CEAS-ASC Workshop 2018

Lattice-Boltzmann Computations of Jet-Installation Noise

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7th September 2018

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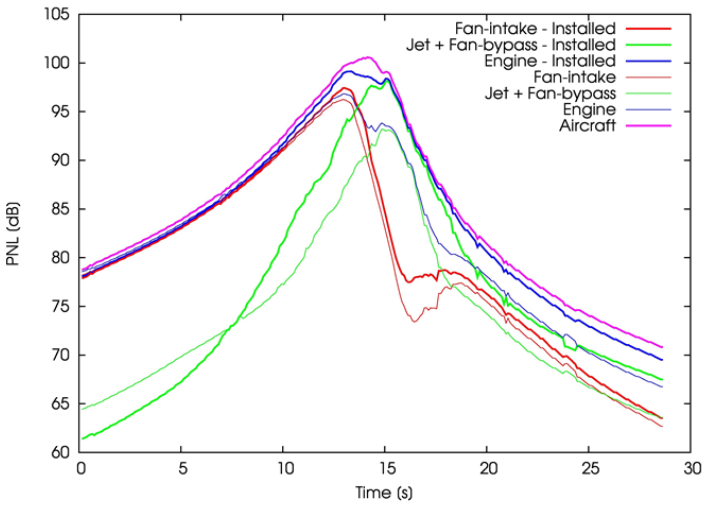
Jet-Installation Noise

- Additional noise source from the interaction between the engine jet flow and the airframe;
- Relevant noise source for take-off and approach conditions;



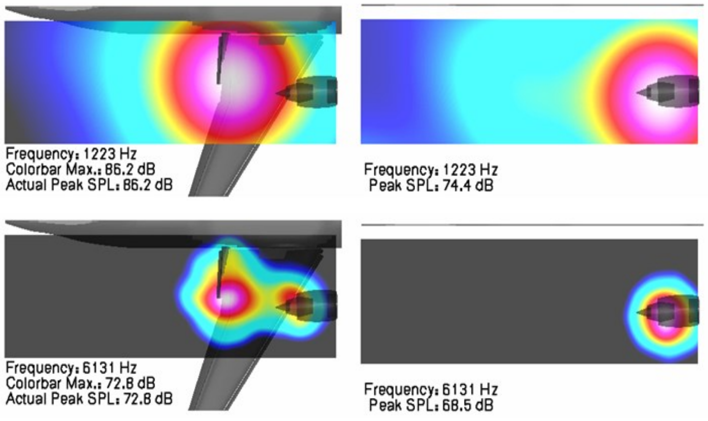
Source: (CASALINO and HAZIR, 2014)

Source: https://www.decodedscience.org/wing-flaps-for-lift-augmentation-in-aircraft/11831/2

- Dominant source for aircraft flyover during a significant amount of time;
- Maximum penalties of approximately 3 dB on the aircraft level;

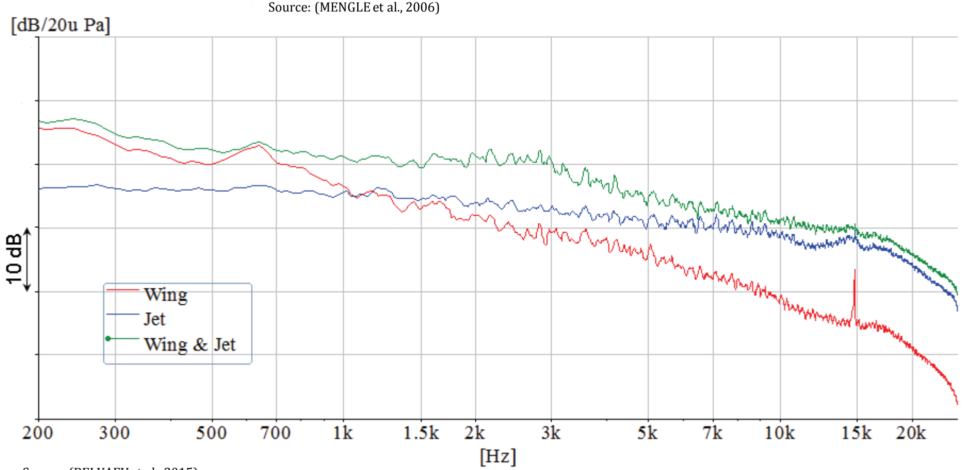
Jet-Installation Noise

- Scattering of instability waves at the wing/flap trailing edge;
- Noise increases of approximately 13 dB on the component level;
- Dominant at low- and mid-frequencies;



Source: (MENGLE et al., 2006)

- Higher levels than the combination of the jet and the airframe;
- Determine underlying phenomena and near-field effects behind the JIN;



Source: (BELYAEV et al., 2015)

Model Geometry

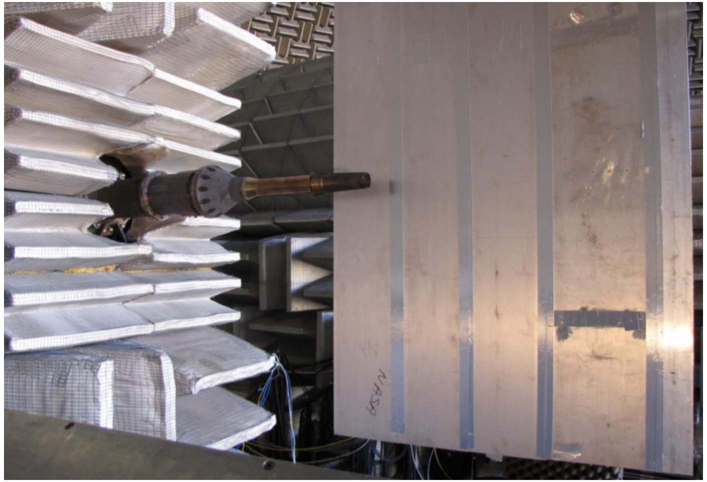
Single-stream nozzle (SMC000) + Flat plate

- Simplified jet-installation noise model;

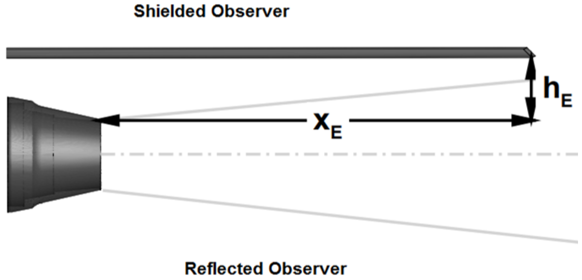
- Experiments from NASA Glenn for validation of computational results;

- Setpoints (03, 07 and 46) for different flow speeds and temperature ratios;

- Several axial and radial positions of the flat plate, relative to jet;



Source: (BROWN, 2011)



