Advanced boost system development for diesel HCCI/LTC applications

2009 DOE Peer Review

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May 21, 2008

Project ID: ace_36_sun

“This presentation does not contain any proprietary or confidential information”

Overview

Timeline

- Project start: Oct. 1, 2007
- Project end: June 30, 2010
- Percent complete: 30%

Budget

- Total project funding
  - DOE: $1,495K
  - Contractor: $1,495K
- FY08 (received): $75.4K
- FY09 (received, Feb. '09): $104K
- FY09 (remaining): $467K
- FY10 (expected): $850K

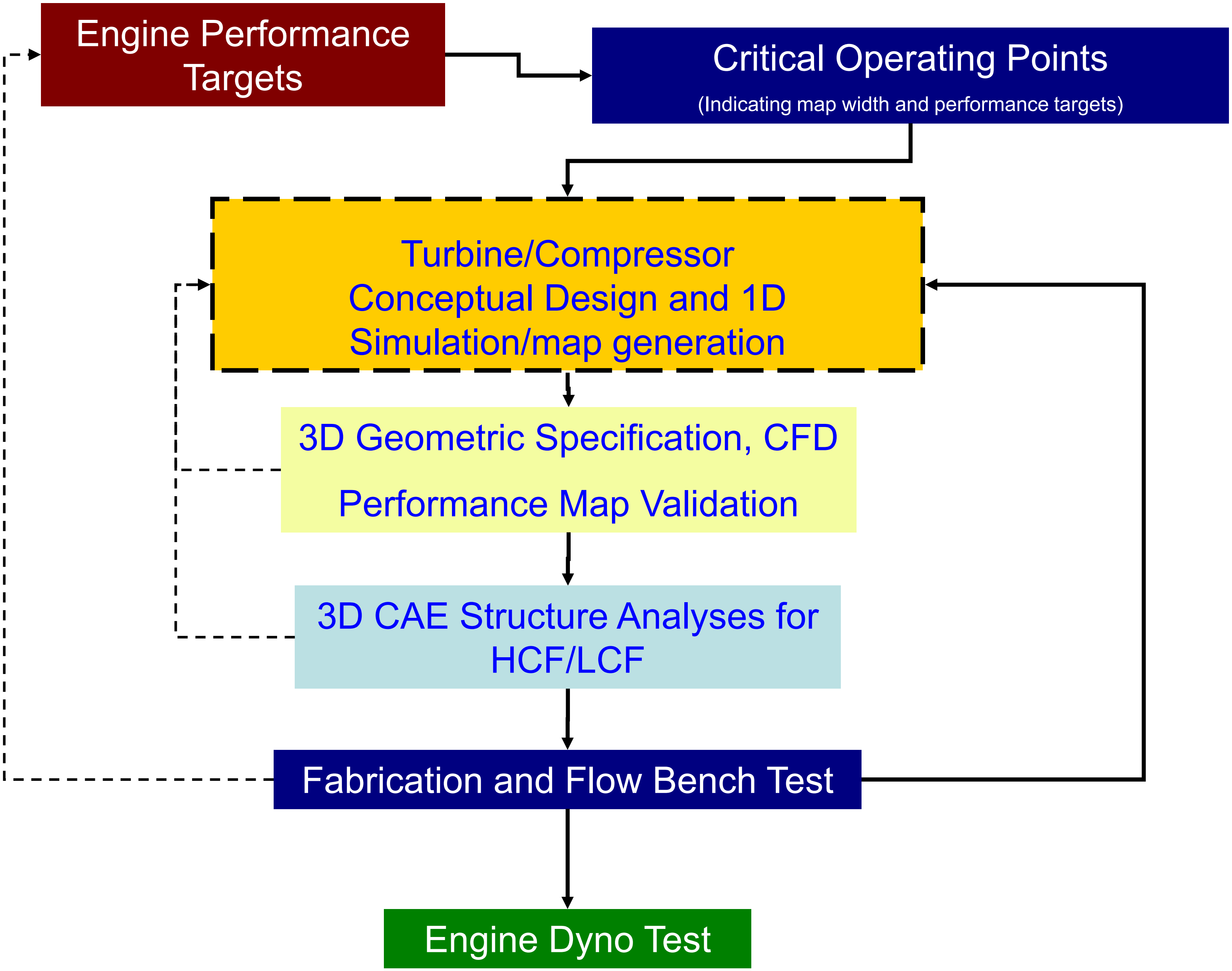
Barriers

- Heavy cooled EGR is needed for all diesel HCCI/LTC, which is accompanied by loss of efficiencies in compressor and turbine
- Heavy EGR and low airflow through compressor (for high pressure EGR) pushes operation point close to compressor surge, esp. during tip-out
- Low oxygen content in the intake and poor turbo efficiency compromise diesel transient response

Partners

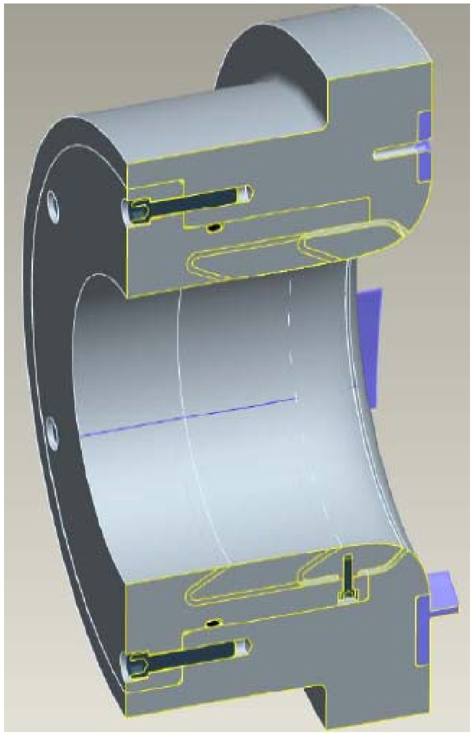
- ConceptsNREC
- Wayne State University

Approach


Engine Performance Targets
Critical Operating Points
(Indicating map width and performance targets)
Turbine/Compressor Conceptual Design and 1D Simulation/map generation
3D Geometric Specification, CFD
Performance Map Validation
3D CAE Structure Analyses for HCF/LCF
Fabrication and Flow Bench Test
Engine Dyno Test

Approach

- *Ultra low solidity airfoil compressor diffuser vane to achieve optimal efficiency and flow range trade-off*
- *Optimal design of compressor blade geometry to shift high efficiency area to low flow area*
- *Mixed flow turbine to reduce secondary flow loss thus improve turbine efficiency over wide operation range*
