Advanced boost system development for diesel HCCI/LTC applications

2010 DOE Peer Review

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Project ID: ace037_sun

Overview

Timeline

- Project start: Oct. 1, 2007
- Project end: Sept. 30, 2011
- Percent complete: 50%

Budget

- Total project funding
  - DOE: $1,495K
  - Contractor: $1,495K
- FY08 (received): $75.4K
- FY09 (estimated): $264K
- FY09 (actual): $235K
- FY10 (estimated): $577K

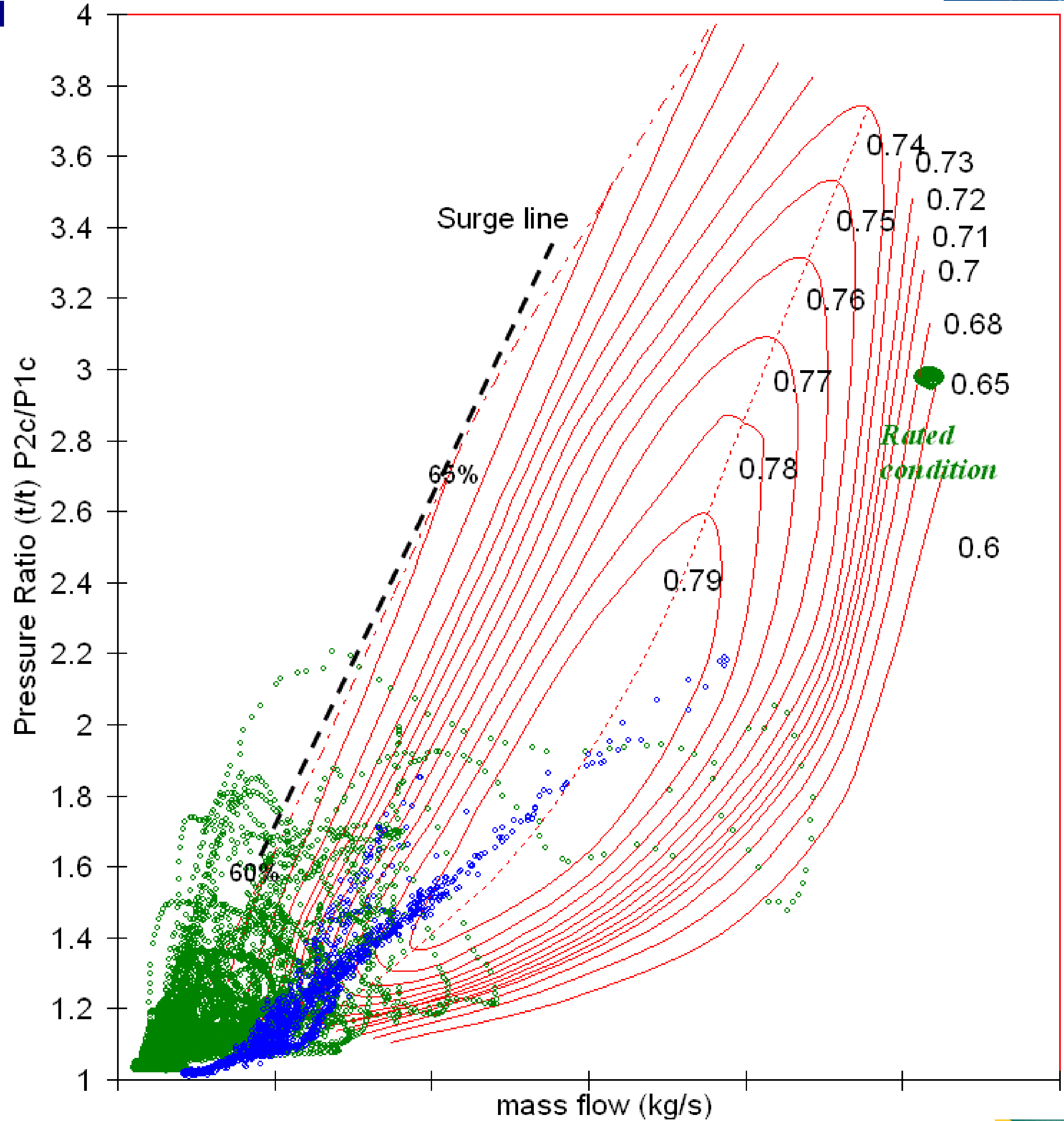
Barriers

- Heavy cooled EGR is needed for all diesel HCCI/LTC, which is accompanied by loss of efficiencies in compressor and turbine
- Heavy EGR pushes operation point close to compressor surge and less efficient areas for compressor and turbine thus compromises engine fuel economy
- Low oxygen content in the intake and poor turbo efficiency compromise diesel transient response

