Advanced boost system development for diesel HCCI/LTC applications

2011 DOE Peer Review

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Project ID: ace037_sun

"This presentation does not contain any proprietary or confidential information"

Overview

Timeline

- Project start: Oct. 1, 2007
- Project end: Sept. 30, 2011
- Percent complete: 70%

Budget

- Total project funding
  - DOE: $1,495K
  - Contractor: $1,495K
- FY08 (received): $75.4K
- FY09 (actual): $235K
- FY10 (actual): $422K
- FY11 (estimated): $762K

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
- *Program targets*: 2-3% fuel economy improvement on customer driving cycles and 15-20 % extension of operation range

Partners

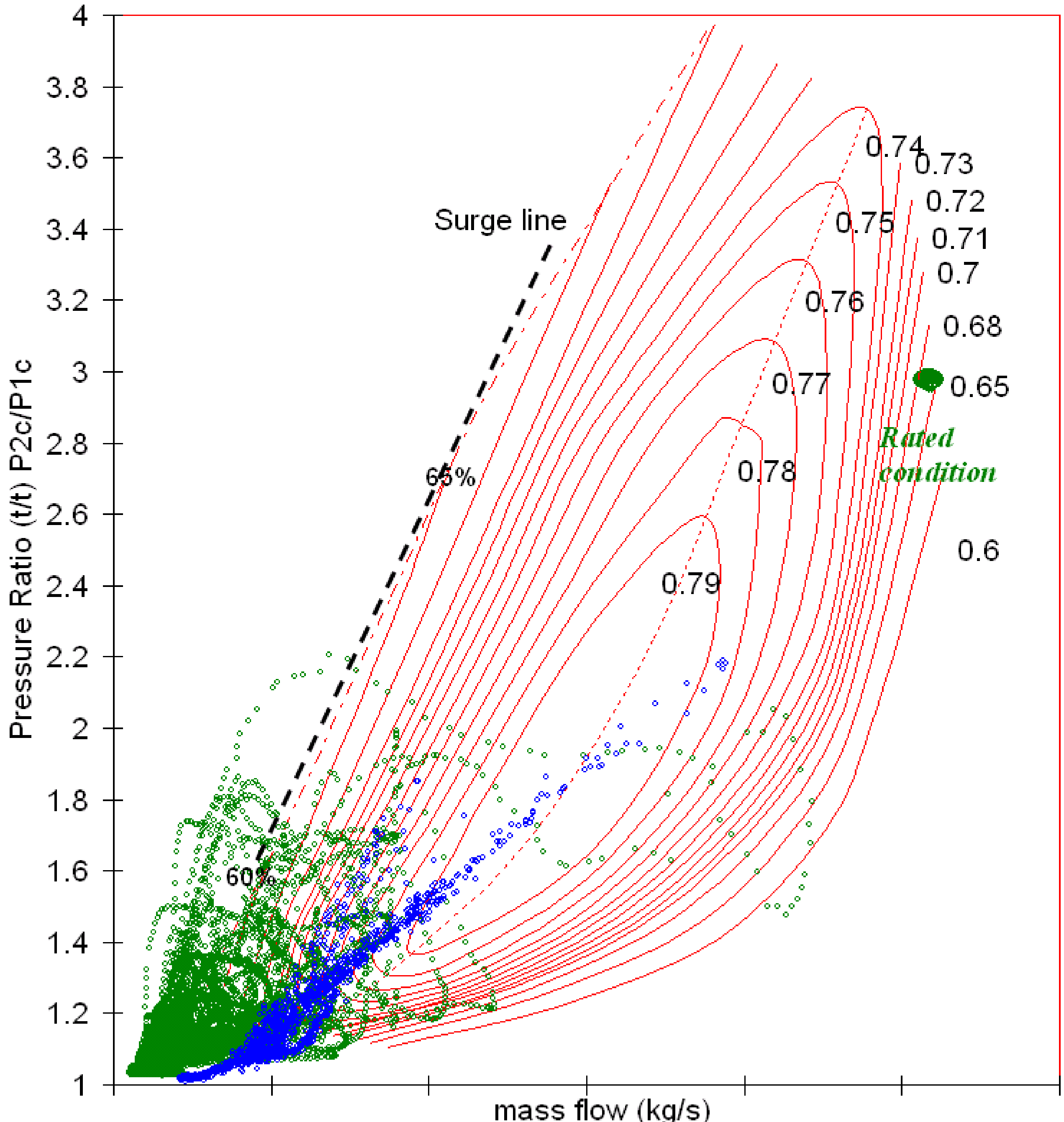
- Ford Motor Co.
- ConceptsNREC
- Wayne State University
- Two turbocharger suppliers

Relevance/objectives

Emission regulation:
Heavy EGR needed for LTC pushes the operation points into less efficient or even surge area

Market competitiveness:
Centrifugal compressor needs to have wide range for high horse power and better efficiency at low end for better fuel economy on customer driving cycles

