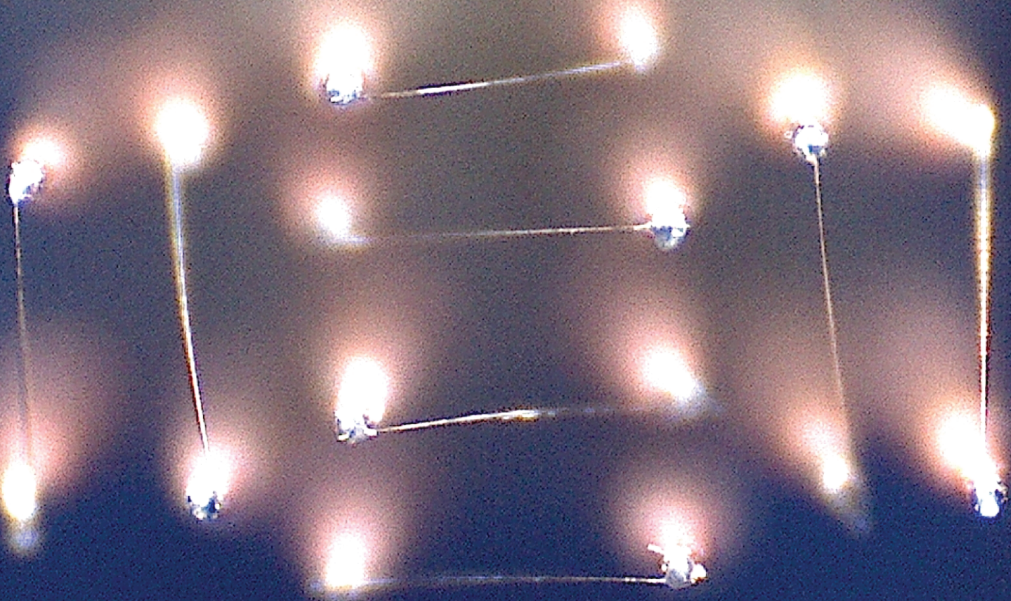


CAMBRIDGE
UNIVERSITY PRESS

25 June 2019

Journal of Fluid Mechanics

VOLUME 869



SUBSCRIPTIONS

The *Journal of Fluid Mechanics* (ISSN 0022-1120) is published *semimonthly* in 24 volumes each year by Cambridge University Press, University Printing House, Shaftesbury Road, Cambridge CB2 8BS, UK/Cambridge University Press, 1 Liberty Plaza, Floor 20, New York, NY 10006, USA. The subscription price (excluding VAT but including postage) for volumes 858–881, 2019, is £4680 or \$8635 (online and print) and £4200 or \$7356 (online only) for institutions; £1296 or \$2400 (online and print) and £1260 or \$2142 (online only) for individuals. The print-only price available to institutional subscribers is £4513 (US \$7942 in USA, Canada and Mexico). Single volumes cost £216 (US \$380 in the USA, Canada and Mexico) plus postage. Orders, which must be accompanied by payment, should be sent to any bookseller or subscription agent, or direct to the publisher: Cambridge University Press, University Printing House, Shaftesbury Road, Cambridge CB2 8BS. Subscriptions in the USA, Canada and Mexico should be sent to Cambridge University Press, Journals Fulfillment Department, 1 Liberty Plaza, Floor 20, New York, NY 10006, USA. EU subscribers (outside the UK) who are not registered for VAT should add VAT at their country's rate. VAT registered subscribers should provide their VAT registration number. Japanese prices for institutions are available from Kinokuniya Company Ltd, PO Box 55, Chitose, Tokyo 156, Japan. Prices include delivery by air. Copies of the *Journal* for subscribers in the USA, Canada and Mexico are sent by air to New York. Periodicals postage is paid at New York, NY, and at additional mailing offices. POSTMASTER: send address changes in USA, Canada and Mexico to *Journal of Fluid Mechanics*, Cambridge University Press, 1 Liberty Plaza, Floor 20, New York, NY 10006, USA. Claims for missing issues can only be considered if made immediately upon receipt of the subsequent issue. Copies of back numbers are available from Cambridge University Press.

