Aeroacoustics of free and installed jets

André V. G. Cavalieri

Acknowledgements:
Peter Jordan (Université de Poitiers)
Anurag Agarwal (University of Cambridge)
Tim Colonius (California Institute of Technology)
Daniel Rodríguez (Universidad Politécnica de Madrid)
William Wolf (Universidade Estadual de Campinas)
Justin Jaworski (Lehigh University)

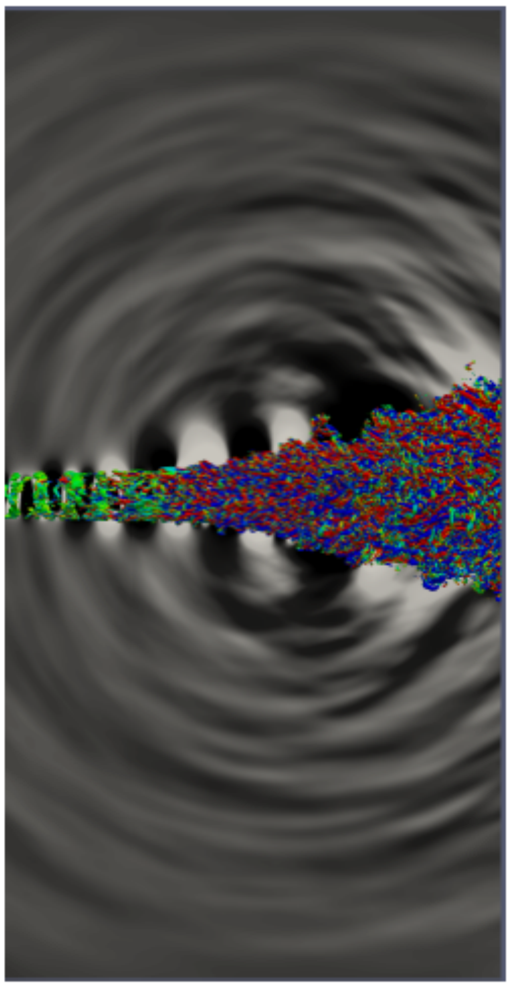
LNCA
get into new ideas
laboratory
of new concepts
in aeronautics

Aeroacoustics of free and installed jets

André V. G. Cavalieri
Students:
Gilles Tissot (post-doc)
Francisco C. Lajús Jr., Kenzo Sasaki (PhD)
Carmen Hernando, Alex Sano, Petrônio Nogueira, Luiz Mourão, Pedro Ormonde (Msc.)
+ Jean Ribeiro, Renato Miotto (Msc., Unicamp)

LNCA get into new ideas laboratory of new concepts in aeronautics

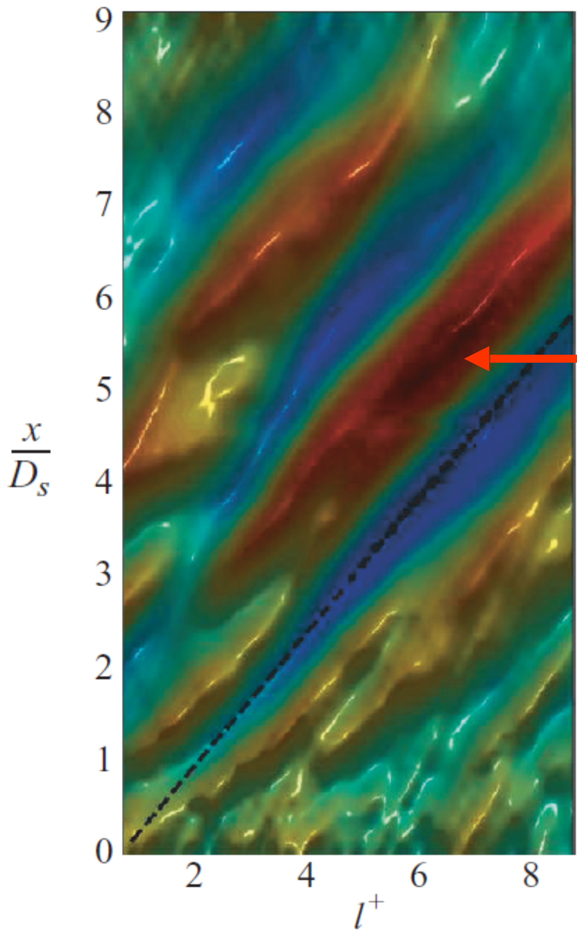
Jet noise: background



Jet LES, Daviller (2011)

- Significant noise source during take-off
- Turbulence as a source of sound
  - What is the acoustically efficient part of the turbulent field?
  - How could one modify turbulence to reduce noise?

