X-noise workshop

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Industrial stakes and state of the art of aircraft broadband noise prediction

Outline

- Stakes of aircraft broadband noise prediction
- Airframe noise
  - Current prediction methods for aircraft design
  - Emerging prediction methods
- A few words on Fan and Open rotor noise
- Conclusion

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Introduction - Where does airframe noise come from ?

- Airframe Noise is one of the main aircraft noise source from commercial aircraft at approach.
- When a body is placed in a turbulent flow, eddies are distorted, which generates noise.
  It is much stronger with geometrical singularities and in accelerated flow area ***[Blake:1986]***
- **The air flow speed is a key driver (sound intensity ~ V^6 approximately)**
- Main airframe noise sources on commercial aircraft are :
  - Wing Systems including High lift devices (slats and flaps)
  - Landing gears
  - Airbrakes
  - Cavities or protuberances on airframe producing possible parasitic airframe noise sources, but mainly tonal

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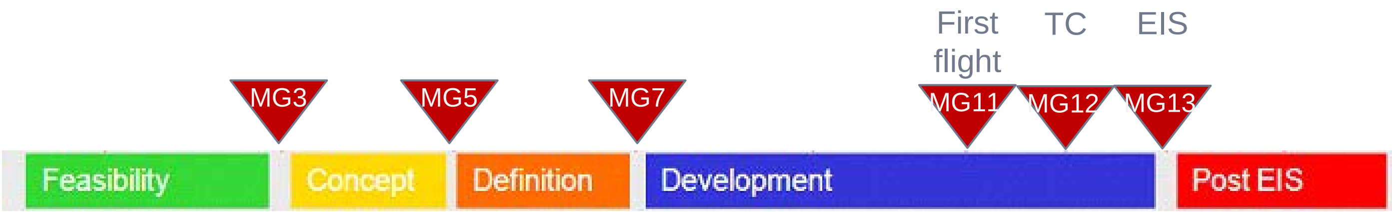
Airframe noise – History of aircraft airframe noise studies at Airbus



There is a growing importance of airframe noise during aircraft development

A320

A340

Flight test measurements + semi-empirical method developed afterwards + troubleshouting

A340-600

+
prediction prior to flight test measurements

A380

+
WTT and CFD
+ Design to noise

A350XWB

+
Trades during feasibility and concepts phase

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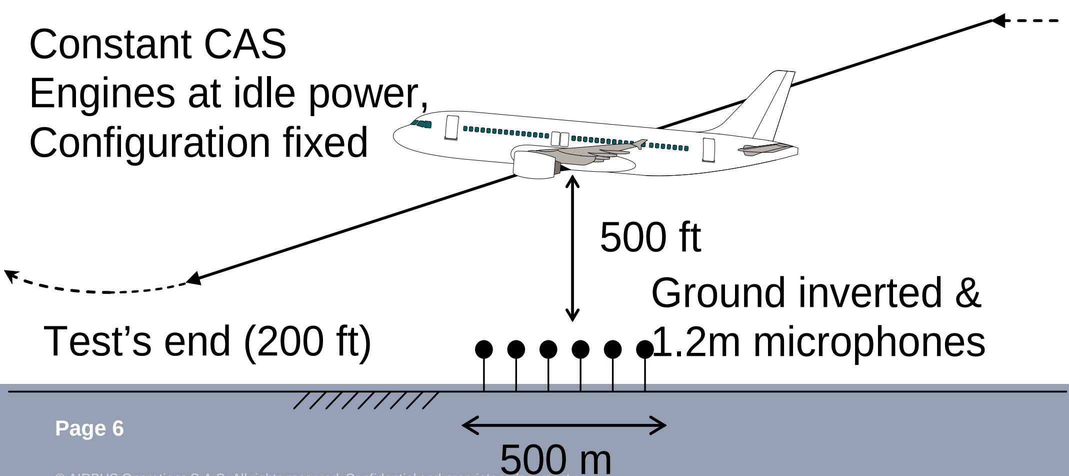
Airframe noise estimation – Noise flight tests

- Specific flight tests are performed by AIRBUS in Tarbes or Moron airports
- Different configurations: slats only, flaps only, slats & flaps both deflected, landing gear retracted or extended
- Airframe noise is extracted: data are corrected for engine noise and projected on a reference approach flight path at standard atmospheric conditions.



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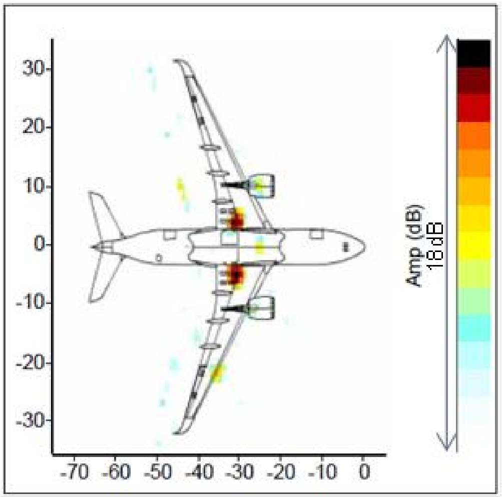
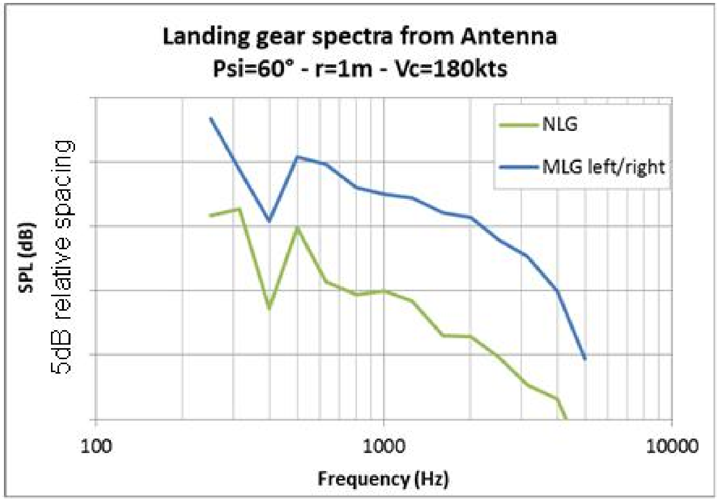
Airframe noise estimation – Noise flight tests

