Combustion noise investigation in helicopter engines

2005~2015 a European history …

FRIENDCOPTER TEENI RECORD

E.Bouty

09/03/2016

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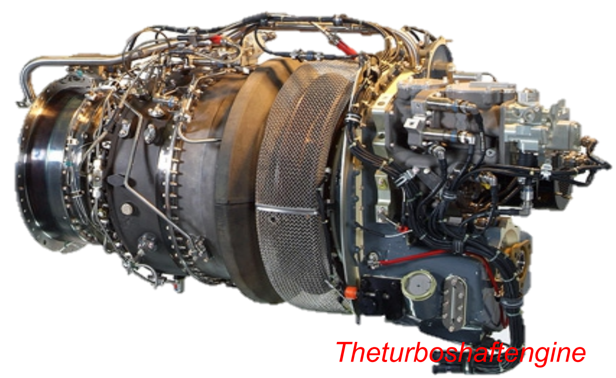
CONTEXT

- Noise sources on a helicopter are multiple and cover a *wide* frequency range !



- Reducing rotors noises leads to increase relative contribution of the engine.
- Acoustic certification (in-flight) limits will become more stringent

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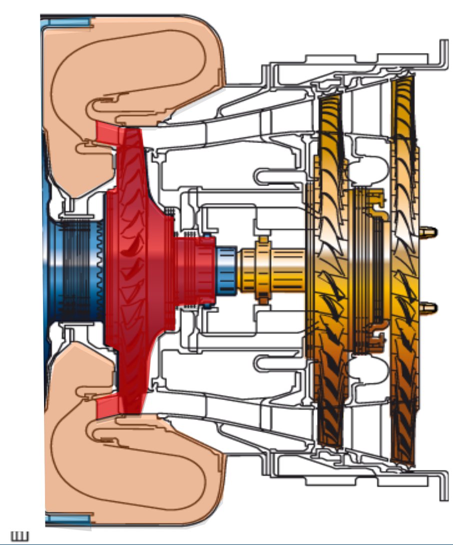
A TURBOSHAFT ENGINE : ARDIDEN

Annularcombustionchamber

- *RQL burners*
- *Turbulent combustion Air/Kerosene*
- *Low-frequency & broadband noise generation*[5]



This study focuses on

downstream, low frequency radiated noise, coming from

combustion chamber.

(Exhaust speed is so low that jet noise is neglected)

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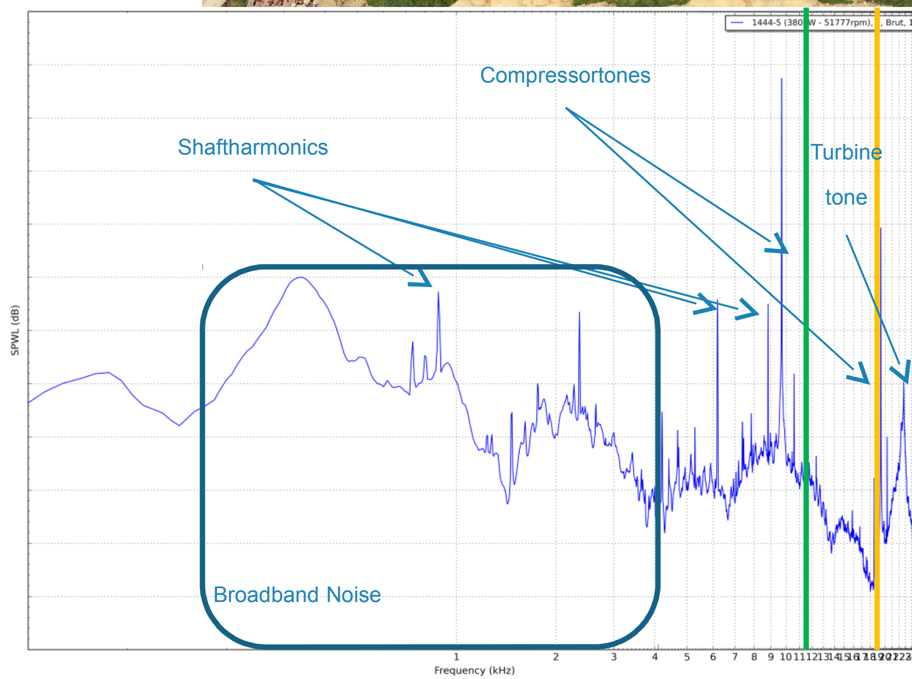
Noise signature of a turboshaft engine « alone »

- Turbomeca has an open-air test bed located at Uzein (close to Pau airport)

- … and the capability of producing certification-quality measurements

- Typical noise Turboshaft engine spectrum



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NOISE SOURCES WEIGHT IN FLIGHT:

THE FRIENDCOPTER PROJECT (2005~2008)

- **Treatingexhaustpipes onbothengineson EC135**

→BENEFIT : 1.2EPNdB@ T/O

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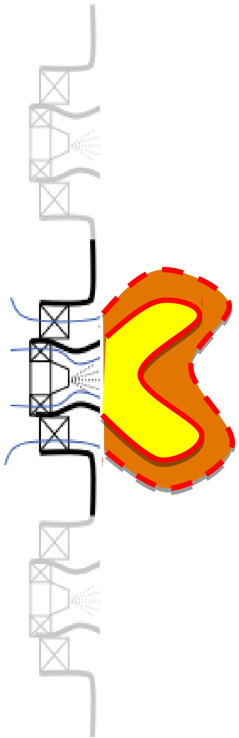
WhatisCombustion Noise ?

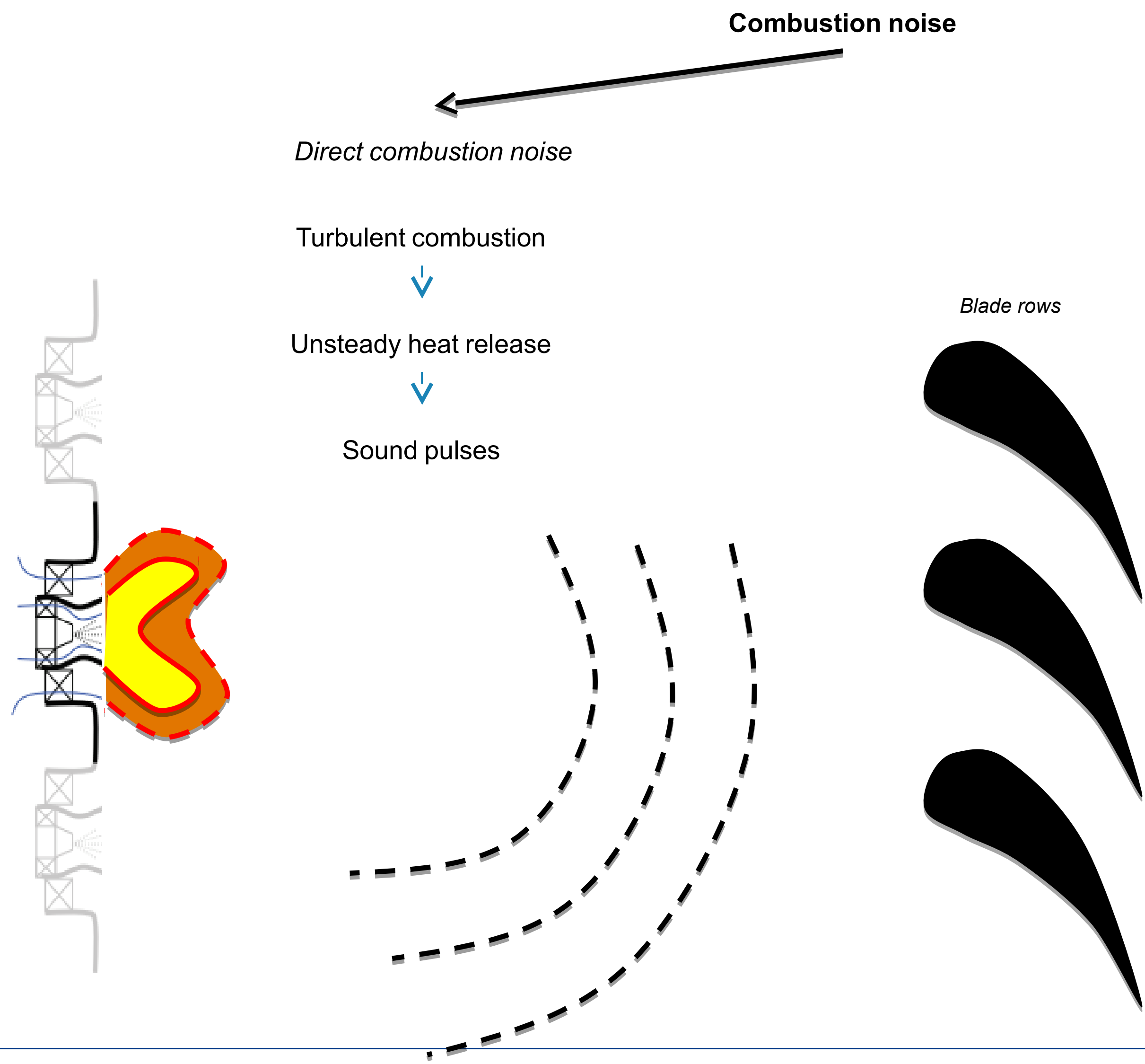
Combustion noise

Direct combustion noise

Indirect combustion noise



WhatisCombustion Noise ?