A hint: near-field pressure = large-scale structures = wavepackets



178 *C. E. Tinney and P. Jordan*

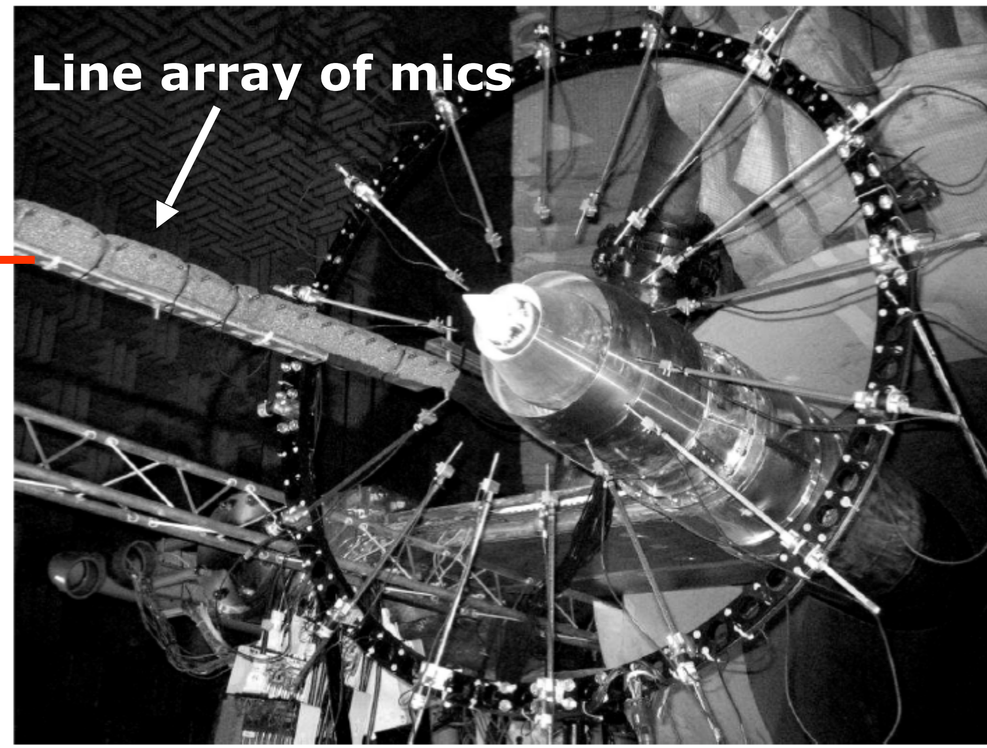
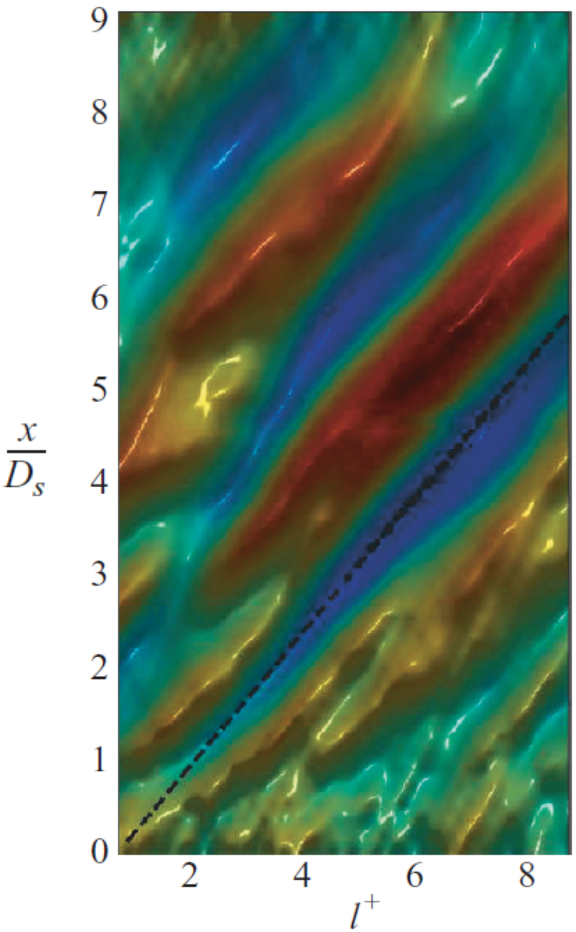


FIGURE 1. Experimental arrangement of the short-cowl co-axial nozzle (SCN) with the azimuthal and line arrays of microphones at the Noise Test Facility (NTF), QinetiQ.

Tinney & Jordan J. Fluid Mech. 2008

$Re=5x10^6$!

A hint: near-field pressure = large-scale structures = wavepackets



14 *K. Gudmundsson and T. Colonius*

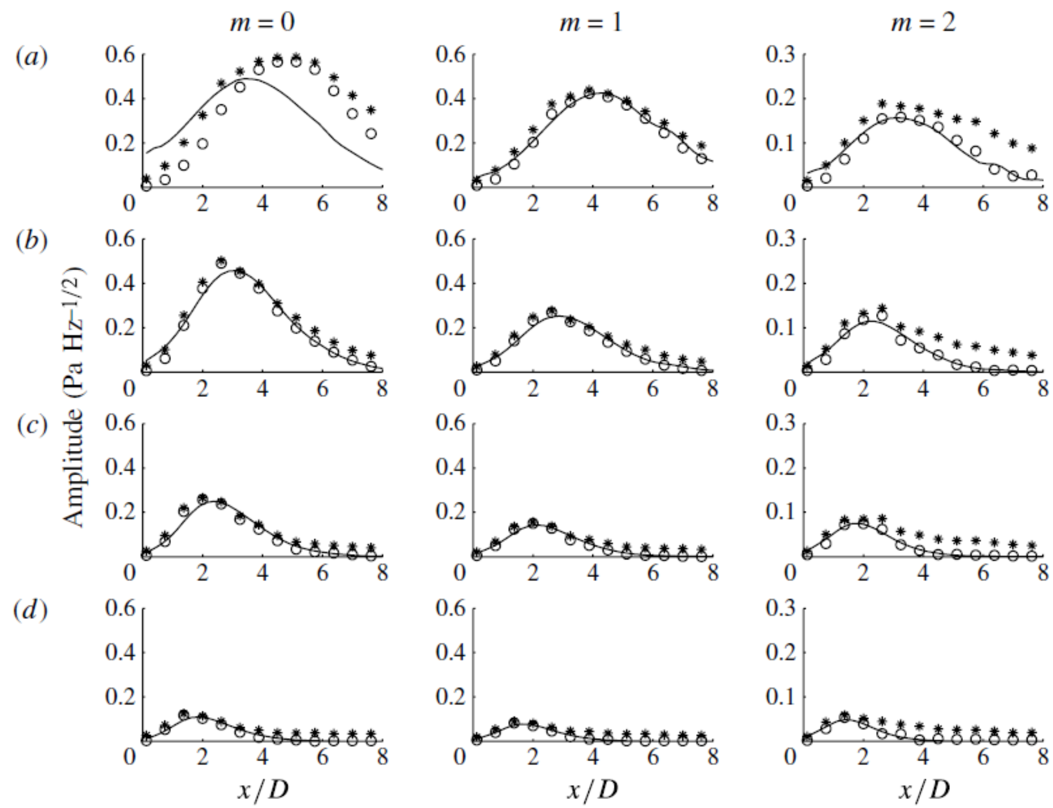
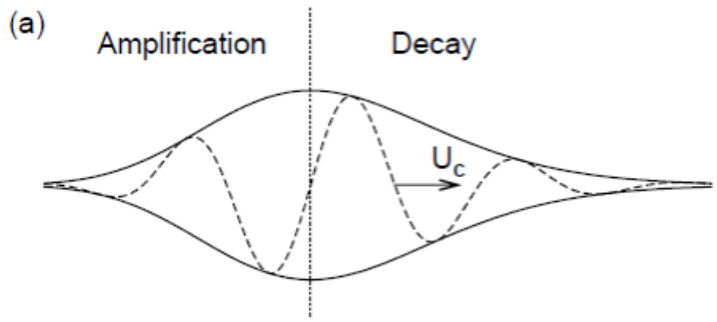


