Dedication of Proceedings to

Professor Anthony Edward Perry

1937–2001

We would like to dedicate this Special Proceedings Issue to Professor Anthony Perry of Melbourne University, Australia. Tony has contributed with many well-known papers, several of them considered classics, to the fields of fluid mechanics and aerodynamics through both the experimental and theoretical approaches. He published extensively, and gave wonderfully original and entertaining presentations in studies of turbulence and structure-based modelling approaches, elegant use of scaling arguments, flow pattern topology, three-dimensional separation and vortex shedding processes. I still remember the first time I met Tony, as part of the great team of Tony and Chong, when they both turned up at a lunch party at Anatol Roshko's house in Pasadena, in the Fall of 1984. I had only just arrived at Caltech, and was not sure who was who in the world of fluid mechanics, but quickly realized Tony was one of the very best. What a wonderful experience it was to meet Tony and Min Chong and to go hiking with them in the hills behind Anatol's house. Tony's energy, joie de vivre and engaging sense of humour were infectious, and these aspects were always there through the intervening years. And so it was with the utmost pleasure that we welcomed Tony, and indeed Min Chong, as invited speakers to our IUTAM Conference in Carry-Le-Rouet in June 2000. We never suspected, based on the incredible level of noise, laughter, and liquid consumption at the "Australian table" at our conference banquet in the port of Marseille, that Tony would now not be with us. This volume of work is dedicated to the memory of a great scientist, and warm-hearted fellow.

Tony Perry at Trinity College, Cambridge (1999)

Charles H. K. Williamson
11 January 2001

Journal of Fluids and Structures (2001) **15,** 375–386
doi:10.1006/jfls.2001.0370, available online at http://www.idealibrary.com on IDEAL®

IUTAM Symposium on Bluff Body Wakes and Vortex-Induced Vibrations (BBVIV-2)

Carry-Le-Rouet (near Marseille), France
13–16 June 2000

Chairmen

Peter W. Bearman	Imperial College, U.K.
Thomas Leweke	IRPHE/CNRS, France
Charles H. K. Williamson	Cornell University, U.S.A.

International Scientific Committee

Morteza Gharib	California Institute of Technology, U.S.A.
Kerry Hourigan	Monash University, Australia
George E. Karniadakis	Brown University, U.S.A.
Masaru Kiya	Hokkaido University, Japan
Peter A. Monkewitz	EPF Lausanne, Switzerland
Christoffer Norberg	Lund Institute of Technology, Sweden
Michael P. Païdoussis	McGill University, Canada
Donald O. Rockwell	Lehigh University, U.S.A.
Michael S. Triantafyllou	Massachusetts Institute of Technology, U.S.A.
Tomomasa Tatsumi	International Institute for Advanced Studies, Japan

Local Organizing Committee

Thomas Leweke (Chairman)	IRPHE/CNRS, France
Stéphane Le Dizès	IRPHE/CNRS, France
Patrice Le Gal	IRPHE/CNRS, France
Michel Provansal	IRPHE/Université Aix-Marseille III, France

The Symposium was organized by the *Institut de Recherche sur les Phénomènes Hors Equilibre* (IRPHE), affiliated with the French *Centre National de la Recherche Scientifique* (CNRS), the *Université de Provence* (Aix-Marseille I), and the *Université de la Méditerranée* (Aix-Marseille II).

0889-9746/01/040375 + 12 $35.00/0

IUTAM Symposium on
Bluff Body Wakes and Vortex-Induced Vibrations

ACKNOWLEDGEMENT

We are grateful for the enthusiastic support for this conference
from the following sponsors:

International Union of Theoretical and Applied Mechanics

European Commission
Research Directorate-General, Human Potential Programme, High-Level Scientific Conferences, Contract no. HPCF-CT-1999-00099.

United States Office of Naval Research
Office of Naval Research, Arlington, VA, U.S.A.
Office of Naval Research International Field Office, London, U.K.

