

TU-Delft/3DS Workshop

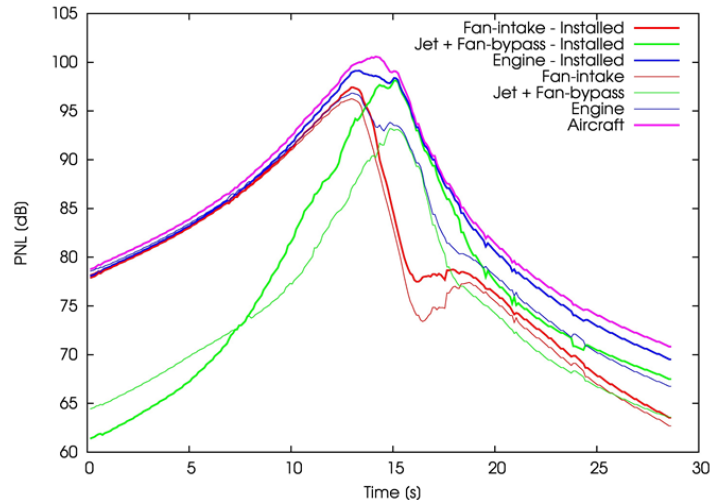
Lattice-Boltzmann Computations of Jet-Installation Noise

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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)

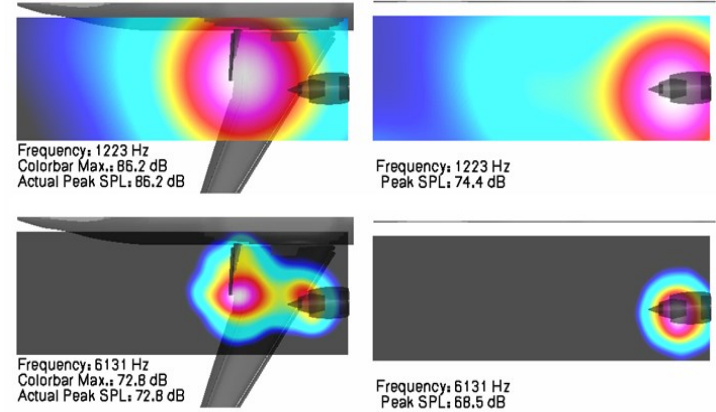


Source: <https://www.decodedscience.org/wing-flaps-for-lift-augmentation-in-aircraft/11831/2>

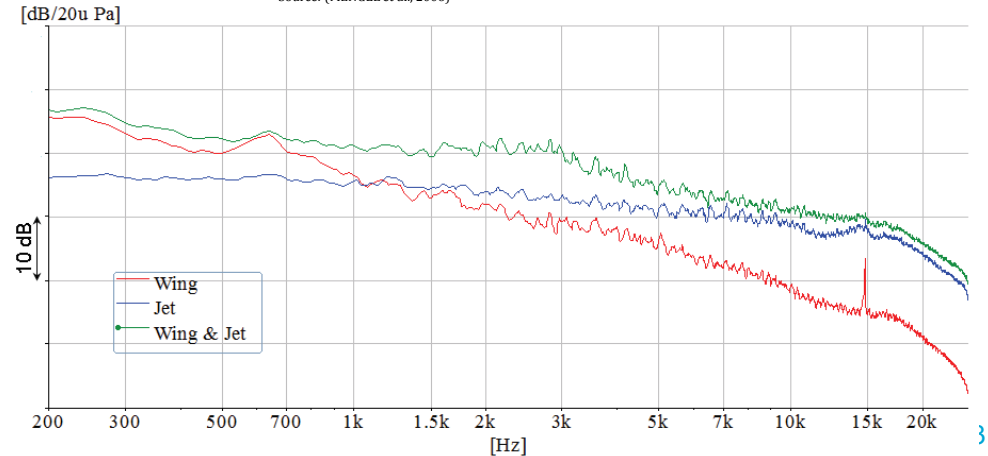
- Dominant source for aircraft flyover during a significant amount of time;
- Maximum penalties of approximately 3 dB on the aircraft level;

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



Source: (MENGLE et al., 2006)



Source: (BELYAEV et al., 2015)

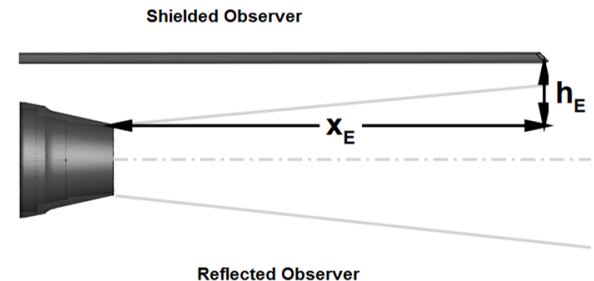
Model Geometry

Single-stream nozzle (SMC000) + Flat plate

- Simplified jet-installation noise model;
- Experiments from NASA Glenn for validation of computational results;
- Several axial and radial positions of the flat plate, relative to jet;
- Setpoints (03, 07 and 46) for different flow speeds and temperature ratios;



