SYMPOSIUM ON "THE INTERNATIONAL CENTER FOR RENEWABLE ENERGY & TURBULENCE/AEROSPACE"
Puerto-Rico may-june 2007

The European Flow and Turbulence Control & Europe/USA Collaborations

Jean-Paul Bonnet
LEA, Université de Poitiers CNRS
France

With thanks to J Delville, E Collin, P Jordan and the Poitiers' group

Flow control is by nature multi-disciplinary, typical TRIADIC (Computation/Theory-applied math./Experiments):

focus here on some european initiatives

- The European Research Community On Flow Turbulence And Combustion ERCOFTAC SIG « Drag Reduction & Flow Control » (K-S Choi)

- The AIRBUS CAFEDA and the European Forum on Flow Control EFFC

European Drag Reduction Meetings

Objectives

- Bring together active researchers working in the field of drag reduction and flow control for an exchange and discussion of most recent results
- Identify area of drag reduction and flow control devices for industrial applications in the context of technology transfer
- Encourage collaborations among researchers in Europe for academic research as well as funding purposes

Drag Reduction & Flow Control SIG
Recent meetings

- *13th European Drag Reduction Meeting, Aussois, France, June 2004.*
- *1st European Forum on Flow Control, Poiters, France, October 2004.*
- *European Drag Reduction and Flow Control Meeting*, Ischia, Italy, April 2006.

Drag Reduction & Flow Control SIG
Future meetings

- *2nd European Drag Reduction and Flow Control Meeting*, Dresden, Germany, September 2008.
- *Workshop on Drag Reduction and Flow Control using Surface Plasma*, Poiters, France…?
- *Workshop on Electro-magnetic Flow Control*, Dresden, Germany...?

ERCOFTAC SIG 20: **European Drag Reduction and Flow Control**

Chairman K-S Choi (Univ. Nottingham)

Recent topics

- Skin friction, flow separation and heat transfer control
- **Passive devices**: riblets, LEBUs, vortex generators, grooves, roughness, compliant coatings
- **Active devices**: surface plasma, spanwise-flow oscillation, blowing & suction, synthetic jets, MEMS, electro-magnetic flow control
- **Additives**: polymers, surfactants, microbubbles
- **Techniques**: Neural network, POD, adaptive control

The AIRBUS CAFEDA and the European Forum on Flow Control

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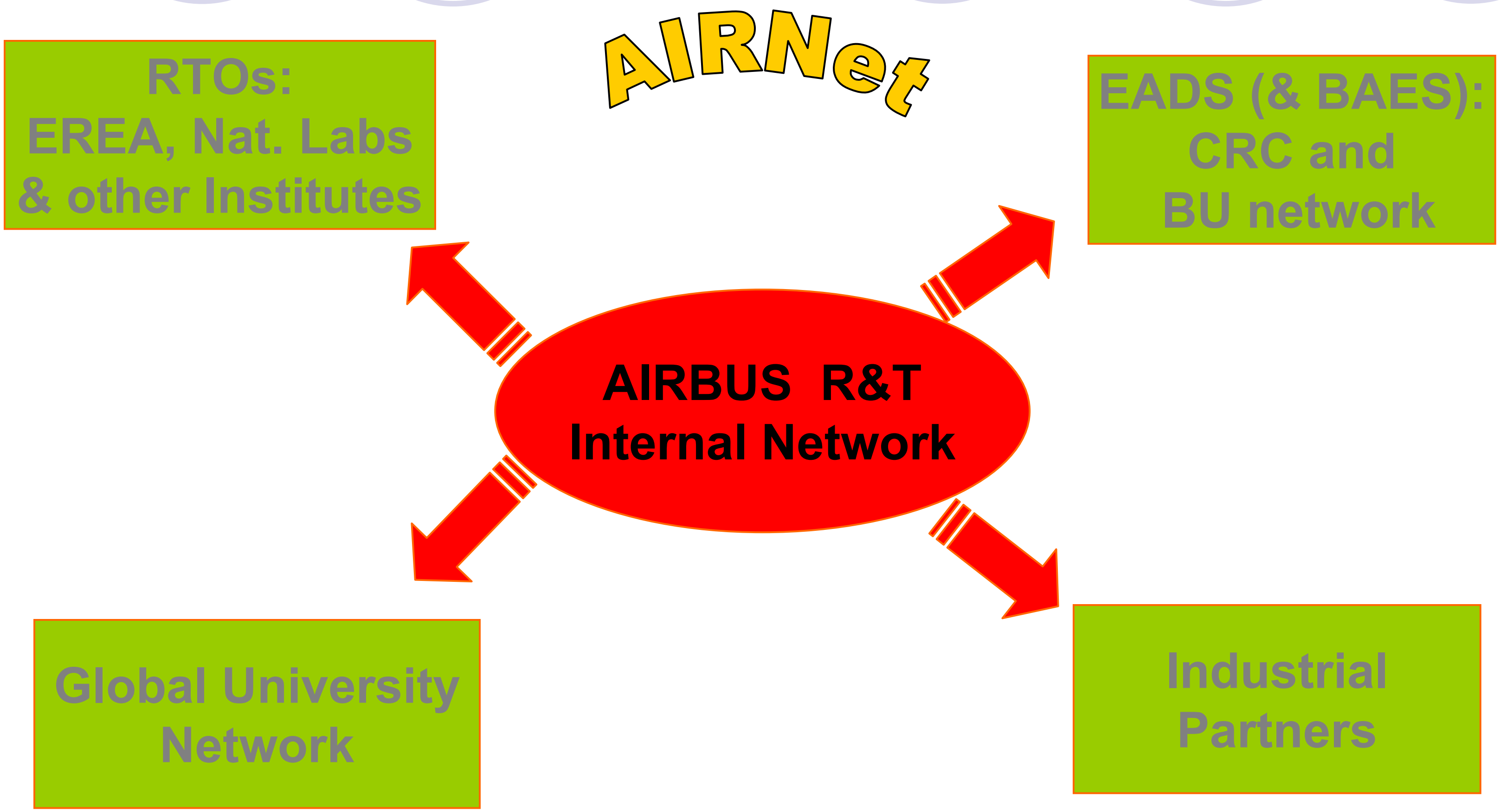
The AIRBUS CAFEDA and the European Forum on Flow Control

European Aeronautics Vision 2020

Challenges	***and associated goals***
Quality and Affordability	*Reduced passenger charges* *Increased passenger choice* *Transformed freight operations* *Reduced time to market by 50%*
Safety	*Reduction of accidents rate by 80%* *Drastic reduction in human error and its consequences*
The Efficiency of the Air Transport System	*3X capacity increase* *99% of flights within 15' of schedule* *Less than 15' in airport before short flights*
Security	*Airborne - zero hazard from hostile action* *Airport - zero access by unauthorised persons or products* *Air navigation - No misuse. Safe control of hijacked aircraft*

…addresses the full scope of customer expectations

AIRNet – The Players



AIRNet – CAFEDA: 2004-2007

Control of Aerodynamic Flows for the Environmentally Driven Aircraft

- The Network Partnership is
  - AIRBUS
  - University of Poitiers — University of Manchester
  - TU Berlin — University of Madrid

- The Network Objective is

  To discover new technologies for the control of external flows around civil transport aircraft and identify potential applications to enable a step-change in aircraft performance in the long term.

→New European Programme *AVERT 2007-2010*

Aerodynamic Validation of Emission Reducing Technologies with more partners

Recent advances in flow control for energy and environmental issues in France and in Europe

Present objectives of flow control:

• Reduce turbulent drag for low consumption then less pollution (1% Cd red. saves 1,6 tons fuel for a long cruise airplane)

• Delay separation for better performances and less noise of aircrafts

• Control mixing, for better combustion, better pollutant diffusion, noise abattement

• Main applications are focused on **aircraft** appplications, but are of genral interest for **energy and environmental issues**

European Forum on Flow Control
EFFC

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European Forum on Flow Control EFFC

- The aim of the Forum is to provide an opportunity for researchers from within and outside Europe to collaborate and exchange ideas in a comprehensive manner **during long (3 months) stays**
- The main thrust of this Workshop is towards aeronautical applications, however it is exclusively not so, since flow control has many uses in other fields.
- Although, as the name suggests, the focus of this meeting is on flow control research being conducted in Europe, we were fortunate to have a large number of participants from many other countries for the first two sessions
- The EWFC will be similarly organized and conducted every two years
- **EFFC-1 : 2004 and EFFC-2 : 2006**

1st EUROPEAN FORUM on FLOW CONTROL EFFC-1

Poitiers, France Sept-Nov 2004

Organized by

Laboratoire d'Etudes Aérodynamiques

CNRS - Université de Poitiers – ENSMA

Chairmen: JP Bonnet, J Delville, P Jordan and F Alvi (FSU)

Sponsored by :

- **AIRBUS within** the AIRNet programme Berlin/Madrid/Manchester/Poitiers – Control of Aerodynamic Flows for the Environmentally Driven Aircraft, **CAFEDA**

- **Centre National de la Recherche Scientifique** (GDR « contrôle des décollements »)

- **ERCOFTAC SIG 20 "drag reduction and flow control"** Chaired by K-S Choi

European Forum on Flow Control EFFC-1

Sep- Nov 2004

- **13** Researchers from: Australia (2), France (7), Germany (1), Spain (2), United States (1)

UNIVERSITÉ

RECHERCHE
Centre d'études aérodynamiques et thermiques

Chercheurs internationaux à Poitiers

Jean-Paul Bonnet, directeur de recherches au CNRS.