Ministère de la Défense — Délégation Générale pour l'Armement (DGA)
French Ministry of Defence — Procurement Agency

Ministère de l'Education Nationale, de la Recherche et de la Technologie
French Ministry of Education, Research, and Technology

Centre National de la Recherche Scientifique (CNRS)
French National Centre for Scientific Research

Conseil Général des Bouches-du-Rhône (Departmental Council)

Conseil Régional Provence-Alpes-Côte d'Azur (Regional Council)

Université de Provence

Université de la Méditerranée

PREFACE

The present Special Issue makes up the Proceedings of the IUTAM Symposium on Bluff Body Wakes and Vortex-Induced Vibrations held at Carry-le-Rouet (near Marseille), France, 13–16 June 2000. This is the second conference on this subject in recent years, the first conference (BBVIV-1) having been held in Washington, DC, in June 1998; the Marseille conference was thus given the acronym BBVIV-2. The papers in this volume were selected by the Scientific Committee from amongst the oral presentations made at the Symposium. The Symposium itself attracted 100 participants from 18 countries and, apart from a few who were unable to be present, gathered together the most active researchers in the field. The scientific programme included 8 invited lectures, 38 oral presentations and 22 poster presentations. People responsible for the posters were given a few minutes each to make a short presentation on their work. A total of 91 abstracts had been received, and these were reviewed by the Scientific Committee and the Chairmen. It was agreed by all present that the general standard of the presentations and the scientific level achieved were high.

The complete set of abstracts, of both oral and poster presentations, were provided to all participants at the conference site. A detailed list of all presentations is included in a later section of these Proceedings. The topical sessions at the conference had the following titles:

- Wake Fundamentals (4 talks of 20 minutes, 6 poster presentations)
- Vortex-Induced Vibrations (6 talks, 2 posters)
- Forced Oscillations (3 talks, 5 posters)
- Sphere Wakes (5 talks, 3 posters)
- Three-dimensional Effects (4 talks)
- Three-dimensional Instability (4 talks)
- Wake Manipulation (3 talks, 3 posters)
- Wake Control (4 talks, 3 posters)
- Flexible Structures (5 talks)

One of the main purposes of the Symposium was to bring together people working on the wakes of fixed bluff bodies with those studying vortex-induced vibrations of bluff bodies. Papers on the wake structure of fixed bluff bodies were divided into two main areas: those dealing with two-dimensional shapes, or those with only small amounts of three-dimensionality, and those on spheres. Presentations were almost equally divided between experimental and computational work and several addressed the question of vortex shedding control, both passive and active. There were separate sessions on theoretical aspects with a number of presenters following the interesting non-linear model equation approach, showing that they were able to predict many of the physical features.

Vortex-induced vibration (VIV) is a subject that has been around for a long time, and key parameters include structural damping and mass ratio, i.e. the mass of the structure to the mass of displaced fluid. The flow can be studied by considering bluff bodies forced to oscillate, or elastically-mounted bluff bodies free to oscillate, and presentations on both approaches were given at the conference. Much is known about VIV of structures in air where mass ratios are high. Offshore oil production has stimulated an interest in large amplitude VIV for cylinders with mass ratios near unity. A number of new phenomena have been observed, including different modes of shedding, and distinct branches to the response curve of amplitude versus normalized velocity. For low mass ratios, the so-called "added mass component" provided by the fluid has a significant effect on oscillation frequency and is found to vary with normalized velocity, as might be expected. These findings provoked extensive and remarkably lively discussion at the conference on the meaning of "added

mass" and whether it should be considered in its ideal flow sense, or whether it should be defined as the component of the total fluid force in phase with acceleration.

A significant outcome of the meeting was the recognition of the advances being made by computational fluid dynamics (CFD). It was demonstrated that considerable insight can be provided by applying CFD to an idealized cylinder experiment with some combination of the mass, damping and stiffness equated to zero. Direct simulations of three-dimensional modes of shedding are now possible, and this prompted some discussion as to what role they play in determining the amplitude of VIV. Others argued that VIV imposes order on the wake and that two-dimensional codes should be adequate for predicting VIV, although at least one researcher showed that distinctly different VIV responses ensued, depending on whether a 2-D or 3-D direct simulation is used. An intriguing result, which was known before the symposium, but reaffirmed at the meeting, is that CFD codes are having great difficulty in predicting the maximum amplitude of oscillation when the combined mass and damping parameter is low. There was much speculation as to why this is. One researcher, using turbulence modelling, had found that the maximum response could be predicted if the flow speed in the computation was very slowly raised, as might happen in some of the experiments. Others, who had tried the same approach, could not attain large enough amplitudes. As the mass and damping tend to zero, the phase angle (by which the transverse fluid force leads the displacement) becomes extremely small, and to predict maximum amplitudes, this angle has to be found to a very high degree of accuracy.