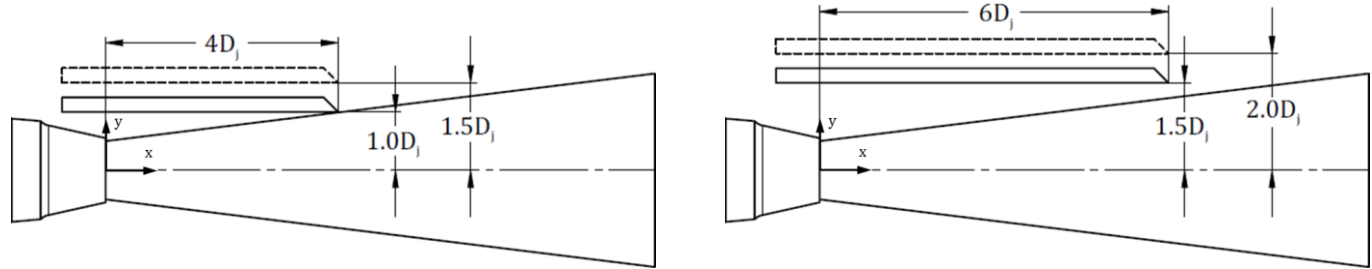
Source: (BROWN, 2011)



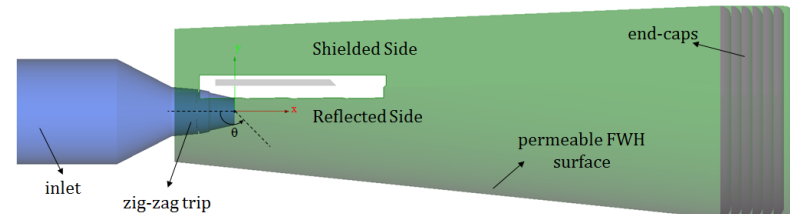
Source: (BROWN, 2011)

Computational Setup

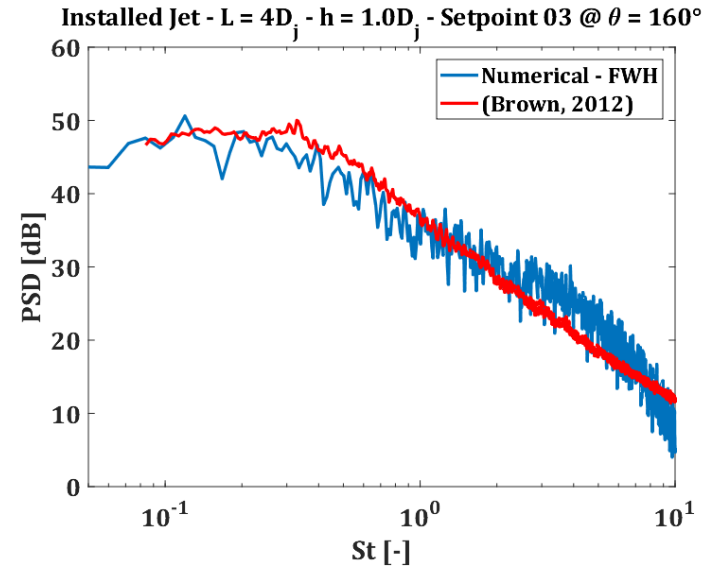
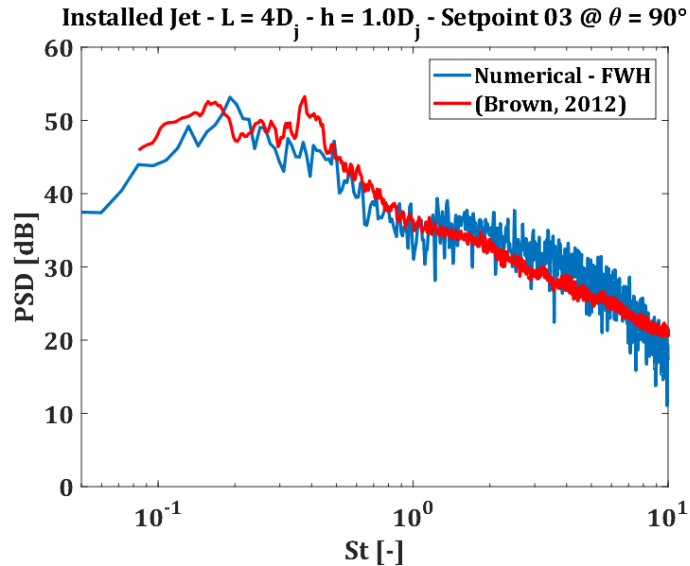
- Two cases with different lengths and radial distances selected;



- Computations performed with the Lattice-Boltzmann method (PowerFLOW software);
- Setpoint 03: $M_a = 0.5$ and $T_R = 0.95$ (low-speed subsonic cold jet);
- Far-field noise computation via FWH permeable surface formulation;