- *CFD guided optimal design of compressor casing treatment to further extend operation range*
- *CAE high/low cycle fatigue (HCF/LCF) analyses to ensure production feasibility*



Accomplishment in 2008

- 1D modeling of compressor and turbine performance;
- 3D CFD performance validation of the compressor and turbine designs (12 iterations on compressor and 9 on turbine);
- 3D CAE analyses for high cycle and low cycle fatigue compliances;
- Fabrication of two compressor wheels with modular compressor configurations (casing treatments, diffusers) and one mixed flow turbine (using Honeywell's turbocharger center housing);
- Flow bench test to validate against 1D and 3D aerodynamic designs/analyses;
- The 1D design software was found very useful in narrowing down design space and providing quick feedback of different design options. However, the 1D software is mostly based on very limited empirical correlations thus highly application dependent. The prediction accuracy is far from satisfactory;

Accomplishment in 2008 (cont.)

- The 3D CFD simulation is very effective in predicting performance even though the near surge conditions cannot be accurately predicted with steady state CFD simulation mostly due to numerical stability issues. Transient CFD simulation will be included in future analyses where applicable and possible

- The first design based on flow bench test data did not fully achieve design target (~5% vs. 10% improvement on compressor efficiency and 8% vs. 10% on turbine side at the speed ratio where it was tested, compared with those used in current production). It does help correlate simulation with flow bench test data and identify areas need further improvement in both numerical analyses and turbocharger designs.

