Société canadienne de CFD Society of Canada

May 2008 | Issue No. 20

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President's Message

A word from the CFDSC 2008 President

As the President of the CFD Society of Canada for 2008, let me express my great pleasure and pride to have been solicited by the Board and the Members to head the CFDSC for this year. My association with the Society betrays my age, as I was one of its founders some years ago, and gave the inauguration speech at the then Hotel du Parc in Montreal, now a McGill student residence.

I take over from Mahmood Khalid of NRC, a dear friend for whom I have the utmost respect as a person and as a scientist. Mahmood has used his tenure in an exemplary way and leaves the Society in an excellent shape in terms of finances, coordination and momentum. In short, the CFDSC is alive and well.

I have watched the Society since its inception ripen, mature and gel into a unique entity that reflects the immense richness of Computational Fluid Dynamics in Canada in terms of algorithmic and applications advances. This richness is reflected in the academic, industrial and government sectors, with a large number of internationally recognized scientists. It suffices to remind people that a number of CFD companies around the world today have a definitive Canadian background: ANSYS with Waterloo, Computational Dynamics with UBC, Applied Mechanics with the Royal Military College, Martec with the Technical University of Nova Scotia and Newmerical Technologies International with McGill.

Undoubtedly, the recent availability of supercomputers to Canadian scientists, through the largesse of the Canadian Foundation for Innovation, is a shot in the arm that should propel our research to new heights, and make many countries take stock of this state-of-the-art computing power. Gone are the days when the utter mention of the need for a supercomputer, such as through our common CANADF experience, meant the death knoll of a meritorious project that would have created a national research infrastructure for CFD some 15 years ago.

I would like to use my limited time at the helm in trying to put a solid structure to our approach that could propel the Society to a new level. To do so, I have consulted individually with members of the Board regarding my vision, and we then met for a whole day in Montreal in late October 2007. We discussed many ideas, and managed to sort out the realistic from the wishful. Our discussions centered on (creating, establishing or enhancing):

- A Strategic Plan: short-, medium- and long-terms
- Expanded membership
- National and international collaboration
- Enhancing the Bulletin
- Updating the logo

- Updating the web site
- Supercomputing platforms for CFDers
- Scholarships to students
- Database of Canadian CFD practitioners and of available CFD codes
- National Summer School for CFD (can become international)
- Relationship with the International Journal of CFD
- Relationship between academia-industry-government
- NSERC recognition of CFD and CFDSC
- Creation of a Network of Centers of Excellence

The results of our discussions and decisions should be gradually evident during this year and next and I will report on them at the Annual General Meeting. Suffices to say that we have started by selecting a new logo and requested Mr. Ali Haider to redesign the web site in a more functional way, reflecting what we have learned from experience. He joined us at the Montreal October meting and at the Ottawa April meeting and we discussed at length what we needed. I urge you to visit the new web site after May 19 and to let him/us know of any comments.

In June of this year, the Society will hold, uninterrupted, its 16th annual conference. This will take place at the University of Saskatchewan, which just celebrated its Centenary. This continuity is quite an achievement for the Society and I would hope for this conference to be the best attended ever, with as much international contact as possible.

We are also putting the idea of a “Summer School in CFD” forward and I invite you to read the Student section and to participate in the Web survey/questionnaire, prepared by your Student representative on the Board.

We have also included a small section in the Bulletin to talk about finances, which are healthy. More details and statistics will be presented at the Annual General Meeting.

We are working hard to increase membership and, thus, this bulletin and all future ones will be distributed electronically to the Chairmen of all departments of Canadian universities susceptible to harbor interest for CFD, encouraging them to distribute them to students and faculty.

Finally, the Society can greatly benefit from interaction with sister societies in the USA, Europe and the Far East. The process has been initiated through contacts with the AIAA (American Institute of Aeronautics and Astronautics), ERCOFTAC (European Research Community on Flow, Turbulence and Combustion) and the Japanese Society of Fluid Mechanics (JSFM). Others would follow once we establish a track record of success.

The suggested collaboration with AIAA would be an official participation of the CFDSC in the CFD Standards Committee. While I am currently an individual member, we would like to nominate a permanent member who can report back and speak in the name of the CFDSC and express opinions that we would reach, together. Dr. Urmila Ghia, who presides over that Committee has consulted with its members and received very positive responses to our overture. Thus, this will be followed upon vigorously and our own suggestion, refreshingly, seems to also have initiated a will for a formal collaboration between ERCOFTAC and AIAA.

As for the JSME, the response of the outgoing President Dr. Koichi Hishida has been reserved as he is leaving it to the incoming President, Professor Shigeo Kida, of Kyoto University and Dr. Eiji Shima of JAXA who will be the chairperson for CFD, to discuss with us how best to collaborate. I will attempt to meet with both when I will be in Japan at the end of May 2008 teaching a CFD of Icing course.

In this issue of the Bulletin, I have invited Professor Charles Hirsch, a founding member of ERCOFTAC and its current Deputy Chairman, to contribute an article quite indicative of the European efforts to put CFD on a more quantitative keel. My wish is for the CFDSC to become an acknowledged and valued participant in such efforts, as we may not have enough funding or critical mass to initiate similar ones on our own. I have been informed by Professor Hirsch that:

1. ERCOFTAC has decided to open its membership worldwide, with the possibility for research and industrial groups to participate, or initiate, Special Interest Groups, Pilot Centres, Workshops, and Conferences.

2. ERCOFTAC is opening up its (QNET-CFD) Knowledge Base, calling for worldwide partnerships.

He suggests a partnership based on joint activities, aiming at increasing the membership of our organizations. I thus invite you to visit http://www.ercoftac.org and to let me know if you are interested in a Special Interest Group. Once we collect this data, I will contact ERCOFTAC and facilitate individual and CFDSC participation.

I thank you all again for your trust and would be most pleased to get from students, academics and practitioners any suggestion that you may have that will contribute to the common good and advancement of CFD in this country.

