



# FED

## Fluids Engineering Division Newsletter

Richard R. Schultz, PE, Editor

Spring 2000

### Chair's Message

I am pleased to report that the Fluids Engineering Division (FED) is having a very productive year. Our 1999 summer conference was held jointly in San Francisco last July with the Japan Society of Mechanical Engineers (JSME). The meeting drew over 800 attendees and 20 exhibitors. 700 papers were presented and published in a CD ROM.

Our year 2000 conference this summer in Boston will be an exciting one. We have a full slate of technical papers, plenary speakers, short courses, tutorials, clinics, and panels. Our newest technical coordinating group, the Coordinating Group on Industry Technology (CGIT) has put together the Industry Exchange Program to appeal particularly to our members from industry. The detailed program and registration information is on the ASME website or may be obtained by calling ASME directly.

The three technical committees and three coordinating groups of the FED will meet while we are in Boston. Participation in the committee and coordinating group meetings is open to all attendees. The schedule of committee meetings will be available at the conference or may be obtained by contacting any one of the committee chairs (see Committees and Coordinating Group Section of this newsletter for a description of their areas of responsibility).

The ASME *Journal of Fluids Engineering* (JFE) has a new technical editor, Dr. Joseph Katz. Dr. Katz replaces Dr.

Demetri Telionis who served as technical editor for ten years. During his tenure Dr. Telionis strengthened the financial position of the journal, expanded the number of pages, reduced the backlog of papers, introduced electronic submission of papers, and was instrumental in establishing an on-line version of the JFE. I wish to extend our utmost thanks to Dr. Telionis for a job well done and our congratulations to Dr. Katz on his appointment as he takes on this very important position.

Finally, I invite you to become involved in the activities of the FED. In addition to our technical programs at the FED summer meeting and the ASME International Mechanical Engineering Congress & Exposition (IMECE), we have many opportunities for you to participate in the activities of the division. Contact any committee chairman or member of the Executive Committee for further information (see p. 7).

### Journal of Fluids Engineering

This is my last contribution to the Newsletter as editor of *The Journal of Fluids Engineering*. About ten years ago, at the beginning of my tenure as the Technical Editor of the JFE, I published an editorial outlining my plans for the JFE (June 1990). I am pleased to report that these plans were carried out successfully. The quality and the prestige of a scientific journal depends entirely on the quality of the submitted contributions and all the

editors can do is provide prompt and professional reviews. But a competent and active editorial board also provides direction, encourages emphasis in areas of contemporary importance and tries to improve the means of communicating the technical information to its readers. Therefore, a short history of the major events over the last ten years is given as a framework for continuity of future planning efforts.

Ten years ago, I stated that we would continue along the directions defined by the founding editor Bob Dean and the second editor Frank White. From its inception, this journal was dedicated to the publication of original articles in all areas of fluid mechanics and fluids engineering. But of all prominent journals publishing work in this field, it is the one that more clearly addresses the needs of the practicing fluids engineers. Special efforts are made to expose the importance of the contributed papers to mechanical engineering. To highlight such contributions, we now regularly publish short discussions on specific articles provided by colleagues from industry who identify the importance of these articles to industry. This genre was launched by the editorial that appeared in the December 1996 issue. Industrial discussions and other short contributions like reports on special workshops and forums and short columns on unanswered questions in fluid mechanics appear occasionally in a special section of the Journal that we call "The Technical Forum."

Continued on Page 2

## Editorial

Continued from page 1

Bob Dean and Frank White established the tradition of publishing review articles of current interest. We have continued this practice and on many occasions, we solicited contributions in areas of considerable contemporary interest. To emphasize more clearly the importance of some emerging fields, we followed a review article with collections of contributed papers on the same topic and recognized the special theme of the issue with an editorial. Examples are the June 1996 issue which was devoted to turbulence modeling, the September 1996 issue dedicated to micro-fluid mechanics and Micro-Electromechanical Systems (MEMS), the December 1997 issue whose theme was cavitation and the December 1998 issue whose theme was rotating flows.

During his tenure, Frank White established standards of experimental uncertainty and numerical accuracy. The Coordinating Groups of Fluid Measurements and Computational Fluid Dynamics of our division have debated and finally formulated detailed guidelines on the reporting of experimental uncertainty and numerical accuracy. These were adopted by the editors of JFE and appeared in the editorials of September 1991 and September 1993 respectively.

Ten years ago we recognized the need to take advantage of the availability of the electronic medium. Indeed, in 1993 we established the JFE Data Bank. In this bank we deposited data that accompany selected contributions to the Journal. More significantly, the *Journal of Fluids Engineering* was the first among the *Transactions of ASME* to become available through the Internet. But there is still a lot of work ahead to fully exploit the electronic tools available today.

