

Banner appropriate to article type will appear here in typeset article

Guidelines for authors

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This file contains instructions for authors planning to submit a paper to the *Journal of Fluid Mechanics*. These instructions were generated in L^AT_EX using the JFM class file, and the source files for these instructions can be used as a template for submissions. The present paragraph appears in the abstract environment. All papers should feature a single-paragraph abstract of no more than 250 words, which provides a summary of the main aims and results. In addition to the figures in the main article a graphical abstract is now required. It will be used as a small thumbnail in the table of contents and on the abstract page, so multiple panels are not suitable and will be rejected. Please confirm that you have included an image to accompany your abstract, which will be used as the graphical abstract for manuscripts published in 2020. The image must be of aspect ratio 1.2:1 (e.g. 6cm x 5cm) and should be submitted in GIF or high resolution JPEG format (300 dpi). Unless very large, vector graphics are preferred to ensure image sharpness regardless of sizing. If you do not have the copyright to the image, please ensure you have permission to reuse the figure. Captions are not required. Text is actively discouraged, but if it must be used, it should be legible in a small thumbnail (2.4cmx2cm) presented in the table of contents. All graphical abstract images will be considered for a JFM cover selection by the JFM Panel. Please note that we publish 24 covers in a year.

Key words: Authors should not enter keywords on the manuscript, as these must be chosen by the author during the online submission process and will then be added during the typesetting process (see [Keyword PDF](#) for the full list). Other classifications will be added at the same time.

MSC Codes (*Optional*) Please enter your MSC Codes here

1. How to submit to the *Journal of Fluid Mechanics*

Authors must submit using the online submission and peer review system [Scholar One](#) (formerly Manuscript Central). If visiting the site for the first time, users must create a new account by clicking on 'register here'. Once logged in, authors should click on the

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33 ‘Corresponding Author Centre’, from which point a new manuscript can be submitted, with
34 step-by-step instructions provided. Authors must at this stage specify whether the submission
35 is a *JFM Paper*, or a *JFM Rapids* paper (see §4 for more details). In addition, authors must
36 specify an editor to whom the paper will be submitted from the drop-down list provided.
37 Note that all editors exclusively deal with either *JFM Paper* or *JFM Rapids* (clearly indicated
38 on the list), so please ensure that you choose an editor accordingly. Corresponding authors
39 must provide a valid ORCID ID in order to submit a manuscript, either by linking an existing
40 ORCID profile to your ScholarOne account or by creating a new ORCID profile. Once your
41 submission is completed you will receive an email confirmation. Book reviews should not
42 be submitted via the online submission site, but should instead be submitted by email to
43 anne.juel@manchester.ac.uk.

44 2. Rules of submission

45 Submission of a paper implies a declaration by the author that the work has not previously
46 been published, that it is not being considered for publication elsewhere and that it has
47 not already been considered by a different editor of the Journal. If you have uploaded your
48 manuscript via the arXiv function, then please include your E-print Number during the
49 submission process.

50 3. Authors responsibilities

51 Authors need to declare in their covering letter to the Editor and during the online submission
52 process whether their manuscript had previously been considered for publication in the
53 *Journal of Fluid Mechanics*. Questions and declarations to that effect must be answered
54 truthfully. Editors, referees, readers and publishers have the right to assume that submitted
55 (and published) manuscripts do not contain scientific dishonesty or fraud comprising, for
56 example, fictitious or manipulated data, plagiarised material (either from previous work of
57 the authors or that of other persons), reference omissions, false priority statements, ‘hidden’
58 multiple publication of the same data or incorrect authorship. Authors must not breach any
59 copyright. The *Journal of Fluid Mechanics* uses the iThenticate software to detect instances
60 of plagiarism in manuscripts submitted to it.

61 3.1. Transparency and Openness Promotion (TOP)

62 The overarching policy of the *Journal of Fluid Mechanics* is that research articles should
63 contain sufficient information to allow others to understand, replicate and verify findings,
64 and compare them with alternative studies. We therefore require that whenever possible:

65 **Understanding** - Articles should be written and will be assessed for clarity, both of the
66 execution of the research and for its outcomes and conclusions.

67 **Replication** - All information required to replicate the study must be provided, within
68 the body of the paper and/or publicly accessible repositories. Examples of what is required
69 include but are not limited by:

- 70 • for analytical studies, the mathematically complete set of equations and boundary
71 conditions, any theorems relied upon, appropriately referenced;
- 72 • for numerical studies, the mathematically complete set of equations and boundary con-
73 ditions, sufficient descriptions of the algorithms or packages used to solve them, appropriately
74 referenced, and the resolution used with respect to the independent variables;
- 75 • for laboratory experiments, the dimensions and construction of any apparatus, the
76 materials used including their relevant physical properties, the protocol adopted for the

77 running of the experiments, the measurement tools used including their resolution and
78 accuracy, including appropriate calibration standards;

79 • for field studies, the raw data collected or used, any protocols or tools used to access the
80 data (e.g. data-mining tools) or to process it.