- Use of microphones array allows
  - determining location of parasitic noise sources easily
  - Estimating the noise levels of individual noise source

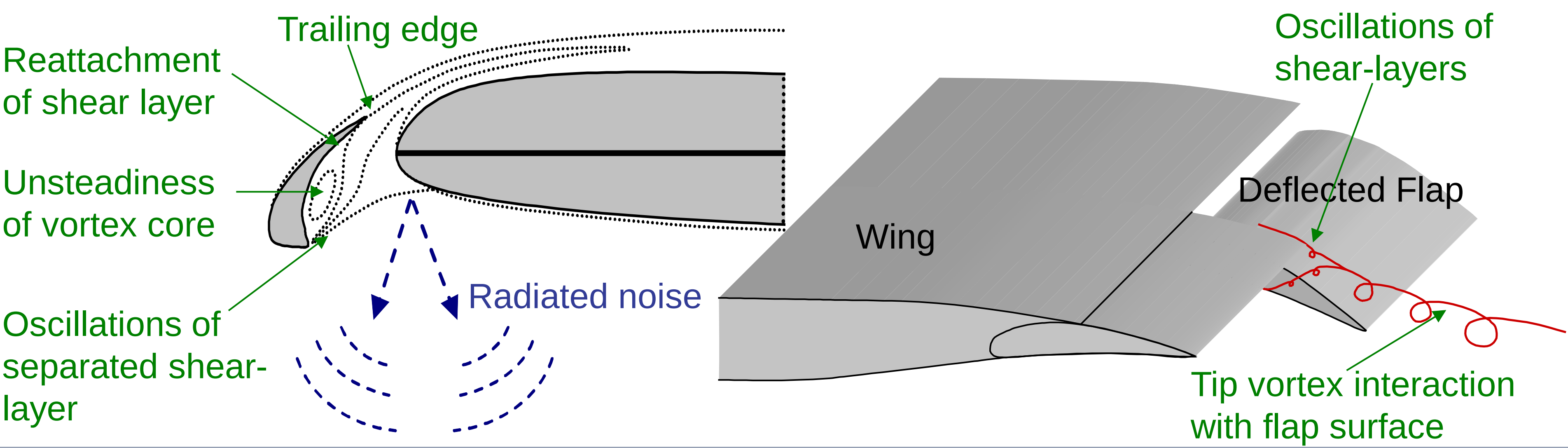




Example of noise map and noise spectra estimated with microphone array for some specific noise sources

Airframe noise estimation – HLD noise sources

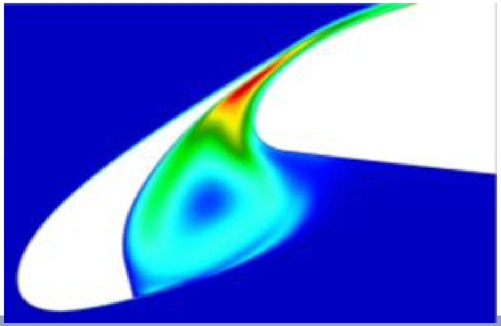
- The Slat and Flap Noise Mechanisms are complex, with a mix of various phenomenon:
  - Trailing edge noise
  - Free shear layer vortex flow and reattachment
  - Unsteadiness of vortex core
  - Oscillations of shear layers, close to the ridges for 3D flap noise
  - Interaction of the tip vortex with the flap suction side surface for 3D flap noise



Airframe noise estimation – HLD noise sources

- Definition of simplified equivalent sources (with the use of wall-pressure measurements), tractable with analytical modeling, such as:
  - Turbulent flow - leading edge interaction noise estimated with Amiet's model
  - Trailing edge noise estimated with Howe's trailing edge noise model
  - Flap side edge noise (shear layer oscillations) estimated with Brooks' model
  - Turbulent flow over the gap between the flap and an undeflected trailing edge estimated
    - Details of these models can be found in AIAA papers 2000-2064 and 2003-3225 from Molin and Roger
- Input data for these models are determined either with dedicated with tunnels tests or using CFD results