And now a short introduction of the new JFE Editor, Professor Joseph Katz is on the faculty of Johns Hopkins University. Joe has made truly great contributions to fluid mechanics and fluids engineering and thus is among the very top fluid mechanicians in the world. But Joe is also a practicing mechanical engineer. He combines the rare virtue and ability to understand and contribute to both the fundamentals of our science and the engineering side of fluid mechanics applications. Starting with the second group of his contributions, I cite his work on the hydroacoustics of turbomachines for which he was awarded the ASME Moody award, his study of rotor-stator interaction in pumps, his work on cavitating flows and the relationship between flow structure and cavitation and his studies on mixing and entrainment in water-fuel interfaces and the mechanism of droplet formation. One of his most significant contributions to mechanical engi-

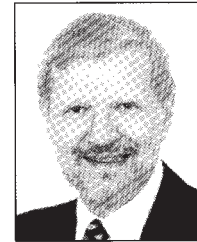
neering is the development of lubricated nozzles for high-speed slurry jets which has been the biggest problem affecting slurry jets used for cutting or machining. A patent has been recently issued for this device. Joe has published extensively on his pioneering work in instrumentation. In this area he implemented PIV (particle-image velocimetry) technology to the study of large-scale wakes in towing tanks, the effects of vortices on bubbly flows, the bottom boundary layer of the coastal ocean and to isotropic and rapidly-strained turbulent flows for which he developed together with C. Meneveau a method for the evaluation (a priori testing) of Sub-Grid Scale (SGS) models for Large Eddy Simulations (LES). He has also worked on holography and holographic PIV. In this field he designed, constructed and deployed a submersible holographic camera for deployment in the ocean. This is the only working instrument of its kind in the world.

Joe Katz has been active in the Fluids Engineering Division, organizing numerous symposia and forums. He has been more active in the Multiphase Flow Committee and it is very fitting that a representative of this dynamic group within the Division undertake the editorship of the Journal at this point. Joe is also serving his second term as an Associate Editor of JFE. I therefore have direct and intimate knowledge of the quality of his editorial work. I have no doubt that the Journal has a bright future with him at the helm. From now on all authors should submit their papers to Joe Katz, at the address listed on the last page of this issue.

Finally I express my gratitude to many individuals who worked with me during the 1990s. Most of all I am indebted to the Associate Editors and the reviewers. The readership should recognize that both editors and reviewers give a lot of their valuable time with no, or minimal recognition. It is my deep conviction that if this Journal has met its goals in the past years, it owes it almost exclusively to the efforts of an excellent group of associate editors. I also thank the team at ASME headquarters and in particular our Copy Editor, Connie Monahan and our Executive Secretary, Pat White. In the entire period of ten years, they have never failed to provide solid performance and professional support. Finally, I thank the Executive Committee of the Division of Fluids Engineering for the trust they have shown in me when they asked me to serve as the Technical Editor of this Journal.

Demetri Telionis  
Technical Editor

## 1999 Fluids Engineering Award



M. P. Paidoussis

The winner of the 1999 Fluids Engineering Award is Dr. Michael P. Paidoussis of McGill University. Mike has been very active in the FED and members knew him through his success-

ful organization of the multi-division international conferences on Fluid-Structure interactions, Aeroelasticity, Flow Induced Vibrations and Noise. The Fluids Engineering Award is the most prestigious award conferred by ASME upon an individual for outstanding contributions made over a period of years to the fluids engineering profession through research, practice and/or teaching.

Michael P. Paidoussis was educated in the Greek Schools of Egypt, McGill University, and the University of Cambridge, receiving his B.Eng. in Mechanical Sciences (with honors) in 1958 and his Ph.D. (Cantab) in Engineering in 1963. He has been Overseas Fellow at GEC in Britain (1958-60) and Research Officer at Atomic Energy of Canada, Ltd. (Applied Physics Division, 1963-67) in Chalk River, Canada. He joined the Department of Mechanical Engineering of McGill University in 1967. Promoted to Professor in 1976, he served as Chairman of the department from 1977 to 1986, and now holds the Thomas Workman chair in Engineering. Since 1960, he has worked on various aspects of fluid-structure interactions and flow-induced vibrations and instabilities. He has published over 140 papers in refereed journals and 90 full papers in refereed conference proceedings, and a book entitled *Fluid-Structure Interactions: Slender Structures and Axial Flow*; he has organized a number of international conferences on fluid-structure interactions. He has received the George Stephenson Prize from the Institution of Mechanical Engineers (IMEchE) in 1976, the Canadian Congress of Applied Mechanics Prize in 1995, and was the Calvin W. Rice Lecturer of ASME in 1992; he is Fellow of IMechE, ASME, CSME, The American Academy of Mechanics, and the Royal Society of Canada (Academy of Sciences). As of 1986, he is editor of the *Journal of Fluids and Structures* (Academic Press).

We congratulate Dr. Paidoussis on his many achievements and upon receiving this important award.

Michael P. Paidoussis

## 1999 Fluids Machinery Award



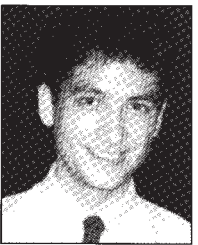
R. B. Furst

Mr. Raymond B. Furst earned his B. S. and M. S. in Mechanical Engineering, and is a registered Professional Engineer in California. Mr. Furst has over fifty

years experience in the turbomachinery, fan and pump fields. He has consulted in the fields of rocket engine propellant turbopumps, jet engine fuel pumps, jet pumps, waterjet propulsion pumps, and high-pressure water pumps for oil well applications. He consulted for the Société Européenne de Propulsion on the design and development of turbopumps for the Ariane 3, 4 and 5 vehicles. While at the Rocketdyne Division of Rockwell International, now the Boeing Company, his responsibilities included the development of the turbo-pumps for the Apollo moon landing program and the four Space Shuttle main engine pumps. His clients also include Allied Signal, Chandler Evans Control Systems Division, Sundstrand Fluid Handling, and Bombardier Motor Company of America.