COPYING

The *Journal* is registered with the Copyright Clearance Center, 222 Rosewood Drive, Danvers, MA 01923. Organizations in the USA which are also registered with CCC may therefore copy material (beyond the limits permitted by sections 107 and 108 of US copyright law) subject to payment to CCC of the per-copy fee of \$16.00. This consent does not extend to multiple copying for promotional or commercial purposes. Code 0022-1120/2019/\$16.00.

ISI Tear Sheet Service, 3501 Market Street, Philadelphia, PA 19104, USA is authorized to supply single copies of separate articles for private use only.

Organizations authorized by the Copyright Licensing Agency may also copy material subject to the usual conditions.

For all other use of material from the *Journal* permission should be sought from Cambridge or the American Branch of Cambridge University Press.

Information on *Journal of Fluid Mechanics* is available on cambridge.org/FLM. For further information on other Press titles access cambridge.org/.

Readers should note that where reference is made to a Web site for additional material relating to an article published in *Journal of Fluid Mechanics* this material has not been refereed and the Editors and Cambridge University Press have no responsibility for its content.

This journal issue has been printed on FSC-certified paper and cover board. FSC is an independent, non-governmental, not-for-profit organization established to promote the responsible management of the World's forests. Please see www.fsc.org for information.

Printed in the UK by Bell & Bain Ltd.



The picture on the cover is based on figure 2(b) of 'A comparative study of the velocity and vorticity structure in pipes and boundary layers at friction Reynolds numbers up to 10^4 ', by S. Zimmerman, J. Philip, J. Monty, A. Talamelli, I. Marusic, B. Ganapathisubramani, R. J. Hearst, G. Bellani, R. Baidya, M. Samie, X. Zheng, E. Dogan, L. Mascotelli & J. Klewicki.

The JOURNAL OF FLUID MECHANICS exists for the publication of theoretical, computational and experimental investigations of all aspects of the mechanics of fluids.

EDITOR

Prof. M. G. Worster, University of Cambridge, mgw.jfm@damtp.cam.ac.uk

DEPUTY EDITORS

Prof. P. F. Linden, University of Cambridge, p.f.linden@damtp.cam.ac.uk

Prof. C. Meneveau, Johns Hopkins University, meneveau@jhu.edu

BOOK REVIEW AND FOCUS ON FLUIDS EDITOR

Prof. A. Juel, University of Manchester, anne.juel@manchester.ac.uk

ASSOCIATE EDITORS

Prof. Silas Alben, University of Michigan,
alben@umich.edu

Prof. N. Balmforth, University of British Columbia,
njb@math.ubc.ca

Prof. O. Bühler, Courant Institute of Mathematical
Sciences, obuhler@cims.nyu.edu

Prof. C. Cenedese, Woods Hole Oceanographic
Institution, ccenedese@whoi.edu

Prof. H. Choi, Seoul National University,
choi@snu.ac.kr

Prof. J.-M. Chomaz, LadHyX-CNRS-Ecole
Polytechnique, jfm.chomaz@ladhyx.polytechnique.fr

Prof. P. A. Davidson, University of Cambridge,
pad3@eng.cam.ac.uk

Prof. J. M. Gordillo, University of Seville,
jgordill@us.es

Prof. M. Juniper, University of Cambridge,
mpj1001@cam.ac.uk

Prof. G. Kawahara, Osaka University,
kawahara@me.es.osaka-u.ac.jp

Prof. J. Kirby, University of Delaware,
kirby@udel.edu

Prof. J. C. Lasheras, University of California,
San Diego, lasherasjfm@eng.ucsd.edu

Prof. J. Magnaudet, Institut de Mécanique des
Fluides de Toulouse, magnau_jfm@imft.fr

Prof. I. Marusic, University of Melbourne,
imarusic@unimelb.edu.au

Prof. M. Matalon, University of Illinois at
Urbana-Champaign, matalon@illinois.edu

Prof. J. F. Morris, Levich Institute, CUNY City
College of New York, jfm@ccny.cuny.edu

