DOCTORAL THESIS IN
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Simulations of compressible flows associatedwith internal combustion engines

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Abstract

Vehicles with internal combustion (IC) engines fueled by hydrocarbon compoundshave been used for more than 100 years for ground transportation.During these years and in particular the last decade, the environmental aspectsof IC engines have become a major political and research topic. Followingthis interest, the emissions of pollutants such as NOx, CO_2 and unburnedhydrocarbons (UHC) from IC engines have been reduced considerably.Yet, there is still a clear need and possibility to improve engine efficiencywhile further reducing emissions of pollutants. The maximum efficiency ofIC engines used in passenger cars is no more than 40% and considerably lessthan that under part load conditions. One way to improve engine efficiencyis to utilize the energy of the exhaust gases to turbocharge the engine. Whileturbocharging is by no means a new concept, its design and integration intothe gas exchange system has been of low priority in the power train designprocess. One expects that the rapidly increasing interest in efficient passengercar engines would mean that the use of turbo technology will become morewidespread.The flow in the IC-engine intake manifold determines the flow in the cylinderprior and during the combustion. Similarly, the flow in the exhaust manifolddetermines the flow into the turbine, and thereby the efficiency of theturbocharging system.In order to reduce NOx emissions, exhaust gas recirculation (EGR) is used.As this process transport exhaust gases into the cylinder, its efficiency is dependenton the gas exchange system in general. The losses in the gas exchangesystem are also an issue related to engine efficiency. These aspects have beenaddressed up to now rather superficially. One has been interested in globalaspects (e.g. pressure drop, turbine efficiency) under steady state conditions.In this thesis, the flow in the exhaust port and close to the valve as wellas in the exhaust manifold is studied. Since the flow in the port can be transonic,we study first the numerical modeling of such a flow in a more simplegeometry, namely a bump placed in a wind tunnel. Large-Eddy Simulationsof internal transonic flow have been carried out. The results show that transonicflow in general is very sensitive to small disturbances in the boundaryconditions. Flow in the wind tunnel case is always highly unsteady in the transonicflow regime with self excited shock oscillations and associated with that

also unsteady boundary-layer separation. The interaction between separationzone and shock dynamics was carried out by one-, and two-point correlationsas well as dynamic mode decomposition (DMD). A clear connection betweenseparation bubble dynamics and shock oscillation was found. To investigatesensitivity to periodic disturbances the outlet pressure in the wind tunnel casewas varied periodically at rather low amplitude. These low amplitude oscillationscaused hysteretic behavior in the mean shock position and appearance ofshocks of widely different patterns.The study of a model

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exhaust port shows that at realistic pressure ratios,the flow is transonic in the exhaust port. Furthermore, two pairs of vortexstructures are created downstream of the valve plate by the wake behind thevalve stem and by inertial forces and the pressure gradient in the port. Thesestructures dissipate rather quickly. The impact of these structures and thechoking effect caused by the shock on realistic IC engine performance remainsto be studied in the future.The flow in a heavy-duty exhaust manifold was studied under steady andengine-like boundary conditions. At all conditions, significantly unsteady flowis generated in the manifold and at the inlets to the turbine and EGR cooler.The inflow to the turbine is dominated by a combination of the blow-downpulse coming from one cylinder, and the scavenging pulse from another at thefiring frequency.

Keywords
LES, Gas exhange, exhaust port, exhaust manifold, POD, DMD, exhaust

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