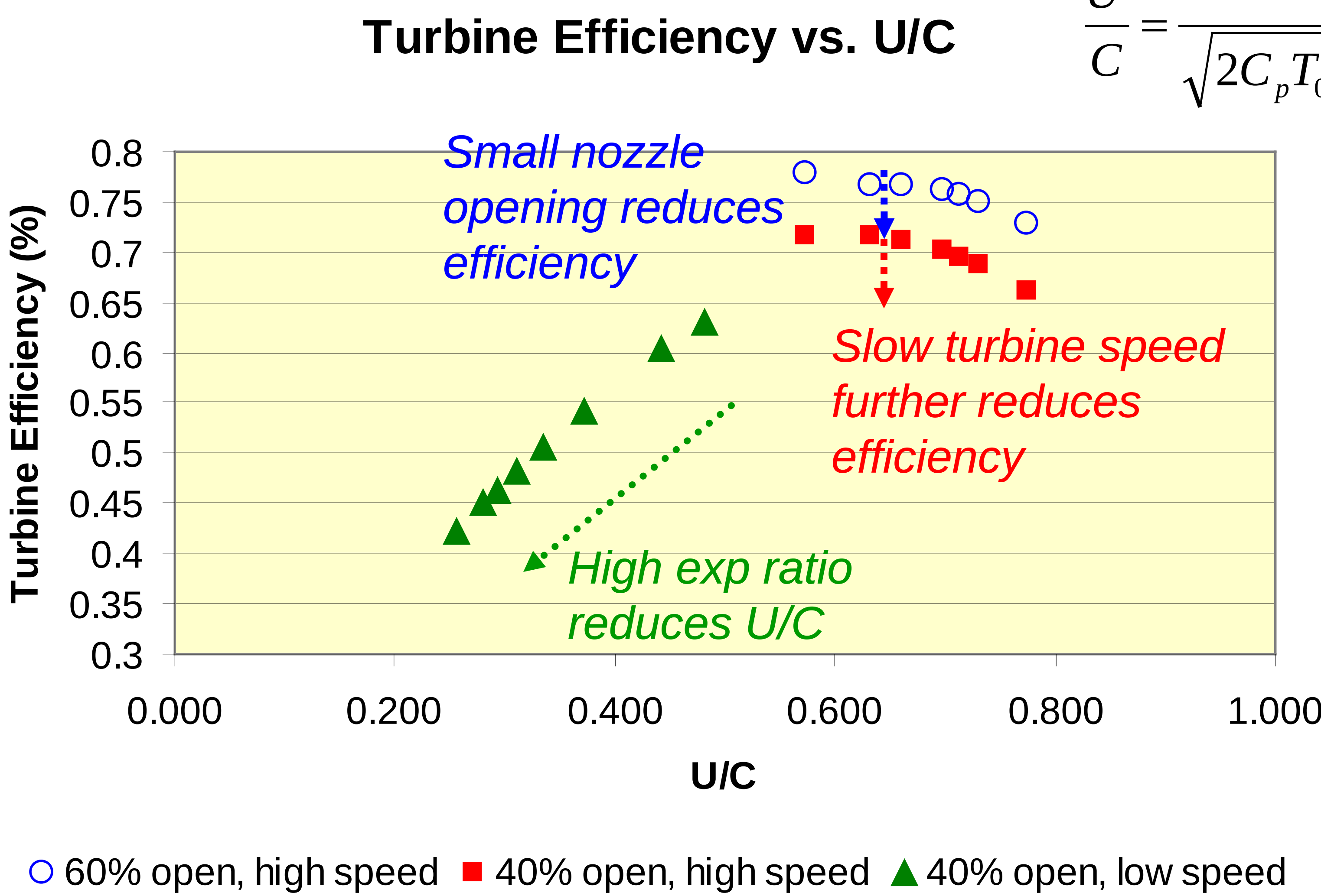
Objectives:
2-3% fuel economy improvement on customer driving cycles and 15-20% extension of turbo operation range



