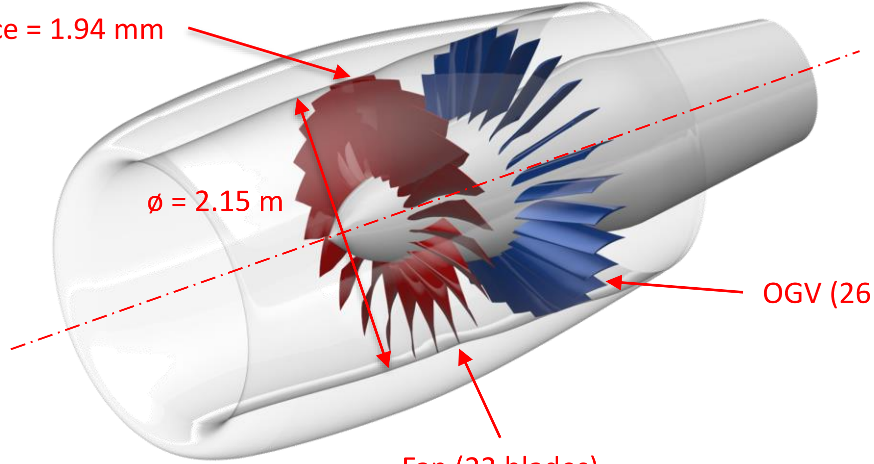
Fan stage geometry

- Modified version of “Low-Noise” NASA/SDT*
  - Original geometry fully scaled to match NOVA fan diameter (2.15 m)
  - Original nacelle axial length increased to match NOVA BLI intake-fan distance (2.35 m)



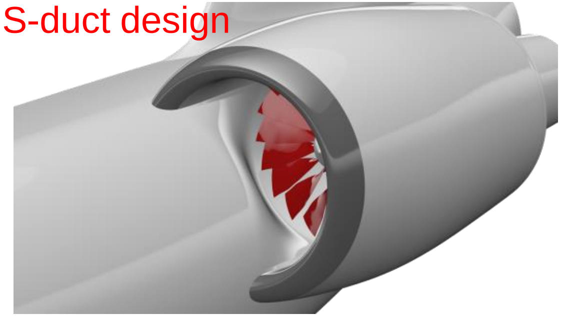
*Envia , “Fan Noise Source Diagnostic Test - Vane Unsteady Pressure Results”, AIAA 2002-2430

Fan stage integration into NOVA fuselage

- Engine integration on NOVA lifting fuselage (courtesy of ONERA)
  - BLI engine
  - 40% buried intake
  - Intake-Fan distance = 2.35 m
  - Tilt angle = 1°
  - Toe angle = 2.5°

ONERA s-duct design costraints

S-duct design



Fuselage length = 38.3 m

Semi-span = 19.05 m

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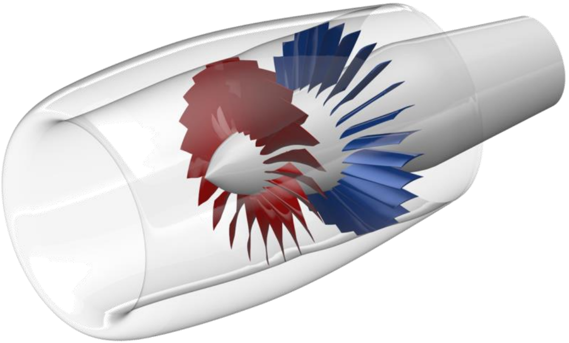
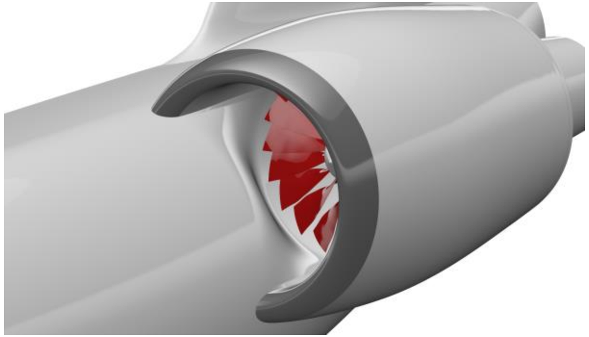
Simulated cases

- Isolated NASA/SDT with modified nacelle



- Installed NASA/SDT with modified nacelle into NOVA fuselage geometry



Mach	Mach Tip	Pressure	Temperature	AoA	Glide angle	Tilt angle	Toe angle
0.25	1.0038	ISA at 1000 ft		4°	6°	1°	2.5°

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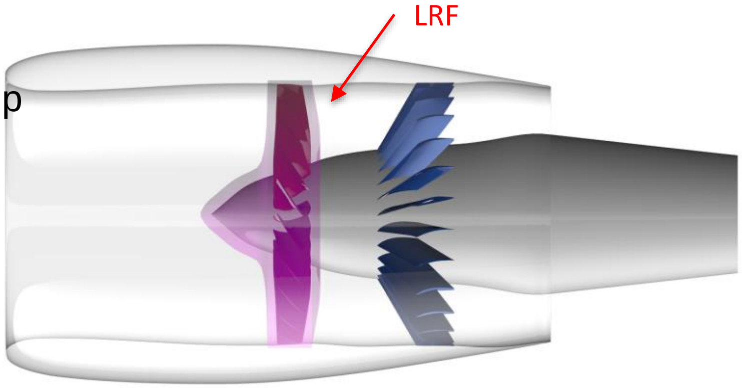
Computational setup