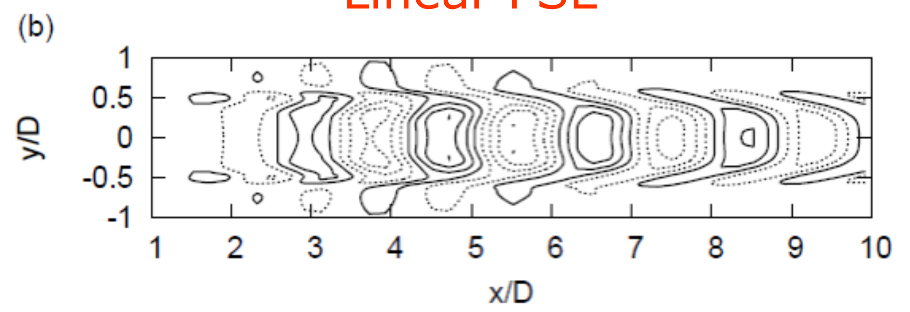
FIGURE 8. Pressure amplitude along the microphone array for the cold $M_\infty = 0.5$ jet: r.m.s. data (∗), first POD mode (○) and PSE predictions (—), at frequencies of $St = 0.20$ (*a*), 0.35 (*b*), 0.5 (*c*) and 0.65 (*d*). Note *m*-dependence of ordinate.

Gudmundsson & Colonius J. Fluid Mech. 2011

A hint: near-field pressure = large-scale structures = wavepackets

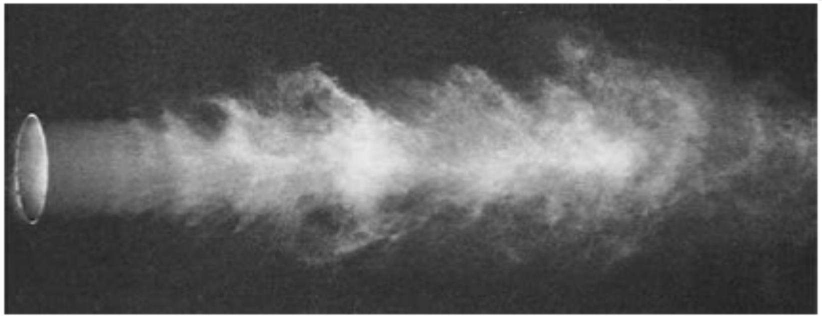


Linear PSE



Large-scale structures: growth and decay of a Kelvin-Helmholtz instability

Crow and Champagne (1971)



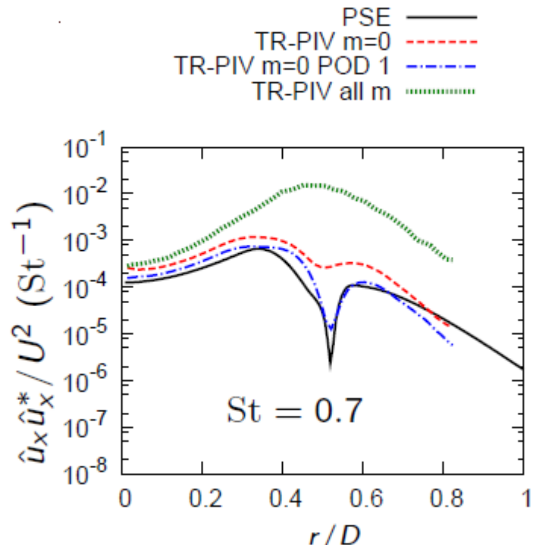
unstable
near nozzle

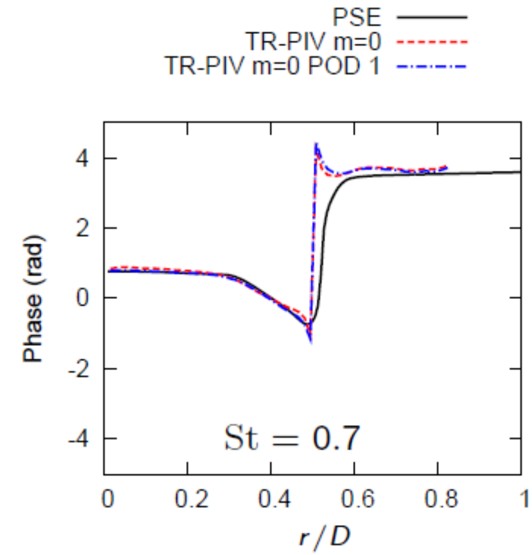
stable
downstream

Experimental signatures of wavepackets in the turbulent and acoustic fields

Velocity:

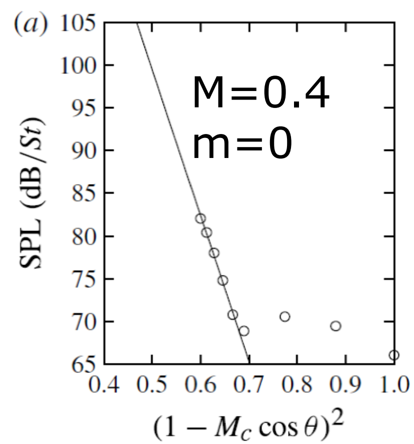
linear PSE x time-resolved PIV

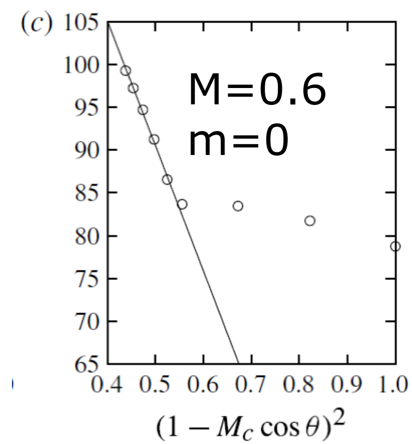




Far-field sound:

superdirectivity (exponential in θ)