Le Ceat, Centre d'études aérodynamiques et thermiques, de l'université de Poitiers, accueille neuf chercheurs internationaux qui travaillent dans le domaine du contrôle des écoulements pour l'aéronautique.

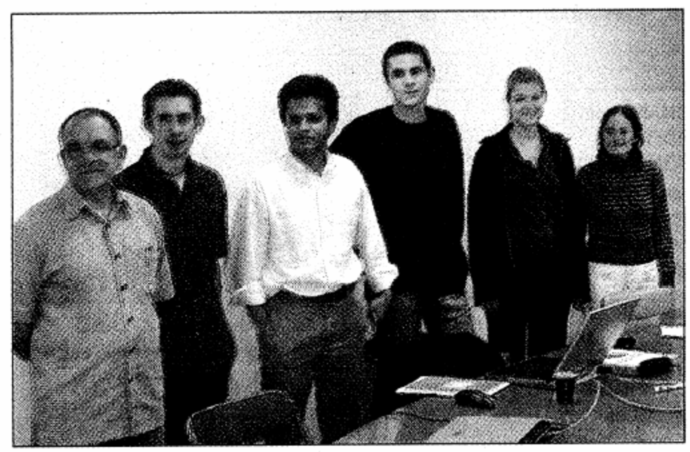
« C'*EST une première en Europe* », souligne Jean-Paul Bonnet, directeur de recherches au CNRS (Centre national de la recherche scientifique), responsable du programme, vice-président de l'université de Poitiers pour la recherche, et chercheur au Ceat (près de l'aéroport de Poitiers-Biard). « *L'idée de ce forum remonte à deux ans avec Airbus, consortium qui s'est rapproché des universités pour une recherche plus fondamentale. Quatre universités ont été retenues : Berlin, Manchester, Madrid, et donc Poitiers, comme laboratoire de références* ».

Ce programme d'accueil permet de « *regrouper des domaines de compétences très complémentaires en matière d'amélioration des performances et de réduction de nuisance des aéronefs. Le contrôle des écoulements (Flow Control) offre de nouvelles perspectives pour les chercheurs.* »

Ces derniers vont travailler de un à trois mois au Ceat. Il y a deux Espagnols, deux Australiens, un Américain, une Allemande, et des Français de Toulouse, Nancy, et Paris.

Julio Soria, professeur à l'université de Victoria en Australie, vient pour la troisième fois en Europe cette année. Il apprécie « *l'intérêt technologique du forum, d'autant qu'il n'y a pas d'industrie aéronautique en Australie* » et précise : « *C'est important pour notre économie compte tenu des distances dans mon pays.* »

« *Ces rencontres, financées par Airbus et le CNRS, doivent déboucher sur des travaux en commun* », indique Jean-Paul Bonnet, « *sur un profil d'aile, par exemple. L'intérêt vient aussi des contacts humains qui font naître des idées* ». Une riche aventure tant humaine que technologique.



Une partie des chercheurs du forum dont Julio Soria (à gauche) d'Australie qui commence à bien connaître l'Europe.

2nd EUROPEAN FORUM on FLOW CONTROL EFFC-2

Poitiers,

France May-July 2006

Organized by

Laboratoire d'Etudes Aérodynamiques

CNRS - Université de Poitiers – ENSMA

Chairmen: JP Bonnet, J Delville, P Jordan and F Alvi (FSU)

www://effc.ceat.univ-poitiers.fr

Sponsored by :

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- **Centre National de la Recherche Scientifique** (GDR « contrôle des décollements »)

The EFFC-2nd session, May-July 2006

JP Bonnet, J Delville and P Jordan, F Alvi (FSU)

- 1st group: Experimental study of unsteady separation on a NACA 0015 airfoil
- 2nd group: Low order description of turbulent flow in view of flow control (EFFC-1 cont'd): Towards Quiet turbulence

EFFC 2006

Main results of the collaborative Studies on Flow Separation Control over a NACA0015

7 Participants

W.L. Siauw, J.P. Bonnet, J. Tensi, J.M. Breux, W.H. Khoo, Poitiers University (LEA-ENSMA-CNRS)

A. Seifert, O. Stalnov, Tel Aviv University (TAU)
B. V. Kumar, F.S. Alvi, Florida State University (FMRL)

C.H. Atkinson, Monash University, Australia (LTRAC)

L.D. Gomes Manchester University

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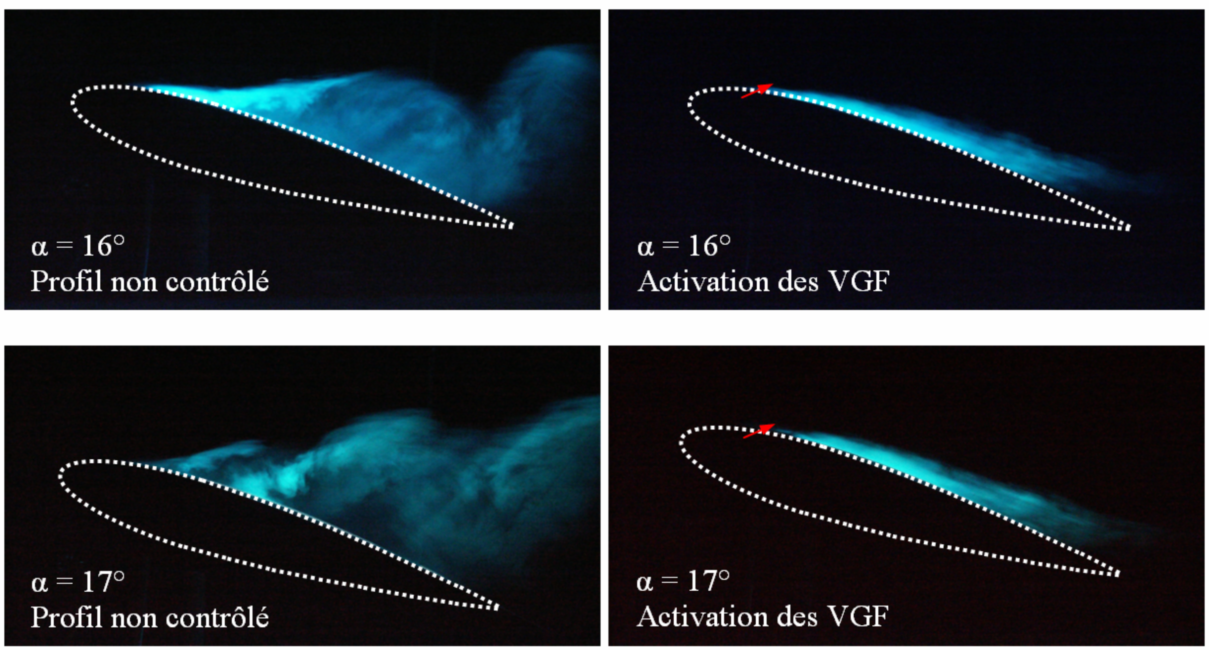
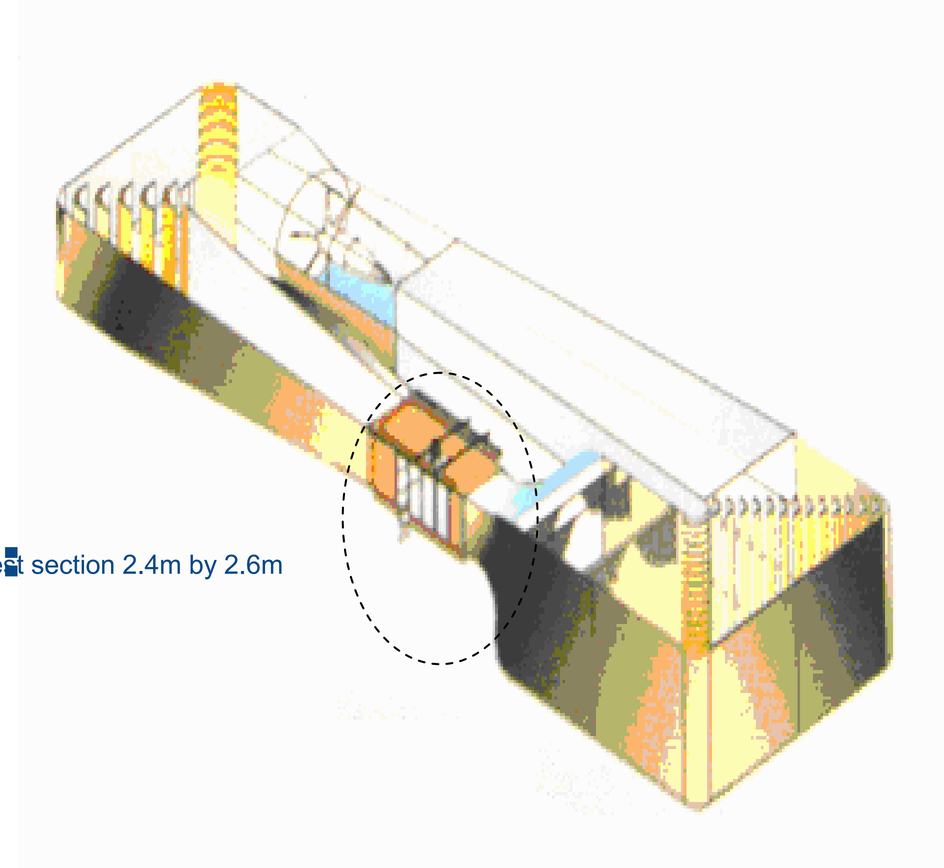
- Objectives
  - Study the effects of different fluidic actuators on the same NACA0015 airfoil
  - Obtain an approximation of the timescales of attachement & separation in view of re-active flow control
  - Develop a multi orifice single chamber synthetic ZNMF actuator