- Symmetry plane (at fuselage centerline)
- FWH permeable approach for far-field noise
- 16 Variable Resolution (VR) regions (medium grid resolution)
  - VR16: tip gap
  - VR15: leading/trailing edges of fan/OGV and nacelle lip
  - VR14: fan/OGV
  - VR13: bypass channel, nacelle and s-duct walls
  - VR12: FWH permeable surface
  - VR11-VR0: fuselage offsets and boxes up to domain boundaries
- Fan geometry rotated through LRF

Grid Resolution	Fan Tip Cell Size (mm)	# Cells	CPUh (10 revs)
Medium*	0.355	611 M	56000

Local Reference Frame



*Gonzalez-Martino et al., “Fan Tonal and Broadband Noise Simulations at Transonic Operating Conditions Using Lattice-Boltzmann Methods“, AIAA 2018-3919

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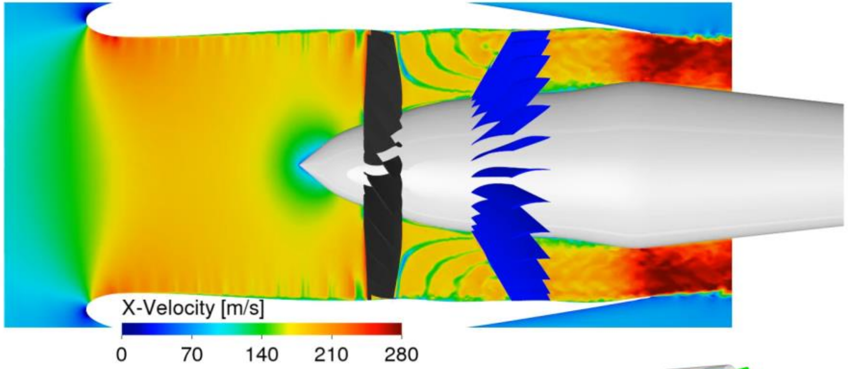
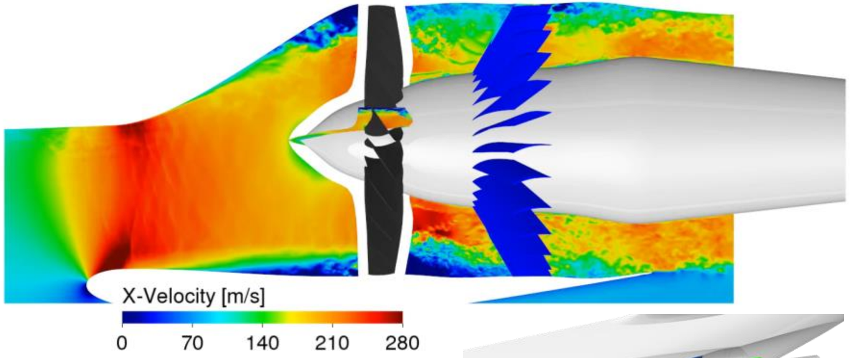
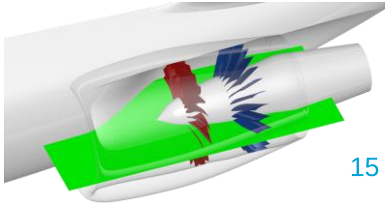
Flow installation effects

- Instatanoeus flow on a plane normal to the fuselage
  - Higher flow acceleration at intake lip
  - Adverse pressure gradient induced flow separation on intake wall
  - Adverse pressure gradient induced flow separation on s-duct surface
  - Different fan wake/OGV interaction