Source: (BROWN, 2011)

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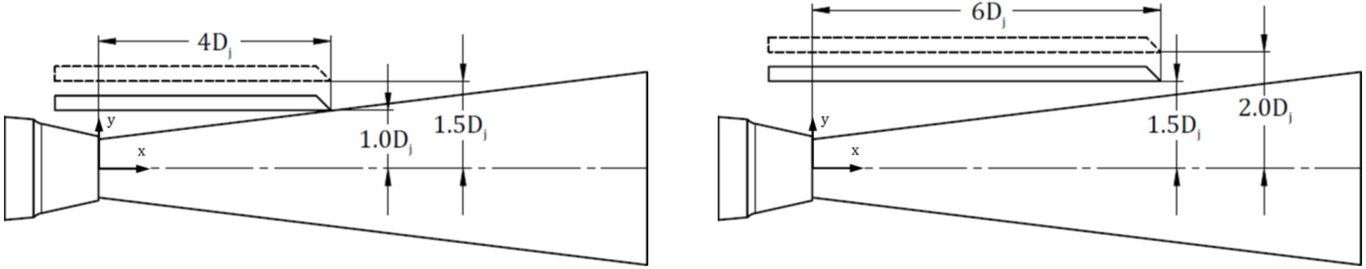
Computational Setup

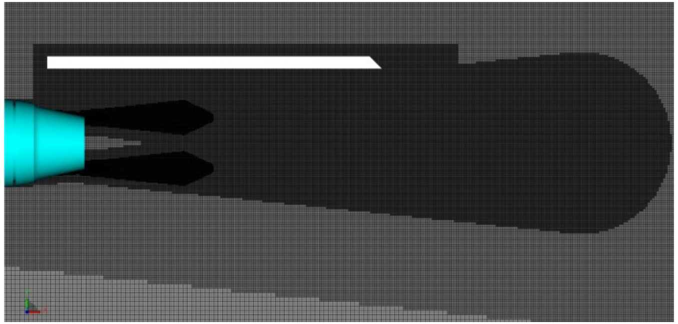
- Two cases with different lengths and radial distances selected;



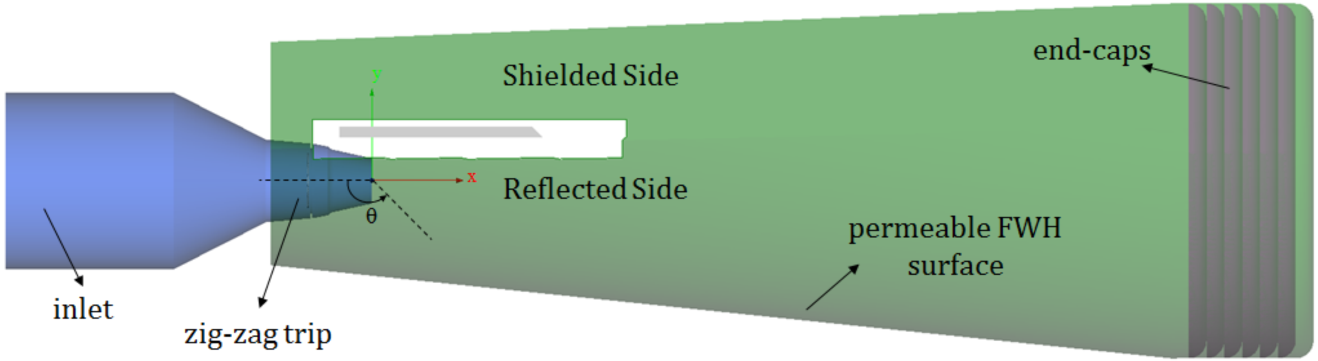
- Computations performed with the Lattice-Boltzmann method (PowerFLOW software);

- Setpoint 03: $M_a = 0.5$ and $T_R = 0.95$ (low-speed subsonic jet);

- Fine resolution: 64 elements at the nozzle exit plane;



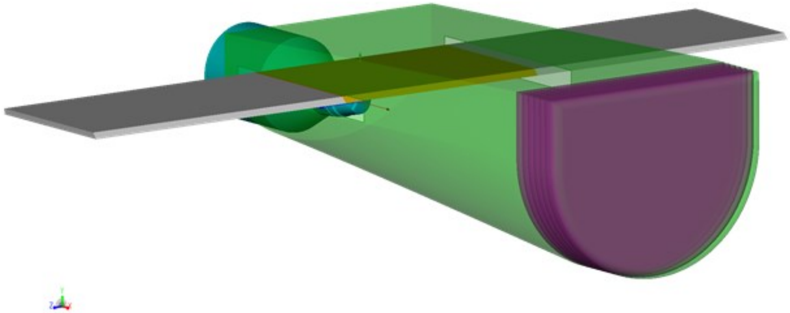
Computational Setup



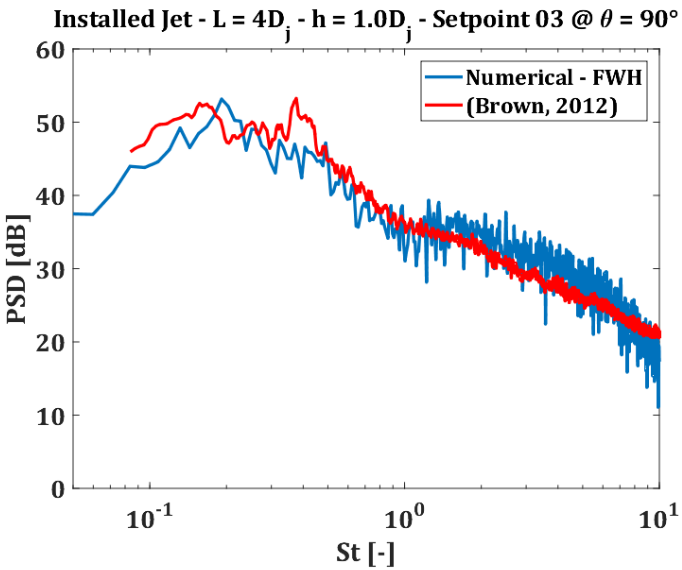
- Far-field noise computation via FWH permeable surface formulation;