Wagdi G. Habashi

2 About CDFSC …

About CFDSC…

Objectives ● The Computational Fluid Dynamics Society of Canada (CFDSC) promotes the application of CFD to provide a better understanding of fluid dynamic processes in all applicable areas and thereby supports the competitiveness of Canadian industry and advances knowledge in the field. These objectives are met by *(1)* establishing a network of CFD practitioners and developers from industry, government and universities, *(2)* identifying national needs and priorities for research in CFD, *(3)* promoting research in CFD and related areas, *(4)* enhancing industry capabilities in CFD by the education and training of professionals, *(5)* promoting the use and increasing the availability of computational tools for CFD, *(6)* promoting communication and exchange within CFD and related disciplines (e.g. environment, biology and chemistry), *(7)* organizing conferences and seminars, and *(8)* representing Canada at international forums.

Membership Annual membership fees of the CFDSC are $50 for regular members, $20 for student members, and $25 for members who are retired.

World Wide Web | www.cfdsc.ca

Address

CFD Society of Canada
P. O. Box 4871, Station E
Ottawa, Ontario, Canada KIS 5J1

Bulletin The Bulletin of the CFDSC is published from two to threes times a year to provide members with information on current CFD issues. The published articles express the views and opinions of their respective authors and do not necessarily represent those of the CFDSC. The Managing Editors are:

Wagdi Habashi | McGill University
Ali Haider | Carleton University

contact@cfdsc.com

Société Canadienne de CFD

Objectifs ● La Société canadienne de CFD (SCCFD) fait la promotion des applications de simulation numérique afin de fournir une meilleure compréhension de la dynamique des fluides et contribue ainsi au développement de la compétitivité industrielle canadienne et à l'avancement des connaissances dans le domaine. Ces objectifs sont atteints en (*1*) établissant un réseau d'utilisateurs et de développeurs de CFD dans les industries, les gouvernements et les universités, (*2*) identifiant les besoins nationaux et les priorités de recherches en CFD, (*3*) faisant la promotion de la recherche en CFD et les domaines reliés, (*4*) rehaussant les capacités en CFD des industries par la formation et l'éducation des professionnels, (*5*) faisant la promotion de l'utilisation et en augmentant la disponibilité d'outils informatiques en CFD, (*6*) faisant la promotion de la communication et des échanges en CFD avec les disciplines reliées (par exemple, en environnement, en biologie et en chimie), (*7*) organisant des conférences et des séminaires, *(8)* représentant le Canada dans les forums internationaux.

Cotisation des membres Les frais annuels d'adhésion sont de 50$ pour les membres réguliers, 20$ pour les membres étudiants, et 25$ pour les membres à la retraite.

World Wide Web | www.cfdsc.ca

Adresse

Société canadienne de CFD
B. P. 4871, Station 'E'
Ottawa, Ontario,Canada K1S 5J1

Bulletin Le bulletin de la SCCFD est publié de deux à trois fois par année afin de fournir aux membres de l'information sur les grands courants reliés à la CFD au Canada. Les articles publiés représentent les opinions des auteurs respectifs et ne représentent pas nécessairement celles de la SCCFD. Les rédacteurs exécutifs sont:

Wagdi Habashi | Université McGill
Ali Haider | Université Carleton

3 CFDSC New Website and Logo

The CFD Society of Canada is pleased to have refreshed its logo and its web site, taking into consideration comments transmitted to it by its members through the Directors at the last Board meeting. This new website will come online on Monday May 19, 2008.

We hope that the new look and functionalities will be enjoyed and appreciated by the members and visitors to the web site. Please feel free to send your comments directly to our Webmaster, Mr. Ali Haider, at ali@safiresky.com.

In the name of the Board of the CFDSC, our great thanks to Mr. Ali Haider for a job very well done.

4 CFDSC Graduate Scholarships (2008–2009)

The CFDSC will award two (2) scholarships per year, valued at $1,000 CAD each, to applicants conducting exceptional research work in computational fluid dynamics.

The field of study may involve the development of CFD techniques and/or the use of CFD techniques to solve important problems.

The applicant must be a full-time student enrolled in a Masters or Ph.D. level graduate studies program at an accredited Canadian University, and be a member of the CFDSC.

Applications can be found on the CFDSC website (http://www.cfdsc.ca/), and must be received by Thursday May 16, 2008.

The Awards will be announced at the 16th Annual Conference of the CFD Society of Canada Saskatoon, Saskatchewan, June 9-11, 2008.

To enlarge the nomination pool, the CFDSC Bulletin will be sent this year to most departments of engineering, applied mathematics and computer science in this country.

5 CFDSC Graduate Scholarships Recipients (2007–2008)

The CFDSC extends its warmest congratulations to the 2007-2008 recipients of its Graduate Scholarship Awards:

Mr. Alireza Farahaninia. Masters Candidate.
"The Effect of Natural Convective Plumes on Water Vapour Diffusion in the Martian Soil".
University of Alberta.

Mr. Mehdi Raessi. Ph.D. Candidate.
"Modeling Surface Tension Dominant Flows with High Density Ratios".
University of Toronto.

6 CFDSC Prizes for Best Student Papers at CFD2007

First and runner-up prizes for best student papers presented at the conference were awarded to:

Ms. Julie Lefrançois of Université Laval, who presented her research carried out under the supervision of Professor Guy Dumas and entitled “Force and Moment Calculation for Moving Bodies in a Lagrangian Vortex Method”.

Ms. Dagmara Biskupska of the University of Toronto Institute for Aerospace Studies who presented her work on a “Parallel Implicit AMR Scheme for Hypersonic Flows with Equilibrium High Temperature Equation of State”, research conducted under the supervision of Professor Clinton Groth.

Congratulations to both students.

7 Call for Lifetime Achievement Award Nominations

The CFD Society of Canada invites nominations for the presentation of its Lifetime Achievement Award, presented to an exceptional Canadian scientist recognized for seminal and longstanding work in Computational Fluid Dynamics.

