

Flow Control of Near-Wall Turbulence

Strömungskontrolle wandnaher Turbulenz

Der Technischen Fakultät der
Friedrich-Alexander-Universität Erlangen-Nürnberg

zur Erlangung des Grades

D O K T O R - I N G E N I E U R

vorgelegt von

Bettina Maria Frohnäpfel

Erlangen, 2006

Als Dissertation genehmigt von der
Technischen Fakultät der
Universität Erlangen-Nürnberg

Tag der Einreichung: 19.12.2006

Tag der Promotion: 30.03.2007

Dekan: Prof. Dr. A. Leipertz

Berichterstatter: Prof. Dr. Dr. h.c. F. Durst

Prof. Dr. T.B. Gatski

Priv.-Doz. Dr. J. Jovanović

Berichte aus der Strömungstechnik

Bettina Maria Frohnapfel

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D 29 (Diss. Universität Erlangen-Nürnberg)

Shaker Verlag
Aachen 2007

Bibliographic information published by the Deutsche Nationalbibliothek

The Deutsche Nationalbibliothek lists this publication in the Deutsche Nationalbibliografie; detailed bibliographic data are available in the Internet at <http://dnb.d-nb.de>.

Zugl.: Erlangen-Nürnberg, Univ., Diss., 2007

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Printed in Germany.

ISBN 978-3-8322-6353-9

ISSN 0945-2230

Shaker Verlag GmbH • P.O. BOX 101818 • D-52018 Aachen

Phone: 0049/2407/9596-0 • Telefax: 0049/2407/9596-9

Internet: www.shaker.de • e-mail: info@shaker.de

Abstract

The present work aims at providing further understanding of the mechanism of turbulent drag reduction (DR). Based on analytical considerations about how turbulence needs to be modified in order to reduce the momentum loss towards solid walls and to yield lower energy losses, a mechanism of turbulent DR is proposed. This mechanism suggests that drag reducing flow control at high Reynolds numbers should be designed to minimize the turbulent dissipation rate at the wall. A review and analysis of existing DNS databases for which DR has been reported shows that the proposed DR mechanism is commonly found. Based on the obtained knowledge a tentative surface structure with grooves aligned in the flow direction is suggested for flow control of near-wall turbulence. A hydraulic model is presented that allows an estimate of the expected wall shear stress reduction which can be converted to DR.

The grooved surface structure is tested both numerically (in collaboration with Dr. Peter Lammers from HLRS Stuttgart) and experimentally. The numerical simulations are carried out for grooves which scale with the thickness of the viscous sublayer. The results obtained show significant DR - based on the wall shear stress reduction - and are in excellent agreement with the hydraulic model predictions. Experimentally, the pressure drop in a channel with grooved surfaces is compared with the one in a smooth channel. It is found that a significant reduction in pressure drop is only obtained for grooves in the order of one viscous length scale, which corresponds to half the Kolmogorov scale. The careful analysis of these results reveals that wall shear stress and pressure drop might lead to different findings when extremely small secondary motions are involved.

Based on the presented analysis it is concluded that drag-reducing techniques that are to be applied at high Reynolds number should be designed to minimize the turbulent dissipation rate at the wall but also to minimize secondary motion. Furthermore, the results obtained suggest that testing of DR techniques has to be done with great care when spanwise variations are involved. The reason for that is the possible appearance of secondary motions which might (partially) consume what is gained by wall shear stress reduction. Finally, the present work shows that flow control does not necessarily have to focus on large-scale coherent structures, as most current research efforts do, but can be achieved by influencing the smallest scales of the turbulent motion.

Acknowledgments

This work received financial support from the Deutsche Forschungsgemeinschaft under grant number Jo240/3-2 and Jo240/5-1, which is gratefully acknowledged.

I would like to especially thank my supervisor Prof. Dr. Dr. h.c. F. Durst. He has first quickened my interest in fluid mechanics and his encouragement to attend one of the Summer Academies in the field of fluid mechanics has brought me into contact with the fascinating subject of turbulence. As the head of the Institute of Fluid Mechanics (LSTM-Erlangen) he has enabled me to work in the field of turbulence research and has constantly supported the present work.

Furthermore, I would like to thank Prof. T.B. Gatski, currently at the Laboratoire d'Etudes Aérodynamique, Université de Poitiers in France, for his acceptance to review this work. It is an honor to have such a well-known expert in the field of turbulence research as a reviewer of my doctoral thesis.

The guidance and experience of the head of the turbulence research group and my co-supervisor at LSTM-Erlangen, Dr. J. Jovanovic, has laid the basis for this work. I would like to express my deep gratitude to him for his constant support, encouragement and inspiration.

All numerical parts of this work have been obtained in close collaboration with Dr. Peter Lammers of the High Performance Computer Center in Stuttgart (HLRS). I wish to express my sincere thankfulness towards him. This collaboration between Erlangen and Stuttgart has been very fruitful and I hope that it will be continued in the future.

Moreover, I would like to thank all colleagues at LSTM-Erlangen. The nice working atmosphere and the support of co-workers and students, the workshop and the administration have made this work possible.

Schließlich möchte ich mich ganz herzlich bei meinen Eltern bedanken, die mir durch Ihre Unterstützung und Förderung die akademische Laufbahn ermöglicht haben.

Erlangen, May 2007

Bettina Frohnapfel

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