Pour célébrer les 150 ans de l'École Centrale de Lyon

effervescences LYON

Partageons nos savoirs et nos interrogations

Cycle : Inventer la connaissance

De la recherche fondamentale à l'application dans la vie quotidienne : l'exemple de recherches en acoustique

par Christophe Bailly,

professeur à l'Ecole Centrale de Lyon

www.efferve-sciences.ec-lyon.fr

Turbulence and Noise Generation
Research team of the Centre Acoustique
LMFA, École Centrale de Lyon & UMR CNRS 5509

CENTRE NATIONAL
DE LA RECHERCHE
SCIENTIFIQUE

« Enjeux et retombées des recherches dans l'acoustique des transports »

efferve' sciences, Lyon, 29 nov. 2007

Christophe Bailly

Ecole centrale de Lyon, LMFA, UMR CNRS 5509
& Institut universitaire de France

http://acoustique.ec-lyon.fr

Plan de la présentation

- Cas du transport aérien
  - enjeux & motivations
  - bruit de jet subsonique
  - transport supersonique
  - avion « silencieux » du futur
  - quelques digressions
- Aperçu de quelques autres applications
  - bruit de cavité & contrôle
  - confort du passager : bruit de rétroviseur
  - écoulement confiné supersonique
  - réfrigérateur acoustique
- Perspectives

First jet flight with fare-paying passengers

- De Havilland DH 106 Comet 1 G-ALYP

  2 May 1952 leaving London to Johannesburg

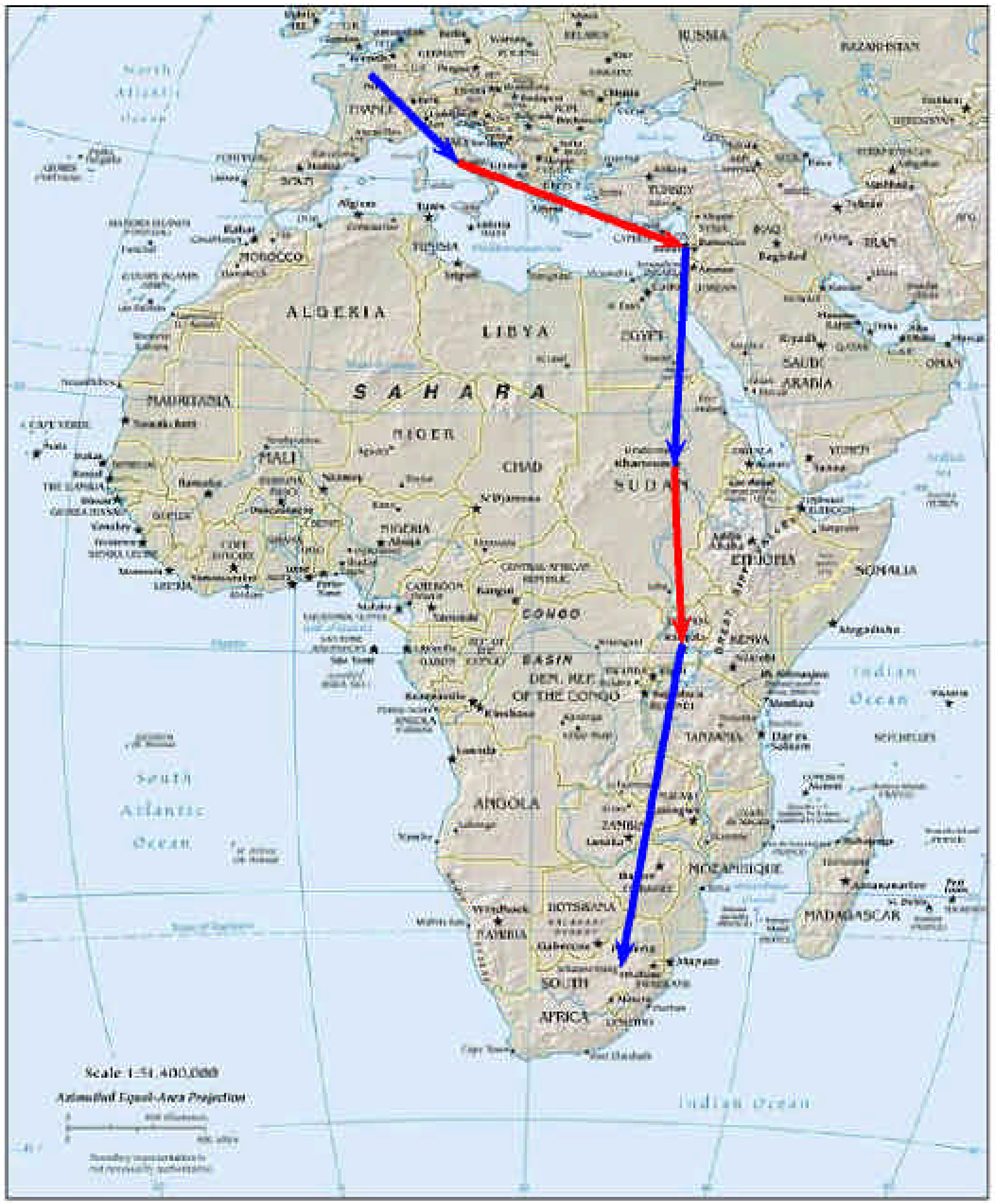
  (5 stops, 36 passengers, return fare 315 £, journey of 23 hours 40')

Heathrow – British Overseas Airways Corporation (BOAC)

http://www.bamuseum.com/

First jet flight with fare-paying passengers

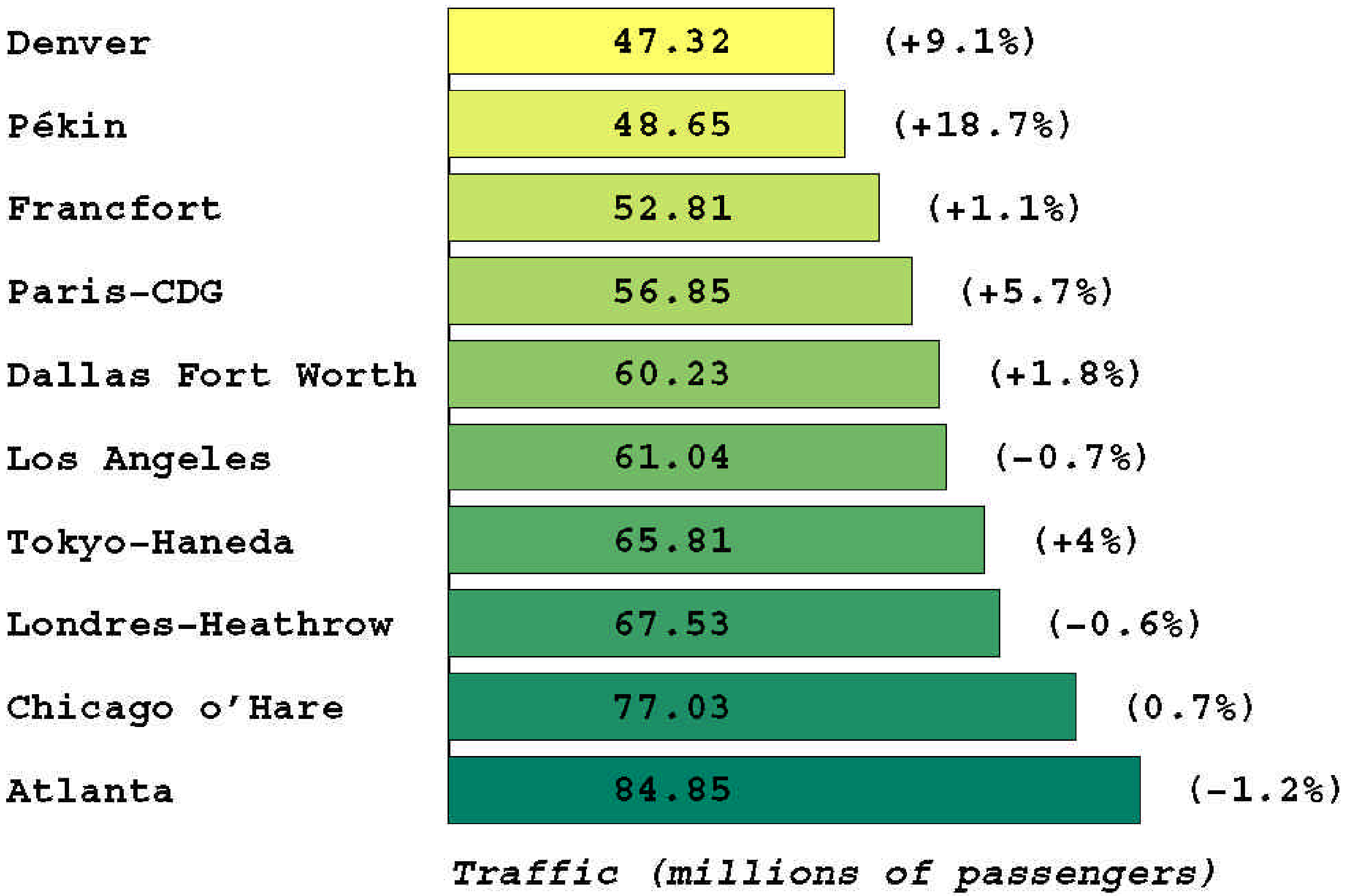
- By way of Rome, Beirut, Khartoum, Entebbe & Livingston



- piston-engine, 27 hours 55′ (on a route 1000 miles shorter)

Traffic growth

- 2006 Top 10 world airports (Airports Council International - July 2007)



- ► long-term traffic forecasts predict that, by 2025, the number of passagers will double

Airport Noise

- Roissy-CDG versus Orly


1974, 23 km from Paris

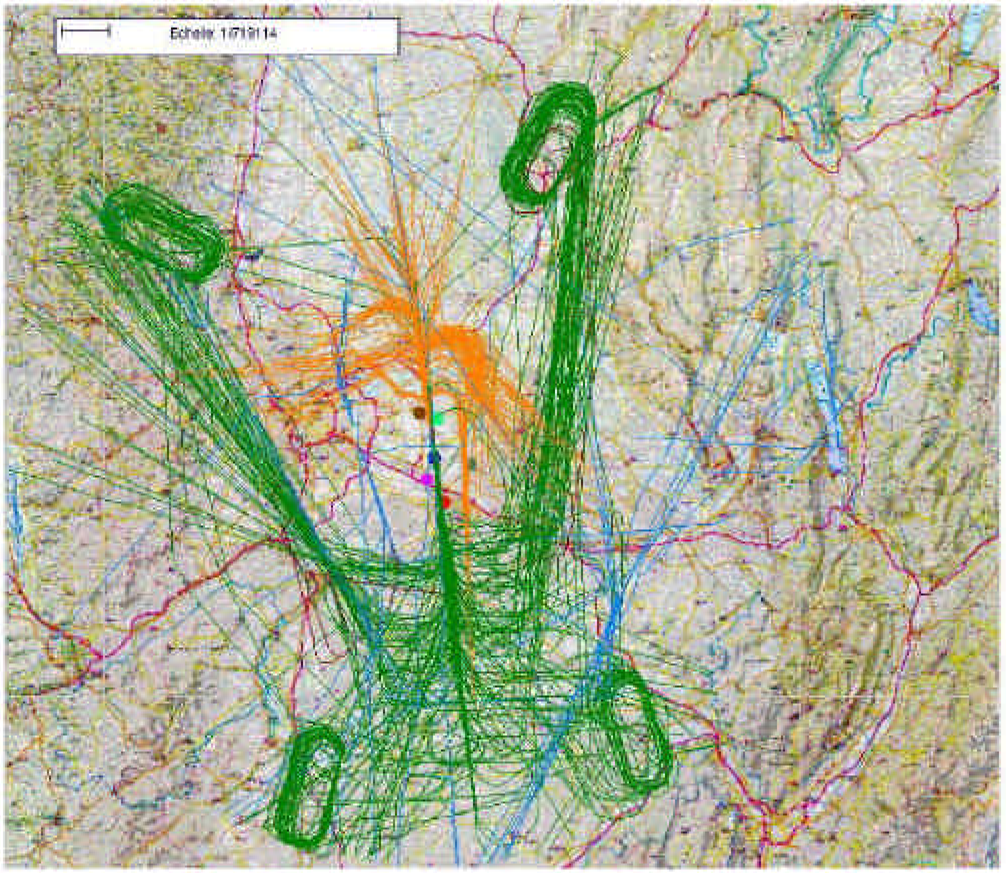

~ 1952 for civil, 14 km from Paris

- Aircraft noise is a major inhibitor of the growth of air transport (airports in key locations are operating at full capacity)
- Traffic growth must be compensated for by quieter aircrafts

Airport Noise

- Saint-Exupéry

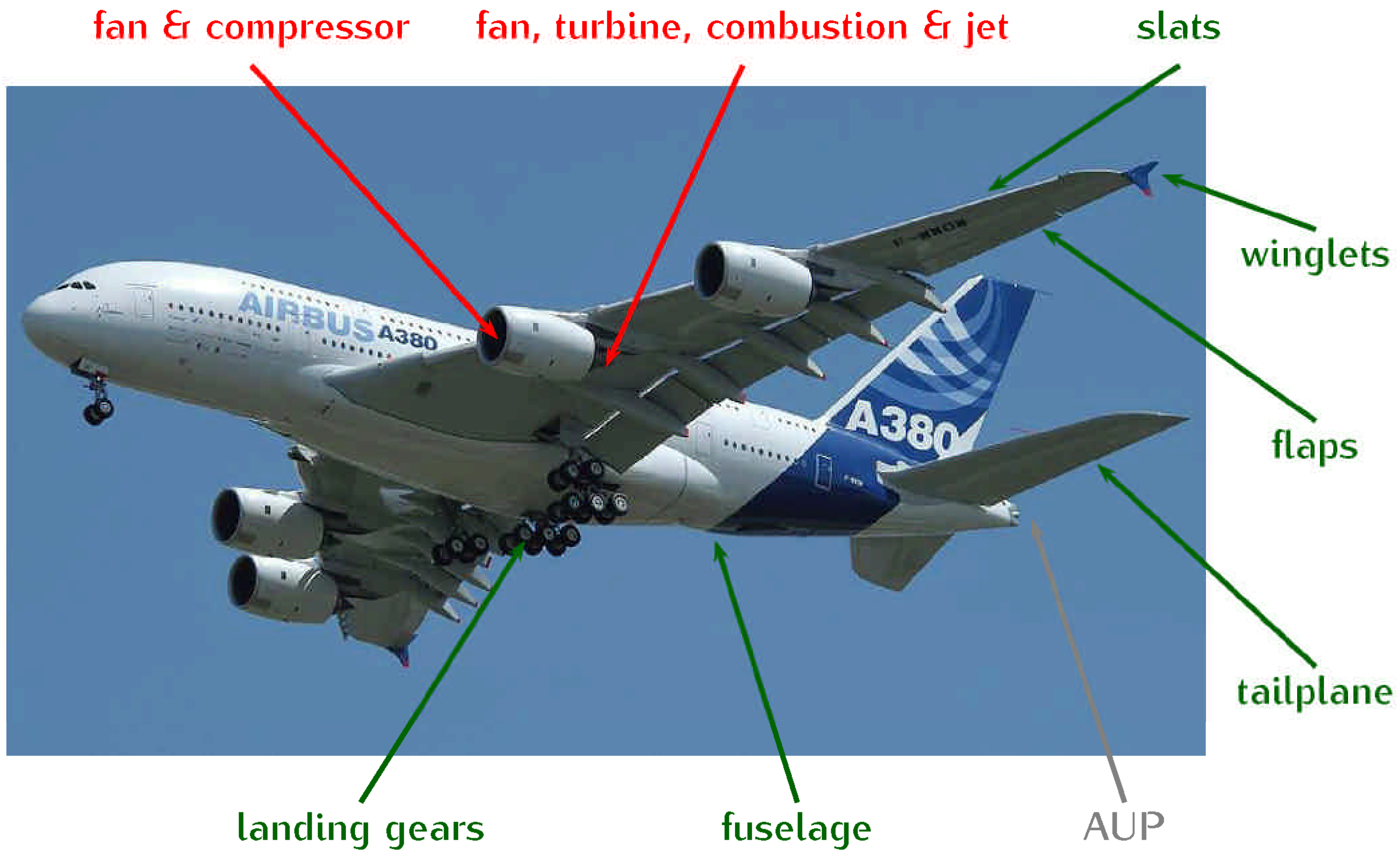
1975, 28 km from Lyon



take-off — landing

Courtesy of Cécile Cuny, aéroport Lyon St-Exupéry.