This award is an exceptional one and is not offered regularly.

For specific information regarding eligibility criteria and nomination procedures please visit our website at http://www.cfdsc.ca.

8 Call for Nominations to the CFDSC Board of Directors

Nominations will be accepted for the CFDSC Board of Directors for all positions ending in 2008 and will be voted upon at the Annual General Meeting that takes place on Tuesday June 10th during the CFD2008 conference.

To nominate a person, simply send an e-mail with the person's name, position, and a short 3 to 5 lines paragraph explaining what the person could bring to the CFDSC. Self-nominations are also allowed. The e-mail should be sent to Ms. Anh Truong, Secretary, as her term is beyond 2008, truong@oddjob.utias.utoronto.ca.

9 CFDSC Executive Committee & Directors

President
Wagdi Habashi
(2008, U, McGill)
Executive Officer
Marilyn Lightstone
(2005-2008, U, McMaster)
Treasurer
François Lesage
(2006-2009, G, DND)
Communications Officer
Jon Pharoah
(2006-2009, U, Queen’s)
Membership Officer
Suzhen Chen
(2005-2008, G, NRC)
Secretary and Student Director
Anh Truong
(2006-2009, Toronto)
Directors
Don Bergstrom
(2007-2010, U, Saskatchewan)
Clinton Groth
(2005-2008, U, Toronto)
Mahmood Khalid
(G, NRC, ex-officio)
Eric Laurendeau
(2007-2010, I, Bombardier)
Eric Thornhill
(2005-2008, G, DND)
Guanghan Wang
(2007-2010, G, Canadian Space Agency)
Dave Whitehouse
(2005-2008, I, Martec)

U : University | G : Government | I : Industry

10 Financial Report

The Society is financially healthy. The main source of income is the memberships collected as part of the registration fees at our Annual conference.

- $50 regular
- $20 student
- $25 retired

The conference attendance has been typically of the order of 130. Operating expenses include the Graduate Scholarships, the two Student Awards prizes at the Annual conference, the production of the Bulletin and the web site, and normal operation expenses.

11 Students' Corner

The field of CFD is advancing rapidly on many fronts and CFD is becoming a primary tool for the analysis, and more recently for the design, of increasingly complex flow-based systems. As such, we see a corresponding increase in the demand for advanced computational resources, reliable data for verification and validation, and honing of the knowledge and expertise required for the efficient use of CFD.

One of the goals of the CFD Society is to address these issues by coordinating with research institutes and universities both in Canada and abroad. We organize conferences where researchers meet, exchange ideas and form collaborations. We also provide workshops and courses parallel to and outside of the conference time frame for those who would like to have a more in-depth understanding of a particular area of CFD.

The success of these short courses has prompted us to consider setting up a special summer CFD school where participants will be able to learn various algorithmic and applicative aspects and applications of CFD from renown researchers in the field, from Canada and abroad. Local courses at Universities cannot be expected to cover all aspects of CFD, but the combined wealth of CFD knowledge in this country can be better leveraged through such summer schools in which Professors and Students would mix.

We would like to know if you, the students, see this idea as useful, and what the subjects of these courses could be. To help you in your reflection, we have suggested a number of those and you could add to them. Your response would be very helpful in guiding us in the decisions regarding the summer school, part of our efforts in promoting a productive CFD research environment in Canada.

We have placed a 1-page electronic questionnaire on our web site, and we urge you to complete it.

12 Membership Report

The CFDSC has 158 active members. Among them, 75% are professors and students from more 20 universities in Canada from coast to coast, 10% are professionals from industry and about 3% are from government research organizations in Canada. Our society has also attracted students and professionals from overseas, such as the United States, Iran, Belgium, The Netherlands, Denmark, China and India.

The CFDSC offers members opportunities for graduate scholarships, student paper awards, conference proceedings and collaboration opportunities. A recent strategy plan being developed by the board will provide members in the near future with CFD summer school programs, facilitating participation in activities of other CFD societies, a database of Canadian CFD practitioners and of available CFD open-source codes, and opportunities to develop relationships between academia, industry and government.

The society is endeavoring to provide excellent services to our members. We welcome professionals from various CFD areas around the world to join and support us. The society's new website, www.cfdsc.ca, provides details on how to become a member of CFDSC.

13 The Upcoming 16th Annual Conference of the CFDSC (CFD2008, University of Saskatchewan)

Venue: The 16th Annual Conference of the CFD Society of Canada (CFD2008) will be held at the University of Saskatchewan in Saskatoon, Canada from Monday June 9 – Wednesday June 11, 2008.

Co-Chairs: Professors Don Bergstrom and Ray Spiteri, University of Saskatchewan

Scope: The goal of the conference is to promote computational fluid dynamics by providing a forum for communication and collaboration between researchers, developers and users, from industry, government and academia, both within Canada and internationally.

Subjects: Papers will cover a large number of topics relevant to CFD, including but not limited to: compressible, incompressible and multiphase flows; reacting flows and combustion; flows in porous media; micro- and nano-scale flows; environmental, biomedical and biological flows; turbulence and turbulence modeling; aero-elasticity and aero-acoustics; numerical methods and algorithm development; mesh generation and adaptation; error estimation and control, and parallel algorithms.

Participants: The Conference is open to academia, industry and government scientists, from Canada and abroad. Student participation is particularly encouraged.

Keynote Speakers: The themes of this year's plenary lectures have been selected to feature new opportunities, as well as research topics that relate to the needs of the resource industry. Speakers will include:

Professor Spencer Sherwin
(Imperial College: bio-fluids);

Professor Tom Gatski
(Old Dominion University and Université de Poitiers: turbulence); and

Professor Jennifer Sinclair Curtis
(University of Florida: multiphase flow).