- The CFD simulation indicated that both surge and chock occur at the inlet of compressor impeller for current impeller design

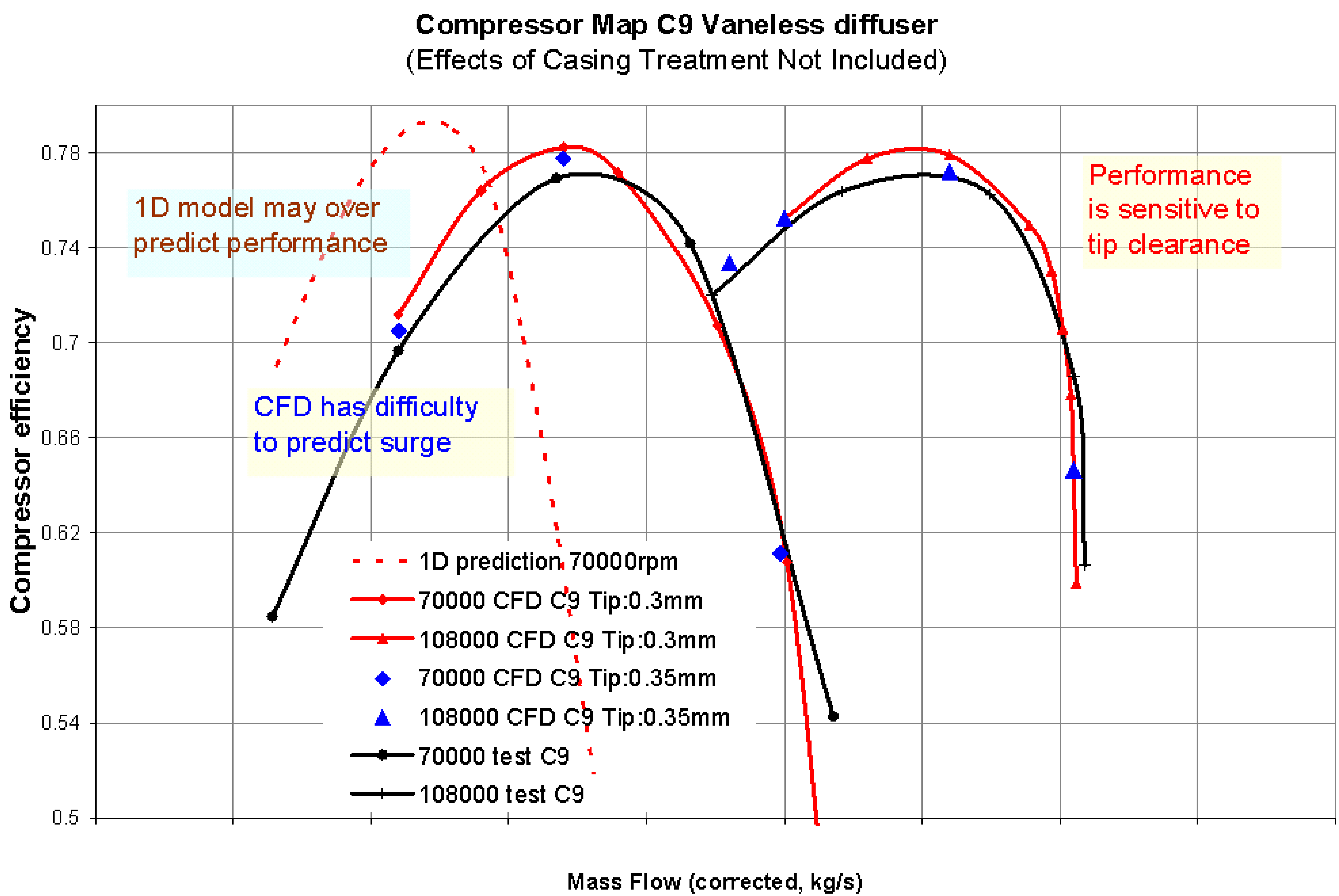
Accomplishment in 2008 (cont.)

- As a result, it was found that optimal compressor casing treatment can provide effective surge control even without efficiency penalty.