81 **Verification** - Most studies can be verified or falsified provided that sufficient detail is given
82 for them to be replicated (see above). Where data is manipulated (for example, bringing
83 together multiple data sets by scaling) the raw (dimensional) data relating to the primary
84 measurements (laboratory) or outputs (numerical) should be provided together with the
85 protocols or tools used to process them.

86 **Comparison** - All graphical information should be supplemented with numerical data
87 or precise algorithms to reproduce it. For example, data points should be provided in a
88 spreadsheet and curves should be defined either explicitly with an equation or as resulting
89 from a precisely defined algorithm.

90 4. Types of paper

91 4.1. *Standard papers*

92 Regular submissions to JFM are termed ‘standard papers’. Note that such papers must contain
93 original research. Papers should be written in a concise manner; though JFM has no page
94 limit, each paper will be judged on its own merits, and those deemed excessive in length will
95 be rejected or will require significant revision.

96 4.2. *JFM Rapids*

97 *JFM Rapids* is devoted to the rapid publication of short, high-impact papers across the full
98 range of fluid mechanics. Manuscripts submitted as *JFM Rapids* must be strictly 10 or fewer
99 printed pages, and must be submitted in L^AT_EX using the jfm.cls class file, so as to ensure
100 that they meet the page limit and to expedite their production. As with standard papers, the
101 principal and over-riding objective is to publish papers of the highest scientific quality.

102 Once a paper is submitted, reviewers are asked to provide reports with a short turnaround.
103 In order to be accepted for publication in *JFM Rapids*, such papers must be strongly endorsed
104 by the referees and should require only minor revisions to improve clarity, usually without
105 recourse to a second round of reviewing. In this case, and at the discretion of the editor, some
106 additional pages may be allowed to address specific points raised by the reviewers, such as
107 the addition of an extra figure or some explanatory text.

108 Papers that are rejected having been submitted to Rapids are rejected on behalf of the
109 whole Journal and may not be submitted for consideration by another associate editor of
110 JFM, whether for Rapids or as a Standard paper.

111 In cases where the editor, guided by the reviewers, judges that a paper has merit but
112 requires substantial revision that will require significant reviewing, a decision of ‘revise and
113 resubmit’ will be given. On re-submission, such papers will be handled as standard JFM
114 papers and if accepted will not subsequently appear as *JFM Rapids*.

115 *JFM Rapids* will be published online within one month of final acceptance. They will
116 appear within a designated section on the *Journal of Fluid Mechanics* website. Each *Rapid*
117 will be cited and indexed as a JFM article but with a distinctive *Rapids* identifier, and will
118 be assigned to a JFM volume.

119 4.3. *JFM Perspectives*

120 Review papers are published under *JFM Perspectives* and are by invitation only.

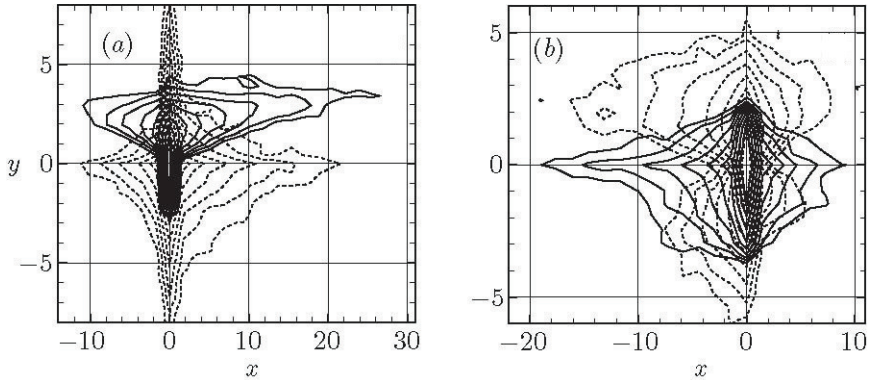


Figure 1: Trapped-mode wavenumbers, kd , plotted against a/d for three ellipses: —, $b/a = 1$; $\cdots \cdots$, $b/a = 1.5$.