Partners

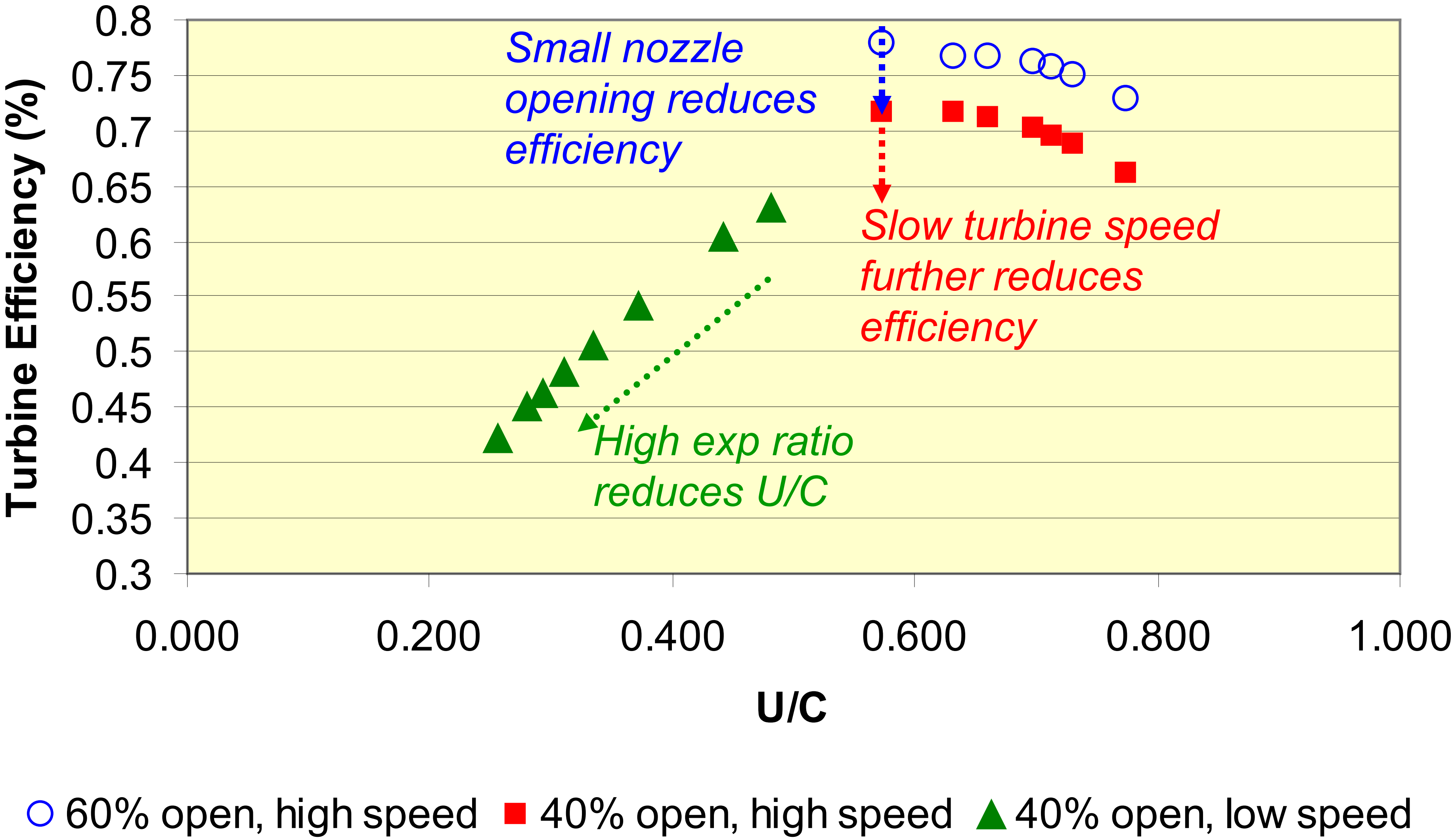
- ConceptsNREC
- Wayne State University
- Turbocharger suppliers

Heavy EGR needed for LTC pushes the operation points into less efficient or even surge

