Case study

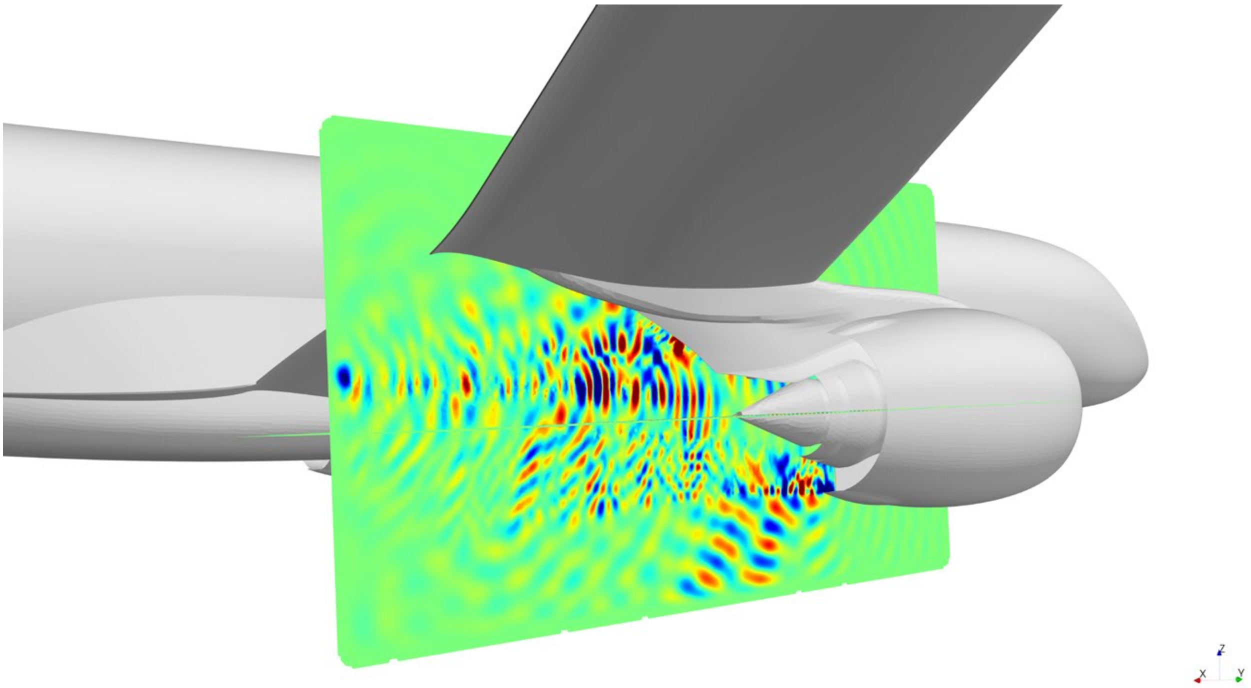
Tackling jet noise with the adjoint wave equations

Researchers extend Actran to perform advanced research

Researchers from Ecole Centrale Lyon of France have used Actran's Python API to extend the solver in an effort to develop new methods for predicting jet noise in aircraft.

At the forefront of aeroacoustic research for many years, Ecole Centrale Lyon of France and the Laboratoire de Mecanique des Fluids et d'Acoustique (LMFA) led by Professor Christophe Bailly have been constantly producing high quality research in close collaboration with companies such as Airbus and Safran. Working on fundamental research that can have significant impacts for industrial applications, researchers are continually developing, deriving, and extending mathematical models that can better predict the noise from jet engines around and aircraft.

Etienne Spieser, a postdoctoral researcher with the lab has been working on developing new jet noise models based on adjoint Green's functions that can more accurately predict the noise from a high subsonic jet similar to the exhaust of an aircraft engine when installed on a wing.



Visualisation of the exhaust noise of an aircraft

Challenge

"The acoustic radiation of a turbofan engine installed on an aircraft in service, differs greatly from that of an isolated engine" notes Mr. Spieser. While an isolated engine already presents many challenges due to the highly rotational outflow from the core of the engine, an installed engine can present even more complexities such as reflections with the wing pylon. Adjustments due to diffraction, jet blockage, or refraction on the shear layer only add to this challenge in addition to the interactions with the shielding area.