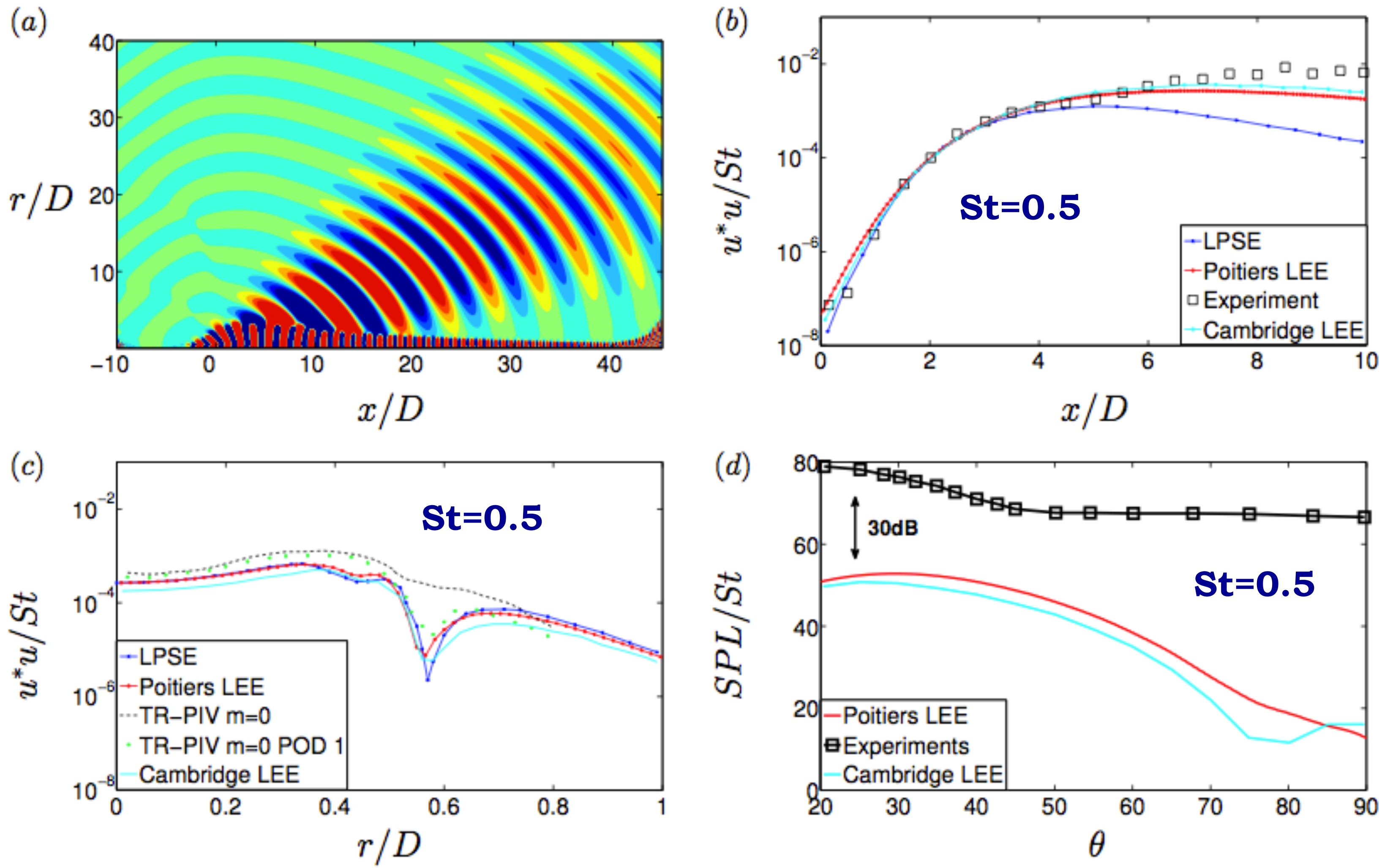




Cavalieri, Rodríguez, Jordan, Colonius, Gervais, JFM 2012, 2013

Linear wavepacket models and subsonic jet noise

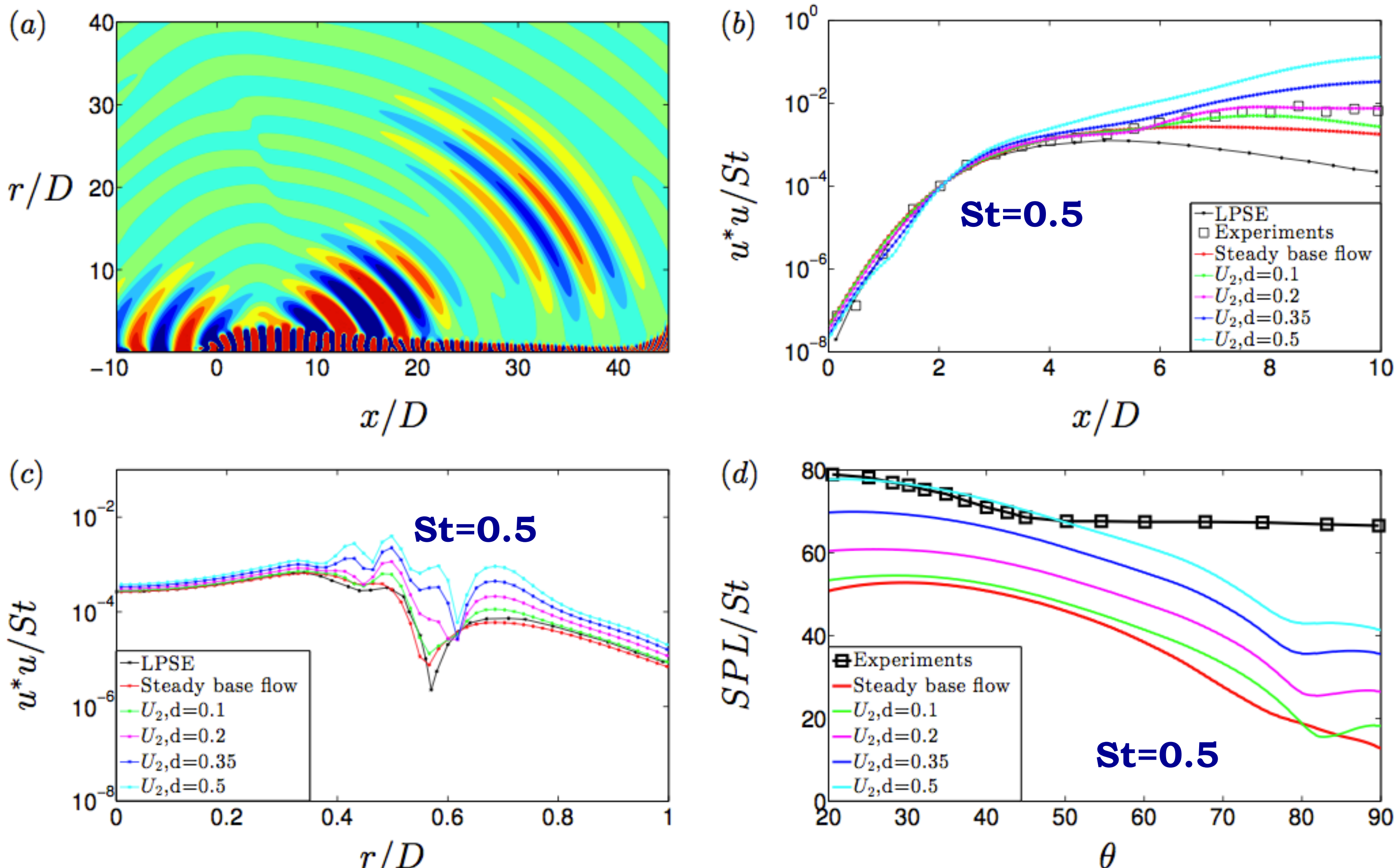
Steady base flow $\mathcal{L}_{\overline{\mathbf{q}}}(\tilde{\mathbf{q}}) = 0$



Linear wavepacket models and subsonic jet noise

Unsteady base flow $\mathcal{L}_{\hat{\mathbf{q}}}(\tilde{\mathbf{q}}) = 0$

Cavalieri & Agarwal JFM 2014
Zhang et al. AIAA 2014, CTR 2014
Baqui et al. JFM 2015



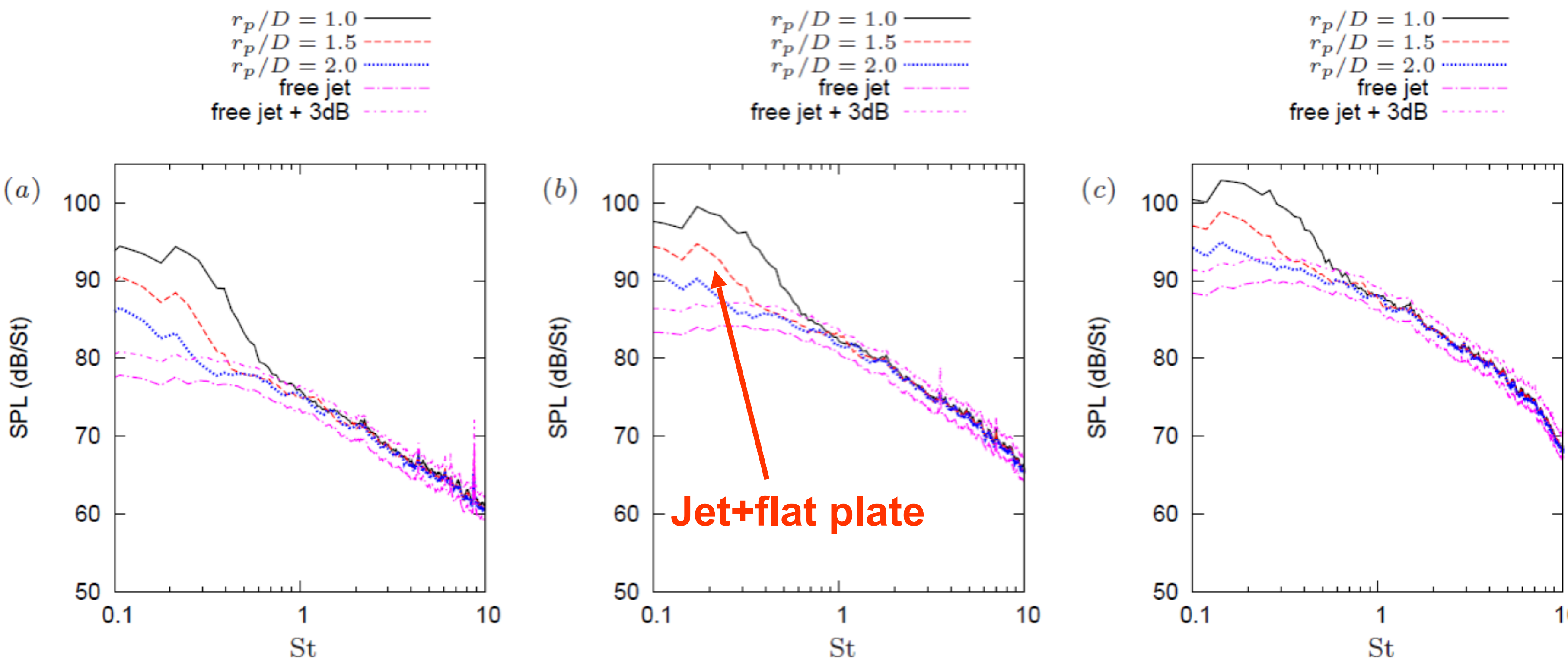
Other ongoing research

- Extend wavepacket theory/computation to more complex flows
  - Installed jets (UHBPR engines: proximity between jet and wing)
    - Funded by INOVA Aerodefesa (Finep, Embraer)
  - Design (flexible? porous?) wings to reduce noise from jet-wing interaction
  - Airframe noise: can airfoil noise be modelled using wavepackets?
    - Collaboration with William R. Wolf (Unicamp), Ricardo Vinuesa, Philipp Schlatter, Dan Henningson (KTH)

- Control of jet noise
  - Chevrons and microjets: effects on wavepackets
  - Towards active control
    - Funded by ANR CoolJazz (France), Science Without Borders (Brazil)

- Students needed!!!