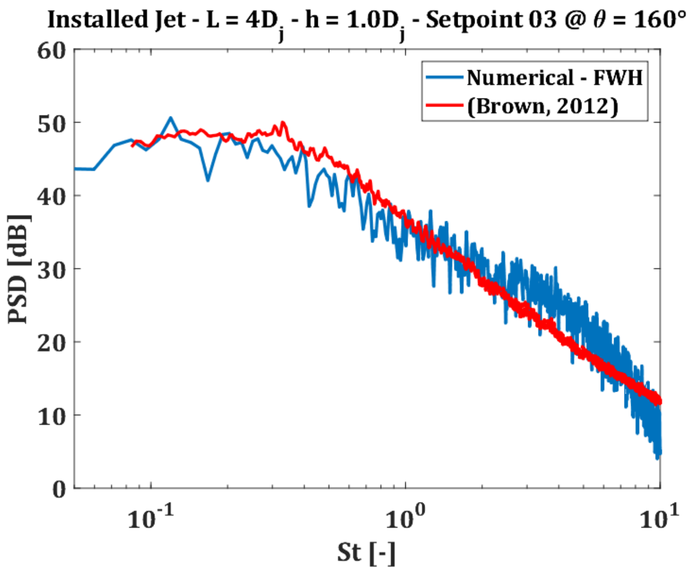
- Caps at the streamwise end of the FWH surface;

- Far-field measurements on several polar angles on both sides of the plate;



Validation





- Good agreement at low frequencies;
- Slight overprediction of noise at medium and high frequencies;
- High-frequency cut-off can be improved with higher resolution;

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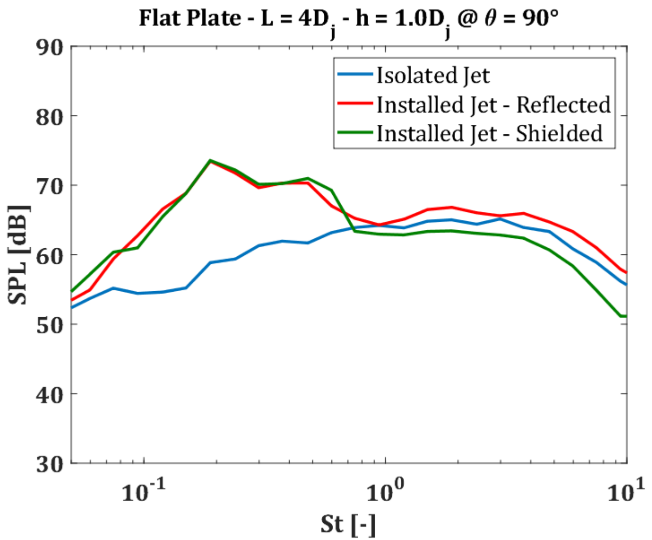
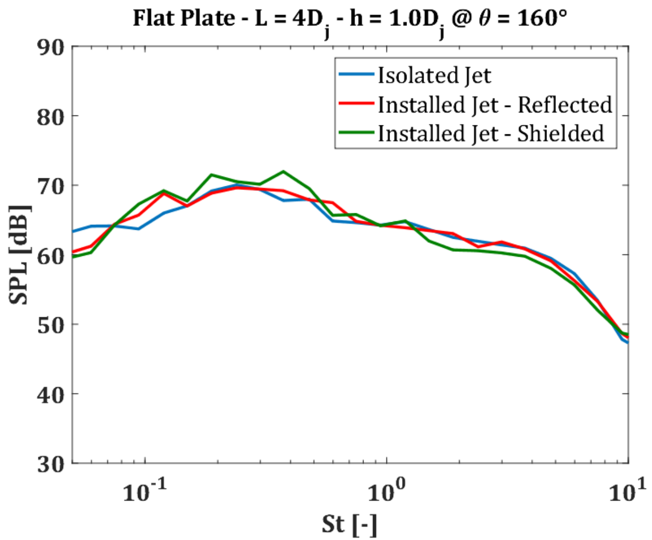
Far-field Spectra





- Amplification of low-frequency noise for the installed configuration (15 dB);
- Installation effects visible up to St = 0.35. For St > 0.35, reflection or shielding of noise occurs;
- Highest penalties occur at the sideline direction (θ = 90°);
- Closer to the jet axis (θ = 160°) the quadrupoles from isolated jet noise are dominant;

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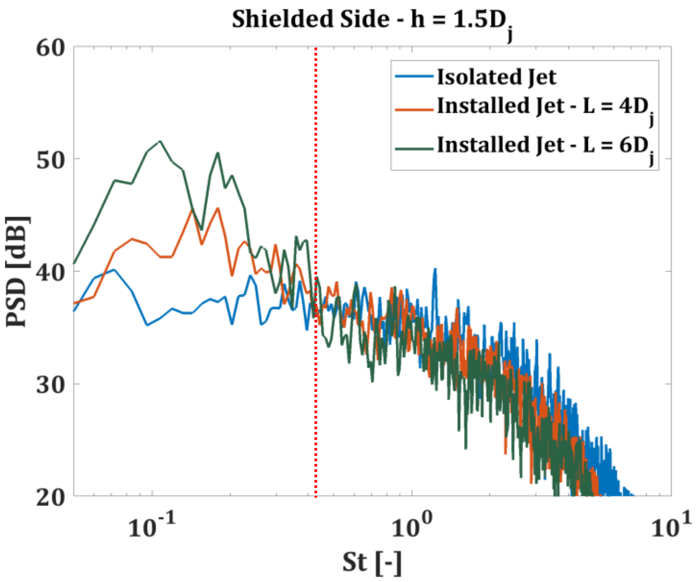
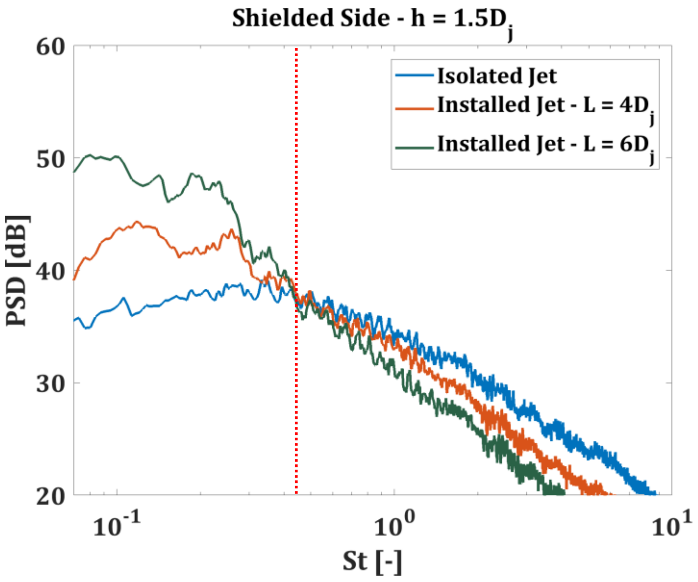
Effect of Surface Length

Numerical



Experimental (NASA Glenn)



- Increase in surface length results in higher noise levels;
- The frequency range of the installation effects remains unchanged;