Velocity



Turbulent kinetic energy

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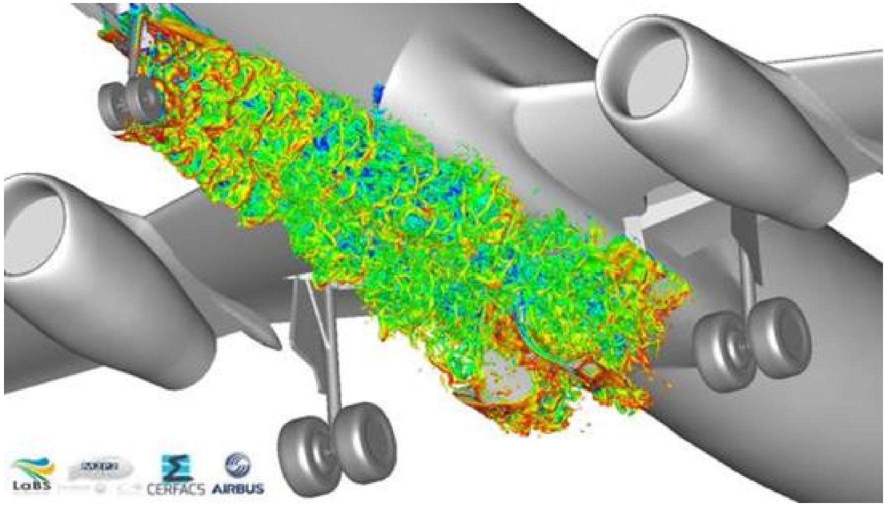
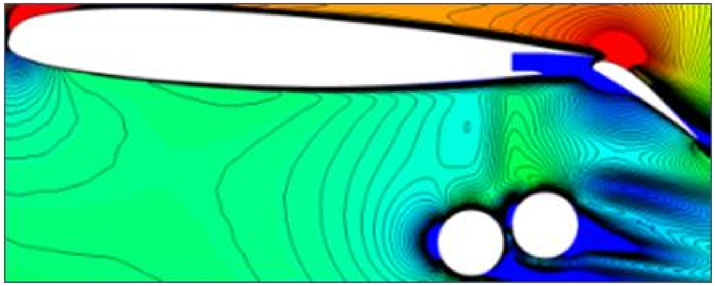
Airframe noise estimation – LG noise sources

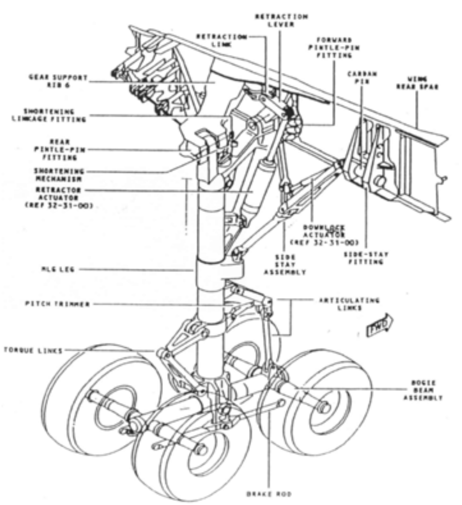
- Landing gear broadband noise is generated from
  - Turbulent flow separation from landing gear structural elements (wheels, legs, struts, stays, …)
  - Interaction of such turbulent wake with downstream gear elements
- All LG components produce noise, whatever its size
- The high-lifted wing circulation strongly modify the landing gear noise

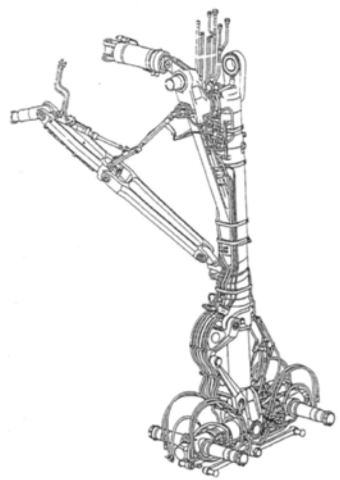




Airframe noise – LG noise – current method

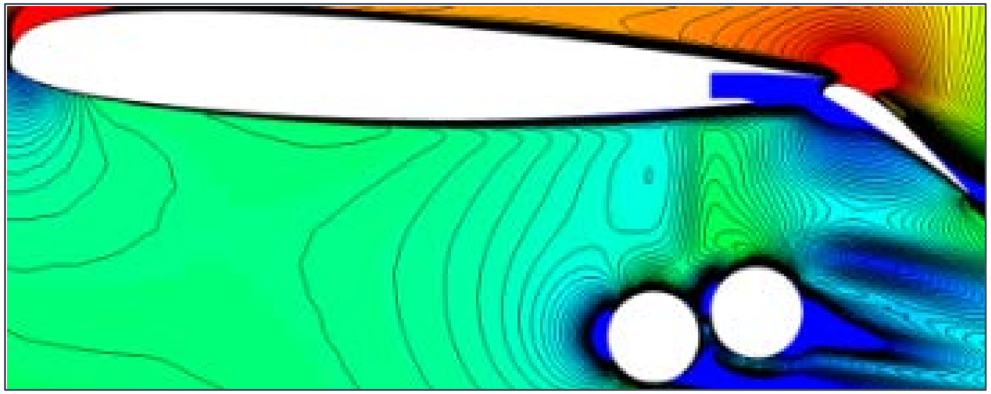
- The prediction model decomposes landing gear components into main categories of noise sources: the wheels, the primary structure, the secondary structure and tyre wake interaction
- The basis is to use empirical constants to fit standard source characteristics to particular components, such as legs, struts, wheels…, using Curle’s theory for acoustically compact sources
  - Details of these models can be found in AIAA papers 1998-2228 and 2002-2581 from Smith and Chow