Early registration deadline: May 16, 2008

Complete information is available on the conference website: www.cfd2008.org, and on the CFDSC website: http://www.cfdsc.ca.

Any additional inquiries should be directed to the conference co-chairs by email at:

cfd.2008@usask.ca

14 The 15th Annual Conference of the CFDSC (CFD2007, University of Toronto): A Report

Venue: The 15th Annual Conference of the Computational Fluid Dynamics Society of Canada was held in the heart of downtown Toronto during May 27-30, 2007.

Co-Chairs: The conference was co-hosted by McMaster University, Ryerson University, and the University of Toronto. Professors Marilyn Lightstone (McMaster University), Jeffrey Yokota (Ryerson University) and Clinton Groth (University of Toronto) were the co-chairs for the meeting.

Participants: The conference attendance was 150 persons, including 90 students. The technical sessions were structured into four parallel sessions that spanned three full days. The conference began with a welcome reception that was held on the 27th floor of the University of Toronto 89 Chestnut Residences. The floor offered a panoramic view of the city, while a pianist entertained delegates.

Keynote Speakers: CFD2007 featured interesting and comprehensive plenary talks by three keynote speakers: Professors Bernardo

Cockburn of the University of Minnesota, Herman Deconinck of the Von Karman Institute for Fluid Mechanics and Kemo Hanjalic of Delft University of Technology. Professors Cockburn and Deconinck gave overviews of discontinuous Galerkin and residual distribution methods, respectively, while Professor Hanjalic talk dealt with advances in the modeling and simulation of turbulent flows.

Special Course: Professor Joaquim Martins of the University of Toronto, immediately following the technical program on Thursday May 31, 2007, gave a well-attended one-day short course on Multidisciplinary Design Optimization.

Student Prizes: First and second place prizes for the best student paper presented at the conference were awarded to Julie Lefrançois of Université Laval and Dagamara Biskupska of the University of Toronto Institute for Aerospace Studies.

Sponsors: The conference organizers are grateful to the many companies that sponsored this event and to the authors and reviewers who contributed to the high technical quality of the papers and presentations.

Proceedings: The Proceedings consisting of the abstracts are available on the CFDSC website. Selected papers have been further expanded and will be published in a forthcoming special issue of the International Journal of Computational Fluid Dynamics (Taylor & Francis).

15 News from the CFDSC Community

The CFDSC invites its members to share newsworthy items to be included in this section in future bulletins. Please send to: wagdi.habashi@mcgill.ca

Eric Laurendeau was an invited speaker at the MITACS Validation and Verification Workshop, Banff 2008.

Eric Laurendeau, is currently President of the Aerodynamics Section of the Canadian Aeronautics and Space Institute, CASI.

Wagdi Habashi was an organizer of the SAE International Aircraft and Engine Icing Conference that took place in Seville, Spain, in September 2007. The Conference was attended by 250 persons. He also presented 5 papers at the conference.

Wagdi Habashi has co-organized, with Mark Potapczuk of NASA-Glenn (Director, Icing Branch), a Mini-Symposium on Progress in CFD Simulation of In-Flight Icing, at the ECCOMAS Conference, Venice, in June 2008.

Martec Ltd. has been acquired by Lloyd’s Register. Martec is a Halifax-based advanced engineering company that has developed the Chinook CFD software for explosion and high-speed flow simulation. Martec's activities will be part of the Lloyd's Register Group's Marine Consultancy Services. Marine Consultancy Services comprises specialist engineering services including noise and vibration specialists, structural analysis services, and a wide range of energy efficiency and environmental services.

16 Invited Paper | From ERCOFTAC

The CFDSC has decided at its Board meeting of October, 2007, to enhance its cooperation with a number of similar societies internationally. As a first manifestation of this new emphasis, we are pleased to present a paper from Professor Charles Hirsch, co-founder and current Deputy Chairman of ERCOFTAC, entitled: "NODESIM-CFD: A European Project on Non-Deterministic Simulation for CFD-Based Design Methodologies".

NODESIM-CFD: A European Project on Non-Deterministic Simulation for CFD-Based Design Methodologies

Charles Hirsch and Cristian Dinescu
NUMECA International S.A.
5, Avenue Franklin Roosevelt
1050 Brussels
Belgium

ABSTRACT

Reliable simulation tools capable of quantifying and managing efficiently uncertainties, met in engineering applications related to the aeronautical industry, are required in the advanced design systems of any important manufacturer in order to reduce the design cycle time and costs. The present paper gives an overview of one of the collective efforts in progress at the European level, in the framework of the NODESIM-CFD project, intending to contribute to the development of a new paradigm for CFD based virtual prototyping by incorporating the relevant operational, geometrical and numerical uncertainties in the simulation process. The major scientific and technical objectives are reviewed together with the tasks and the lines of actions foreseen to achieve them. Preliminary results of NODESIM partners will be introduced and the future work directions are discussed.

1.0 INTRODUCTION

One of the major goals of the aeronautical industry is to reduce the design cycle time and the product development costs. The goal is satisfied by relying on the virtual prototyping in conjunction with advanced design optimization methods. This brings forward the problem of developing reliable simulation tools whose predictive performances are critical in providing the necessary input to arrive to optimal design decisions.

For the time being, the design methods in aeronautical industry, and we refer hereafter to the aerodynamic simulation tools based on CFD and their multidisciplinary extensions, rely on deterministic simulations. This means that the input parameters describing the problem under investigation are exactly defined by a unique set of data. In spite of that, the product runs under realistic conditions consisting of a superposition of numerous uncertainties as those related to the boundary and initial conditions, the definition of the geometries due to manufacturing tolerances or roughness, the numerical error sources and the uncertain physical model parameters.

These uncertainties are a serious source of risk in the decision-making process associated to the design stage, which can enhance the risk of failure of a product. Therefore, the reliability of the CFD simulation tools is drastically enhanced by directly considering the management of the uncertainties in the simulation process.