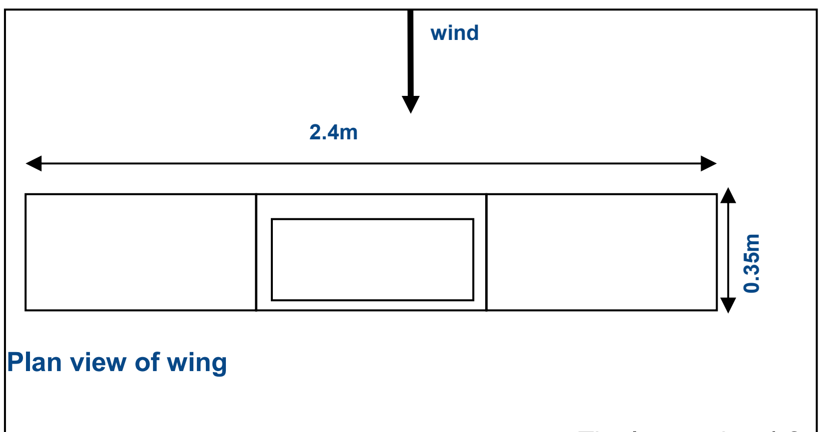
Test Facility

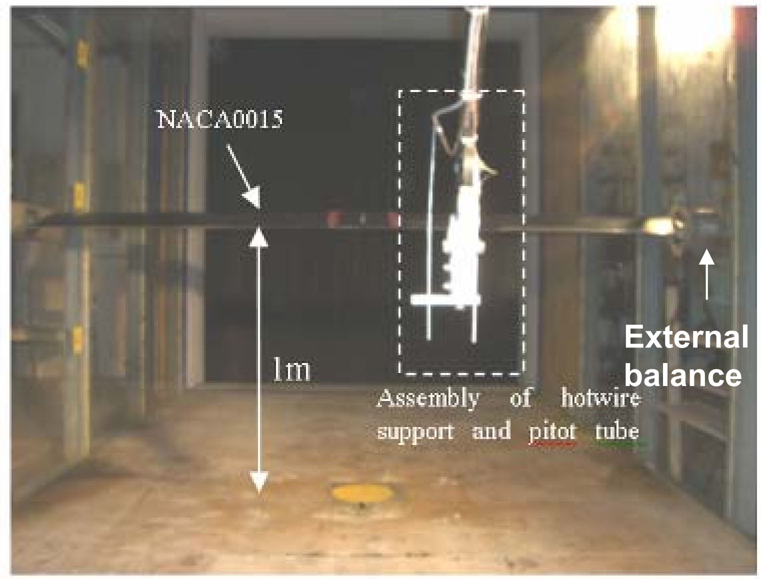
- Closed loop tunnel
- Test section 2.4m by 2.6m
- Turbulence intensity : 0.4% at 40m/s
- Instrumentation
  - Force measurement
  - Pressure measurement
  - Wake suvey



Model & Test Conditions

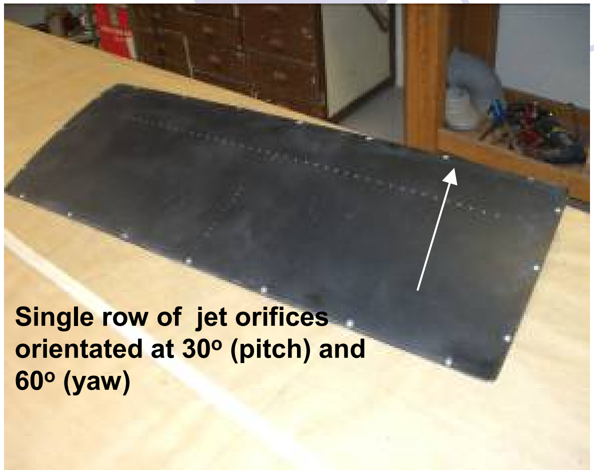
- **Model specification**
  - **NACA0015 - 0.35m (chord) & 2.4m (span)**
  - **Model turbulated by 8 micron carborandum at x/c of 2% to 4%.**
- **Flow conditions**
  - **Free-stream velocity = 40m/s**
  - **Re = 0.96 million**

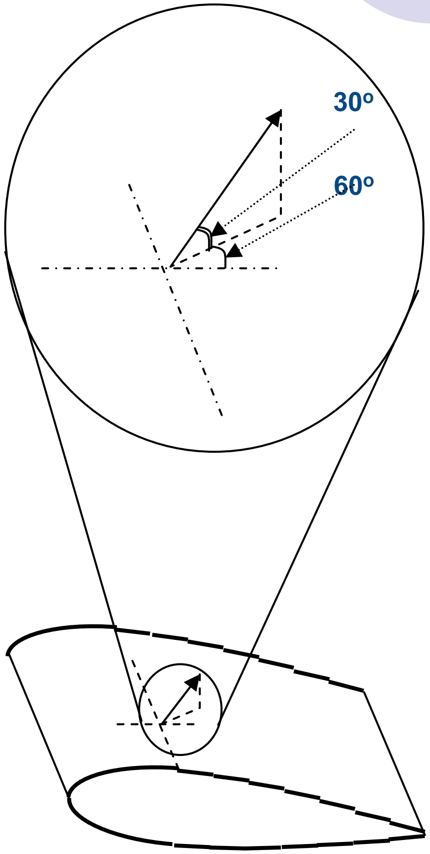




Overview of the test section with the NACA0015 installed at 1m (reference from quarter chord which is the center of rotation) above tunnel floor.

Model Overview

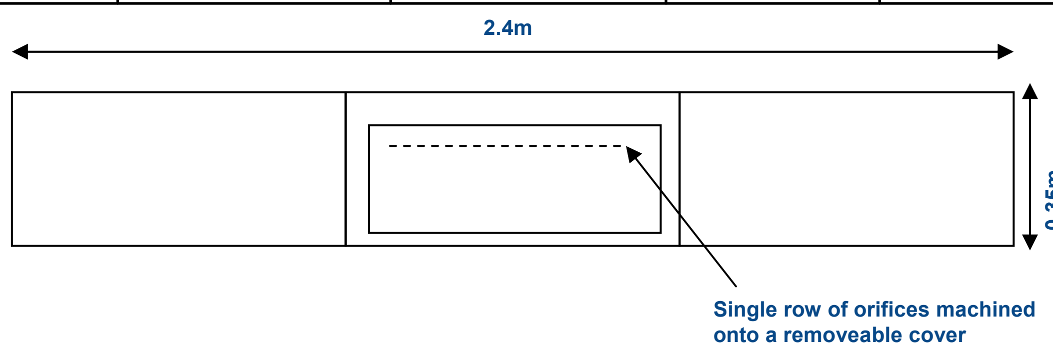




Fluidic Actuators Specifications

	Mode of Deployment	Means of Deployment	Jet Orientation	Position (x/c)	Number of Orifices
Steady "Angled" Jets *(1mm diameter)*	**continuous**	**pressurized cavity**	**30deg (pitch), 60deg (yaw)**	**0.3**	**44**
Steady "Normal" Jets *(1mm diameter)*	**continuous**		**normal to surface**	**0.3**	**51**
Steady "Normal" Jets *(0.5mm diameter)*	**continuous**			**0.3**	**64**
"Normal" ZNMF Jet *(1mm diameter)*	**Amplitude/pulsed modulated**	**piezo-electric**		**0.3**	**56**

- **Orifices distributed approximately 1 third of the airfoil span**



Angled & Normal Steady Jets

Poitiers University (LEA-ENSMA)
Monash University (LTRC)
Florida State University (FMRL)

Participants : W.L. Siauw, J.P. Bonnet, J. Tensi, J.M. Breux, W.H. Khoo, F.S. Alvi, V. Kumar, C.H. Atkinson, T. Stephens, L.D. Gomes