Isolated engine

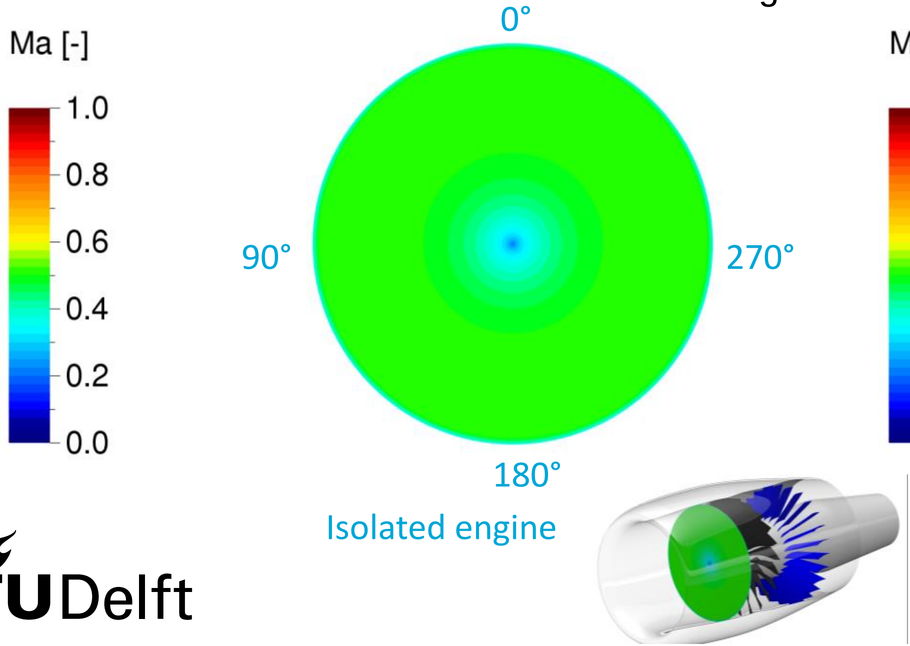


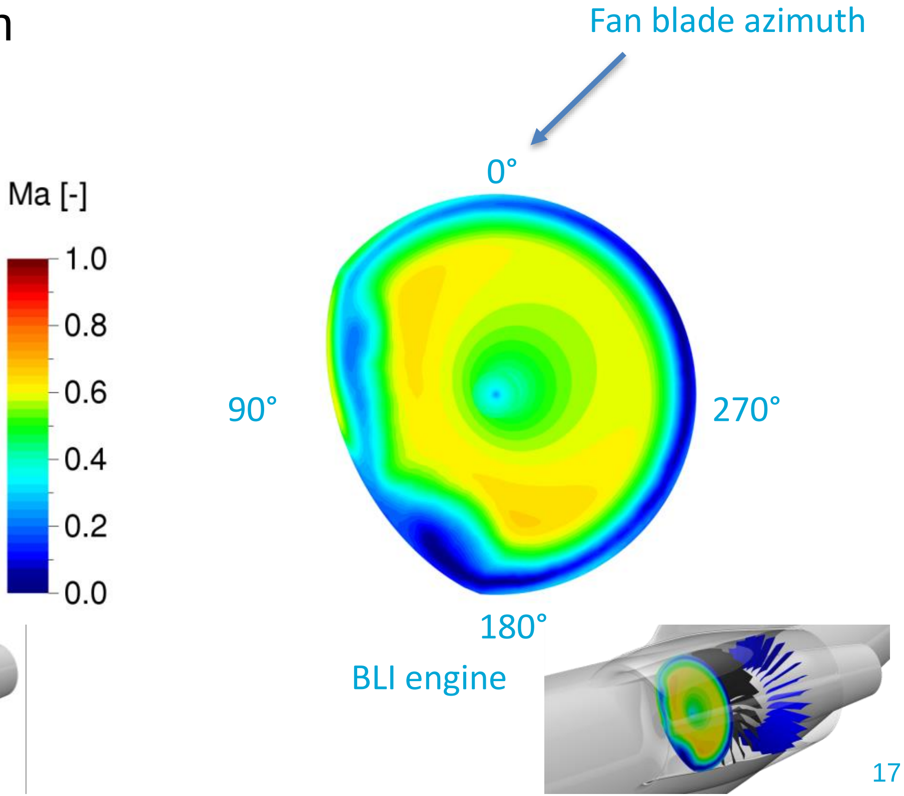


BLI engine

Flow installation effects

- Mean flow on a plane upstream the fan
  - Strong flow distortion and non-uniformity
  - Flow acceleration in blade inboard regions





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Fan blade sectional air-loads

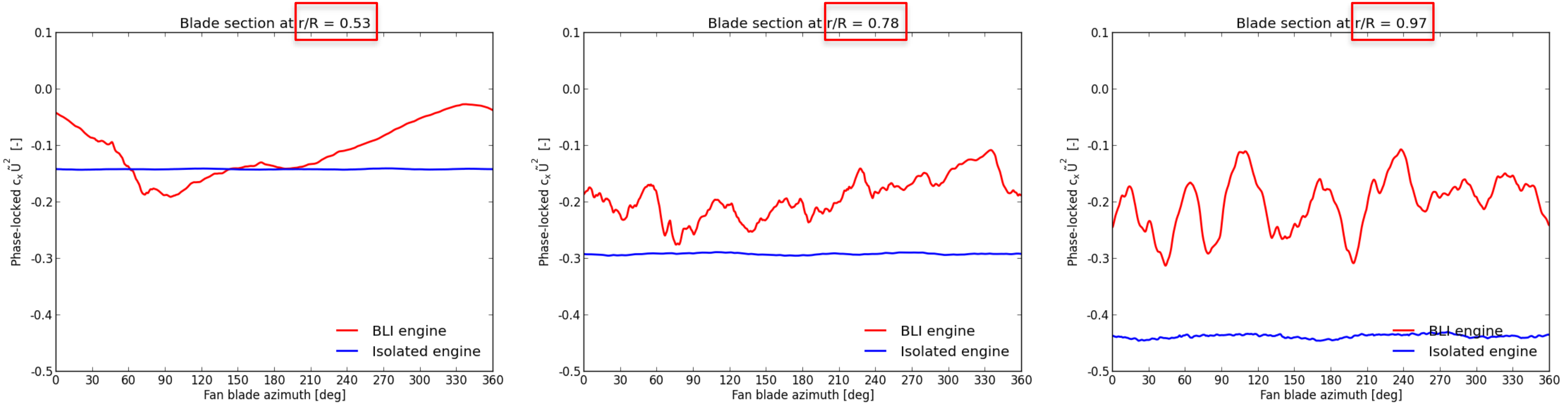
Negative Cx as the meaning of thrust

$$\tilde{U} = \frac{u}{a_\infty}$$

Local flow velocity

Freestream speed of sound

- Phase-locked $c_x\tilde{U}^2$ at three fan blade span-wise locations
  - Inboard: low-frequency unsteadiness → mean flow distortion
  - Outboard: high-frequency unsteadiness and lower mean value → turbulence ingestion