121 5. File types

122 Authors are strongly encouraged to compose their papers in \LaTeX , using the [jfm.cls](#) style
 123 file and supporting files provided, with the [jfm-instructions.tex](#) file serving as a template
 124 (please note that this is mandatory for *JFM Rapids*). A PDF of the \LaTeX file should then be
 125 generated and submitted via the submission site. For the review process the pdf file should
 126 be no more than 10MB. There is no need to submit the \LaTeX source files alongside the PDF,
 127 but upon provisional acceptance of the paper, the \LaTeX source files, along with individual
 128 figure files and a PDF of the final version, will need to be submitted for typesetting purposes.
 129 Authors may also compose standard papers in Word, though this will lead to the paper
 130 spending a longer period in production. If using Word, please note that equations must NOT
 131 be converted to picture format and the file must be saved with the option ‘make equation
 132 editable’. All submitted video abstract files should be formatted as MP4 (H.264). MP4 has
 133 full compatibility across commonly used browsers, whereas other video formats will only
 134 work on selected browsers. This will ensure the greatest possible dissemination of this work.

135 6. Preparing your manuscript

136 Authors should write their papers clearly and concisely in English, adhering to JFM’s
 137 established style for mathematical notation, as provided in Section 12. We encourage the
 138 submission of online supplementary material alongside the manuscript where appropriate
 139 (see Section 6.3). Metric units should be used throughout and all abbreviations must be
 140 defined at first use, even those deemed to be well known to the readership. British spelling
 141 must be used, and should follow the *Shorter Oxford English Dictionary*.

142

6.1. Figures

143 All authors need to acquire the correct permissions and licences to reproduce figures, which
 144 should be submitted with the production files. Further information on applying for permission
 145 to reuse figures can be found [here](#). Images should be submitted in EPS or high-resolution
 146 TIFF format (1200 dpi for lines, 300 dpi for halftone and colour in RGB format, and 600
 147 dpi for a mixture of lines and halftone) and all labels should be editable. Unless very large,
 148 vector graphics are preferred to ensure image sharpness regardless of sizing. The minimum
 149 acceptable width of any line is 0.5pt. Each figure should be accompanied by a single caption,
 150 to appear beneath, and must be cited in the text. Figures should appear in the order in which
 151 they are first mentioned in the text and figure files must be named accordingly (‘Abstract.eps,

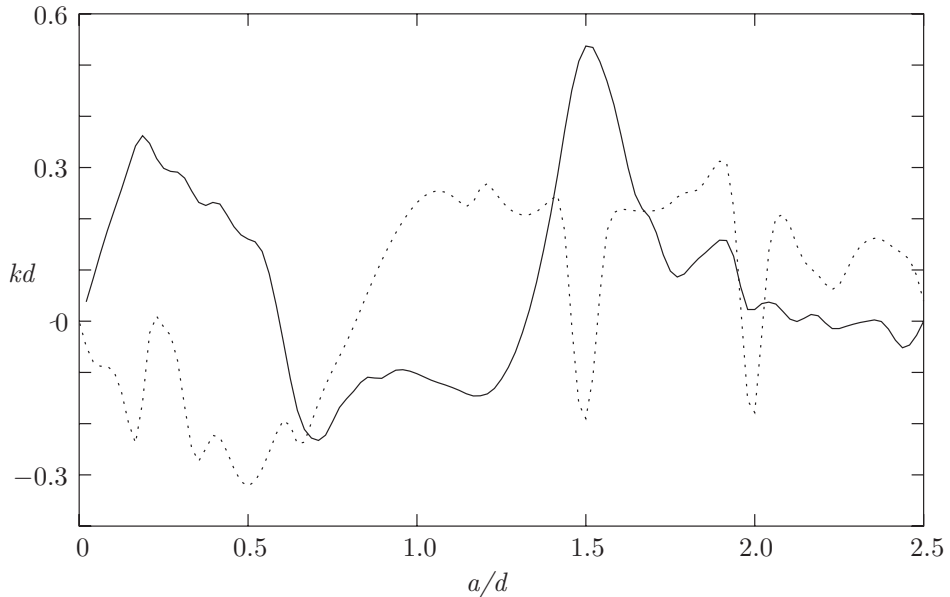


Figure 2: The features of the four possible modes corresponding to (a) periodic and (b) half-periodic solutions.

a/d	$M = 4$	$M = 8$	Callan <i>et al.</i>
0.1	1.56905	1.56	1.56904
0.3	1.50484	1.504	1.50484
0.55	1.39128	1.391	1.39131
0.7	1.32281	10.322	1.32288
0.913	1.34479	100.351	1.35185

Table 1: Values of kd at which trapped modes occur when $\rho(\theta) = a$.

152 Fig1.eps', 'Fig2a.tiff', etc) to assist the production process (and numbering of figures should
 153 continue through any appendices). Words *figure 1*, *table 1* and *movie 1* should be lower case.
 154 For example see figures 1 and 2. Failure to follow figure guidelines may result in a request
 155 for resupply and a subsequent delay in the production process. Note that *all* figures will be
 156 relabelled by the typesetter, so please ensure all figure labels are carefully checked against
 157 your originals when you receive your proofs.