Installed jets: experimental results



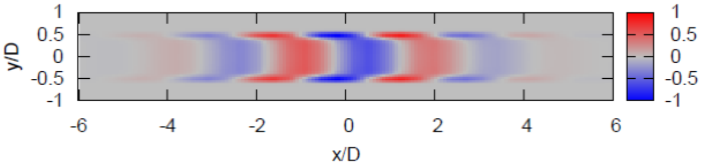
M = 0.4 M = 0.5 M = 0.6

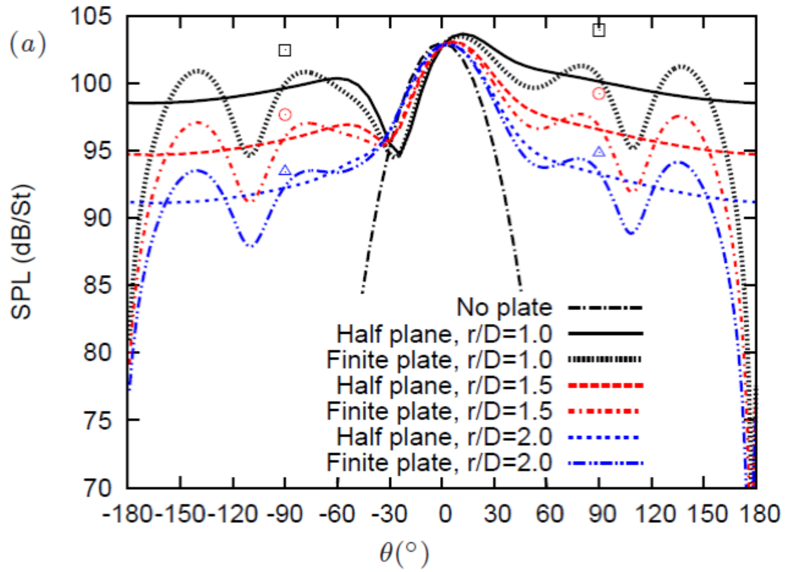
Increase of 10-15 dB!

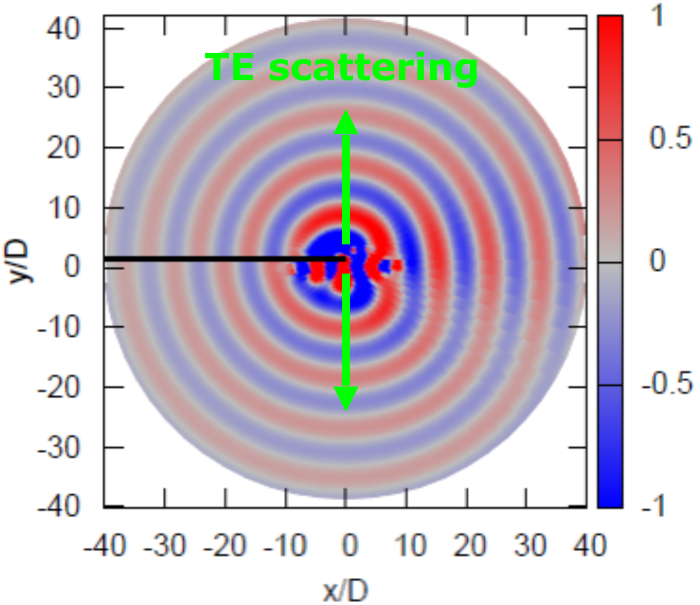
Modelling: jet noise and trailing-edge noise combined

- Sources: wavepackets of free-jet studies
- Effect of neighbouring surfaces
  - Trailing edge: acoustic scattering

Cavalieri et al. J. Sound Vib. 2014





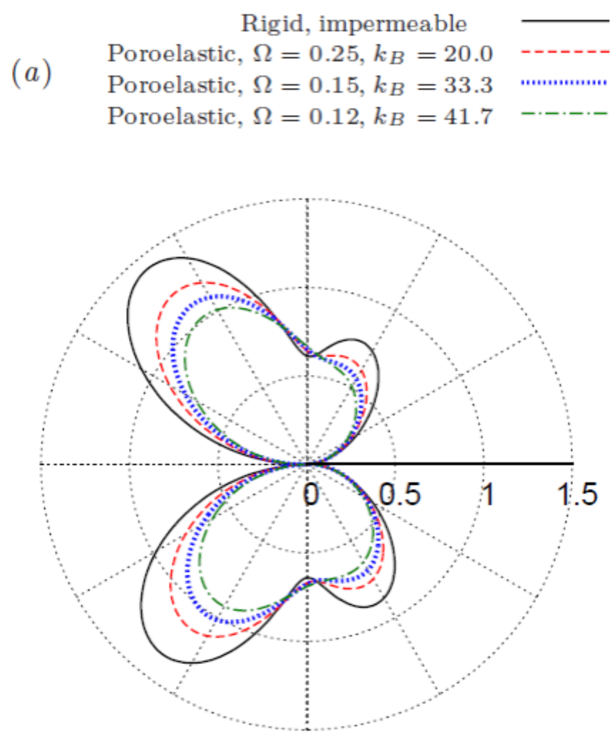


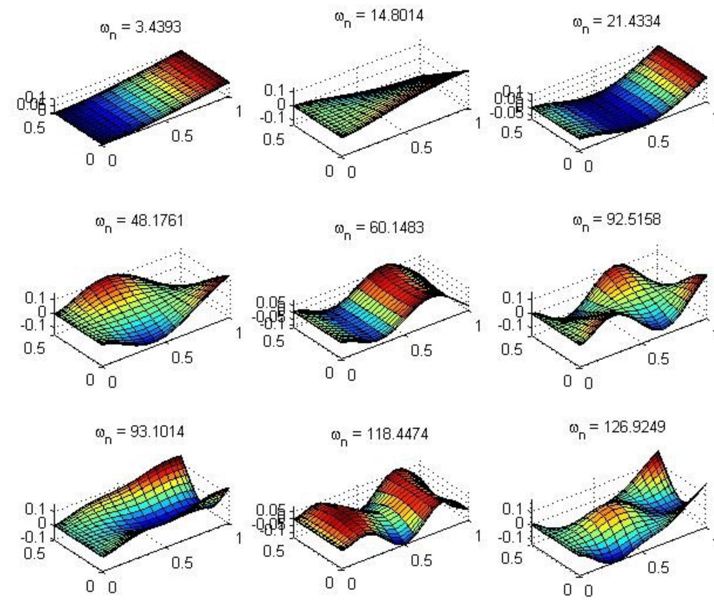
Modelling: jet noise and trailing-edge noise combined, flexible wings