Blade Inboard → Blade Outboard

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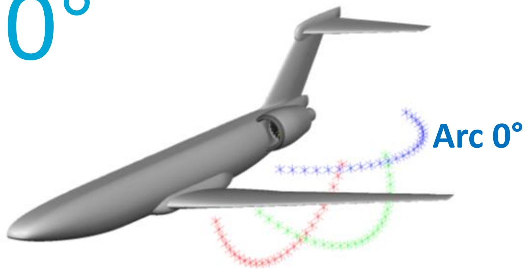
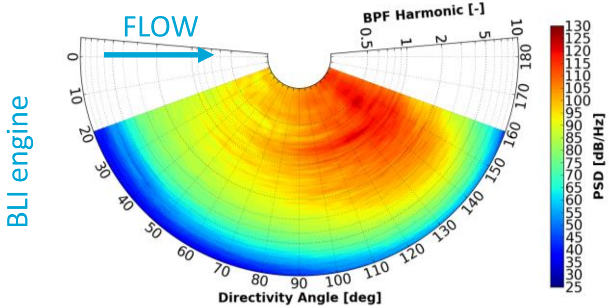
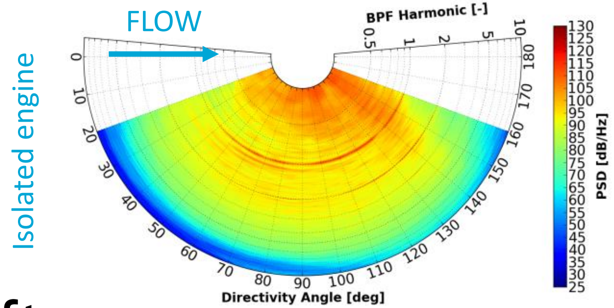
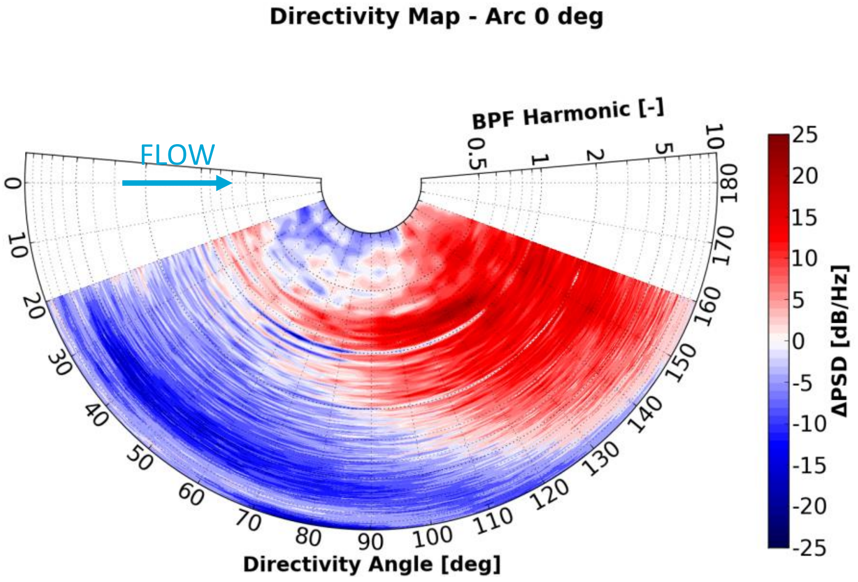
Far-field noise directivity - Arc 0°

- PSD on 10 m radius arc centered around the fan center









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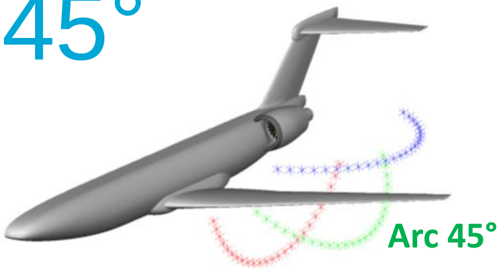
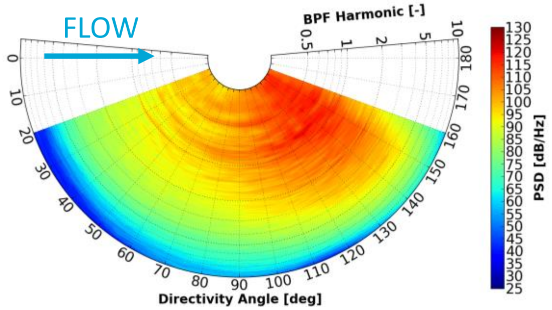
Far-field noise directivity - Arc 45°

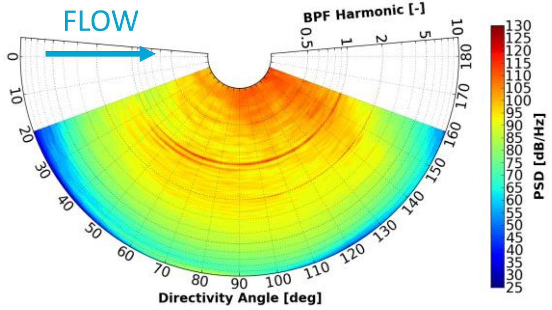
- PSD on 10 m radius arc centered around the fan center