Aircraft noise sources



Aircraft noise sources

- Noise source localization by microphone array

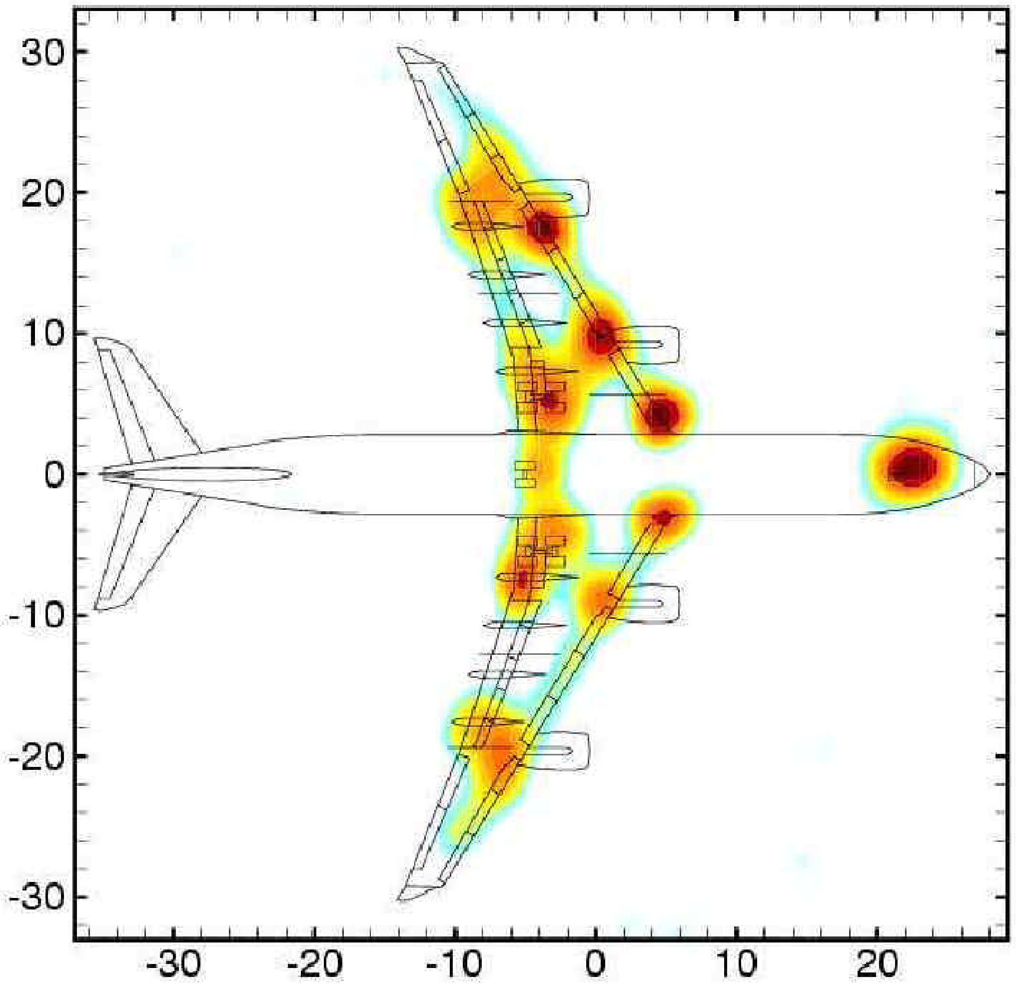
A340 flight tests

Cross-shaped array for lower frequency range (0.2 to 5 kHz, size 32 m, ONERA) and multi-arm spiral array for upper frequency range (2 to 8 kHz, size 4 m, DLR), 196 microphones.

Courtesy of Henri Siller, DLR, Berlin.
See AIAA Papers 2005-3007, 2005-2981 & 2006-2463

Aircraft noise sources

- Noise source localization by microphone array



A340 flight tests

Landing approach configuration - noise sources at 5 kHz one-third octave band for an emission angle of 90°

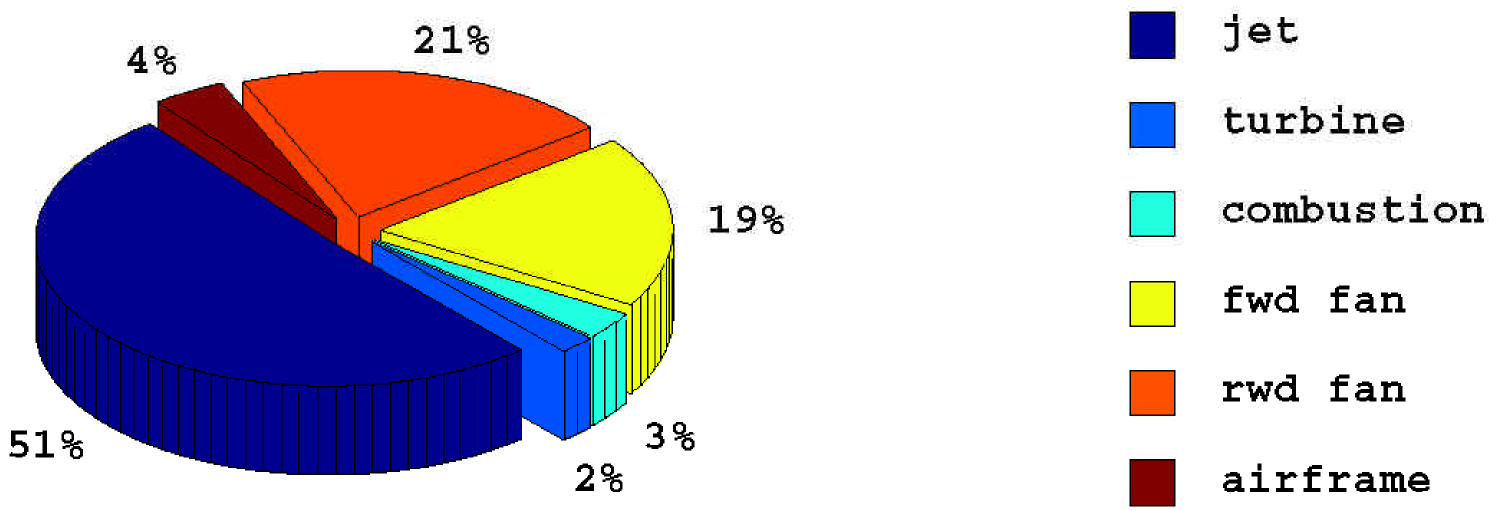
⤳ landing gears, slat horns and also high-lift devices

Courtesy of Henri Siller, DLR, Berlin.
See AIAA Papers 2005-3007, 2005-2981 & 2006-2463

Aircraft noise

- Jet noise during take-off remains the major component of total aircraft community noise (between a third and half of the energy)

Typical noise source breakdown



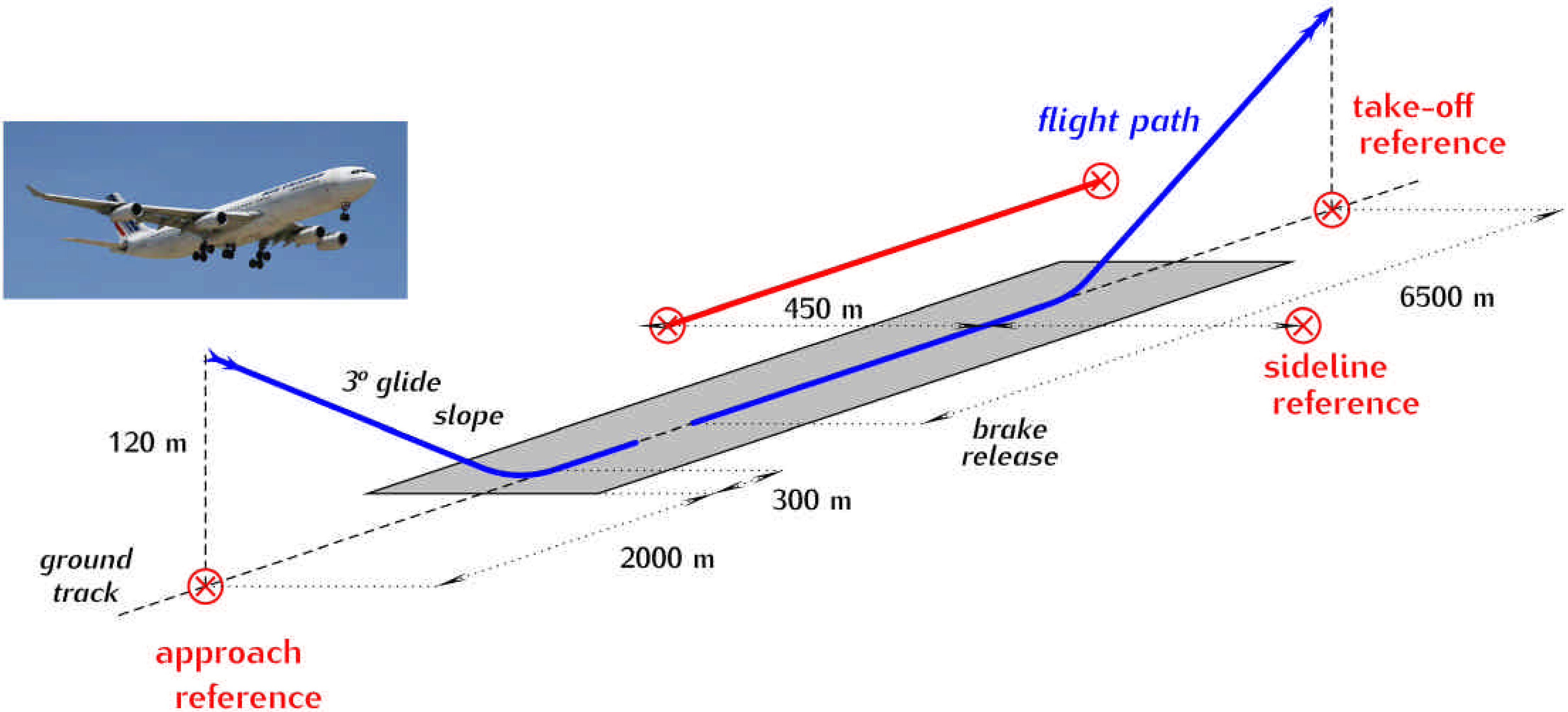
typical long range aircraft with 4 current engines at the sideline point

(only certification point in which engines always operating at full power)

Hubert & Illa, AIAA Paper 2007-3728

- Three noise certification reference points

  sideline reference : the only point in which the engines are always operating at full power

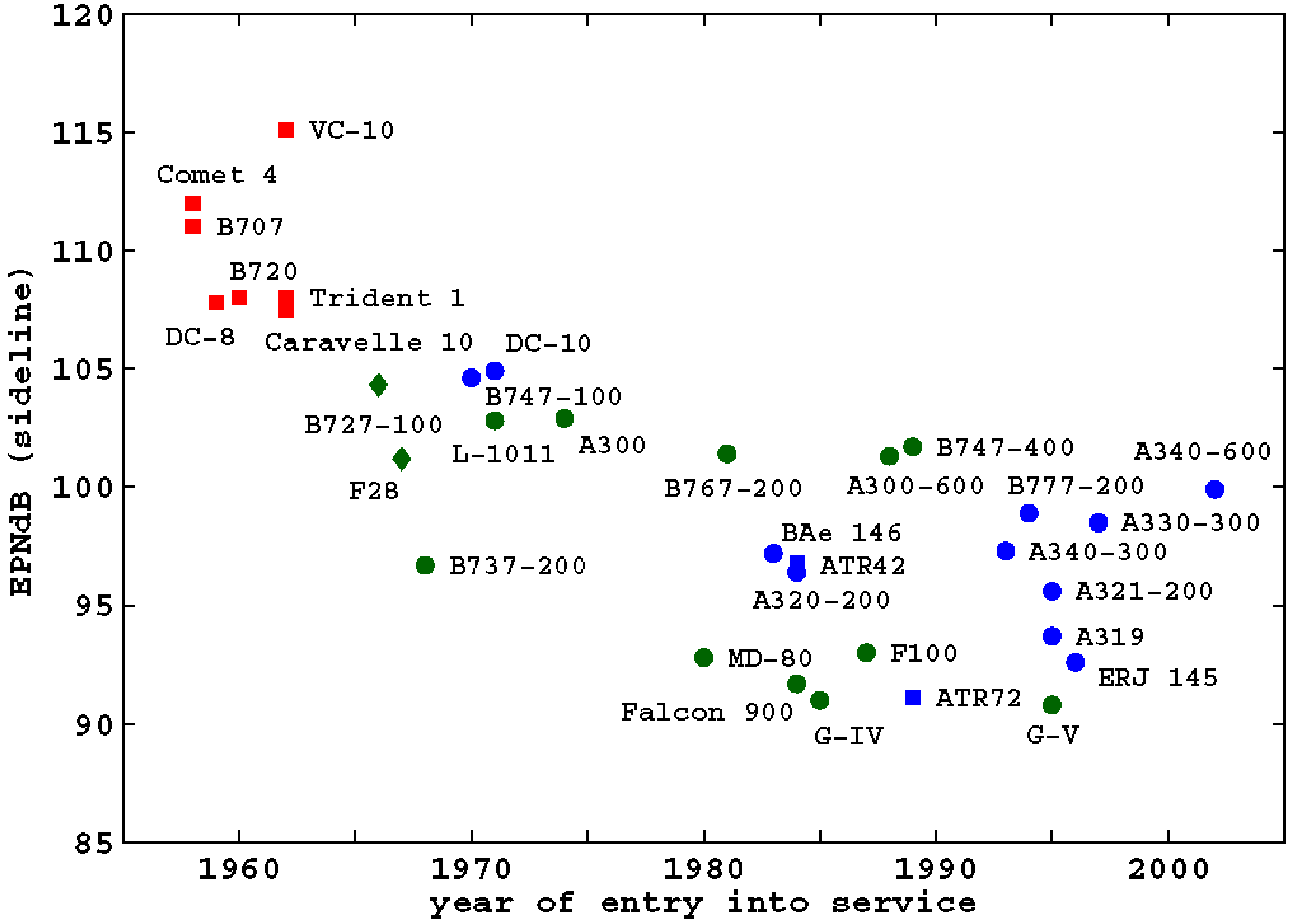


Progress of airplane noise levels

- Sideline noise level

Data taken from Federal Aviation Administration FAA-AC-36-1H (certified)