Mr. Furst is the recipient of numerous awards and they include the ASME Henry R. Worthington Medal in 1988 for contributions to the pumping profession and two NASA awards for contributions to rocket engine turbopump design and analytical procedure improvement. He is also the recipient of five patents in the pumping field. He is a Fellow of the Institute for the Advancement of Engineering. By the Fluid Machinery Design Award, we acknowledge the many valuable contributions of Raymond Furst.

## Robert T. Knapp Award



T. Manning

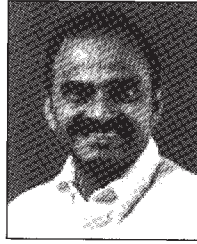
The Knapp Award is given to the author(s) of the best paper presented to the Fluids Engineering Division, within the last two years, dealing with analytical, numerical, or labo-

ratory research.

The 1999 Knapp award was won by Mr. T. A. Manning and Dr. S. K. Lele of Stanford University, for their paper

"Shock Vortex Interaction in Supersonic Jet Screech: An Update," presented at the 1998 FED Summer Meeting in Washington, D.C.

The paper represents advances in understanding the jet screech generation process by numerical simulations of an isolated instability wave-vortex / shock interaction in two dimensions. This study builds on their earlier work and amongst its many findings, reported that the



S. K. Lele

acoustic amplitude was found to decay only slightly from its free-stream amplitude, contradicting a previous theoretical result. Also, even if sound is produced, the reduction in amplitude is far greater than the reduction in fluctuations associated with the instability wave, suggesting that the instability wave amplitude must reach some threshold in order to generate sound when interacting with the compression wave.

The award was presented during the 3rd ASME / JSME Joint Fluids Engineering Conference & 1999 FED Summer Meeting / Exhibition, in San Francisco, CA.

## Lewis F. Moody Award



K. M. Kalumuck

The Lewis F. Moody Award is given to the author(s) of the best paper presented to the Fluids Engineering Division dealing with a topic useful in mechanical engineering practice.

Dr. Kenneth M. Kalumuck and Georges L. Chahine of DYNAFLOW, INC., Fulton, MD, have been selected for the 1999 Lewis F. Moody Award. Their paper, "The Use of Cavitating Jets to Oxidize

Organic Compounds in Water," was presented at the 1998 FED Summer Meeting in Washington D.C.

The paper describes application of hydrodynamic cavitation to contaminated water by the use of submerged cavitating liquid jets to trigger wide spread cavi-

tion and induce oxidation in the bulk solution. Cavitating jet oxidation of p-nitrophenol was found to exhibit a two order of magnitude increase in energy efficiency compared to ultrasonic means.

This outstanding accomplishment was recognized at the 3rd ASME / JSME Joint Fluids Engineering Conference & 1999 FED Summer Meeting / Exhibition, in San Francisco, CA in July. Sincere congratulations to Drs. Kalumuck and Chahine for this award-winning paper.

## 1999 Young Engineer Paper Contest

The 1999 Young Engineer Paper Contest was held at the IMECE in Nashville, TN. For this year's competition, after detailed review of all papers submitted, the committee selected three finalists: Shriram Pillapakam of the New Jersey Institute of Technology, Tan Boon Keng of Nanyang Technological University and Scott Thomson of Brigham Young University. These authors each received a \$300 award to defray costs of attending the meeting and presenting their papers. Based on the written papers and the oral presentations at the 1999 IMECE, the Committee selected first prize for the paper entitled "Development of a Temperature Profile Measurement Technique Based on Molecular Tagging Velocimetry" by Scott Thomson. Each author received a certificate and the first place author received a \$500 prize. The next contest will be held at the 2000 IMECE in Orlando, Florida. The contest is open to undergraduates and to first year graduate students. All young engineers, with an interest in fluids engineering, are encouraged to participate.

## Helmut Weber Obituary

Dr. Helmut Weber, a Life Member of ASME, passed away in April 2000. He resided in San Diego, California as a retired consultant. Dr. Weber had recently served as the Chair of the Committee on Professional Development of the FED for nine years. In addition, he will be remembered for his service on the Board on Professional Development from 1988 to 1992 and as Representative to the Board for two of those years. During his 44 years as an ASME member, Helmut Weber was also a recipient of the ASME Dedicated Service Award in 1990. Helmut Weber will be fondly remembered for his many years of support to ASME.

# Committees & Coordinating Groups

The Fluids Engineering Division has three coordinating groups and three technical committees. The functions of the coordinating groups and committees are related to the areas of fluids engineering reflected by their names.

Participation in the committees and coordinating groups is on a voluntary basis. Each committee and group meets twice each year—once at the FED Summer Meeting and once at the International Mechanical Engineers Congress & Exposition. Schedules for these meetings can be found on the web site just prior to each meeting—or at the registration desk at the site hotel. If ASME members wish to participate in a committee or coordinating group proceedings—they are free to do so; this is one of the many benefits of ASME membership in the Fluids Engineering Division.

Specific activities and functions of each of the committees and coordinating group activities are described in the following paragraphs. Usually the contact point is the Chair—however if difficulty in contacting the Chair arises, please contact Richard R. Schultz (208 526-9508; FAX: 208 528-0628; srr@inel.gov).