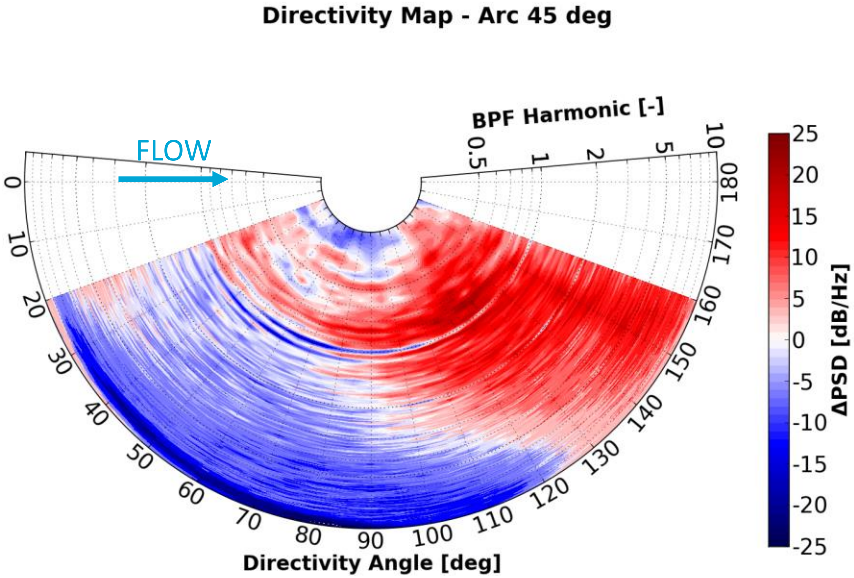


BLI engine



Isolated engine





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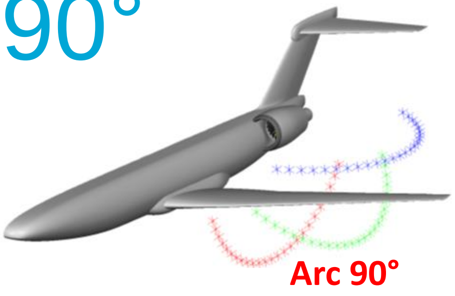
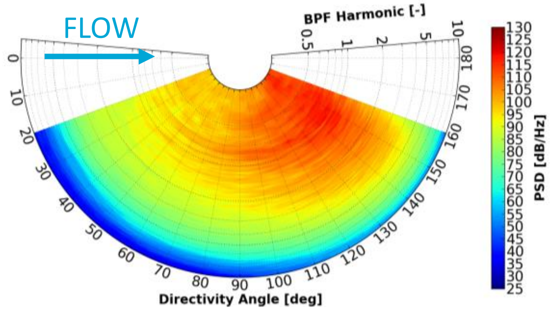
Far-field noise directivity - Arc 90°

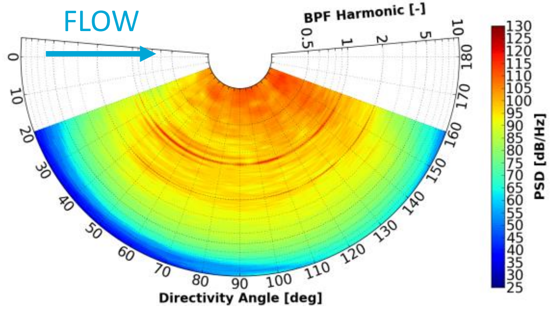
- PSD on 10 m radius arc centered around the fan center