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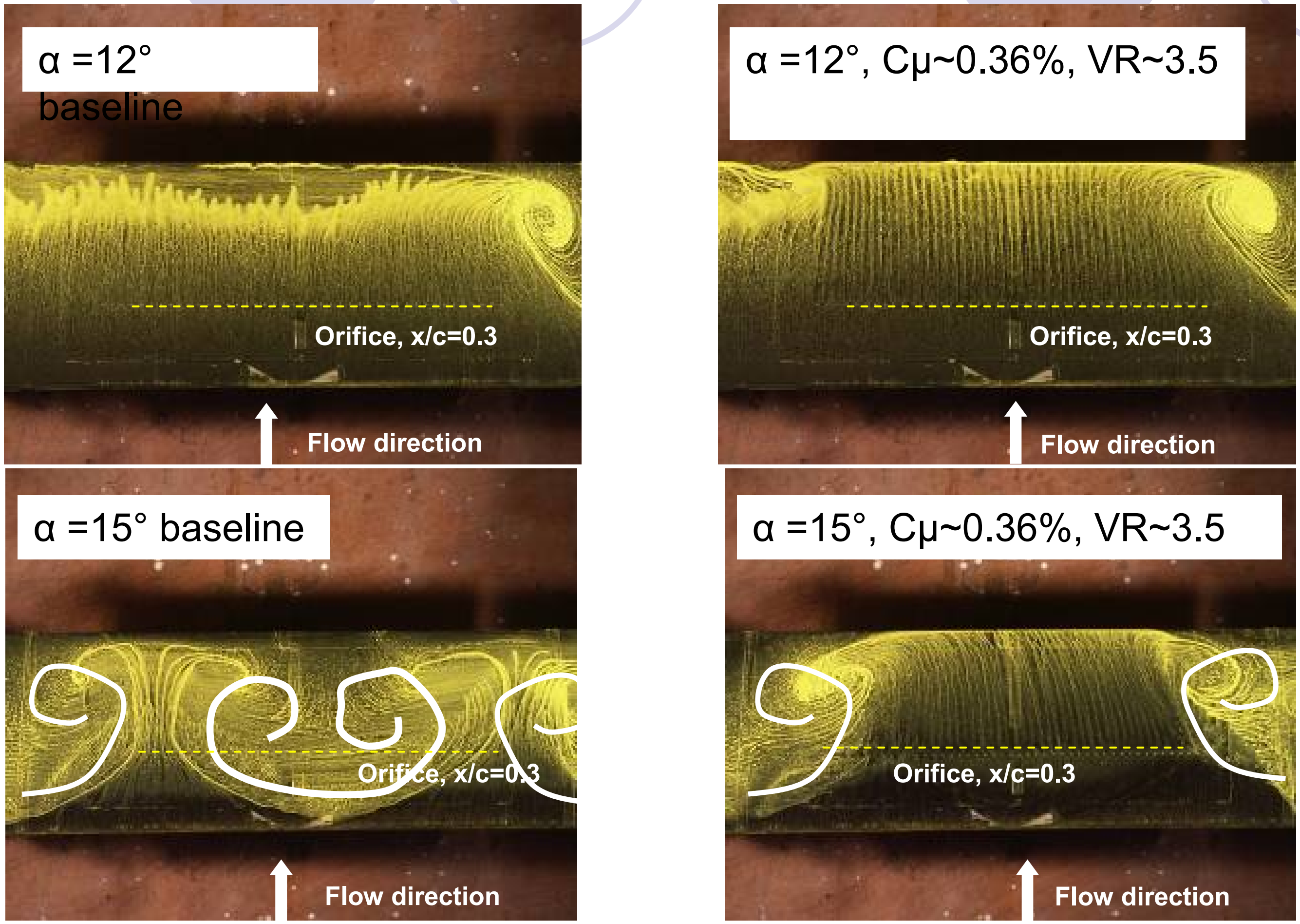
Results (Angled Steady Jet, orifice diameter = 1mm at x/c=0.3) :

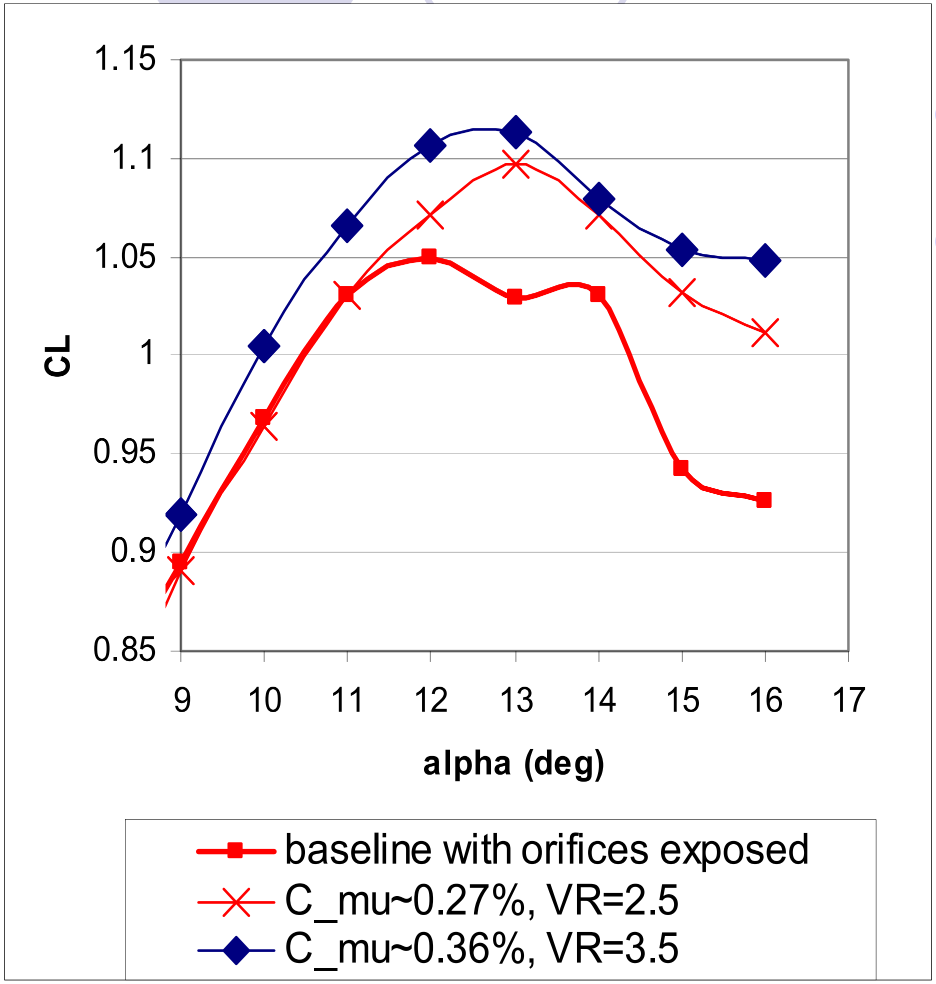
Surface flow visualization at 12° & 15°



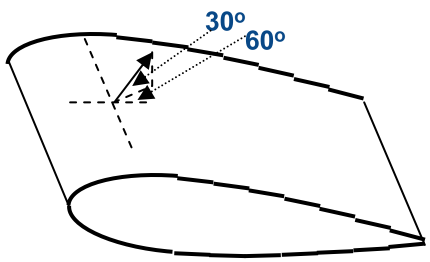
- **(12° to 16°) Full attachment was observed.**
- **At 15°, stall cells at the central portion was eliminated.**
- **In all cases, adjacent stall cells (if exist) becoming stronger.**

Results (Angled Steady Jet, orifice diameter = 1mm at x/c=0.3) :

Lift coefficient comparison during actuator deployment



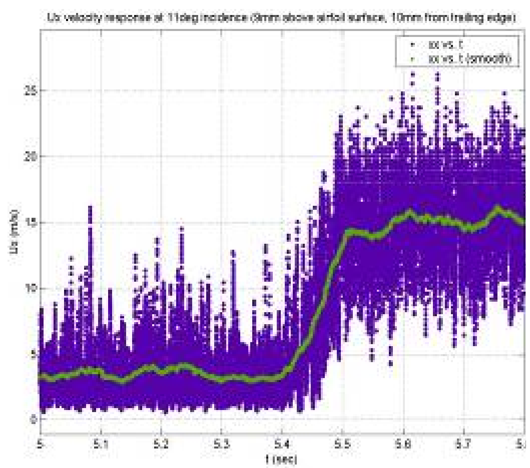
- At Cµ~0.36%, Cl improve between 3% and 14% (16º).
- Stall characteristic is more gradual when jets were deployed

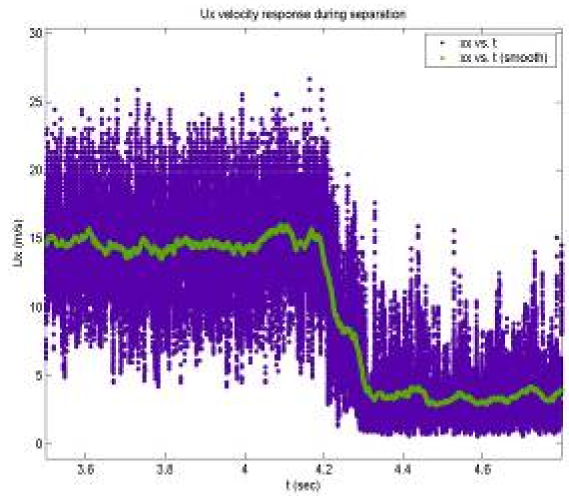


* Lift improvement could be 3 times more since jets were deployed over 1/3 of airfoil span