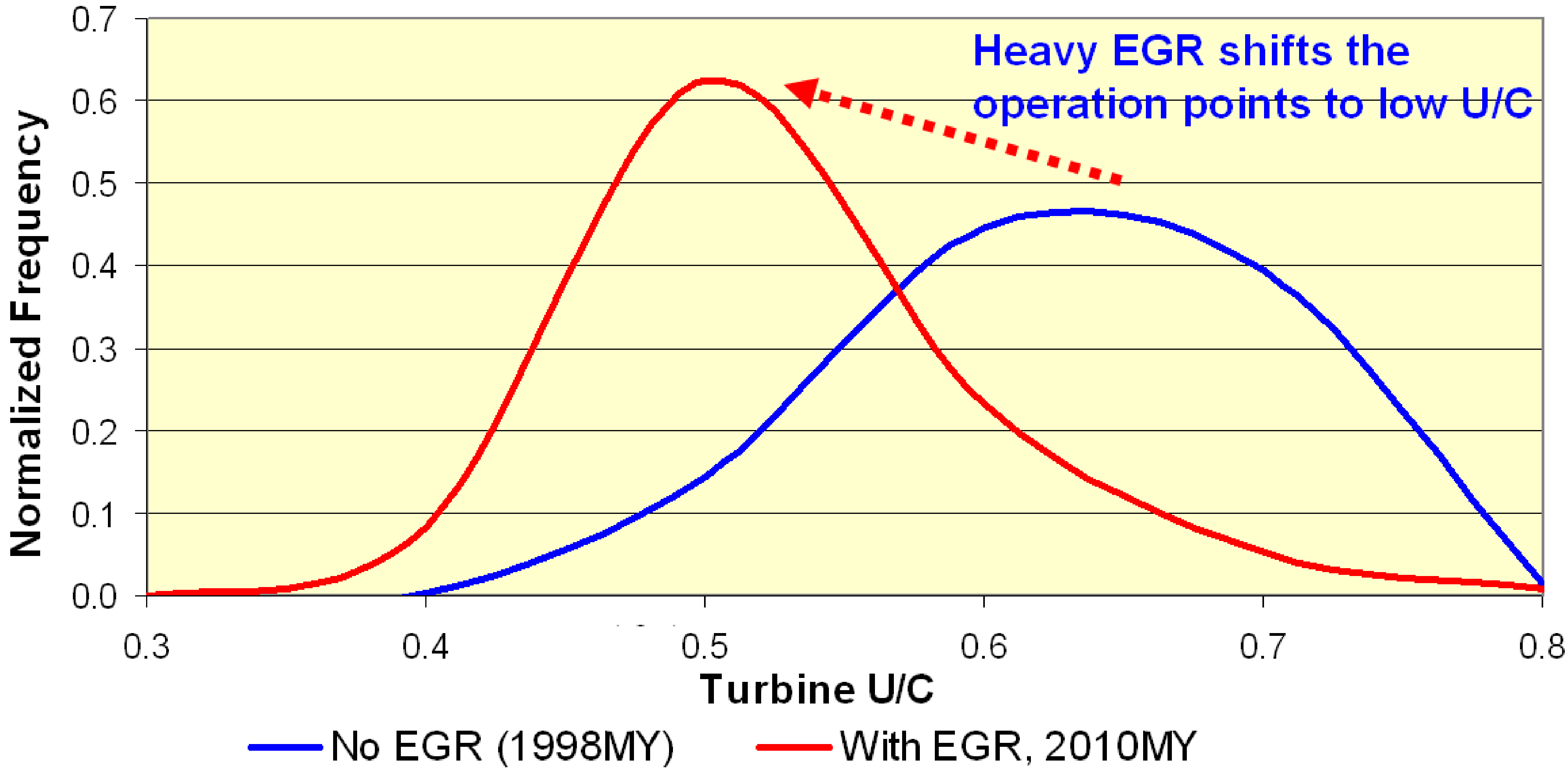


Turbine Efficiency vs. U/C

$$\frac{U}{C} = \frac{U}{\sqrt{2C_p T_0 \left[1 - (\pi_T)^{-0.285}\right]}}$$



Turbine Speed Ratio (U/C) Distribution over EPA City Cycle

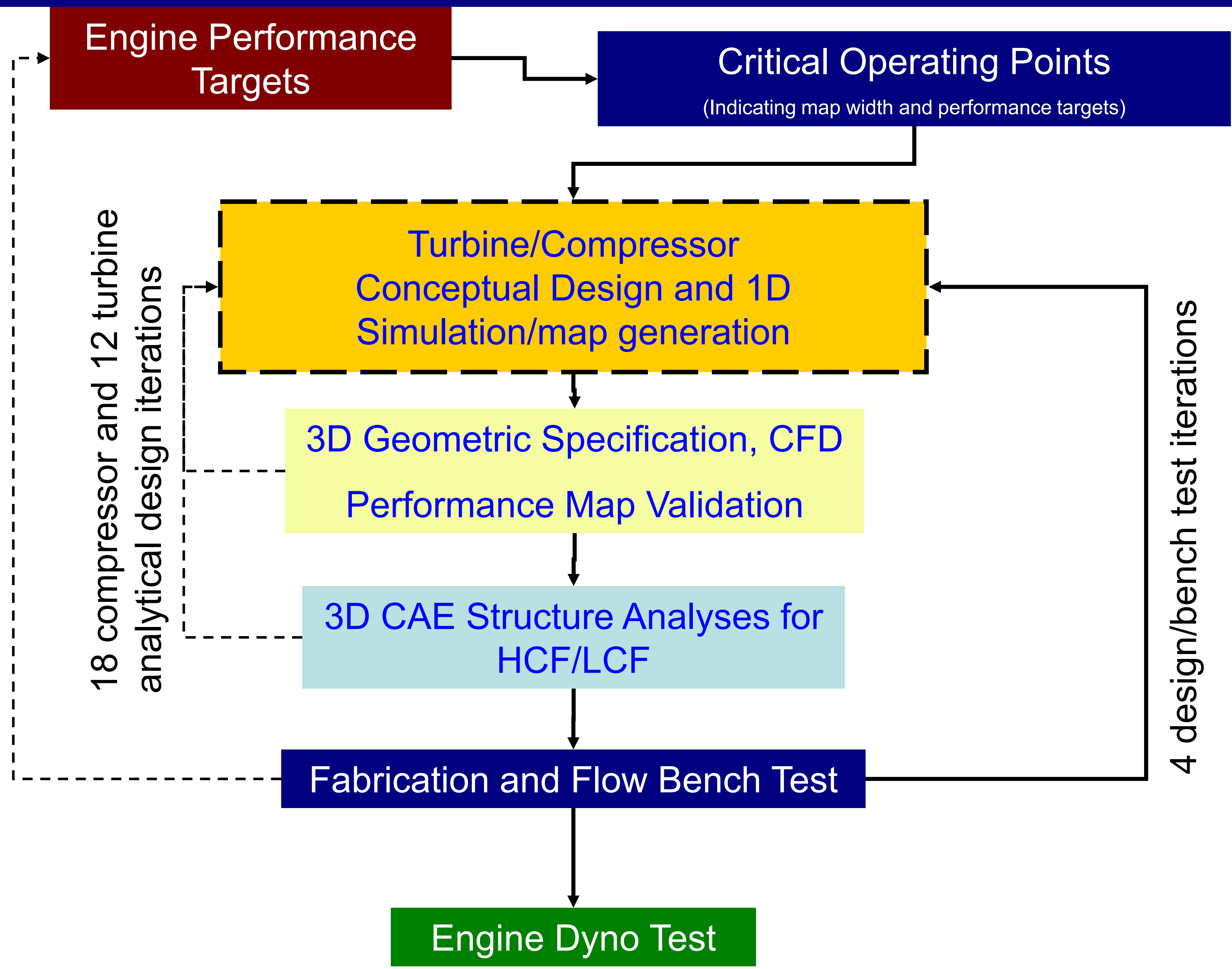


As more EGR is used, turbine spends more time in low U/C area.
Therefore turbine needs to be more efficiency in U/C areas