CONCEPTS NREC

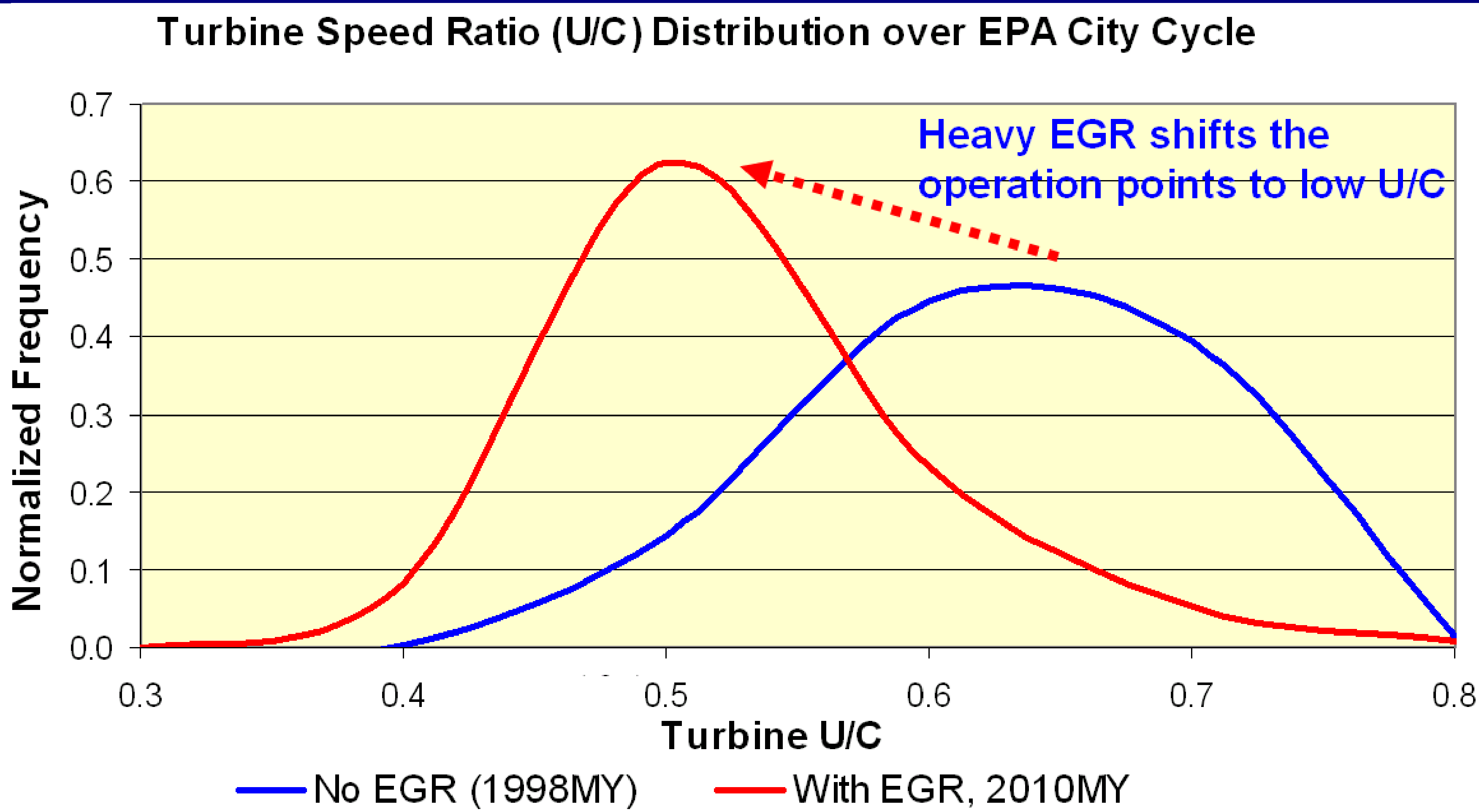
Relevance/objectives

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



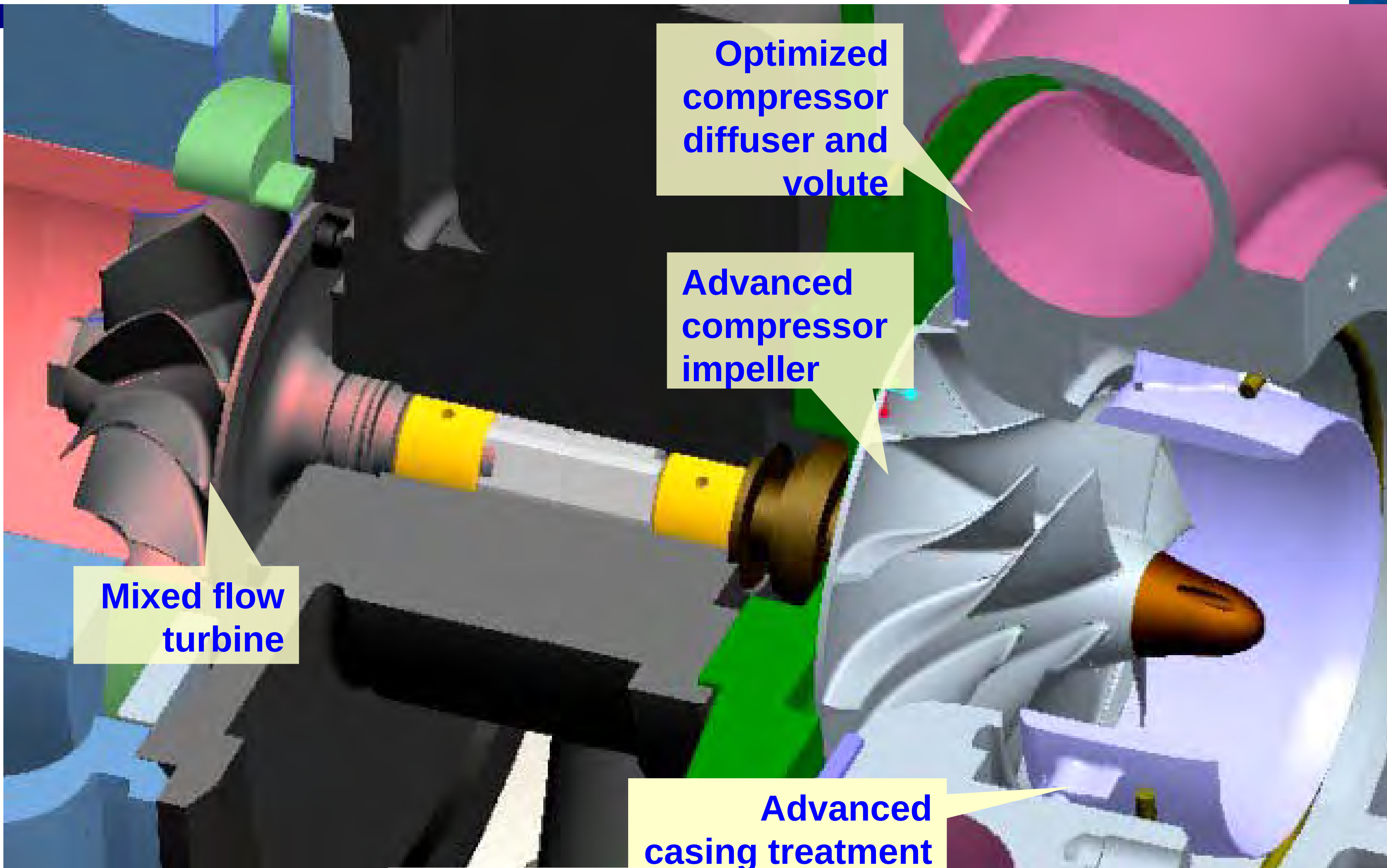
Conventional radial flow VGT has low efficiency at small nozzle open positions and low U/C. Heavy EGR, bigger turbo pushes part load turbine operation points into less efficiency areas

Relevance/objectives



As more EGR is used for NOx reduction, turbine spends more time in low U/C area. Conventional turbine blade, optimized for low/none EGR applications 10-15 years ago, performs well at high U/C but not at low U/C. Therefore future diesel application requires that turbine should have high efficiency in low U/C areas.