- Based on CFD analyses on various compressor inlet guide vanes (VIGV), so far an optimal VIGV configuration with desired operation range enhancement without compromise in compressor efficiency has not been identified;

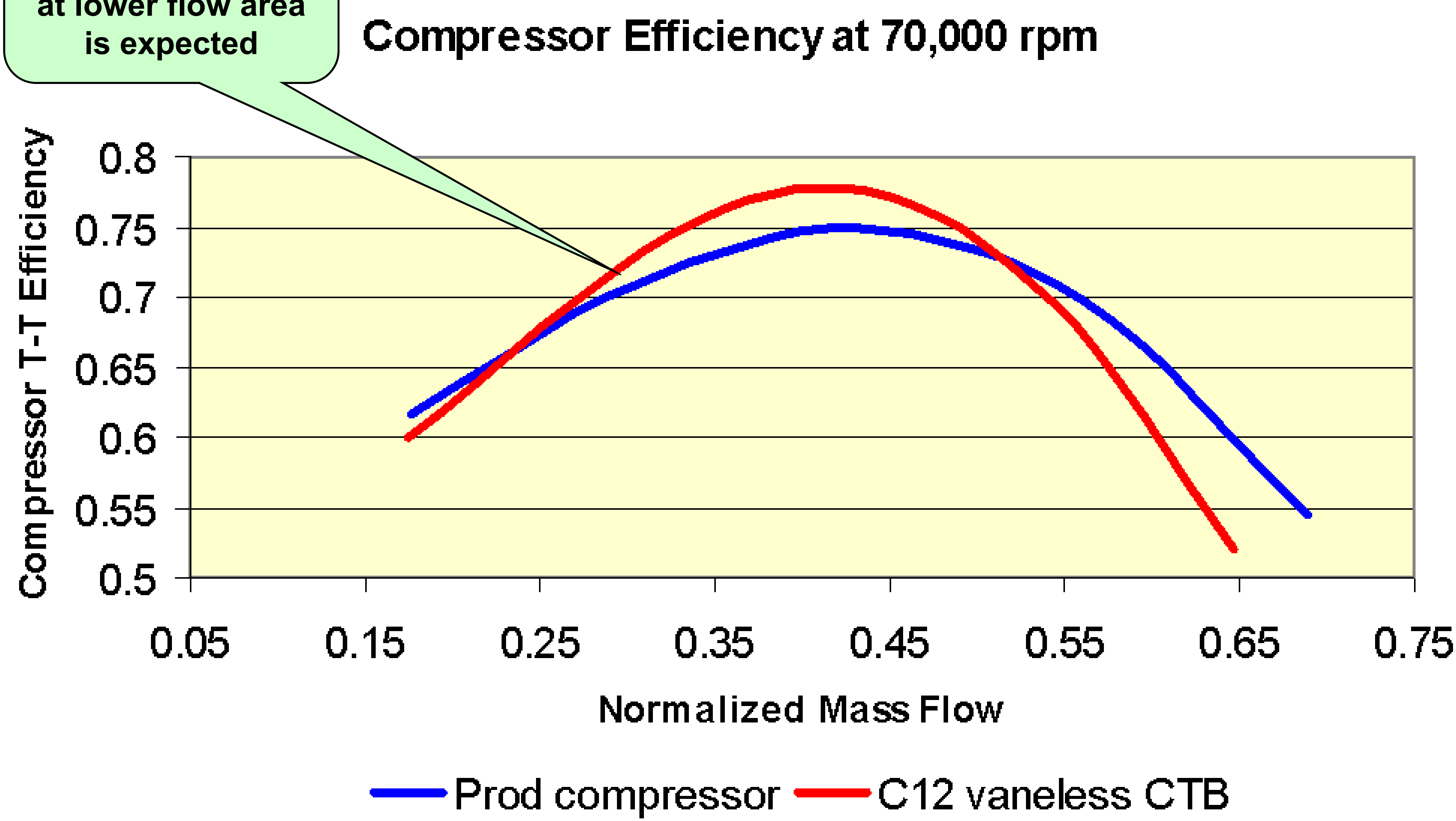
- The mixed flow turbine demonstrated encouraging performances. The turbine performance correlates well with 1D and 3D simulation. However, due to the constraints of the cold flow bench as well as the turbocharger center housing to which the turbine was matched, the efficiency at low speed ratio could not be demonstrated; (test validation on an alternative hot flow bench will be pursued in 2009)