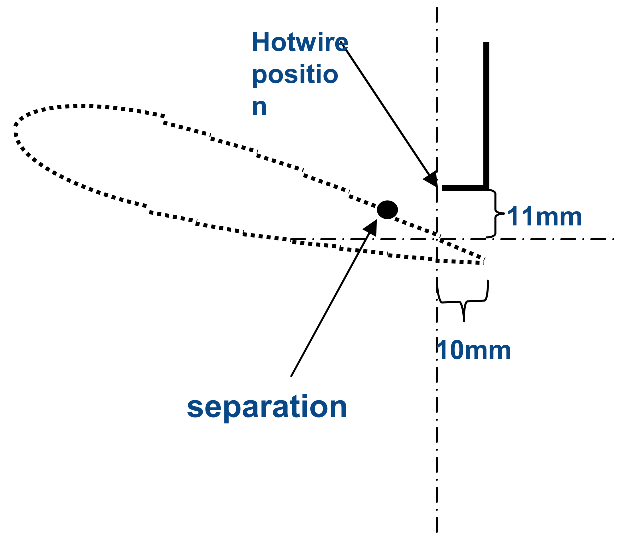
Results (Directed Steady Jet, orifice diameter = 1mm at x/c=0.3) :

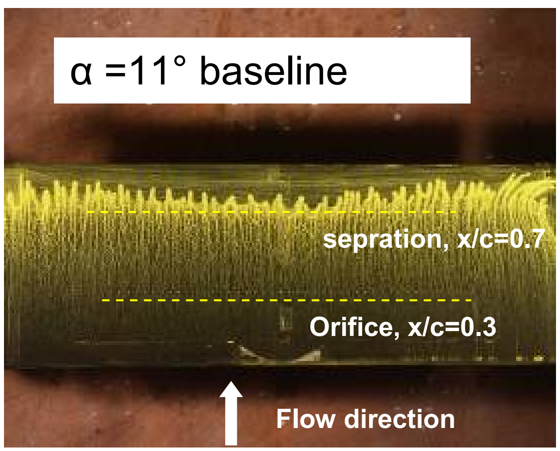
Time scale of attachment & separation at 11° incidence

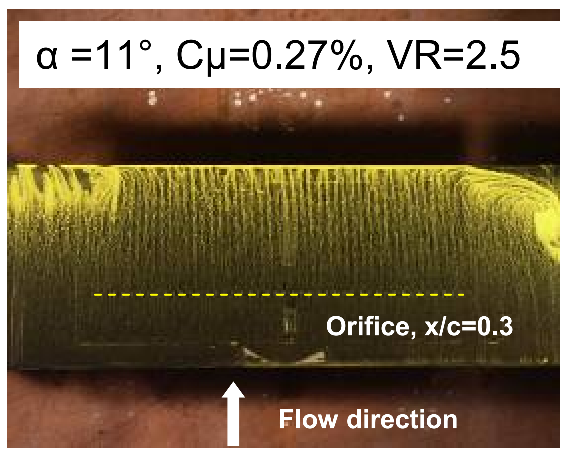




- **Qualitatively, typical times of attachment & separation are observed to be of the order of 0.1sec** (T+~42 based on sep lenght)







Zero-Net-Mass-Flux Jets

participants: A. Seifert and O. Stalnov
Tel-Aviv University (TAU)

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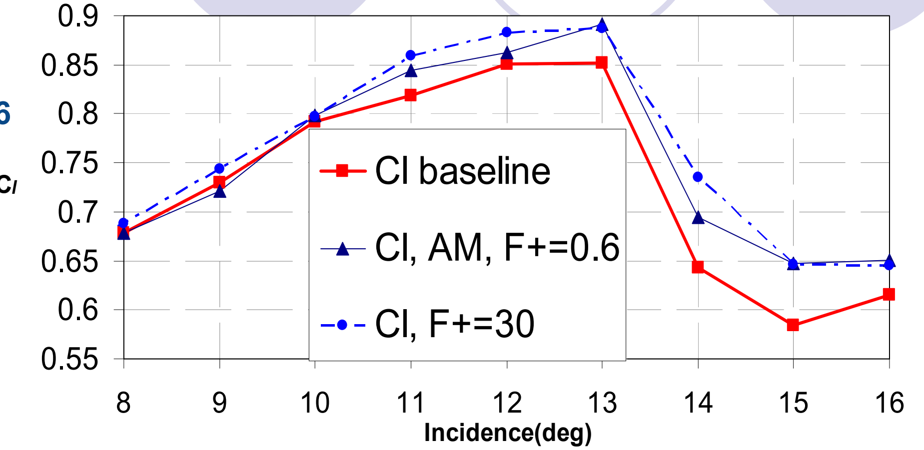
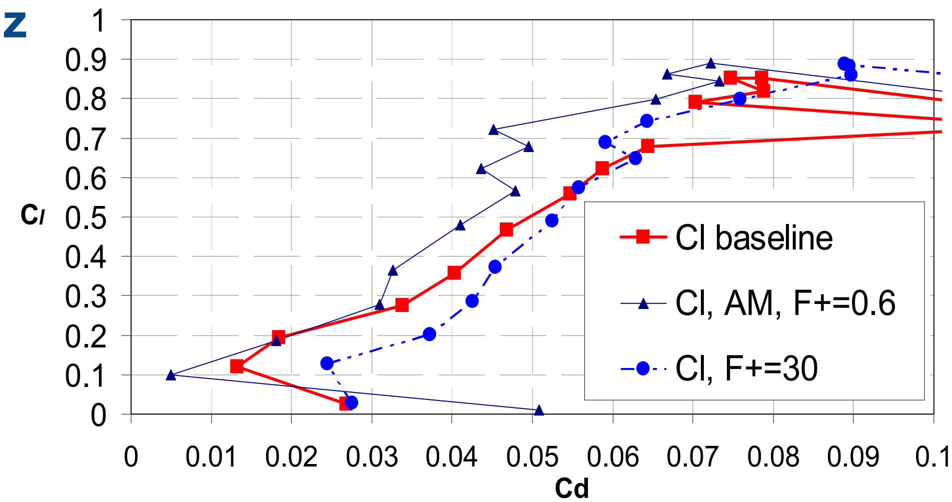
ZNMF actuator - wing Integration

- Integral part of the model cover
- 14 localized PZT actuators
- Four, 1mm diameter holes for each localized actuator
- Perpendicular to surface
- Located at x/c=0.3

Effects of ZNMF Deployment

- Conditions at lower speed:
  - Reynolds number = 0.25×10^6 free stream velocity = 10m/s
  - Incidence = 13°
  - Cμ=0.32%, VR=3
  - Provides stall control
- Amplitude modulation (AM)
  - Actuator operated at 1.95kHz (F^+=30)
  - Modulated with a sine wave at 41 Hz (F^+=0.6)
- Effects on Cl & Cd
  - Better drag reduction characteristics at low incidences
  - Cl improvement up to 4.1%(could be 3 times better)





Development of Multi Orifice Single Chamber Zero-Net-Mass-Flux Jets

participants: L.D Gomes
Manchester University
WL Siaw Université de Poitiers

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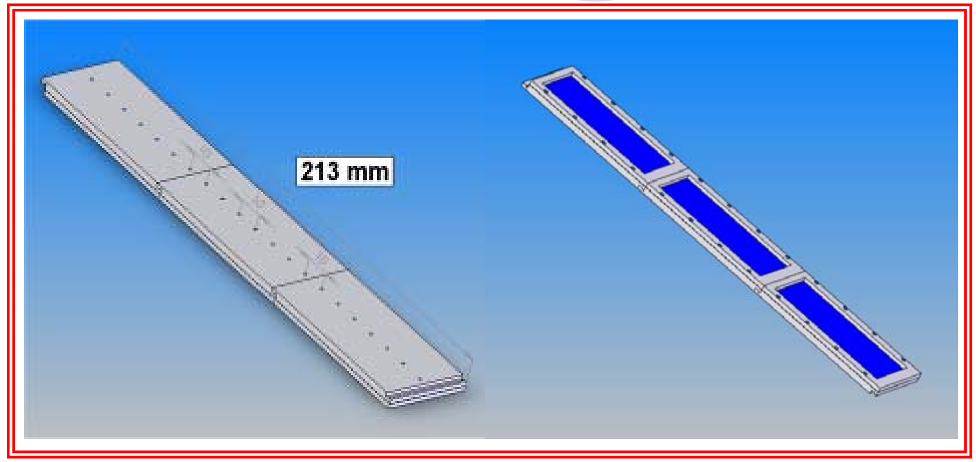
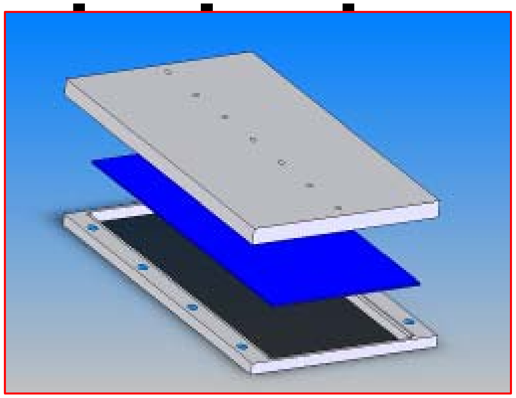
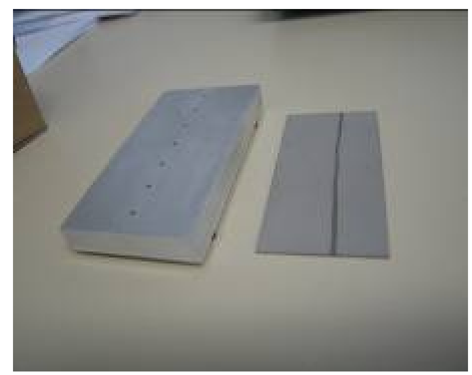
Design of Multi-Orifice Single Chamber Actuator