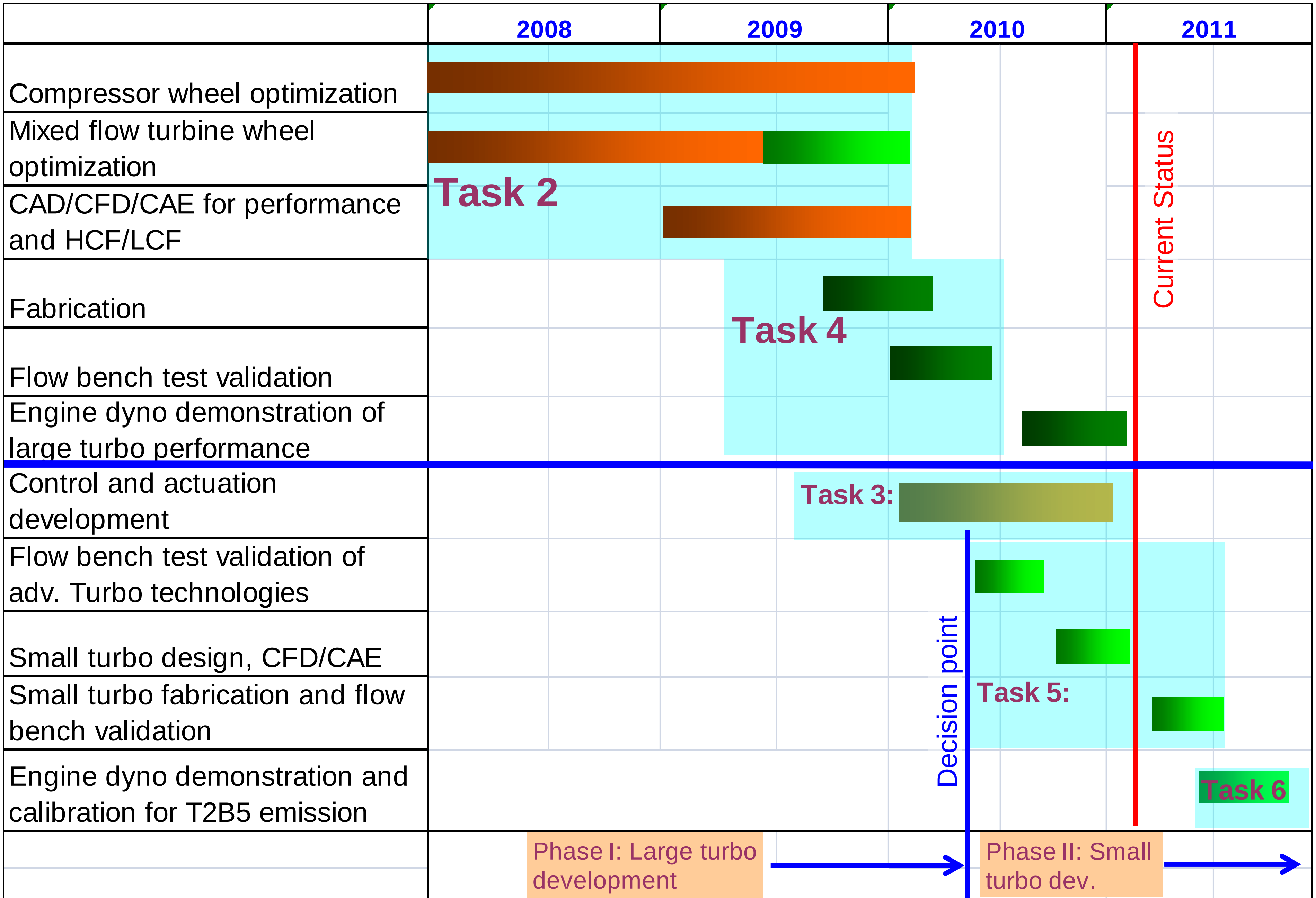
Objectives


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

Objectives

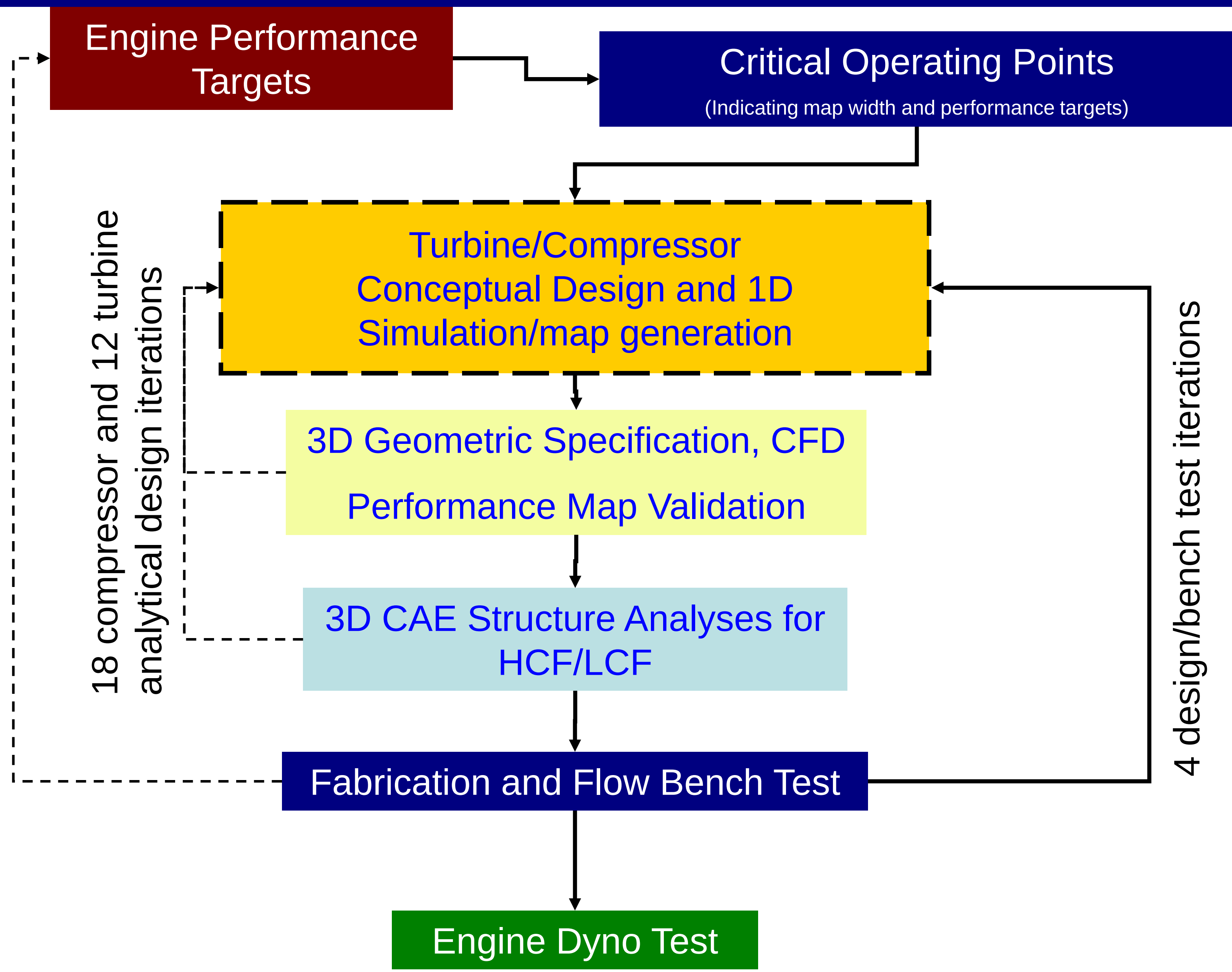
1. About 20-40% of engine power is used to drive turbocharger for diesel applications. Therefore this study aims at 10-15% turbocharger efficiency improvement, which will translate into 2-3% fuel savings
2. Development of large turbo for MD diesel application (Phase 1):
   - Optimization of compressor blade geometry to extend operation range to enable more powerful engine while shifting high efficiency area to cover customer driving cycles to enable better fuel economy on engine
   - CFD guided advanced compressor casing treatment to further extend operation range (patent pending)
   - Mixed flow turbine to achieve improved turbine efficiency over wide operation range, esp. under pulsating exhaust environment
3. Development of small turbo for LD diesel application (Phase 2):
   - Migrate the same technology to small turbo designs
   - Advanced variable geometry turbine technologies (LD diesel is more power demanding thus new invention is needed)

Milestone



2008
2009
2010
2011
Compressor wheel optimization
Mixed flow turbine wheel optimization
CAD/CFD/CAE for performance and HCF/LCF
Fabrication
Flow bench test validation
Engine dyno demonstration of large turbo performance
Control and actuation development
Flow bench test validation of adv. Turbo technologies
Small turbo design, CFD/CAE
Small turbo fabrication and flow bench validation
Engine dyno demonstration and calibration for T2B5 emission
Task 2
Task 4
Task 3:
Task 5:
Task 6
Current Status
Decision point
Phase I: Large turbo development
Phase II: Small turbo dev.