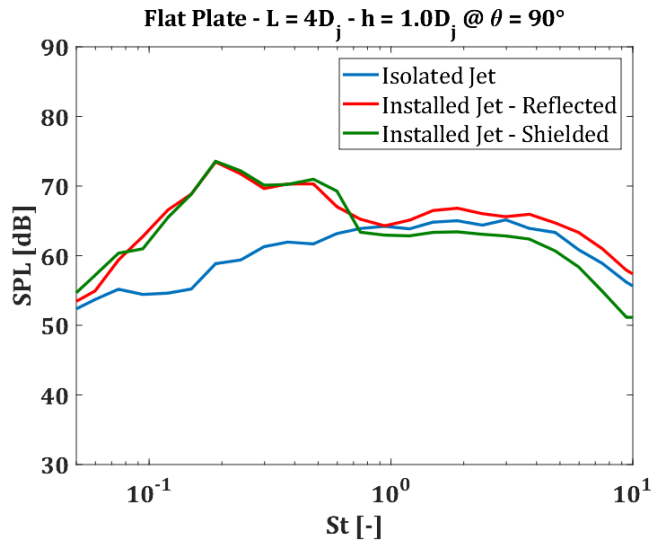


Validation

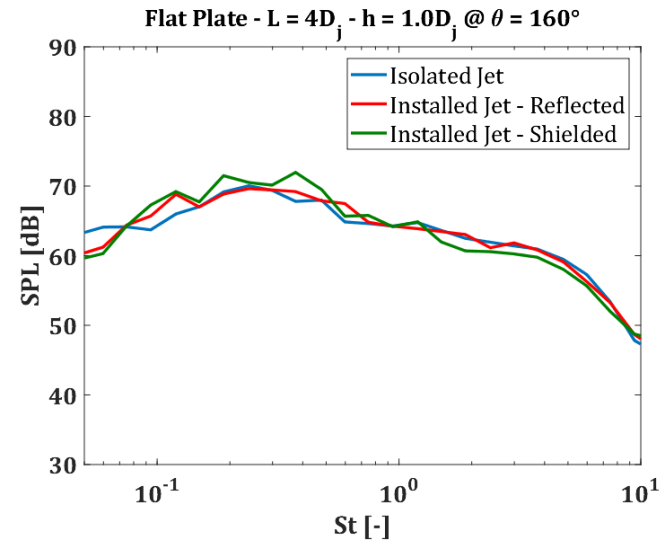


- Good agreement at low frequencies;
- Slight overprediction of noise at medium and high frequencies;
- High-frequency cut-off can be improved with higher resolution;

Far-field Spectra

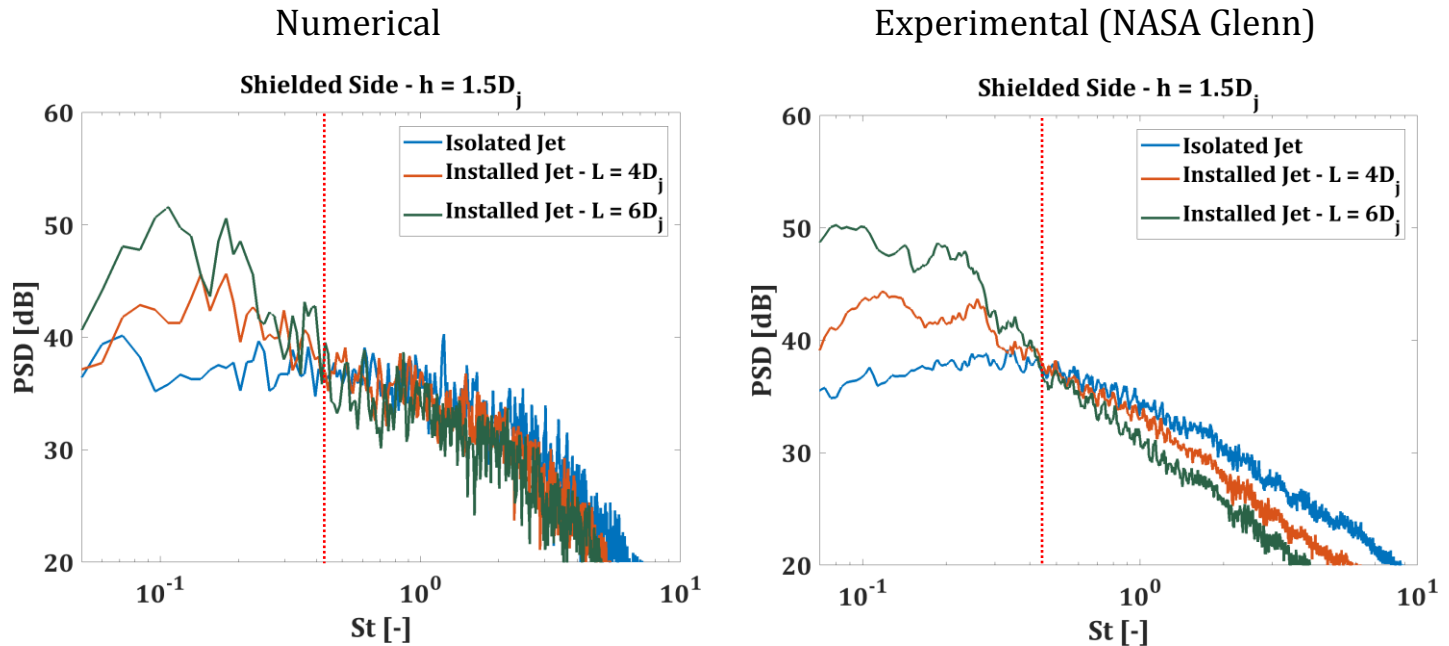


- Amplification of low-frequency noise for the installed configuration (15 dB);
- Installation effects visible up to $St = 0.35$. For $St > 0.35$, reflection or shielding of noise occurs;



- Highest penalties occur at the sideline direction ($\theta = 90^\circ$);
- Closer to the jet axis ($\theta = 160^\circ$) the quadrupoles from isolated jet noise are dominant;