- **Study and enhance the performance of a multi-orifice ber**



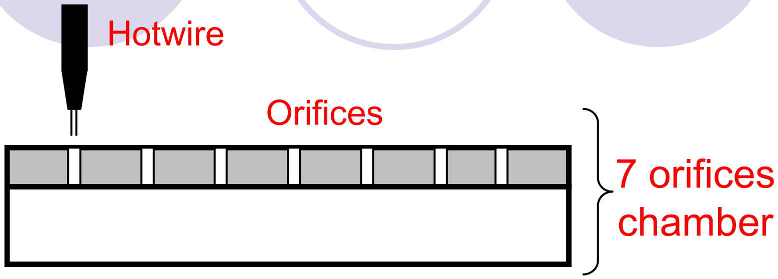


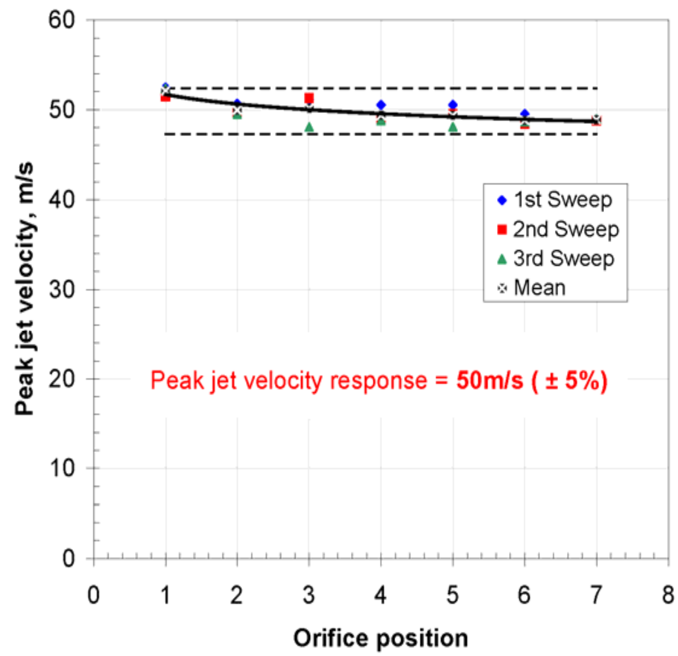


Design of the first prototype

Characteristics of Multi-Orifice Single Chamber Actuator

- **Test conditions:**
  - Excitation frequency = 1,270Hz
  - Excitation voltage = 140V_{pp}
  - Height of hotwire probe from surface ≈2D_o
  - Orifice diameter, D_0 = 1.2mm
  - Hotwire diameter = 1.0mm
- **Averaged peak jet velocity reached** = **50m/s**
- **Further work to exceed 100m/s**
  - Optimization of chamber volume, increasing input voltage range (up to +/-250V) to further augment the output vel.
  - Assessment of actuator power consumption and efficiency





EFFC II Part 2 : Quiet turbulence and low order techniques

Peter Jordan & Joël Delville

**Laboratoire d'Etudes Aérodynamiques,
CNRS UMR 6609, Université de Poitiers, France**

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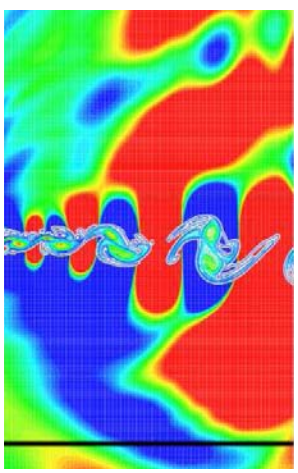
Collaborative research programme EFFC 2006

2nd group: theory and computation :

(J Delville and P Jordan + 10 participants)

Post processing and closed-loop methods for turbulent flow control

Towards Quiet turbulence (Data base from Wei-Freund DNS)



Bernd NOACK	**TU Berlin**
Michael SCHLEGEL	TU Berlin
Dandy ESCHRICHT	TU Berlin
Maja WÄNSTRÖM & W GEORGE **Chalmers**	
Oksana STALNOV & Avi SEIFERT TAU **Tel Aviv**	
Laurent CORDIER	Nancy/Poitiers
Caroline Braud	**IMFL Lille**
WEI	**Stanford**
Jonhatan FREUND	**Urbana**

- **Before we can make a flow quiet we need to know what makes it noisy,**

- **Activity focused on analysis tools for improved fundamental understanding,**

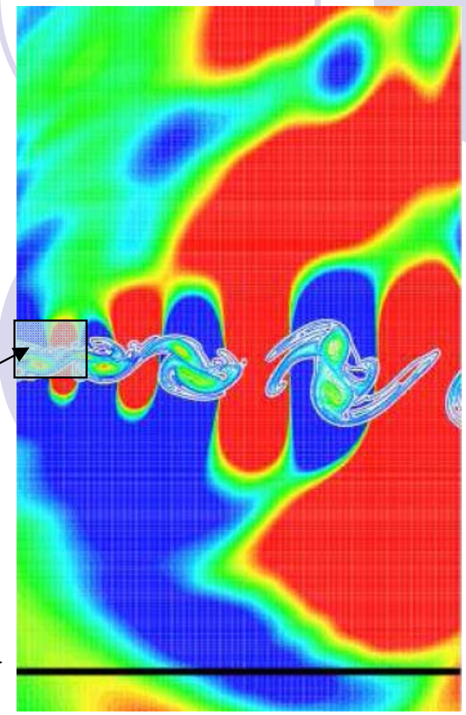
From CFD data bases:

1. 2D Noise controlled mixing-layers of M. Wei and J. Freund **(DNS)**

2. Round jet, *Re=3600*, *M=0.9* of E. Gröschel & W. Schröder **(LES)**

2. Identifying quiet modes in 2-D mixing-layer

M. Wei, J. Freund, P. Jordan, D. Eschricht & F. Thiele



Control zone

Survey zone

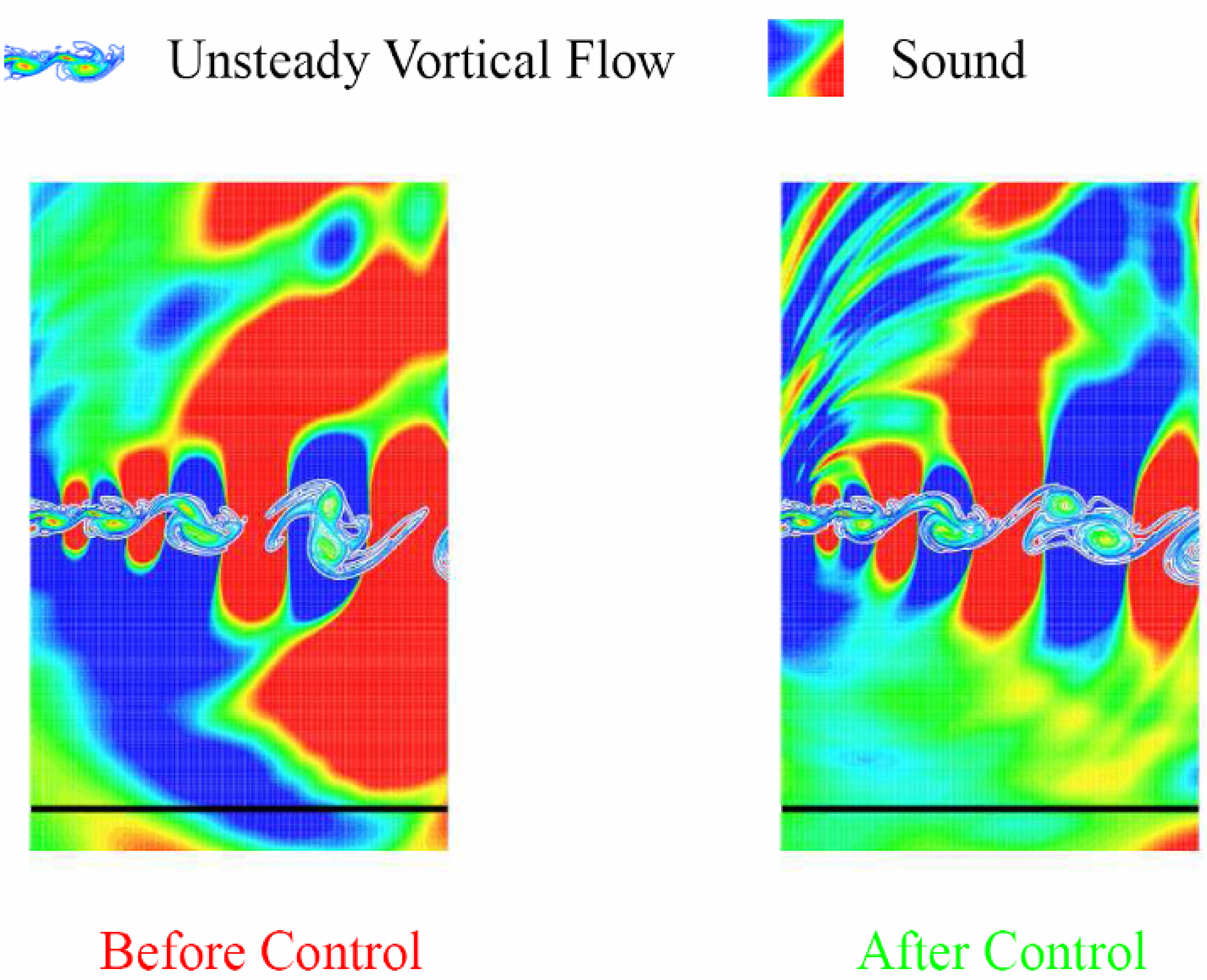
Adjoint method

Black Box approach… but efficient

11 dB noise reduction (2D…)

