

# Lecture Notes in Mathematics

Edited by A. Dold and B. Eckmann

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## Approximation Methods for Navier-Stokes Problems

Proceedings, Paderborn, Germany 1979

Edited by R. Rautmann



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## Approximation Methods for Navier-Stokes Problems

Proceedings of the Symposium Held by the  
International Union of Theoretical and  
Applied Mechanics (IUTAM)  
at the University of Paderborn, Germany,  
September 9 – 15, 1979

Edited by R. Rautmann

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Extract from a speech after the Conference dinner

I am sure you will all have noticed the remarkable emblem of Paderborn which is reproduced on our Conference programmes: this depicts three hares, each having two ears, but each ear being shared between two hares. Each hare is moreover in pursuit of the tail of the hare in front, an activity that appears to be both futile and painful on account of the centrifugal forces sustained by the ears! And yet we at this meeting are not unlike these three hares - we represent three different approaches to problems of fluid mechanics - existential, numerical and asymptotic - and we have a natural tendency to drift apart into areas which yield most easily to our respective techniques. At this meeting, through listening to each other, we have been drawn back by our ears to some of the hard-core problems concealed in the Navier-Stokes equations, which lie at the centre of the circle of pursuit. The local organizing committee deserves our thanks, not only for the warmth of their hospitality here in Paderborn, but also for the success in drawing these three groups together to promote the stimulating cross-fertilisation of ideas from which we have all so greatly benefited. The triangular pursuit of the hares of Paderborn is perhaps more fruitful and rewarding than might at first be supposed!

H.K. Moffatt.

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## PREFACE

Recently Navier-Stokes problems have found growing interest:

- Hilbertspace methods (or more general function-space approaches) in connection with embedding theorems open new ways to existence and regularity theory and lead to new theorems on (non-)uniqueness, asymptotical decay and constructive approximation of the solutions.
- Semigroup methods result in existence and regularity theorems in the framework of different function-spaces.
- Group theoretic methods provide us with a systematic approach to bifurcation.
- Bifurcation methods lead to a new theory of hydrodynamic stability.
- Dynamical systems offer geometric models for the unfolding in time of Navier-Stokes solutions and for the transition to turbulence.
- Refined potential theoretic approaches enable us to asymptotically describe flows behind obstacles and flows in regions having non-compact boundaries.
- Refined finite element methods (including error-estimates), difference methods (satisfying suitable stability conditions), spectral methods and fast Stokes solvers result in numerical solutions of flow problems in complicated two-dimensional and even in three-dimensional geometries.
- Refined modeling ideas of flows, e.g. at high Reynolds numbers, lead again to new formulations of promising mathematical questions.

The exchange of ideas about these new aspects and approximations was the aim of the Symposium on "Approximation Methods for Navier-Stokes Problems", which the International Union of Theoretical and Applied Mechanics (IUTAM) held in the Department of Mathematics, University of Paderborn, September 9-15, 1979.

More than 70 German or foreign mathematicians, fluid dynamicists and numerical analysts took part. Thirty-five invited lectures, additional short communications and a round-table discussion on present-day research trends gave a vivid insight into the state of the art and led to stimulating interdisciplinary contacts. The discussions demonstrated lively interaction among the different working areas in the common interest field of the Navier-Stokes equations. Therefore the following papers submitted by the invited lecturers purposely had not been grouped into special areas. The many-faceted cross-connections which, according to the unanimous opinion of the participants, became evident during the symposium could thus be best maintained.-

I would like to thank the members of the Scientific Committee very cordially for the good cooperation in preparing and conducting the meeting. Special thanks should be given to the colleagues and co-workers in the Department of Mathematics at the University of Paderborn. Without their help this Symposium would not have been possible. Thanks should also be given to all participants who contributed to the success of the Symposium! Also I would like to thank the editors of the *Lecture Notes in Mathematics* and the *Springer-Verlag* for their friendly assistance during the planning stages and the speedious completion of this volume.