## **Coordinating Group on Fluid Measurements**

The Coordinating Group on Fluid Measurements (CGFM) is the hub for experimental measurements within the FED. The CGFM membership includes specialists in instrumentation, experimental techniques, design of experiments, measurement accuracy and uncertainty, and data acquisition and analysis. The group membership is composed of individuals from each of the Technical Committees as the topic of fluid measurements permeates all of the FED. As a Coordinating Group, the group charter is to work closely with the technical committees and to provide updates on the latest developments in fluid measurements through programs at technical meetings and other technology transfer activities.

During recent FED meetings the CGFM has cooperated on such recurring symposia and forums as Laser Anemometry, Experimental and Numerical Flow Visualization, Measuring and Metering Unsteady Flows, and Measurement Techniques in Multiphase Flows. In addition, the group hosts technical sessions including recurring programs in Fluid Measurements and Instrumentation and Fluid Measurement Uncertainty Applications. Along with these recurring

themes, the group organizes or participates in upcoming topical sessions on Cryogenic Fluid Flows, Liquid Crystal Thermometry, Flow Measurements in Opaque Multiphase Fluids, and Experimental Needs for CFD Development and Verification.

For more information, visit the CGFM web site at <http://www.asme.org/divisions/fed/cgfm.html>. The CGFM encourages all who are interested in planning, organizing, or participating in technical sessions in the general area of fluid measurements to become involved. For more information on the CGFM, or to receive future meeting notifications and minutes, feel free to contact the Chair: Professor Jack Braun of the University of Akron (330-972-7734) or the Vice-Chair: Professor Gerald Morrison of Texas A&M University (409-845-5414).

## **Coordinating Group on Computational Fluid Dynamics**

The Coordinating Group on Computational Fluid Dynamics (CGCFD) is a body dedicated to providing a means for researchers and applications scientists and engineers to disseminate CFD related information through symposia and forums at ASME meetings. In addition, CGCFD encourages acceptance of CFD by industry and provides for networking of CFD professionals worldwide. At the upcoming FED Summer Meeting in Boston, MA, the CGCFD is organizing a number of symposia and forums including topics such as finite element applications in fluid mechanics, high speed jet flows, flows in manufacturing processes, numerical developments in CFD, advances in free surface and interface flows, and bifurcation, instability, and hysteresis in fluid flow. The Group is also going to present a tutorial on "Boundary Conditions and Large Eddy Simulations" organized by Prof. Urmila Ghia of the University of Cincinnati, and a panel session on the "Need for Bench Marking Industrial Flows for CFD Code Validation" organized by Dr. B.G. Shiva Prasad of Dresser-Rand.

At the 1999 IMECE CGCFD elected its new officers, who will assume responsibility in July 2000. The new Chair of the Group is Prof. Urmila Ghia, Department Head of Mechanical, Industrial and Nuclear Engineering at the University of Cincinnati. At the present time she is serving as Vice-Chair of the Group. New Vice-Chair of the Group was elected Prof.

Peter Raad, Professor of Mechanical Engineering at the Southern Methodist University in Dallas, Texas, and Associate Dean of the School of Engineering and Applied Science. Both have already made significant contributions to the CGCFD and in their new capacities will provide an inspired leadership. If questions arise, please contact Prof. George Vradis (Chair of the Group) of Polytechnic University at 516-755-4388, [gvradis@poly.edu](mailto:gvradis@poly.edu); Prof. Urmila Ghia (Vice-Chair of the Group) of the University of Cincinnati at 513-556-4612, [urmila.ghia@uc.edu](mailto:urmila.ghia@uc.edu); or Prof. Peter Raad (incoming Vice-Chair) of the Southern Methodist University at (214) 768-3043; [peter@seas.smu.edu](mailto:peter@seas.smu.edu).

## **Coordinating Group on Industrial Technology**

The Coordinating Group on Industrial Technology (CGIT) was formed in 1999 and had its first meeting in San Francisco last June. The primary function of CGIT is to develop symposia, forums, and panels that specifically address technology issues important to industry and to work with the other technical committees and coordinating groups of FED. Although the specifics on the organization of CGIT and the specific symposium and forum topics are currently being defined—it is expected that a complete slate of activities will be available for release soon.

If questions arise, please contact the Chair: Professor Dhaubhadel of the Case Co. (630-887-2009) or the Vice Chair: John Navickas of the Boeing Co. (714-372-1432).

## **Fluid Applications and Systems Technical Committee**

The Fluid Applications & Systems Technical Committee (FASTC) programs focus on providing state-of-the-art knowledge to support mature, developing, and emerging applications in the general field of fluid mechanics. FASTC does this by providing an interface between designers, developers, and researchers. FASTC activities also include programs designed to enhance learning and discussion. Examples include panel discussions, tutorials, and clinics earmarked for promoting participation from industry.

FASTC is organized into three subcommittees: Fluid Transients, chaired by Professor Jim Liou: 208-885-6202, Fluid Machinery, chaired by Dr. Adiel

## Fluids Engineering Div.

(Continued from page 4)

Guinzburg: 818-568-7622, and Emerging and Developing Applications, chaired by Professor Jim Liburdy: 541-737-7017.

You are encouraged to contact these individuals with your ideas for organizing symposiums or forums in these areas.

