Extended Range Turbocharger Maps
Measurement and Benefit for Simulation

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Extended Range Turbocharger Maps

Content

- Introduction to TC Mapping
- Turbine Mapping Limits
- Turbine Mapping Extension
- Summary
- Outlook on Advanced TC Mapping Methods
Extended Range Turbocharger Maps
Hot Gas TC Test Bench

FEV’s Hot Gas TC Test Bench
Extended Range Turbocharger Maps

Turbine Map Representation

Mass flow

Efficiency

Efficiency = f (U/Co)
Extended Range Turbocharger Maps
Turbine in Engine Operation

Turbine Behavior in Steady State Engine Operation

Engine (TC 112 cyl.) operating at steady state rated power

- Engine Simulation

Transient range increases with:
- Low cylinder numbers
- Small exhaust manifold volume
- Downsizing!
- Pulse charging!
Extended Range Turbocharger Maps
Turbine Mapping Limits

Measured Turbine Map

This comparison shows:

- Turbine operation at one steady state engine operation point
- Complete turbine map
Extended Range Turbocharger Maps
Turbine Mapping Limits

Measured Turbine Map

- One Speed Line
- Engine Simulation
- Hot Gas TC Test Bench

- Surge / Min Power
- Max Power

\[ \pi_C \]

\[ n = \text{const} \]

Effective Turbine Efficiency / -

Blade Speed Ratio \( U/Co / - \)
GT-Power Turbine Map Extrapolation - “def”
Extended Range Turbocharger Maps
Turbine Map Extrapolation

GT-Power Turbine Map Extrapolation – User’s Manual

\[ \eta = 1 - \left( 1 - BSR \right)^b \]  
\[ (1.4 \xi b \xi 2.2) \]

range 1.5-2.0
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Turbine Map Extrapolation

GT-Power Turbine Map Extrapolation - Low U/Co

\[ b = 2.2 \]

\[ b = 1.4 \]
GT-Power Turbine Map Extrapolation - High U/Co

U/Co = 0.9 – 1.1

U/Co = 1.2 – 1.4

l = 1.5

l = 2.0
Extended Range Turbocharger Maps
Turbine Mapping Limits

Measured Turbine Map

<table>
<thead>
<tr>
<th>Effective Turbine Efficiency</th>
<th>0.7</th>
</tr>
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<tbody>
<tr>
<td>0.6</td>
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<td>0.4</td>
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<td>0.3</td>
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<td>0.2</td>
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<table>
<thead>
<tr>
<th>Blade Speed Ratio U/Co</th>
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</thead>
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<tr>
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<td>0.8</td>
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<tr>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td>1.2</td>
<td></td>
</tr>
</tbody>
</table>

- Engine Simulation
- Hot Gas TC Test Bench
Extended Range Turbocharger Maps
CCLU Turbine Mapping

Compressor Closed Loop Concept

Why?

Compressor pressure ratio control
Compressor pressure level control

→ TC operated beyond open loop power limits defined by compressor surge and min. back pressure
CCLU Turbine Mapping Testing Set Up
Turbine Map Measured with CCLU
Interception at high U/Co
Extended Range Turbocharger Maps

Zero Power Turbine Mapping

Zero Power Turbine Mapping Concept

Goal: $\eta_{I \text{ eff}} = 0$ and $\pi_I = \min$

→ Replace compressor wheel with bladeless zero power disc
Extended Range Turbocharger Maps
Zero Power Turbine Mapping

Zero Power Turbine Mapping Testing Set Up

Extended Range Turbocharger Maps
Zero Power Turbine Mapping

Complete Turbine Speed Line

- Zero Power Measurement
- Open Loop Measurement
- Closed Loop Measurement
Extended Range Turbocharger Maps
Complete Turbine Map

Complete Turbine Map

![Graph showing the effective turbine efficiency vs. blade speed ratio. The graph has a y-axis labeled "Effective Turbine Efficiency / -" ranging from 0.0 to 0.7, and an x-axis labeled "Blade Speed Ratio U/Co / -" ranging from 0.0 to 1.2. The red area highlights a specific region on the graph.]
Extended Range Turbocharger Maps
Benefit for Simulation

Effect on Simulation

![Graph showing the effect of blade speed ratio on engine simulation](image)

- Effective Turbine Efficiency vs. Blade Speed Ratio U/Co
- New extrapolation
- Concept phase extrapolation
- Engine Simulation

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Extended Range Turbocharger Maps

Summary

- Turbine Mapping Limited by Compressor Surge and Back Pressure
- Compressor Closed Loop Turbine Mapping
- Zero Power Turbine Mapping
Complete Turbine Map

- Twin Scroll Turbines?
- Temperature Dependency?
- Low Speeds?
Extended Range Turbocharger Maps
Overview on Advanced TC Mapping Methods

Twin Scroll Turbine Mapping

\[ \pi_{12} = \frac{p_{T\text{In}1}}{p_{T\text{In}2}} \]
Extended Range Turbocharger Maps
Overview on Advanced TC Mapping Methods

High Mass Flow and Temperature TC Mapping

- 25 – 1200 °C
- 0,04 – 1 kg/s
Extended Range Turbocharger Maps Overview on Advanced TC Mapping Methods

Brake Test Bench for Low Speed Turbine Mapping

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Extended Range Turbocharger Maps
Turbine Map Data

Turbine Maps Sum up 4 Turbine Performance Parameters:

- Pressure Ratio \( \pi_T \)
- Mass Flow \( \dot{m}_{T \text{ Red}} \)
- Speed \( n_{T \text{ Red}} \)
- Efficiency \( \eta_{T \text{ Eff}} = \eta_{T \text{ Is}} \eta_{m} \)

Why reduction? \( \rightarrow \) Turbine behavior independent inlet conditions

Why effective efficiency? \( \rightarrow \) Efficiency independent of diabat errors of \( T_4 \)
Extended Range Turbocharger Maps
CCLU Turbine Mapping

CCLU Turbine Mapping Concept

\[ \dot{m}_c, \ p_1, \ p_2 \downarrow \text{ at } \pi_c = \text{const} \]

\[ \dot{m}_{c \text{ corr}} = \dot{m}_c \frac{\sqrt{T_1}}{p_1} \frac{p_{Re f}}{\sqrt{T_{Re f}}} = \text{const} \]

Comp. Pressure Ratio

Surge

Back Pressure

\( n = \text{const} \)

Compressor Power

\( \Delta p_1 \uparrow \)

\( \Delta p_1 \downarrow \)

Turbine Efficiency

\( \eta_{T\text{ Eff}} \)

\( \Delta p_1 \uparrow \)

\( \Delta p_1 \downarrow \)

\( \frac{u}{c_0} \)
Extended Range Turbocharger Maps
Zero Power Turbine Mapping

Turbine Map at Zero Efficiency

\[
\lim_{\pi_T \to \pi_{\text{Crit}}} U / Co \ (n \neq 0) = \text{const} \neq 0
\]

\[
U / Co \ (n = 0) = 0
\]