1D/3D Simulation and Flow Bench Test Correlation

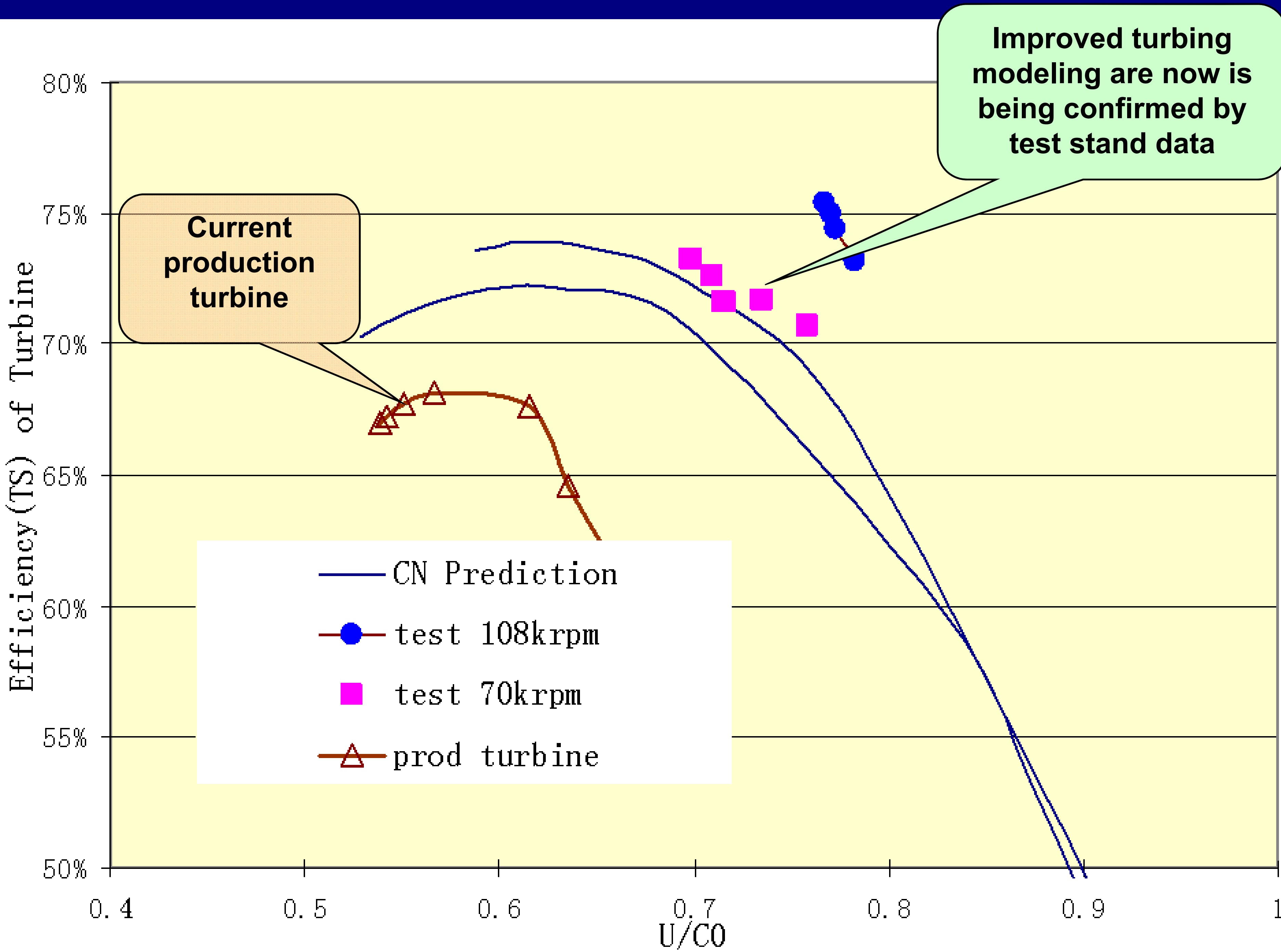


Flow bench test on one compressor design: Compressor efficiency improved but not sufficient