& FAA-AC-36-2H (uncertified)



Motivations & challenges

- International Civil Aviation Organization (ICAO)

« Noise continues to be the single most significant cause of objections to the operation and expansion of airports in developed and developing countries alike, and public pressure against existing operations and the development of new infrastructure could have a negative influence on the future growth of the aviation industry. » (Executive committee, August 2007)

$\rightsquigarrow$ Aircraft noise reduction at source

- Advisory Council for Aeronautics Research in Europe (ACARE)
European aeronautics : the 2020 vision for a quieter Europe
(January 2001)

« reduce perceived noise by half »

« eliminate noise nuisance outside airport boundaries »

Motivations

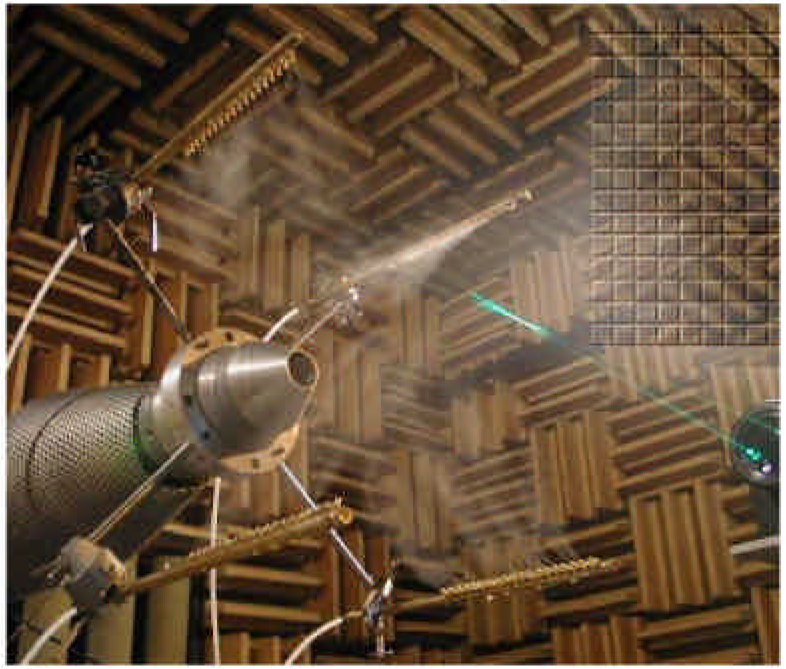
- physics-based predictions for real jets, *i.e.* dual, hot, with co-flow, shock-cells and noise reduction devices

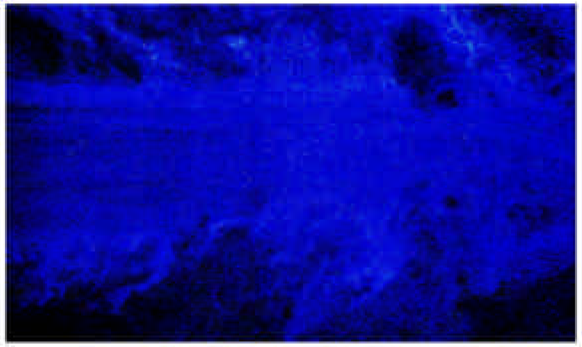
chevron nozzle (sawtooth nozzle)
Trent 800 engine - Boeing 777-200 ER
net engine benefit of ~ 2.5 EPNdB
at takeoff certification conditions (GEAE)

- ► providing reliable predictions and reference solutions
- ► understanding of jet noise mechanisms
- ► giving insight for flow control and noise reduction

Physics of subsonic jet noise

Experiments in high-speed anechoic wind-tunnel

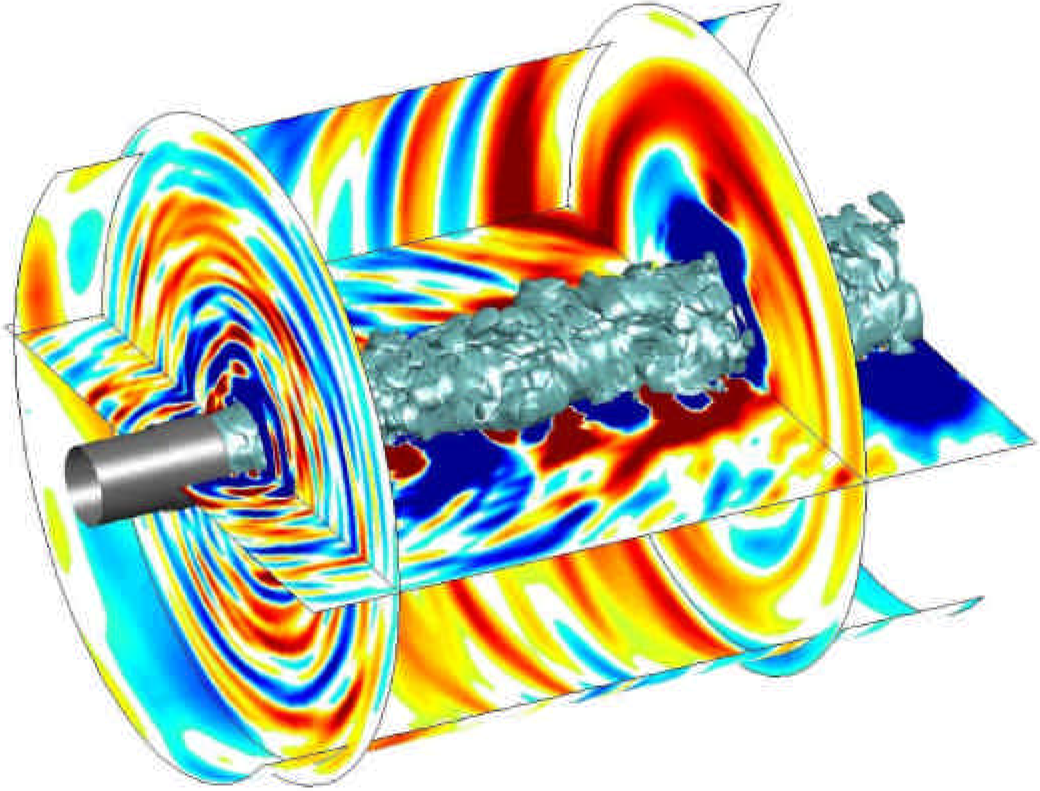




$Re_D \simeq 5.2 \times 10^5 \quad M = 0.6$

V. Fleury (Ph.D. Thesis ECLyon, 2006)

Direct Noise Computation on supercomputers

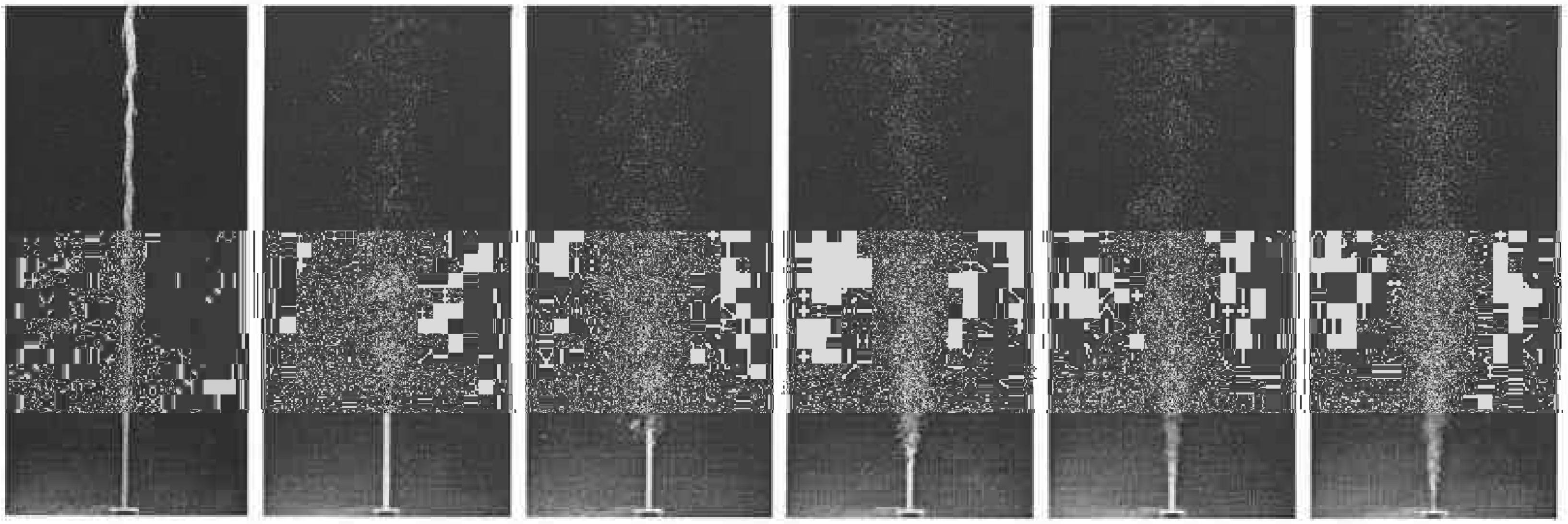


$Re_D = 7.8 \times 10^5 \quad M = 0.9$

S. Barré (Ph.D. Thesis ECLyon, 2006)

Subsonic jet flow

- Reynolds number $Re_D = u_j D / \nu$

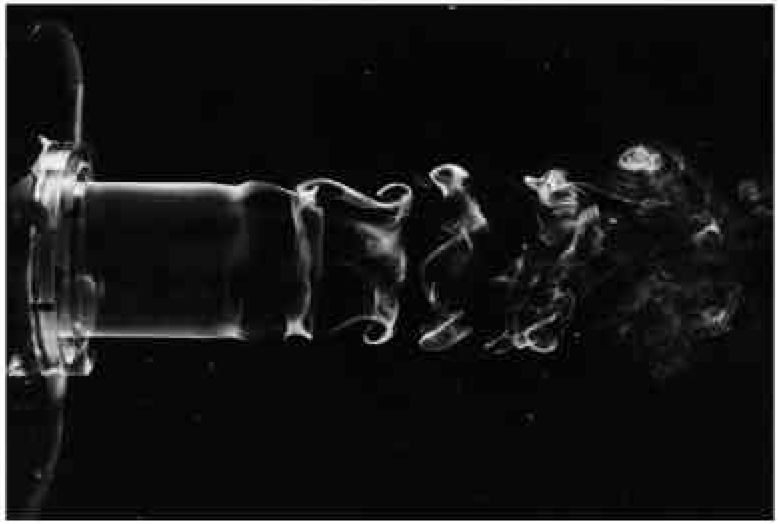


Kwon & Seo (2005)

$Re_D = 177$

to

$Re_D = 5142$



Kurima, Kasagi & Hirata (1983)

$Re_D \simeq 5.6 \times 10^3$

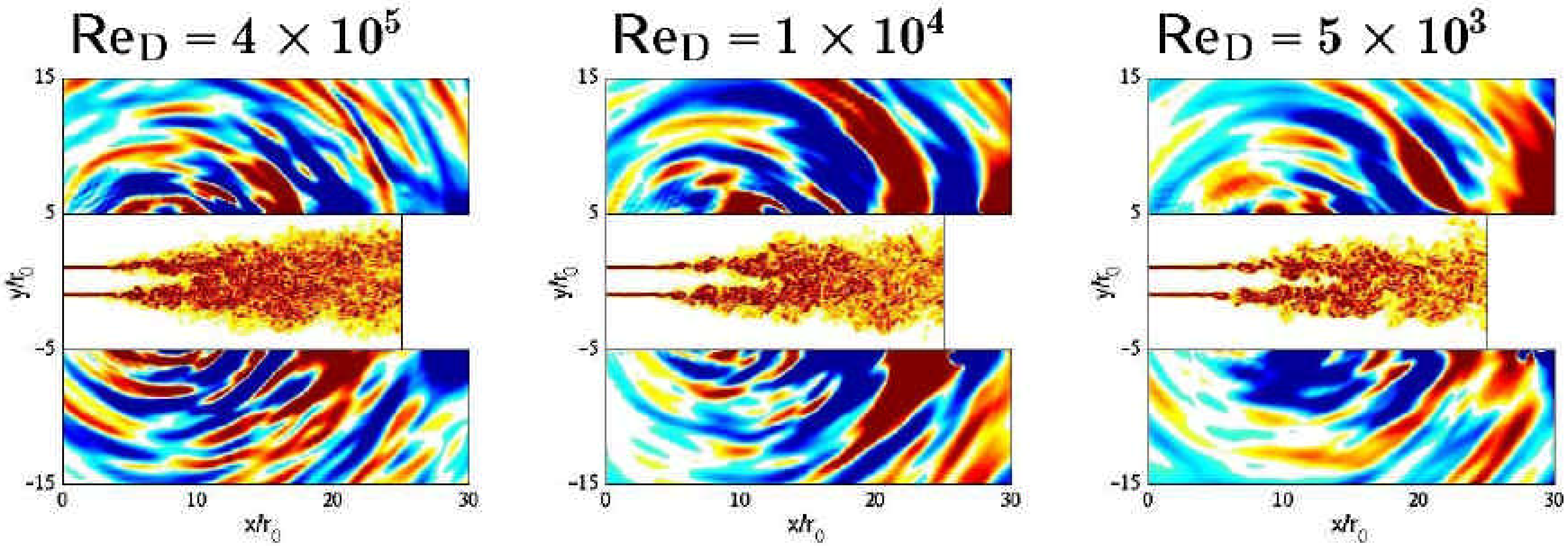
Mollo-Christensen (*MIT*, 1963)