Strategies

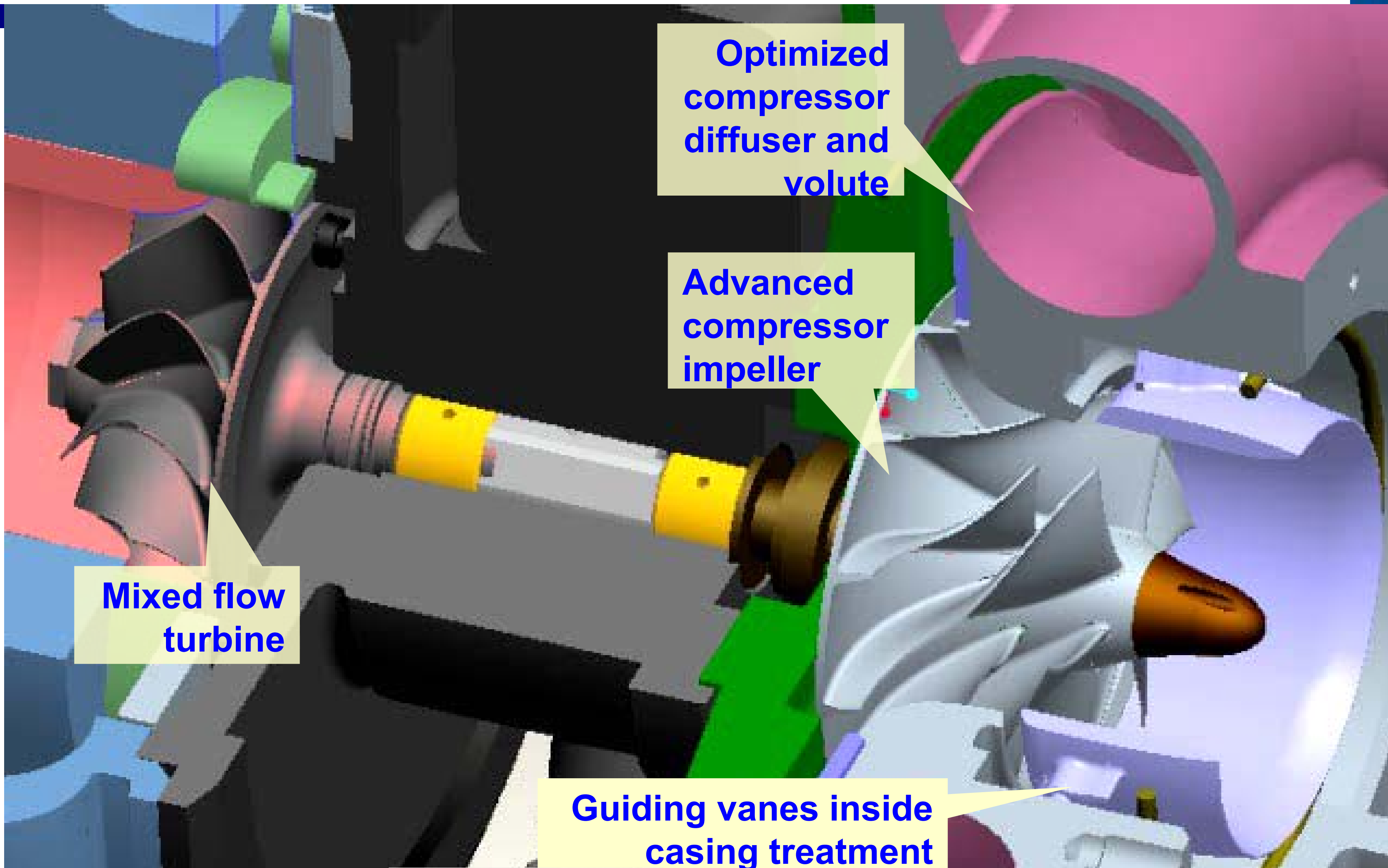
- *About 20-40% of engine power is used to drive turbocharger for diesel applications. Therefore turbocharger efficiency improvement will translate into fuel savings*
- *Focus of this study will include:*
  - *Optimization of compressor blade geometry to shift high efficiency area to cover customer driving cycles*
  - *CFD guided optimal design of compressor casing treatment to further extend operation range*
  - *Mixed flow turbine to achieve improved turbine efficiency over wide operation range, esp. under pulsating exhaust environment*
  - *Other advanced compressor and turbine technologies*

Approach

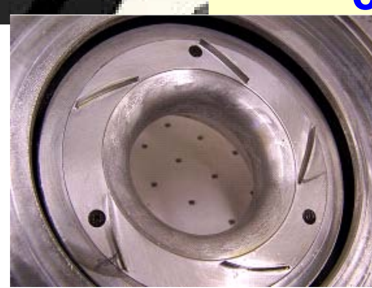


Approach: integration of numerical analyses and flow bench test validation

Approach



Optimized compressor diffuser and volute
Advanced compressor impeller
Mixed flow turbine
Guiding vanes inside casing treatment