In the present context, when the CFD techniques reached their maturity and the hardware and software technologies record considerable advances, the demands from industry for simulation tools accounting for these uncertainties seem feasible. This fact motivated 17 teams from the aeronautical and power generation fields, research establishments and universities to cooperate in the European project NODESIM-CFD [13] in order to address this topic. The acronym NODESIM-CFD stands for "Non-Deterministic Simulation for CFD Based Design Methodologies".

The paper is structured as follow: section 2 presents the scientific and technological objectives of the project, section 3 emphasizes the tasks and actions foreseen to achieve the objectives while section 4 contains our conclusions and perspectives on future work.

2.0 SCIENTIFIC AND TECHNOLOGICAL OBJECTIVES

As seen in section 1, the design decisions depends strongly on the reliability of the simulation software and consequently the software tools must comply with strict requirements concerning the quality assurance, i.e. the verification and the validation (V&V) of the software components and the minimization of the related simulation uncertainties.

But the range of real life applications will generally be, partially or totally, outside the strict validation range [14], fact that shows that even extending the validation base of V&V there are still uncertainties that cannot be eliminated. On these kinds of uncertainties the effort inside NODESIM-CFD project is focused.

The main technical goal of the NODESIM-CFD project is to insert these uncertainties within the simulation process by applying *non-deterministic* methodologies in order to obtain, instead of a single predicted value, an associated *domain of variation* of the predicted output quantities.

A second main goal is an industrial one, namely to provide software tools for the quantification and management of uncertainties associated to aerodynamic and multi-physics applications which through their numerical predictions will contribute to the design confidence enhancement, the reduction of risks and the improvement of safety.

It is expected that these general goals to be achieved if actions towards the following five measurable scientific and technological objectives are directed:

- **A) Identification and quantification of the uncertainty parameters** afferent to a broad range of aeronautical applications from the following domains:
    - engine aerodynamics
    - wing aerodynamics
    - conjugate heat transfer
    - fluid-structure interaction.
- **B) Development of non-deterministic methodologies,** for the management of uncertainties, belonging to one of the following categories:
    - perturbation techniques and adjoint based methods
    - efficient Monte Carlo methods
    - Polynomial Chaos methods.
- **C) Applications to subsystems and systems** of the developed non-deterministic methodologies and their adjacent software tools in order to test and validate them.
- **D) Introduction of the non-deterministic simulations into the design and decision process**, with an emphasis on the development of aerodynamic optimization algorithms that provide robust designs with respect to operational, geometrical and numerical identified uncertainties.
- **E) Stimulation of the scientific co-operation, through internal and external dissemination, and exploitation** by
    - transfer of knowledge among developers and industrial end-users,
    - scientific publications

- dedicated presentations on relevant applications.

3.0 TASKS AND ACTIONS

This section intends describing the main tasks and their related actions undertaken or in progress considered necessary to reach the proposed objectives. In principal, to each objective a work package with specific tasks is associated.

The first objective has been accomplished by an intensive and thorough analysis of the potential uncertainties to be accounted for. Three classes of uncertainties were identified based on the collected information from each team partner:

- operational uncertainties
- geometrical uncertainties
- numerical uncertainties.

Details about the mechanisms conducting to this classification and difficulties related to quantification are given in the contributions [4] and [1] to the present symposium. In what follows, there are summarized the main identified uncertainties and the problem of their quantification is sketched.

For the first two classes of uncertainties, according to [4], it has been distinguished between two categories of flows: external flows around aircraft and internal flows in compressors and gas turbines. Among the operational uncertainties the most important ones have been identified as being the Mach number and the incidence for both flow categories. Regarding the geometrical uncertainties, the manufacturing tolerances and roughness received attention as the main sources of uncertainty in defining the actual geometries. The third class of uncertainties is related to the definition of the problem to be solved, usage of physical sub-models, boundary conditions, numerical modelling and validation. In [1] there is studied the influence of boundary conditions' treatment on the accuracy and mesh convergence.

Even several uncertainties can be identified for each specific application it has been found that one should concentrate on a small number of representative uncertainties [4]. Moreover, the most difficult part seems to be how to quantify the representative uncertainties in a precise manner. This precise quantification is the input for the non-deterministic methodologies under development.

Preference has been given to the statistical description through a probability distribution function (pdf), but this brought the following problems:

- what type of pdf should be selected for each identified uncertainty
- how to prescribe the input parameters characterizing the selected pdf

These problems are to be solved by using or corroborating an expert opinion, experimental data or analytical/numerical input. In this respect, two software tools have been developed:

- a distribution fitting tool [2]
- a beta pdf defining tool

The first tool looks for identifying the best fitting between one classical pdf, belonging to a database of 11 classical pdfs, to an experimental distribution. So, the output will be the type of pdf, which matches the experimental one and the characteristic parameters of the identified pdf.

The second tool allows quantifying an uncertain variable through a beta pdf. Starting from an expert opinion consisting of the minimum, the maximum and the most likely values of the uncertain variable a beta pdf is generated.

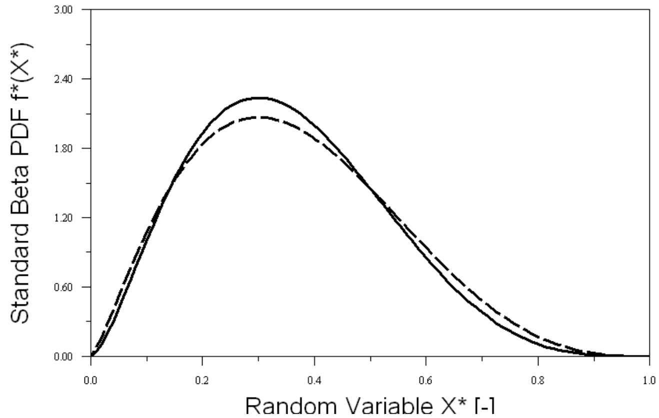

Figure 1 Standard beta pdfs: PERT approach (solid line), Holland's approach (dashed line)