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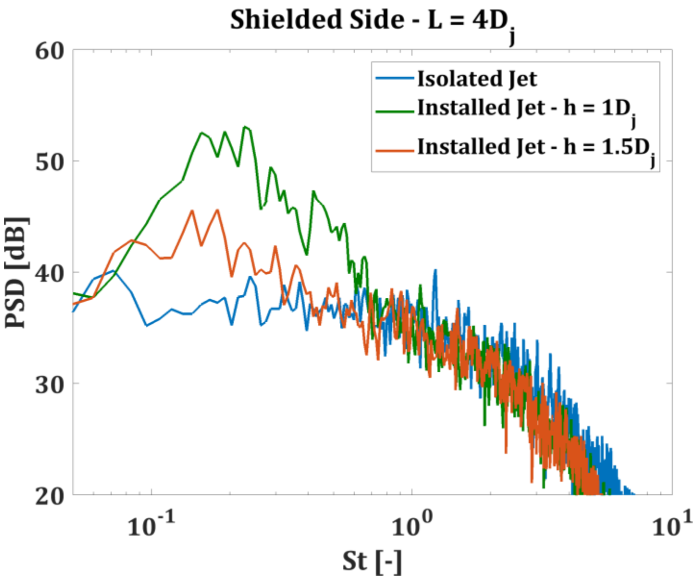
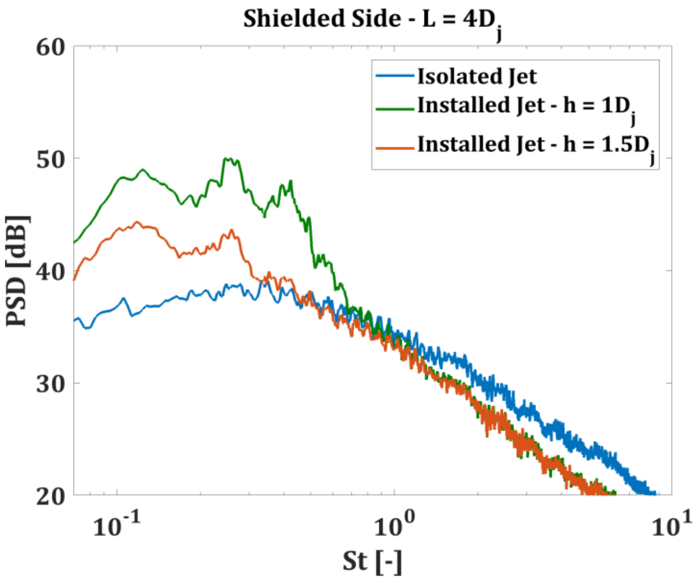
Effect of Surface Height

Numerical



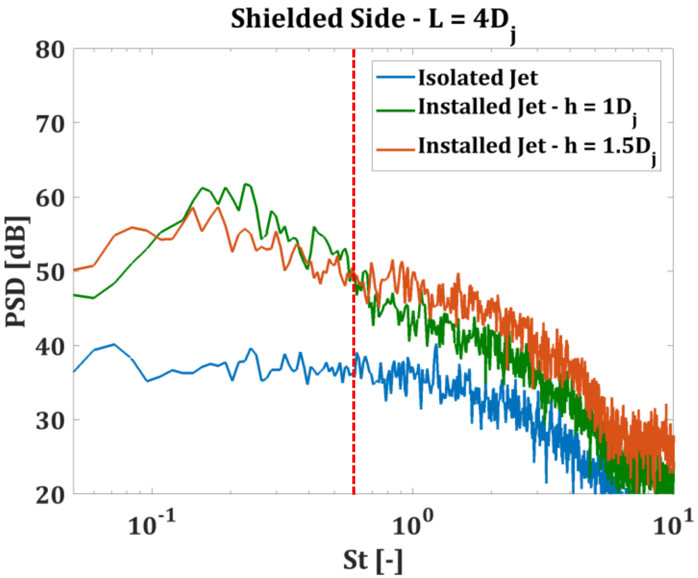
Experimental (NASA Glenn)



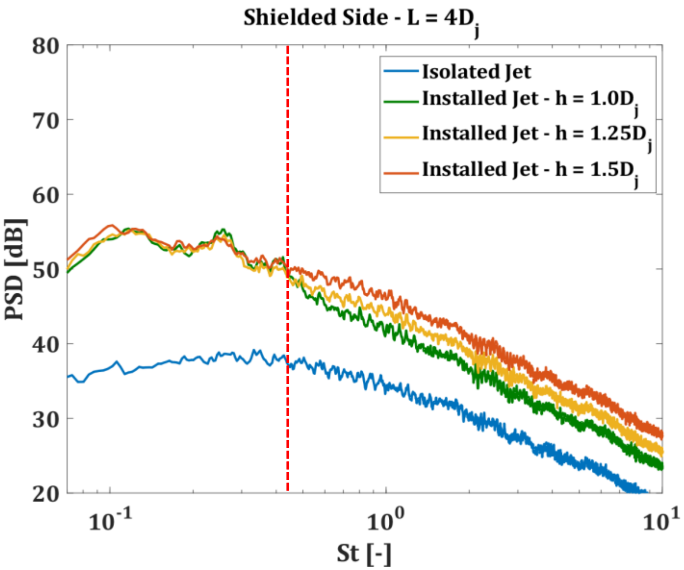
- Decreases in the surface height result in higher noise levels;
- The upper frequency limit where the installation effects occur also increases;

Effect of Surface Height

Numerical



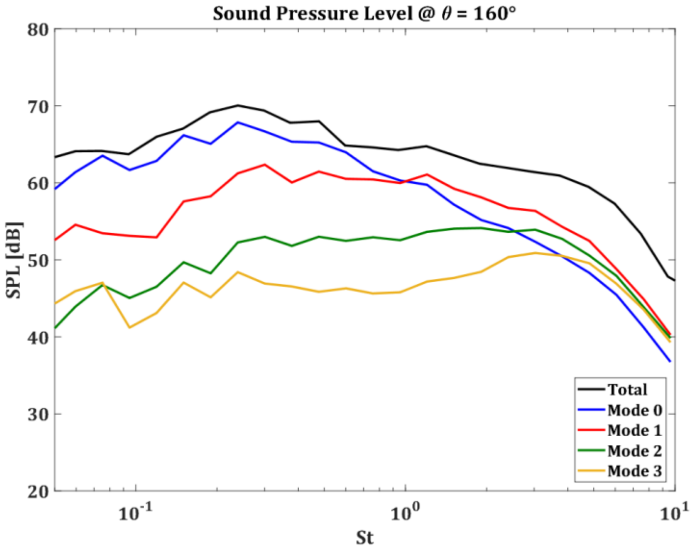
Experimental (NASA Glenn)