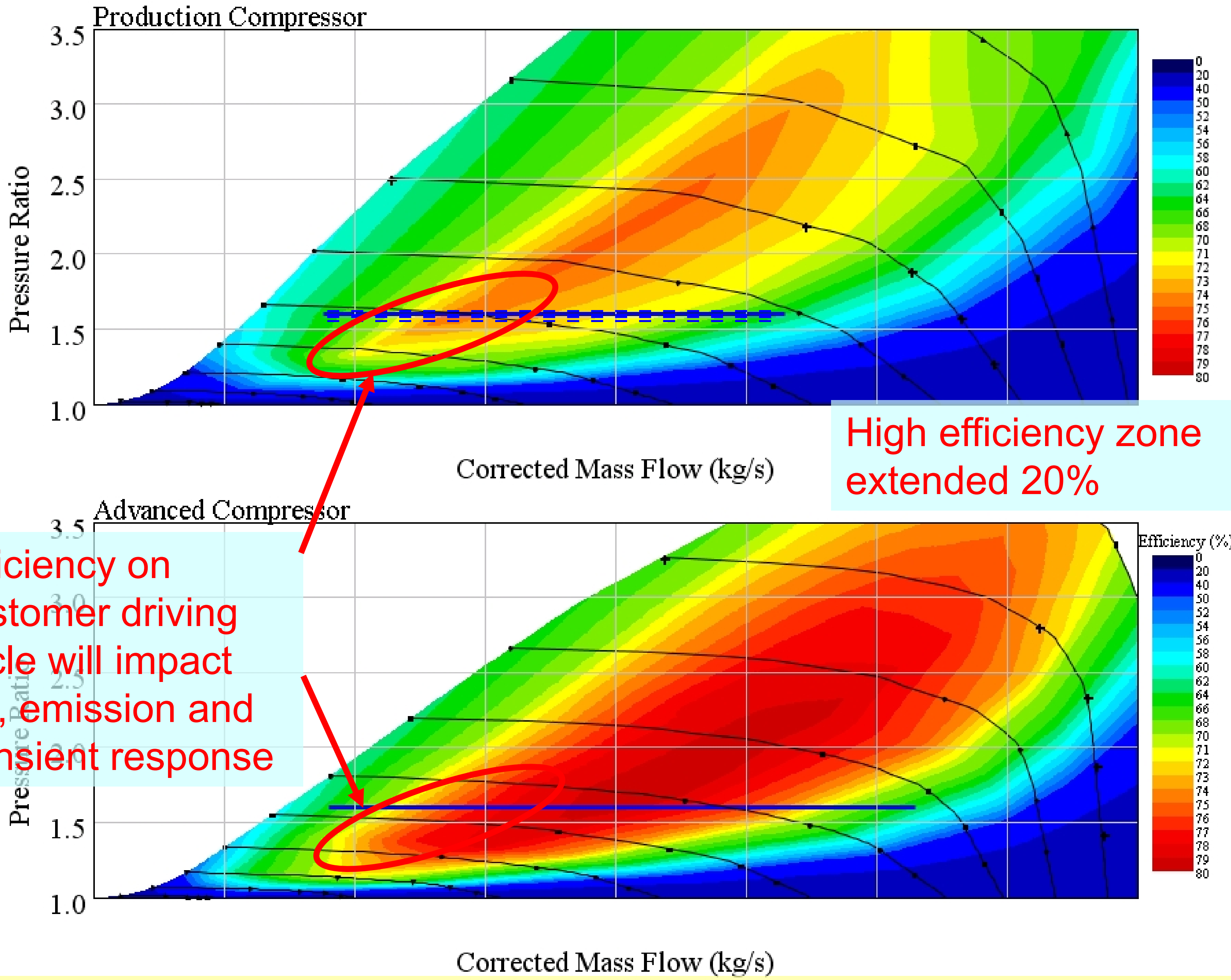


Approach

- *Optimal design of compressor blade geometry to shift high efficiency area to low flow area*
- *Mixed flow turbine to improve efficiency and shift peak efficiencies to low speed ratio (U/C) to adapt to high EGR applications*
- *CFD guided optimal design of compressor casing treatment to further extend operation range/surge margin*
- *CAE high/low cycle fatigue (HCF/LCF) analyses to ensure production feasibility. Support of turbocharger supplier on HCF/LCF assessment is critical.*

Accomplishment in 2009

- Four additional 1D and 3D “analytical” design iterations for better compressor performances;
- Fabrication of two additional compressor wheels with modular compressor configurations (casing treatments, diffusers) and one mixed flow turbine (matched to two different turbocharger center housings and VGTs);
- 3D CAE analyses for high cycle and low cycle fatigue compliances were conducted on each of the wheels;
- Hot flow bench tests were conducted at turbo supplier’s facility for consistency;
- The combined turbo efficiency has ~12-18% improvement over customer driving cycle; this may translate into ~2-3% FE savings on the cycle according to vehicle cycle simulation;
- Compressor operation range has 5% extension at rated and high efficiency zone has ~20% extension over current production compressor

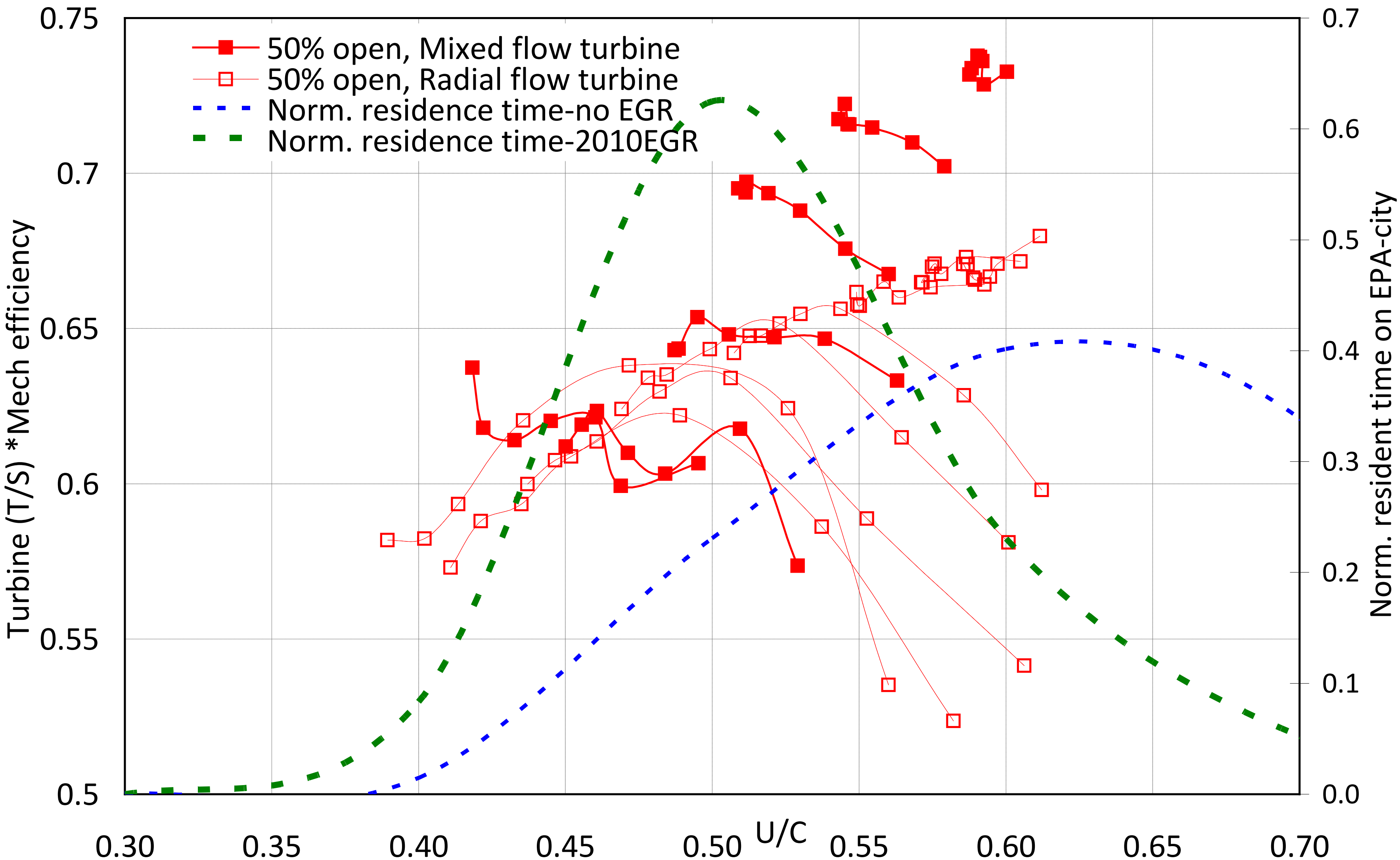


High efficiency zone extended 20%

Efficiency on customer driving cycle will impact FE, emission and transient response