Airframe noise – LG noise – current method

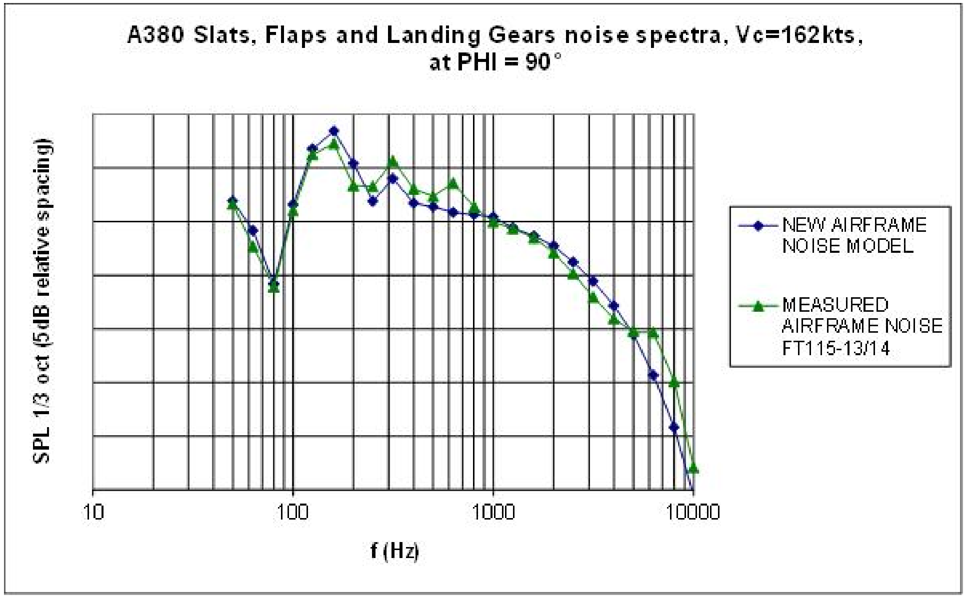
- The effect high-lifted wing circulation on LG noise is accounted for, using either:
  - Flight test data
  - Wind tunnel test data
  - CFD data

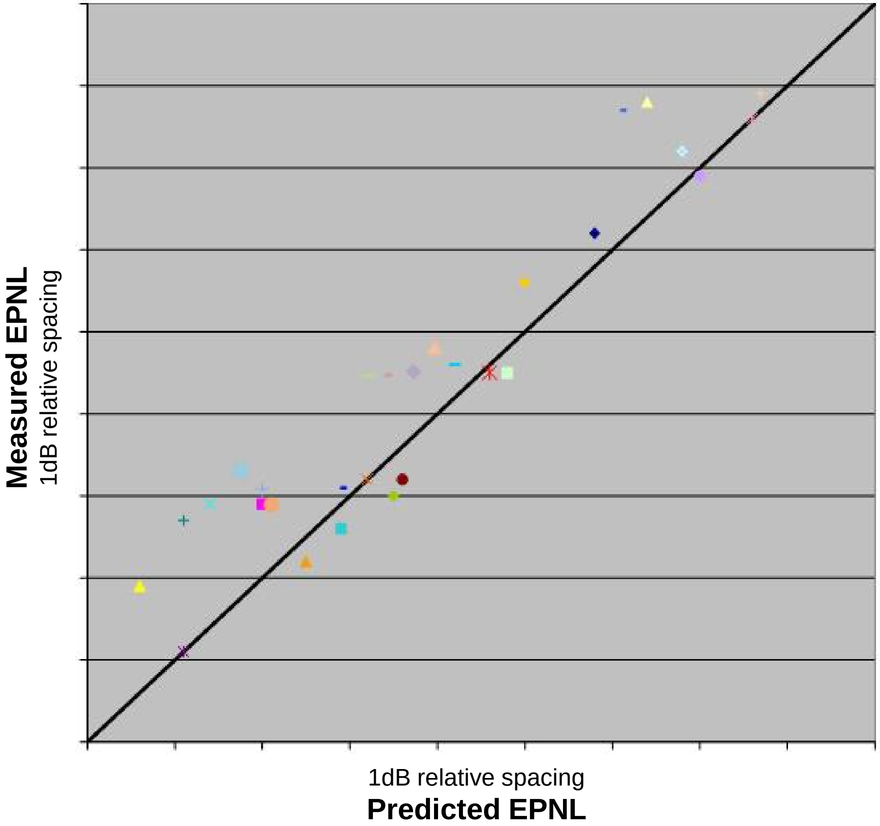


Velocity ratio

Airframe noise – HLD + LG current method – validation

- The current airframe noise model has been calibrated with airframe noise flight test.
- The associated uncertainty is approximately 0.5EPNdB.





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Airframe noise – Emerging methods : research strategy

Continuous research effort on emerging methods, for both HLD & LG, pursued along 2 complementary paths :

- **Mid-Fidelity / fast turnaround time approaches, required to be**
  - As accurate as current prediction methods
  - Delivering fast (Setup & run within 1 day)
  - Better versatility wrt geometrical configurations, still classical concepts

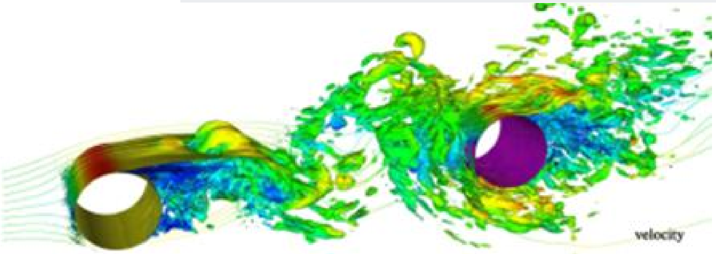
- **High-Fidelity / longer turnaround time approaches, required to be**
  - More accurate than current prediction methods
  - Delivering not necessarily fast (Setup & run within weeks)
  - Fully applicable on any geometry, including very innovative concepts.
  - Enabling physical understanding of physical phenomena