In the past FASTC has sponsored symposia and forums (sometimes in conjunction with other committees or coordinating groups) such as Fluid Measurements and Instrumentation, Industrial and Environmental Applications of Fluid Mechanics, Fluid Machinery Forum, Industrial Applications of Swirling Flow, and Computational Methods for Analysis of Fluid Machinery. Every four odd years (next one to take place in 2001) FASTC offers a Pumping Machinery Symposium—one the most well attended and successful symposiums. FASTC recently added two new themes to its programs: "Fluid Flow in Micro-Systems: Measurements, Analysis and Applications" as an emerging theme and the "Forum on Industrial Compressors" as a way to expand in the area of fluid machinery.

If you would like to participate in FASTC activities, or if you have any questions or suggestions, please contact the Chair: Professor Ali Ogut of the Rochester Institute of Technology: (Phone: 717-475-2542; [adoeme@rit.edu](mailto:adoeme@rit.edu)), or Vice-chair, Dr. Adiel Guinzburg of Boeing (818-586-7622). You can also obtain additional information by visiting the FASTC Web Site: <http://www.asme.org/divisions/def/fastc>

## Fluid Mechanics Technical Committee (FMTC)

The Fluid Mechanics Technical Committee (FMTC) serves as the focal point within ASME for technical activities in fundamental fluid mechanics. The main activity of FMTC is to organize symposia and forums related to all aspects of basic fluid mechanics. The committee strives to provide timely technical information to the ASME membership through well-organized technical sessions and to foster dialog among the membership. Currently, there is a major emphasis on the development of rolling three-year plans for symposia and forum development. Typically, the symposia and forums are planned and organized through one of our four sub-committees. The FMTC sub-committees and the respective chairs are as follows: External Flows (Dr. Ganesh Raman, 312-567-3554); Internal Flows (Dr. George Papadopoulos, 201-512-0037); Unconventional/ Emerging Topics (Dr.

Dennis Siginer, 973-596-3331); Unsteady Flows (Dr. Bill Keith, 203-440-4058). Members are welcome to participate and to help organize the technical sessions and other activities of the FMTC.

General information about FMTC including planned symposia / forums as well as the past minutes of business meetings can be found on our web page (<http://www.asme.org/divisions/fed/FMTC>). For further information you may contact either the FMTC Chair: Professor M. Volkan Otugen of Polytechnic University (516-755-4385) or the Vice-Chair: Professor Ganesh Raman of Illinois Institute of Technology (312-567-3175).

## Multiphase Flow Technical Committee

The Multiphase Flow Technical Committee (MPFTC) organizes symposia and forums related to gas-liquid and fluid-solid flows in odd years and computational and experimental methods in even years at the FED Summer Meetings. Generally, multiphase flow is a huge technological activity that transcends what has been the traditional scope of past meetings. Serving our membership therefore calls for new initiatives that go beyond these traditional boundaries. The IMECE offers a great opportunity for the organization of joint activities with other divisions which also have a strong multiphase flow component such as Heat Transfer, Manufacturing, Acoustics, and others. The planning of joint symposia with these divisions is well under way.

An upcoming major event, for the world's multiphase flow community, will be ICMF-2001, the 4th International Conference on Multiphase Flow to be held in New Orleans from May 27 to June 1, 2001. The organizer is Prof. Stathis Michaelides of Tulane University, a past Chair of MPFTC. The 2001 FED Summer Meeting will be co-located with ICMF-2001 in a neighboring hotel. Registrants for either meeting will have free access to both meetings, and all registrants will receive a CD-ROM containing the proceedings of both meetings.

If you have questions or suggestions please contact the Chair: Dr. Andrea Prosperetti of the Johns Hopkins University (410-516-8534) or the Vice Chair: Dr. Steven L. Ceccio of the University of Michigan (313-936-0433). With the Boston meeting in June 2000 Dr. Prosperetti will be leaving the Chair of the MPFTC in the capable hands of Prof. Steven Ceccio (Dept of Mechanical Engineering, University of Michigan) who was elected last November at the Nashville meeting; a colleague of Prof. Ceccio's - Prof. Great Tryggvason - was elected secretary.

## ASME Journals Now Online

<http://www.asme.org/pubs/journals/online/>

Now through June 30, 2000, you have FREE online access to the full text of the 17 Transaction Journals of The American Society of Mechanical Engineers. Just log onto ASME's Technical Publications website: [www.asme.org/pubs/journals/online](http://www.asme.org/pubs/journals/online)

You will find full-text articles available in HTML, in Sectioned HTML, and as PDF files. You can more easily access smaller files in Sectioned HTML and more conveniently print at your desktop using PDF files, which mirror the print version of the journal.