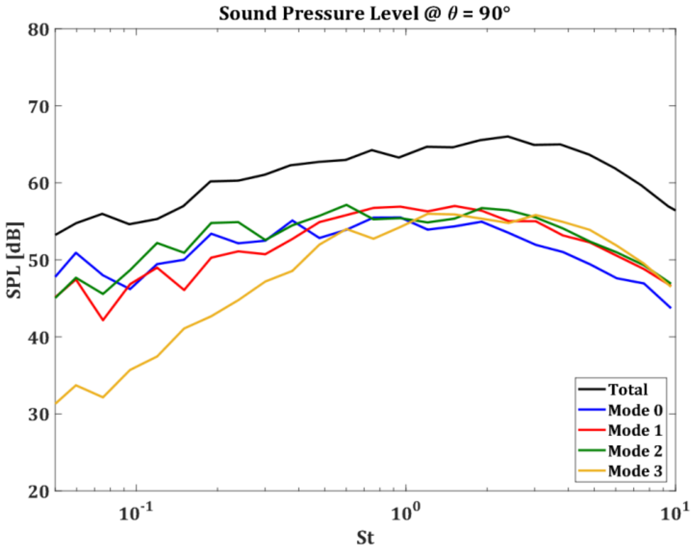


- Noise levels show an exponential scaling with the distance to the nozzle axis;
- The upper frequency limit also seems to scale with ***h***;

Far-field Azimuthal Decomposition

Isolated Jet





- Near the jet axis (θ = 160°), the axissymetric mode is dominant for lower frequencies (superdirectivity), with the higher modes progressively decreasing;
- On the sideline direction (θ = 90°), the helical modes (m = 1 and m = 2) show similar levels as the axisymmetric;

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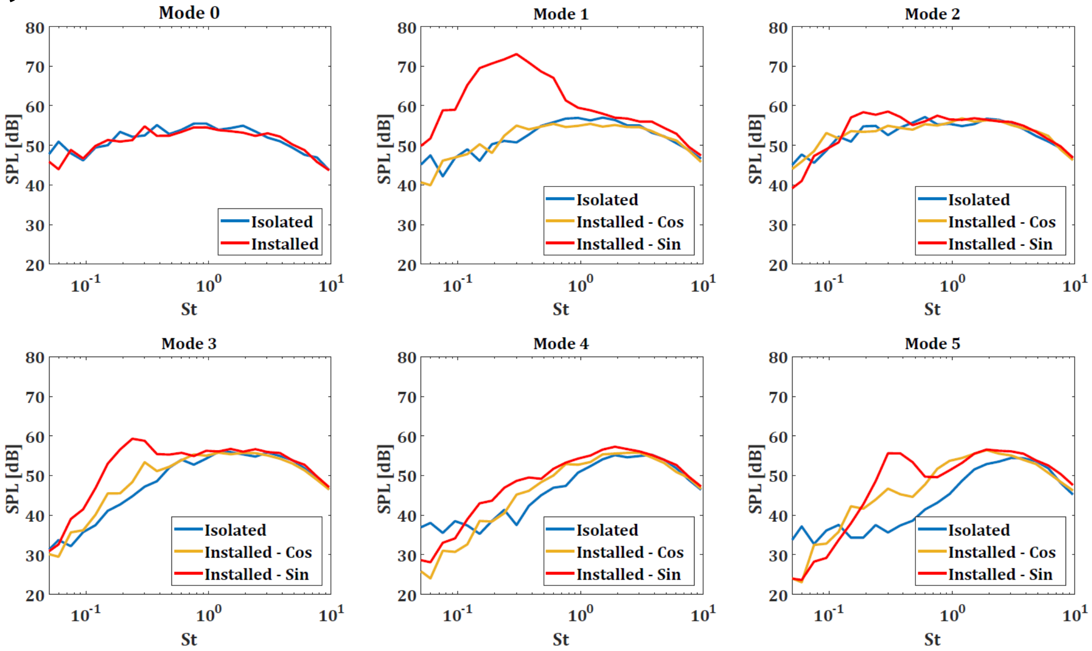
Far-field Azimuthal Decomposition

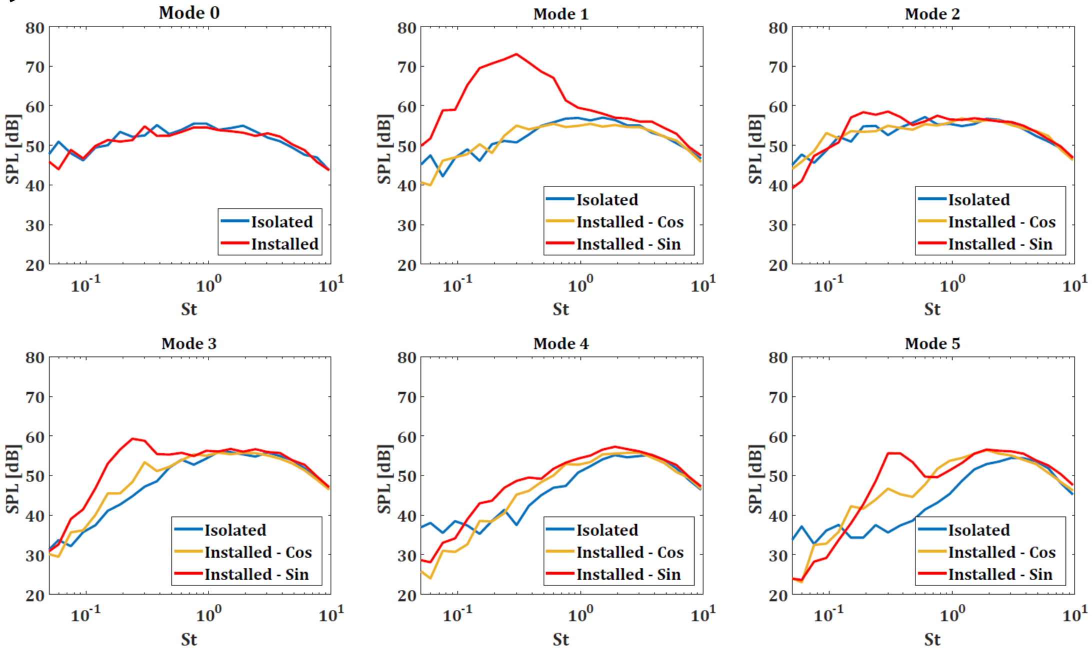
Installed Jet



- Azimuthal array now centered at the flat plate;
- A phase opposition of 180° between shielded and reflected sides cancel the even harmonics of the series;