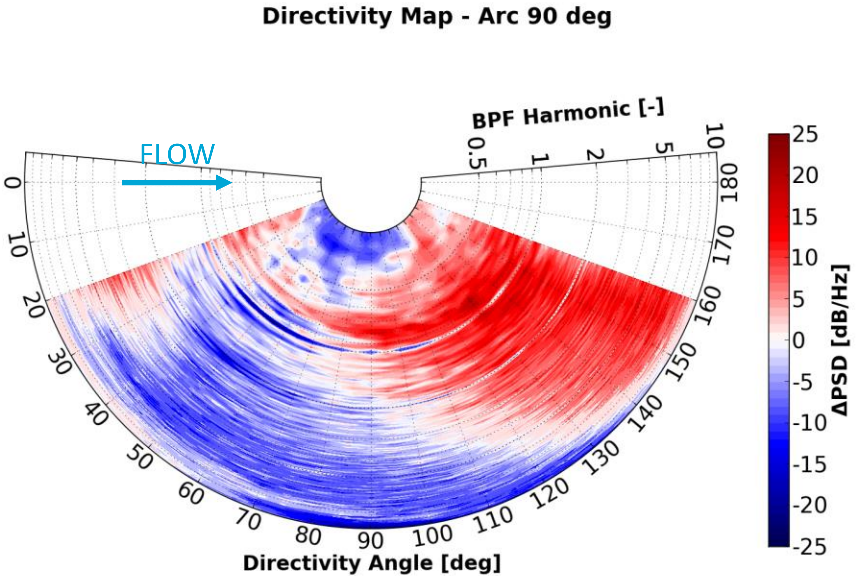


BLI engine



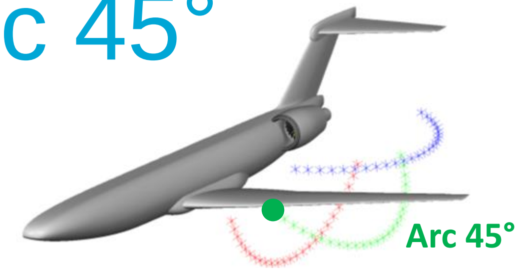
Isolated engine

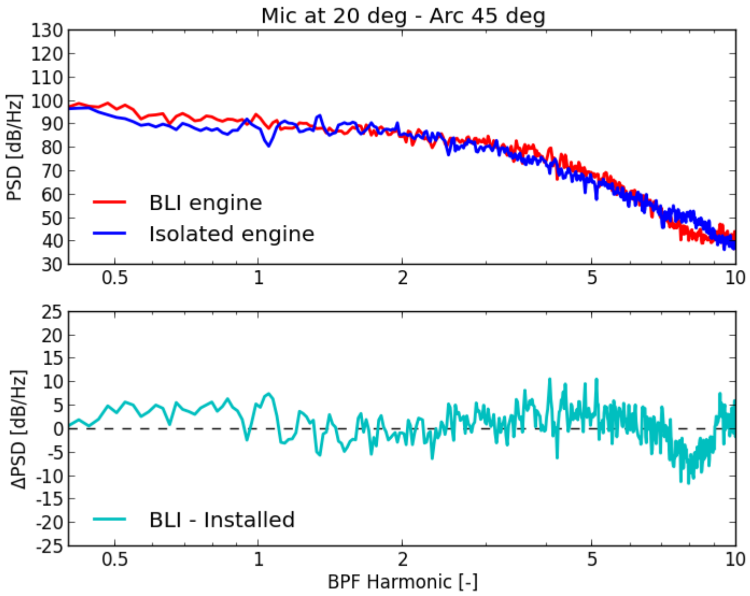


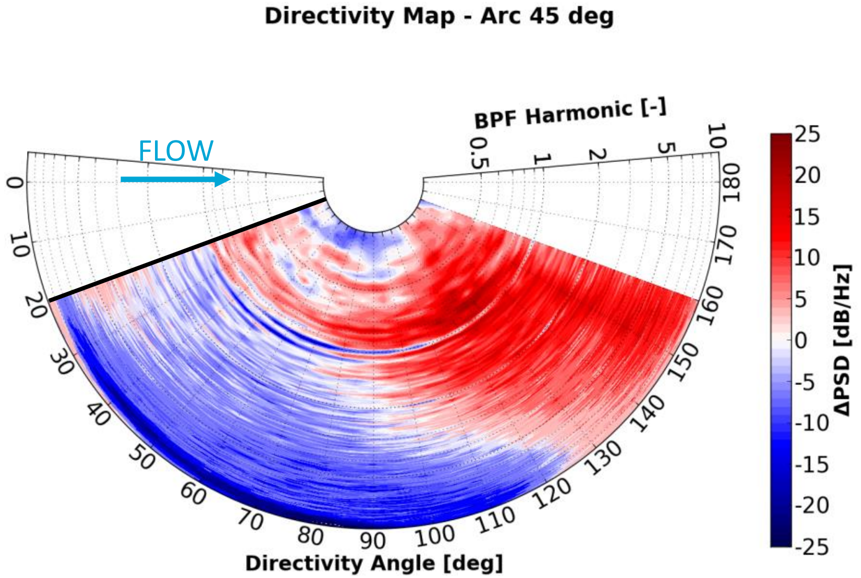


Far-field noise – Mic at 20°/Arc 45°

- PSD for directivity angle of 20° on Arc at 45°







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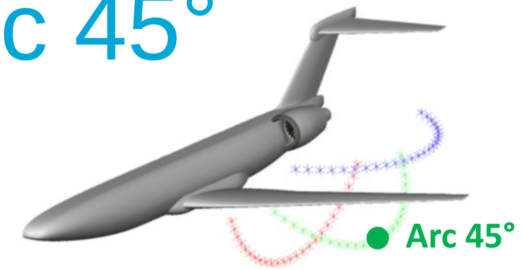
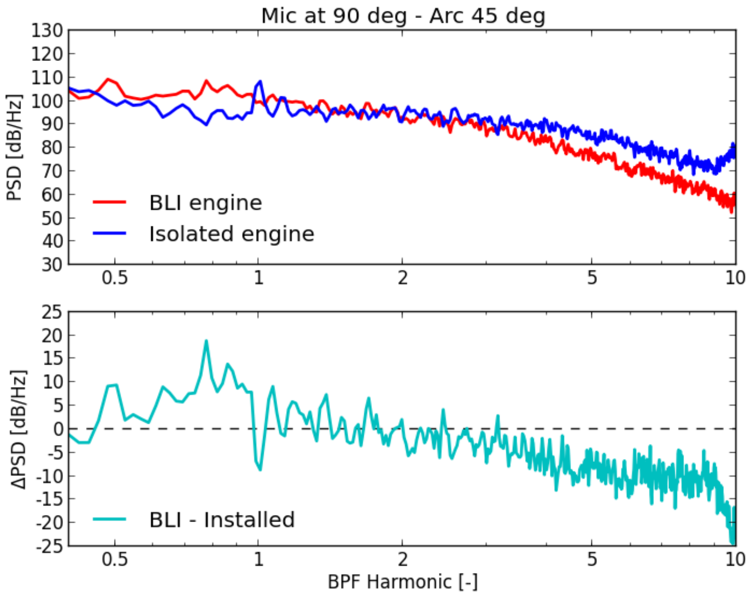
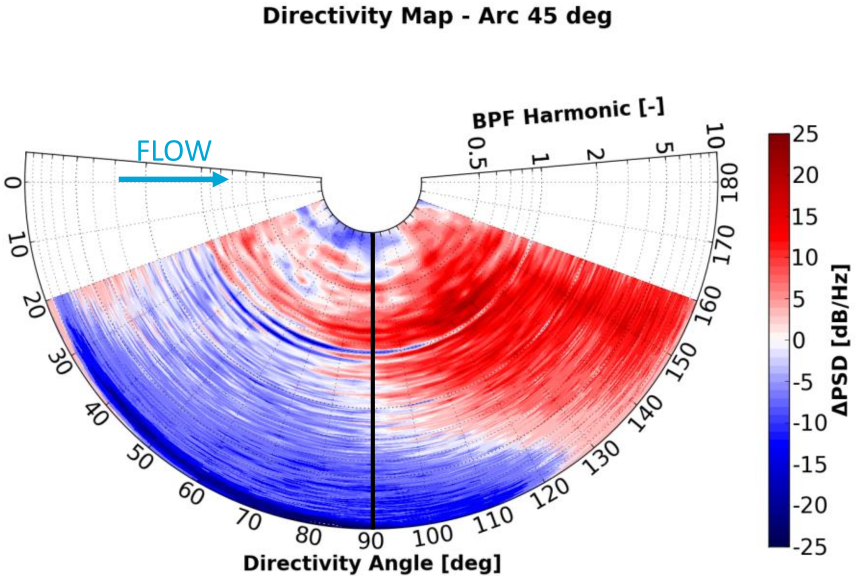
Far-field noise – Mic at 90°/Arc 45°