## Your Subscription

Beginning July 1, 2000, you will have access to the full online editions only if you have a paid subscription to the printed journal. However, visitors to the website can access a paper on a pay-per-view basis with Article Purchases, a unique service providing for the purchase and delivery of articles directly to your desktop. For more information on Article Purchases, please see the home page for any one of the online transactions journals and click on Article Purchases. Here is a listing of the ASME Transactions journals:

- Journal of Applied Mechanics
- Journal of Biomechanical Engineering
- Journal of Dynamic Systems & Control
- Journal of Electronic Packaging
- Journal of Energy Resources Technology
- Journal of Engineering Gas Turbines & Power
- Journal of Engineering Materials and Technology
- Journal of Fluids Engineering
- Journal of Heat Transfer
- Journal of Manufacturing Science & Technology
- Journal of Mechanical Design
- Journal of Offshore Mechanics and Arctic Engineering
- Journal of Pressure Vessel Technology
- Journal of Tribology
- Journal of Turbomachinery
- Journal of Vibrations & Acoustics

## International Mechanical Engineering Congress & Exposition (IMECE)

November 5–10, 2000

Walt Disney  
World Dolphin Hotel  
Orlando, Florida

[www.asme.org/conf/congress00](http://www.asme.org/conf/congress00)

(800) The ASME

# TECHNICAL BRIEF

## Direct numerical simulations of bubbly flows

**M**ultiphase bubbly flows occur in both industrial and natural processes. Boiling heat transfer, cloud cavitation, aeration and stirring of reactors in water purification and waste water treatment plants, bubble columns and centrifuges in petrochemical industry, cooling circuits of nuclear reactors, propagation of sound in the ocean, the exchange of gases and heat between the oceans and the atmosphere, and explosive volcanic eruptions are just a few examples. Understanding the evolution and properties of bubbly flows is therefore of major technological as well as scientific interest.

For engineering applications, computational modeling of bubbly flows relies on equations that describe the average flow field. The two-fluid model, where separate equations are solved for the gas and the liquid phase, is the most common approach. Since no attempt is made to resolve the unsteady motion of individual bubbles, closure relations are necessary for the unresolved motion and the forces between the bubbles and the continuous phase. Closure relations are usually determined through a combination of dimensional arguments and correlation of experimental data. The situation is analogous to computations of turbulent flows using the Reynolds averaged Navier-Stokes equations where momentum transfer due to unsteady small-scale motion must be modeled. For the turbulent motion of single phase flows, direct numerical simulations, where the unsteady Navier-Stokes equations are solved on fine enough grids to fully resolve all flow scales, have had a major impact on closure modeling. While the need for such an approach for multiphase flows has been recognized by investigators for a long time, the difficulty in following the motion of a deforming phase boundary, separating fluids of widely different properties, have proven to be considerable. Until recently, progress has only been achieved by the use of simplified models, where inertia or viscosity are left out, or the bubbles are modeled as very small point particles. During the last few years, however, simulations of the full problem, where inertia, viscosity, interface deformation, and surface tension effects are all included have appeared.

While the availability of very large parallel computers is, first and foremost, responsible for the recent progress, development of suitable numerical methods has also played a major role. The methods fall in two categories: (1) capturing of phase boundaries on a fixed grid and (2) following phase boundaries by moving

unstructured grids. The first type is based on writing one set of equations for the complete flow field. Interfacial conditions are included as generalized body force terms (delta functions) and the density and viscosity must be allowed to change abruptly at the interface. The phase boundary is tracked either by a marker function (Volume of Fluid, Level Set, or phase field methods), or by connected marker points (Immersed Boundary methods). A marker function is simpler to implement, but connected marker points offer higher accuracy and greater flexibility. The second type, moving unstructured grids, offers the greatest flexibility and accuracy, but at the cost of considerable programming complexity.

A number of simulations using an immersed boundary method have already cast considerable light on the evolution of flows containing many bubbles. Esmaeeli & Tryggvason (1996, 1998) used direct numerical simulations to examine the motion of a number of freely evolving bubbles at low, but finite Reynolds numbers (around 1-2, depending on volume fraction and dimensionality). The simulations were done using periodic domains and included up to 324 two-dimensional bubbles and 8 three-dimensional ones. The results showed that a regular array is unstable and that it breaks up through two-bubble interactions of the "drafting, kissing, and tumbling" type. Although many aspects of the flow are similar to Stokes flow, the evolution of the free array differs by the strong two-bubble interactions. In Esmaeeli & Tryggvason, 1999, the evolution was examined at a higher Reynolds number (around 20-30 for the lowest volume fraction) and the differences with the lower Reynolds number case quantified. The effect of the number of bubbles in each period was examined for the two-dimensional system and it was found that the rise Reynolds number and the velocity fluctuations in the liquid (the Reynolds stresses) generally increase with the size of the system. While some aspects of the fully three-dimensional flows, such as the dependency of the rise velocity on the Reynolds number, are predicted by results for two-dimensional bubbles, the structure of the bubble distribution and the magnitude of the Reynolds stresses, is not. The rise velocity of a single bubble is in good agreement with experimental results for clean systems. The dependency on the void fraction also compares favorably with experimental observations.