Far-field Azimuthal Decomposition

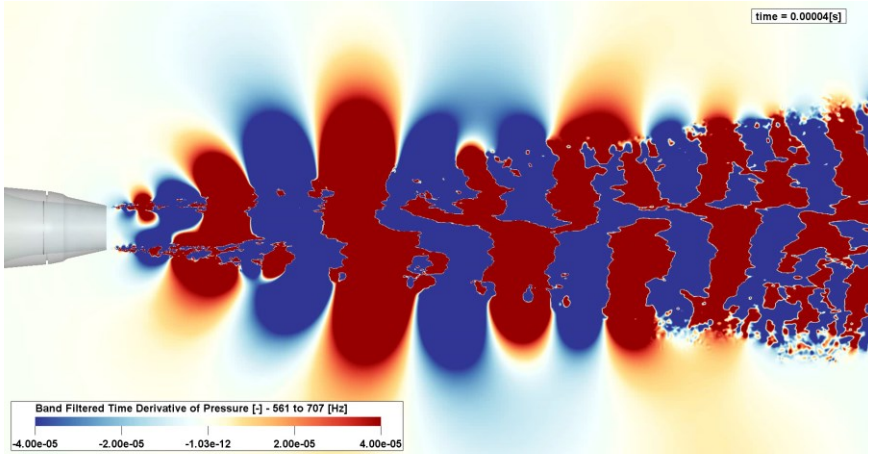
Installed Jet

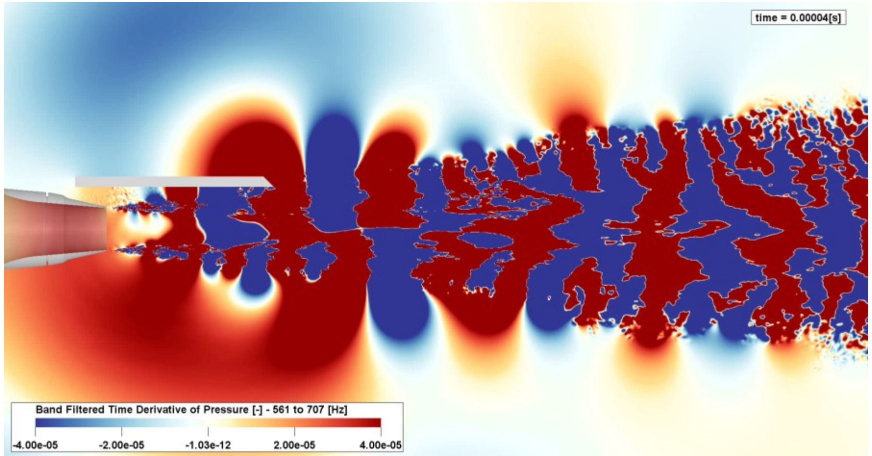


- Acoustic dipoles on the surface have a sin(Φ) dependence in the azimuthal direction;
- The azimuthal decomposition shows that the surface dipoles are the main observable installation effect;

Time Derivative of Pressure Field

- Band-pass filter for frequency analysis;
- 0.18 < *St* < 0.21 Hz;
- Spatial and temporal modulation on the isolated jet generate noise;
- Scattering at the flat-plate trailing edge is the dominant source;
- Radiation perpendicular to the plate and in the upstream direction;





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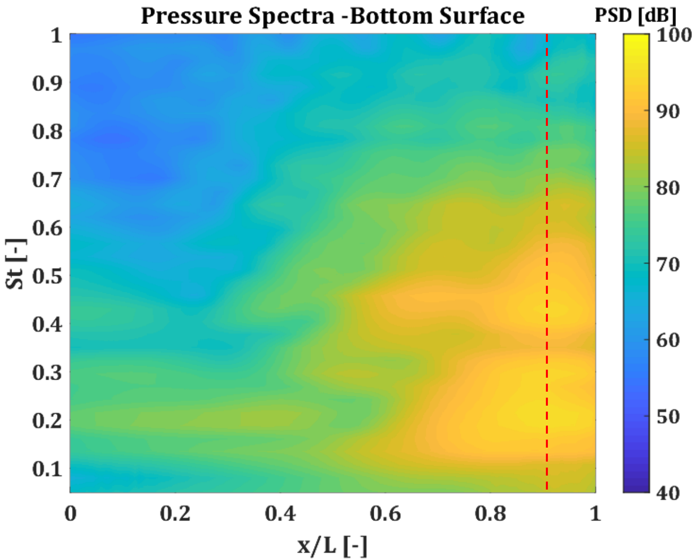
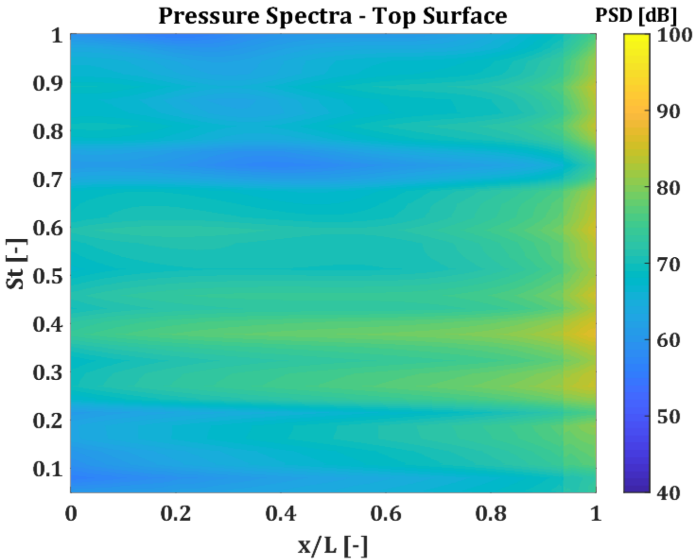
Surface Pressure Fluctuations



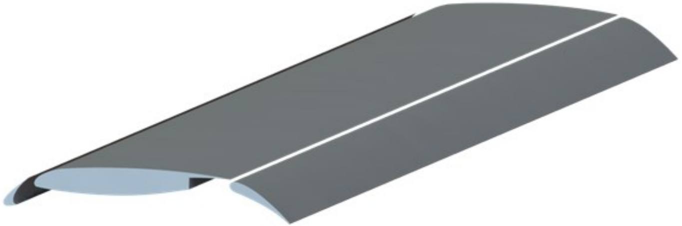


- On the reflected side of the surface, maximum fluctuations occur upstream of the trailing edge ($x/L = 0.91$);

- Destructive interference on the reflected side, between the convecting waves from the jet and the ones scattered by the trailing-edge (phase-shifted);

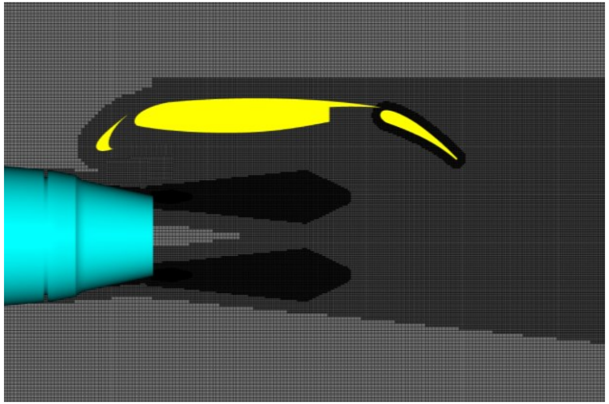
Jet-Wing Model

- SMC-000 Nozzle + MD30P30N Wing;