- PSD for directivity angle of 90° on Arc at 45°





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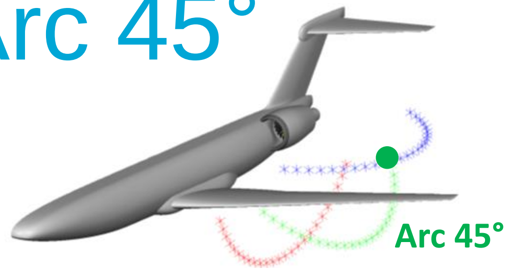
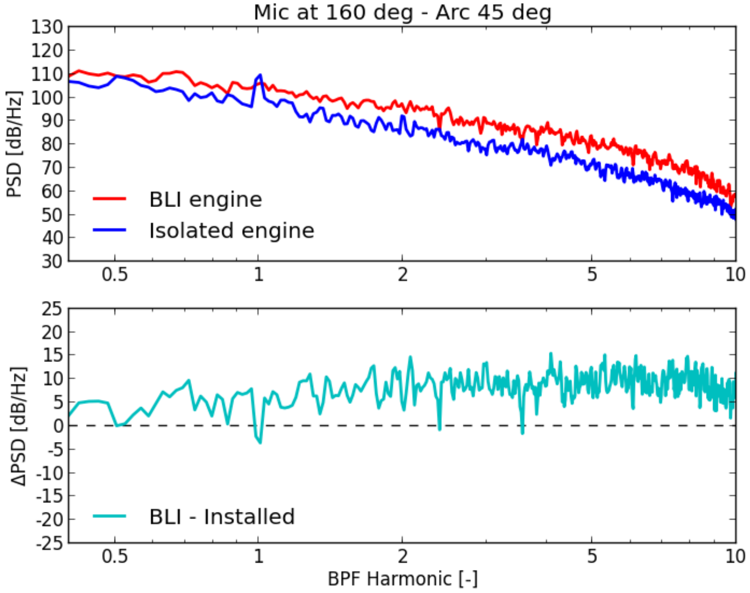
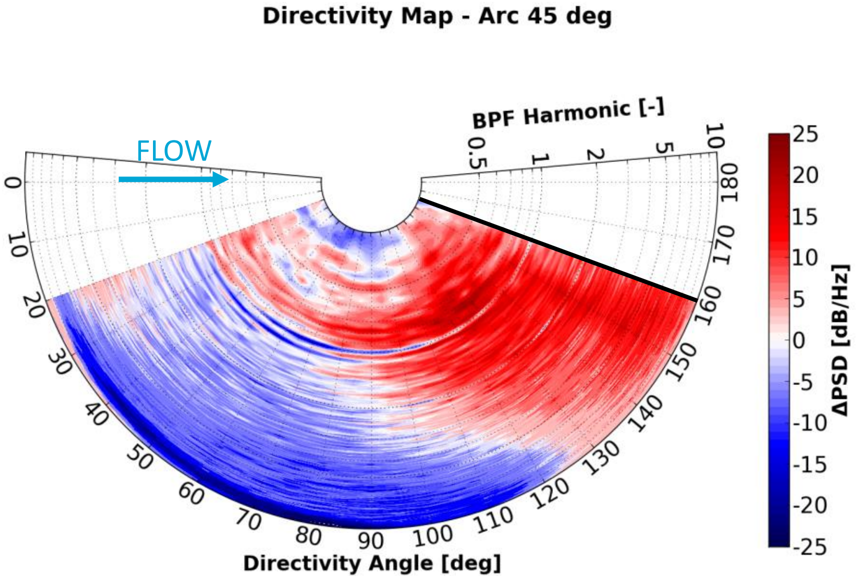
Far-field noise – Mic at 160°/Arc 45°

- PSD for directivity angle of 160° on Arc at 45°







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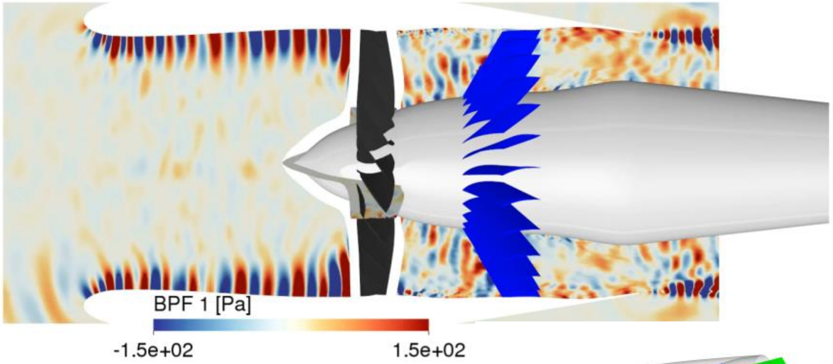
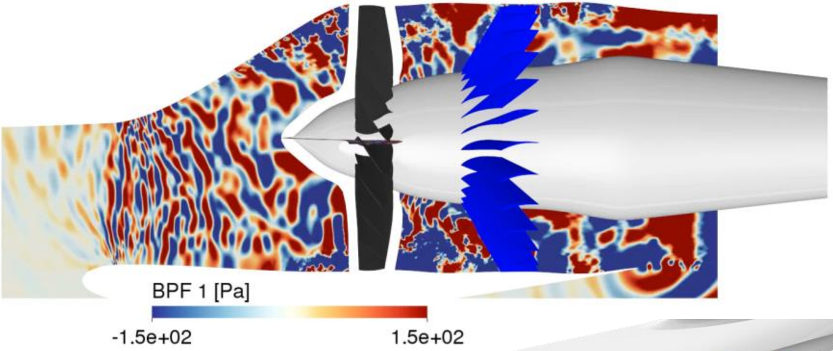
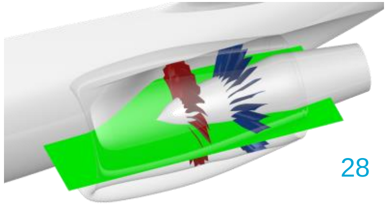
Band-pass filtered pressure around BPF1