158

6.2. Tables

159 Tables, however small, must be numbered sequentially in the order in which they are
 160 mentioned in the text. Words *table 1*, *table 2* should be lower case throughout. See table 1
 161 for an example.

162

6.3. Online supplementary material

163 Relevant material which is not suitable for inclusion in the main article, such as movies or
 164 numerical simulations/animations, can be uploaded as part of the initial submission. Movies
 165 must be submitted in .mp4 format and have the file designation of 'Movie'. Each movie must
 166 be numbered in the order they are mentioned and titled movie 1, movie 2 etc and accompanied

167 by a separate caption. To ensure maths terms display correctly they should be bounded by
168 $\$$ and written in TeX, e.g. movie 1. Side view of numerical Schlieren contours from case
169 E1N at $z = Lz/2$. Each movie should be no more than 50MB. Upon publication these
170 materials will then be hosted online alongside the final published article. Likewise, should
171 there be detailed mathematical relations, tables or figures which are likely to be useful only
172 to a few specialists or take up excessive space in the article, these should also be published
173 online as supplementary material [designated as ‘Other supplementary material’]. Note that
174 supplementary material is published ‘as is’, with no further intervention made during the
175 Production process, all ‘draft’ information should be removed.

176 7. Editorial decisions

177

7.1. Revision

178 If a revision is requested, you should upload revised files following the same procedure as
179 for submitting a new paper. You begin by clicking on ‘Manuscripts with decision’ in your
180 Corresponding Author Centre, and then on ‘Create a revision’. (Note that if you abandon the
181 process before completing the submission, to continue the submission, you must click on
182 ‘Revised manuscripts in draft’.) There is a new first page showing the decision letter and a
183 space for your reply to the reviewer’s/editor’s comments. You also have the opportunity at
184 this stage to upload your reply to the comments as separate files. All the values filled in on
185 original submission are displayed again. The ID number of the paper will be appended ‘.R1’.
186 Also note that if a manuscript is submitted as a *JFM Rapid*, but requires substantial revision,
187 it will be re-designated as a standard paper, and the ID and paper type will be amended to
188 reflect this.

189

7.2. Provisional acceptance

190 If the paper is accepted as suitable for publication you will be sent a provisional acceptance
191 decision. This enables you to upload the final files required for production: (1) the final PDF
192 or word version of the paper, designated as a ‘Main Document’; (2) any source files (see
193 section 5) which must be designated as ‘Production Files’ and uploaded as a single .zip or
194 .tar file; (3) a completed author publishing agreement form which is available to download
195 at [Cambridge Core](#). For Open Access there is a one-off fee, further information can be found
196 at [JFM open access - FAQs](#). If your research is publicly funded and your organisation comes
197 under one of Cambridge University Press’s Read and Publish agreements you may be entitled
198 to free Open Access. Please check your eligibility [here](#).

199

7.3. Acceptance

200 On receipt of the production files you will be sent an email indicating completion of the
201 acceptance process.

202 8. Publication process

203 Once a paper has been accepted for publication and the source files have been uploaded,
204 the manuscript will be sent to Cambridge University Press for copyediting and typesetting,
205 and will be assigned a digital object identifier (doi). When the proof is ready, authors will
206 receive an email alert containing a link to the PDF of the proof, and instructions for its
207 correction and return. It is imperative that authors check their proofs closely, particularly the
208 equations and figures, which should be checked against the accepted file, as the production
209 schedule does not allow for corrections at a later stage. Once ready, papers will be published

210 online on [Cambridge Core](#) in the current ‘open’ volume. Each volume will be kept open
 211 for approximately two weeks. Note that the PDF published online is the Version of Record
 212 and no further alterations/corrections to this document will be allowed. The corresponding
 213 author is emailed a link to the published article when it is published online.

214 **9. Corrigenda**

215 The Journal will publish corrigenda that alter significant conclusions made in a paper. Such
 216 corrigenda should be submitted to an associate editor, who will consider the submission
 217 similarly to a new paper and may consult referees if appropriate. When published, corrigenda
 218 are clearly linked with the original articles to which they refer, and the articles to them.

219 The Journal does not normally publish corrigenda to amend typographical errors, so it is
 220 extremely important that authors make very careful checks of their manuscript at every stage,
 221 including the reading of proofs, prior to publication.

222 **10. Obtaining help**

223 Technical support for the online submission system is available by clicking on the ‘Get Help
 224 Now’ link at the top-right corner of each page of the submission site. Any other questions
 225 relating to the submission or publication process should be directed to the JFM Editorial
 226 Assistant, Mrs Amanda Johns, at JFMEditorial@cambridge.org.