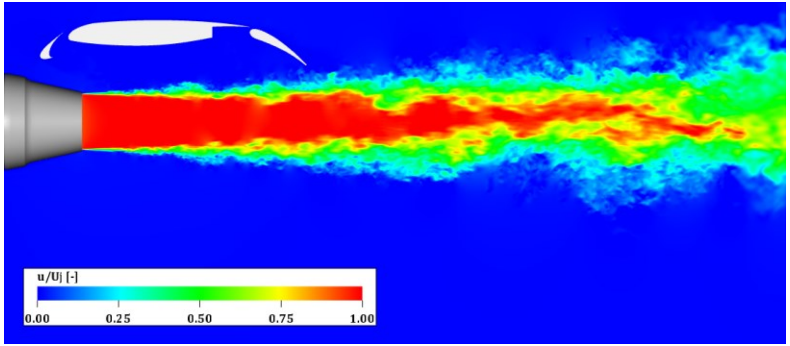


- More complex geometry, but similar dimensions to the flat plate;

- The flap trailing-edge has the same position of the flat plate t. e.;

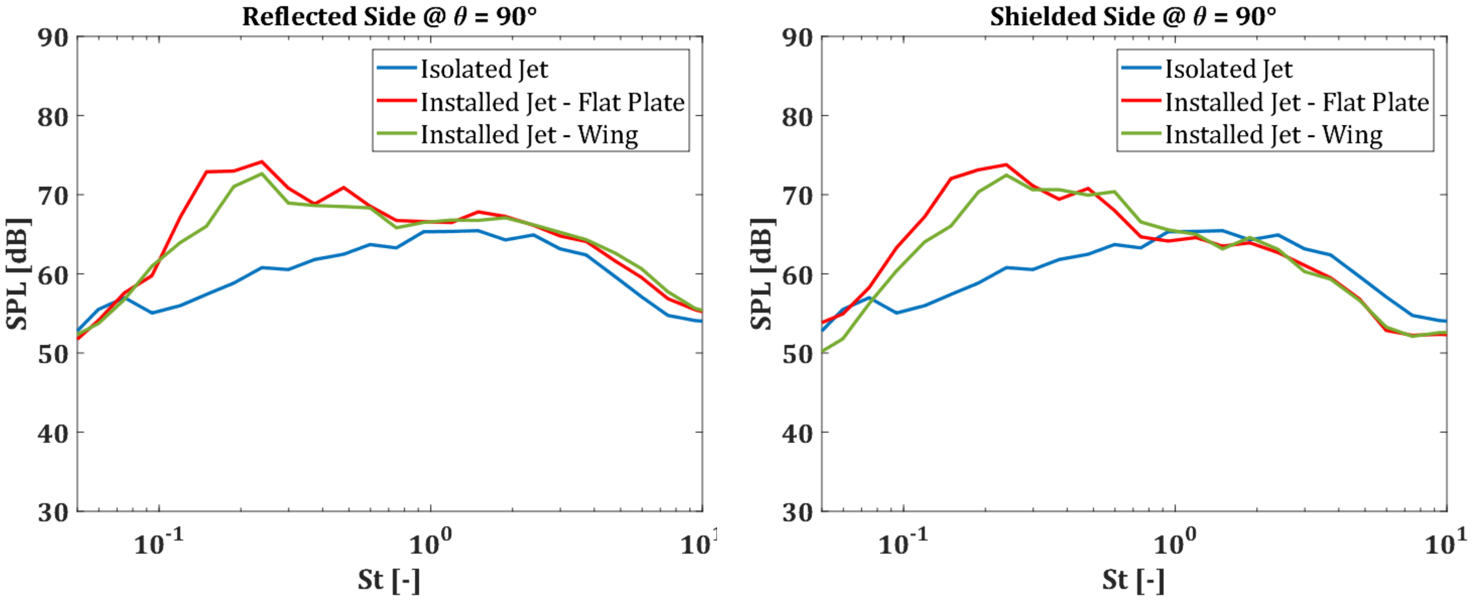


- Initial simulation: jet flow only;



Jet-Wing Model

Far-field Spectra



- Similar spectral shape for flat plate and wing;
- Slightly lower noise levels for the wing case (likely due to higher distance between the wing main element and the jet);

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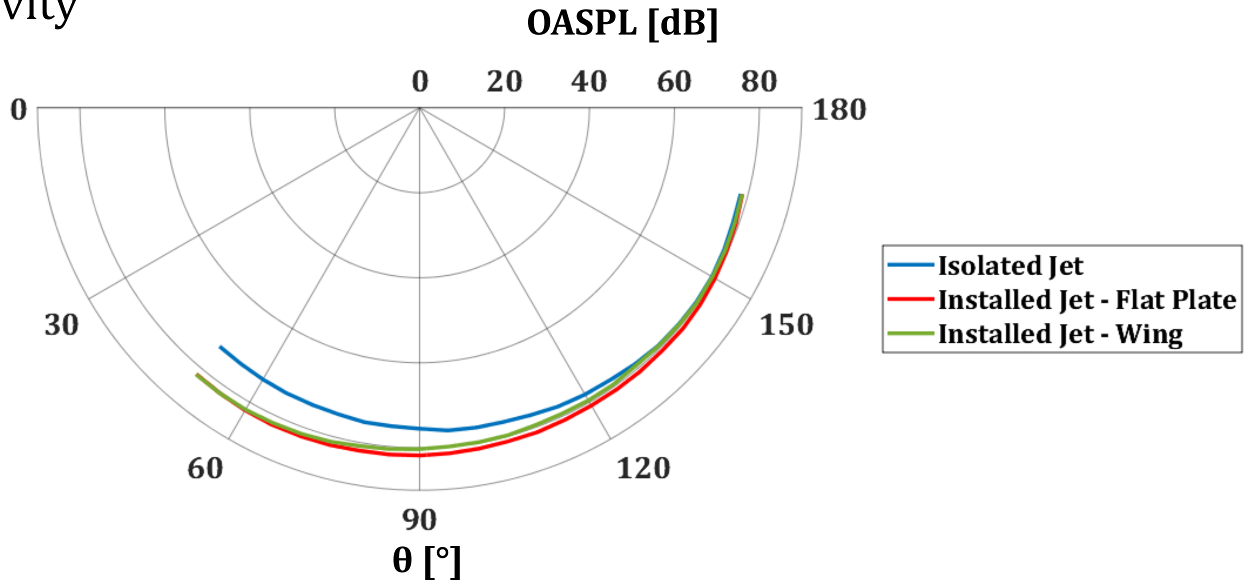
Jet-Wing Model