- CFD computed pressure waves around BPF1
  - Isolated engine: low/high pressure areas extending upstream from each fan blade and co-rotating with fan propagate mainly upstream in the sideline direction
  - BLI engine: highly irregular pressure waves pattern propagating mainly upstream in the axial direction and downstream in the sideline direction



Isolated engine





BLI engine

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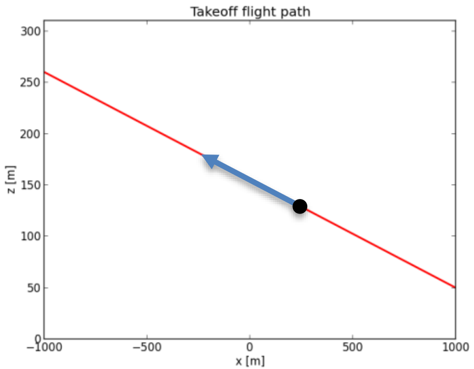
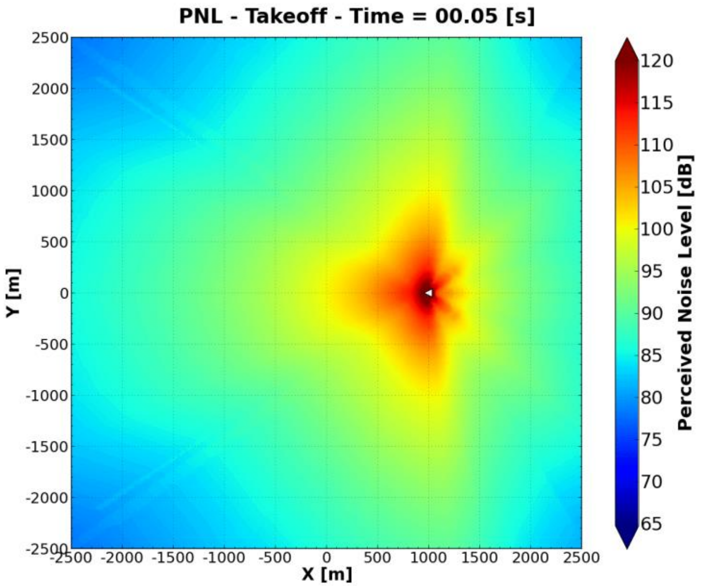
PNL on-the-ground

- Perceived Noise Level vs time during a takeoff fight path





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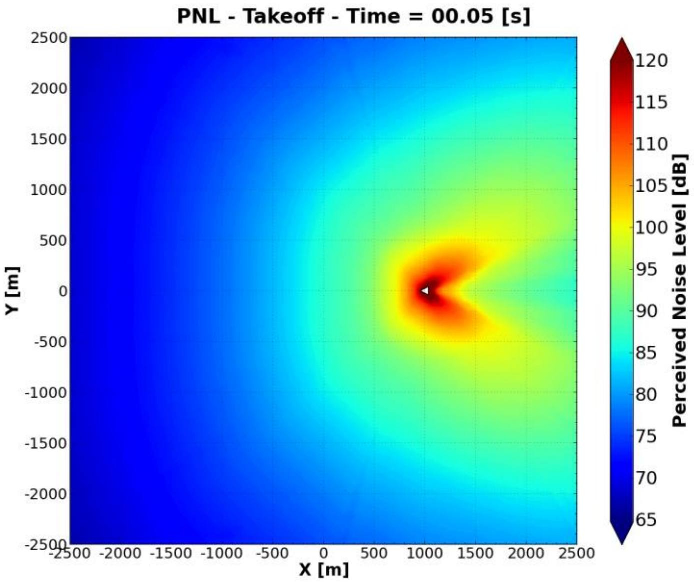

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Conclusions and future outlooks

- LBM solver Simulia PowerFLOW used to address fan noise implications of NOVA BLI-like engine configuration
- Aerodynamic installation effects:
  - Flow distortion and non-uniformity → low-frequency air-loads variation
  - Separation on intake and s-duct walls → high-frequency air-loads variation
- Aeroacoustic installation effects:
  - Increase of noise sources intensity, but different propagation behavior
    - Isolated engine: noise radiated mainly upstream in the sideline direction
    - BLI engine: noise radiated mainly upstream in the axial direction and downstream in the sideline direction
- As future outlooks:
  - Analysis of boundary layer/fan interaction mechanisms
  - Analysis of fan wake/OGV interaction mechanisms

Thank you for your attention!

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