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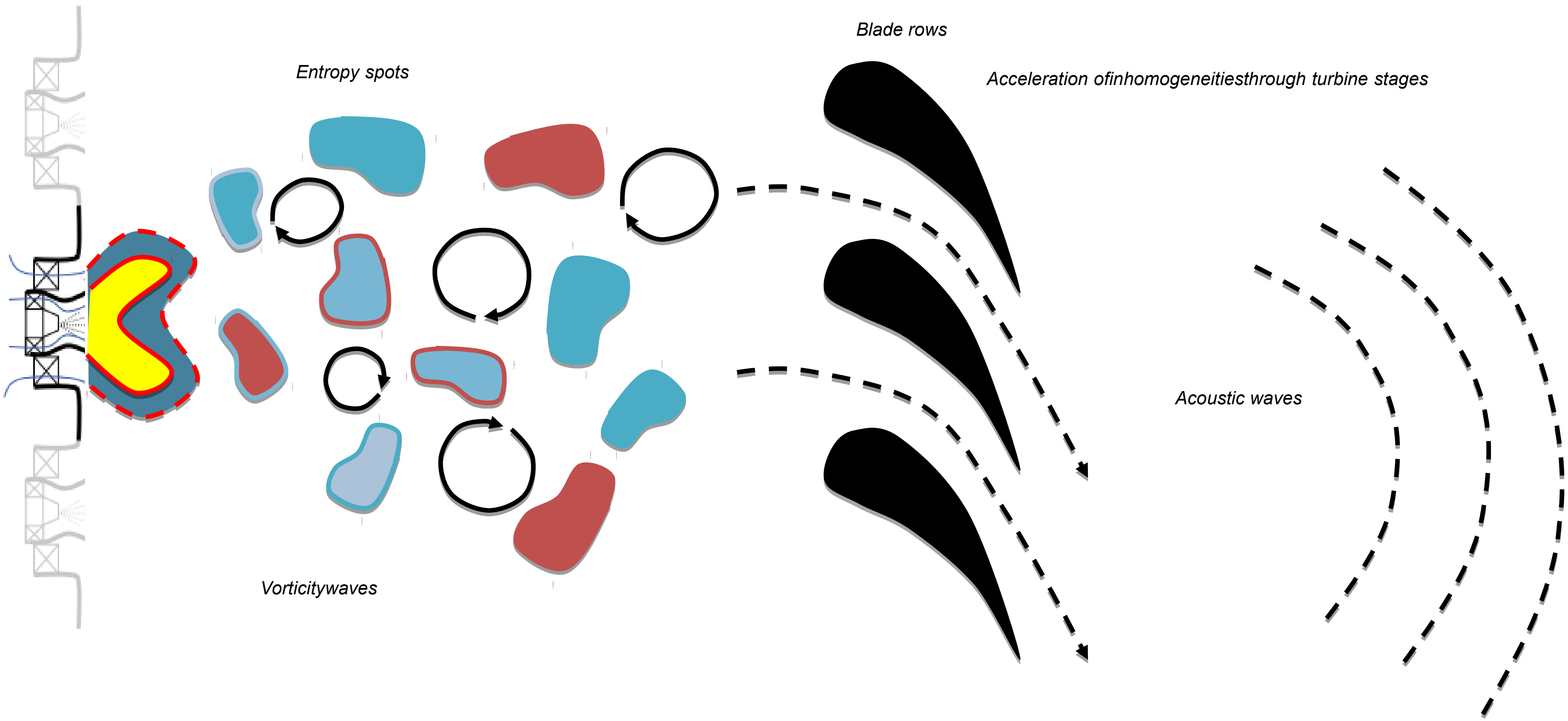
WhatisCombustion Noise ?

Combustion noise

Indirect combustion noise



COMBUSTION NOISE KNOWLEDGE

Combustionnoise wasfully investigated in academic cases

Direct noise

- Free-field turbulent and laminar flames where reactive zones can be acoustically seen as a collection of sound pulses[1,2]
- Acoustic
- Phenom

Indirect noise

- Noise generation through a 1-D subsonic and supersonic nozzles using a compact assumption and frequency dependent formulation[7,8,9].
- overall noise

Howto evaluatecombustion noise levels in a real aero-engine from the combustion chamber to the far-field ?

[1]Strahle, J. Fluid Mechanics,1972
[2]Talei, J. Fluid Mechanics, 2011
[3]Hassan, J. Fluid Mechanics, 1974
[4] Chiu and Summerfield,ActaAstronautica, 1974
[5]Baillyat al., Int. J. ofAeroacoustics, 2010
[6] Bragg, J. Inst. of Fuel, 1963
[7]Rajaram, AIAA Journal, 2006

[7] Marble andCandel, J. Sound andVib., 1977
[8] Giauque et al., J. Eng. Gas Turbines Power, 2012
[9] Duran et Moreau, J. Fluid Mechanics 2013
[10] Bake et al., J. Sound andVib., 2009

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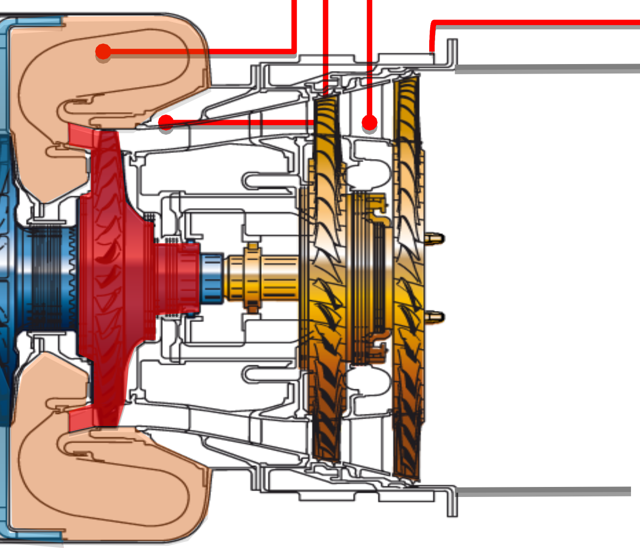
Experimental investigation:

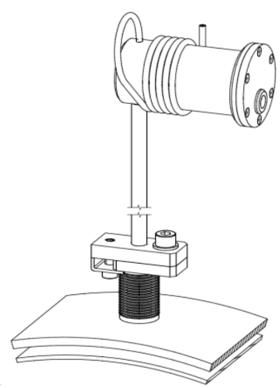
TEENI project (2009-2013)

➔ Purpose : simultaneous measurement of internal and external sensors

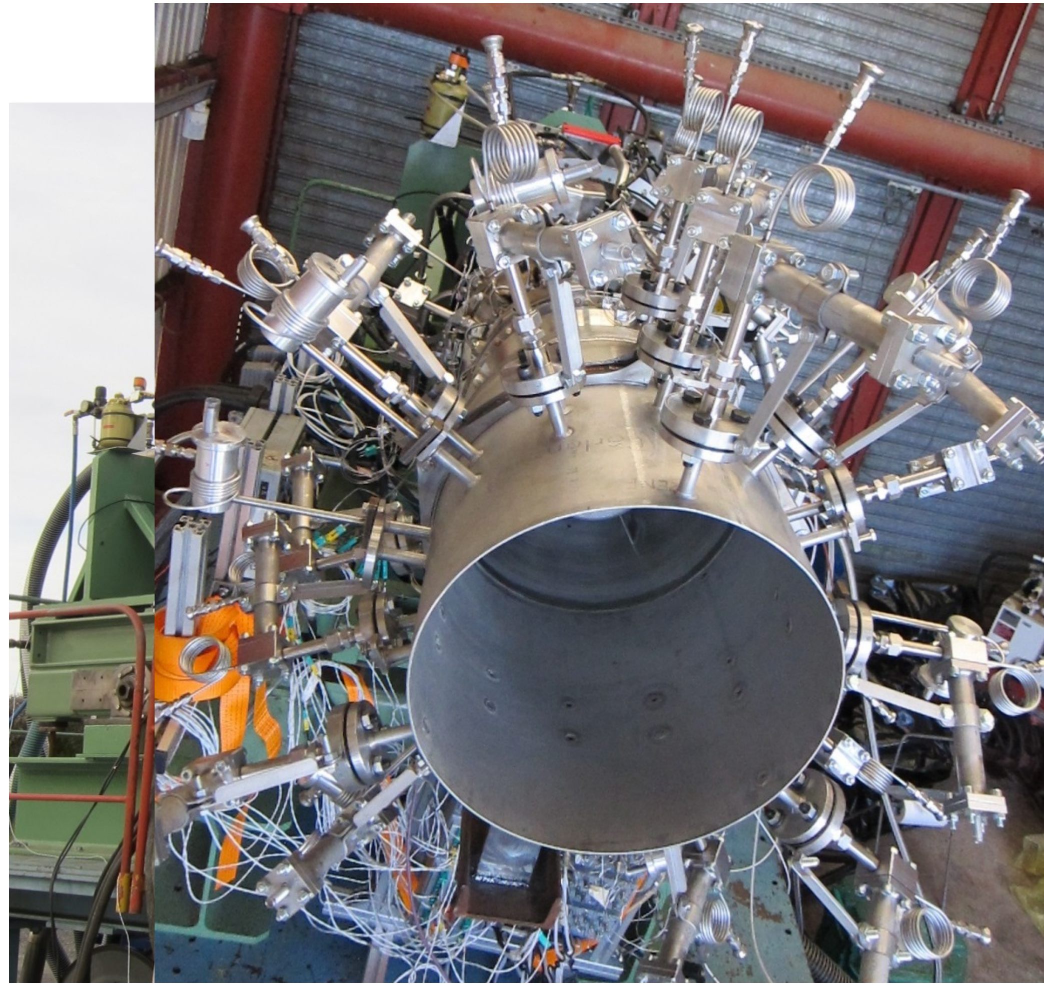
Unsteady pressure probes

- *combustion chamber (2)*
- *High-Press. turbine (2)*
- *Power turbine (2)*
- *Nozzle (30)*





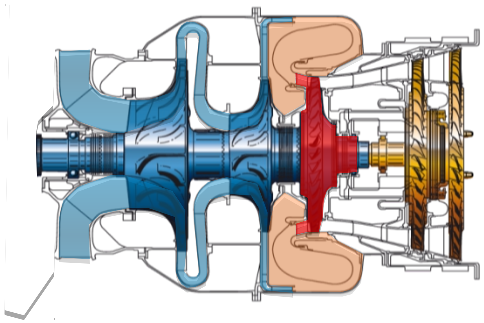
Pressure probe designed by DLR



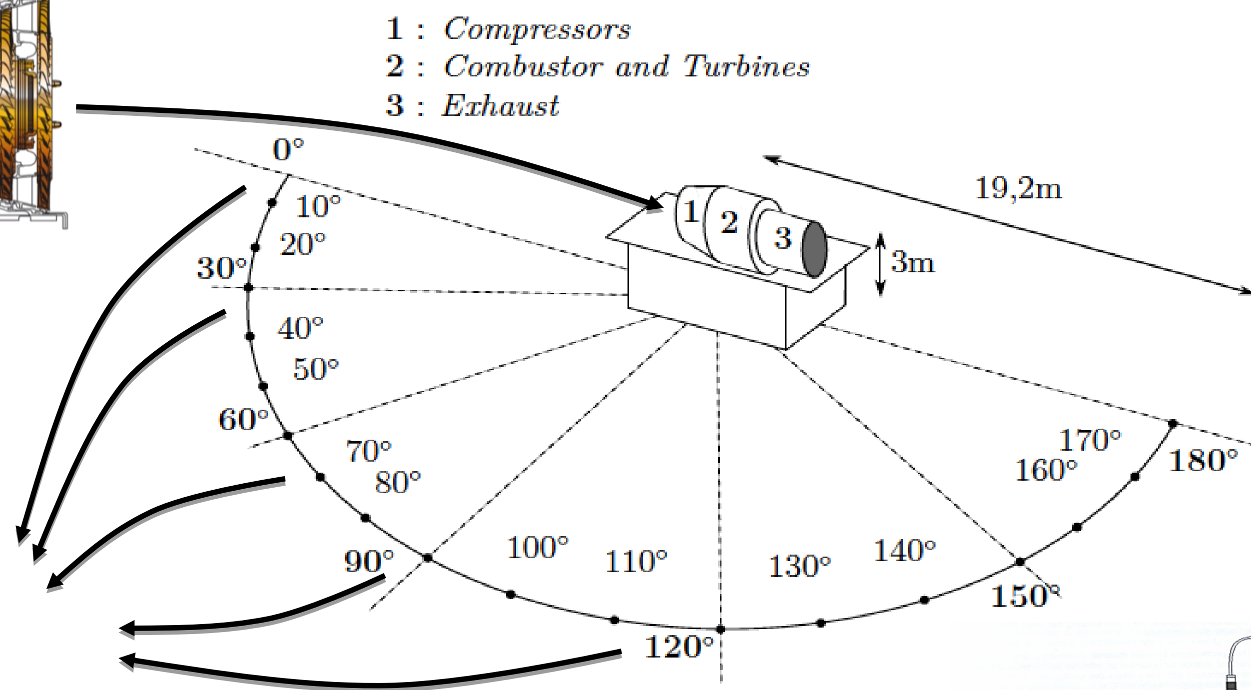
Experimentalinvestigation:

TEENIproject(2009-2013)

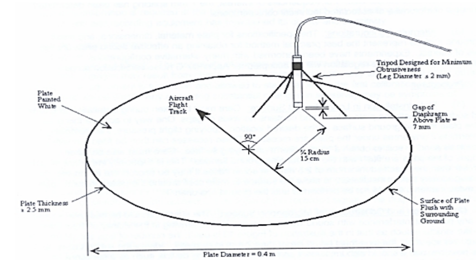
→ **Purpose:simultaneousmeasurementofinternalandexternalsensors**



Turboshaftengine



Acoustic far-field measurements



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Experimentalinvestigation:

AcousticFar-fieldof theengine

Significant acoustic levels atlow-frequency

Narrow-bandhump at 200 Hz

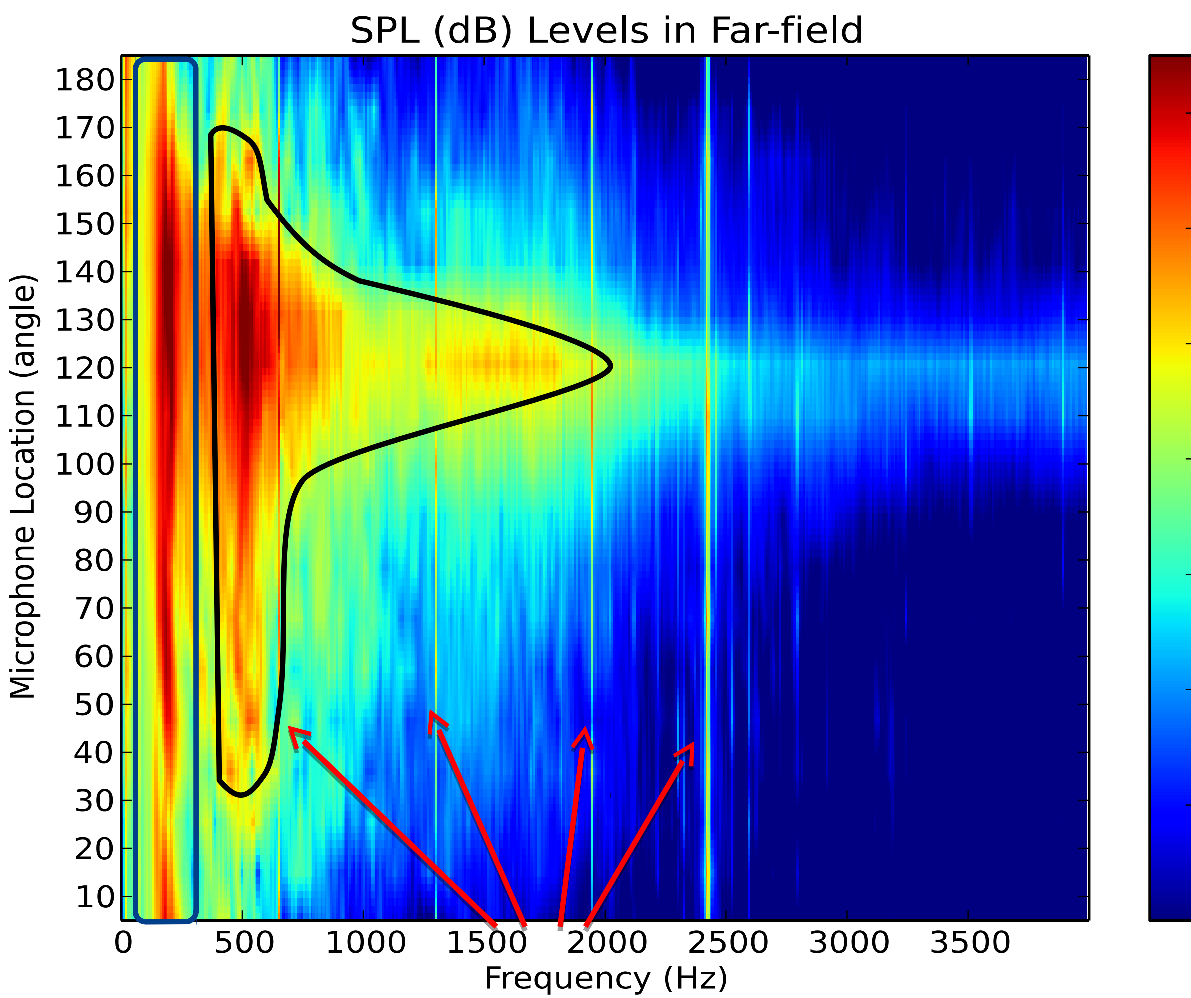
- *No directivity*

Broadband hump centered

around500 Hz up to 1500 Hz

- *Main directivity angle 120°-130°*

Tonal noise related to rotating devices within the engine



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Experimental investigation: Internal identification of broadband noise sources

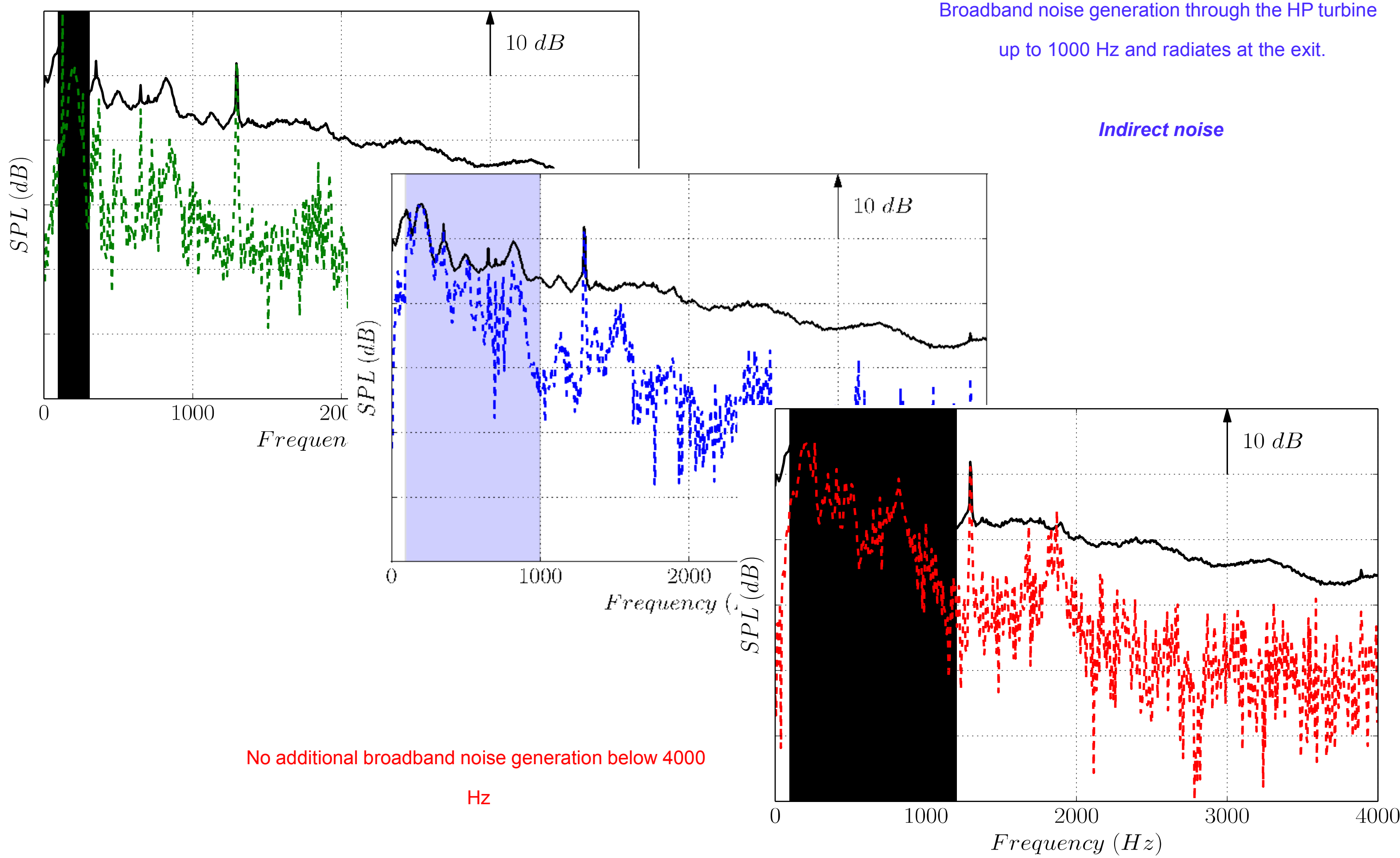
➔ **Three-sensors technique applied betweentwo probes at a given internal location anda pressure probe at the turbine exit**

Narrow-band contribution at 200 Hz coming from the combustion chamber and propagated through turbine stages.

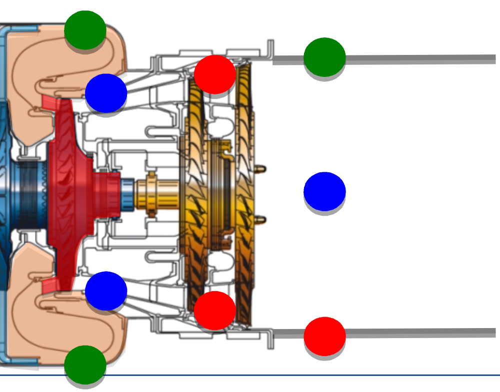
Direct Noise

Broadband noise generation through the HP turbine up to 1000 Hz and radiates at the exit.

Indirect noise



No additional broadband noise generation below 4000 Hz



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RECORD Project (2012-2015)

RECORD

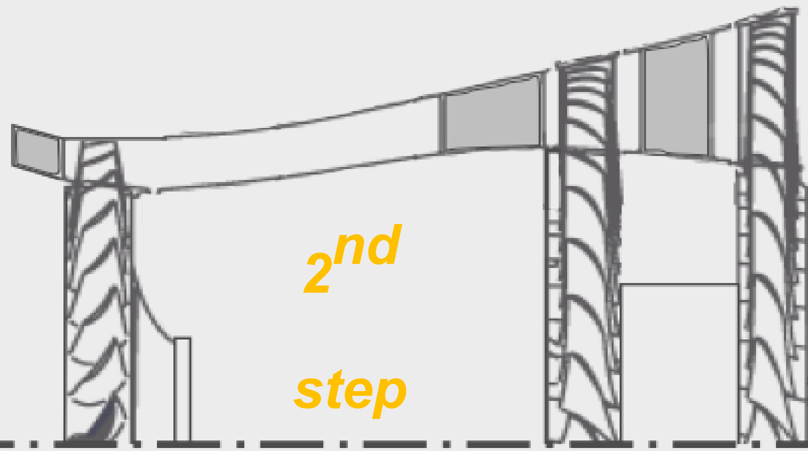
Combustion chamber

1^{st} step

Turbulent combustion & turbulent flow

- *Acoustic waves*
- *Entropy spots*
- *Vorticity*

Turbine stages



2^{nd} step

Acoustic generation and transmission

- *Direct combustion noise*
- *Indirect combustion noise*

Far-field

Acoustic propagation through exit jet flow

3^{rd} step

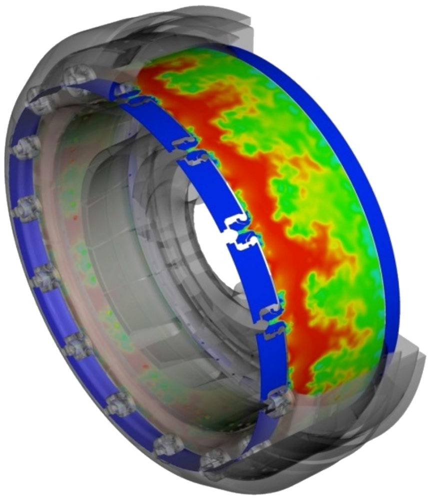
Modelling combustion noise : Which Tools?