This is mandatory to fulfil needs during aircraft design phases

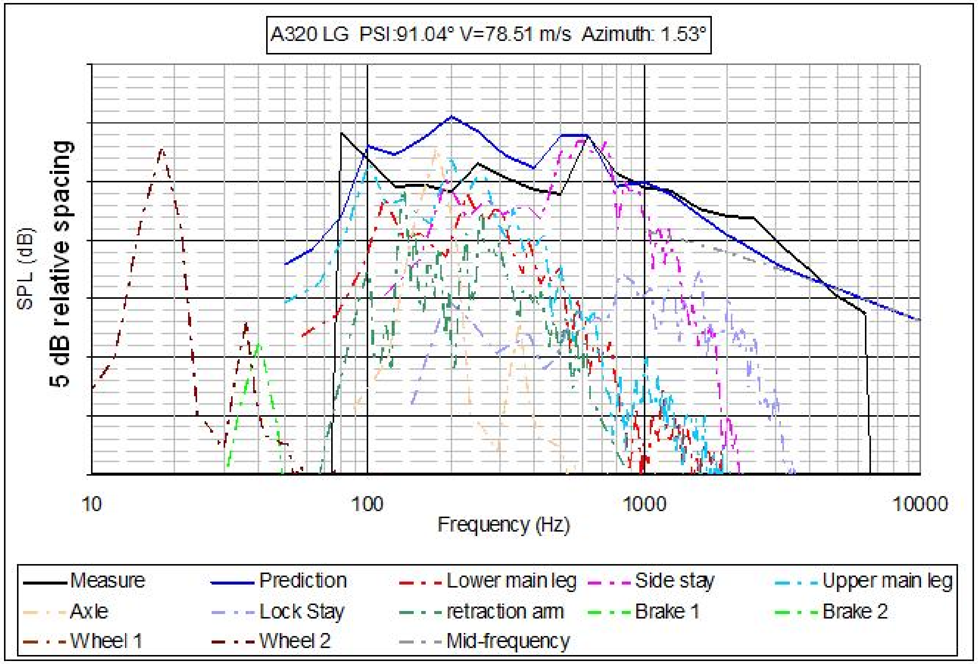
Airframe noise – Emerging methods LG: Mid-Fidelity / fast turnaround time

Component-based noise prediction model PHYSICS from UoS

- The landing gear is decomposed in a series of basic elements
- DES performed on components to obtain unsteady flowfields around a series of given elements.
- FWH solver used to extract farfield acoustic and directivity information for these components & build database.
- Acoustic scaling laws used to scale components of different sizes and yield noise emitted :
  - The frequency is scaled with Strouhal number.
  - The acoustic pressure squared is scaled with Curle's law.
- Planned for use in aircraft development in 2 years



(Courtesy of ANTC – University of Southampton)



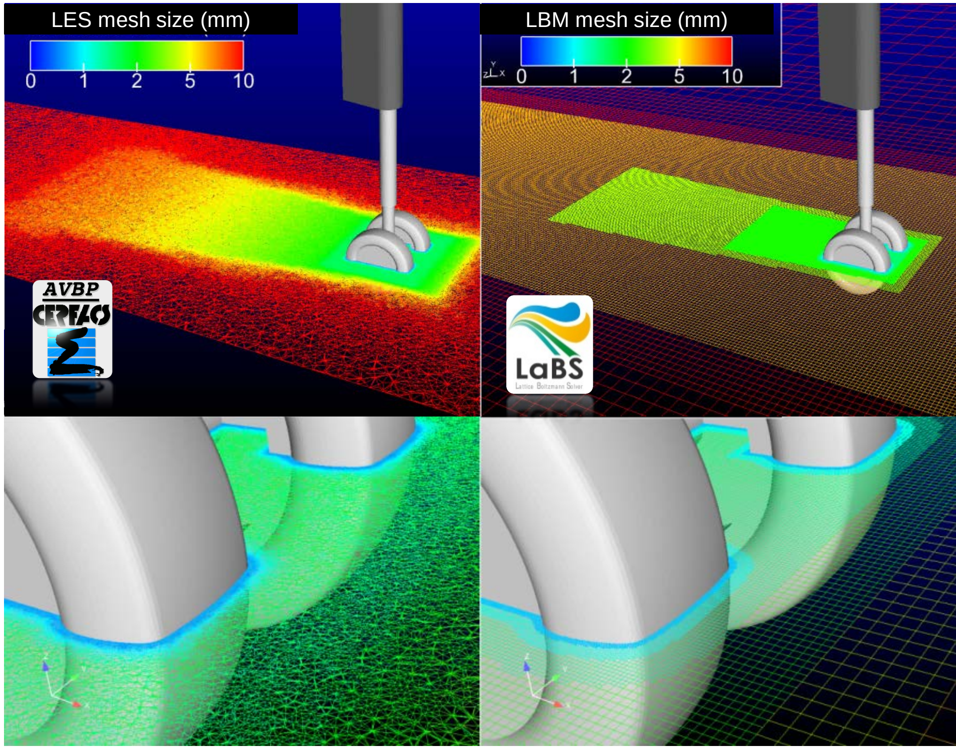
Airframe noise – Emerging methods LG: High-Fidelity / longer turnaround time

High order unsteady CFD is the most promising way to represent noise generating phenomena accurately

- Large Eddy Simulation is the classical approach (LES solver *AVBP*)
  - Very accurate results (thanks to low numerical dissipation/dispersion) **[Giret_AIAA2012]**
  - Very mature approach
  - But long meshing & computation phases, even on massively parallel cluster

