Compressible Fluid Flow through Narrow Channels

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study field: Thermomechanics and Fluid Mechanics

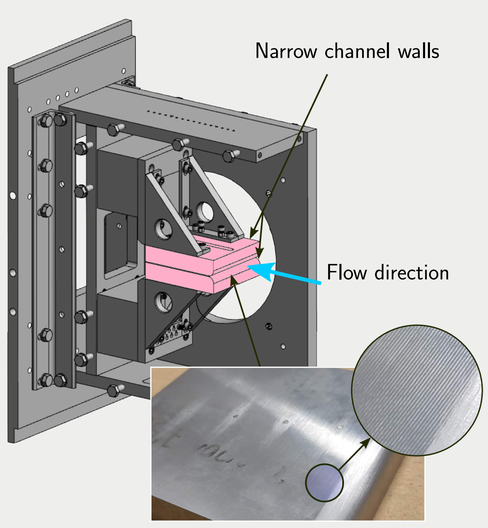
Motivation

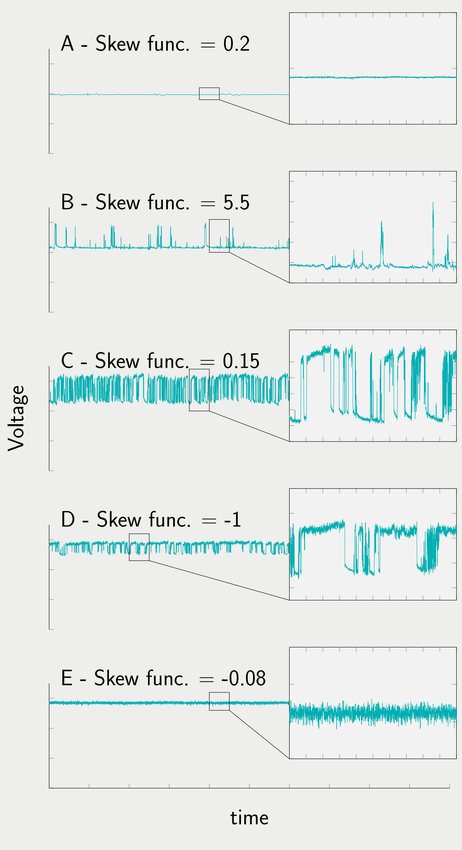
The turbulence transition in pipe and channel flow represents up to now an important topic, since it is the nature of the flow, which substantially affects the friction and associated losses. With increasing miniaturization and more detailed numerical simulations of the various small flow parts of the turbomachines, the need for experimental data is still there to explore the narrow channel flow phenomena and to validate numerical codes.
The thesis presents the results of the project which aimed to experimentally and numerically explore the compressible viscous flow in narrow channels of the rectangular cross-section of the high aspect ratio. Main objectives of this work were to explore the nature of the flow in such channels using a number of experimental methods including hot-film probe, explore the influence of two types of surface roughness and discuss the effects associated with the phenomenon of aerodynamic choking due to friction.

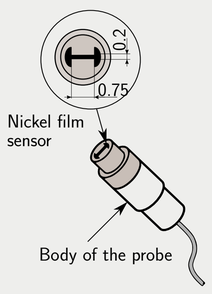
Objectives of the Thesis

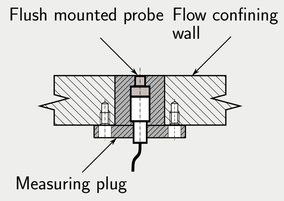
1) To determine what is the nature of the flow in the investigated channels using the available measurement techniques, including hot-film anemometry, and numerical simulations. And to describe the influence of the two different types of surface roughness on the flow development and possible transition to turbulence.
2) To explore whether the critical conditions separates from the sonic conditions due to effects of friction under the conditions of aerodynamic choking.
3) To determine whether the boundary layer might get thinner and the shear stress reduced in the region close to the channel exit.