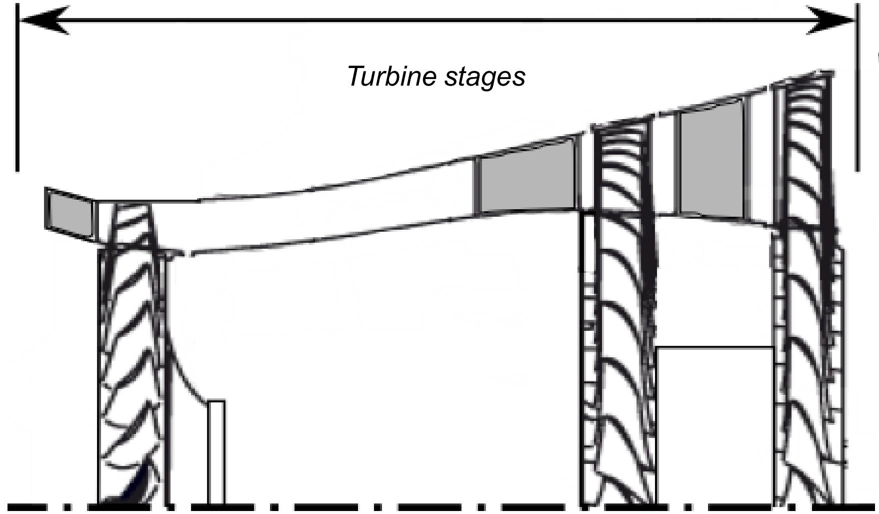
RECORD Project (2012-2015)

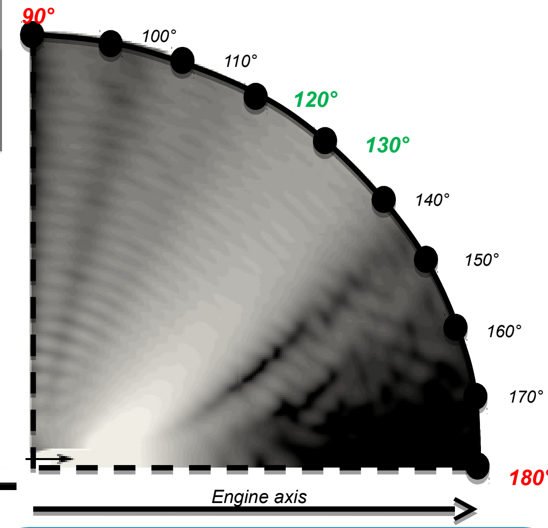
CERFACS

CENTRE EUROPÉEN DE RECHERCHE ET DE FORMATION AVANCÉE EN CALCUL SCIENTIFIQUE

RECORD







Capture of flow unsteadiness generated by the turbulent combustion

Turbulent, compressible and reactive LES solver

AVBP

Modeling of the acoustic behavior of turbine stages in the scope of combustion noise

*2D actuator disk theory**CHORUS***

Propagation of acoustic waves through low-Mach number hot jet andto thefar-field

No-Mach Helmholtz solver

AVSP-f

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CONOCHAIN

Hybrid method

Turbulent, compressible and reactive LES solver

AVBP

3D complex geometry

Operating conditions of the combustion chamber

2D actuator disk theory ***CHORUS***

Cheap analytical method for acoustic

0D mean flow information between the blade rows

Geometry of the turbine stages

No-Mach Helmholtz solver

AVSP-f

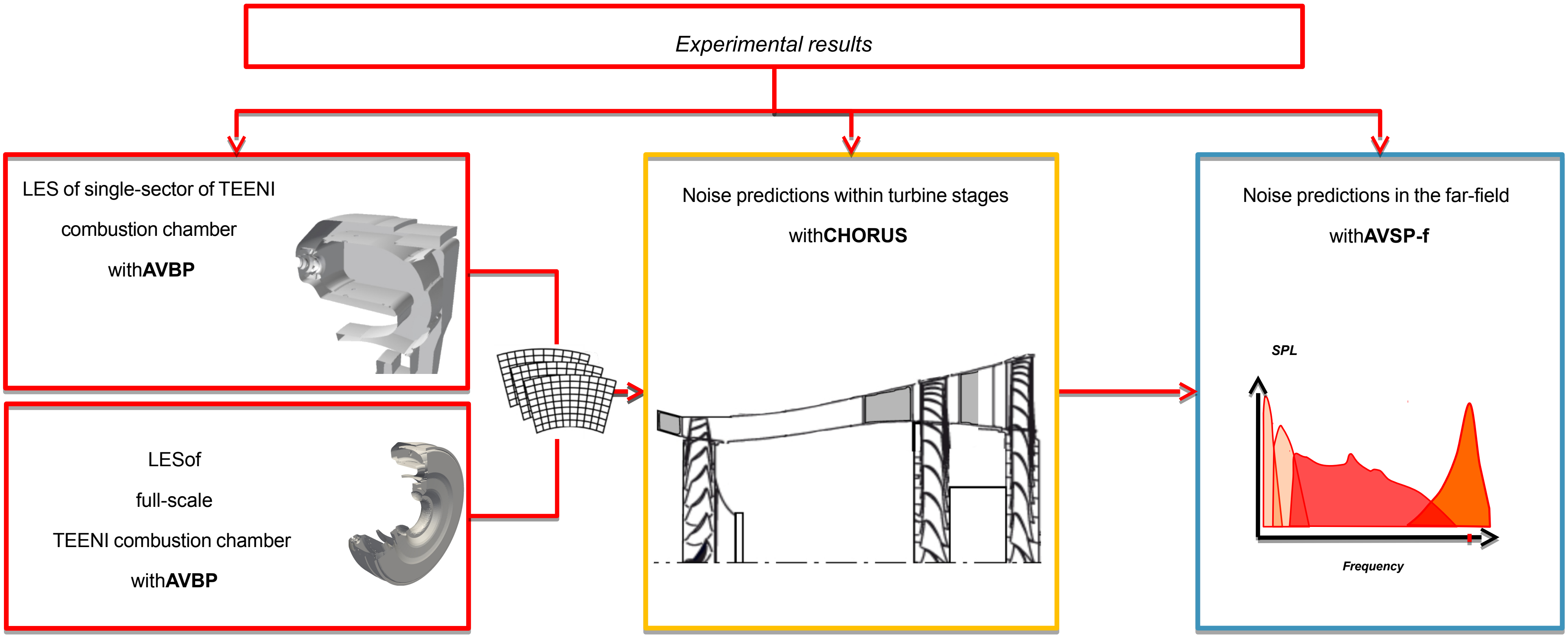
Acoustic propagation in frequency domain

3D complex geometry of the exit nozzle

Exit mean flow predictions

ValidationFlowchart

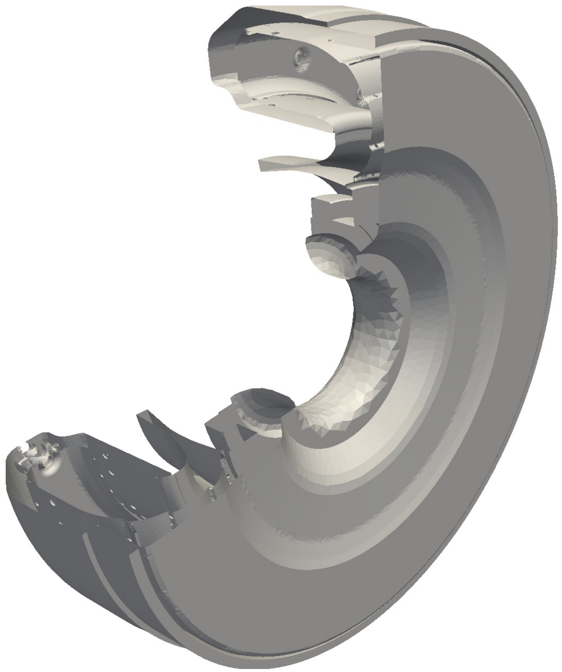
Do we need a full 360° LES of a combustion chamber to compute combustion noise levels within a helicopter engine ?



LESCalculationsin the CombustionChamber

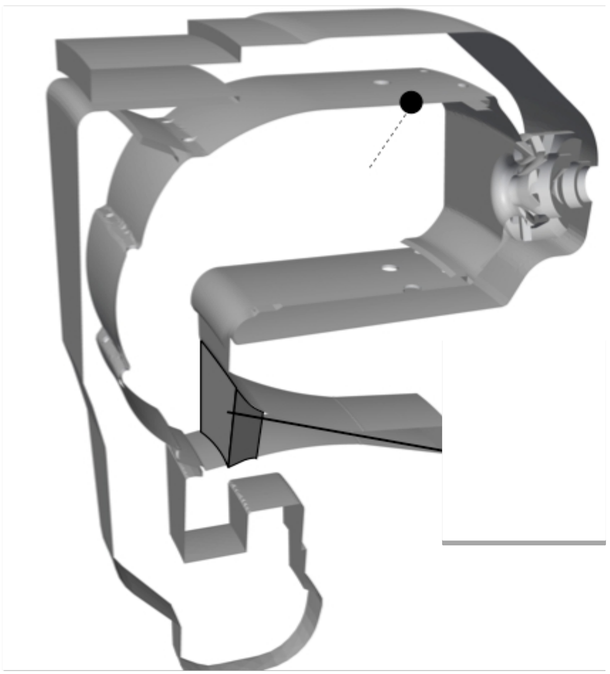
Full-scalecombustionchamber

- Provides high-fidelity predictions of the unsteadiness at the combustor exit
- Most realistic case to compute combustion noise
- High computational cost



Single-sectorof the annularcombustion chamber

- Flow is supposed to be periodic (impacts the extraction of fluctuations at the combustor exit)
- Reasonable CPU cost



