

Ultrasonic Doppler Velocity Profiler for Fluid Flow

FLUID MECHANICS AND ITS APPLICATIONS

Volume 101

Series Editor: R. MOREAU
MADYLAM
Ecole Nationale Supérieure d'Hydraulique de Grenoble
Boîte Postale 95
38402 Saint Martin d'Hères Cedex, France

Aims and Scope of the Series

The purpose of this series is to focus on subjects in which fluid mechanics plays a fundamental role.

As well as the more traditional applications of aeronautics, hydraulics, heat and mass transfer etc., books will be published dealing with topics which are currently in a state of rapid development, such as turbulence, suspensions and multiphase fluids, super and hypersonic flows and numerical modeling techniques.

It is a widely held view that it is the interdisciplinary subjects that will receive intense scientific attention, bringing them to the forefront of technological advancement. Fluids have the ability to transport matter and its properties as well as to transmit force, therefore fluid mechanics is a subject that is particularly open to cross fertilization with other sciences and disciplines of engineering. The subject of fluid mechanics will be highly relevant in domains such as chemical, metallurgical, biological and ecological engineering. This series is particularly open to such new multidisciplinary domains.

The median level of presentation is the first year graduate student. Some texts are monographs defining the current state of a field; others are accessible to final year undergraduates; but essentially the emphasis is on readability and clarity.

For further volumes:
<http://www.springer.com/series/5980>

Yasushi Takeda
Editor

Ultrasonic Doppler Velocity Profiler for Fluid Flow

 Springer

Editor

Yasushi Takeda

Hokkaido University, Sapporo, Japan

Tokyo Institute of Technology, Tokyo, Japan

ISSN 0926-5112

ISBN 978-4-431-54025-0

ISBN 978-4-431-54026-7 (eBook)

DOI 10.1007/978-4-431-54026-7

Springer Tokyo Heidelberg New York Dordrecht London

Library of Congress Control Number: 2012946915

© Springer Japan 2012

This work is subject to copyright. All rights are reserved by the Publisher, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilms or in any other physical way, and transmission or information storage and retrieval, electronic adaptation, computer software, or by similar or dissimilar methodology now known or hereafter developed. Exempted from this legal reservation are brief excerpts in connection with reviews or scholarly analysis or material supplied specifically for the purpose of being entered and executed on a computer system, for exclusive use by the purchaser of the work. Duplication of this publication or parts thereof is permitted only under the provisions of the Copyright Law of the Publisher's location, in its current version, and permission for use must always be obtained from Springer. Permissions for use may be obtained through RightsLink at the Copyright Clearance Center. Violations are liable to prosecution under the respective Copyright Law.

The use of general descriptive names, registered names, trademarks, service marks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.

While the advice and information in this book are believed to be true and accurate at the date of publication, neither the authors nor the editors nor the publisher can accept any legal responsibility for any errors or omissions that may be made. The publisher makes no warranty, express or implied, with respect to the material contained herein.

Printed on acid-free paper

Springer is part of Springer Science+Business Media (www.springer.com)

Preface

The ultrasonic velocity profile (UVP) method was originally developed for cardiovascular measurements in the human body by Japanese researchers in medical engineering almost 50 years ago, but it has not been extensively used until recently. This long delay was presumably because the research team lacked expertise in fluid dynamics and thus was unable to achieve an adequate understanding and interpretation of the results.

Roughly 30 years ago, I was looking for a technique that could be used to measure the flow of opaque liquid metal when a colleague in medical engineering told me about the ultrasonic velocity method. I modified an existing instrument and demonstrated that the ultrasonic method could indeed measure the flow in a liquid metal. This success stimulated me to extend the ultrasonic method so that it could be used to measure many kinds of fluid flows. In the course of time, diverse flow configurations were tested to verify and validate the method. The results of this testing and validation demonstrated that the ultrasonic velocity method, referred to simply as UVP, was a powerful new tool in experimental fluid mechanics (EFD).

After using the UVP method for physics studies of fluid flow, I realized that it might bring us a revolutionary change in EFD—namely, a change of emphasis from measuring average velocity profiles in space, or velocity time series at a fixed position in space, to one where the objective was to measure the instantaneous velocity distribution (i.e., the instantaneous velocity as a function of both space and time).

All the early developmental work was designed to confirm and emphasize this change in perspective. Many researchers in Europe and Japan were involved in the effort, and this book is a compilation of that research.

Originally this book was planned as a textbook for current users of the UVP method. Its purpose was later extended both to show the capability of the method for various types of applications and to encourage more use of the method. Publication of the book is the result of teamwork by the many researchers whose names appear in the following pages. I deeply appreciate their extensive and energetic work.

I would like to point out that a Users and Researchers Community has been formed, referred to as ISUD (International Symposium on Ultrasonic Doppler method in fluid flow). A symposium is held every 2 years, and the reader is encouraged

to visit their website for more details. Finally, I would like to acknowledge that we have received constant support from Mr. G. Gogniat of Met-Flow S.A. (Lausanne)[†]. I am grateful to him for his support, without which the ultrasonic velocity method would not have been developed to the extent that we now enjoy. I am also grateful to all the people who worked to make this book possible.