To examine how the results change as the number of bubbles is increased Bunner and Tryggvason (1999), using a fully parallel version of the method, studied three-dimensional systems with up to 216 buoyant bubbles. The governing

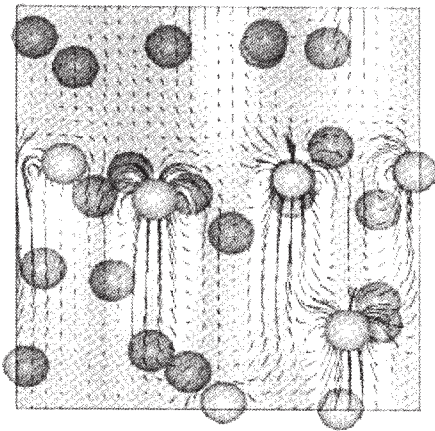
parameters were selected such that the average rise Reynolds number is about 20-30, depending on the void fraction, and deformations of the bubbles are small. Although the motion of the individual bubbles is unsteady, the simulations are carried out for a long enough time so that the average behavior of the system is well defined. Simulations with different numbers of bubbles are used to explore the dependency of various average quantities on the size of the system. The average rise velocity and Reynolds stress are independent of system size for systems with 27 or more bubbles, but larger systems are needed to determine the variance of the bubble velocities and the dispersion coefficients. Examination of the pair distribution function for the bubbles shows a preference for horizontal alignment of bubble pairs, independent of system size, but the bubble distribution remains nearly uniform. The energy spectrum for the largest simulation quickly reaches a steady state, showing no growth of modes much longer than the bubble diameter.

The figures below show results from two simulations used to investigate the effect of bubble deformation. In both cases, the motion of 27 bubbles in a periodic domain is followed for a relatively long time. In the first frame, the deformations of the bubbles are small, but in the second frame the surface tension is smaller and the bubbles deform as they rise. The velocity field and the vorticity squared are shown in a plane through the middle of the computational domain. Bubbles behind the plane are darker than the bubbles in front of the plane. The nearly spherical bubbles quickly reach a well defined average rise velocity (rise Reynolds number of about 25) and remain nearly uniformly distributed. For the void fraction simulated here, 2%, the deformable bubbles behave in a similar way, except the velocity fluctuations are much larger. At higher void fraction, the nearly uniform distribution seen here transitions to a completely different state where the bubbles accumulate in vertical streams, rising much faster than when they are uniformly distributed. This behavior can be explained by the dependency of the lift force on a bubble of the deformation of the bubbles.

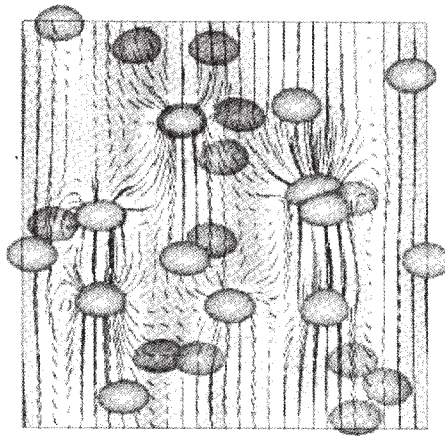
Direct numerical simulations of multiphase flows offer the opportunity to understand how small scale motion, due to individual bubbles and the collective interaction of bubbles, influences the large-scale flow. In addition to new insight, such simulations will lead to improved closure models for engineering predictions. For additional references and a more detailed discussion, see the papers listed below.

## Technical Brief

(Continued from page 6)



One frame from a simulation of 27 nearly spherical bubbles rising with an average rise Reynolds number of 20.



One frame from a simulation of 27 deformed bubbles rising with an average rise Reynolds number of 20.

## REFERENCES

- Esmaeeli, A. and G. Tryggvason, G. "An Inverse Energy Cascade in Two-Dimensional, Low Reynolds Number Bubbly Flows." *J. Fluid Mech.*, 314 (1996), 315-330.
- Esmaeeli, A. and Tryggvason, G., Direct numerical simulations of bubbly flows. Part I-Low Reynolds number arrays, *J. Fluid Mech.*, 377 (1998), 313-345.
- Esmaeeli, A. and Tryggvason, G., Direct numerical simulations of bubbly flows. Part II-Moderate Reynolds number arrays, *J. Fluid Mech.*, 385 (1999), 325-358.
- B. Bunner and G. Tryggvason. Direct Numerical Simulations of Three-Dimensional Bubbly Flows, *Phys. Fluids*, 1999, to appear.
- B. Bunner and G. Tryggvason. An Examination of the Flow Induced by Buoyant Bubbles, *Journal of Visualization*, 1999, to appear.
- Further information can be obtained from the authors:
- Gretar Tryggvason email: gretar@umich.edu; www: <http://www-personal.engin.umich.edu/~gretar/>
- Bernard Bunner email: bunner@umich.edu; www: <http://www-personal.engin.umich.edu/~bunner/> at the Department of Mechanical and Applied Mechanics, The University of Michigan, Ann Arbor, MI 48109-2121.

## 1999-2000 Fluids Engineering Division

[www.asme.org/divisions/fed](http://www.asme.org/divisions/fed)

Dr. Philip A. Pfund, Chair  
Consultant  
Ph: (630) 840-4784  
Fx: 330.497.0639  
pfund@cannet.com

Prof. David E. Stock, IMECE '99  
and FEDSM '00 Conferences Chair  
Washington State University  
Ph: 509.335.3223  
Fx: 509.335.4662  
stock@mme.wsu.edu

Dr. Tim O'Hern, IMECE '00  
Conference Chair  
Sandia National Labs.  
Ph: 505.844.9061  
Fx: 505.844.8251  
tjohern@sandia.gov

Dr. U. S. Rohatgi, Secretary  
Brookhaven National Laboratory  
Ph: 516.344.2475  
Fax: 516.344.7650  
rohatgi@bnl.gov

Dr. Christopher J. Freitas, Sen. Mem.  
Southwest Research Institute  
Ph: 210.522.2317  
Fx: 210.522.3042  
cfreitas@swri.edu