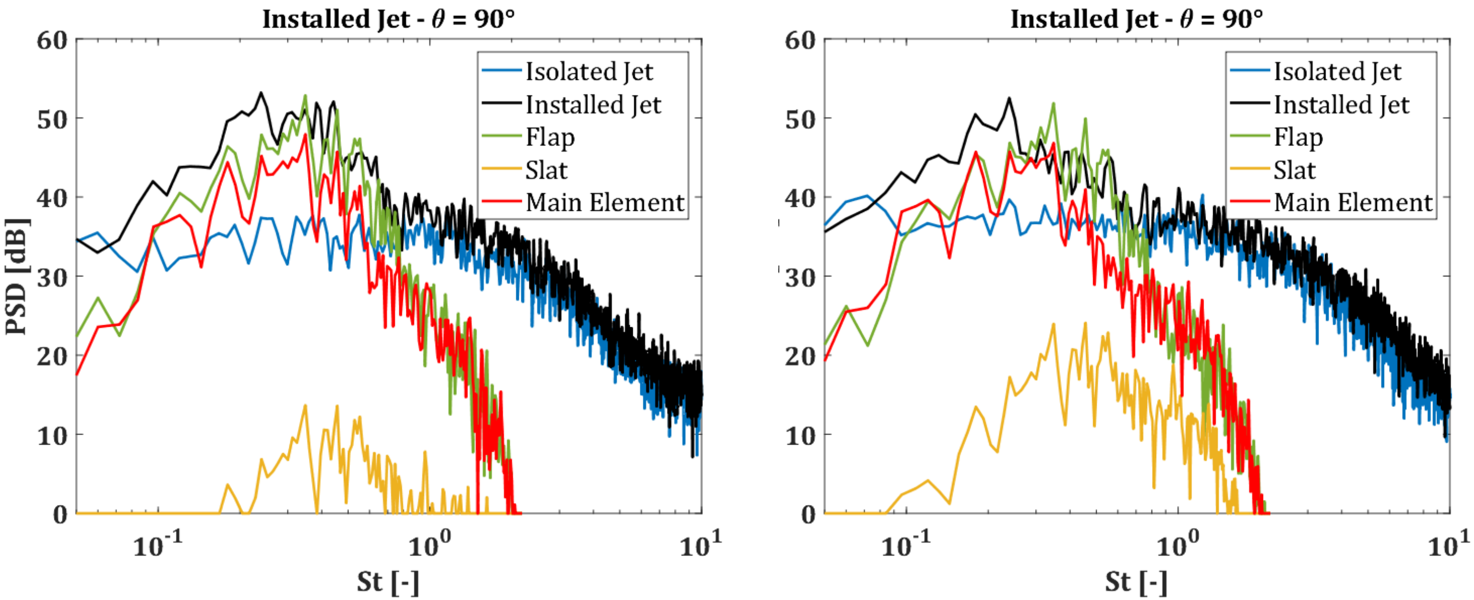
Directivity



- Slightly higher overall noise levels for the flat plate case at θ = 90°;
- The flap is not a horizontal surface, therefore the acoustic dipoles there will not have axes in the θ = 90° direction, but rather at θ = 60°;

Jet-Wing Model

Breakdown of Noise Sources

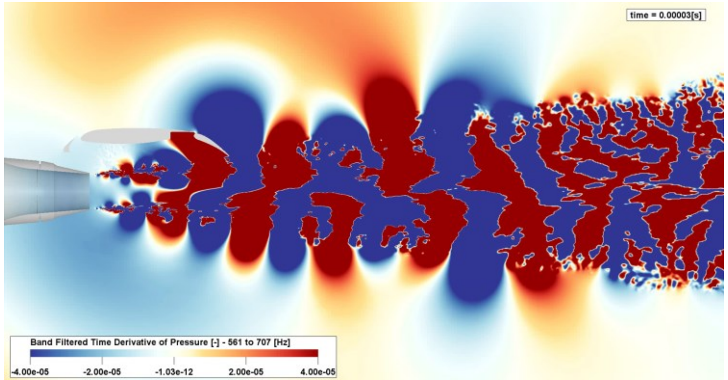


- The flap has the most pressure fluctuations in the entire geometry, followed by the main element;
- From θ = 60° to θ = 90°, the slat levels increase, whereas the flap levels decrease at lower frequencies and the main element at mid frequencies;

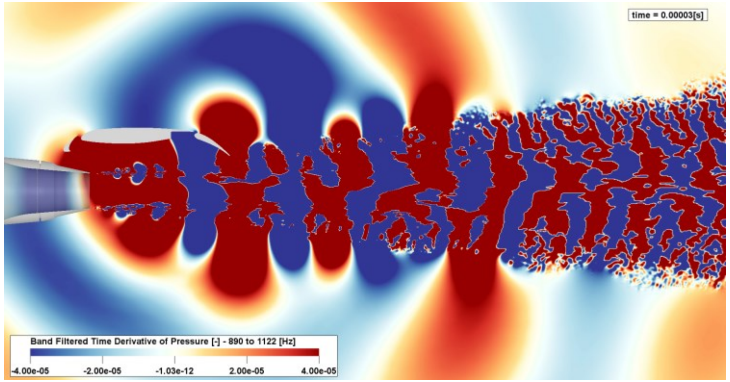
Jet-Wing Model

Dilatation Field

- 0.18 < St < 0.21;



- 0.27 < St < 0.34;



- Scattering seems to occur only at the flap trailing edge;
- Impinging structures on the slat and main element generate the pressure fluctuations on those surfaces;
- Waves tend to radiate perpendicular to the flap. On the upper side, the installation effects for high polar angles can be masked by the isolated jet noise;

Concluding Remarks

- Installation effects with a flat plate are responsible for noise increases of approx. 15 dB;
- Longer surfaces result in higher noise levels, but moving the plate in the radial direction changes the levels, as well as the frequency of noise amplification;
- Scattering at the flat plate trailing edge was shown to be the dominant source;
- Destructive interferences on the reflected side, near the trailing edge, tend to place the region of maximum fluctuations upstream of the plate t. e.;
- Replacing the surface with a wing geometry results in slightly lower noise levels (change in overall radial distance);
- The flap is responsible for most pressure fluctuations (scattering), but the main element also contributes to the overall noise;

Future Work

- Investigate other setpoints (higher Mach number and heated jets);
- Replace the nozzle geometry for a nacelle configuration;
- Include external flow and angle of attack on the simulations;

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