Predicting maximum amplitude remains one of the challenges facing CFD specialists. In addition to those mentioned above, important new results were displayed on a number of other topics, including: sphere wakes, wakes of cylinders at or near a free surface, flow around multiple cylinders, and the extraction of energy from bluff body wakes.

It must be mentioned that much of the present stimulus for research on fixed bluff bodies over the last 10 years, and the strong resurgence of investigations into vortex-induced vibration over the last 5 years, have come from the focussed support program of the Ocean Engineering Division of the U.S. Office of Naval Research, monitored by Dr Tom Swean. Their support has provided a strong impetus for the two conferences on Bluff Body Wakes and Vortex-Induced Vibration (BBVIV-1 and BBVIV-2), and in both cases, the ONR have provided funds for publication and availability of the Proceedings.

This IUTAM Symposium was held in a resort hotel complex directly on the coast, which possessed a sufficient level of isolation to ensure that the scientific sessions were always very well attended. The hospitality and meals provided by the hotel were excellent, and they played a significant part in bringing the participants together for many interesting discussions. In the Chairman's final remarks of the conference, it was mentioned that the food was so superb and plentiful, that it gave new meaning to the expression "added mass", upon which so much debate had been focussed. Immense thanks are due to all those involved in the local organization of the event for setting up so many of the essential details for the success of the conference. One can say with confidence that everybody was able to leave the meeting with some new research ideas to follow up.

T. Leweke
P. W. Bearman
C. H. K. Williamson

Marseille, January 2001

Opening Address

FLUID MECHANICS IN THE COMING CENTURY

TOMOMASA TATSUMI

IUTAM Bureau Member – International Institute for Advanced Studies, Kyoto, Japan

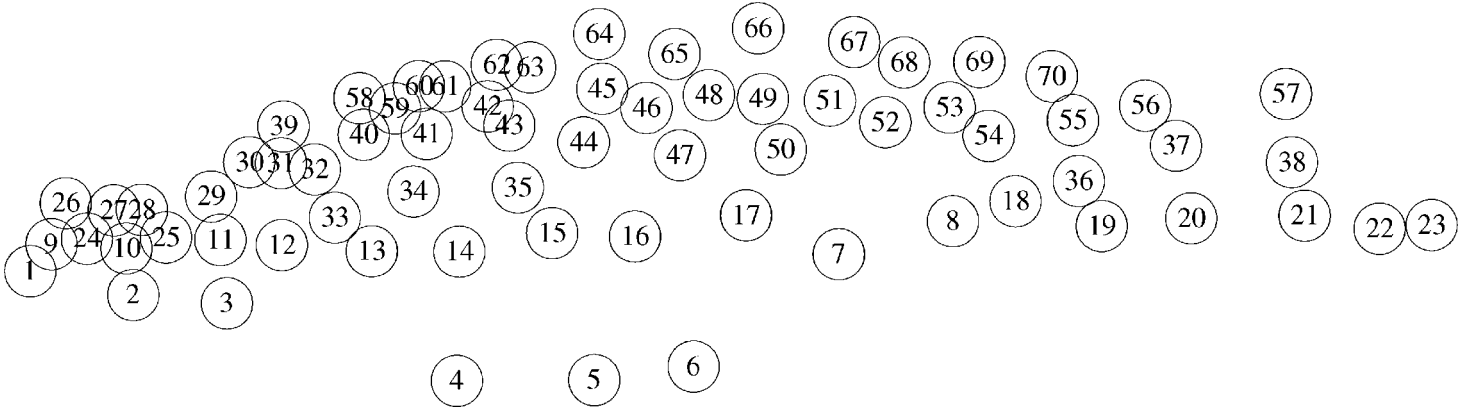
IUTAM. The present Symposium on "Bluff Body Wakes and Vortex-Induced Vibrations" is one of the "IUTAM Symposia", which are sponsored by the International Union of Theoretical and Applied Mechanics (IUTAM). Actually, this subject has been selected from many proposals made by various research groups in the world and adopted by the General Assembly of IUTAM. Another important activity of IUTAM is to organize the "International Congresses of Theoretical and Applied Mechanics" (ICTAM), which are held every 4 years in various cities in the world. The most recent ICTAM held in France was the 17th Congress in 1988, Grenoble, and one of the last was the 19th Congress held in 1996, Kyoto, Japan. Then, in the year of 2000, the 20th Congress was held in Chicago, U.S.A.