- Lattice Boltzmann Method is the challenger (LBM solver *LaBS*)
  - Also very accurate results (for low Mach)
  - Approach not yet so mature
  - 10x faster setup & computations (thanks to immersed boundaries & octree meshes)

➔ LBM seems a better option



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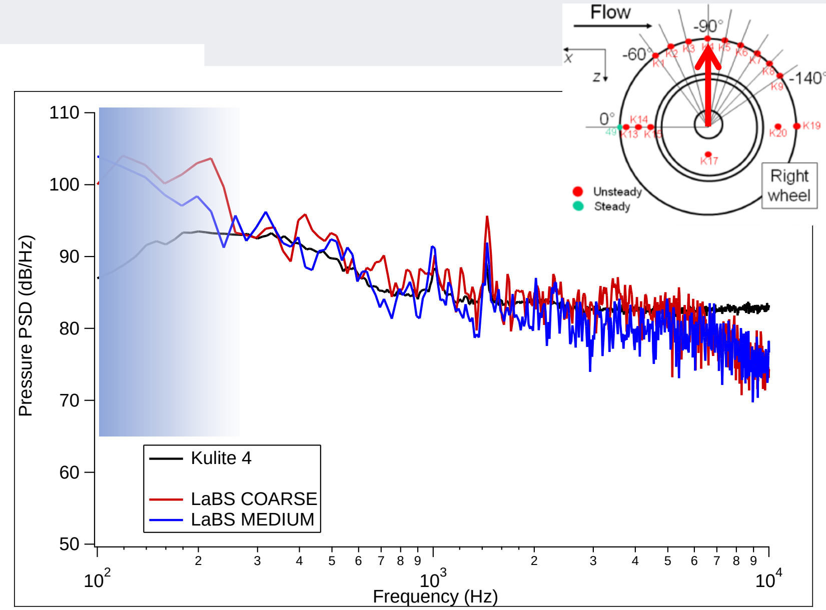
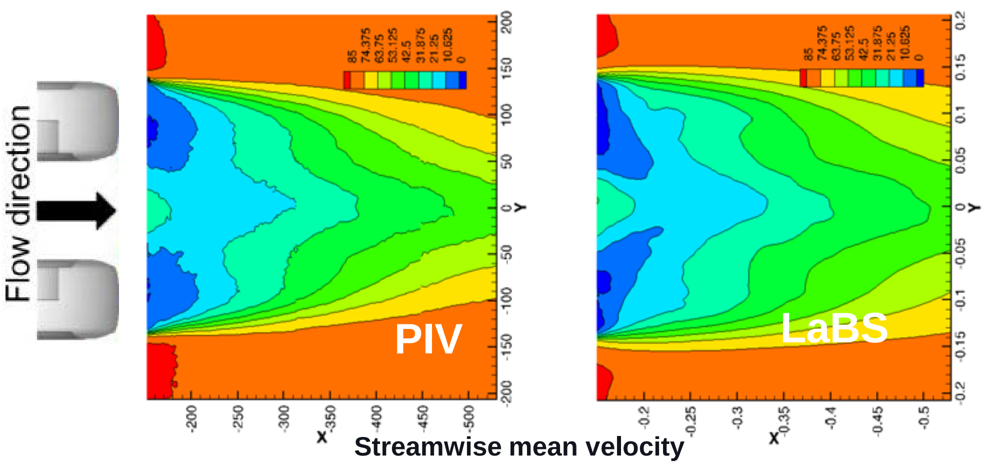
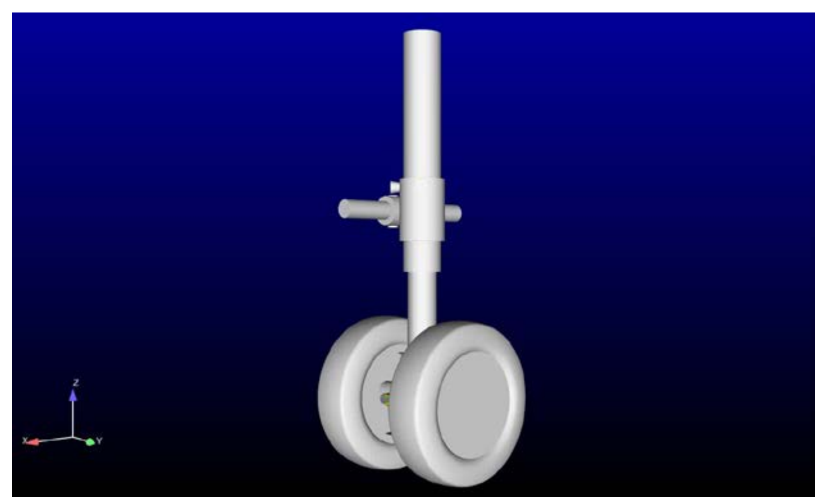
Airframe noise – Emerging methods LG: High-Fidelity / longer turnaround time

- Evaluation ongoing at Airbus on LAGOON test case:
  - Very promising results on flow (mean & RMS fluct.) and wall PSD **[Sengissen_AIAA2015]**
  - Direct prediction of noise using FWH coupling is ongoing
- Already applicable to
  - Capture the detailed physics of the flow, and help understanding noise generating phenomena.
  - Give guidelines for designing low noise solutions
- Possible use for direct noise predictions in the frame of an aircraft developement forseen in about 3 years