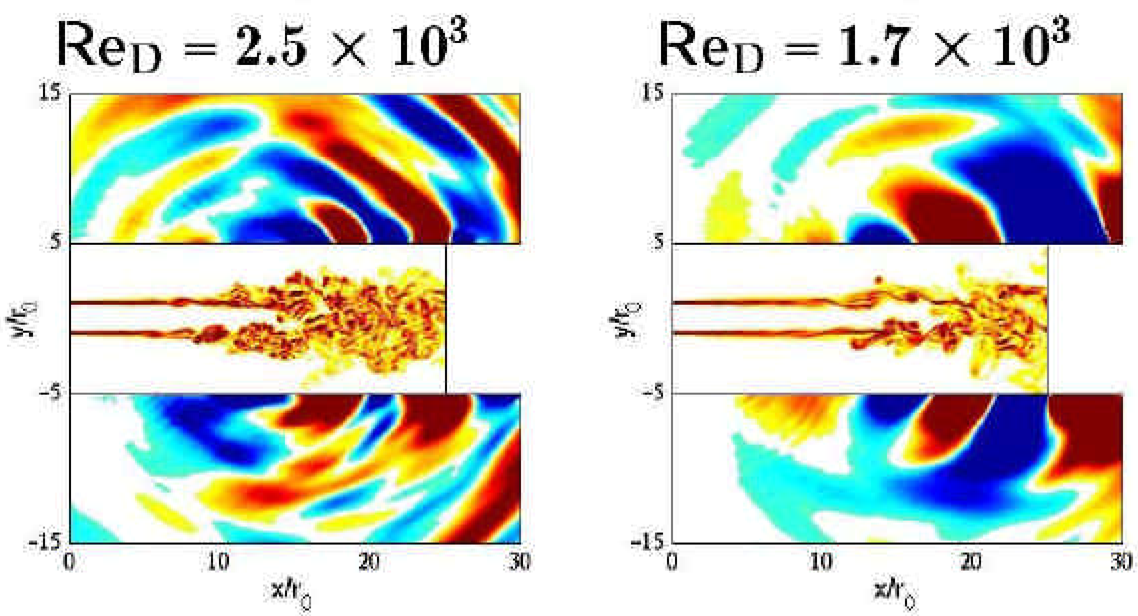
$Re_D = 4.6 \times 10^5$

Physics of jet noise

- Reynolds number dependence

Theoret. Comput. Fluid Dyn. (2006)
Bogey & Bailly, *J. Fluid Mech.*, 2007, 583





Jets at $M = 0.9$

snapshot of vorticity and pressure

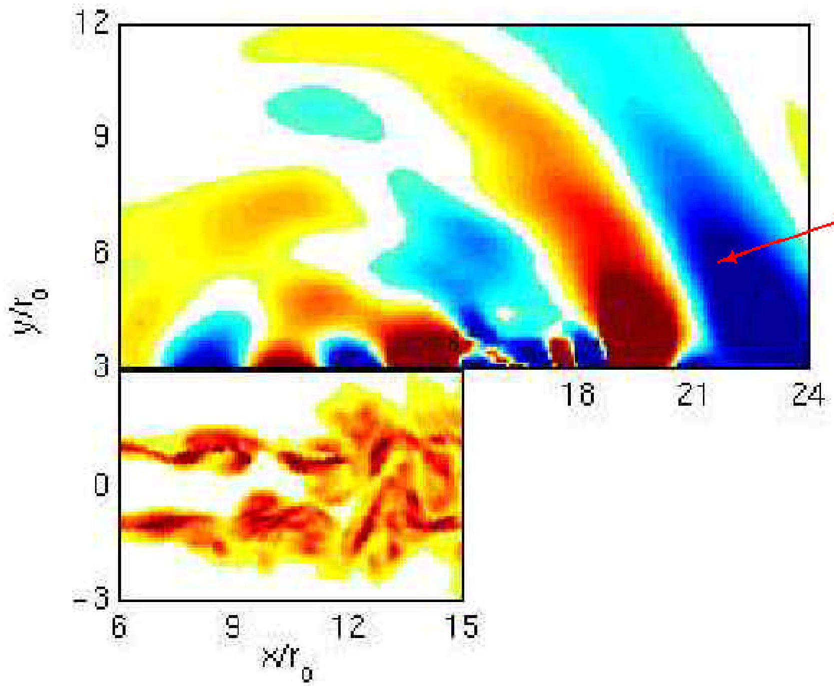
plane $z = 0$

Physics of jet noise

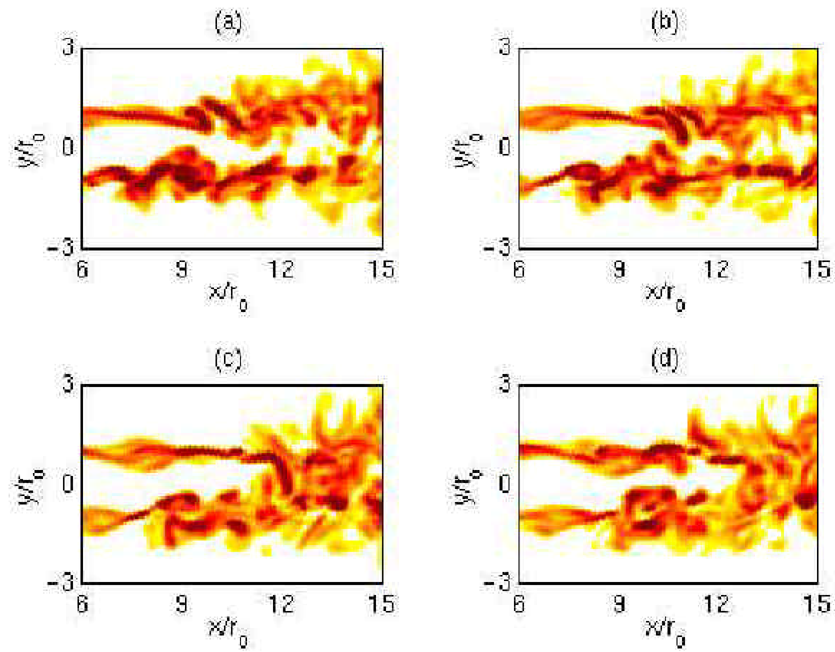
- Previous study : simultaneous flow / noise visualizations

  Jet at $M = 0.9$ and $Re_D = 65000$

Particular downstream sound wave



Vorticity norm around the emission time



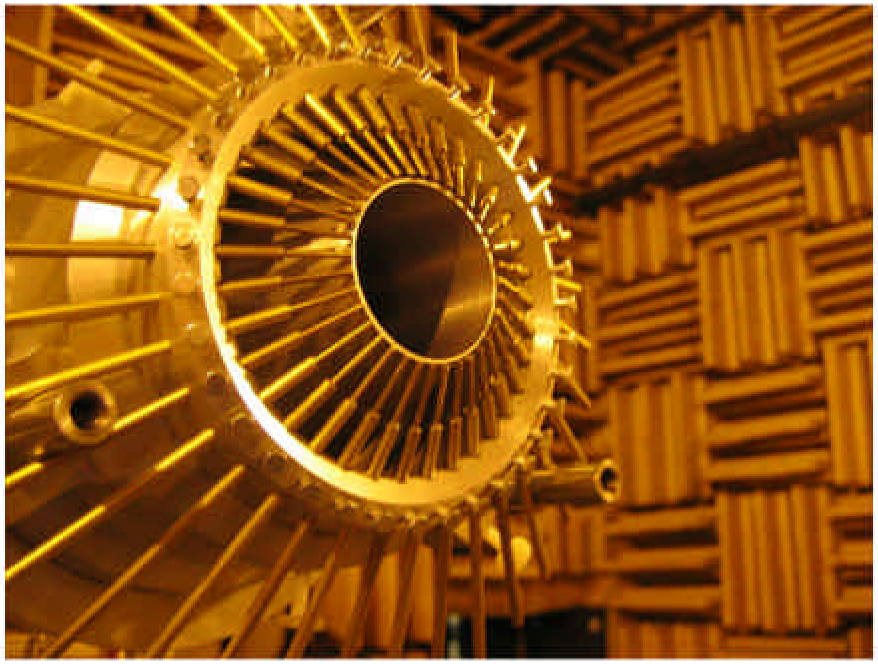
$\rightsquigarrow$ **periodic intrusion of vortical structures into the potential core** (with sudden acceleration of these structures)

Bogey *et al.*, *Theoret. Comput. Fluid Dyn.*, 2003, 16(4)

- **Efforts on jet noise reduction**

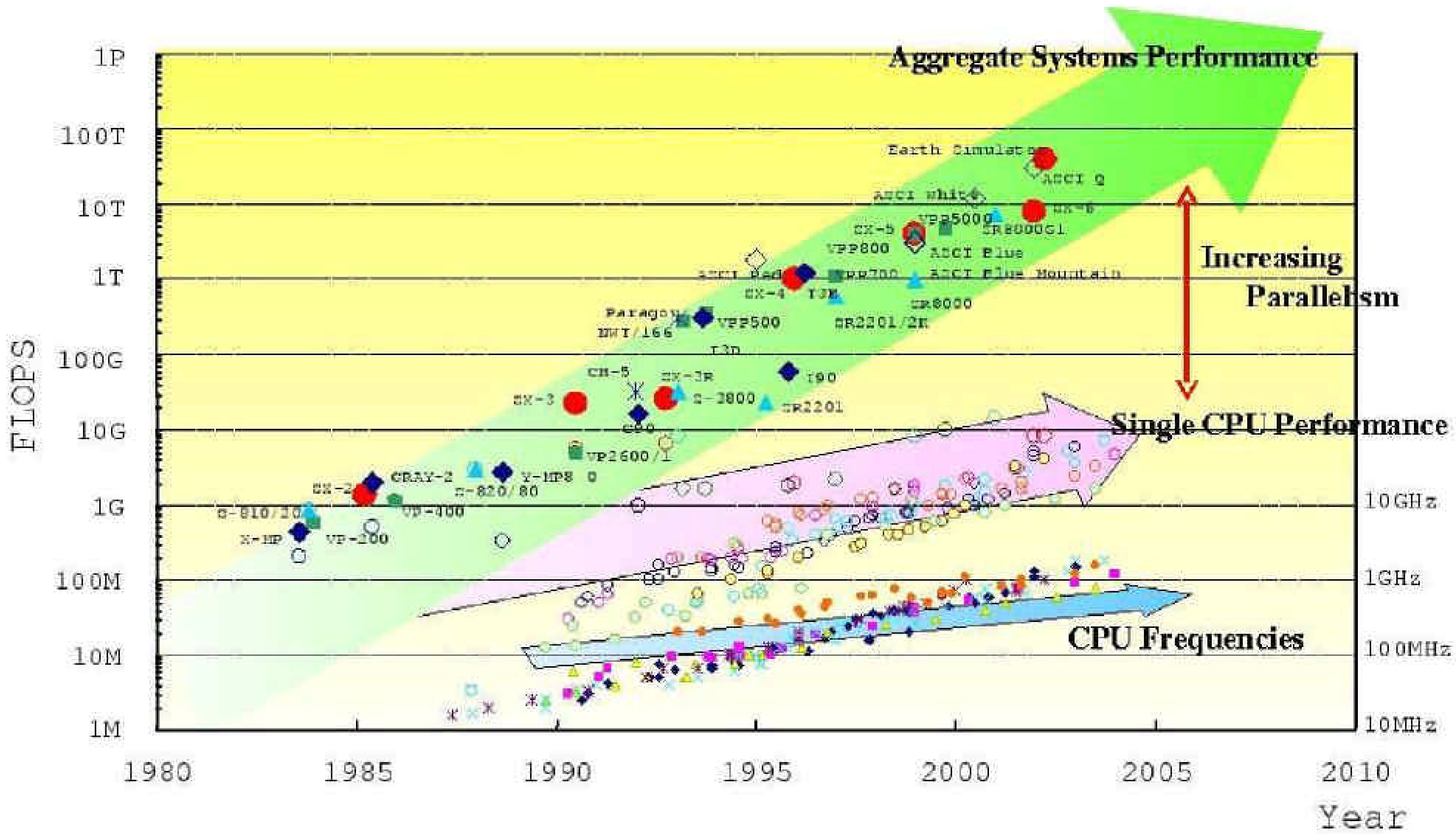
  shape optimization, variable geometry chevrons or fluidic actuators

Chevrons tested on 777-300ER
(GE90- 115B engines)



Castelain (Ph.D., ECLyon, 2006) *et al.*
AIAA Paper 2006-2705

- Évolution des ressources informatiques



http://www.top500.org

Ressources informatique scientifique

- ## BlueGene/L

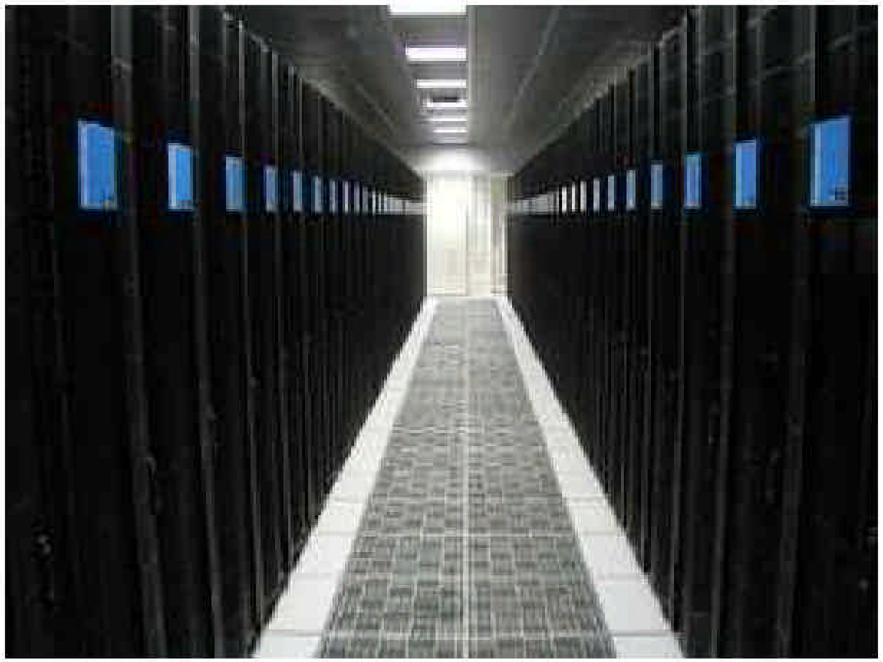
  Lawrence Livermore National Laboratory, CA, USA for DOE/NNSA/LLNL
  IBM, 131072 CPUs, **367 TFlops, rank 1**

► Two other systems exceeded 100 TFlop/s, Cray XT4/XT3 (rank 2) and Cray Red Storm (rank 3), both located in California.