- Ongoing work: Acoustic BEM written for the elastic modes of a (possibly porous) plate

Cavalieri, Wolf, Jaworski AIAA 2014

Cavalieri, Donadon, Wolf AIAA 2015

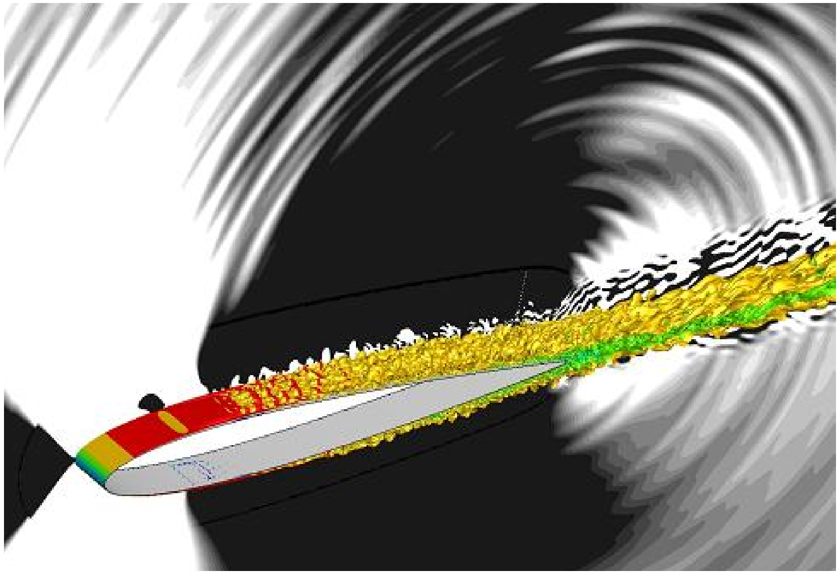




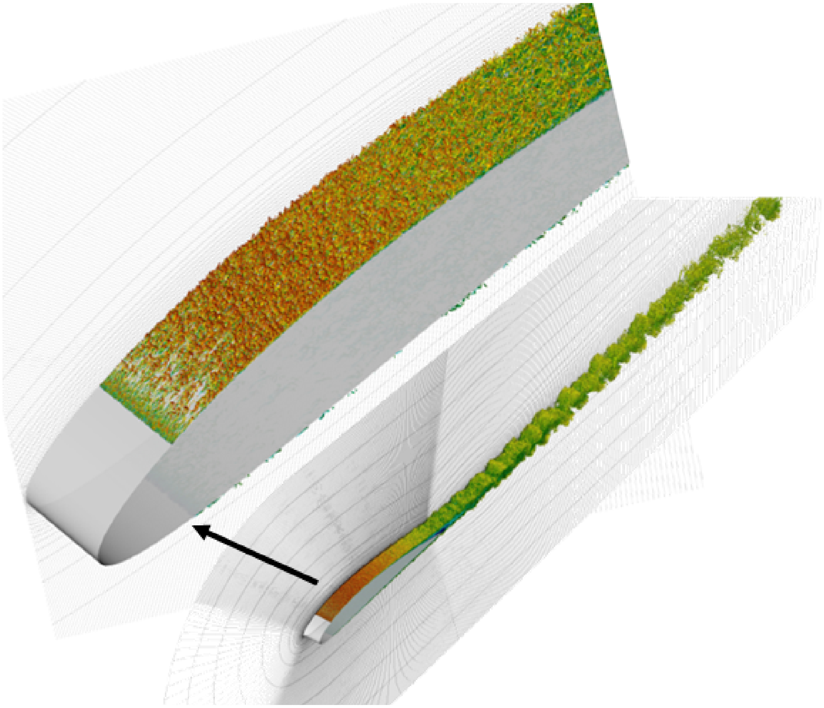
Airframe noise

- Wavepackets in boundary layers?
  - Extension of jet-noise theory to airframe noise
  - Probe numerical databases in search for sound-producing turbulent structures