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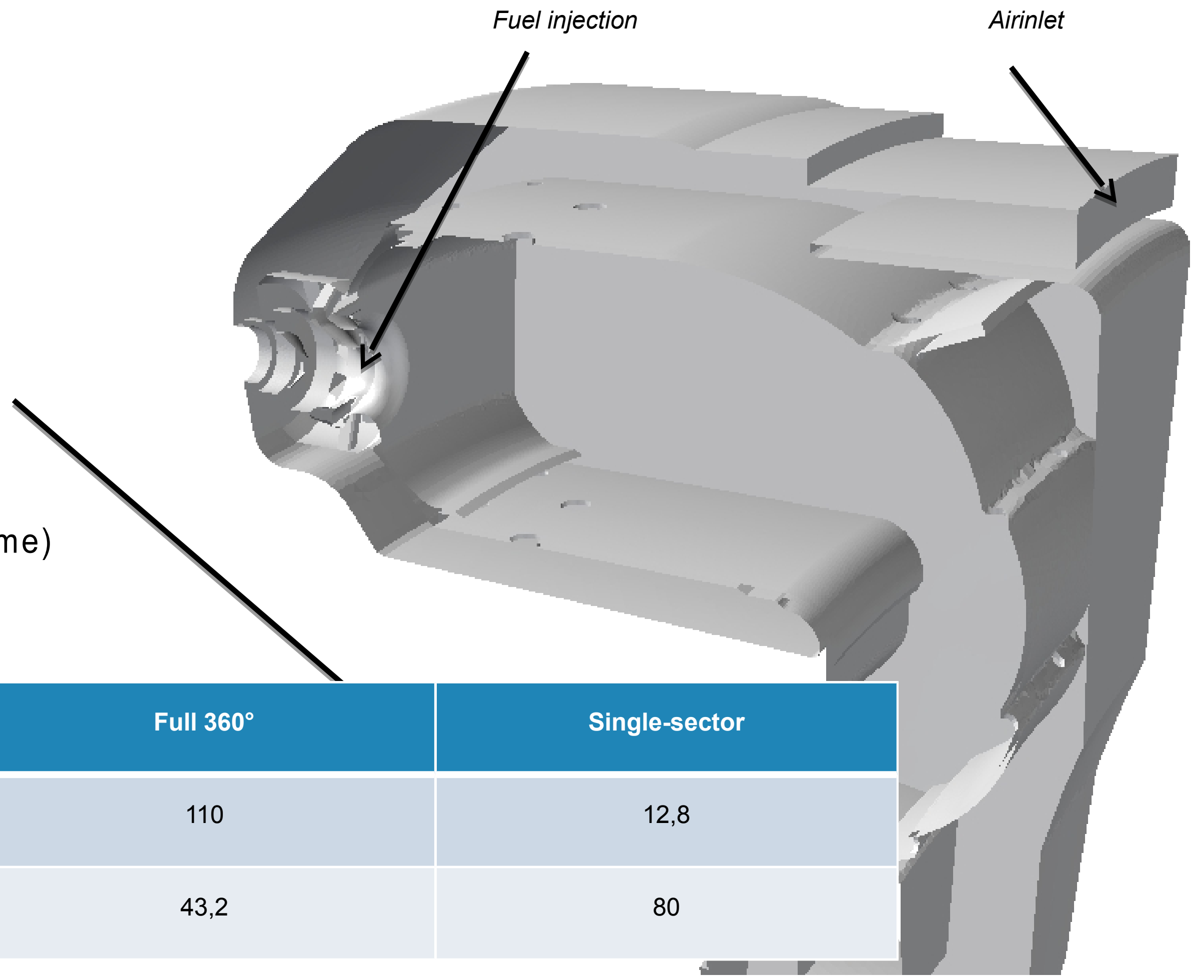
LES of the combustion chamber

Operating point corresponding tohigh power case (take-off)

In the LES domain

- Gaseous fuel
- Flame tube + Casing
- Remove of the first stator
- Building of an equivalent nozzle
  - Identical Mach number variation vs.curvilinear abscissae



Numerical parameters

- TTG scheme (Third order in space and time)
- SGS model :Smagorinsky
- Chemical scheme for kerosene/air flame: Tworeactions
- Turbulent
- Pressure

LES	Full 360°	Single-sector
Mesh size (TETs)(Moc)	110	12,8
Physical time (ms)	43,2	80

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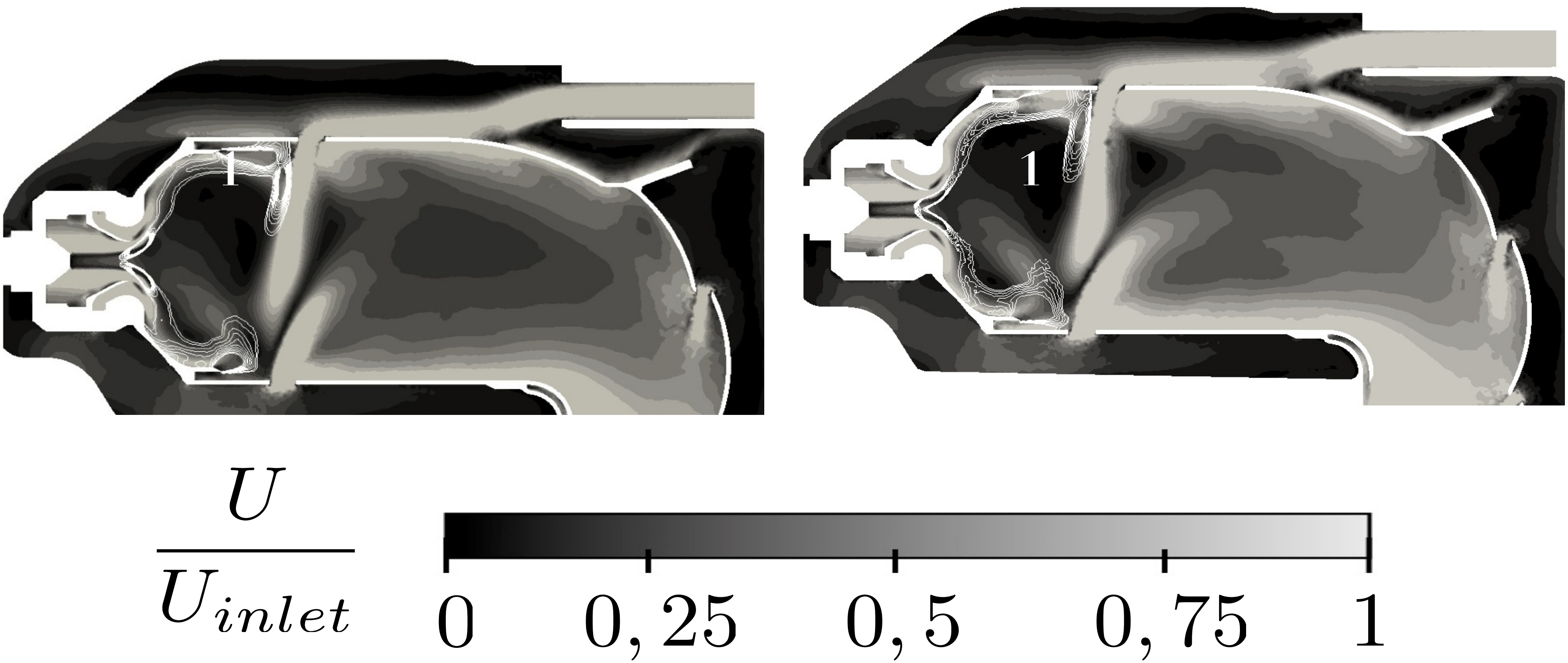
Averaged quantities

- **Magnitude of the mean velocity field**

Single-sector *Full 360°*

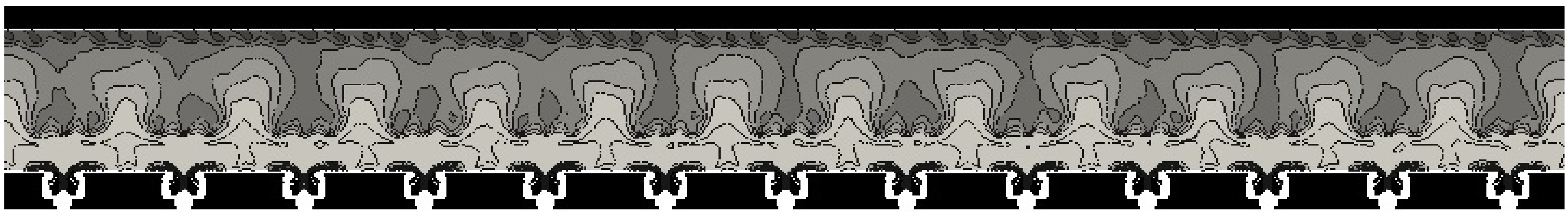


Comparisons between single-sector and full 360°LES

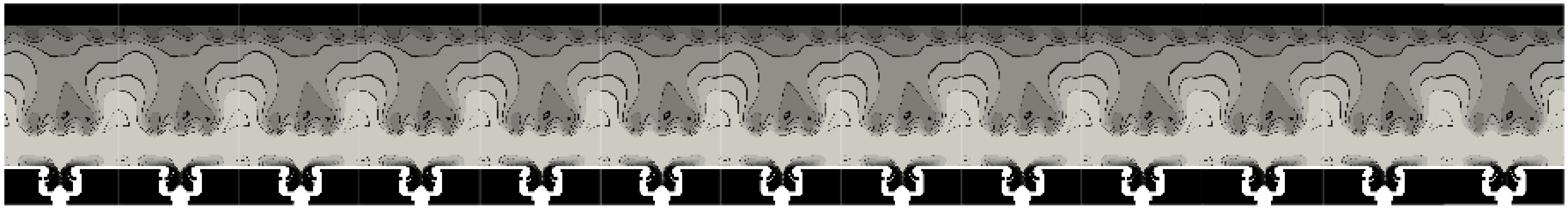
Averaged quantities

- **Magnitude of the mean temperature field over a meridian plane**

Full 360°



Single-sector



$$\frac{T - T_{inlet}}{T_{flame} - T_{inlet}}$$

Comparison to unsteady pressure measurements inside the combustion chamber

- Unsteady pressure behaviour is significantly different between full-scale and sectored computations