Ressources informatique scientifique

- Tera-10

  Bruyères-le-Châtel, CEA-DAM, Bull, 9968 CPUs, **64 TFlops, rank 12**



⇝ one of the three most powerful supercomputers in Europe

- 27 Terabytes of memory
- area of 800 m^2
- total power of 1.5 megawatts
- 50 M€ investment, budget of 10 M€ /yr, 60 engineers

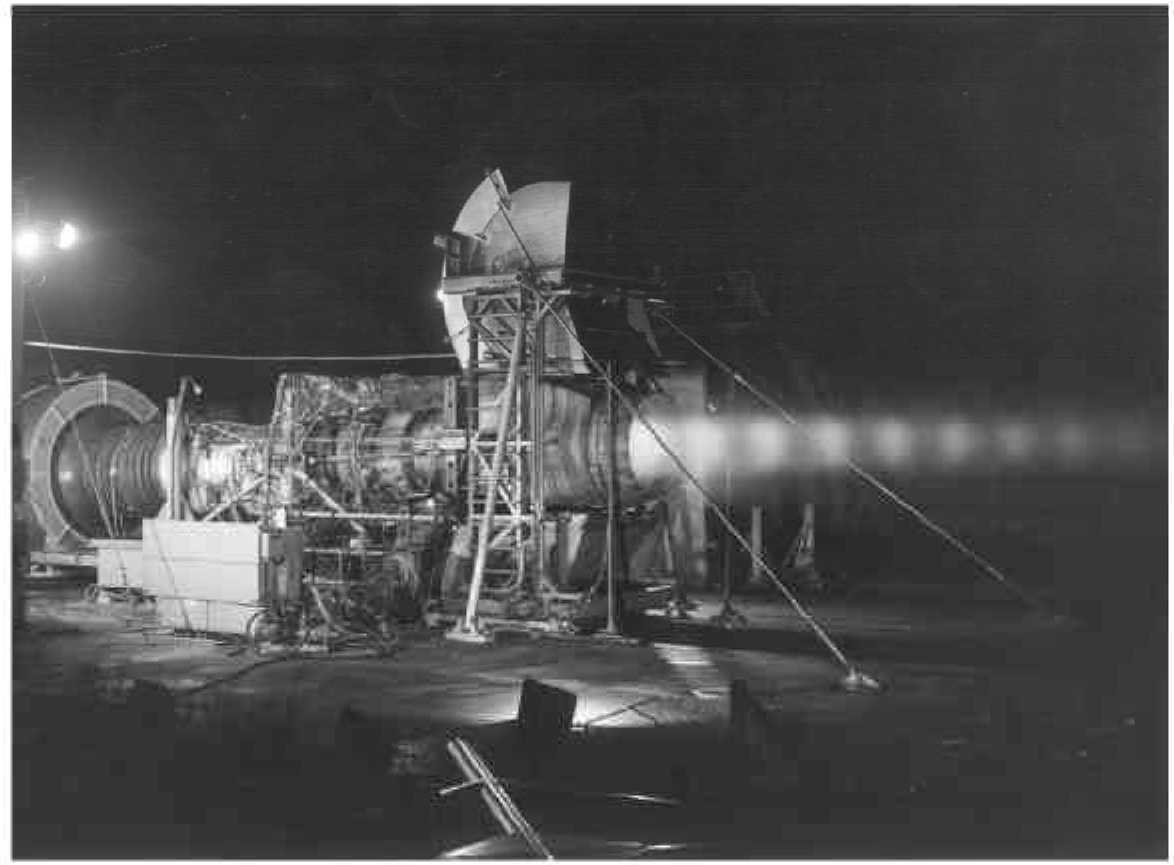
► Next generation will reach 100 TFlops (expected in 2009)

USA 56.20%, UK 8.40%, Germany 4.80%, Japan 4.60%, China 2.60%, France 2.60%, Canada 2%, Sweden 2%, Taiwan 2%, ...

Military and supersonic transport aircrafts

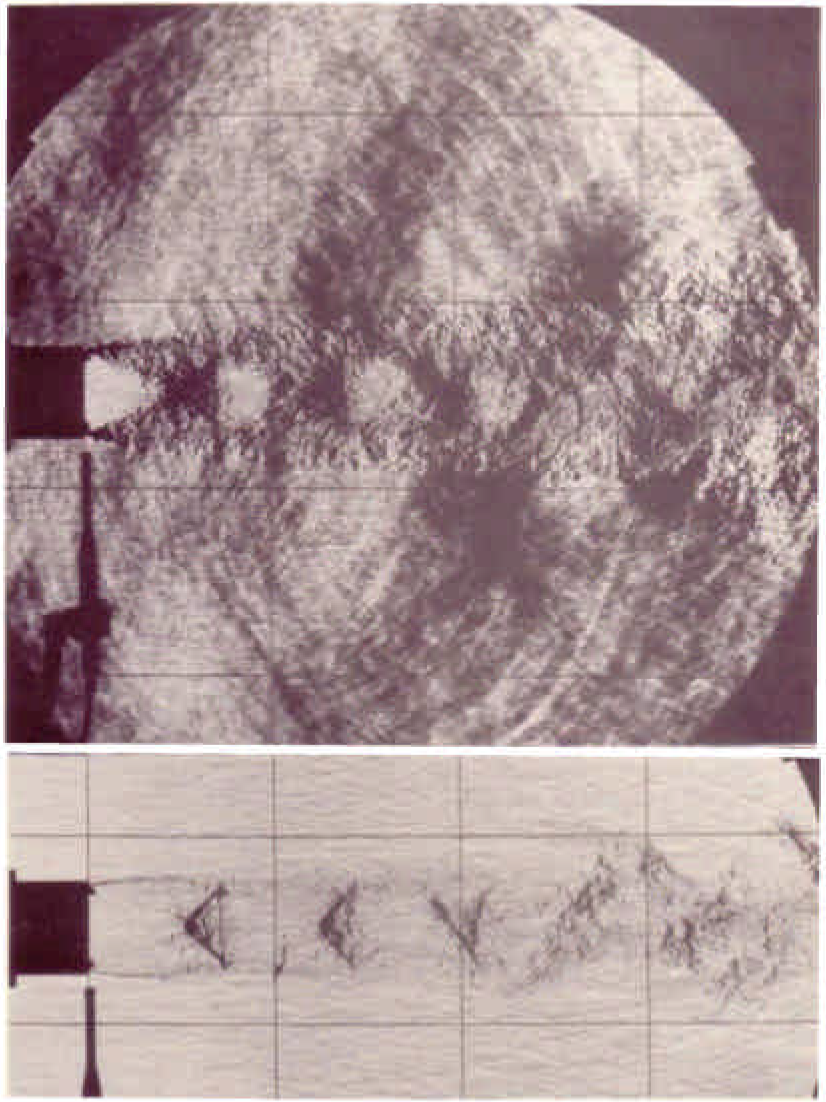
- Supersonic jet noise

Bell X-1 (1947) flying at Mach 1.07
(altitude 19 km → 22 km)



Olympus 593 Mark 610
(Rolls-Royce & Snecma, 1966)

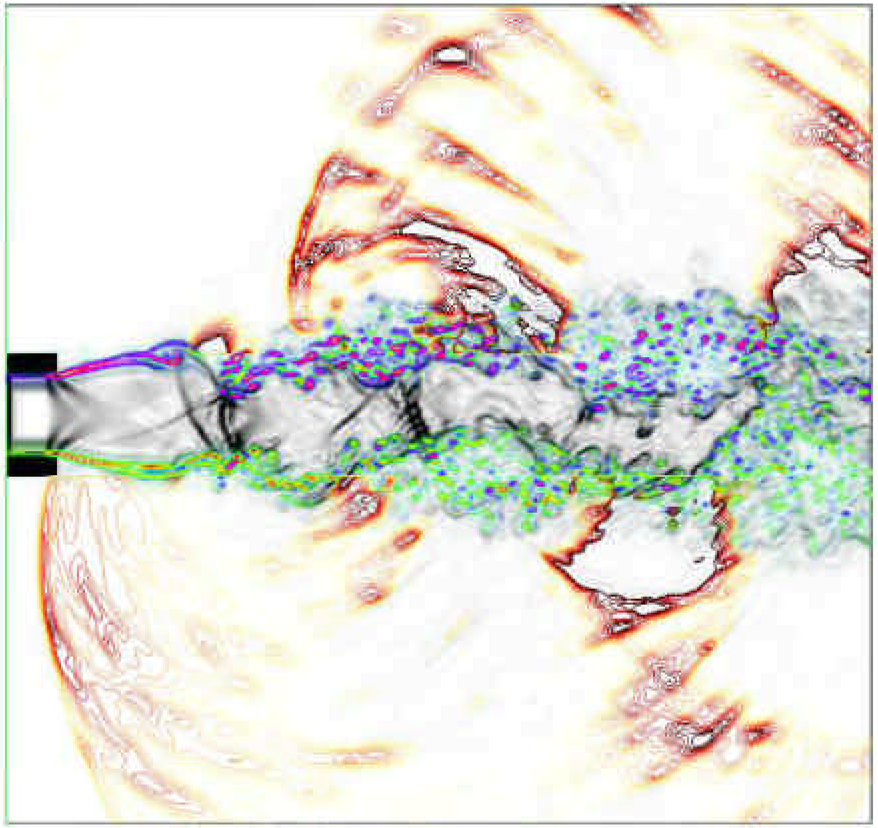
Supersonic jet noise



$p_R/p_\infty = 2.48$, $D = 5.76$ cm

$p_e/p_\infty = 2.48$, $M_j = 1.67$

Westley & Wooley, Prog. Astro. Aero., 43, 1976



Computation of the generation of screech tones in an underexpanded supersonic jet

$M_j = 1.55$ & $Re_h = 6 \times 10^4$

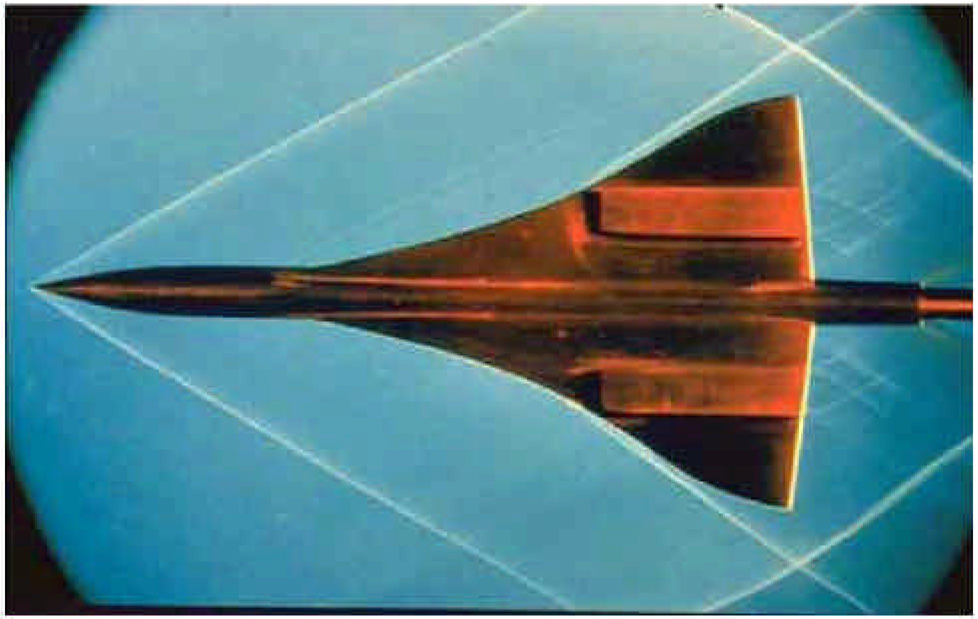
$p_e/p_\infty = 2.09$

Berland, Bogey & Bailly, *Phys. Fluids*, 19, 2007

Military or supersonic transport aircrafts

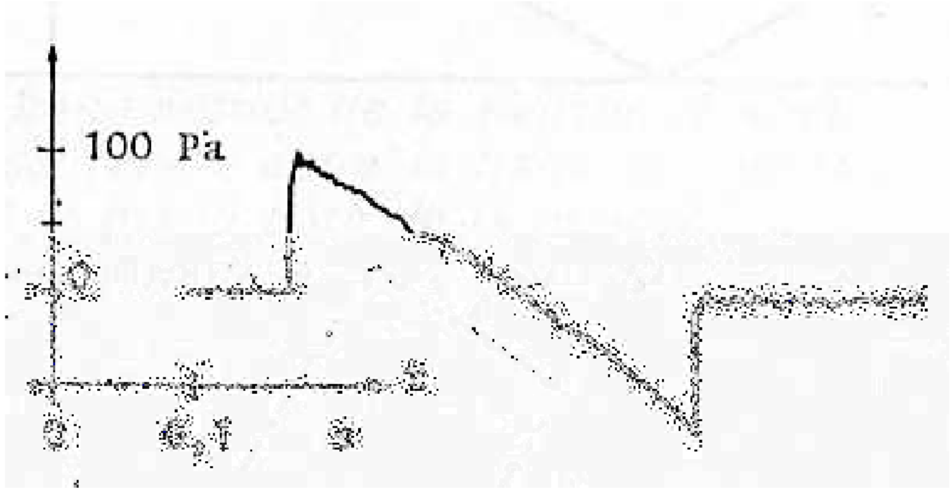
- Sonic boom : a special case of airframe noise

F/A-18 Hornet
passing through the sound barrier
(Navy Ensign John Gay, July 7, 1999)



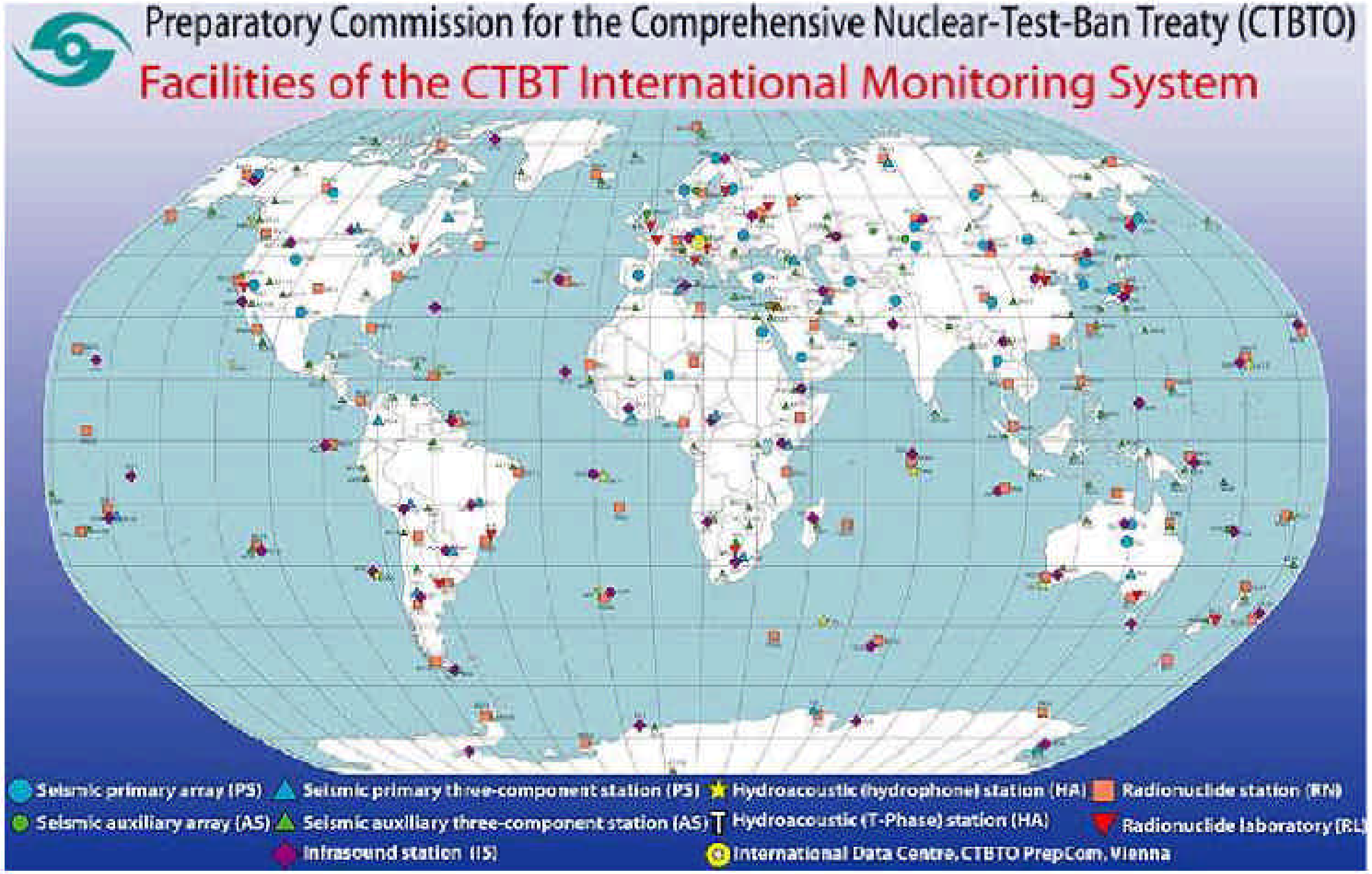
Concorde - Shock waves at Mach 2.2 in wind tunnel (ONERA)

