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Hypersonic Flows for Reentry Problems

Vol.1

J.-A. Désidéri R. Glowinski J. Périaux (Eds.)

Hypersonic Flows for Reentry Problems

Volume I:
Survey Lectures and Test Cases for Analysis

Proceedings of a Workshop
Held in Antibes, France, 22–25 January 1990

With 114 Figures

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Preface

One of the most challenging problems of modern engineering is undoubtedly the prediction of hypersonic flows around space vehicles in reentry conditions. Indeed, the difficulties are numerous: first of all, these flows are very difficult to model, since very complex physical and chemical phenomena take place during the reentry phase; secondly, temperature, velocity and enthalpy are very high and densities are very low, making the reentry process very difficult to reproduce in ground-based experiments.

The past three decades have seen important efforts in computational fluid dynamics relying on the use of supercomputers to simulate these very complicated flows. The numerical simulation based on imperfect models and methods which were essentially designed for transonic and supersonic flows has still a long way to go in order to be able to predict these hypersonic reentry flows very accurately.

This situation has motivated very strong international cooperative efforts with, as the most visible consequences, the Europe/United States Short Courses on Hypersonics, which were held in Paris, in 1987 [1,2], Colorado Springs in 1989 [3], and Aachen in 1990 [3].

The workshop on Hypersonics whose results are presented and analysed in these volumes is also a direct consequence of this international cooperation. This scientific event was an initiative of P. Perrier, Head of the Theoretical Aerodynamics Department of DASSAULT AVIATION, who played a key role in the identification of the critical problems and the realisation of experiments, within the Hermès R&D program framework.

During this workshop, which took place in Antibes, France, in January 1990, about 200 engineers and scientists from Europe, the United States, Japan and Australia presented results associated with the solution of 8 test problems. These 8 problems were carefully selected by an International Committee as representative of real life difficulties existing during the reentry of space vehicles, such as the European Hermès and the US Orbiter.

Actually, during the workshop, the technical presentations of the test problem results were completed by 10 invited lectures given by leading scientists on topics related to modeling, experimental aspects and numerical simulations of hypersonic flows.

Volume 1 contains the invited lectures and descriptions of the test problems. Volume 2 is in a sense more technology oriented. For each problem a synthesis of the results obtained by the various workshop participants is followed by the presentation of the experimental and computational contributions.

The preparation of this workshop and of the proceedings has been quite a formidable task.

We would like to express our particular thanks to R. Abgrall, A. Dervieux, M. Mallet and B. Stoufflet for their continuous and friendly scientific assistance in the preparation and the development of the workshop and the realisation of these volumes.

The development of the workshop was a success due to the very close cooperation of the following people whose talents cover very large and impressive spectra in science and engineering, organization and management, and last but not least, fund raising abilities among others:

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The organizers would like to acknowledge the quality of the invited and contributed presentations and also the Chairmen of the various sessions and of the Evaluation Committee since they did an outstanding job under considerable pressure to keep the workshop on schedule.

The organizers would like to address their warmest thanks to those institutions and companies that have supported the workshop, namely AGARD, CIRA, CNES, CRAY, DASSAULT AVIATION, ESA.

Special thanks are due to the Service des Relations Extérieures of INRIA, which masterminded a more than pleasant week on the French Riviera that most participants enjoyed tremendously, for its help and assistance in the preparation of the workshop.

The editors would like to thank Springer-Verlag and more particularly Professor W. Beiglböck for kindly agreeing to publish these highly specialized proceedings.

Last, but not least, the editors would like to acknowledge Sabine Landgraf and Sylviane Gosset for their help and patience with us during the processing of the full manuscript.

We hope that you, the reader, will find these volumes a classic reference that will be used frequently in the years to come.

December 1990

Jean-Antoine Désidéri, INRIA Sophia Antipolis and GAMNI/SMAI
Roland Glowinski, University of Houston and INRIA
Jacques Périaux, Dassault Aviation and GAMNI/SMAI.

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[3] J. Ballmann, J.J. Bertin, J. Périaux, Editors, Proceedings of the Second and Third Joint Europe/US Short Courses in Hypersonics, Colorado Springs, USA, January 16–20, 1989, and Aachen, Germany, October 1–5, 1990, Progress in Scientific Computing, Birkhäuser Boston, to appear.

Contents

Problems for Analysis

INTRODUCTION

When advanced hypersonic projects came to existence in Europe, mainly with the HERMES proposal, it was obvious that technological and scientific levels had to be enhanced. The availability of sufficient knowledge in hypersonic is mandatory before any realistic time schedule for development can be ascertained. Low cost in development relies now on a numerical simulation - experimental test and flight test progressive methodology : use of a mix of the best of each method as soon as possible is a key to success of advanced aerospace programs.

The past efforts made in the sixties in Europe and U.S. and more recent work on U.S. side, for Shuttle Orbiter design, do not seem sufficient for giving confidence in design of advanced reentry vehicles. Significant improvements in experiments in physical and chemical sciences have been accomplished recently ; but moreover the general methodology of design has to take into account the major role played now by CFD in new project design ; quality of CFD evidently relies on correctness in physical and chemical modelling as well as on the numerical modelling of the PDE problem to be solved. The rational approach of modelling with computer codes embodies capabilities of rebuilding complex flows impossible to be rebuilt in ground test facilities ; but it needs to be comforted by an elementary experimental validation on a limited number of basic models. It is clear that such effort has not been pushed in the past ; validation is now recognized as a necessary step in the evaluation of level of technology, therefore it is a part of any feasibility study of new hypersonic projects.