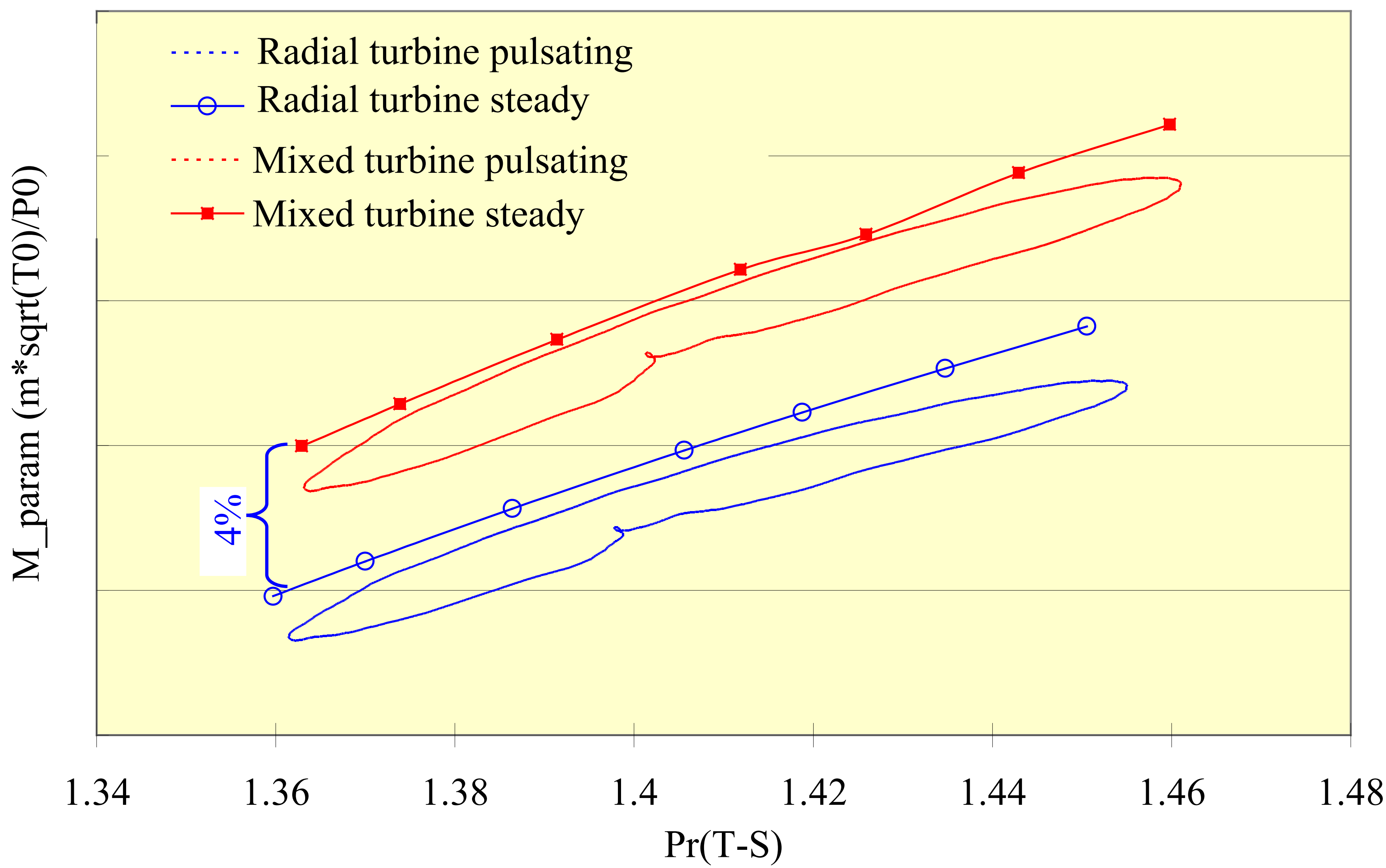
Advanced compressor has better efficiency and operation range than production compressor

Turbine efficiency and normalized residence time on EPA city cycle vs. turbine speed ratio



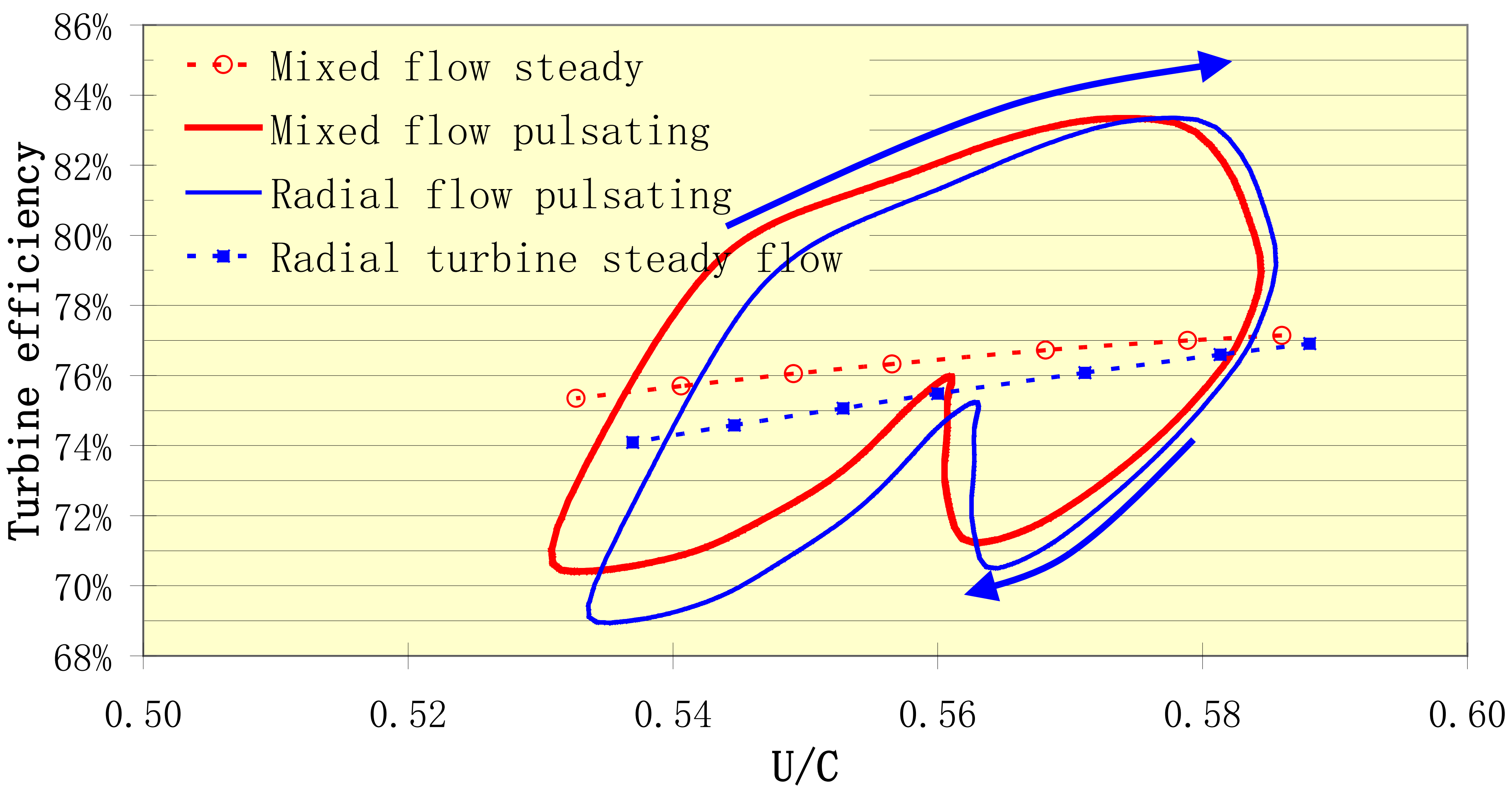
Efficiency improves 8-10% and shifts to low U/C