N-wave pattern measured close to the ground from Concorde



Long-range propagation in the Earth's atmosphere

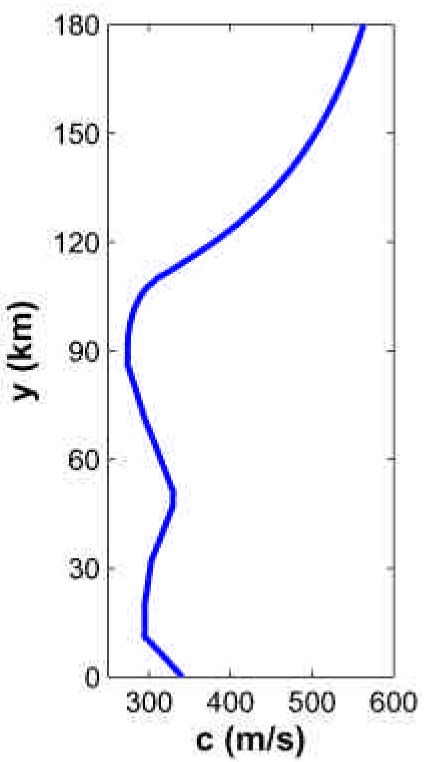
- Infrasound propagation ($f \leq 1$Hz) http://www-dase.cea.fr
  Comprehensive Nuclear-Test-Ban Treaty (CTBT)

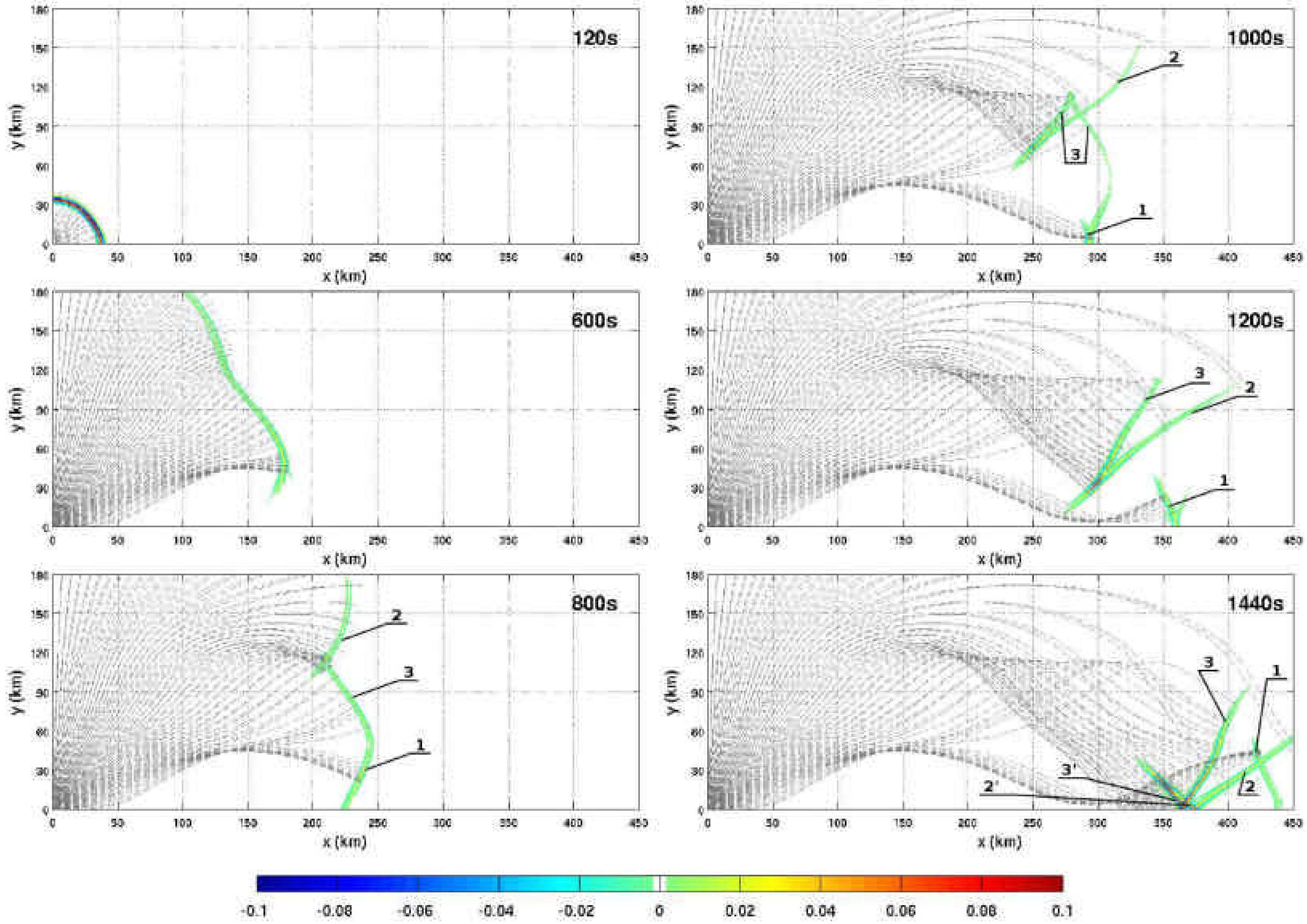


► **Generation of infrasound signals** : supersonic aircraft, space shuttle, rockets, meteorite, active volcano, industrial or military explosions, bombings, ...

« Misty Picture » experience (1987)

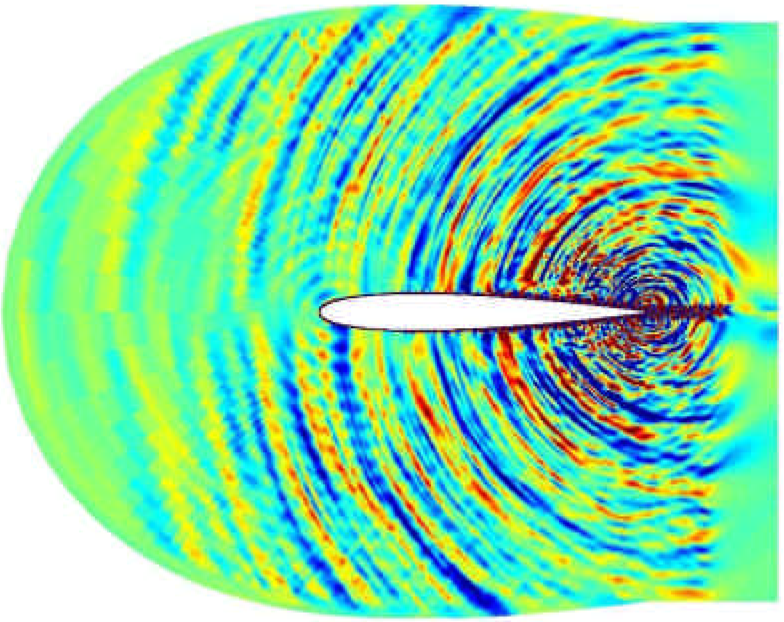
- Time history of the pressure field





Turbulence & aerodynamic noise generation

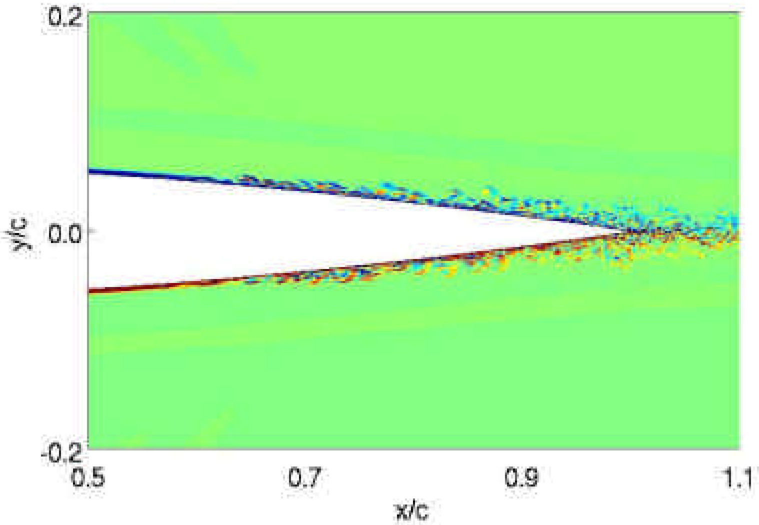
- Direct Noise Computation around a NACA 0012 airfoil
  Chord-based Reynolds number $Re_c = 5 \times 10^5$ – Mach number $M_\infty = 0.22$



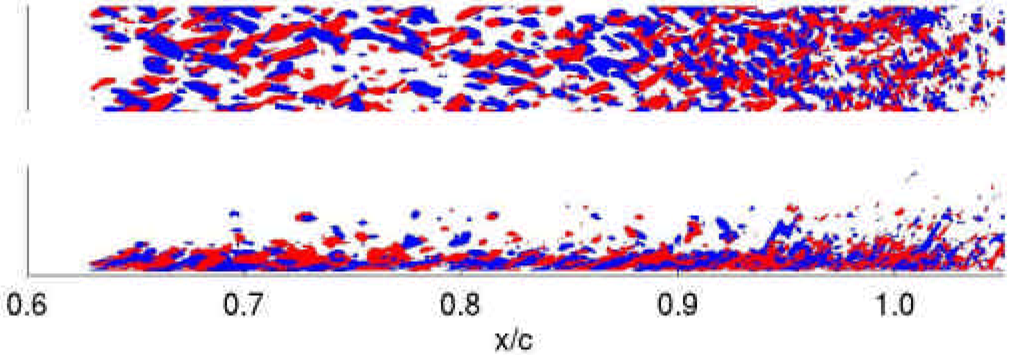
fluctuating pressure field

(color scales between ±5 Pa)

Marsden *et al.*, 2006, AIAA Paper 2006-2503
to appear in *AIAA Journal* (2008)



ω_z vorticity around the trailing edge



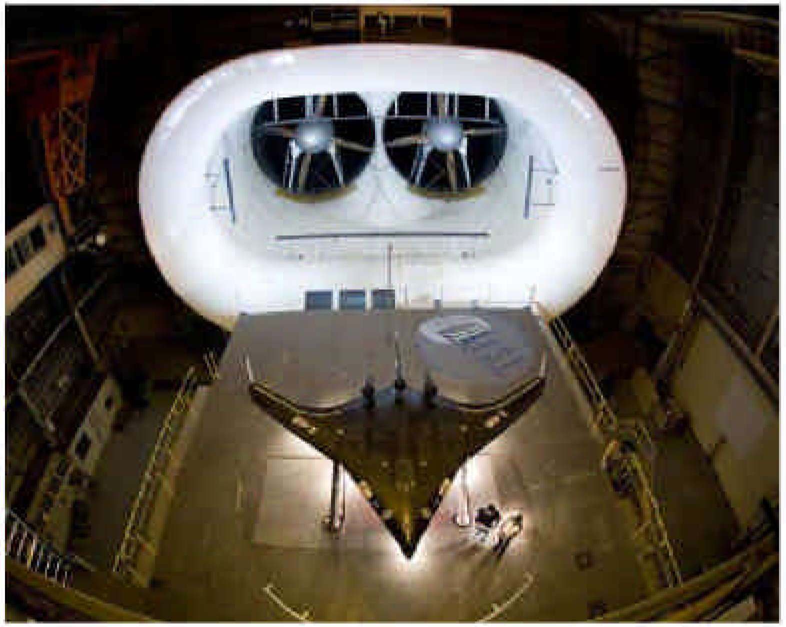
ω_x vorticity, blue and red surfaces correspond to $\pm 1.5 \times 10^5$ s^{-1}

« Quiet » aircraft

- X-48B Blended Wing Body (NASA)

B-2 stealth bomber

remote-controlled scale model (21ft wingspan)



Langley wind tunnel (NASA)

« Silent » aircraft

- **Silent Aircraft Initiative - SAX-40**

  Project managed by Ann Dowling from Cambridge University's Engineering department (UK) in collaboration with the MIT (US)

  40 researchers to design a new airplane $\leadsto$ **vast noise reduction at low altitude**

Next Airbus airplane - A350-XWB (Xtra Wide-Body)

- Specifications : Carbon Fibre Reinforced Plastic (CFRP) panelled fuselage, ...