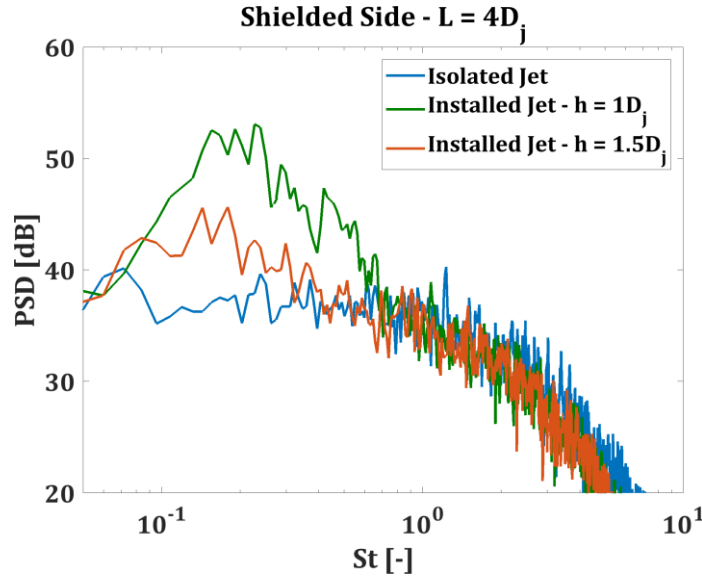
Effect of Surface Length



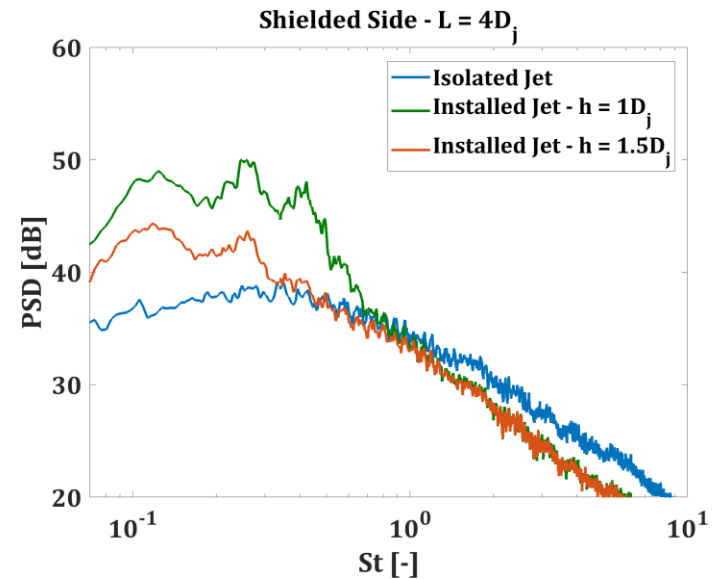
- Increase in surface length results in higher noise levels;
- The frequency range of the installation effects remains unchanged;

Effect of Surface Height

Numerical



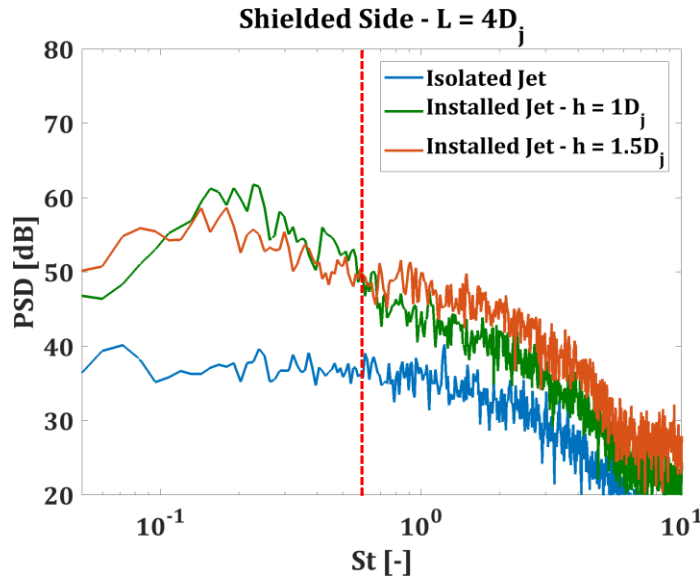
Experimental (NASA Glenn)



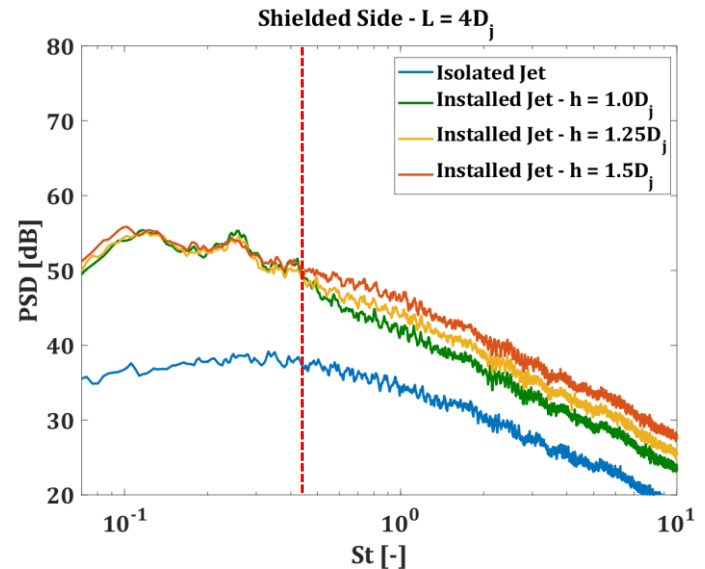
- Decreases in the surface height result in higher noise levels;
- The upper frequency limit where the installation effects occur also increases;