Mass flow of mixed flow turbine vs. radial flow turbine



Mixed flow turbine has better flow capacity that may help downsizing

Turbine efficiencies, radial flow vs. mixed flow under stead state and transient conditions



Transient CFD simulation indicated that mixed flow turbine can effectively utilize exhaust energy, esp. at low U/C area

Accomplishment in 2009 (cont.)

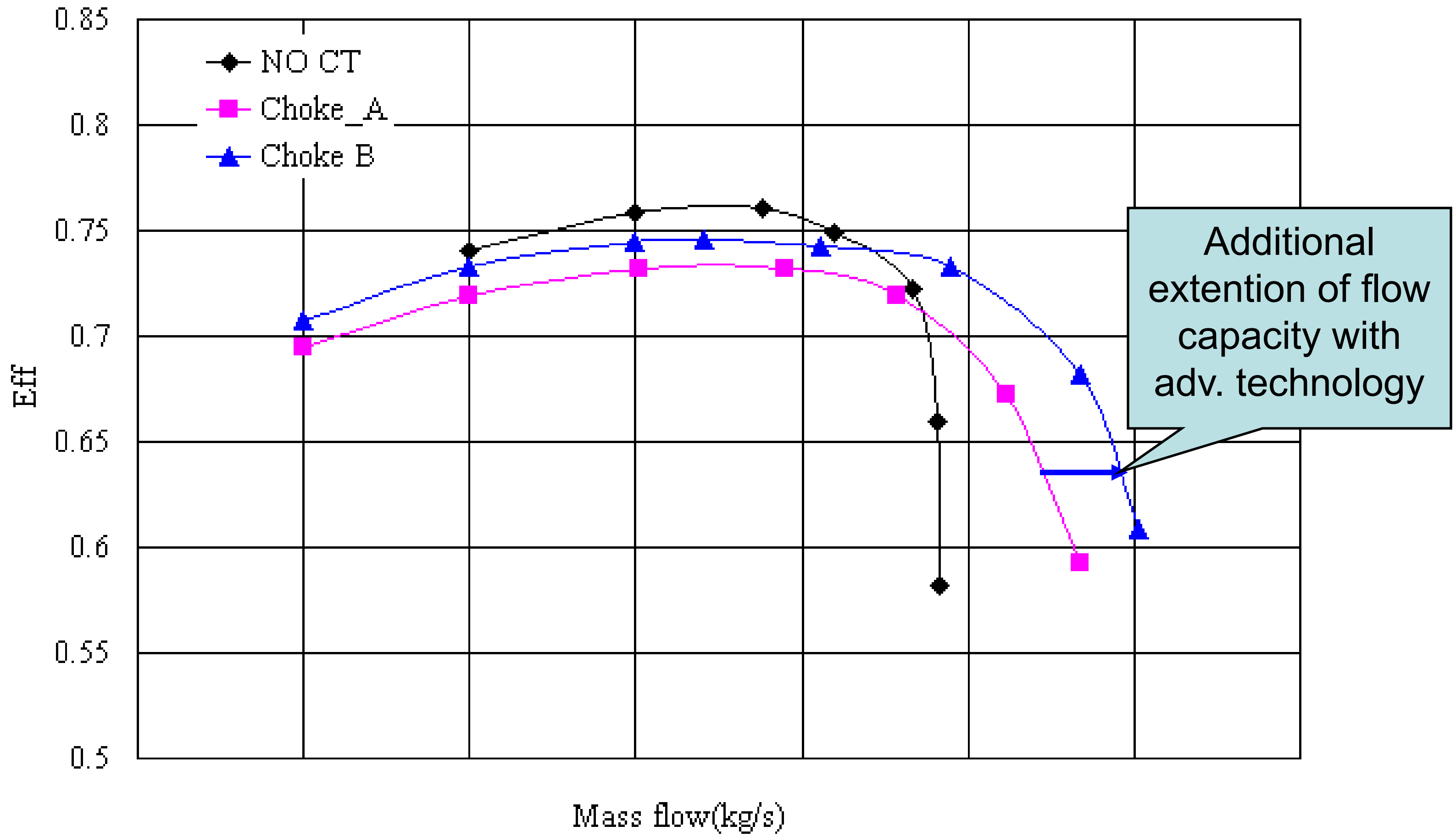
- Technology for additional improvement in compressor operation range has been identified and numerically validated;

- Technology for additional improvement in turbine efficiency, which critical for further improvement of FE on customer driving cycles and transient response, has also been identified and numerically validated;

- The details of the above technologies cannot be disclosed at this point.