http://www.eads.net

Plan de la présentation

- Cas du transport aérien
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- Aperçu de quelques autres applications
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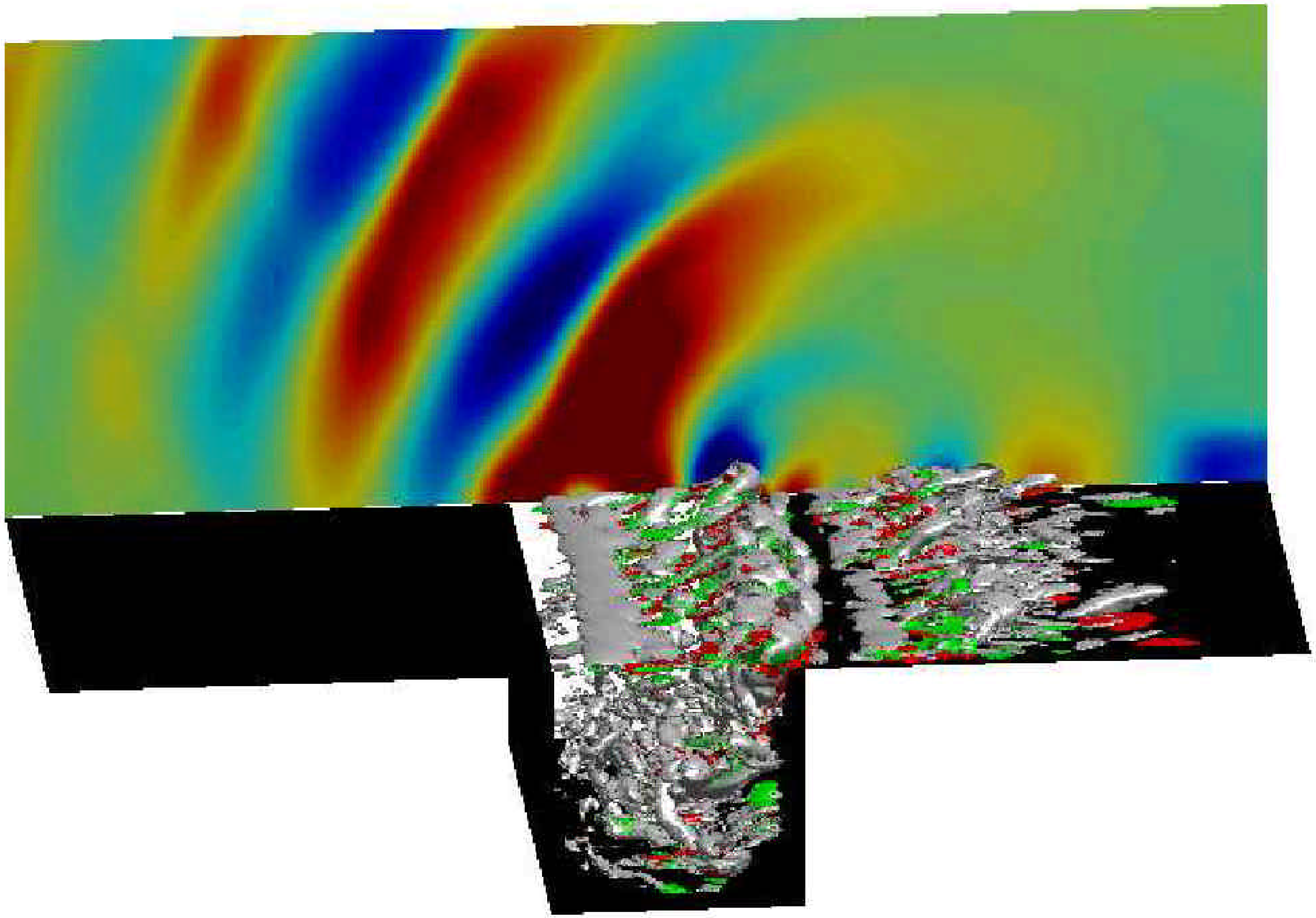
Noise radiated by a rectangular cavity



M= 0.6, $Re_D = 28700$, $L/D = 1$, $L/W = 0.5$, $L = 2$ mm

Gloerfelt, Bogey, Bailly & Juvé, AIAA Paper 2002-2476

Q-criterion

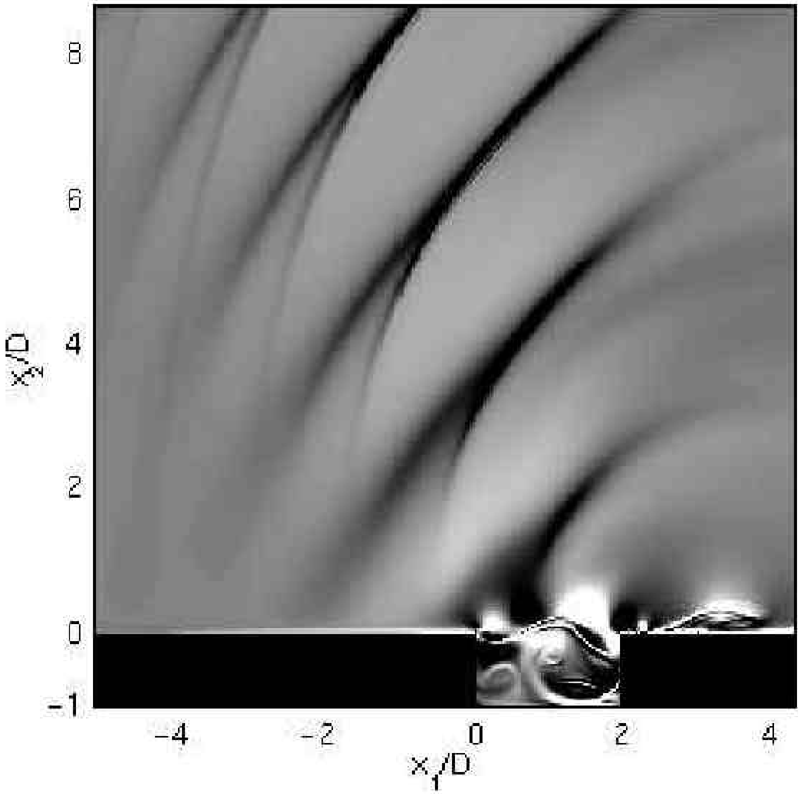
$$Q = \frac{1}{2}\left(\omega_{ij}\omega_{ij} - s_{ij}s_{ij}\right)$$

$\omega_{yz} > 0$ $\omega_{yz} < 0$

Noise radiated by a rectangular cavity

- Direct computation of aerodynamic noise

DNS



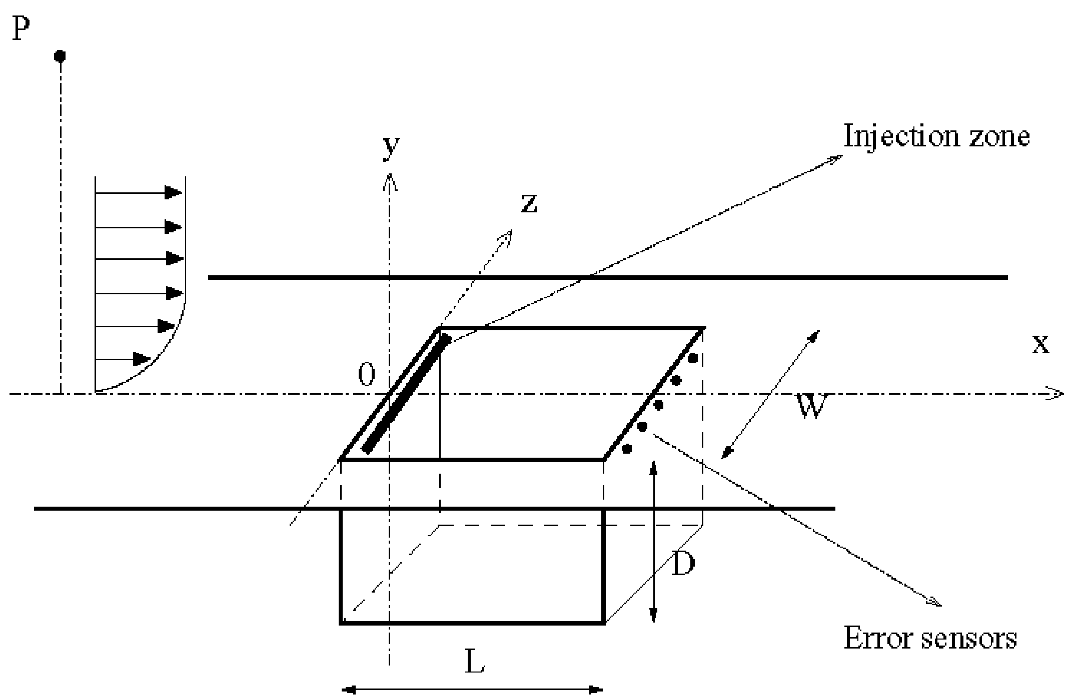
Karamcheti's experiment

full scale DNS, $L/D = 2$ ($D = 2.54$ mm), $M = 0.7$, $Re_D = 41000$

Gloerfelt, Bailly & Juvé, 2003, *J. Sound Vib.*, 266(1)

Adaptative active control of cavity noise

- **Feedback** algorithm (leaky LMS, IIR filter)



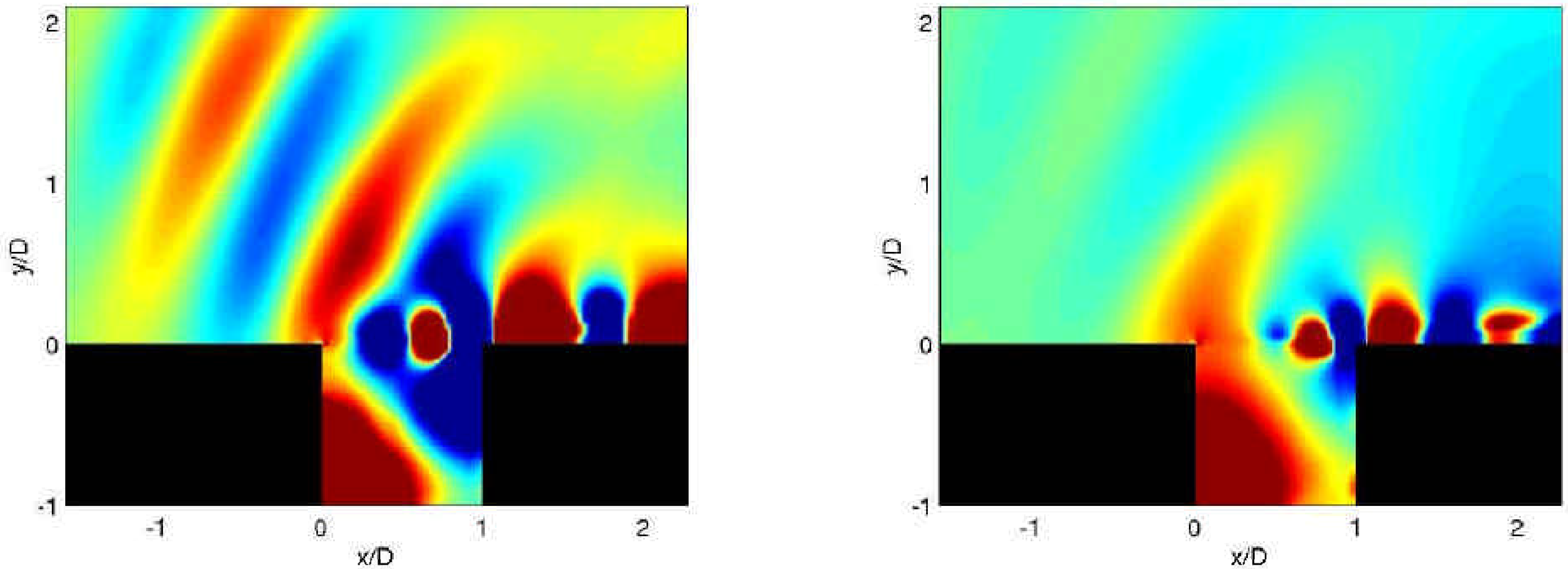
3-D cavity : $L/D = 1$, $L/W = 1.28$, $L = 2$ mm

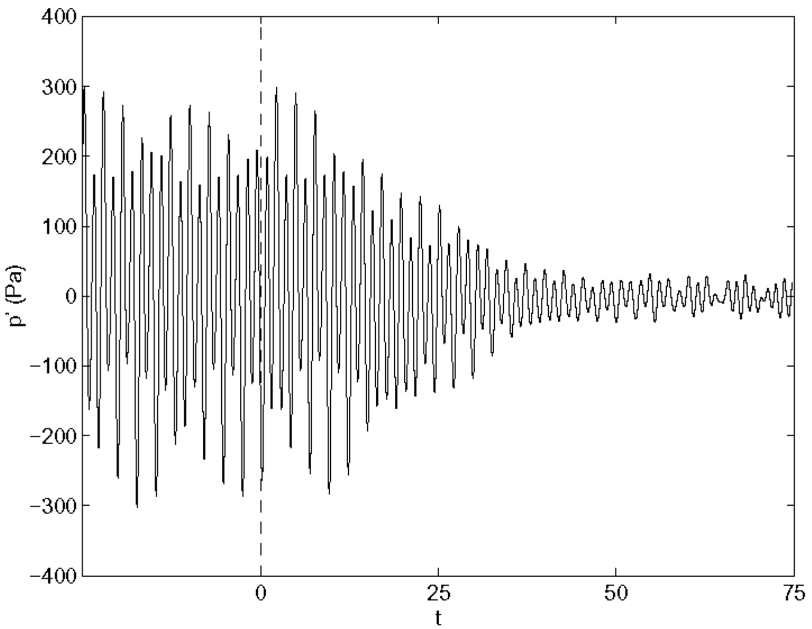
M= 0.6, $Re_D = 28700$, $L/\delta_\theta = 57$

Laminar incoming boundary layer, 1.8 million grid-points

Ref. Marsden, Gloerfelt & Bailly, 2003, *C. R. Acad. Sci.*, 331.