Prof. P. Nott, Indian Institute of Science,
prnott@iisc.ac.in

Prof. M. Onorato, University of Turin,
miguel.onorato@unito.it

Prof. J. J. Riley, University of Washington,
rileyj@u.washington.edu

Prof. S. Sarkar, University of California,
San Diego, ssarkar@eng.ucsd.edu

Prof. S. Sherwin, Imperial College,
jfluidmech@imperial.ac.uk

Prof. R. Verzicco, Università di Roma 'Tor Vergata',
verzicco_jfm@uniroma2.it

Prof. S. Waters, University of Oxford,
waters@maths.ox.ac.uk

Prof. J. S. Wettlaufer, University of Oxford,
John.Wettlaufer@maths.ox.ac.uk

Prof. K.-Q. Xia, The Chinese University of Hong
Kong, xia.jfm@phy.cuhk.edu.hk

RAPIDS EDITOR

Prof. É. Guazzelli, MSC, CNRS Université de Paris, elisabeth.guazzelli@univ-paris-diderot.fr

RAPIDS ASSOCIATE EDITORS

Prof. C. P. Caulfield, University of Cambridge, c.p.caulfield@damtp.cam.ac.uk

Prof. J. O. Dabiri, Stanford University, jodabiri@stanford.edu

Prof. D. S. Henningson, KTH Mechanics, jfm@mech.kth.se

Prof. D. Lohse, University of Twente, lohse.jfm.tnw@utwente.nl

PERSPECTIVES EDITOR

Prof. P. F. Linden, University of Cambridge, p.f.linden@damtp.cam.ac.uk

PERSPECTIVES ASSOCIATE EDITORS

Prof. M. Brenner, Harvard University,
brenner@seas.harvard.edu

Dr Berengere Dubrulle, French National Centre for
Scientific Research CNRS, France,
berengere.dubrulle@cea.fr

Prof. Rich Kerswell, University of Cambridge, UK,
r.r.kerswell@damtp.cam.ac.uk

Prof. J. Magnaudet, Institut de Mécanique des
Fluides de Toulouse, magnau_jfm@imft.fr

Prof. Sarah Waters, University of Oxford, UK,
waters@maths.ox.ac.uk

EDITORIAL OFFICE

FAX 44 1223 325802; JFMproduction@cambridge.org

SUMMARY OF INSTRUCTIONS FOR AUTHORS

Full instructions are available on the JFM web page at cambridge.org/flm

Submission

Authors wishing to have papers published in the *Journal* should submit them via the online submission and refereeing system, ScholarOne Manuscripts, at <https://mc.manuscriptcentral.com/jfm>. Papers may be submitted to any editor or associate editor but JFM Rapids articles (10 printed pages or fewer) must be submitted to Professors Guazzelli, Caulfield, Dabiri, Henningson or Lohse who should be consulted in advance. Submission of a paper implies a declaration by the author that the work is not being considered for publication elsewhere and that it has not already been considered by a different editor of the *Journal*. Conference Reports must be submitted within three months of the meeting.

Preparation of papers

Authors are encouraged to write their papers clearly, concisely and attractively, so that their work will be readily understood. A brief summary of editorial requirements for notation, English and presentation is available on the JFM web page (address above). Authors are urged to use the JFM latex style macros. The [referee] option should be used for initial submission. The style file and template files are available at cambridge.org/core/journals/journal-of-fluid-mechanics/information/instructions-contributors. While use of the JFM latex style file is preferred (and note that this is mandatory for JFM Rapids submissions), ordinary latex or plain tex files can also be accepted. Other software, such as Word, will be converted to latex by the Press or retyped. Manuscripts not prepared using the JFM latex style file should be typed in double spacing, with references listed at the end in alphabetical order of authors and with a separate list of figure captions.

Extensive detailed mathematical relations, tables or figures likely to be useful only to a few specialists will not be printed, but will be available as an electronic supplement to the online version or from the JFM Editorial Office.

Movies

Refereed movies that are integral to a paper can be supplied during the submission process and will be published as supplementary materials.

Accepted papers

Once a paper is accepted, final production files (e.g. the LaTeX source) must be uploaded to the ScholarOne Manuscripts site. Full details are given on the JFM web page. Do not email files to the JFM Editorial Office unless requested to do so.

Charges

There is no charge for publication, but the cost of any colour figures in standard articles must be borne by authors. Authors will receive a PDF file of their published article via email. For standard articles only, offprints can be purchased if ordered when the proofs are returned.

Address questions or comments to Mrs Amanda Johns (Editorial Assistant) or Mrs Alison James (Production Editor) at the Journals Department, Cambridge University Press, Shaftesbury Road, Cambridge CB2 8BS, UK; tel: 44 (0)1223 347922; fax: 44 (0)1223 325802; e-mail: JFMproduction@cambridge.org.