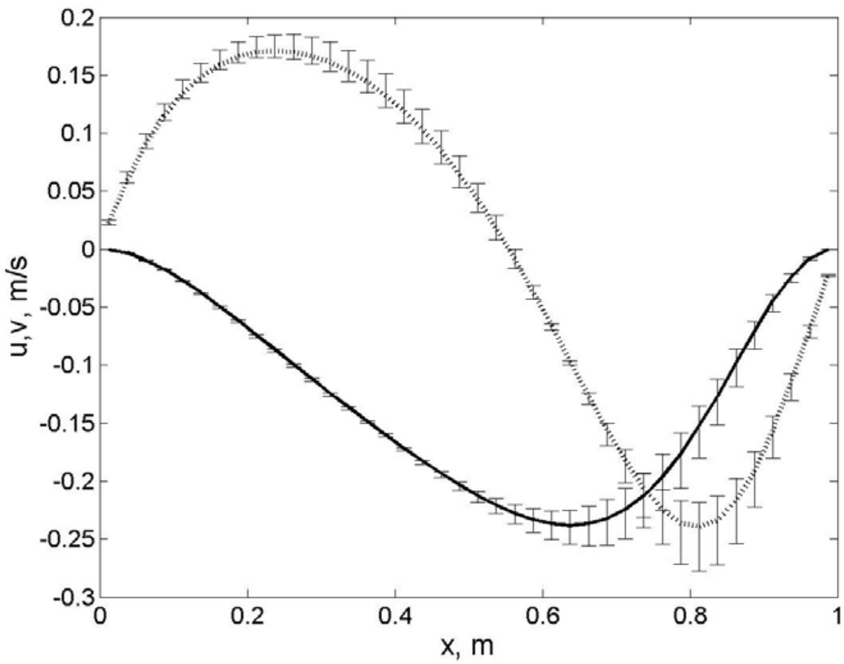

Figure 2 Mean velocity along horizontal centre line: u-solid line, v-dashed line (courtesy Sergey Smirnov, VUB)

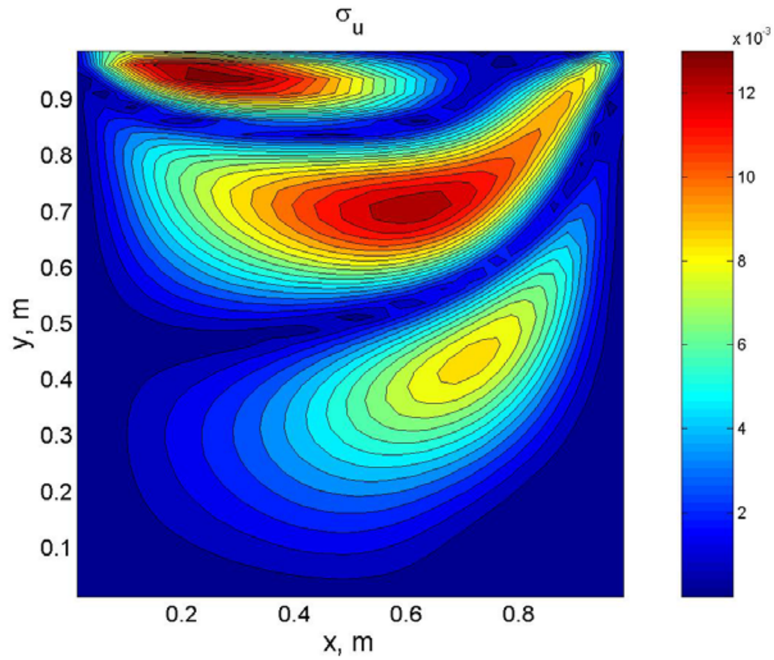

Figure 3 Standard deviation of u-component velocity (courtesy Sergey Smirnov, VUB)

Two approaches have been implemented: the conventional PERT approach [12] and Holland's approach [9]. Figure 1 shows examples of beta pdfs constructed by employing each of the two approaches.

The ongoing work related to the second objective will generate the theoretical core of the NODESIM-CFD project. Three categories of non-deterministic methodologies are under development, which are recalled hereafter, and subsequent validations are foreseen:

- perturbation techniques with adjoint methods
- Monte Carlo (MC) methods with surrogate methods
- Polynomial Chaos methods (PCMs)

For the first category of techniques, actions are in progress towards the automatic differentiation and the management of uncertainties with respect to a given mesh quality. In [3], there is studied the propagation of the error, due to purposely addition of the Jameson type artificial dissipation, required by the space discretization, in the numerical solutions of the compressible Navier-Stokes system with linearized and adjoint linearized versions of an unstructured flow solver. Solution error is used as an indicator for further mesh adaptation. In the same line, [16] gives an example of usage of an adjoint method for analysing the mesh error effects on outputs of interest as lift and drag. A cell vertex finite volume flow solver is used together with the automatic differentiation engine TAPENADE [18], developed by one of the NODESIM partners.

The second category of MC methods, which in principle can deliver the complete statistics, has to circumvent the main drawback represented by the high computational cost. Therefore, most of the MC analysis systems of the involved partners are to be combined with surrogate models based on various approaches as artificial neuronal networks, response surface methods, design of experiments etc. Preliminary results have been obtained for blade optimization with respect to geometrical uncertainties by using MC method and surrogate models. Also, efforts are directed to the sampling techniques as extending the Latin Hypercube method to correlated variables or Kriging methods.