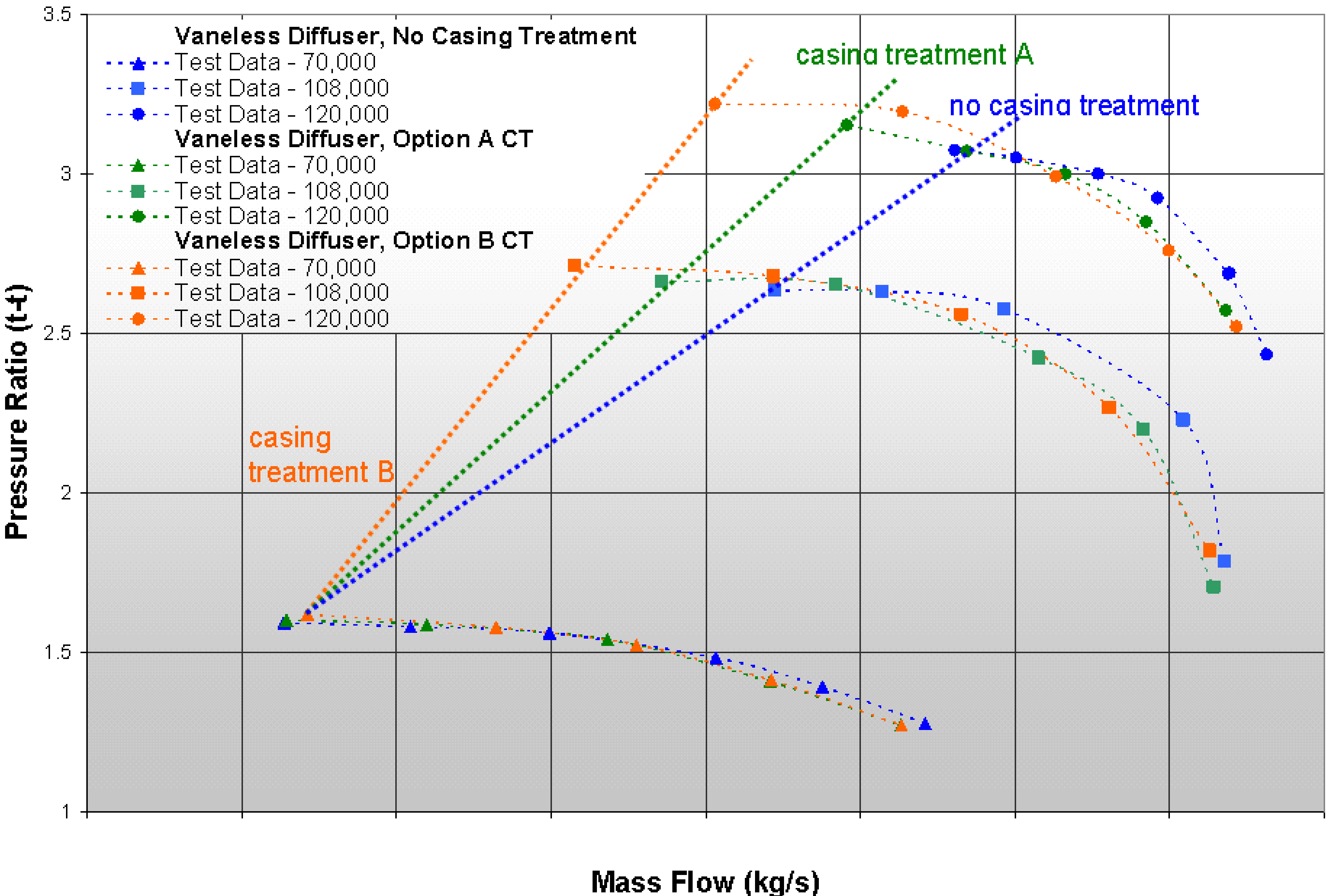
More improvement, esp. at lower flow area is expected