227 **11. Cambridge Author Services - in partnership with American Journal Experts**

228 We suggest that authors whose first language is not English have their manuscripts checked
 229 by a native English speaker before submission. This is optional but will help to ensure that
 230 any submissions that reach peer review can be judged exclusively on academic merit. Further
 231 information can be found at [Language services](#), and we suggest that authors make contact as
 232 appropriate. Please note that use of language editing services is voluntary and at the author's
 233 own expense. Use of these services does not guarantee that the manuscript will be accepted
 234 for publication nor does it restrict the author to submitting to a Cambridge-published journal.

235 **12. Notation and style**

236 Generally any queries concerning notation and journal style can be answered by viewing
 237 recent pages in the Journal. However, the following guide provides the key points to note. It
 238 is expected that Journal style and mathematical notation will be followed, and authors should
 239 take care to define all variables or entities upon first use. Also note that footnotes are not
 240 normally accepted. Abbreviations must be defined at first use, glossaries or lists/tables of
 241 abbreviations are not permitted.

242 *12.1. Mathematical notation*

243 *12.1.1. Setting variables, functions, vectors, matrices etc*

244 • **Italic font** should be used for denoting variables, with multiple-letter symbols avoided
 245 except in the case of dimensionless numbers such as *Re*, *Pr* and *Pe* (Reynolds, Prandtl,
 246 and Péclet numbers respectively, which are defined as `\Rey`, `\Pran` and `\Pen` in the template).
 247

248 • **Upright Roman font** (or upright Greek where appropriate) should be used for:
 249

250 (i) (vI) label, e.g. T. t (transpose)

251

252 (ii) Fixed operators: sin, log, d, Δ , exp etc.

253

254 (iii) Constants: i ($\sqrt{-1}$), π (defined as `\upi`), e etc.

255

256 (iv) Special Functions: Ai, Bi (Airy functions, defined as `\Ai` and `\Bi`), Re (real part,
257 defined as `\Real`), Im (imaginary part, defined as `\Imag`), etc.

258

259 (v) Physical units: cm, s, etc.

260

261 (vi) Abbreviations: c.c. (complex conjugate), h.o.t. (higher-order terms), DNS, etc.

262

263 • **Bold italic font** (or bold sloping Greek) should be used for vectors (with the centred
264 dot for a scalar product also in bold): $\mathbf{i} \cdot \mathbf{j}$

265

266 • **Bold sloping sans serif font**, defined by the `\mathsfbi` macro, should be used for
267 tensors and matrices: \mathbf{D}

268

269 • **Calligraphic font** (for example \mathcal{G} , \mathcal{R}) can be used as an alternative to italic when the
270 same letter denotes a different quantity use `\mathcal` in \LaTeX

271 12.1.2. *Other symbols*

272 Large numbers that are not scientific powers should not include commas, but should use a
273 non-breaking space, and use the form 1600 or 16 000 or 160 000. Use \mathcal{O} to denote ‘of the
274 order of’, not the \LaTeX \mathcal{O} .

275 The product symbol (\times) should only be used to denote multiplication where an equation
276 is broken over more than one line, to denote a cross product, or between numbers. The \cdot
277 symbol should not be used, except to denote a scalar product of vectors specifically.

278 13. Citations and references

279 All papers included in the References section must be cited in the article, and vice versa.
280 Citations should be included as, for example “It has been shown (Rogallo 1981) that...” (using
281 the `\citep` command, part of the natbib package) “recent work by Dennis (1985)...” (using
282 `\citet`). The natbib package can be used to generate citation variations, as shown below.

283 `\citet[pp. 2-4]{Hwang70}`:

284 Hwang et al (1970, pp. 2-4)

285 `\citep[p. 6]{Worster92}`:

286 (Worster 1992, p. 6)

287 `\citep[see][{}]{Koch83, Lee71, Linton92}`:

288 (see Koch 1983; Lee 1971; Linton and Evans 1992)

289 `\citep[see][p. 18]{Martin80}`:

290 (see Martin 1980(@, p. 18)

291 `\citep{Brownell04, Brownell07, Ursell150, Wijngaarden68, Miller91}`:

292 (Brownell 2004; Brownell and Su 2007; Ursell 1950; Wijngaarden 1968; Miller 1991)

293 (Briukhanovetal et al 1967)

294 Bouguet (2008)

295 (Josep and Saut 1990)

296 The References section can either be built from individual `\bibitem` commands, or can be
297 built using BibTex. The BibTex files used to generate the references in this document can be

298 found in the zip file [jfm-ifcs](#).

299 Where there are up to ten authors, all authors' names should be given in the reference list.

300 Where there are more than ten authors, only the first name should appear, followed by *et al.*

301 JFM discourages citations of manuscript posted on social media sites (such as Research-
302 Gate) or on pre-print servers (e.g. ArXiv), that have not been peer-reviewed or published in
303 journals.