Mechanics of Viscous Fluid. The present century may be characterized by the great progress in mechanics of the "viscous fluid" governed by the Navier–Stokes equation. Until the last century, fluid mechanics has mostly been concerned with the "inviscid fluid". Although the mathematical theory due to the Euler equation supplied us with useful mathematical results and elegant theorems for fluid motions, it often caused serious discrepancy from the physical reality such as functional singularities in the solutions and the d'Alembert's paradox of vanishing drag for moving bodies. A big revolution has been achieved around the last turn of the century by two epoch-making works of O. Reynolds (1894) on "turbulent flows" and L. Prandtl (1904) on the "boundary layer". The classification of the real viscous flows in terms of the magnitude of Reynolds number $\mathrm{Re} = UL/\nu$, U and L being the velocity and the length-scales of the flow and ν the kinematic viscosity of the fluid, and introduction of suitable analytical and numerical methods for the corresponding magnitude of Re, enabled us to obtain mathematical solutions of the Navier–Stokes equation for almost all fluid flows of theoretical or practical significance.

Mechanics of Turbulence. An obvious exception from the above optimistic summary is "turbulent flows", including the subject of the present Symposium. In spite of great advances in turbulence research during this Century initiated by the "statistical theory" of Sir Geoffrey Taylor (1935) and the "local equilibrium theory" of A.N. Kolmogorov (1941) and largely helped by the rapid progress in high-speed numerical computation, the theory is still lacking theoretical unity and much more works have to be done in the coming Century before the theory is accomplished as the "mechanics of turbulence".

Fluid Mechanics in the Coming Century. The great success of mechanics of the "viscous fluid" developed during this century has resulted in a rich variety of engineering applications, including the subject of the present Symposium, "Bluff Body Wakes and Vortex-Induced Vibrations". Such a tendency will be pushed even further toward the next century. The study of more "complex" fluid flows associated with thermal convection, combustion, phase change, chemical reaction, nuclear and thermo-nuclear reactions, which have already been included in applied fields of the present fluid mechanics, will certainly constitute the central part of the fluid mechanics in the coming century. The fluid dynamical problems may not be limited to engineering subjects, but they will be extended to fluid phenomena in other fields such as biological and life science, space and cosmic science, and environmental and energy technologies. Theoretically speaking, the enlargement of the subjects to huge scales such as environmental, global, planetary or even cosmical phenomena opens a novel

scope of fluid mechanics. Just like modern fluid mechanics has been largely supported by the developments in molecular physics of matter, the fluid mechanics of huge-scale phenomena must be built up on the theoretical basis of contemporary fluid mechanics of human scale. Even a brief survey as stated above may be sufficient to guarantee a rich and fascinating future for Fluid Mechanics in the coming century.



1 - Françoise BATAILLE 2 - Marianna BRAZA 3 - Iphigenia BRAZA 4 - Michael TRIANTAFYLLOU 5 - Charles WILLIAMSON 6 - George TRIANTAFYLLOU 7 - Tomomasa TATSUMI 8 - Marie Pierre CHAUVE 9 - Yong Tian CHEW 10 - Rupad DAREKAR 11 - Richard WILLDEN 12 - Masaru KIYA 13 - Charles DALTON 14 - Julio SORIA 15 - Min Seong CHONG 16 - Anthony PERRY 17 - Michael PAÏDOUSSIS 18 - David BEAL 19 - Raghuraman GOVARDHAN 20 - Valérie BLONDEAU 21 - Julio MENEGHINI 22 - Hiroshi HIGUCHI 23 - Jean LEMAY 24 - Anne CROS 25 - Emmanuel VILLERMAUX 26 - Pierre ALBARÈDE 27 - ? 28 - Kerry HOURIGAN 29 - Olivier CADOT 30 - Christophe ELOY 31 - Lionel MATHELIN 32 - Peter MONKEWITZ 33 - John OWEN 34 - Hugh BLACKBURN 35 - Petros ANAGNOSTOPOULOS 36 - Patrice LE GAL 37 - Guido BURESTI 38 - Siao Chung LUO 39 - Lionel SCHOUVEILER 40 - Josie CARBERRY 41 - Brice VALLÈS 42 - Cesareo SIQUEIRA 43 - David JEON 44 - Thomas GAUTHEROT 45 - Donald ROCKWELL 46 - Peter BEARMAN 47 - Albin SZEWCZYK 48 - Emmanuel GUILMINEAU 49 - An-Bang WANG 50 - Anatol ROSHKO 51 - Peter STANSBY 52 - Mohammad GHARIB 53 - Christoffer NORBERG 54 - Patrice MEUNIER 55 - John CHAPLIN 56 - Hayden MARCOLLO 57 - Thomas LEWEKE 58 - Benoît PIER 59 - Yves-Marie SCOLAN 60 - Ling QIAN 61 - Michel PROVANSAL 62 - Baoshan ZHU 63 - Stéphane ÉTIENNE 64 - Franz HOVER 65 - Sanjay MITTAL 66 - Bartosz PROTAS 67 - Anthony LEONARD 68 - Christoph BRÜCKER 69 - Maciej PODOLSKI 70 - Stéphane LE DIZÈS