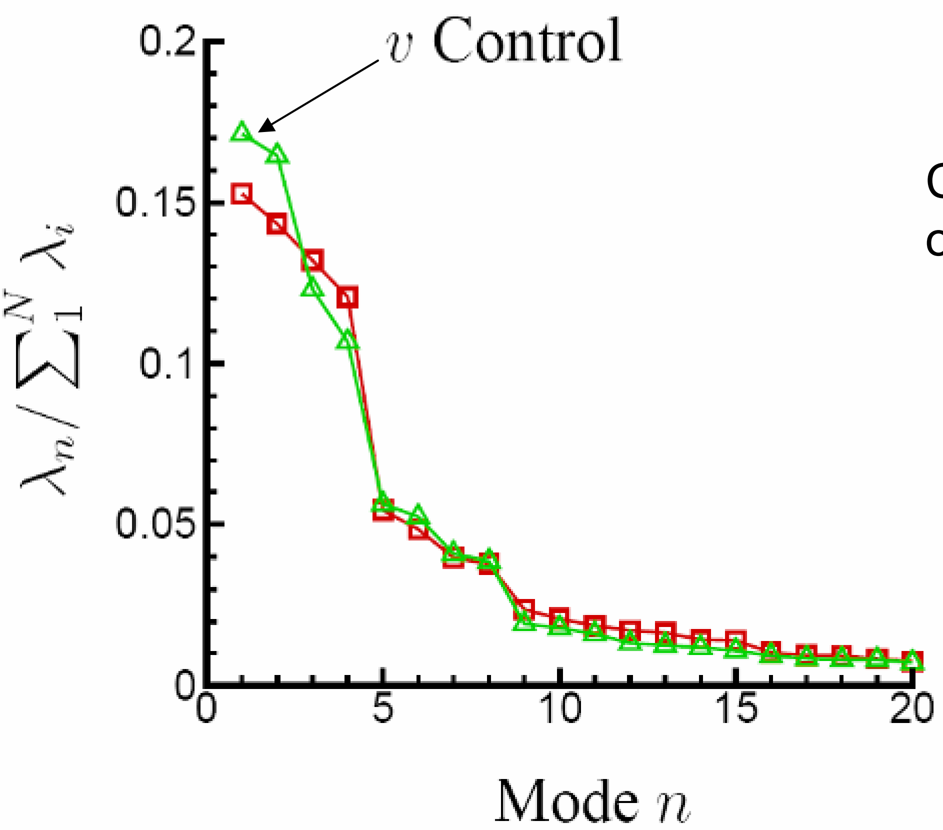
Wei M, Freund J., « A noise-controlled shear flow », JFM 2006

Controlled and uncontrolled flows



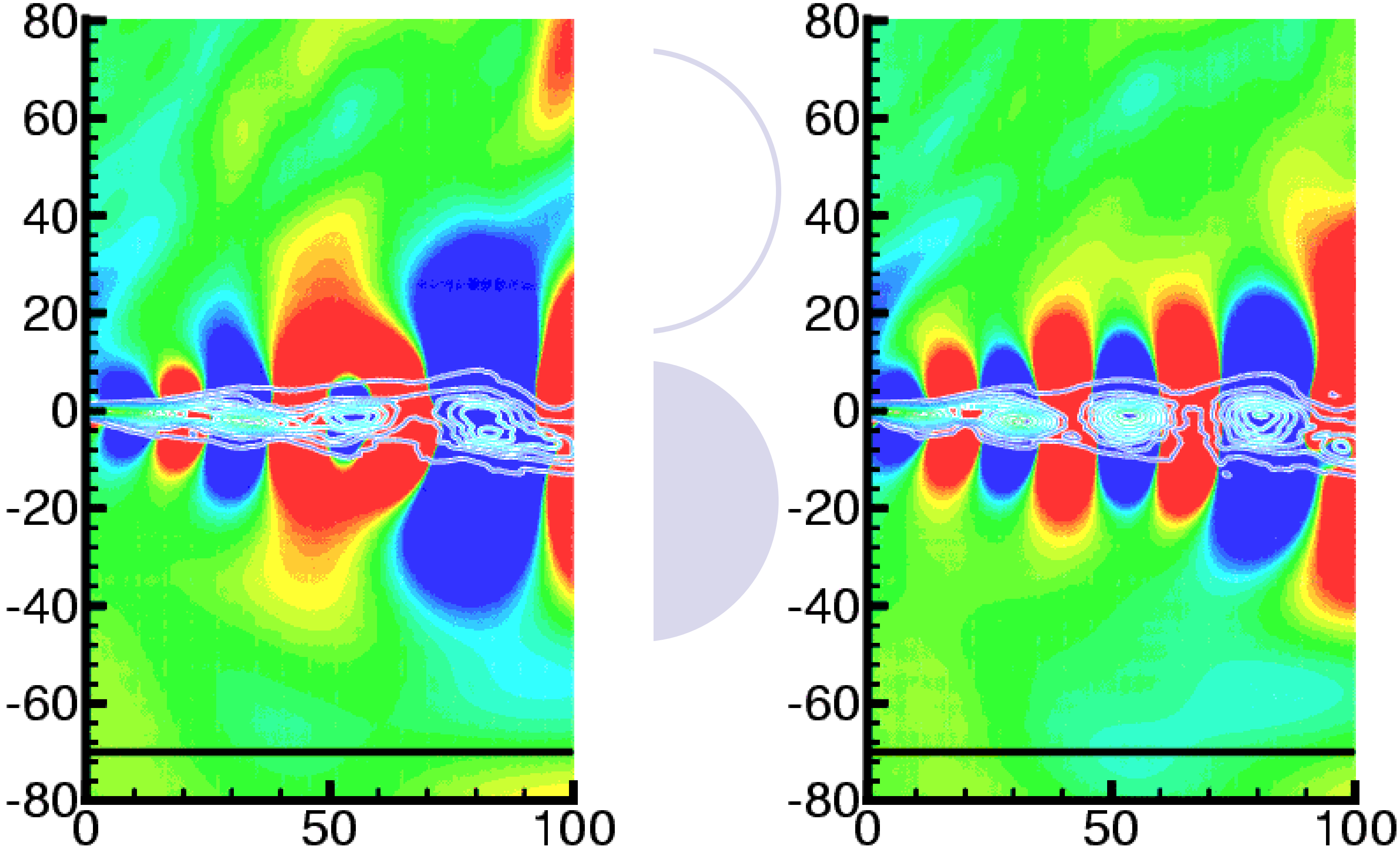
Proper Orthogonal Decomposition

$$\vec{q}(\mathbf{x},t) = \sum_i a_i(t)\vec{\psi}_i(\mathbf{x})$$



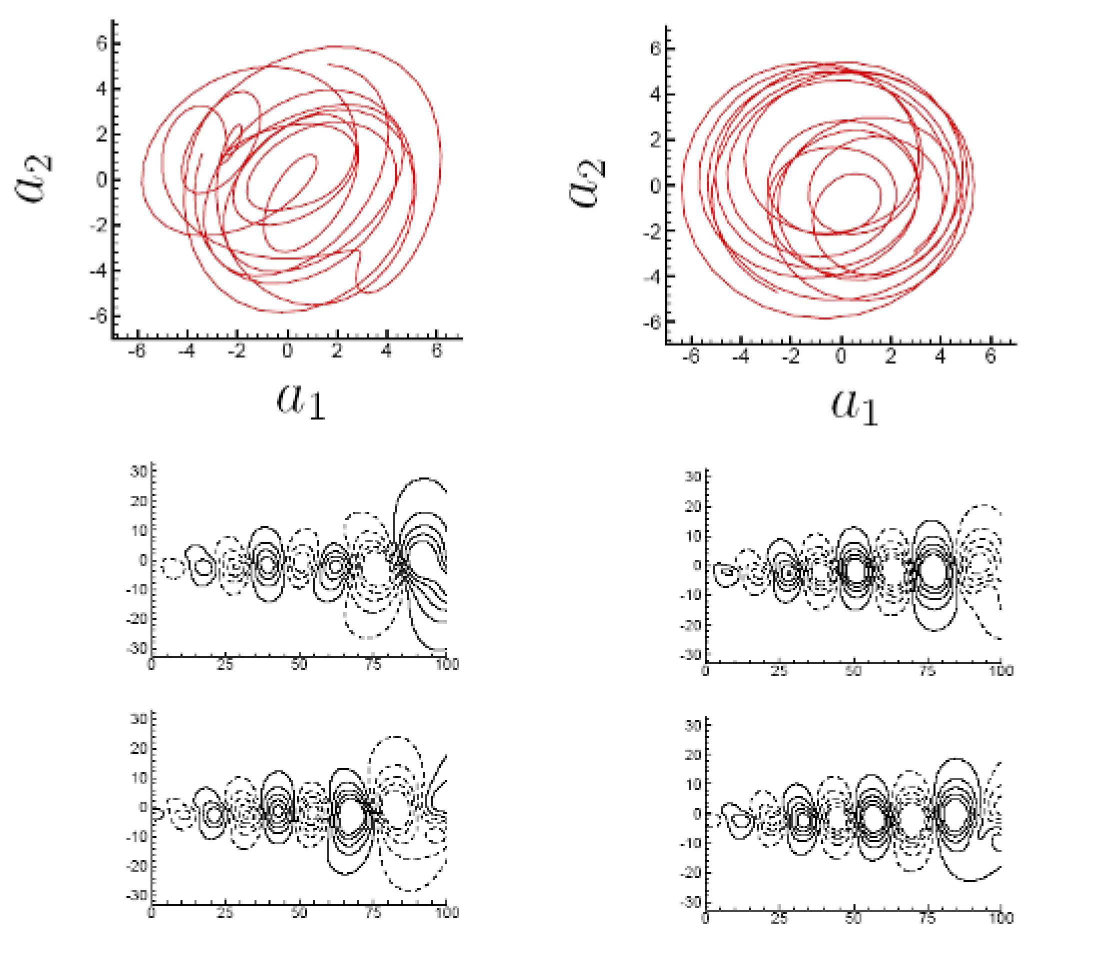
Control ---
organization (!)