Approach/*Strategies*



Approach: integration of numerical analyses and flow bench test validation

Approach

1. Large turbo development

- *Optimal design of compressor blade geometry to shift high efficiency area to low flow area*
- *Advanced compressor casing treatment to extend surge margin/operation range.*
- *Mixed flow turbine to improve efficiency and shift peak efficiencies to low speed ratio (U/C) to adapt to high EGR applications*
- *CAE high/low cycle fatigue (HCF/LCF) analyses to ensure production feasibility. Support of turbocharger suppliers on HCF/LCF assessment is essential.*
- *Hot flow bench (supported by turbo suppliers) test validation*
- *Engine dynamometer at Ford for BSFC demonstration*

2. Small turbo development

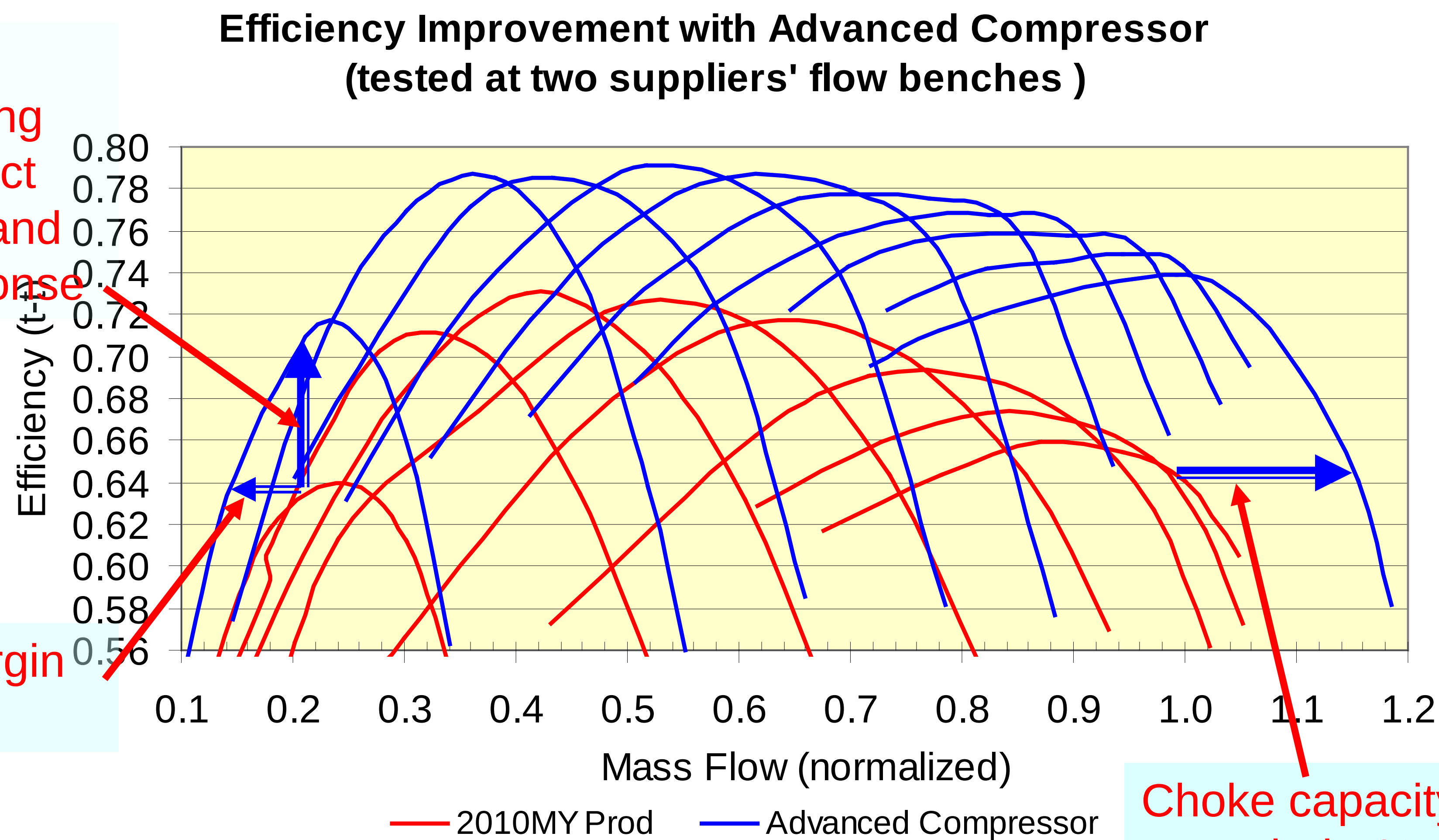
- *Similar methodology as used in large turbo development except small turbo has 30% more operation range*
- *More technical innovations are needed (e.g. adv. VGT technology, relative large compressor impeller with ruled surface, etc.) and will be investigated*

Technical Accomplishment in 2010

- Hot flow bench tested were conducted at two suppliers' facilities that consistently demonstrated substantial efficiency and flow range enhancement over 2010MY production turbo;
- An advanced compressor casing treatment concept was flow bench tested that extended choking flow capacity by 12% w/o compromising efficiency (on top of 15% of surge margin improvement);
- The large turbo developed during Phase 1 has been tested on engine dyno, which demonstrated ~2% BSFC improvement at light loads over a Ford 2010MY diesel engine. Some hardware variances and bearing failure had adversely affected the results. We are confident that a back to back comparison test (in the next few weeks) will demonstrate more than 3% BSFC improvement target at light load.
- In Phase 2, advanced turbo development for a small diesel application (w/ 30% increase in power density over MD diesel), we have completed compressor design, 3D CAE analyses for high cycle and low cycle fatigue compliances
- Investigation of advanced variable geometry turbine concept: design, analyses, fabrication and flow bench test completed. Preliminary test data were very encouraging. Additional refinement is needed.

Technical Accomplishment in 2010 (cont.)