Thanks to CNES and ESA some support to the necessary effort in experimental and theoretical work has been brought in Europe as part of the HERMES project preliminary studies; it has been very useful for all

the research or industrial community working on hypersonic. The success of HERMES Research for Development (RfD) program, covering large number of scientific organizations in Europe encouraged after 3 years an attempt to a confrontation of the computation and experiments on carefully selected problems.

Opening such a confrontation to all world scientists would allow a more general evaluation of the uncertainties in CFD rebuilding of the physics and help to define guidelines for future work.

A Scientific Committee has selected a few number of problems of gradual difficulties. Schematic problems were retained ; they are basically helpful to check quality of flow rebuilding from scientific and industrial points of view. Moreover selection of basic problems helps to better evaluate it in an open international context.

In January 1990, the first international workshop on hypersonic flows for reentry vehicles was a successful event by the number of participants and many encouraging results ; unequal difficulties were encountered by participants in the tests cases. It proves the achievements done in CFD as well as the large improvement remaining to be done. Reference tests cases have proven their pertinence by stressing a lot of unsolved or poorly solved problems with existing computers ; some evidence of the origin of the problems encountered are either in numerical scheme, or on discretization and also on physical relevant modelling.

The material collected in this book takes advantage of revision of many contributions after the workshop, first theory vs experiment confrontation, has taken place ; some additional contributions appeared after this event but were retained due to their added value. However it appears that better results could be obtained with more regular or on more refined meshes on the selected cases. Consequently a Part II Workshop will take place in 1991 and will complement the work presented here.

The workshop was made possible by the active cooperation of CNES-ESA through DASSAULT AVIATION, INRIA and GAMNI/SMAI. It would have been difficult to exploit all the material selected before the

event presented in sessions without the help of all the Members of Scientific Reviewing Committee and and the chairmen of the sessions . Preliminary synthesis done for the final session of the workshop have been carefully revisited with last materials and are presented before the experimental-numerical comparisons. Some gratitude has to be expressed to the authors of the synthesis as well as to the authors of contributions.

Particular thanks are due to Doctor J.PERIAUX of DASSAULT AVIATION and Doctor J.A. DESIDERI, INRIA who help to materialize the target of the workshop and of these proceedings in cooperation with the authors , session chairmen and participants : all contributed to the success of the Workshop.

INVITED LECTURES

Workshop on Hypersonic flows for reentry problems
January 22 - 25th 1990 (Antibes)

Inaugural Address
J. CARPENTIER

Before introducing the subject of this workshop, I would like to congratulate INRIA and GAMNI-SMAI for their joint organization of this event. The purpose of this workshop is to bring together experts actively working in Hypersonics and to ask them to discuss about the knowledge of flows at high Mach numbers and large angles of attack.

This initiative is particularly appropriate in the perspective of new European and American space projects.

Before discussing the specific field of Hypersonics, it is worth considering the ways of progress concerning aerodynamics, in general.

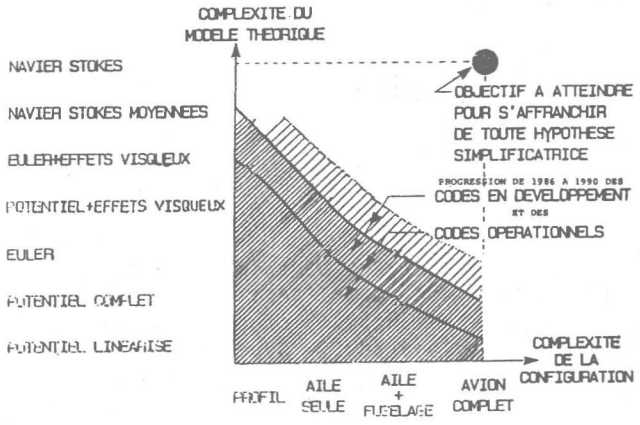
The exploration of the high speed flights began with a joint approach between wind tunnel tests and experimental vehicles (viewgraph 1). This joint approach has been very sccessful. Among the many examples of these success, we can quote, in the States, the supersonic flights of the Bell X1 in 1947 and the hypersonic flights of the North American X15 which attained M6 in 1961. In Europe also, each aeronautical nation led and experimental investigation, more or less tightened to the realization of prototypes. Among the forerunners, we could mention the Dassault OURAGAN and the Nord-Aviation Griffon. This

Introduction to the workshop

J. CARPENTIER

* *Wind Tunnel Limitations*
* *Experimental Vehicles*
* *Computational Fluid Dynamics*
* *The necessity of a joint approach :*
  - *CFD*
  - *Ground experimentation*
  - *Flight experimentation*
* *Conclusions.*

LIMITE DES POSSIBILITES DE TRAITEMENT



one was a turboramjet aircraft, and with this new type of engine, the Griffon attained M2,2 in 1957 (climbing). An ONERA experimental missile, STATALTEX powered by ramjet flew at M5 (38.000 m) in 1962.

But the apparition of numerical computers has completely renewed the possibility of computation.

For instance, this chart (viewgraph 2) shows the progress of Computational Fluid Dynamics for the determination of the flow in the subsonic field on the X axis is presented the configuration complexity. The simplest is an airfoil which needs only 2D computations. The most complex is a complete aircraft.

On the Y axis, you can see different computation methods from the simplest potential methods to the complete Navier-Stokes method.

It is possible to calculate the flow around an aircraft with the simplest method. It is also possible to calculate the flow around an airfoil with a complex method. But this is not the case for a complete aircraft.

The limit of the domain covered by CFD for subsonic flow is moving from year to year. You can see here the progress from 1986 till now.

But the ultimate target is not to-morrow.

And it's the same if not worst for higher speeds and especially for hypersonics where we have to take account of reacting flows.