**Technical Editor**  
Dr. Demetri P. Telionis  
Virginia Polytech & State  
University  
Ph: 540-231-7492  
Fx: 540-231-4574  
Telionis@vt.edu

**Honors & Awards**  
Dr. Kirti N. Ghia  
University of Cincinnati  
Ph: 513-556-3243  
Fx: 513-556-5039  
Kghia@cdfdl.uc.edu

**Membership / Newsletter Editor**  
Richard R. Schultz, P.E.  
Idaho National Engineering and  
Environmental Lab.  
Ph: 208-526-9508  
Fx: 208-526-2930  
Srr@inel.gov

**Professional Development**  
Dr. Helmut E. Weber  
Flow Energy Engineering  
Ph: 619-265-0500  
Weberh@asme.org

**Web Master**  
Dr. Deji Demuren  
Old Dominion University  
Ph: 757-683-6363  
Fx: 757-683-5344  
demuren@mem.odu.edu

**ASME Staff**  
Alexander Majewski  
Manager, Engineering Programs  
ASME International  
Ph: (212) 591-7284  
Fx: (212) 591-7671  
MajewskiA@asme.org

**FLUIDS APPLICATIONS  
AND SYSTEMS TECHNICAL  
COMMITTEE**  
Prof. Ali Ogut, Chair  
Rochester Institute of Technology  
Ph: 716.475.2542  
Fx: 716.475.7710  
adoeme@rit.edu

Dr. Adiel Guinzburg, Vice-Chair  
The Boeing Company  
Ph: 818.586.7622  
Fx: 818.586.0159  
adiel.guinzburg@boeing.com

**FLUID MECHANICS TECHNICAL  
COMMITTEE**  
Prof. M. Volkan Otugen, Chair  
Polytechnic University  
Ph: (516) 755-4385  
Fx: (516) 755-4526  
votugen@rama.poly.edu

Prof. Ganesh Raman, Vice-Chair  
Illinois Institute of Technology  
Ph: (312) 567-3175  
Fx: (216) 567-7230  
Raman@mnae.iit.edu

**MULTIPHASE FLOW TECHNICAL  
COMMITTEE**  
Prof. Andrea Prosperetti, Chair  
Johns Hopkins University  
Ph: 410.516.8534

Prof. Steven L. Ceccio, Vice-Chair  
University of Michigan  
Ph: 313.936.0433  
Fx: 313.764.4256

**COORDINATING GROUP ON  
COMPUTATIONAL FLUID  
DYNAMICS**  
Dr. George Vradis, Chairman  
Polytechnic University  
Ph: 516.755.4388  
Fx: 516.755.4526  
gvradis@duke.poly.edu

Prof. Urmila Ghia, Vice-Chairman  
University of Cincinnati  
Ph: 513.556.4612  
Fx: 513.556.3390  
Ughia@uceng.uc.edu

**COORDINATING GROUP ON  
FLUID MEASUREMENTS**  
Prof. M. Jack Braun, Chairman  
University of Akron  
Ph: 330.972.7734  
Fx: 330.972.6027  
mbraun@uakron.edu

Prof. Gerald L. Morrison, Vice-Chairman  
Texas A&M University  
Ph: 409.845.5414  
Fx: 409.845.3081  
gmorrison@mengr.tamu.edu

**COORDINATING GROUP ON  
INDUSTRY TECHNOLOGY**  
Dr. Manoranjan Dhaubhadel, Chair  
Case Corporation  
Ph: 630-887-2009  
Fx: 630-887-3838  
mdhaubhadel@casecorp.com

John Navickas, Vice-Chair  
The Boeing Company  
Ph: 714-372-1432  
Fx: 714-896-5250  
john.navickas@boeing.com

# 2000 ASME Fluids Engineering Division Summer Meeting (FEDSM)

**Sheraton Boston Hotel**

**Boston, Massachusetts**

**June 11-15, 2000**

This year's conference brings together a variety of programs that allow you to learn what's new in fluids engineering, network with colleagues and exchange ideas. This conference offers you Technical Sessions, Workshops, Forums, Special Tutorials, Clinics, Exhibits and the Industry Exchange Program (IEP).

If you are involved in fluids engineering applications and research in the automotive, aerospace, biomedical, manufacturing, process, power, or other industries, then you shouldn't miss this conference!

For complete program details, log on to the FEDSM website at [www.asme.org/conf/fed00](http://www.asme.org/conf/fed00), or e-mail [Postynl@asme.org](mailto:Postynl@asme.org), or call 212-591-7793.

## ASME Career Fair

**Tuesday, June 13th, 11 am – 7 pm, Sheraton Boston**

*Brush up on your interviewing skills*

*Network among your peers*

*Stop by during your lunch hour or after work during our convenient hours*

ASME will be hold a Career Fair this summer at the 2000 FEDSM in Boston. The fair will be held on Tuesday, June 13th, from 11 am to 7 pm, at the Sheraton Boston Hotel.

Entry to the fair is free. Career Fair registrants will be included in an online database that will be viewed by the top engineering employers in industry. You can still register to have your resume included in this database even if you cannot attend the event in person.

**To register, please go to:**

**[www.resumelink.com/society/registration/asmesummercf.htm](http://www.resumelink.com/society/registration/asmesummercf.htm)**