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



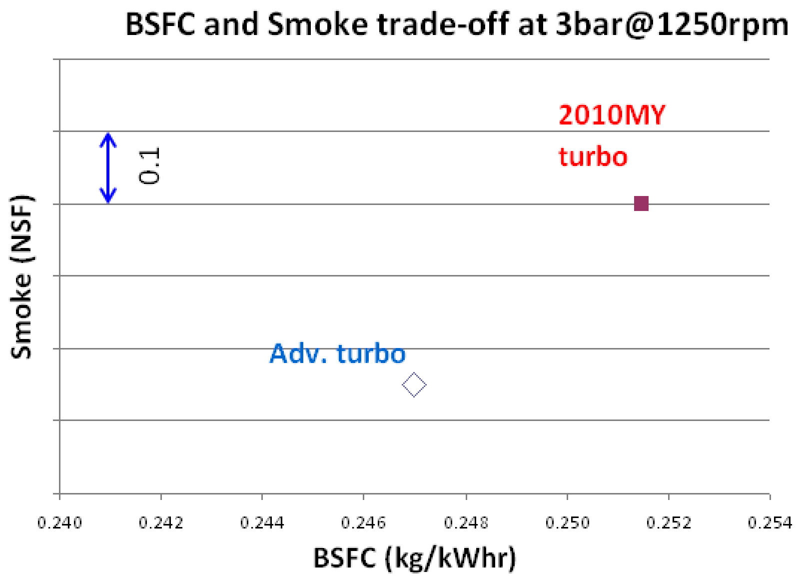
Surge margin enhanced

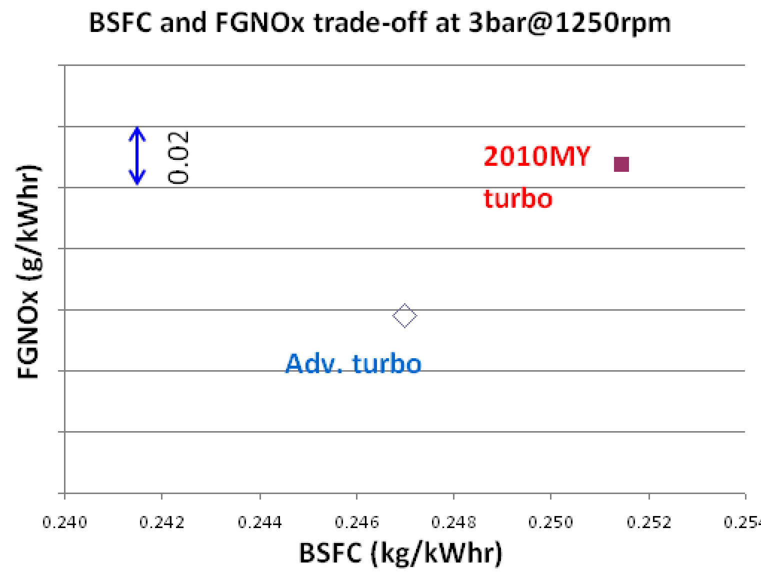
Choke capacity extended 12%

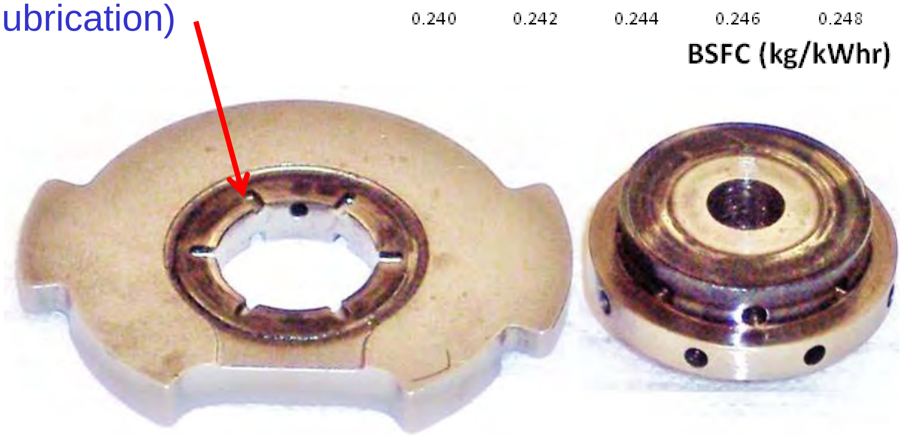
Advanced compressor with adv. casing treatment demonstrated better efficiency and wider operation range than a 2010MY production compressor that enables BSFC and performance improvement

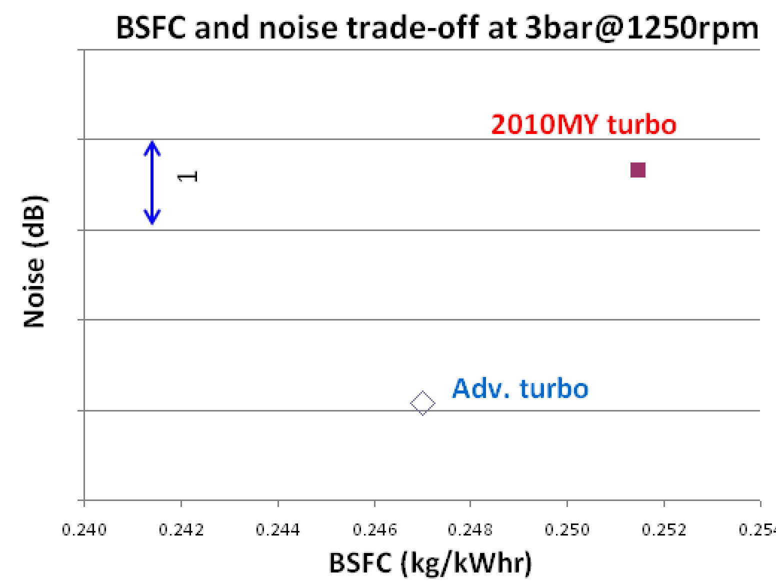
Technical Accomplishment in 2010 (cont.)

The advanced turbo experienced thrust bearing failure during the dyno test which adversely affected test data (due to extra tip clearance, loss of lubrication)









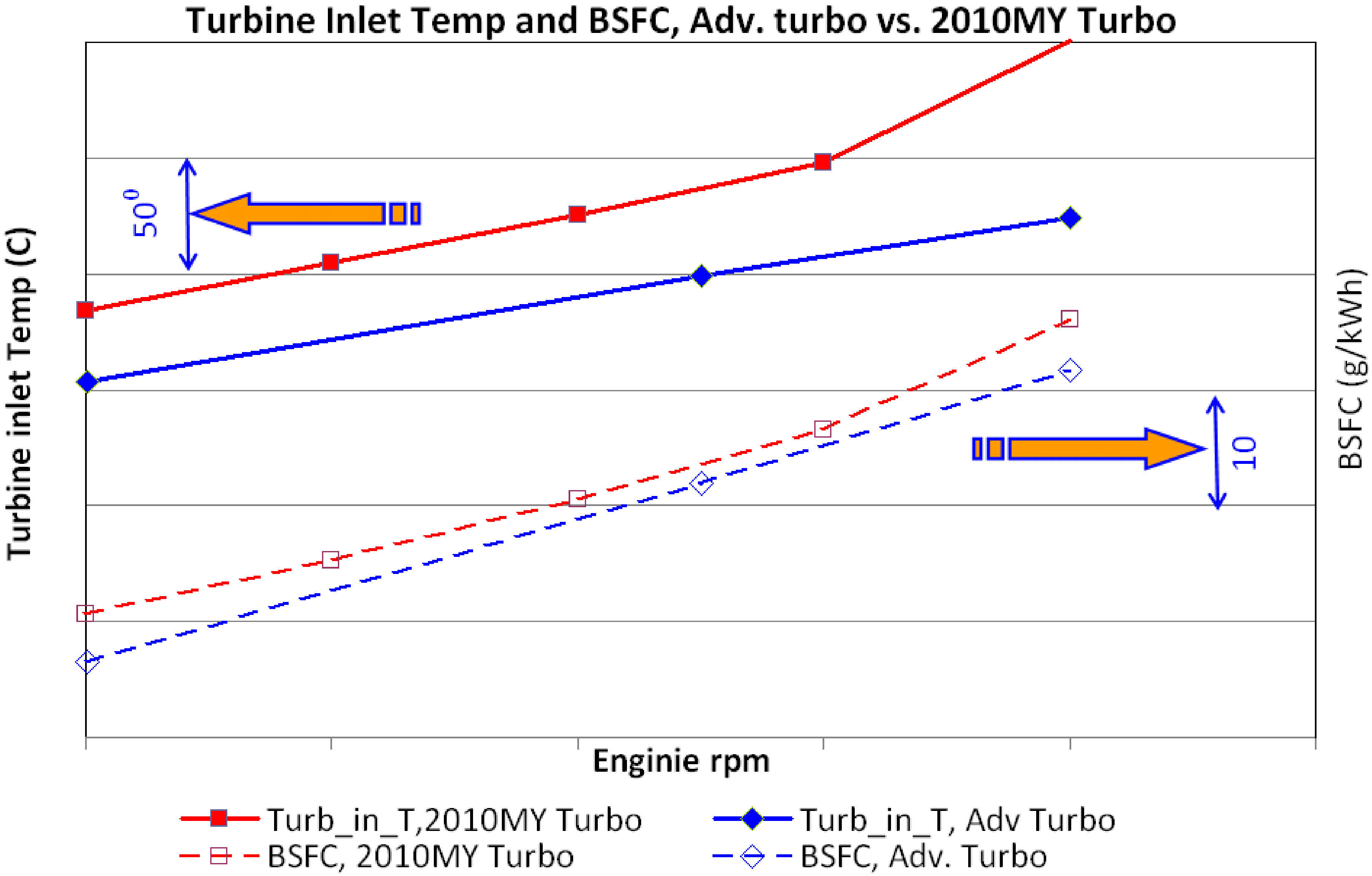
The advanced turbo on a steady state engine dynamometer test has, more than expected, demonstrated ~2% BSFC improvement over 2010MY turbo, despite the bearing failure and hardware variances