R. Rautmann

## VORWORT

Navier-Stokes-Probleme haben in den letzten Jahren wachsendes Interesse gefunden:

- Hilbertraum-Methoden (oder Ansätze in allgemeineren Funktionenräumen) zusammen mit Einbettungssätzen eröffnen neue Zugänge zur Existenz- und Regularitätstheorie und führen zu neuen Sätzen über (Nicht-) Eindeutigkeit, asymptotisches Verhalten und konstruktive Approximierbarkeit von Lösungen.
- Halbgruppenmethoden ergeben neue Existenz- und Regularitätssätze in unterschiedlichen Funktionenräumen.
- Gruppentheoretische Methoden ermöglichen die systematische Behandlung von Verzweigungsproblemen.
- Bifurkationsmethoden führen zu einer neuen Theorie der hydrodynamischen Stabilität.
- Dynamische Systeme bieten geometrische Modelle der zeitlichen Entwicklung Navier-Stokes'scher Lösungen und des Übergangs in Turbulenz.
- Verfeinerte potentialtheoretische Methoden ermöglichen die asymptotische Beschreibung von Strömungen im Nachlauf von Körpern und in Gebieten mit nichtkompakten Rändern.
- Verfeinerte finite Elemente-Verfahren (mit Fehlerabschätzungen), Differenzenverfahren (mit entsprechenden Stabilitätsbedingungen), Spektralmethoden und schnelle Stokes-Solver ermöglichen die numerische Lösung komplizierter zweidimensionaler Strömungsaufgaben und grundsätzlich auch schon dreidimensionaler Probleme.
- Verfeinerte Modellvorstellungen von Strömungen, wie z.B. bei hohen Reynoldszahlen, führen ihrerseits zu neuen und vielversprechenden mathematischen Fragestellungen.

Dem Gedankenaustausch über diese vielfältigen neuen Aspekte und Approximationen diene das Symposium über "Approximationsmethoden für Navier-Stokes-Probleme", das von der Internationalen Union für Theoretische und Angewandte Mechanik (IUTAM) vom 9. bis 15. September 1979 im Fachbereich Mathematik der Gesamthochschule Paderborn veranstaltet wurde. Am Symposium nahmen mehr als 70 deutsche und ausländische Mathematiker sowie Fachleute der Strömungslehre und ihrer numerischen Methoden teil. 35 eingeladene Vorträge, zusätzliche Kurzvorträge und ein Rundgespräch über aktuelle Forschungsrichtungen vermittelten einen lebendigen Einblick in den derzeitigen Wissensstand und führten zu anregenden interdisziplinären Kontakten.

Die fachlichen Gespräche zeigten die rege Wechselwirkung zwischen den verschiedenen Arbeitsrichtungen im gemeinsamen Gebiet der Navier-Stokesschen Gleichungen. Bewußt sind daher die folgenden Beiträge der eingeladenen Referenten nicht nach Spezialgebieten gruppiert worden. Die vielfältigen Querverbindungen, die sich nach der wohl einhelligen Meinung der Tagungsteilnehmer ergeben haben, dürften so am besten zum Ausdruck kommen.



Den Mitgliedern des Wissenschaftlichen Komitees möchte ich sehr herzlich für die gute Zusammenarbeit bei der Vorbereitung und Durchführung der Tagung danken. Ein besonderer Dank gilt den Kollegen, Mitarbeiterinnen und Mitarbeitern im Paderborner Fachbereich Mathematik, ohne deren Hilfe die Tagung nicht hätte durchgeführt werden können. Gedankt sei auch allen Tagungsteilnehmern, die zum Gelingen des Symposiums beigetragen haben! Besonders möchte ich auch den Herausgebern der *Lecture Notes in Mathematics* und dem Springer-Verlag für das freundliche Entgegenkommen bei der Vorbereitung und für die schnelle Fertigstellung dieses Bandes danken.

R. Rautmann

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