Effect of Surface Height

Numerical

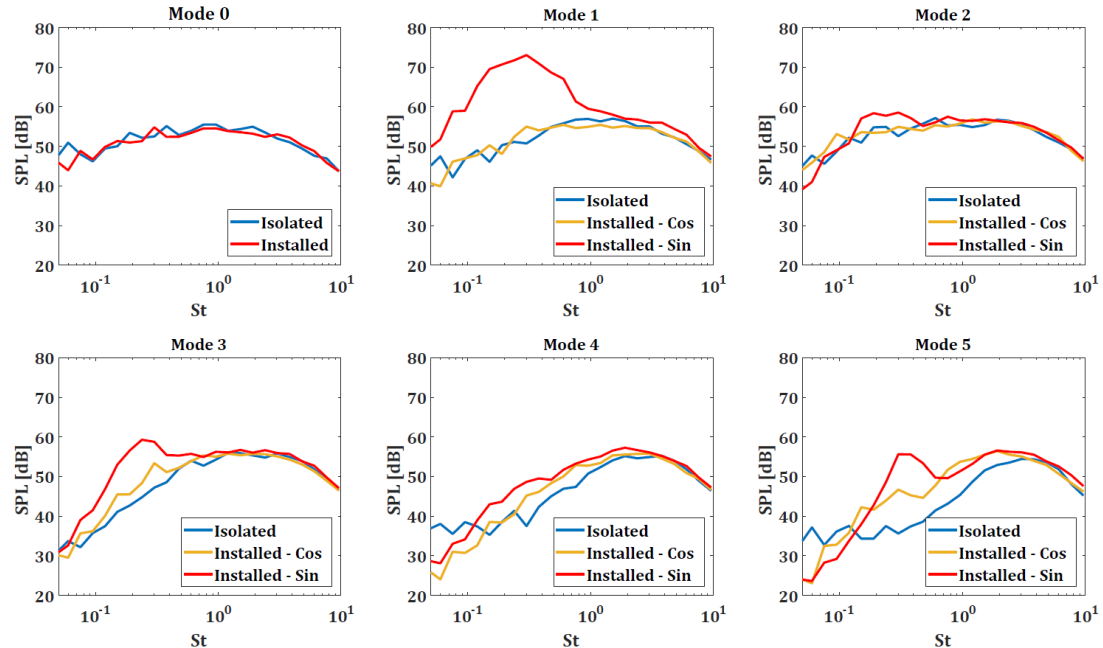


Experimental (NASA Glenn)



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

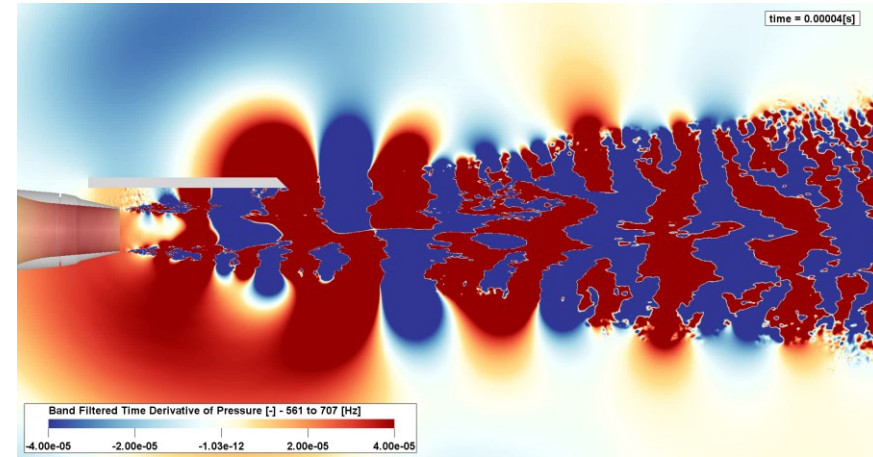
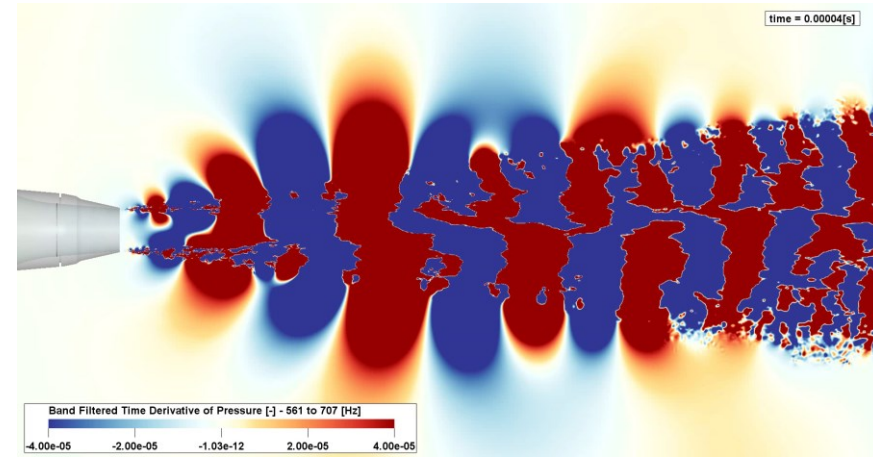
Far-field Azimuthal Decomposition



- Acoustic dipoles on the surface have a $\sin(\Phi)$ dependence in the azimuthal direction;
- A phase opposition of 180° between shielded and reflected sides cancel the even harmonics of the series;