Light load engine dyno test

Technical Accomplishment in 2010 (cont.)

Full load engine dyno test

The advanced turbo also has better efficiency at the same full load which translates into lower turbine inlet temperature and BSFC over production turbo



The engine dyno test is consistent with the turbo flow bench test results, i.e. the advanced turbo has better efficiency over wider operation range compared with a 2010MY turbo even though the turbo was running with an old, underperforming thrust bearing on the engine

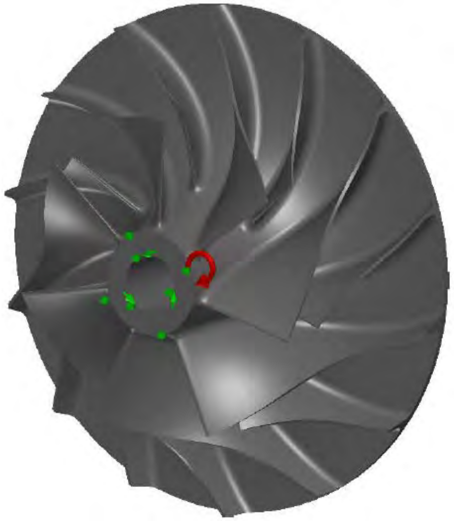
Technical Accomplishment in 2010 (cont.)

Large turbo with arbitrary surface impeller

30% wider flow capacity

Lower manufacturing cost

Small turbo with ruled surface impeller

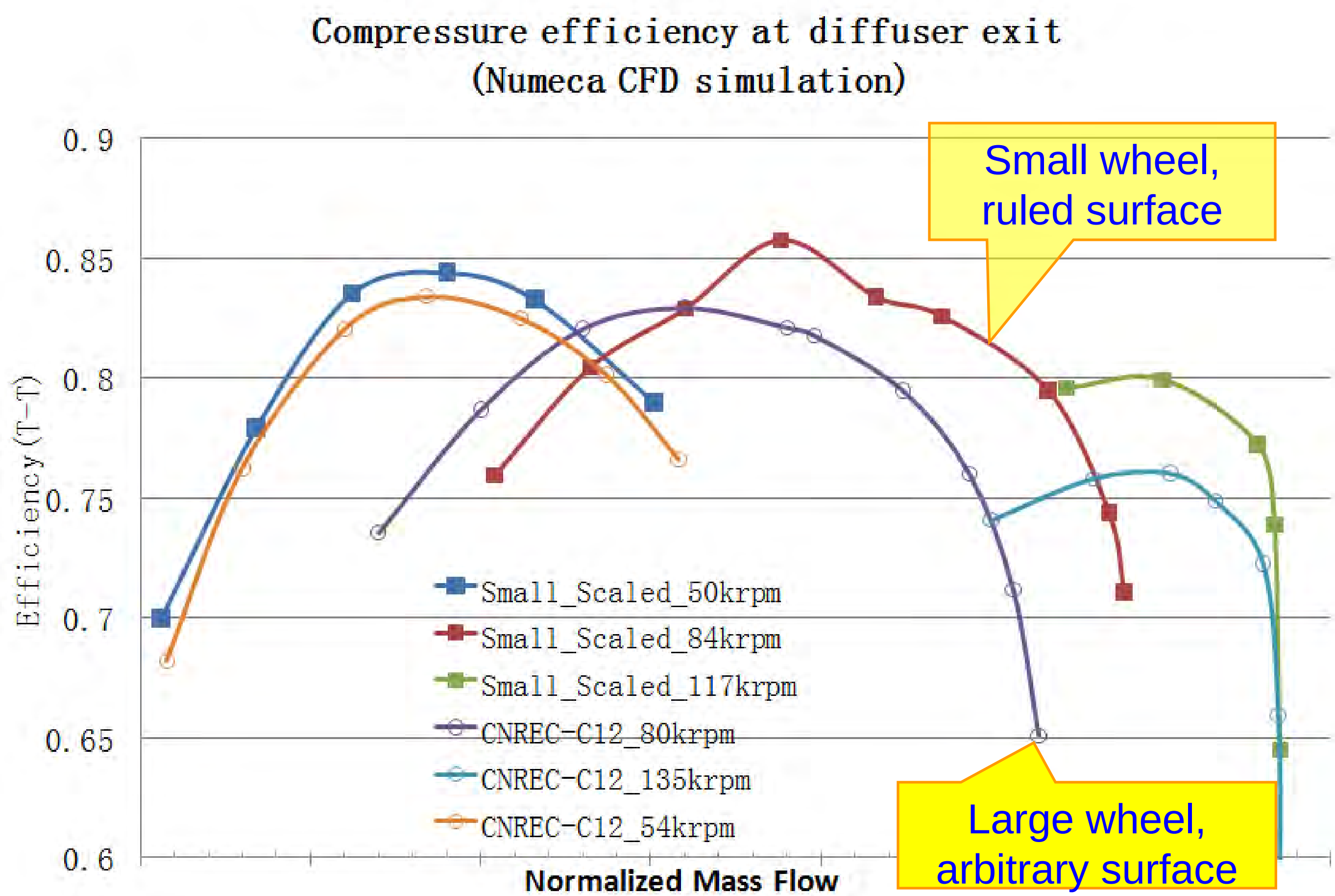


Compressor design strategy changes from MD turbo to LD turbo

Concepts NREC

Wayne State University

Technical Accomplishment in 2010 (cont.)