COMPLETE LIST OF PRESENTATIONS

Invited Lectures

Session: Wake Fundamentals

SESSION: VORTEX-INDUCED VIBRATIONS

Blackburn, H. M., Govardhan, R. & Williamson, C. H. K. p. 481
A complementary numerical and physical investigation of vortex-induced vibration

Etienne, S. & Scolan, Y.-M. [7]
Vortex shedding and induced vibrations of multiple cylinders at arbitrary Reynolds numbers

Gharib, M. R. & Leonard, A. p. 533
Vortex-induced vibration, mass ratio effects and introducing effective stiffness

Govardhan, R. & Williamson, C. H. K. p. 489
Response and vortex formation modes of an elastically-mounted cylinder at high and low mass-damping

Guilmineau, E. & Queutey, P.
Dynamics simulation of a hydroelastic structure with very low mass and damping

Hover, F. S. & Triantafyllou, M. S. p. 503
Free vibrations of a cylinder with upstream wake interference

Kamemoto, K. & Zhu, B.
Oscillation characteristics of a circular cylinder in a uniform flow with intermittent touching to a close structure

Stansby, P. K. & Rainey, R. C. T. p. 513
On the big dynamic response of a rotating cylinder in a current

SESSION: FORCED OSCILLATIONS

Anagnostopoulos, P. [8]
Numerical visualization of aperiodic vortex structures in the wake of a transversely excited cylinder

Carberry, J., Sheridan, J. & Rockwell, D. p. 523
Forces and wake modes of an oscillating cylinder

Chew, Y. T., Luo, S. C. & Guo, T. [9]
A new formula for in-line force calculation of oscillatory flow past a circular cylinder

Choi, H. & Choi, S. [10]
Effect of periodic rotary oscillation on flow past a circular cylinder

Jarża, A. & Podolski, M. [11]
Random and periodical velocity fluctuations in vortex formation region behind cylinder in lock-on regime

Jeon, D. & Gharib, M. p. 533
On circular cylinders undergoing two-degree-of-freedom forced motions

Qian, L. & Vezza, M.
Development of a vorticity based method for studying bluff body flow problems

Rodriguez, O. & Pruvost, J. [12]
Wakes of an oscillating cylinder

SESSION: SPHERE WAKES

Brücker, C. p. 543
Spatio-temporal reconstruction of the unsteady wake of axi-symmetric bluff bodies via time-recording DPIV

SESSION: WAKE CONTROL

SESSION: FLEXIBLE STRUCTURES

REFERENCES

[1] PERRY, A. E. & CHONG, M. S. 2000 Interpretation of flow visualization. In *Flow Visualization: Techniques and Examples* (eds A. J. Smits & T. T. Lim). London: Imperial College Press.
[2] SARPKAYA, T. 2001 Hydrodynamic damping and quasi-coherent structures at large Stokes numbers. *Journal of Fluids and Structures* **15** (to appear).
[3] BURESTI, G. & LOMBARDI, G. 1999 Application of continuous wavelet transforms to the analysis of experimental turbulent velocity signals. In *Proceedings of the* 1*st International Symposium on Turbulence and Shear Flow Phenomena*, pp. 767–772. Santa Barbara, CA, U.S.A.
[4] LUO, S. C., YAZDANI, M. G., CHEW, Y. T. & LEE, T. S. 1994 Effects of incidence and afterbody shape on flow past bluff cylinders. *Journal of Wind Engineering and Industrial Aerodynamics* **53,** 375–399.