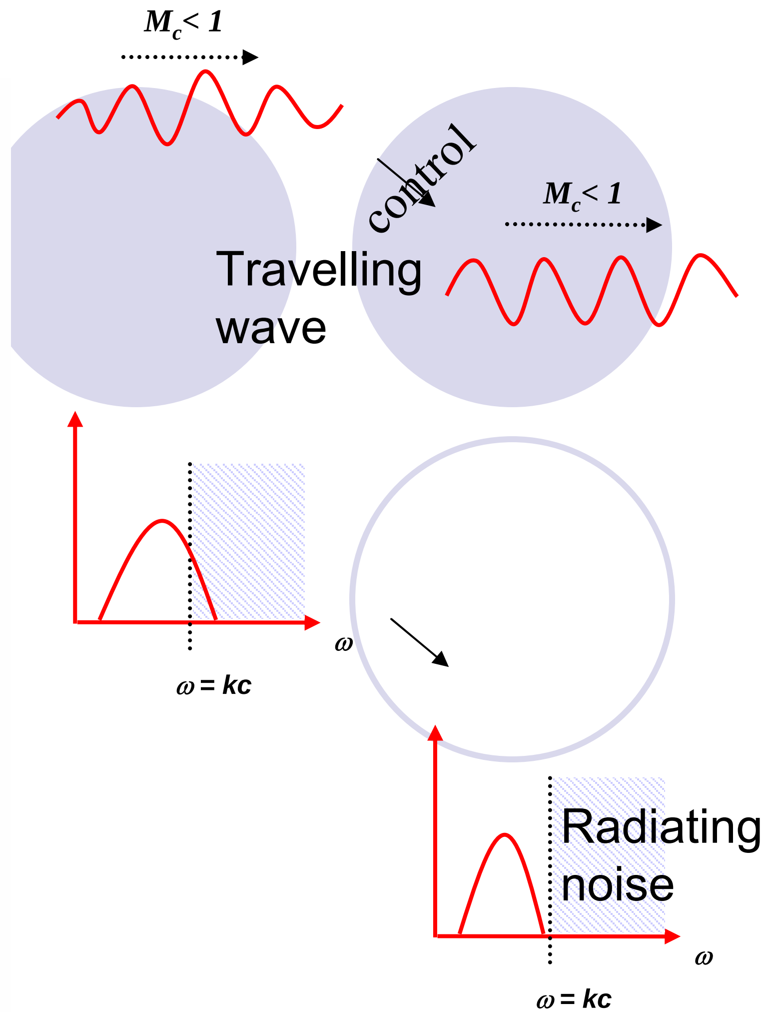
Low-order behaviour of flows



Low-order behaviour of flows

Uncontrolled | **Controlled**





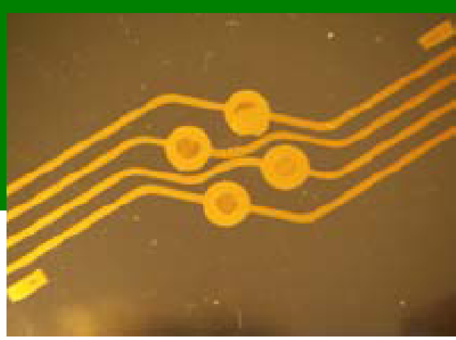
Imperial College London

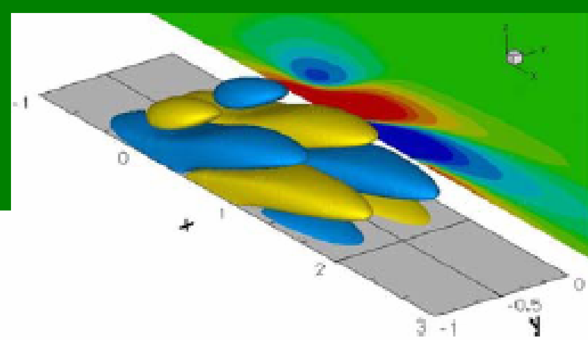
IUTAM Symposium on

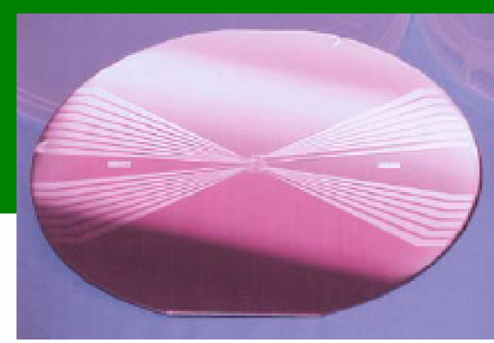
Flow Control and MEMS

http://www.imperial.ac.uk/aeronautics/research/iutamsyposium

19 – 22 September 2006







Special session on EFFC-2 results

EFFC: a scientific AND human adventure!

UNIVERSITÉ

POITIERS
Recherche aérodynamique sur le contrôle des écoulements.

Equations, soufflerie et matière grise

Le Laboratoire d'études aérodynamiques (LEA) de Poitiers, un des quatre reconnus par Airbus, reçoit depuis trois mois une quinzaine de chercheurs venus de tous horizons. Leur mission : faire progresser la recherche dans le domaine du contrôle des écoulements.

16 chercheurs sont réunis à Poitiers.

Bruit, consommation de kérozène, taux d'émission de CO_2 : autant de paramètres que les avions devront réduire de moitié à l'horizon 2020, afin de satisfaire aux objectifs fixés par le Conseil consultatif de la recherche aéronautique européenne (ACARE). Un enjeu de taille pour Airbus. Pour y répondre, l'avionneur européen a donc fait appel à quatre laboratoires universitaires, dont le laboratoire d'études aérodynamiques de Poitiers, spécialisé dans les méthodes de contrôle des écoulements.

Porteuse d'espoirs

Cette discipline, relativement neuve, est porteuse de nombreux espoirs : elle permet de réduire la résistance des matériaux et de faciliter leur pénétration dans l'air. Avec à la clé des gains de consommation en kérozène et une réduction de la pollution sonore. Le pôle poitevin se voit renforcé depuis le mois de mai par 16 chercheurs internationaux (Angleterre, Suède, Allemagne, Hollande, USA, Israël, Portugal et Australie), conviés jusqu'à la fin juillet au forum européen intitulé « European Forum on Flow Control ». Le tout dans des conditions idéales. « *Nous prenons toutes les dépenses en charge* explique Jean-Paul Bonnet, vice-président du conseil scientifique de l'Université et coordonnateur du forum. *Ils n'ont rien d'autre à penser qu'à travailler...* ». Le but de ce forum ? Faire naître un échange entre chercheurs à travers des « brainstorming » et permettre l'émergence d'idées novatrices. « *Un des problèmes de la recherche, c'est que beaucoup de groupes travaillent en parallèle sans se concerter* reconnaît Luis Gomès, chercheur portugais de l'université de Manchester. *Là, ça nous oblige à bosser ensemble et à confronter nos différentes façons de voir les choses* ».

Objectifs ambitieux

Dans l'état actuel des connaissances, les objectifs « 2020 » paraissent toutefois relativement ambitieux, la barre ayant été placée assez haut. « *Réduire le bruit de six décibels, personne ne sait faire aujourd'hui. C'est assez irraisonnable. Il faudrait une innovation technologique majeure pour y parvenir* » reconnaît Jean Brillaud, directeur de l'ENSMA (Ecole nationale supérieure de mécanique et d'aérotechnique). Avec équations mathématiques, expériences en soufflerie et beaucoup de matière grise, les jeunes chercheurs espèrent bien apporter des débuts de réponses à cette nouvelle discipline.

Mathieu Delagarde

CENTRE PRESSE

VENDREDI 21 JUILLET 2006

3 - TOUTE

And now?

- For a 2008, EFFC can evolve towards WFFC? An Europe / USA joint venture (FSU, Syracuse, others?)

- More on flow separation on « academic situation »: ramp for « adaptative control strategies » in a « triadic approach »?

By nature, flow control is multi-disciplinary domain.

- Other actuators: surface plasmas, MEMS
- More on sound sources and their control in jets ?