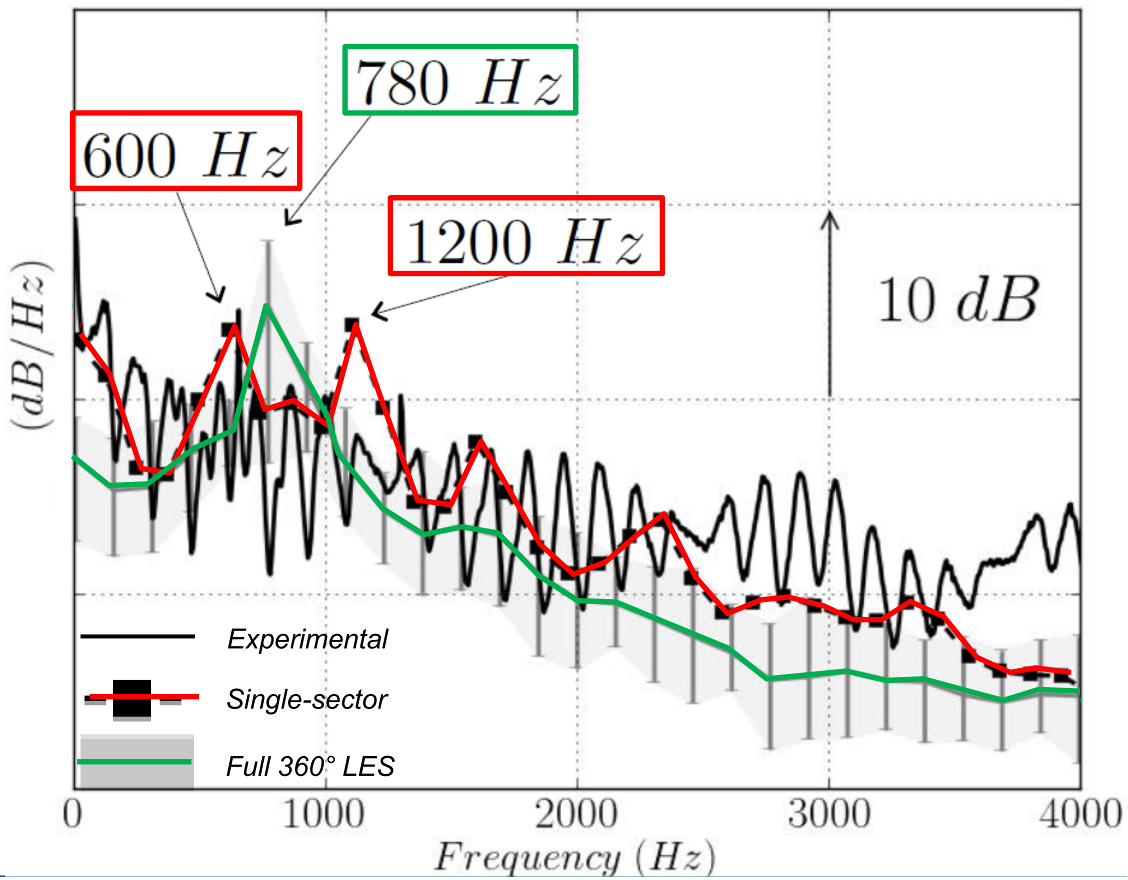
- Peaks correspond to calculated modes

- Longitudinal modes found by single sector calculations

- Azimuthal modes found by 360° calculation

- Periodicity imposed on sectored computation masks early azimuthal modes

- But broadband content not too bad in both cases



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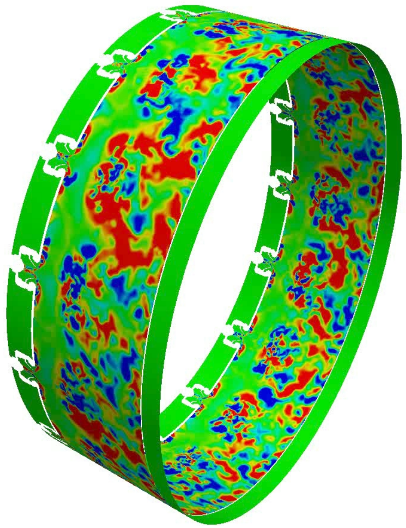
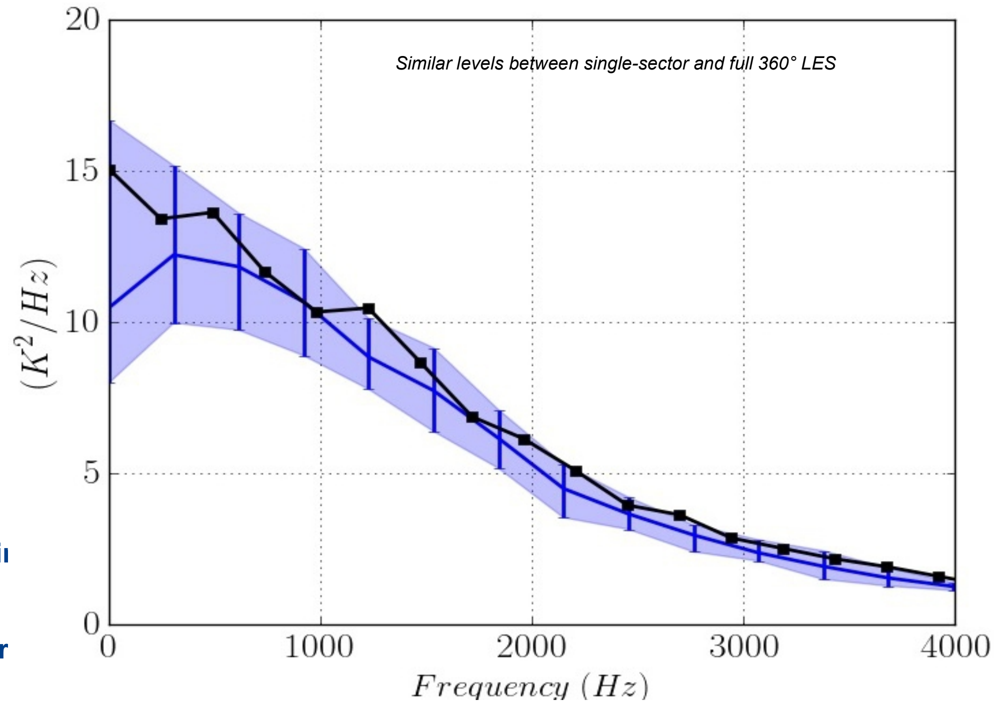
Comparisons between temperature fluctuations PSDs

➔ ***Entropy spots are mainly generated by interaction between burnt gases and dilution jetflows***





- **Sector-by-s ... S are i**
- **But single-sector symmetry condition artificially forces theplanar modewr**
- **A smart phase-averaging (filtering) process can make single sector entropyplanar mode more relevant for acoustic broadband noise calculation purpose**

CHORUS : an actuator disktheory

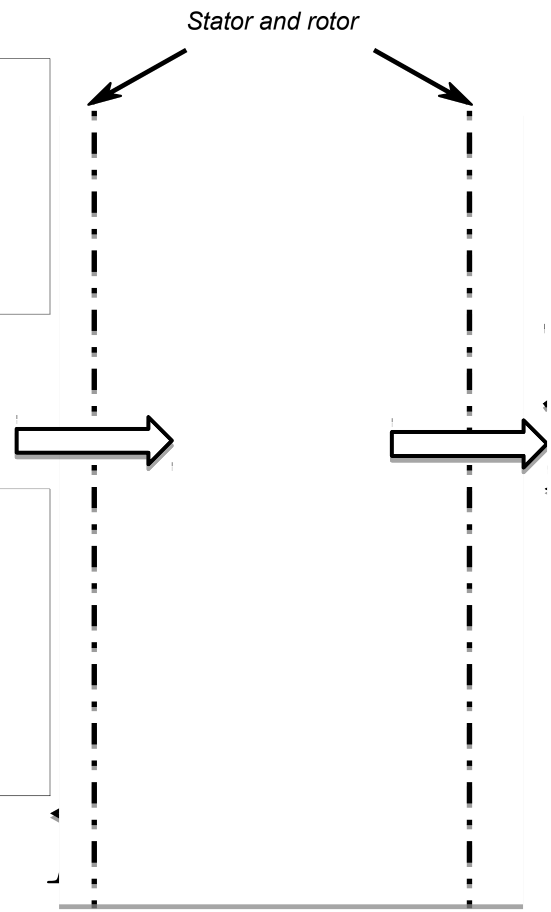
Acoustic modelling ofturbinestages :

2D unwrapped mean flow

- *Inviscid*
- *Steady*
- *Isentropic*

Compactness

- *Axial blade chord << Wavelength*
- *Azimuthal wavelength >> pitch length*



Jump relations through the blade rows

Phase-shift to take into account the blade rows spacing

Acoustic power is computed mode-by-mode

CHORUS : an actuator disktheory

Jump relations for thestatorcase

- Conservation of the entropy fluctuation
- Conservation of the fluctuating mass flow rate
- Conservation of the stagnation temperature fluctuation (Isentropic expansion)
- For a subsonic flow at the trailing edge
  - Kutta'scondition
- For a supersonic flow
  - Conservation of the fluctuating mass flow rate for a isentropic1D choked nozzle

Expressed in terms of

Entropy	$\dfrac{s'}{C_p}$
Velocity Mag.	$\dfrac{w'}{c}$
Velocity angle	θ'
Pressure	$\dfrac{p'}{\gamma p}$

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CHORUS : an actuator disktheory

Jump relations for the rotor case

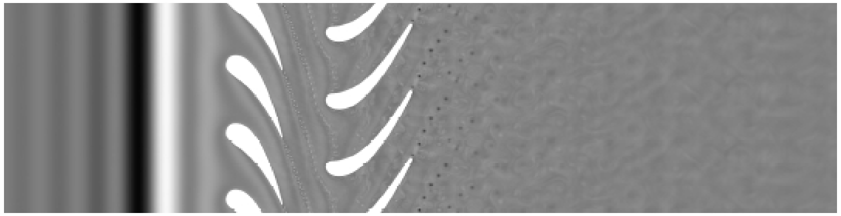
- Conservation of the entropy fluctuation
- Conservation of the fluctuating mass flow rate
- Conservation of therothalpy fluctuation
- For a subsonic flow at the trailing edge
  - Kutta's condition in the moving reference frame
- For a supersonic flow
  - Conservation of the fluctuating mass flow rate for a isentropic 1D choked nozzle in the moving reference frame

Expressed in terms of

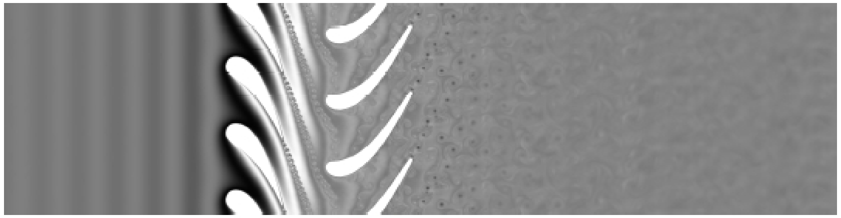
Entropy	$\frac{s'}{C_p}$
Velocity Mag.	$\frac{w'}{c}$
Velocity angle	θ'
Pressure	$\frac{p'}{\gamma p}$

CHORUS : an actuator disk theory

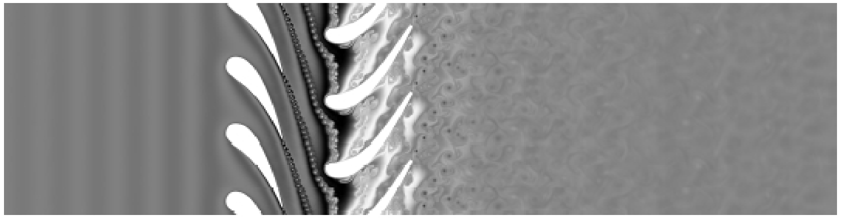
- 2-Dand3-Dnumerical simulations showed a scattering of the planar ent waves through the blade rows.
- Mean flow distortion leads to a spatial scattering of the entropy waves
- A damping function proposed byLeykois used to take into account thi scattering mechanism through the blade rows.