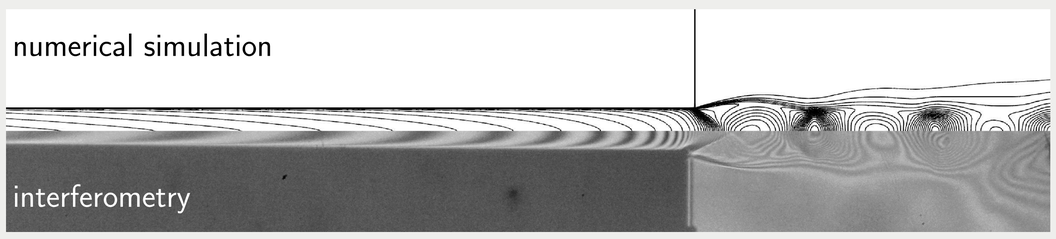
Objective # 1

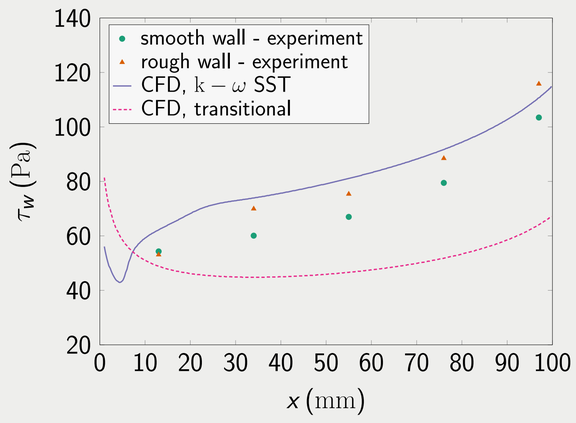


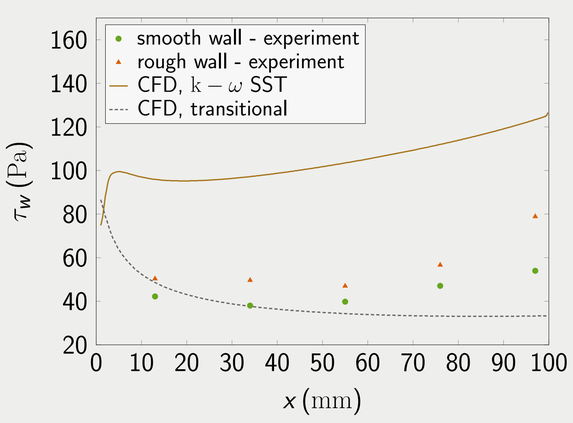






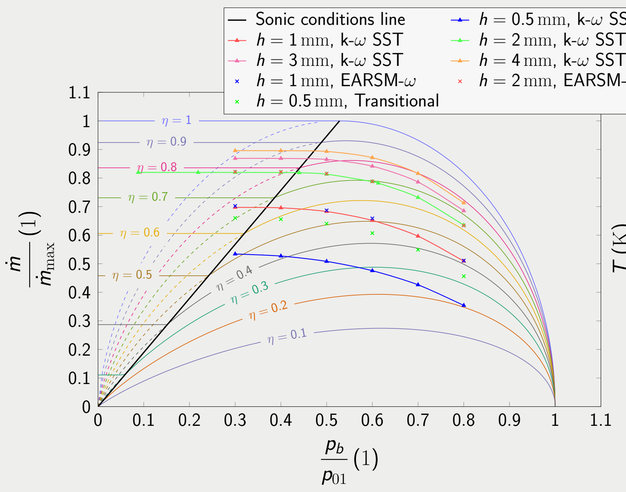




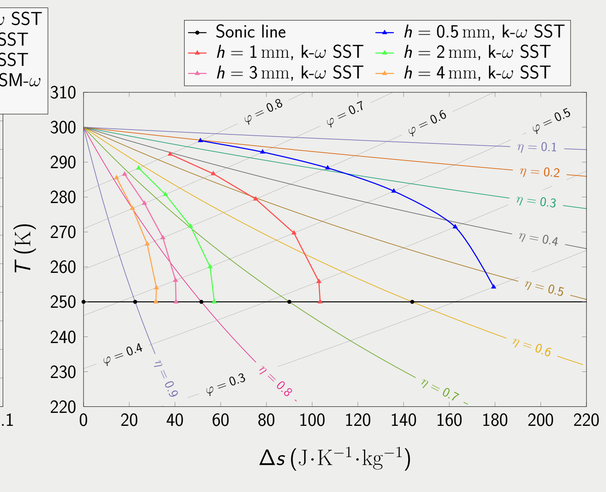


Design of experiment enabling the use of hot-film probe for both qualitative and quantitative measurements. Comparison with numerical simulations and other measurement methods including interferometry.