Next steps

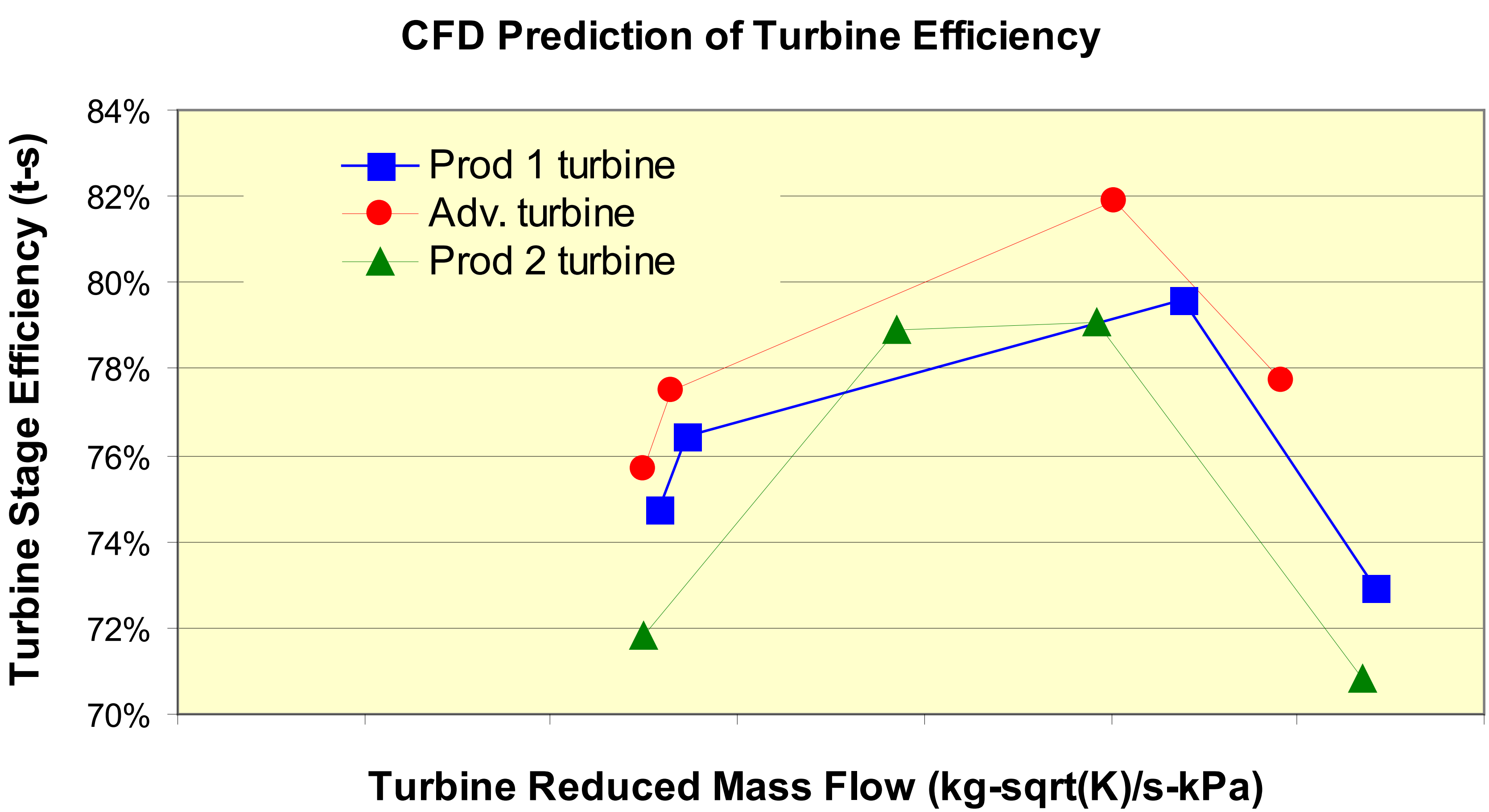
- Further improvement on compressor operation range with other advanced compressor technologies;



CFD simulation of compressor efficiencies with different compressor technologies

Next steps (cont.)

Further improvement on turbine efficiency with other adv. turbine technologies



CFD simulation of turbine efficiencies with adv. turbine technologies

Milestone

	Milestone			
	2008	**2009**	**2010**	**2011**
Compressor wheel optimization	**Task 2**		Current Status Phase I: Large turbo development (6.7L)	
Mixed flow turbine wheel optimization				
CAD/CFD/CAE for performance and HCF/LCF				
Fabrication		**Task 4**		
Flow bench test validation				
Futher development with adv. Compressor/turbine technologies		**Task 3:**		Phase II: Small turbo development (<5L)
Flow bench test validation of adv. Turbo technologies				
Small turbo design, CFD/CAE				
Small turbo fabrication and flow bench validation			**Task 5:**	
Engine dyno demonstration and calibration for T2B5 emission				**Task 6:**

2010 Objectives

- Further improvement in compressor efficiency and flow capacity with the advanced compressor technology (6-9% more)
- Further improvement in mixed flow turbine efficiency with advanced turbine technology (5-8% at low and high mass flow area)
- Test validation of the above turbo performance on a large turbochargerr
- Migration of the optimal design to a small turbocharger for light duty diesel application on a <5L diesel

Summary

- Challenging a relatively matured technology turns out to be much more difficult than we had anticipated;
- Substantial progresses have been made in compressor/turbine operation range and efficiencies, esp. the efficiencies on customer driving cycles:
  - The combined turbo efficiency has ~12-18% improvement over customer driving cycle; this may translate into ~2-3% FE savings on the cycle according to vehicle cycle simulation;
  - Compressor operation range has 5% extension at rated and high efficiency zone has ~20% extension over a current production compressor;
- There exist small gaps between demonstrated performance improvement and program target. Additional technologies have been identified and numerically validated to fill the gaps