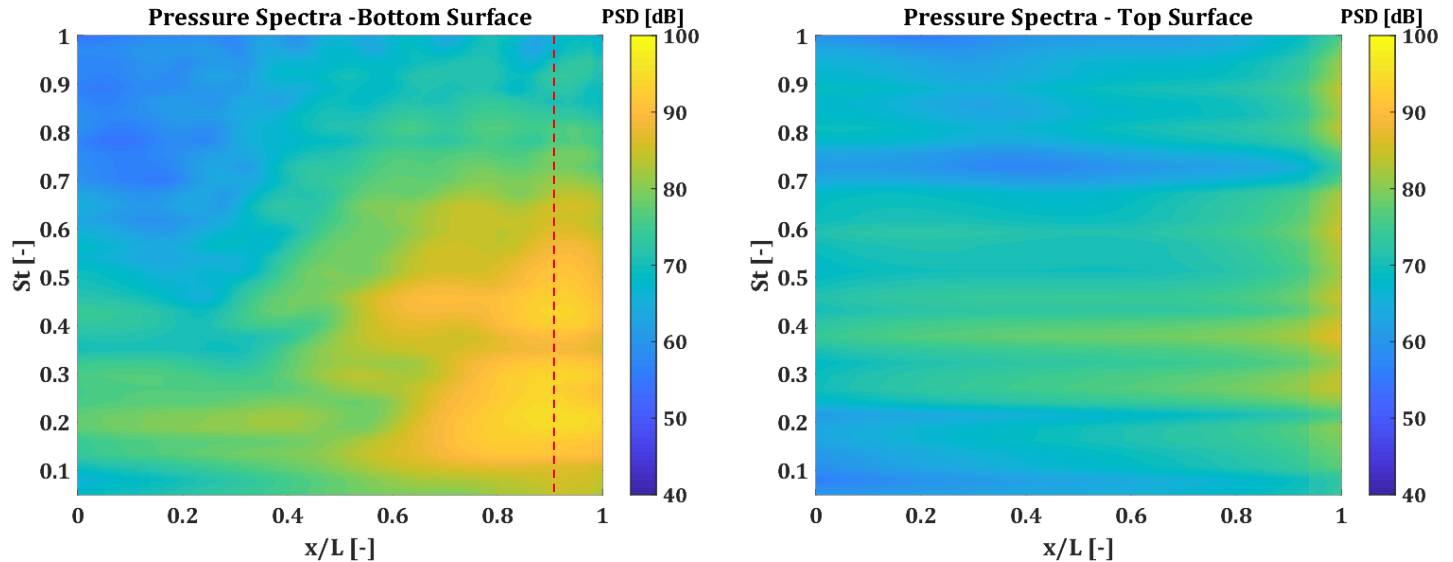
Time Derivative of Pressure Field

- 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;



Surface Pressure Fluctuations

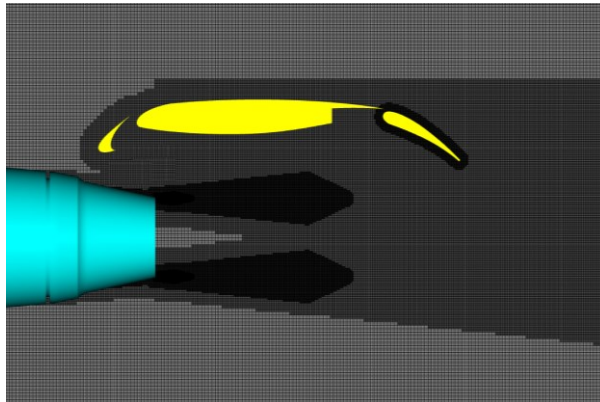
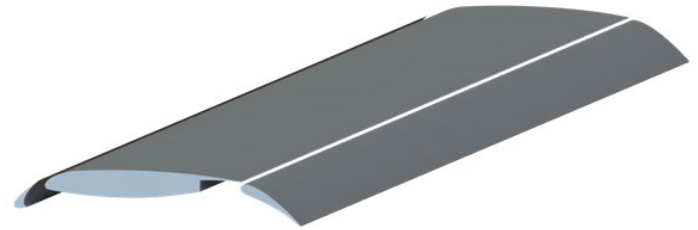
- Integration of pressure fluctuations at spanwise stripes;



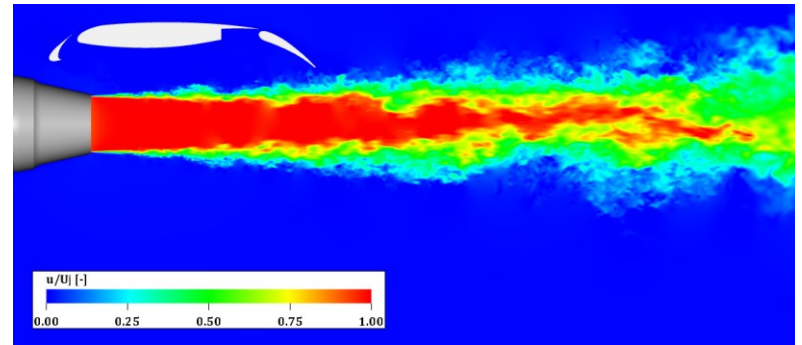
- On the reflected side of the surface, maximum fluctuations occur upstream of the trailing edge ($x/L = 0.91$);
- Destructive interference on the reflected side, between the convecting waves from the jet and the ones scattered by the trailing-edge (phase-shifted);

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.;