Objective # 2



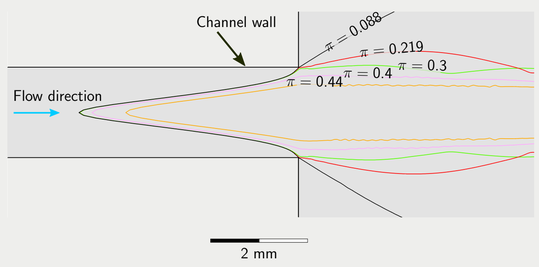
Discharge diagram with the computed expansion curves for various channel heights using different turbulence models.



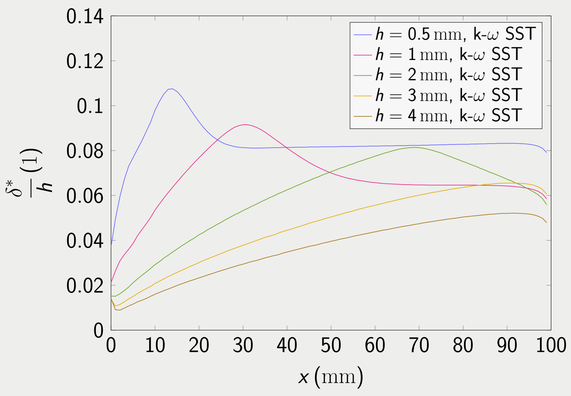
Narrow channel expansion curves for various channel heights drawn in $T - \Delta s$ diagram together with lines of constant efficiency η and lines of constant exit pressure ratio φ.

Theoretical and numerical analyses of flow choking summarized in charts.

Objective # 3



Sonic lines computed using $\mathrm{k} - \omega$ SST turbulence model in the exit part of the narrow channel of the height of $2\,\mathrm{mm}$ for various pressure ratios π.



Normalised displacement thickness $\frac{\delta^*}{h}$ along the channel for various channel heights and pressure ratio $\pi = 0.3$ as computed using k-ω SST turbulence model.

Numerical study of the flow conditions close to channel outlet and boundary layer thickness along the channel.

Conclusions

It was observed that despite the channel length to channel height ratio ranging from 50 to 200, the flow was mostly transitional except the flow in the smallest channel of the height $h = 0.5\,\mathrm{mm}$. The effects of the surface roughness were explored using both qualitative and quantitative measurements by means of hot-film probe. The later provided distribution of the wall shear stress at five locations along the channel for two chosen regimes. Further, the analysis revealed inapplicability of the one-dimensional theory for the estimation of the friction factor. The theoretical analysis of the flow choking supported by numerical simulations shows that due to frictional losses, the actual choking is shifted towards the lower back pressure ratios. These findings were summarized in charts, which comprehensively illustrate derived relations.

List of Publications

A1. PRAUSOVÁ, H.; BUBLÍK, O.; VIMMR, J.; HÁLA, J.; LUXA, M. Numerical and Experimental Investigation of Compressible Viscous Fluid Flow in Minichannels. In: *Proceedings of Computational mechanics 2019*. Pilsen, 2019, pp. 160–163.

A2. LUXA, M.; HÁLA, J. *Measurements on NACA 0010-64 profile*. Prague, 2018. Research report, Z-1596/18. Institute of Thermomechanics of the Czech Academy of Sciences.

A3. HÁLA, J.; LUXA, M.; PRAUSOVÁ, H.; BUBLÍK, O.; VIMMR, J. Clearance Gap Flow: Extended Pneumatic Measurements and Simulations by Discontinuous Galerkin Finite Element Method. *EPJ web of conferences*. 2016, vol. 114. Available from DOI: 10.1051/epjconf/201611402034.

A4. PRAUSOVÁ, H.; BUBLÍK, O.; VIMMR, J.; LUXA, M.; HÁLA, J. Clearance gap flow: Simulations by Discontinuous Galerkin Method and Experiments. *EPJ Web of Conferences*. 2015, vol. 92. Available from DOI: 10.1051/epjconf/20159202073.

A5. HÁLA, J.; LUXA, M.; BUBLÍK, O.; PRAUSOVÁ, H.; VIMMR, J. Compressible Viscous Flow in Minichannel - Experiment and Numerical Studies. In: *Computational Mechanics 2014 - Book of extended abstracts*. Pilsen, 2014, pp. 39–40.

A6. HÁLA, J.; LUXA, M. Numerical and Experimental Studies of the Flow Through Narrow Gap. In: *Colloquium Fluid Dynamics 2014 Proceedings*. Prague, 2014, pp. 15–16.

A7. HÁLA, J. *Compressible Fluid Flow through Minichannel*. Prague: Master Thesis, CTU in Prague, Faculty of Mechanical Engineering, 2014.

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