Tokyo, Japan

Yasushi Takeda

[†]Mr. G. Gogniat passed away on 19. April 2012 before a completion of this book.

Contents

1 Introduction	1
Yasushi Takeda	
Part I Fundamentals	
2 Ultrasonic Wave for Fluid Flow	21
Yasushi Takeda and Yuji Tasaka	
3 Ultrasonic Doppler Method	43
Hideki Murakawa, Michitsugu Mori, and Yasushi Takeda	
4 Measurement of Fluid Flow	71
Yuichi Murai, Noriyuki Furuichi, Yasushi Takeda, and Yuji Tasaka	
Part II Applications	
5 Practical Applications	107
Yuji Tasaka, Beat Birkhofer, Noriyuki Furuichi, Hiroshige Kikura, Hisato Minagawa, Yuichi Murai, Hideki Murakawa, Masaaki Motozawa, Samsun Nahar, Hironari Obayashi, Tatsuo Sawada, A.K. Jeelani Shaik, Yasushi Takeda, Kenichi Tezuka, Yoshiyuki Tsuji, Takatoshi Yanagisawa, Sanehiro Wada, Johan Wiklund, and Erich J. Windhab	
6 Industrial Applications	201
Noriyuki Furuichi, Beat Birkhofer, Yuichi Murai, A.K. Jeelani Shaik, Johan Wiklund, and Erich J. Windhab	

7 Extended Techniques 227
Hideki Murakawa, Tatsuya Kawaguchi, Hironari Obayashi,
Yuichi Murai, and Yuji Tasaka

Appendix 263

Index 271

Contributors

Editors

Yasushi Takeda, Chief Editor

Yuji Tasaka, Co-Editor

Hideki Murakawa, Co-Editor

Authors

Beat Birkhofer (Sect. 5.3.1, 5.4, 6.2) Sika Services AG, Zürich, Switzerland

Noriyuki Furuichi (Sect. 4.2.6, 5.1, 6.1) National Metrology Institute of Japan, National Institute of Advanced Industrial Science and Technology (AIST), Tsukuba, Japan

Tatsuya Kawaguchi (Sect. 7.5) Tokyo Institute of Technology, Tokyo, Japan

Hiroshige Kikura (Sect. 5.5) Tokyo Institute of Technology, Tokyo, Japan

Hisato Minagawa (Sect. 5.6) The University of Shiga Prefecture, Shiga, Japan

Michitsugu Mori (Sect. 3.2) Hokkaido University, Sapporo, Japan

Yuichi Murai (Sect. 4.2, 5.3.2, 5.6, 6.3, 7.2, 7.3) Faculty of Engineering, Hokkaido University, Sapporo, Japan

Hideki Murakawa (Sect. 3.1, 3.3, 5.6, 7.1) Graduate School of Engineering, Kobe University, Kobe, Japan

Masaaki Motozawa (Sect. 5.5) Tokyo University of Science, Chiba, Japan

Samsun Nahar (Sect. 5.8) Swiss Federal Institute of Technology Zürich (ETH-Zürich), Zürich, Switzerland

Hironari Obayashi (Sect. 5.2.3, 7.4) Japan Atomic Energy Agency (JAEA), Ibaraki, Japan

Tatsuo Sawada (Sect. 5.5) Keio University, Yokohama, Japan

A.K. Jeelani Shaik (Sect. 5.3.1, 5.4, 5.8, 6.2) Institute of Food, Nutrition and Health, Swiss Federal Institute of Technology Zürich (ETH-Zürich), Zürich, Switzerland

Yasushi Takeda (Chapter 1, Sect. 2.7, 3.1, 3.2, 4.1.4, 5.8) Hokkaido University, Sapporo, Japan

Tokyo Institute of Technology Tokyo, Japan

Yuji Tasaka (Chapter 2, Sect. 4.1, 5.1, 7.2, & Appendix) Faculty of Engineering, Hokkaido University, Sapporo, Japan

Kenichi Tezuka (Sect. 5.7) Tokyo Electric Power Company, Yokohama, Japan

Yoshiyuki Tsuji (Sect. 5.2.1) Nagoya University, Nagoya, Japan

Saneshiro Wada (Sect. 5.2.2) Tokyo Electric Power Company, Yokohama, Japan

Johan Wiklund (Sect. 5.3.1, 5.4, 6.2) The Swedish Institute for Food and Biotechnology (SIK), Göteborg, Sweden

Erich J. Windhab (Sect. 5.3.1, 5.4, 5.8, 6.2) Institute of Food, Nutrition and Health, Swiss Federal Institute of Technology Zürich (ETH-Zürich), Zürich, Switzerland

Takatoshi Yanagisawa (Sect. 5.7) Japan Agency for Marine-Earth Science and Technology (JAMSTEC), Yokosuka, Japan