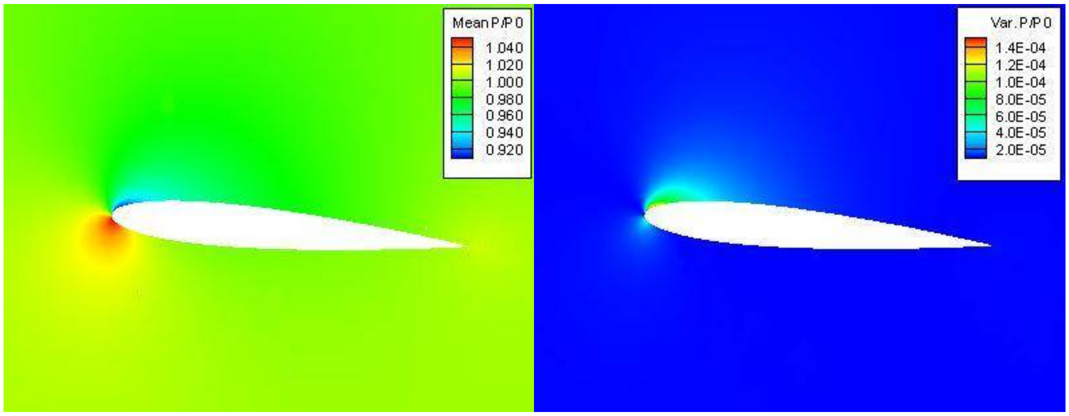

Figure 4 The mean (left) and the variance (right) pressure fields around NACA 0012 airfoil computed with the Probabilistic Collocation Method [11] and FINE™/Hexa environment [6] as deterministic flow solver (courtesy Alex Loeven, TUDelft)

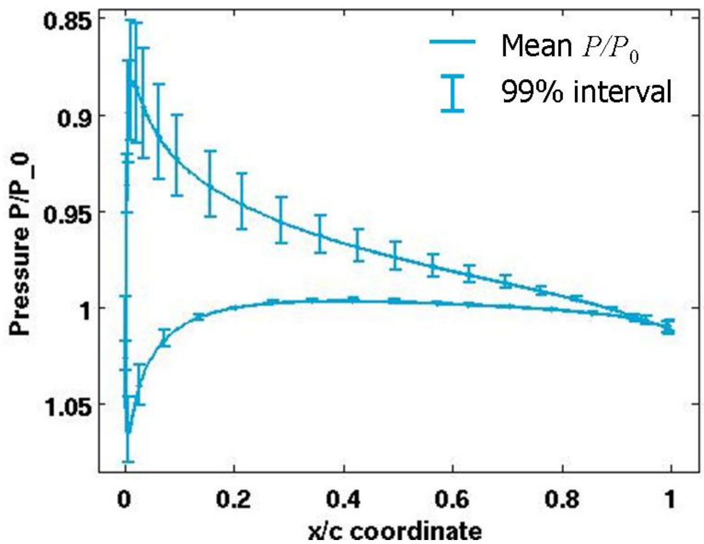

Figure 5 The mean pressure distribution on the upper and lower surfaces of NACA 0012 airfoil computed with the Probabilistic Collocation Method [11] and FINE™/Hexa environment [6] as deterministic flow solver (courtesy Alex Loeven, TUDelft)

The third category accounts for two main types of PCMs: intrusive and non-intrusive. In general, PCM consider that the uncertainties generate additional stochastic dimensions and the conserved or transported variables depend on these new dimensions.

In the intrusive PCM, each variable is subjected to a Polynomial Chaos expansion (PCE), in terms of orthogonal polynomials, which separates the deterministic dimensions, contained in the PCE- coefficients, and the stochastic dimensions. The weight function attached to a family of orthogonal polynomials represents the pdf of the considered uncertainty. PCE is further inserted in the flow governing equations and a Galerkin projection on the basis of stochastic space is performed. The outcome is the set of coupled governing equations for the PCE-coefficients, which can be numerically integrated. This coupling brings the intrusive character of the method because the actual implementation requires modifying the deterministic flow solver.

The non-intrusive methods look for finding ways to avoid this coupling and to use an existing deterministic flow solver as a black box. In such methods, the deterministic solver is run for several sample points in the stochastic space and later the outcomes of the runs are post-processed to extract the relevant statistical descriptors. The following non-intrusive versions are under development: Probabilistic Collocation Method [11], Probabilistic Radial Basis Function approach [10] and Chaos Collocation [15].

For both types of PCM, the principal interest is concentrated on the assessment of the effects due to nonlinear character of the flow governing system and to improve the computational efficiency.

Sample results obtained with an intrusive Polynomial Chaos method [17] implemented in a block structured flow solver [5] are given hereafter. Figure 2 presents the distributions of the mean velocities along the horizontal centerline in a lid driven cavity problem. Viscosity has been considered uncertain with a standard deviation of 10% with respect to its mean value. Figure 3 emphasizes the standard deviation afferent to the horizontal component of the velocity vector. Further details about the implementation issues and other test cases are shown in [17].

The potential of Probabilistic Collocation method [11] is illustrated, for the subsonic flow around a NACA 0012 airfoil, in figure 4 and figure 5. Figure 4 gives the mean and variance pressure fields computed with a fourth order version of the method, while figure 5 shows the plot bar of the pressure distributions on the airfoil surfaces. FINE™/Hexa [6] environment has been used as black box deterministic solver.

Apart from being less complex then intrusive method, the non-intrusive methods still need using intelligent techniques for sampling of the stochastic space. This means that selecting less sample points one has less runs to perform and a higher computational efficiency is achieved.

In [10], an efficient non-intrusive method entitled Probabilistic Radial Basis Function (PRBF) approach has been developed and validated. PRBF is an extension of Probabilistic Collocation method [11], where the radial basis functions used to describe the surface response are combined with efficient sampling techniques as Latin Hypercube, Halton, Hammersley, and central voronoi tessellation. The PRBF approach proved its superior efficiency with respect to a Probabilistic Collocation method [11] when multiple uncertainties are accounted for. Also, the potential of the PRBF approach is tested on a steady flow around NACA 0012 airfoil where four uncertainties are simultaneously considered: two are of operational origin (the free-stream Mach number and the angle of attack) and the other two are of geometrical origin (camber and thickness).

