Advances in Turbulence X
Proceedings of the Tenth European Turbulence Conference
H. I. Andersson & P.-Å. Krogstad (Eds.)

The Effect of Compressibility in Turbulence Models

S. Heinz[1], H. Foysi[2]
[1]Fachgebiet Strömungsmechanik
Technische Universität München, D-85747 Garching, Germany.
Contact address: *heinz@flm.mw.tum.de*

1 Introduction

Calculations of compressible turbulent reacting flows are relevant to many technological developments. The best way to address problems of practical relevance is to apply Reynolds-averaged Navier-Stokes (RANS) equations combined with scalar probability density function (PDF) equations for reacting flows ([1],[2]). With regard to the modeling of incompressible flows, the performance of RANS / PDF methods is relatively well investigated: there exist sufficient data to assess their characteristic advantages and disadvantages. However, the suitability of RANS / PDF methods for simulations of compressible flows is much less investigated because of the sparse data which are available for that. Due to the relevance to predictions of compressible reacting flows, this question will be addressed by analyzing the structure of a $k - \omega$ turbulence model in terms of recently obtained direct numerical simulation (DNS) data of supersonic channel flow ([3],[4]). Two specific questions that will be addressed in this way are: Are currently applied standard models for the production of the turbulence frequency ω supported by DNS data? Does compressibility have a significant effect on the production of turbulence ([5],[6])?

2 Direct numerical simulation

Three simulations of compressible channel flow, labeled as IL ($Re_\tau = 180$, $M = 0.3$), CL ($Re_\tau = 555$, $M = 3$) and CH ($Re_\tau = 1030$, $M = 3.5$) are presented in this paper. The flow is driven by a uniform body force, both channel walls are cooled and kept isothermal so that there is heat transfer out of the channel allowing supersonic fully-developed flow. No-slip conditions are applied for the velocity field at the walls, and periodic boundary conditions are used in stream- and spanwise directions. Passive scalar transport is considered in such a way that a scalar is injected at the lower wall and removed at the upper wall (for further details refer to [3-4]). The comparison of IL with CL and CL with CH data allows the assessment of Mach and Reynolds number effects, respectively, as can be seen by looking at the flow characteristics which are presented in Fig. 1.

3 $k-\omega$ analysis of DNS and turbulence model development

In a first step, the DNS data were considered within the frame of a standard $k-\omega$ model. This means, the DNS data for the mean mass density, velocity, temperature, mass fraction, turbulent kinetic energy and turbulence frequency were inserted into the $k-\omega$ model, which provides the DNS data for model parameters which are given in Fig. 2. Such a $k-\omega$ analysis of DNS data represents a way to assess Reynolds and Mach number effects in terms of standardized turbulent transport efficiencies (the parameters of the turbulence model). As may be seen by means of Fig. 2, the intrinsic compressibility effects at these low Mach numbers in supersonic channel flow are relatively small. The Reynolds number on the other hand has a significant influence.

In a second step, the DNS data for the model parameters (see Fig. 2) were used for the parametrization of these parameters, a requirement needed for the development of turbulence models. This resulted in the fact that currently applied parametrizations of C_μ (the coefficient of the turbulence viscosity) and standardized production S_ω of ω are not supported by DNS data for the flow considered. Thus, new models for these quantities were developed and used in applications of the $k-\omega$ model, which were performed by means of the FLUENT code [7]. The comparison of these simulation data with DNS demonstrates the good performance of the new models.

References

[1] Pope, S.B., 2000, *Turbulent Flows*, Cambridge University Press, Cambridge

[2] Heinz, S., 2003, *Statistical Mechanics of Turbulent Flows*, Springer-Verlag, Berlin, Heidelberg, New York

[3] Foysi H. Friedrich, R., 2003, DNS of Passive Scalar Transport in Turbulent Supersonic Channel Flow, Proc. 3rd Int. Symp. Turbulence and Shear Flow Phenomena, Sendai, Japan, June 25-27, 1121-1126

[4] Foysi, H., Sarkar, S., Friedrich, R., 2003, On Reynolds Stress Anisotropy in Compressible Channel Flow, Proc. 3rd Int. Symp. Turbulence and Shear Flow Phenomena, Sendai, Japan, June 25-27, 1103-1108

[5] Sarkar, S., 1995, The Stabilizing Effect of Compressibility in Turbulent Shear Flow, *J. Fluid Mech.* 282, 163-186

[6] Heinz, S., 2003, A Model for the Reduction of the Turbulent Energy Redistribution by Compressibility, *Phys. Fluids* 15, 3580-3583

