Aerothermodynamics and exergy analysis of turbocharger radial turbine with heat transfer

Shyang Maw Lim
smlim@kth.se

The aim of this project is to investigate the exhaust flow impact on heat transfer and performance of a turbocharger radial turbine operating under engine-like flow conditions. Based on the three-dimensional (3D) and unsteady flow field predicted by using Detached Eddy Simulation (DES), the exergy budget is computed to quantify the aerothermodynamics losses. The relative importance of thermal and viscous internal irreversibilities in each physical component of the system (e.g. intake manifold, scroll, wheel) is assessed, thus quantifying the contributions from each system component towards heat loss. Furthermore, the exergy concept is applied to the turbine performance maps provided by the turbocharger manufacturers, and the effectiveness of the turbine system in utilizing the available exhaust flow energy is assessed quickly.

Introduction and Motivation:
Large temperature gradients and significant heat loss characterise the exhaust manifold and turbocharger’s turbine. Most of the heat transfer research focuses on correlating heat loss and turbine performance by using the first law of thermodynamics, with little effort directed towards understanding aerothermodynamic loses and underlying physics. Moreover, contradicting results about the effect of heat transfer on turbine performance were reported. An exergy based method is presented as a powerful tool to analyze the aerothermodynamics of turbomachinery with heat transfer, and to study the effectiveness of available energy utilization.

Setup:
The turbine operating at maximum efficiency point on a low speed line is simulated under hot gas stand conditions (constant mass flow) and under pulsatile, engine-like conditions incorporating the exhaust manifold. Different wall thermal conditions (i.e. adiabatic and constant wall temperatures $T_w$ [K]= 1002, 830, and 487) are imposed to model heat loss. The rotation of the wheel is handled by the sliding mesh technique.

Results:
1. Exergy budget (lower left) shows that while heat loss increases the exergy destroyed by heat transfer and the total internal irreversibilities, turbine power reduction due to heat transfer is comparatively small.
2. Bejan number (middle) shows that thermal irreversibilities increase with heat loss. It also indicates that upstream physical component is more sensitive to heat loss.
3. Exergetic utilization map (lower right) can be constructed from the provided turbine performance map. The result shows that there is a need for having a more effective way to harvest the available exhaust energy (than a single stage turbine).

Summary and Conclusion:
Results show that exergy-based method is an effective tool to analyze the aerothermodynamic losses and exhaust energy utilization in a turbine system with heat transfer. Exergetic utilization map, which is constructed from turbocharger’s manufacturer provided performance map, could potentially be incorporated into one-dimensional simulation tools (e.g. GT-Power) for a quick assessment of available energy utilization in the engine system. This particular approach and analysis is currently extended to the turbine integrated with the exhaust manifold operating under engine-like pulsatile conditions.

Acknowledgements:
Advisors: Mihai Mihaescu, Anders Dahlkid, Christophe Duwig, Laszlo Fuchs.