Adaptative active control of cavity noise





pressure signal in the acoustic field

control starts at $t = 0$

Automotive industry

- Aerodynamic noise : dominant source inside the passenger compartment for $U \geq 110 - 130$ km.h^{-1} and $f \geq 1$kHz

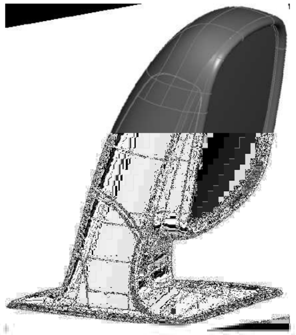
  ⇝ customer demand rather than regulations for interior noise

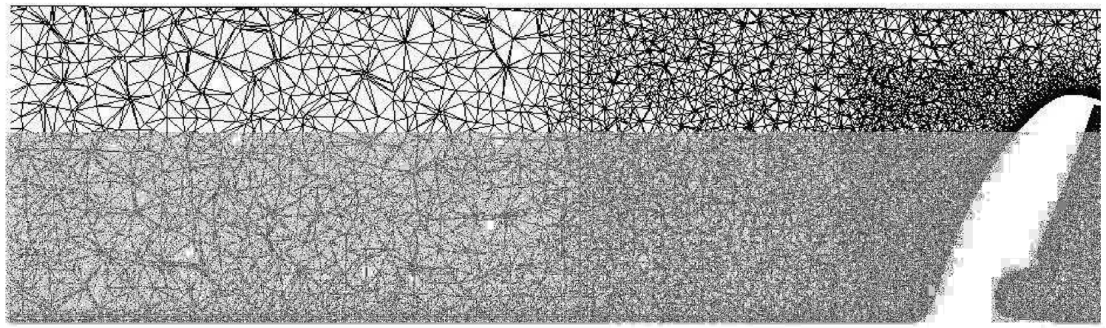
  (psychoacoustics – ground transports)

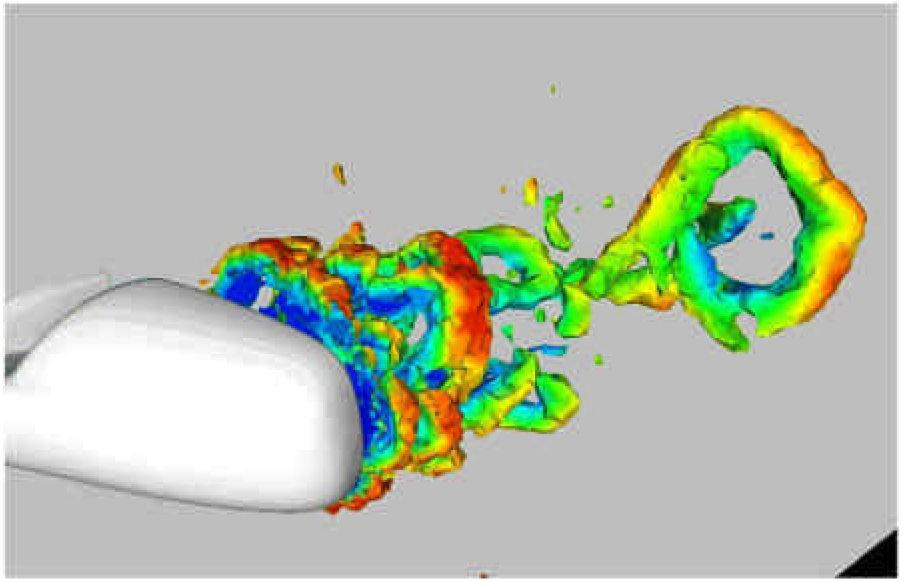
PSA PEUGEOT CITROËN

Bruit rayonné par un rétroviseur

- Impact de concepts innovants
  LES et analogie de Ffowcs Williams & Hawkings







rétroviseur 22cm × 13cm

$U_\infty = 40\text{m.s}^{-1}$

LES / Fluent 6.1

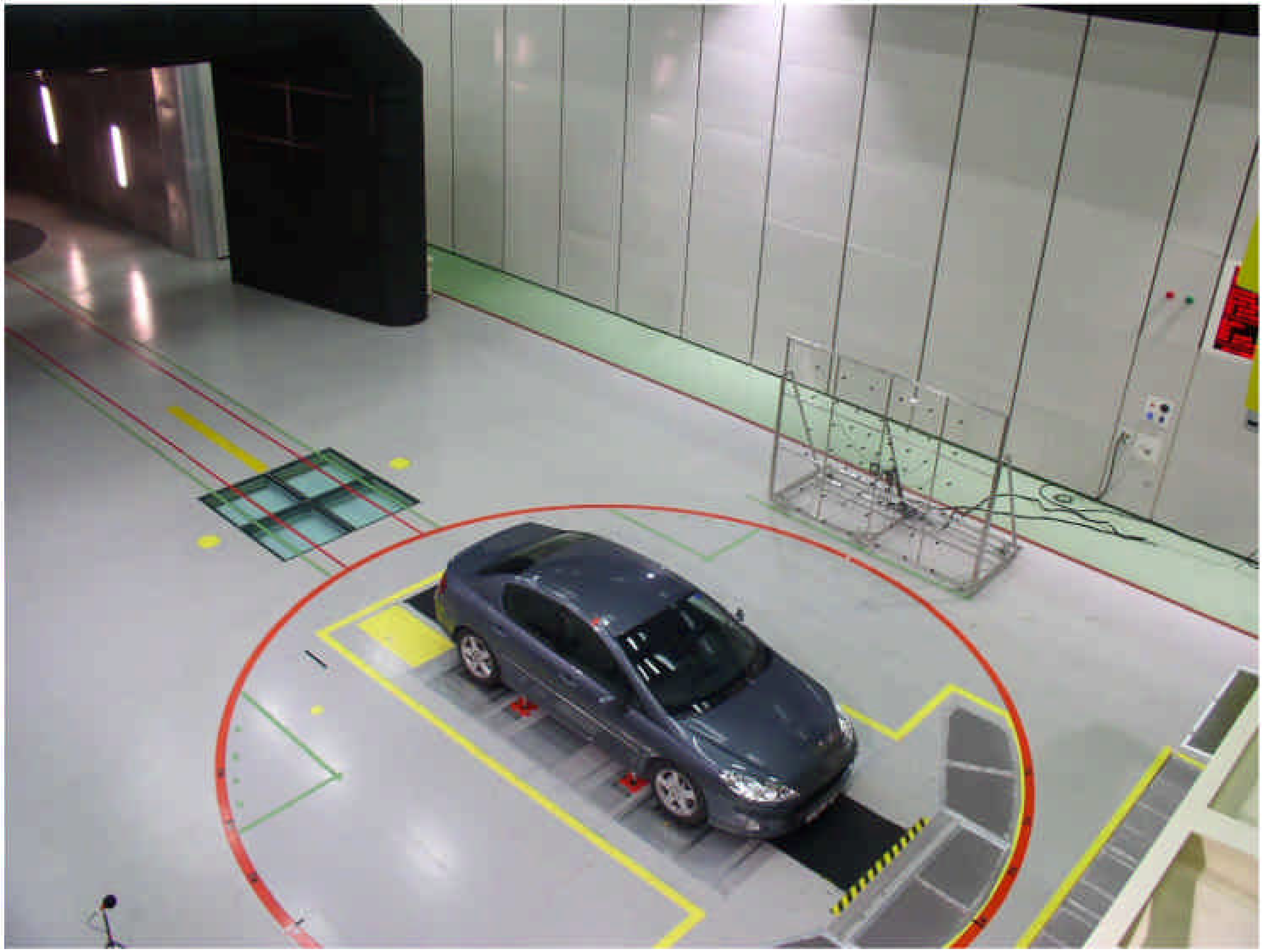
Smagorinsky $C_s = 0.1$ + loi de paroi

iso-surfaces critère Q

Posson & Pérot, AIAA Paper 2006-2719

Automotive industry

- **S2A semi-anechoic wind tunnel (Saint-Cyr l'École)**
  PSA Peugeot-Citroën, Renault & Cnam



$U \leq 240$ km/h
convergent section 24 m^2
(6.5×3.7)

$U = 160$ km/h

turbulence $< 0,4\%$
background noise 69 dB(A)
cut-off frequency 125 Hz

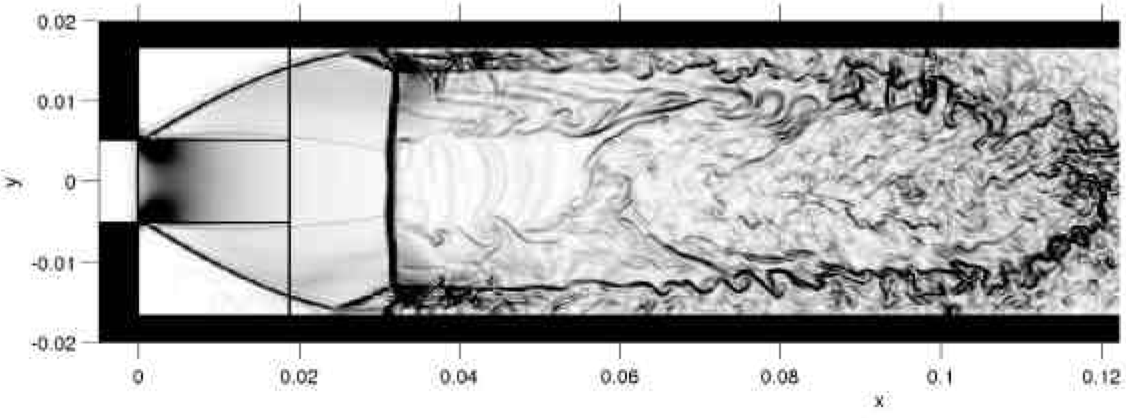
http://www.gies2a.fr

Transonic ducted flow

- ## Sudden expansion of transonic flow

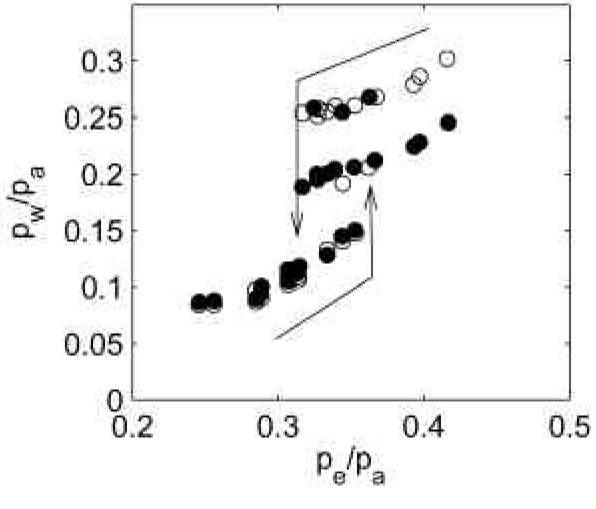
Noise generated by valves in pipe systems of power plants

$\tau = 0.31$

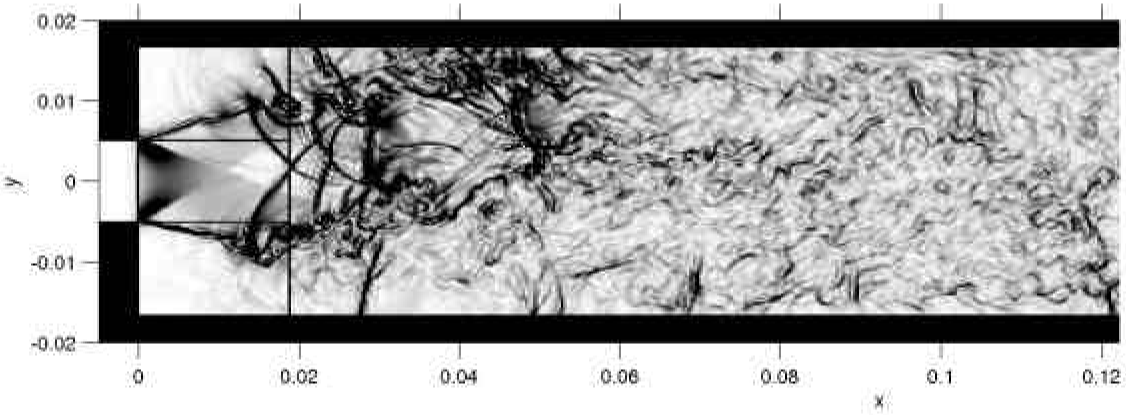


symmetrical & oscillating

hysterisis / pressure ratio τ

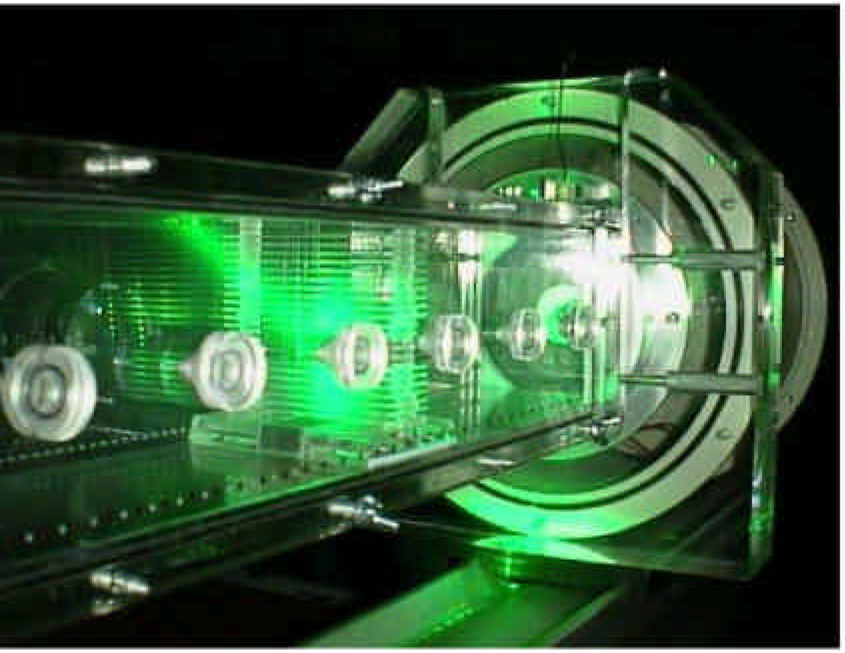


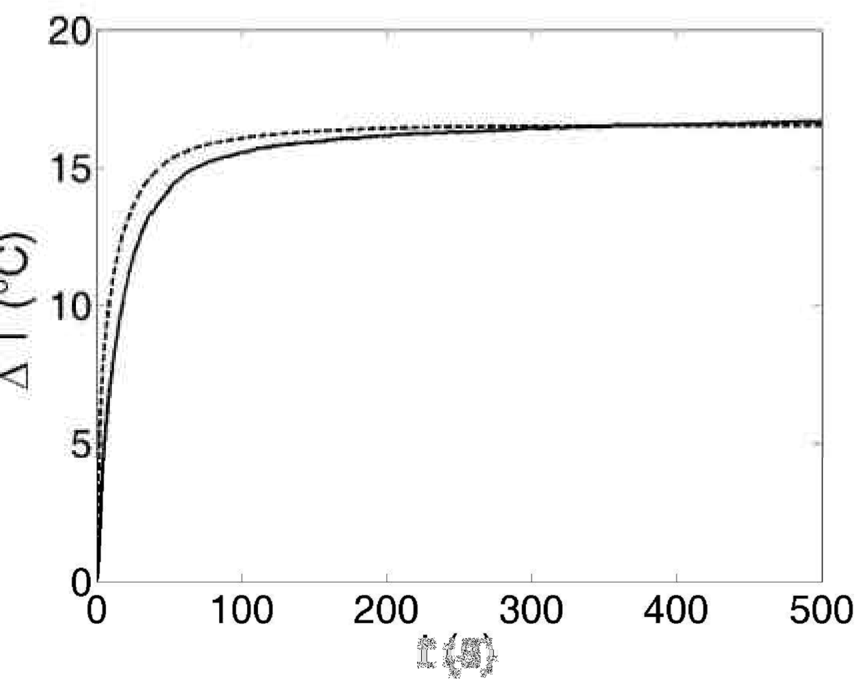
$\tau = 0.32$



asymmetrical & non oscillating

T. Emmert, Ph.D. ECLyon (2007) & P. Lafon (LaMSID, EDF & CNRS)





Arganthaël Berson (Thesis ECLyon, 2007)

$L \simeq 3$ cm, $p' \simeq 3000$ Pa

Domaines de l'acoustique

Vue synoptique des métiers de l'acoustique, avec les quatre champs d'activités, les domaines de l'ingénierie et les secteurs spécialisés (de l'extérieur vers le centre).

Adapté de Lindsay, *J. Acoust. Soc. Am.*, 36, 1964, par Michel Bruneau et Catherine Potel pour la Société Française d'Acoustique (SFA).

Remerciements

- « CAA team » Christophe Bogey (CR CNRS) & Olivier Marsden (MdC)
- Envie de faire un stage, voire une thèse ?

http://acoustique.ec-lyon.fr