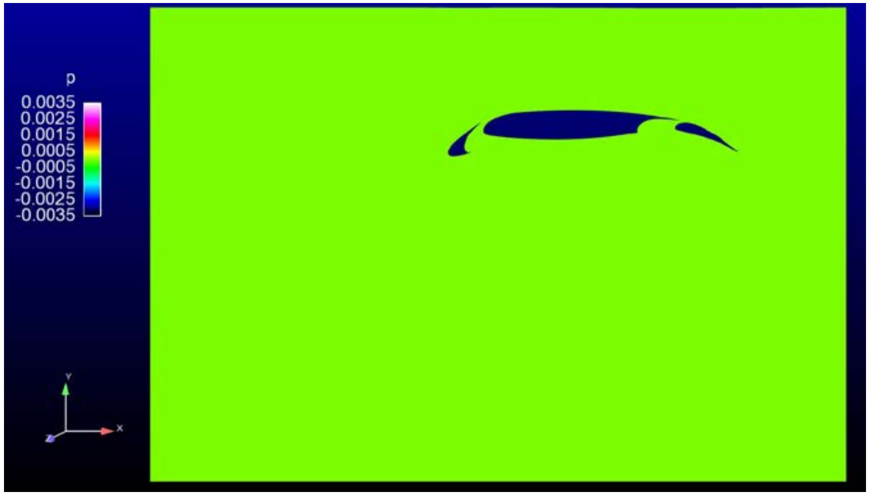






Sengissen et al., *Simulations of LAGOON landing-gear noise using Lattice Boltzmann Solver*, AIAA2015-2993

Airframe noise – Emerging methods HLD Mid-Fidelity / fast turnaround time

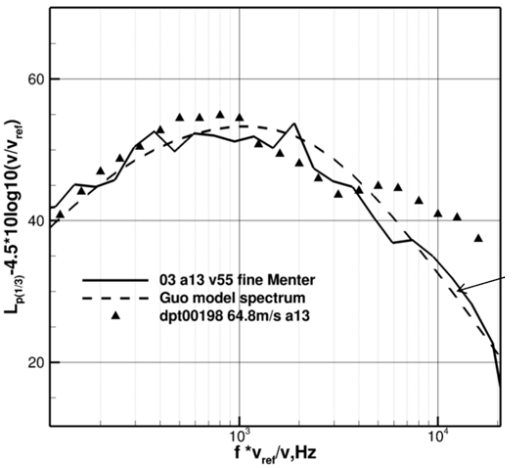


Methods based on linearized Euler Equations, and variants (APE) : solver Piano

- Stochastic fluctuations reconstructed from RANS, method called Random Particle Mesh (RPM) **[Ewert_AIAA20**]**
- Source terms injected in APE or LEE for propagation/ diffraction by the airfoil

Comparison to WTT measurement

- Quite fast turnaround times
- Some promising result with respect to velocity effect
- But still better maturity and validation required (in particular on parameter effects: velocity, AoA…) to fulfill needs before use for aircraft development

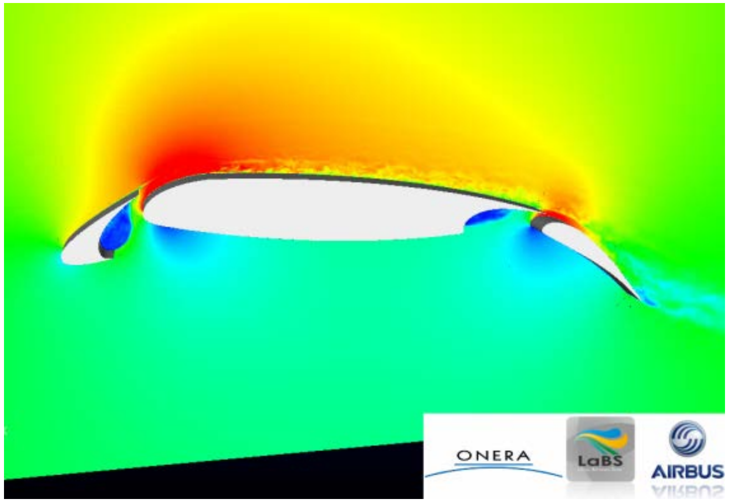


Airframe noise – Emerging methods HLD High-Fidelity / longer turnaround time

High order unsteady CFD is also very promising, even if unsteady attached flows are difficult to represent.

Lattice Boltzmann Methods :

- Assessment in progress with LaBS
- Very promising results already obtained by Exa with PowerFlow
- Could reach maturity for use in aircraft development by 4 years



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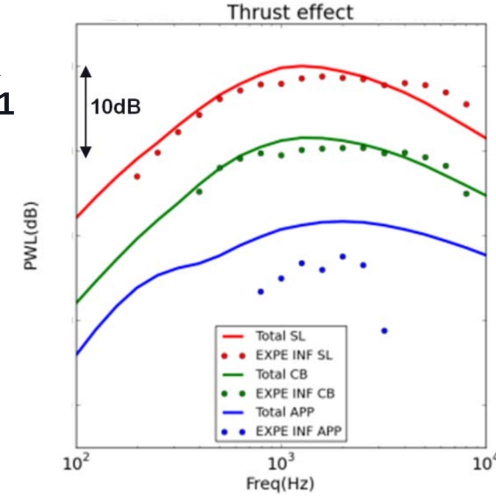
A few words on Fans & Open Rotors