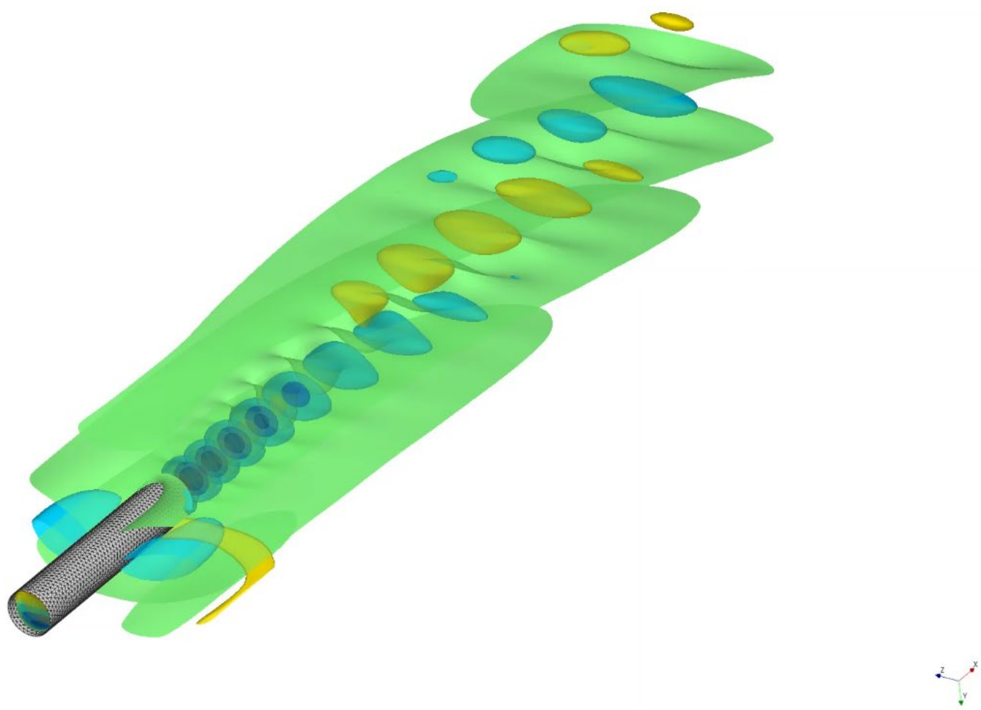
While the Actran turbomachine (TM) module excels when applied to the fan of the engine, finite element formulations may struggle to provide accurate predictions for exhaust noise due to the highly complex rotational flow and the size of the system when reaching high frequencies. As an alternative formulation to account for the complex flow, Actran DGM would be well suited for this purpose however, the amount of data required is extremely large.

Predicting the noise spectra by computing the adjoint Green's functions for the Pierce equation could help provide a better model for such problems. Green's functions are typically used to perfectly describe how a source propagates to an observer or microphone location. Unfortunately, Green's functions vary significantly for each problem and need to be recalculated whenever the geometry of the source changes. Furthermore, Green's functions typically cannot consider other objects that may influence the acoustic wave propagation between the source and the observer. This is where the adjoint Green's functions can help. By turning around the classic operator process where a source is propagated to an observer, the observer becomes the source that is propagating to the field. This is called the reciprocity principle for linear acoustics.

Solution

Even though they are similar in nature, the Pierce equation can provide a better representation of an acoustic wave in a high-speed flow (Mach 0.9), than the Möhring equation currently implemented in Actran. However, solving this equation through a finite difference code currently available at LMFA can prove challenging for considering objects within the flow. The Pierce equation can be retrieved by post-processing the mean flow and compensating for the source amplitude.

To do this, Mr. Spieser in collaboration with Hexagon's expert team, used Actran's built-in Python functions that enabled him to manipulate the equations in a finite element context; an approach that is better suited for industrial applications. "Actran's API is an indisputable asset of Actran TM opening many possibilities," notes Mr. Spieser. Using an industrial solver can have many



Jet noise visualisation based on the adjoint Green's functions

benefits especially when it comes to complex geometry and industry-established conditions such as perfectly matched layers (PML). By building the Pierce equation within Actran TM, Mr. Spieser was able to reduce the memory requirements from 43 GB to 1.7 GB, obtaining the same level of accuracy. By using Actran's extensible capabilities he was finally able to calculate the adjoint Green's functions required for calculating the noise spectrum at a 90° angle.

Results

By using the adjoint Green's function for the Pierce equation with the mixing noise model of Tam & Aurialt, Mr. Spieser was able to obtain the noise spectra for a series of Strouhal numbers, which is a non-dimensional number associated with wave frequency. The model is able to accurately predict nearly the entire spectrum of interest, retrieving the peak amplitude frequency and achieving good correlation with measurements performed by the lab.

Further investigations for other angles show that the model is promising but has trouble correlating perfectly with measurements because the Tam & Aurialt model does not account well for jet directivity. Future investigations will focus on an installed jet as Mr. Spieser notes "the tailored Green's functions are expected to greatly improve, taking into account of the acoustic propagation effects encountered."

Outlook

While this simple jet noise application (although there is no simple jet noise application!) has shown the promise of the approach, Mr. Spieser has already started working on applying it to even more realistic configurations. The high quality of the available data will definitely provide a boost that will help achieve even better accuracy at a lower cost.

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