[5] OZONO, S. 1999 Flow control of vortex shedding by a short splitter plate asymmetrically arranged downstream of a cylinder. *Physics of Fluids* **11,** 2928–2934.
[6] WANG, A.-B., TRÁVNÍČEK, Z. & CHIA, K.-C. 2000 On the relationship of effective Reynolds number and Strouhal number for the laminar vortex shedding of a heated circular cylinder. *Physics of Fluids* **12,** 1401–1410.
[7] ETIENNE, S., SCOLAN, Y.-M. & MOLIN, B. 1999 Numerical study of flow around an array of circular cylinders at high Reynolds number. In *Proceedings of the 7th International Conference on Numerical Ship Hydrodynamics*. Nantes.
[8] ANAGNOSTOPOULOS, P. 2000 Numerical study of the flow past a cylinder excited transversely to the incident stream. *Journal of Fluids and Structures* **14,** 819–882.
[9] PAN, L. S., CHEW, Y. T. & LIU, G. R. 2001 A general formula for calculating forces acting on a 2-D arbitrary body in any incompressible flows. *Journal of Fluids and Structures* **15** (to appear).
[10] KANG, S., CHOI, H. & LEE, S. 1999 Laminar flow past a rotating circular cylinder. *Physics of Fluids* **11,** 3312–3321.
[11] JARŻA, A. & TARNOWSKI, T. 1999 Turbulent flow around circular cylinder in oscillatory inlet conditions. *Transactions of the IFFM* **105,** 3–16.
[12] RODRIGUEZ, O. 1997 Experimental analysis of the wake instabilities of an oscillating cylinder near synchronisation: influence of the amplitude parameter. In: *Proceedings of the 7th International Offshore and Polar Engineering Conference — Vol. III*, pp. 694–701. Golden, CO: International Society of Offshore and Polar Engineers.
[13] GHIDERSA, B. & DUŠEK, J. 2000 Breaking of axisymmetry and onset of unsteadiness in the wake of a sphere. *Journal of Fluid Mechanics* **423,** 33–69.
[14] VALLÈS, B., ANDERSSON, H. I. & JENSSEN, C. B. 2001 Oblique vortex shedding behind tapered cylinders. *Journal of Fluids and Structures* (submitted).
[15] PERSILLON, H. & BRAZA, M. 1998 Physical analysis of the transition to turbulence in the wake of a circular cylinder by three-dimensional Navier–Stokes simulation. *Journal of Fluid Mechanics* **365,** 23–88.
[16] CADOT, O. & KUMAR, S. 2000 Experimental characterization of viscoelastic effects on two- and three-dimensional shear instabilities. *Journal of Fluid Mechanics* **416,** 151–172.
[17] SIQUEIRA, C. L. R., MENEGHINI, J. R. & SALTARA, F. 2000 Three-dimensional simulation of the flow about an oscillating circular cylinder at low Reynolds numbers. In *Proceedings of the* 2000 *ASME Fluids Engineering Division Summer Meeting*. New York: American Society of Mechanical Engineers.
[18] LALANNE, L., LE GUER, Y. & CREFF, R. 2001 Dynamivs of a bifurcating flow within an open heated cavity. *International Journal of Thermal Sciences* (to appear).
[19] MATHELIN, L., BATAILLE, F. & LALLEMAND, A. 2001 Near wake of a circular cylinder submitted to blowing. Part II: boundary layers evolution. *International Journal of Heat and Mass Transfer* (to appear).
[20] MITTAL, S. & KUMAR, V. 1999 Finite element study of vortex-induced cross-flow and in-line oscillations of a circular cylinder at low Reynolds numbers. *International Journal for Numerical Methods in Fluids* **31,** 1087–1120.
[21] PANCHAPAKESAN, N. R. & SORIA, J. 1999 Separation control using surface oscillations — some preliminary results. In *Proceedings of the 2nd Australian Conference on Laser Diagnostics in Fluid Mechanics and Combustion*. Melbourne.
[22] POSDZIECH, O. & GRUNDMANN, R. 2001 Electromagnetic control of seawater flows around circular cylinders. *European Journal of Mechanics B/Fluids* (submitted).

IUTAM-BBVIV2 Group Photograph

- 16 June 2000 -