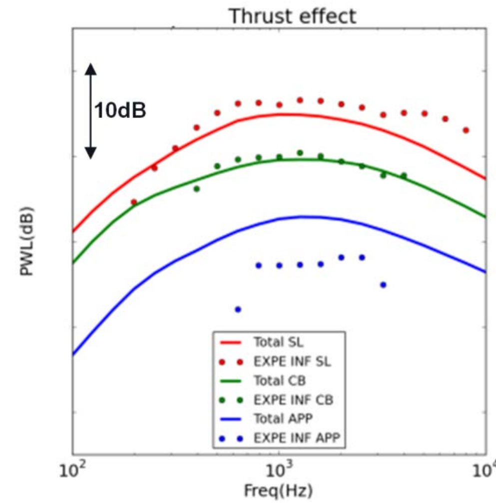
- Situation similar as for airframe noise
- Semi-analytical methods informed by RANS CFD computations show good results and can be used for design optimisation
  - But they cannot predict all 3D geometry effects due to their simplifying assumptions

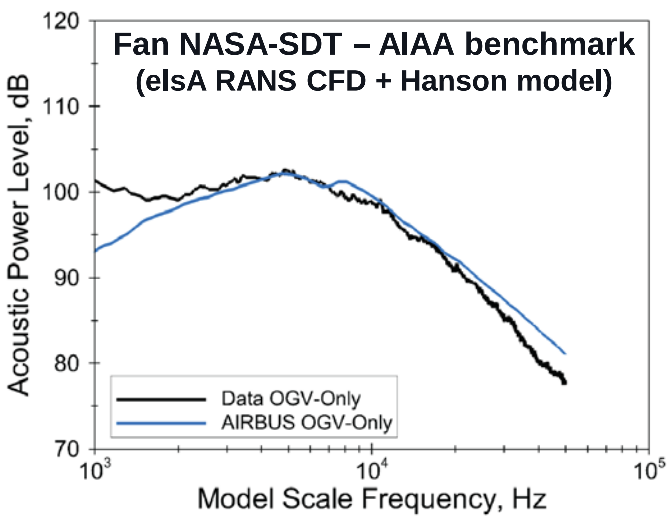
CROR design1



elsA RANS CFD + Amiet model

CROR design2

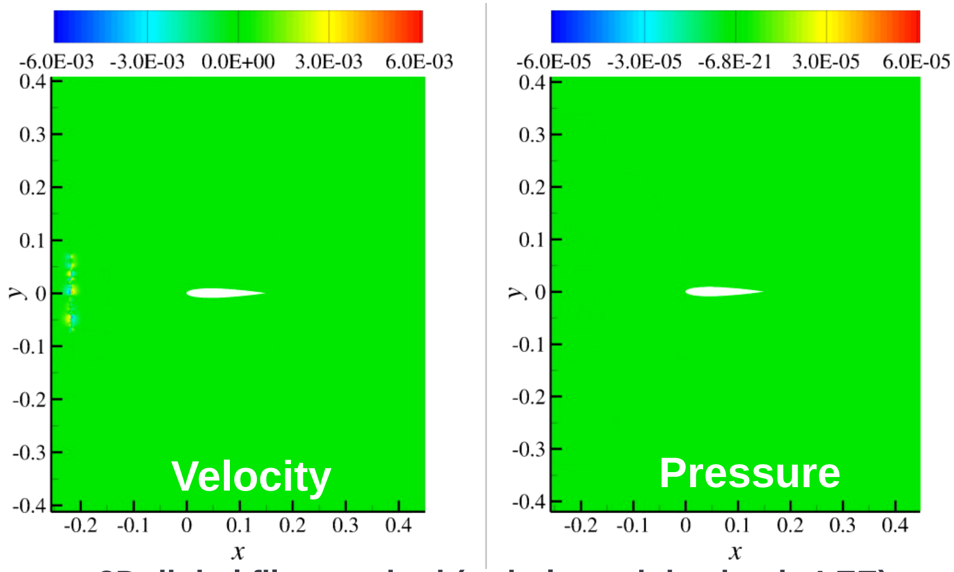




A few words on Fans & Open Rotors

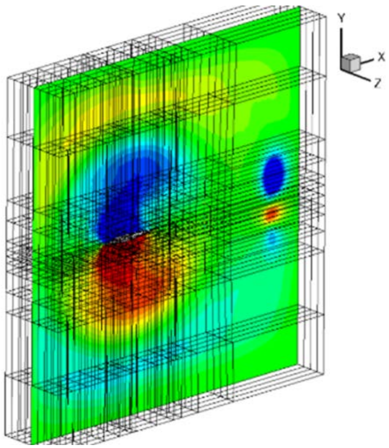
- Same high fidelity methods as for airframe can be used :
  - Stochastic methods: digital filters, RPM
  - DES for wake interaction noise
  - LES, LBM for all sources
- But high speed rotors present additional difficulties :
  - High Mach numbers (issue especially for LBM)
  - Thin boundary layers => very dense meshes required for TE noise and small time steps
  - Rotating meshes => sliding planes or chimera technique
  - Unsteady background flow for stochastic methods
- First results on complete 3D configurations emerging this year (LBM, DES)…

  => AIAA BBN prediction benchmark



2D digital filter method (turbulence injection in LEE)

3D digital filter method



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Conclusion - Pros and cons of each method

Methods	Cost	Quickness	Representativity of existing concept	Capability to predict future concept
Flight test	---	-	+++	NA
Large scale wind tunnel test	--	---	++	++
Small scale wind tunnel test	-	-	+	+
Full unsteady CFD/CAA	-	+	++	++
Stochastic	+	++	+	+
RANS-informed analytical, or component-based	++	+++	+	-
Semi-empirical	+++	+++	+	--

All methods will continue to co-exist in a near/medium future

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