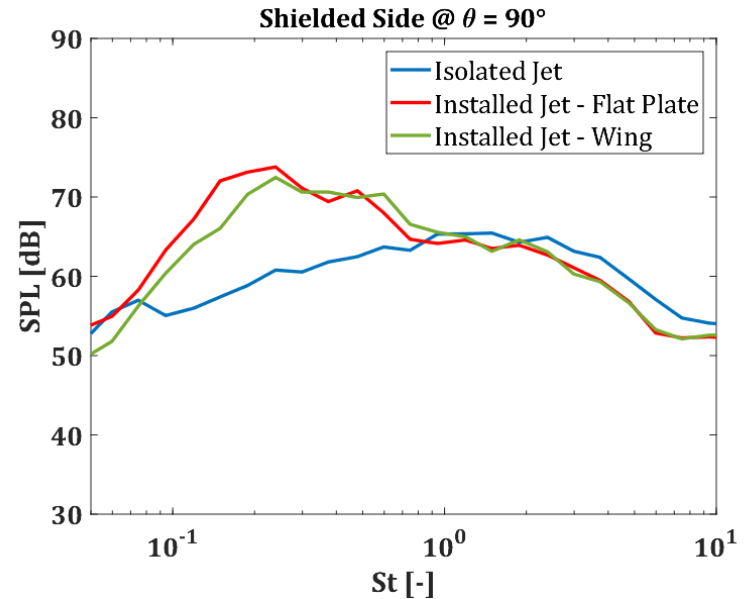
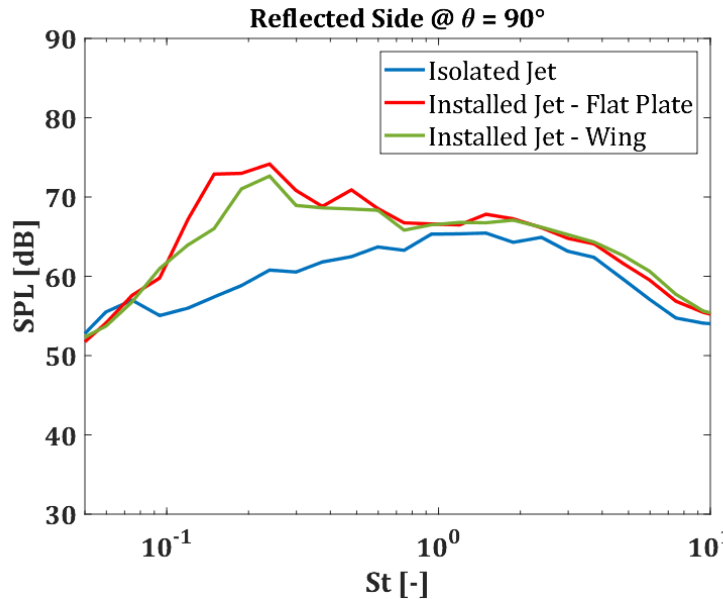


- Initial simulation: jet flow only;



Jet-Wing Model

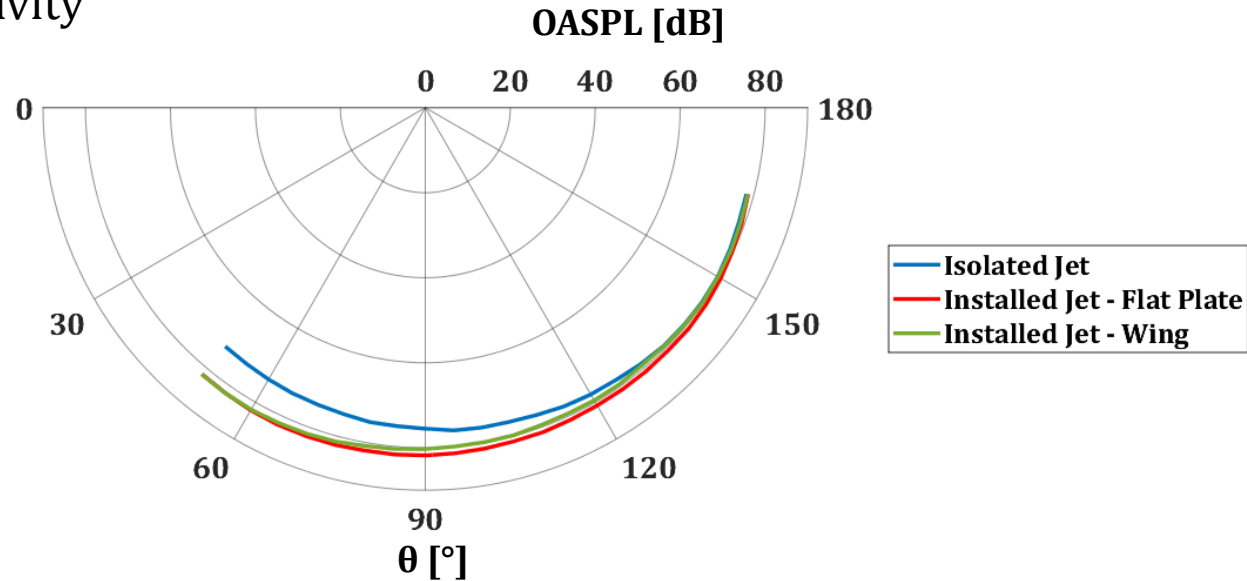
Far-field Spectra



- Similar spectral shape for flat plate and wing;
- Slightly lower noise levels for the wing case;