Among the identified uncertainties the geometrical ones are the most challenging in terms of modelling and managing them. In particular, the manufacturing or dynamic geometric variability of the profile and the roughness have been identified as being of major interest. If for MC methods the geometrical uncertainties can be handled by re-meshing the computational domain, this issue is not so straightforward for PCMs. In what follow, the main three approaches under development are summarized.

For the intrusive PCM described in [17] preliminary investigations showed that one of the critical points is represented by the way the random fields associated with geometrical uncertainties met in industrial applications are to be decomposed. A feasible solution is the modal decomposition performed by Garzon [7] through a Principal Component Analysis.

In [10] where a non-intrusive method is proposed, the geometrical uncertainties are handled in a straightforward way by re-meshing each computational domain associated to each support point.

A different approach is taken in [15], where in order to avoid the stochastic mapping [20] or re-meshing [10], a chaos collocation method is combined with a fictitious domain with least-square spectral element method in order to solve convection-diffusion and the stationary heat conduction problems in random domains.

The third listed objective aims at validating the non-deterministic methodologies on representative test cases and for various uncertainties sources. Firstly, a data base of test cases has been built up with different levels of complexity. Academic test cases and industrial ones coexisted and have been classified after the range of applications:

- external flows around wings
- propulsion flows
- multi-physics

A short list of test cases has been obtained by selecting those which have common geometries, flow regimes and were of common interest for several partners. So, there are test cases that will be subjected to investigations with different non-deterministic methods facilitating relevant comparisons among the results and assessment. Analysis of the results will allow identifying the best-adapted non-deterministic method for each of applications.

For the time being, results are reported, in this symposium, mainly for the flows around wings. Computational results related to subsonic flows can be found for NACA 0012 in [1] and [10] while for RAE 2822 in [3] and [4]. Interest in transonic flow is reported in [1] and [3] for ONERA M6 wing and in [1] for NACA0012. For supersonic flow one can find results in [3] for NACA0012.

With respect to multiphysics applications, in [19] are reported results, on academic test cases, for a newly developed Unsteady Adaptive Stochastic Finite Element (UASFE) method. This UASFE method is to be used further in fluid-structure interaction problems associated with flutter of aeroelastic structures met in aeronautical industry.

The fourth objective foresees a transfer of knowledge among the developers' teams and the end-user partners. This is a two way process: a direct action is dedicated to the actual transfer of the non-deterministic software modules, coupling with end-users' in-house codes and training. After transfer the non-deterministic modules are to be used in the design optimization systems of the end-user partners, i.e. the non-deterministic results will be considered in the decision process.

As shown in [8], the results of the design process are dependent on the method chosen to manage the identified and quantified uncertainties. This shows that the transfer of knowledge must contain also a reverse action. An important feed-back is expected from the end-users towards the developers on the appropriateness of a specific uncertainty propagation method with respect with a range of applications, flaws of the non-deterministic methodologies to be corrected and suggestions of improvement.

The last objective aims realizing an external dissemination of the knowledge acquired during the project through standard channels: academic and application oriented publications, presentations in conferences, congresses and symposiums. Specific dissemination actions oriented to research and industrial organisation are also planned. Most of them will be dedicated presentations and demonstrations on representative case studies by partners. Finally, actions towards exploitation will be taken and few of the expected results expressed by partners are given hereafter:

- generic uncertainty analysis tools to be incorporated in industrial design systems
- application of probabilistic methods to CFD modelling
- integration of the uncertainty analysis tools in a Knowledge Based System

4.0 CONCLUSIONS AND FUTURE WORK

The paper has given an overview of the scientific and technological objectives of the NODESIM-CFD project. The tasks and lines of actions foreseen to achieve the proposed objectives have been detailed. Few of the tasks have been accomplished as the identification and quantification of different classes of uncertainties. Examples of software tools used to fit distributions over experimental ones or to construct beta pdf based on expert opinion have been emphasized.

Based on this critical information related to the classes of uncertainties, non-deterministic methodologies have been identified as most suitable and are under development. Preliminary results are contained in the NODESIM-CFD partners' contributions [1, 3, 4, 8, 10, 15, 16, 17, 19] while other tasks are in progress, the development of computationally efficient software modules and their validation particularly.

For the time being, studies have been conducted in assessing the effects induced by the mesh error or the error due to added artificial dissipation in numerical scheme on relevant outputs as lift and drag. Also, intensive efforts are directed to the efficient handling of the geometrical uncertainties.

Future work will be focused on the validation process of the non-deterministic methodologies. This process will allow identifying the appropriate methodologies for each range of applications and consequently will help the end-user partners to choose in a rational way which methodology, embedded in a software module, to be transferred in their design systems. This transfer will be a first step towards applying non-deterministic methodologies to industrial applications.

Finally, it is believed by NODESIM-CFD partners that the outcome of this project will contribute, next to other similar efforts, to the emergence of a new paradigm for CFD based simulations, which purposely considers the management of uncertainties as part of the simulation process. These preliminary results sustain the critical importance of including non-deterministic CFD methodologies in the design optimization systems in order to manage the operational, geometrical and numerical uncertainties but also show that important efforts are still necessary to do it in a computationally efficient way.

As a by-product, this new paradigm could also trigger a conceptual improvement of the nowadays efforts necessary to arrive to international accepted standards for V&V. Next to these efforts for building databases, providing guidelines and best practice advices which lead to establishing confidence limits, the knowledge to be gained from using non-deterministic simulation tools could help refining these limits. Such refinement would be possible due to the capability of the non-deterministic methodologies to integrate the influences of the present uncertainties in complex systems as the fluid-thermal-mechanical systems met in aeronautical industry.

Acknowledgement

This work was supported by the project NODESIM-CFD "Non-Deterministic Simulation for CFD-based Design Methodologies" funded by the European Community represented by CEC, Research Directorate-General, in the 6th Framework Program, under Contract No. AST-CT-2006-030959.

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