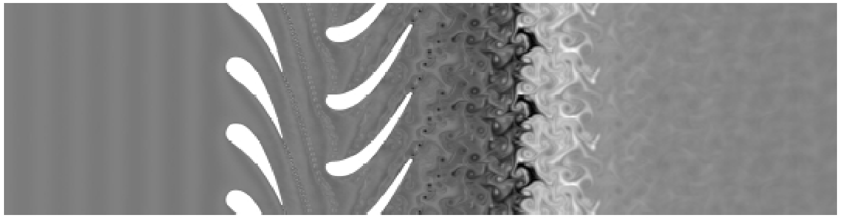
(a) $tf_0 = 0.1$



(b) $tf_0 = 0.15$



(c) $tf_0 = 0.18$



(d) $tf_0 = 0.24$

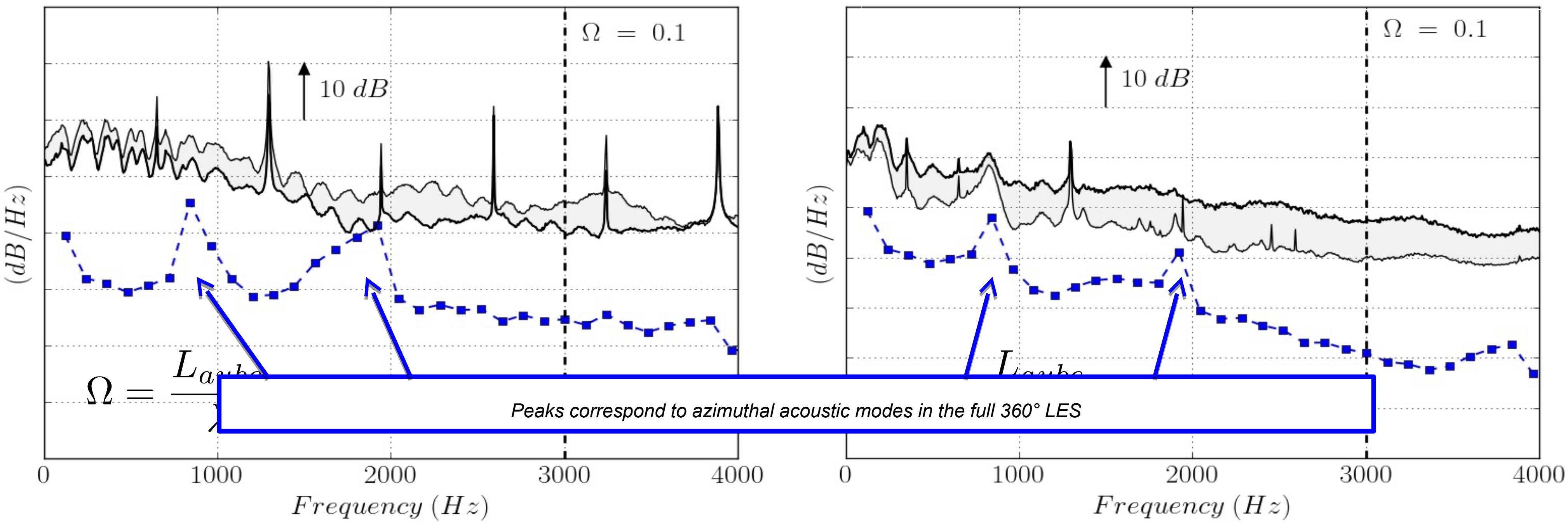
Experimental / Calculations comparisons in turbines

➔ **Predictions of combustion noise levels using [-2, -1, 0, 1, 2] azimuthal modes extracted from the full 360° LES**

Experimentalresults

Direct noise

In thehigh-pressure turbine | *At the turbine exit*



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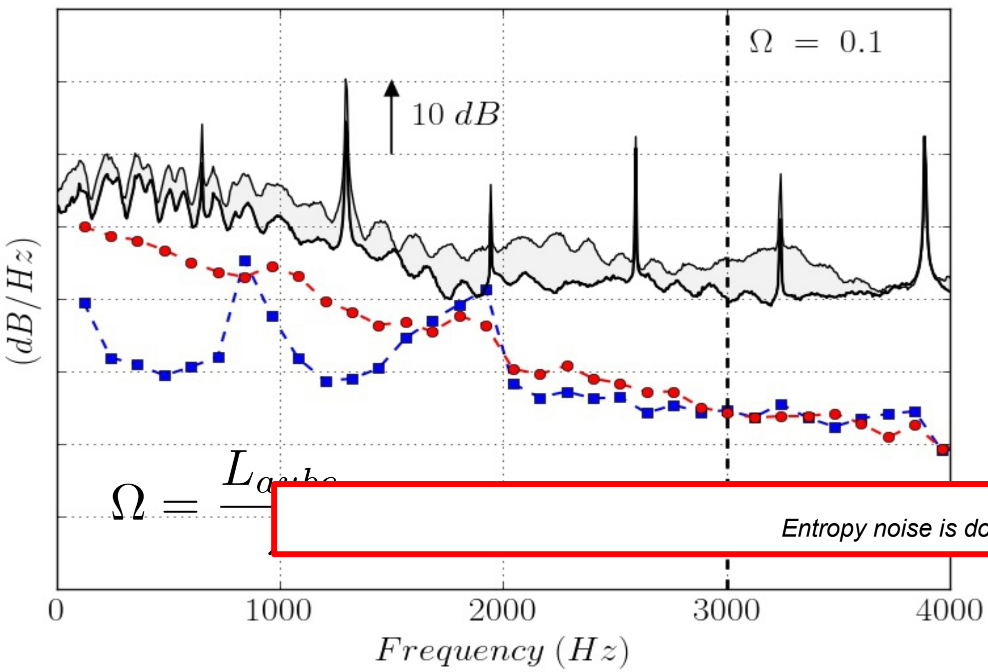
Experimental / Calculations comparisons in turbines

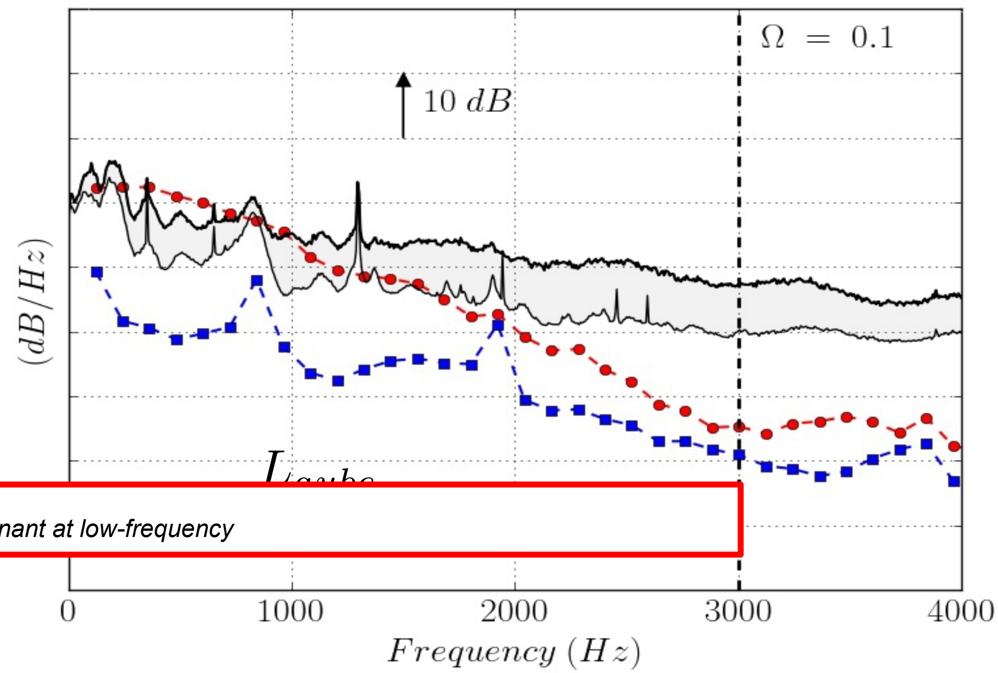
➔ **Predictions of combustion noise levels using two first azimuthal modes extracted from the full 360° LES**

Experimentalresults ***Direct noise*** ***Entropynoise***

In thehigh-pressure turbine



At the turbine exit



Entropy noise is dominant at low-frequency

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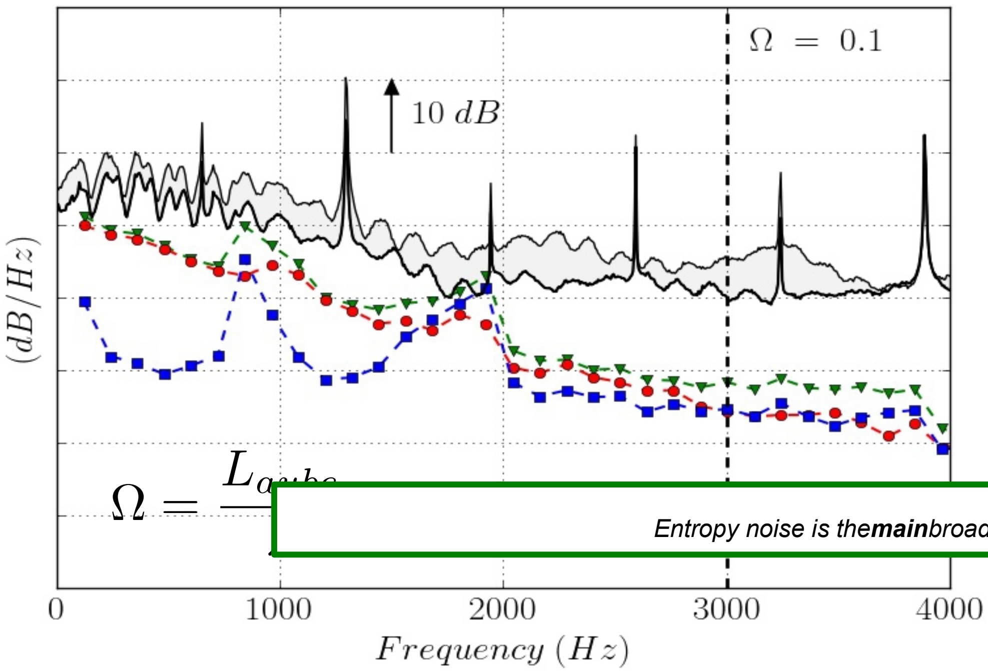
Experimental / Calculations comparisons in turbines