304 **Supplementary data.** Supplementary material and movies are available at
305 <https://doi.org/10.1017/jfm.2019...>

306 **Acknowledgements.** Acknowledgements may be included at the end of the paper, before the References
307 section or any appendices. Several anonymous individuals are thanked for contributions to these instructions.

308 **Funding.** Please provide details of the sources of financial support for all authors, including grant numbers.
309 For example, "This work was supported by the National Science Foundation (grant number XXXXXXXX)".
310 Multiple grant numbers should be separated by a comma and space, and where research was funded by
311 more than one agency the different agencies should be separated by a semi-colon, with 'and' before the
312 final funder. Grants held by different authors should be identified as belonging to individual authors by the
313 authors' initials. For example, "This work was supported by the Deutsche Forschungsgemeinschaft (A.B.,
314 grant numbers XXXX, YYYY), (C.D., grant number ZZZZ); the Natural Environment Research Council
315 (E.F., grant number FFFF); and the Australian Research Council (A.B., grant number GGGG), (E.F., grant
316 number HHHH)".

317 Where no specific funding has been provided for research, please provide the following statement: "This
318 research received no specific grant from any funding agency, commercial or not-for-profit sectors."

319 **Declaration of interests.** A **Declaration of interests** statement is now mandatory in the manuscript PDF.
320 Please included a statement in your manuscript at the end of the main text with regards to any known
321 competing financial interests or personal relationships that could appear to have influenced the work reported
322 in this paper. These must also be declared in your covering letter to the Editor. Please note that if there are
323 no conflicts of interest, the declaration in your PDF should read as follows: **Declaration of Interests.** The
324 authors report no conflict of interest.

325 **Data availability statement.** The data that support the findings of this study are openly available in
326 [repository name] at [http://doi.org/\[doi\], reference number \[reference number\]](http://doi.org/[doi], reference number [reference number]).

327 **Author ORCID.** Authors may include the ORCID identifiers as follows. F. Smith, <https://orcid.org/0000-0001-2345-6789>; B. Jones, <https://orcid.org/0000-0009-8765-4321>

329 **Author contributions.** Authors may include details of the contributions made by each author to the
330 manuscript, for example, "A.G. and T.F. derived the theory and T.F. and T.D. performed the simulations. All
331 authors contributed equally; to analysing data and reaching conclusions, and in writing the paper."

332 14. Appeals process

333 The *Journal of Fluid Mechanics* has an appeal procedure which provides authors with the
334 opportunity to respond to the editorial decision on their manuscript, should they think that
335 their manuscript was treated in an unfair manner during the peer-review process. Authors
336 have the right to appeal to the Editor or Editor-in-Chief against any decision taken on their
337 manuscript at any stage. An appeal will be considered at the direction of the Editorial Board
338 of the Journal.

339 14.1. How do I appeal?

340 **Step 1.** Requests to have the decision on a submission re-considered should be made in
341 the first instance to the Associate Editor who handled the submission and made the decision.
342 Send a rebuttal letter to the Associate Editor, explaining clearly why you disagree with the
343 decision on your manuscript and including a detailed response to any points of contention in
344 the referees' reports. The Associate Editor will consider your appeal and either invite you to
345 submit a revised paper or confirm the original decision.

346 **Step 2.** In case you remain unsatisfied with the Associate Editor's response after Step 1 or
 347 at any stage should you consider that your submission was treated unfairly, you should send a
 348 letter of appeal to the Editor-in-Chief via the Journal email (JFMEditorial@cambridge.org).
 349 Your letter should explain clearly the grounds for your appeal.

350 **Step 3.** The Editor-in-Chief will consider the grounds of your appeal and if he considers
 351 there to be a *prima facie* case to consider may assign one of the Deputy Editors to consider
 352 the appeal in detail. All appeal requests are handled on a case by case basis and the Deputy
 353 Editor's or Editor-in-Chief's decision is final. Appeals are normally considered on the basis
 354 of whether or not the process of review was conducted appropriately. Papers will not routinely
 355 be sent for further review.

356 Appendix A.

357 This appendix contains sample equations in the JFM style. Please refer to the \LaTeX source
 358 file for examples of how to display such equations in your manuscript.