Sano, Nogueira, Cavalieri, Wolf AIAA 2015

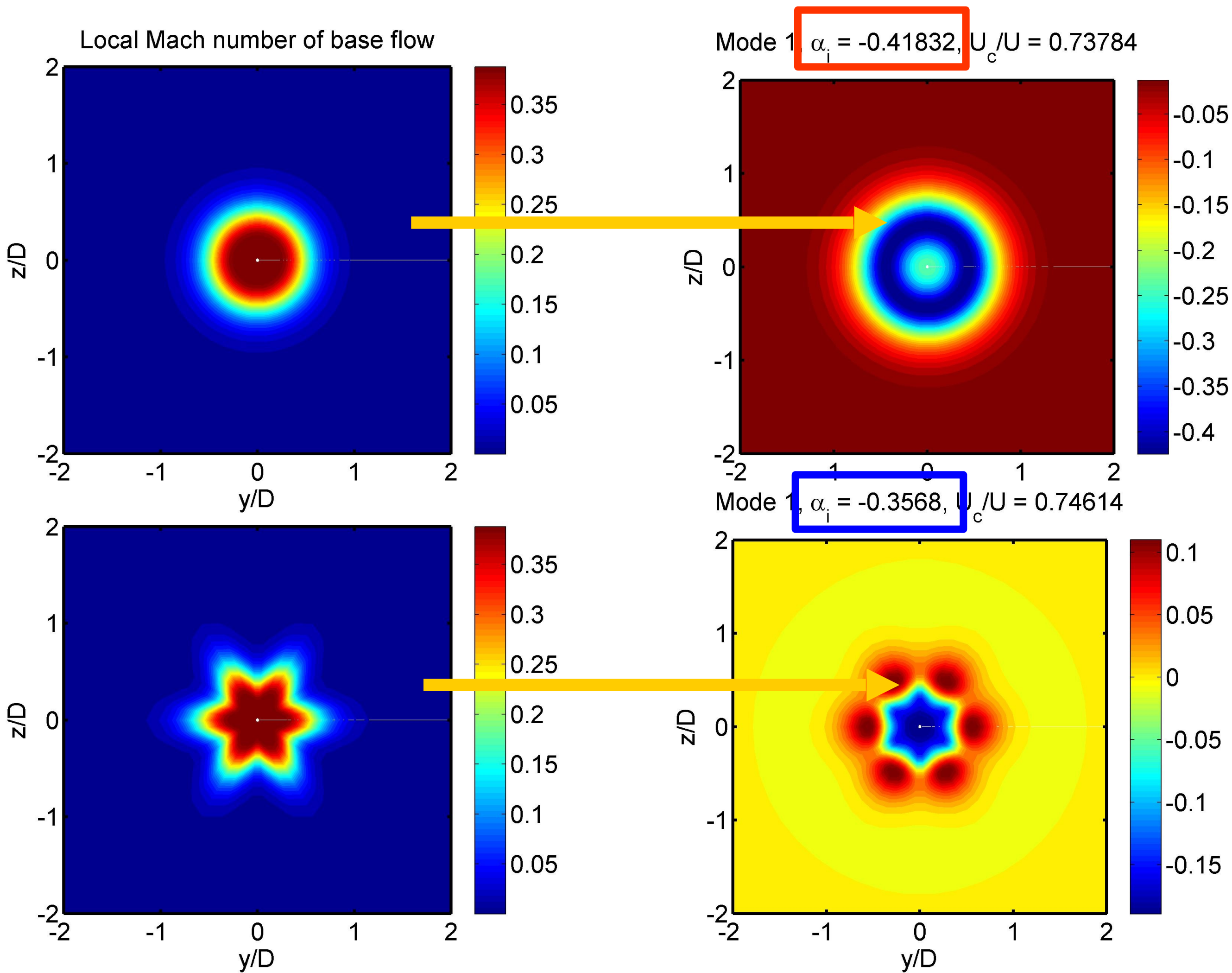


Vinuesa et al. 2015



Control of jet noise

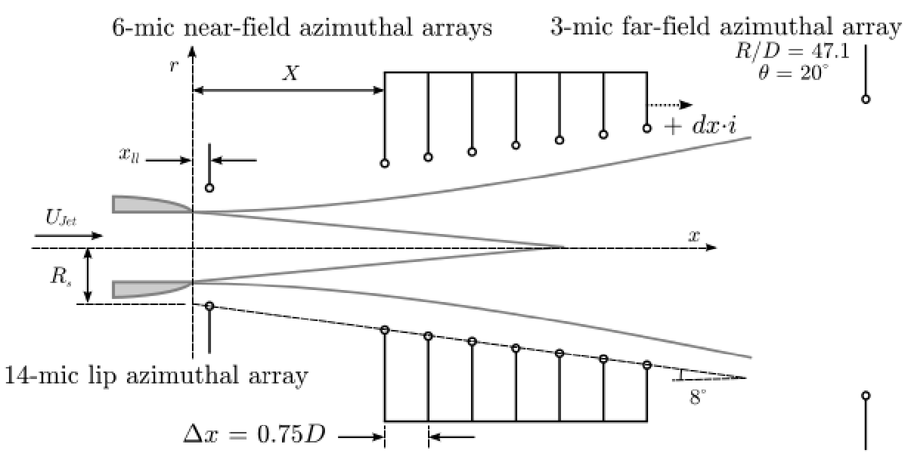
- Chevrons and microjets: reduction of wavepacket amplification



Lajús Jr., Cavalieri, Deschamps AIAA 2015

Towards active control

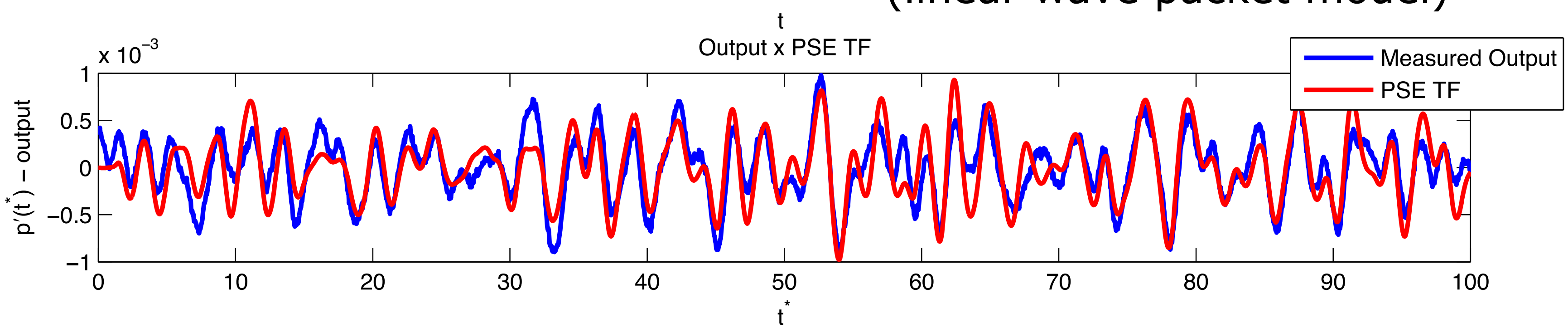
- Use linear theory to derive transfer functions for estimation of states and derivation of control laws



Sasaki, Piantanida, Cavalieri, Jordan AIAA 2015
Silvestre, Cavalieri, Jordan AIAA 2015

Prediction of pressure at **downstream** microphones:

pressure at **upstream** microphones
+
transfer function
(linear wave packet model)



Turbulent jet, experimental!

Contact

André V. G. Cavalieri

andre@ita.br