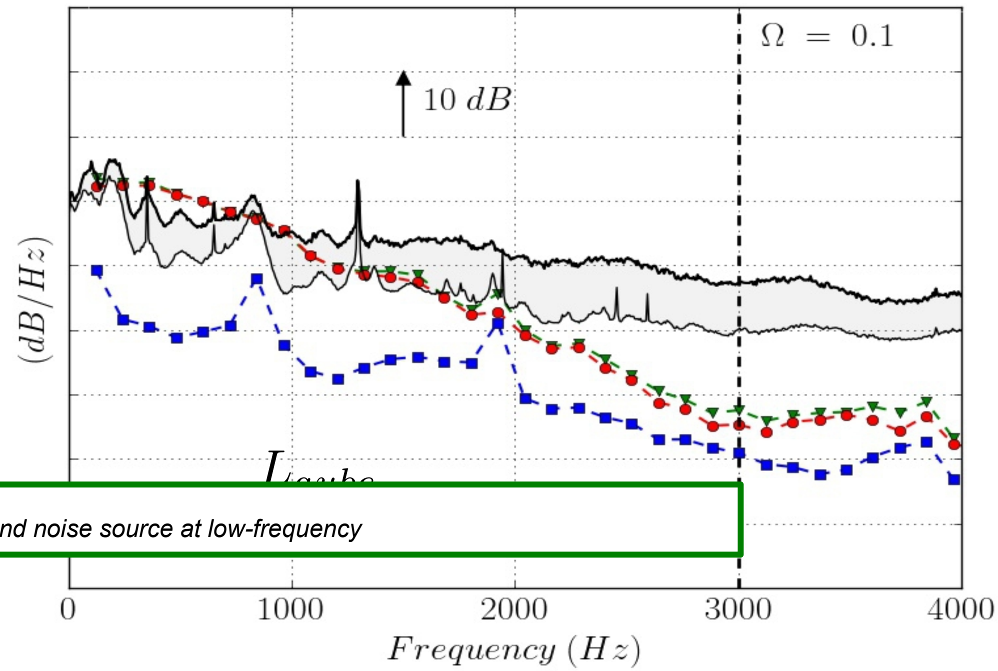
Predictions of combustion noise levels using two first azimuthal modes extracted from the full 360° LES

Experimental results | ***Direct noise*** | ***Entropy noise*** | ***Total noise***

In the high-pressure turbine



At the turbine exit



Entropy noise is the ***main*** *broadband noise source at low-frequency*

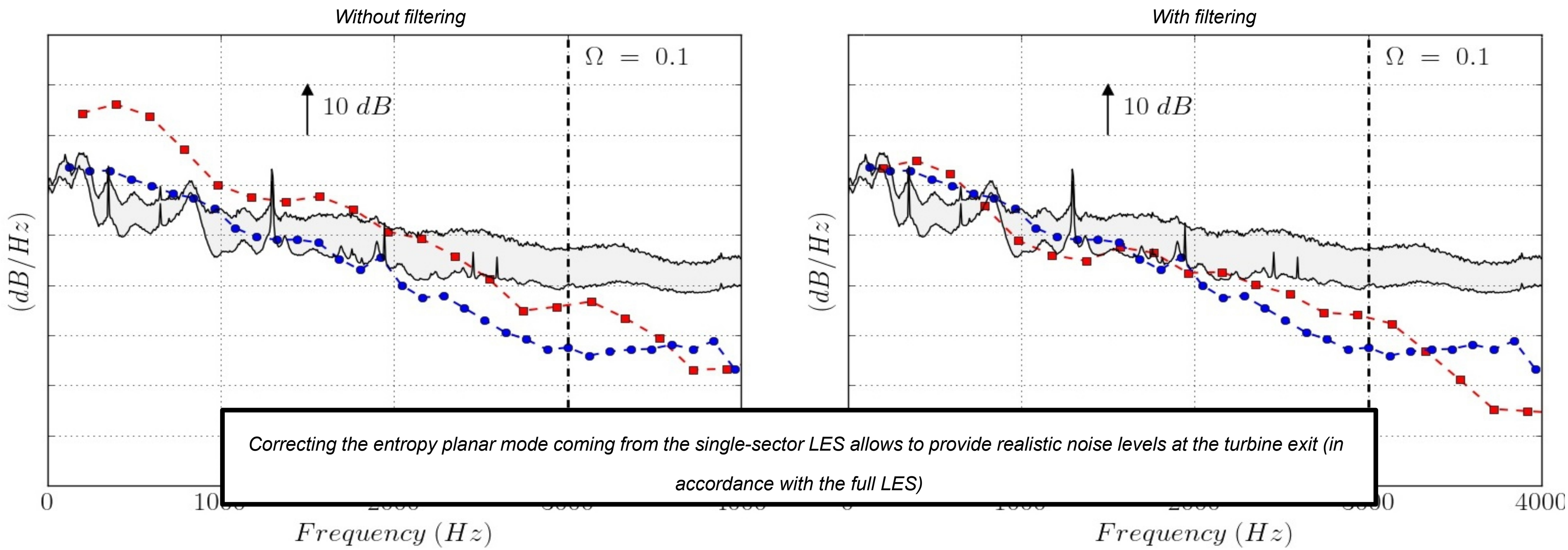
Experimental / Calculations comparisons in turbines

At the turbine exit, total combustion noise predictions with a single-sector LES (planar modes) and a full 360° LES.

Experimental results

Full 360°

Single-sector



Correcting the entropy planar mode coming from the single-sector LES allows to provide realistic noise levels at the turbine exit (in accordance with the full LES)

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The last step : Far-field computation

Characteristics of the exit mean flow of a turboshaft engine

Low-Mach number

Single jet flow

Strong temperature gradients

***CHORUS**acoustic predictions from a single-sector LES (only planar modes)*

Acoustic solver

AVSP-f

Helmholtz solver

No-Mach

Density gradients

Far-field acoustic levels at low-frequency

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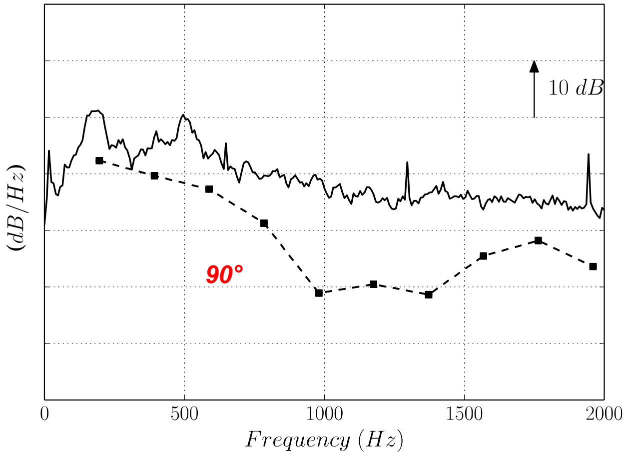
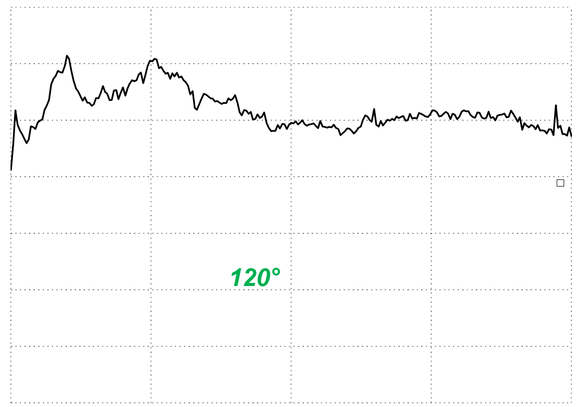
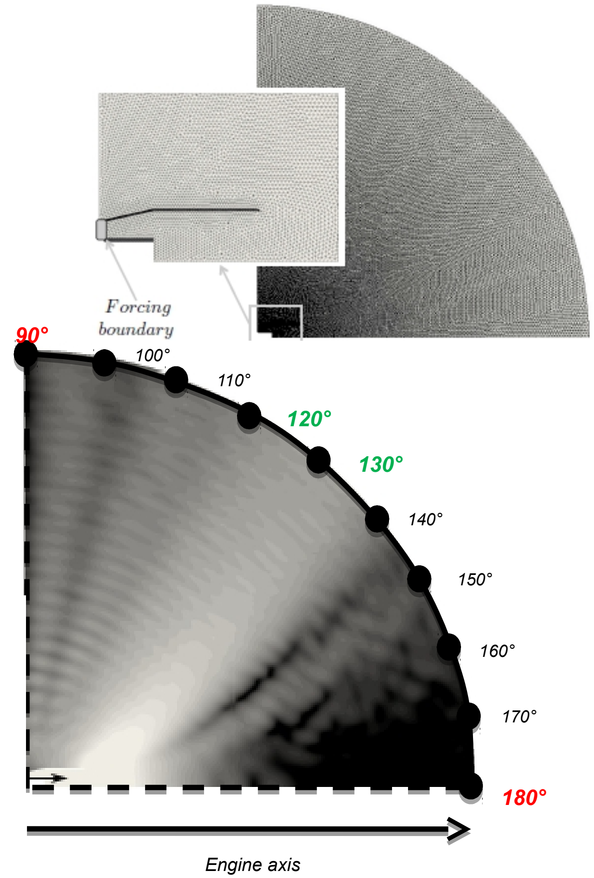
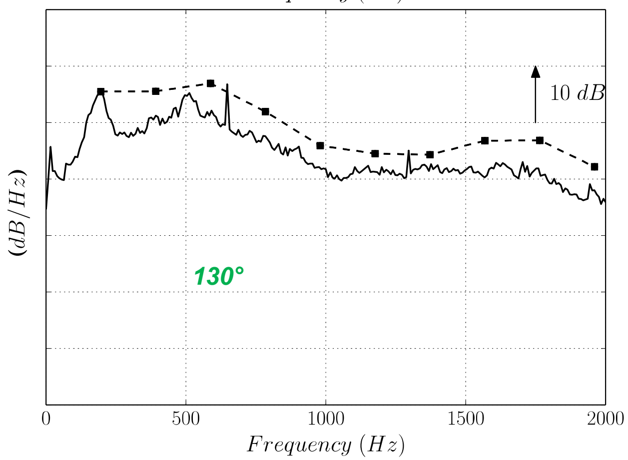
ComparisoninFarfield

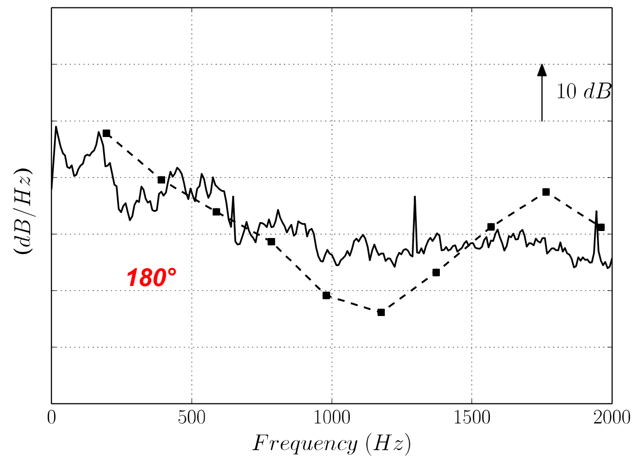
Comparison in far field (19,2m)











Deviations at the limits of the domain show that hypothesis on propagator model are probably too strong (M=0) + mesh frontier at 90°

Conclusion

A mixed experimental / calculation approach has been applied for understanding combustion noise:

- New sensors and experimental analysis methods have been developed
- AVBP innovative use for acoustics
- Development of CHORUS and refinement of existing models for generation of indirect noise / propagation.
- Development of the CONOCHAIN methodology

Very good simulation results achieved for a first run without calibration !

- Good representation of acoustics inside the combustion chamber is only achievable with full 360° model
- … but sectored calculation seem sufficient for broadband noise prediction (coupled with CHORUS)
- Radiation model with no Mach induces side effects on the limit of the domain.

Indirect combustion noise is more important than Direct combustion noise for Turboshaft application

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Thank you for your attention