$$359 \quad (\nabla^2 + k^2)G_s = (\nabla^2 + k^2)G_a = 0 \quad (\text{A } 1)$$

$$360 \quad \nabla \cdot \mathbf{v} = 0, \quad \nabla^2 P = \nabla \cdot (\mathbf{v} \times \mathbf{w}). \quad (\text{A } 2)$$

$$361 \quad G_s, G_a \sim 1/(2\pi) \ln r \quad \text{as} \quad r \equiv |P - Q| \rightarrow 0, \quad (\text{A } 3)$$

$$362 \quad \left. \begin{array}{l} \frac{\partial G_s}{\partial y} = 0 \quad \text{on} \quad y = 0, \\ G_a = 0 \quad \text{on} \quad y = 0, \end{array} \right\} \quad (\text{A } 4)$$

$$363 \quad -\frac{1}{2\pi} \int_0^\infty \gamma^{-1} [\exp(-k\gamma|y-\eta|) + \exp(-k\gamma(2d-y-\eta))] \cos k(x-\xi)t dt, \quad 0 < y, \quad \eta < d, \quad (\text{A } 5)$$

$$364 \quad \gamma(t) = \begin{cases} -i(1-t^2)^{1/2}, & t \leq 1 \\ (t^2-1)^{1/2}, & t > 1. \end{cases} \quad (\text{A } 6)$$

$$365 \quad -\frac{1}{2\pi} \int_0^\infty B(t) \frac{\cosh k\gamma(d-y)}{\gamma \sinh k\gamma d} \cos k(x-\xi)t dt$$

$$366 \quad G = -\frac{1}{4}i(H_0(kr) + H_0(kr_1)) - \frac{1}{\pi} \int_0^\infty \frac{e^{-k\gamma d}}{\gamma \sinh k\gamma d} \cosh k\gamma(d-y) \cosh k\gamma(d-\eta) \quad (\text{A } 7)$$

367 Note that when equations are included in definitions, it may be suitable to render them
 368 in line, rather than in the equation environment: $\mathbf{n}_q = (-y'(\theta), x'(\theta))/w(\theta)$. Now $G_a =$
 369 $\frac{1}{4}Y_0(kr) + \widetilde{G}_a$ where $r = \{[x(\theta) - x(\psi)]^2 + [y(\theta) - y(\psi)]^2\}^{1/2}$ and \widetilde{G}_a is regular as $kr \rightarrow 0$.
 370 However, any fractions displayed like this, other than $\frac{1}{2}$ or $\frac{1}{4}$, must be written on the line, and
 371 not stacked (ie 1/3).

$$\begin{aligned}
372 \quad \frac{\partial}{\partial n_q} \left(\frac{1}{4} Y_0(kr) \right) &\sim \frac{1}{4\pi w^3(\theta)} [x''(\theta)y'(\theta) - y''(\theta)x'(\theta)] \\
373 \quad &= \frac{1}{4\pi w^3(\theta)} [\rho'(\theta)\rho''(\theta) - \rho^2(\theta) - 2\rho'^2(\theta)] \quad \text{as } kr \rightarrow 0. \quad (\text{A } 8)
\end{aligned}$$

$$374 \quad \frac{1}{2}\phi_i = \frac{\pi}{M} \sum_{j=1}^M \phi_j K_{ij}^a w_j, \quad i = 1, \dots, M, \quad (\text{A } 9)$$

375 where

$$376 \quad K_{ij}^a = \begin{cases} \partial G_a(\theta_i, \theta_j)/\partial n_q, & i \neq j \\ \partial \overline{G}_a(\theta_i, \theta_i)/\partial n_q + [\rho'_i \rho''_i - \rho_i^2 - 2\rho_i'^2]/4\pi w_i^3, & i = j. \end{cases} \quad (\text{A } 10)$$

$$\rho_l = \lim_{\zeta \rightarrow Z_l^-(x)} \rho(x, \zeta), \quad \rho_u = \lim_{\zeta \rightarrow Z_u^+(x)} \rho(x, \zeta) \quad (\text{A } 11a, b)$$

$$377 \quad (\rho(x, \zeta), \phi_{\zeta\zeta}(x, \zeta)) = (\rho_0, N_0) \quad \text{for } Z_l(x) < \zeta < Z_u(x). \quad (\text{A } 12)$$

$$\tau_{ij} = (\overline{u_i u_j} - \overline{u_i} \overline{u_j}) + \overline{(\overline{u_i u_j^{SGS}} + u_i^{SGS} \overline{u_j})} + \overline{u_i^{SGS} u_j^{SGS}}, \quad (\text{A } 13a)$$

$$\tau_j^\theta = (\overline{u_j \theta} - \overline{u_j} \overline{\theta}) + \overline{(\overline{u_j \theta^{SGS}} + u_j^{SGS} \overline{\theta})} + \overline{u_j^{SGS} \theta^{SGS}}. \quad (\text{A } 13b)$$

$$378 \quad \mathbf{Q}_C = \begin{bmatrix} -\omega^{-2} V'_w & -(\alpha^t \omega)^{-1} & 0 & 0 & 0 \\ \frac{\beta}{\alpha \omega^2} V'_w & 0 & 0 & 0 & i\omega^{-1} \\ i\omega^{-1} & 0 & 0 & 0 & 0 \\ iR_\delta^{-1}(\alpha^t + \omega^{-1} V''_w) & 0 & -(i\alpha^t R_\delta)^{-1} & 0 & 0 \\ \frac{i\beta}{\alpha \omega} R_\delta^{-1} V''_w & 0 & 0 & 0 & 0 \\ (i\alpha^t)^{-1} V'_w & (3R_\delta^{-1} + c^t (i\alpha^t)^{-1}) & 0 & -(\alpha^t)^{-2} R_\delta^{-1} & 0 \end{bmatrix}. \quad (\text{A } 14)$$

$$379 \quad \boldsymbol{\eta}^t = \hat{\boldsymbol{\eta}}^t \exp[i(\alpha^t x_1^t - \omega t)], \quad (\text{A } 15)$$