[7] FLUENT Inc., 2003, *FLUENT 6.1 User's Guide*, Lebanon, New Hampshire, USA

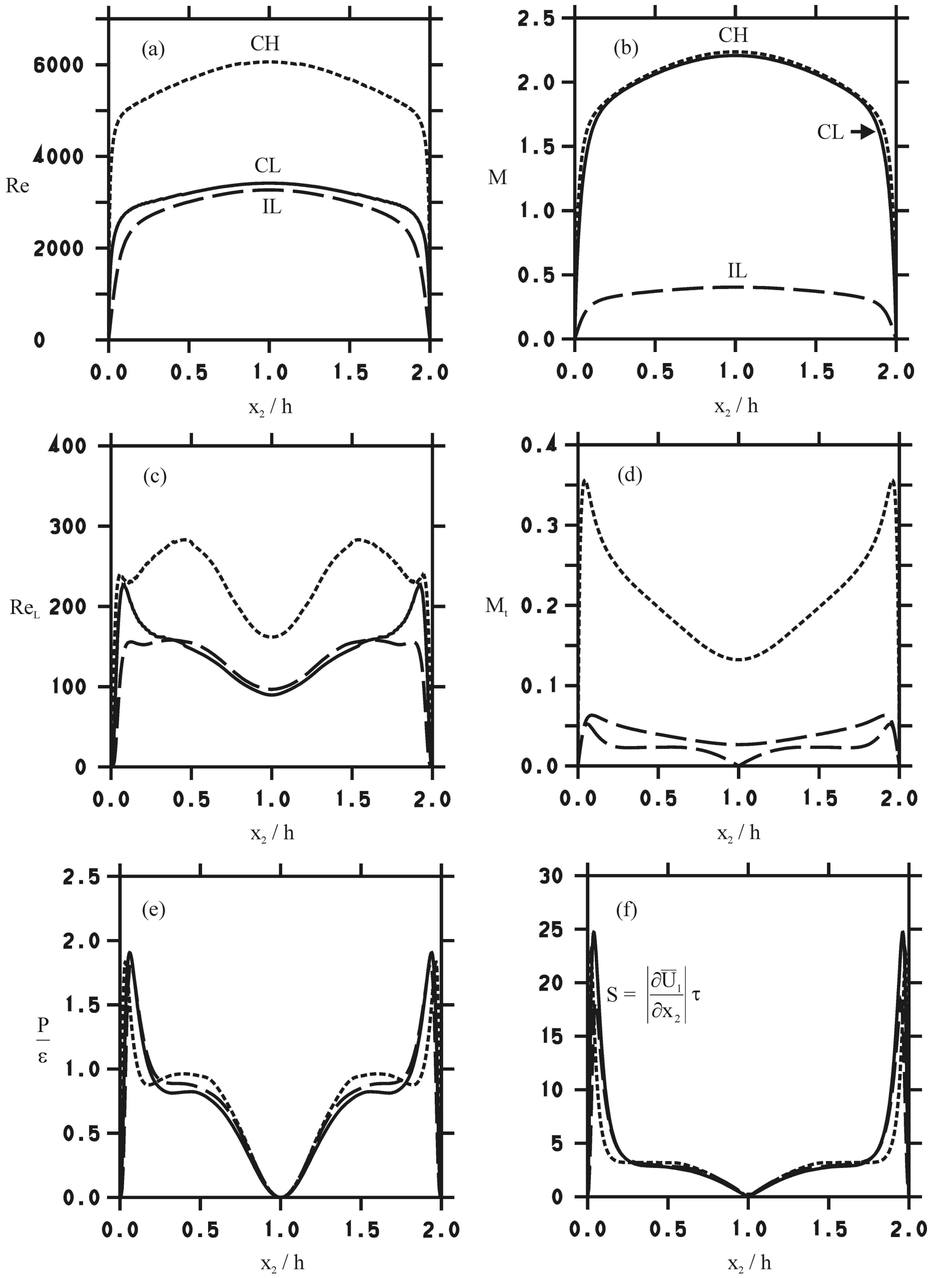

Figure 1: DNS data for the local Reynolds numbers Re, Mach numbers M, turbulence Reynolds Re_L and Mach numbers M_t, the production-to-dissipation ratio P/ϵ of k and time scale ratio S. The line coding is given in (a) and (b).

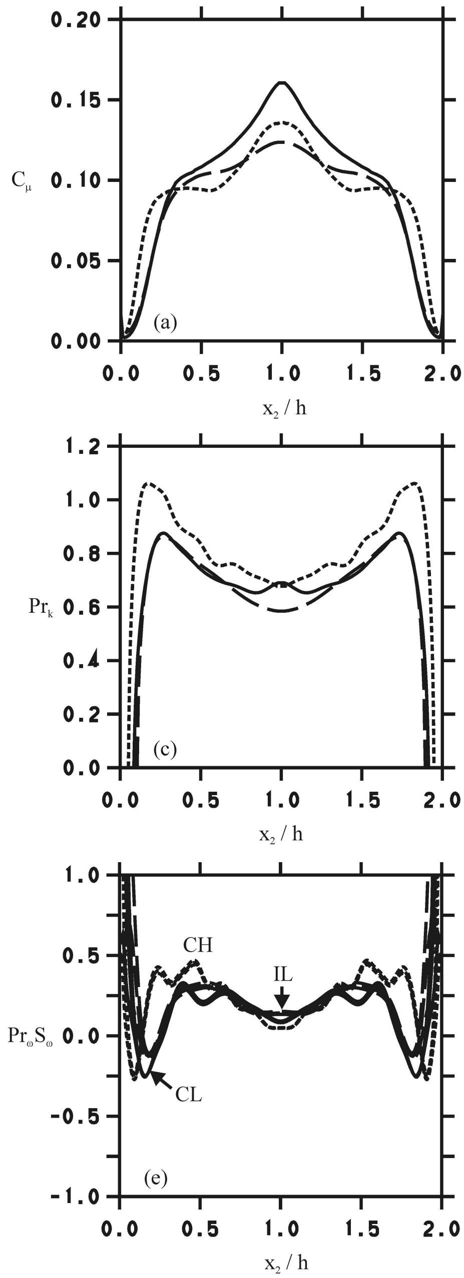

Figure 2: DNS data for turbulence model parameters. C_μ is used to parametrize the turbulence viscosity, Sc_t is the turbulent Schmidt number, Pr_k, Pr_t and Pr_ω are turbulence Prandtl numbers, and S_ω is the standardized production of ω.