Jet-Wing Model

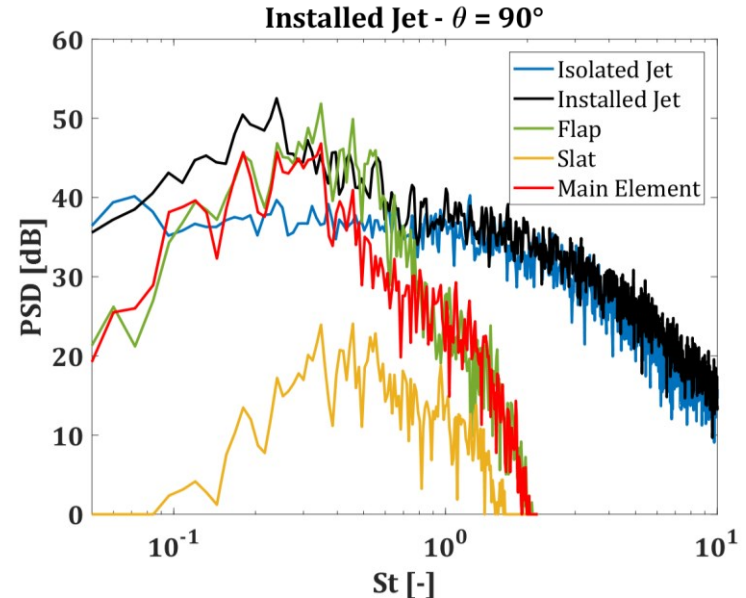
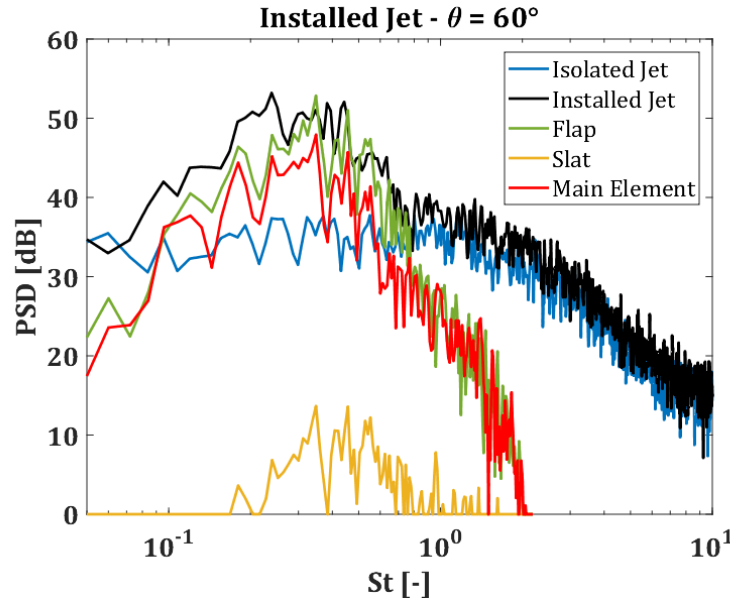
Directivity



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

Jet-Wing Model

Breakdown of Noise Sources

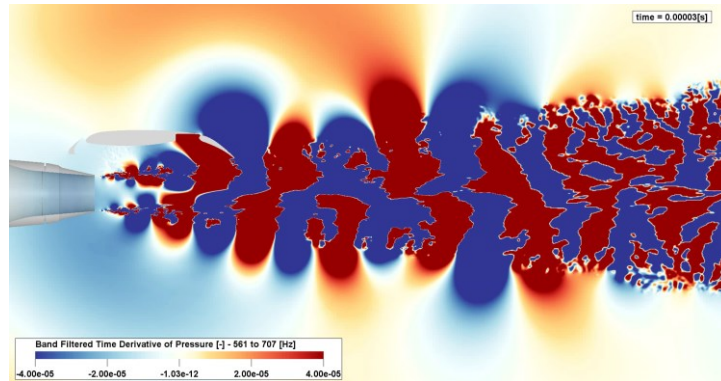


- The flap has the most pressure fluctuations in the entire geometry, followed by the main element;
- From $\theta = 60^\circ$ to $\theta = 90^\circ$, the slat levels increase, whereas the flap levels decrease at lower frequencies and the main element at mid frequencies;

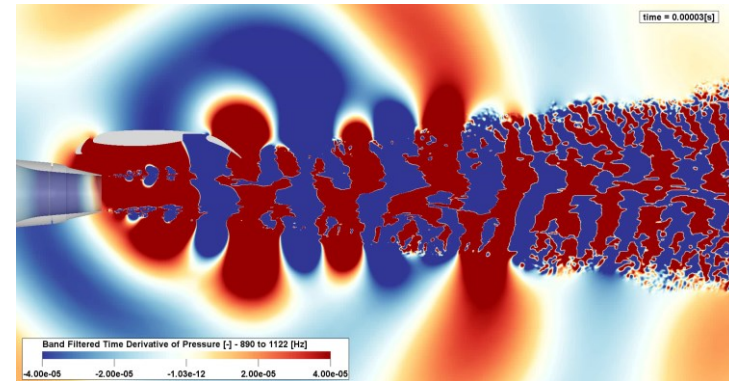
Jet-Wing Model

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;
- Replacing the surface with a wing geometry results in slightly lower sideline noise levels (change in directivity);
- The flap is responsible for most pressure fluctuations (scattering), but the main element also contributes to the overall noise;
- Treatment on airframe surfaces should mitigate jet-installation 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;