380 where $\hat{\boldsymbol{\eta}}^t = \mathbf{b} \exp(i\gamma x_3^t)$.

$$381 \quad \text{Det}[\rho\omega^2 \delta_{ps} - C_{pqr}^t k_q^t k_r^t] = 0, \quad (\text{A } 16)$$

$$382 \quad \langle k_1^t, k_2^t, k_3^t \rangle = \langle \alpha^t, 0, \gamma \rangle \quad (\text{A } 17)$$

$$383 \quad \mathbf{f}(\theta, \psi) = (g(\psi) \cos \theta, g(\psi) \sin \theta, f(\psi)). \quad (\text{A } 18)$$

$$384 \quad f(\psi_1) = \frac{3b}{\pi [2(a + b \cos \psi_1)]^{3/2}} \int_0^{2\pi} \frac{(\sin \psi_1 - \sin \psi)(a + b \cos \psi)^{1/2}}{[1 - \cos(\psi_1 - \psi)](2 + \alpha)^{1/2}} dx, \quad (\text{A } 19)$$

385

$$\begin{aligned}
386 \quad g(\psi_1) &= \frac{3}{\pi[2(a+b\cos\psi_1)]^{3/2}} \int_0^{2\pi} \left(\frac{a+b\cos\psi}{2+\alpha} \right)^{1/2} \left\{ f(\psi)[(\cos\psi_1 - b\beta_1)S + \beta_1 P] \right. \\
387 \quad &\times \frac{\sin\psi_1 - \sin\psi}{1 - \cos(\psi_1 - \psi)} + g(\psi) \left[\left(2 + \alpha - \frac{(\sin\psi_1 - \sin\psi)^2}{1 - \cos(\psi - \psi_1)} - b^2\gamma \right) S \right. \\
388 \quad &\left. \left. + \left(b^2 \cos\psi_1\gamma - \frac{a}{b}\alpha \right) F\left(\frac{1}{2}\pi, \delta\right) - (2 + \alpha) \cos\psi_1 E\left(\frac{1}{2}\pi, \delta\right) \right] \right\} d\psi, \quad (\text{A } 20)
\end{aligned}$$

389

$$390 \quad \alpha = \alpha(\psi, \psi_1) = \frac{b^2[1 - \cos(\psi - \psi_1)]}{(a + b\cos\psi)(a + b\cos\psi_1)}, \quad \beta - \beta(\psi, \psi_1) = \frac{1 - \cos(\psi - \psi_1)}{a + b\cos\psi}. \quad (\text{A } 21)$$

391

$$\left. \begin{aligned}
H(0) &= \frac{\epsilon \bar{C}_v}{\tilde{v}_T^{1/2}(1 - \beta)}, & H'(0) &= -1 + \epsilon^{2/3} \bar{C}_u + \epsilon \hat{C}'_u; \\
H''(0) &= \frac{\epsilon u_*^2}{\tilde{v}_T^{1/2} u_P^2}, & H'(\infty) &= 0.
\end{aligned} \right\} \quad (\text{A } 22)$$

392 LEMMA 1. Let $f(z)$ be a trial Batchelor (1971, pp. 231–232) function defined on $[0, 1]$.
393 Let Λ_1 denote the ground-state eigenvalue for $-d^2g/dz^2 = \Lambda g$, where g must satisfy $\pm dg/dz +$
394 $\alpha g = 0$ at $z = 0, 1$ for some non-negative constant α . Then for any f that is not identically
395 zero we have

$$396 \quad \frac{\alpha(f^2(0) + f^2(1)) + \int_0^1 \left(\frac{df}{dz} \right)^2 dz}{\int_0^1 f^2 dz} \geq \Lambda_1 \geq \left(\frac{-\alpha + (\alpha^2 + 8\pi^2\alpha)^{1/2}}{4\pi} \right)^2. \quad (\text{A } 23)$$

397 COROLLARY 1. Any non-zero trial function f which satisfies the boundary condition
398 $f(0) = f(1) = 0$ always satisfies

$$399 \quad \int_0^1 \left(\frac{df}{dz} \right)^2 dz. \quad (\text{A } 24)$$

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