Design of LD turbo:

- More than scaling down from large wheel since small LD diesel has 30% more power density than large MD diesel
- Explore low cost (ruled surface), large wheel concept for higher efficiency over even wider operation range

Scale up and compare the efficiency: the small LD compressor wheel shows better efficiency than the large MD(C12) wheel. We need advanced casing treatment to extend flow capacity.

Collaboration with other institutions

- Partners
  - Ford (lead, system integration/simulation, control, dyno test)
  - ConceptsNREC (design, analysis, development, fabrication)
  - Wayne State University (CAE and CFD)
  - Two turbocharger suppliers (bench test, fabrication support, design review)

- Technology Transfer
  - Work with existing turbocharger suppliers to incorporate the findings from this research into their new turbo development
  - Under discussion with other parties for potential technology transfer

Proposed Future Work

- Migrate turbo technologies developed on MD/large turbo to LD/small turbo;
  - Since the LD turbo has 30% wider operation range thus the development of LD turbo is more than a “scaling” down;
  - Continue to investigate other advanced turbo concepts for additional operation range extension and efficiency improvement
- Control and actuation system development
- Fabrication and flow bench test validation of LD/small turbo performance
- Engine dyno test demonstartion:
  - Steady state and transient calibration
  - Engine dyno test demonstration for fuel economy improvement at Tier II Bin5 emission level.

Summary

- Flow bench test validation of a compressor with advanced casing treatment;
  - Flow bench test at suppliers' sites confirm the benefits that were numerically predicted in 2009;
- Engine dyno test of HD/large turbo performance
  - Preliminary data showed 2% BSFC reduction at light load and full load areas
  - The bearing failure and other hardware variances adversely affected the results. The engine with back to back hardware comparison will be back in the test cell for additional tests soon.
- LD/small turbo development:
  - Lessons learned from MD/large turbo development will be incorporated into the LD/small turbo development for even better efficiency over wider operation range.

Overall, the team is confident to deliver the program targets, i.e. 2-3% FE savings over customer driving cycles with 15-20% extension of operation range.

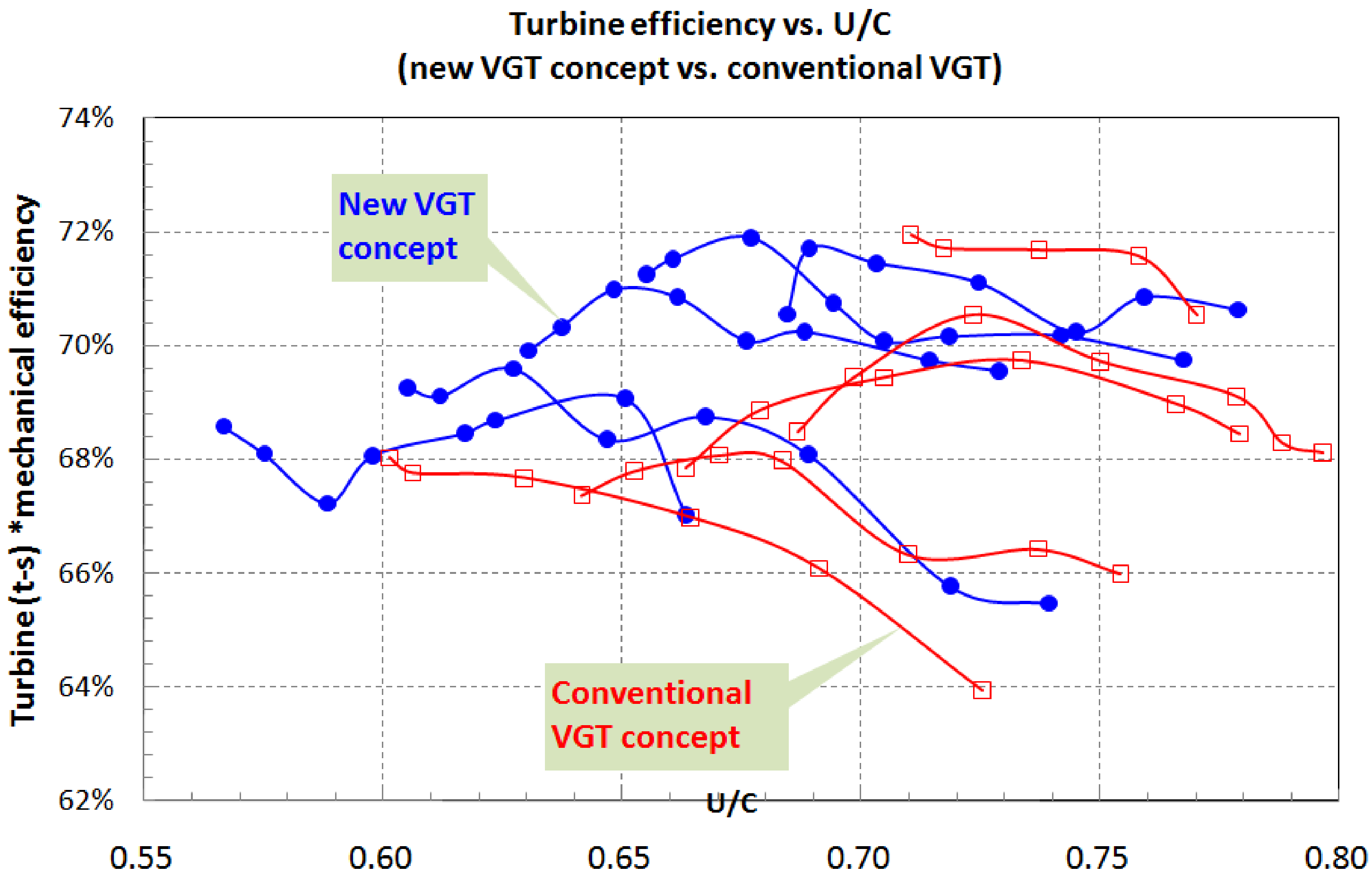
Technical Back-up Slides

Technical Accomplishment in 2010 (cont.)

Advanced VGT concept:

High efficiency at low U/C and high efficiency over wide operation range

Conventional VGT has significant loss between nozzle and turbine blades at off-design operation conditions



CFD simulation of turbine efficiencies with adv. VGT technologies

Details of the VGT concept is proprietary and cannot be disclosed at the moment

Concepts NREC

Wayne State University