Flow bench test: Mixed flow turbine efficiency improved

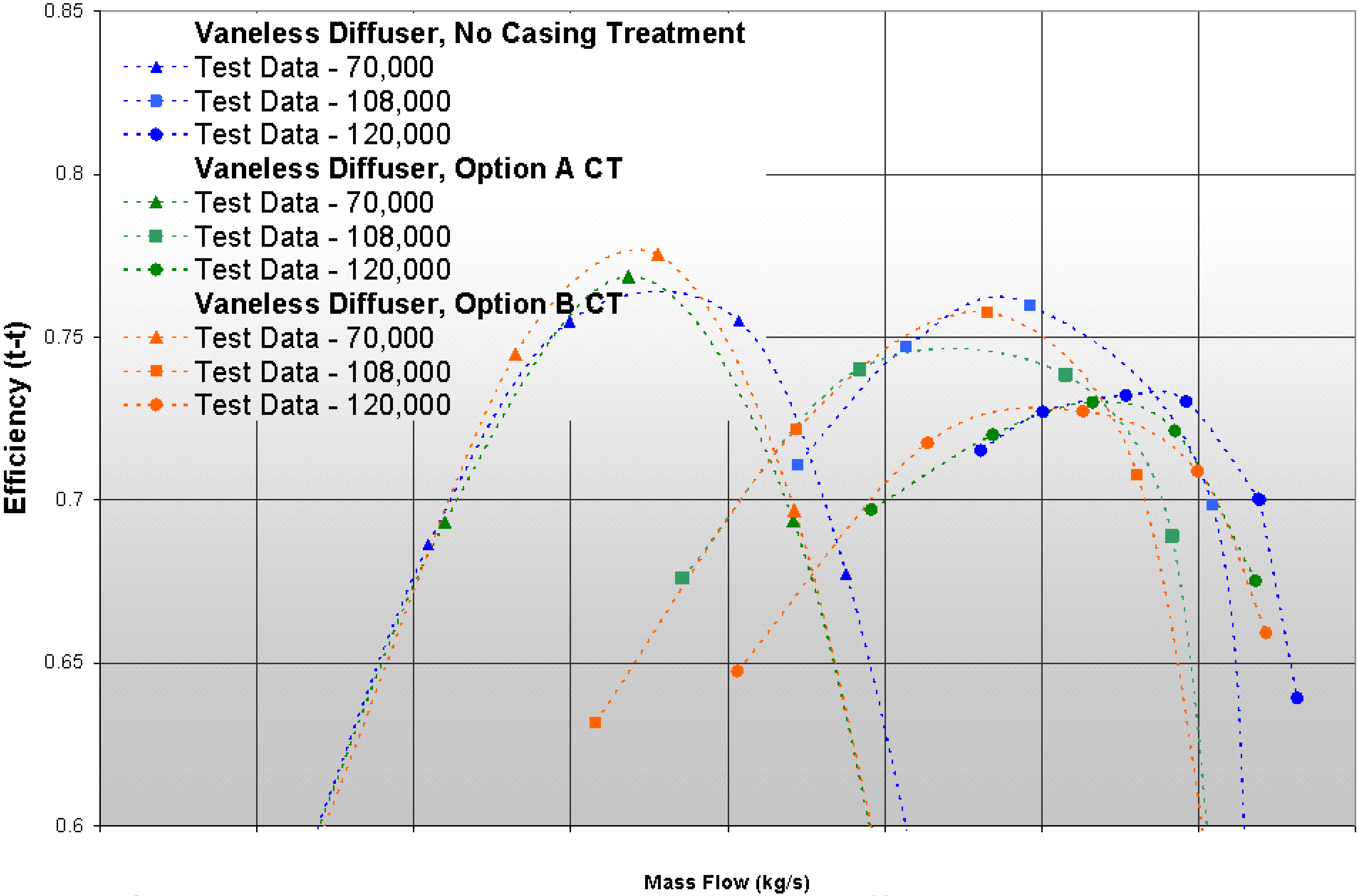


Technical accomplishment in 2008



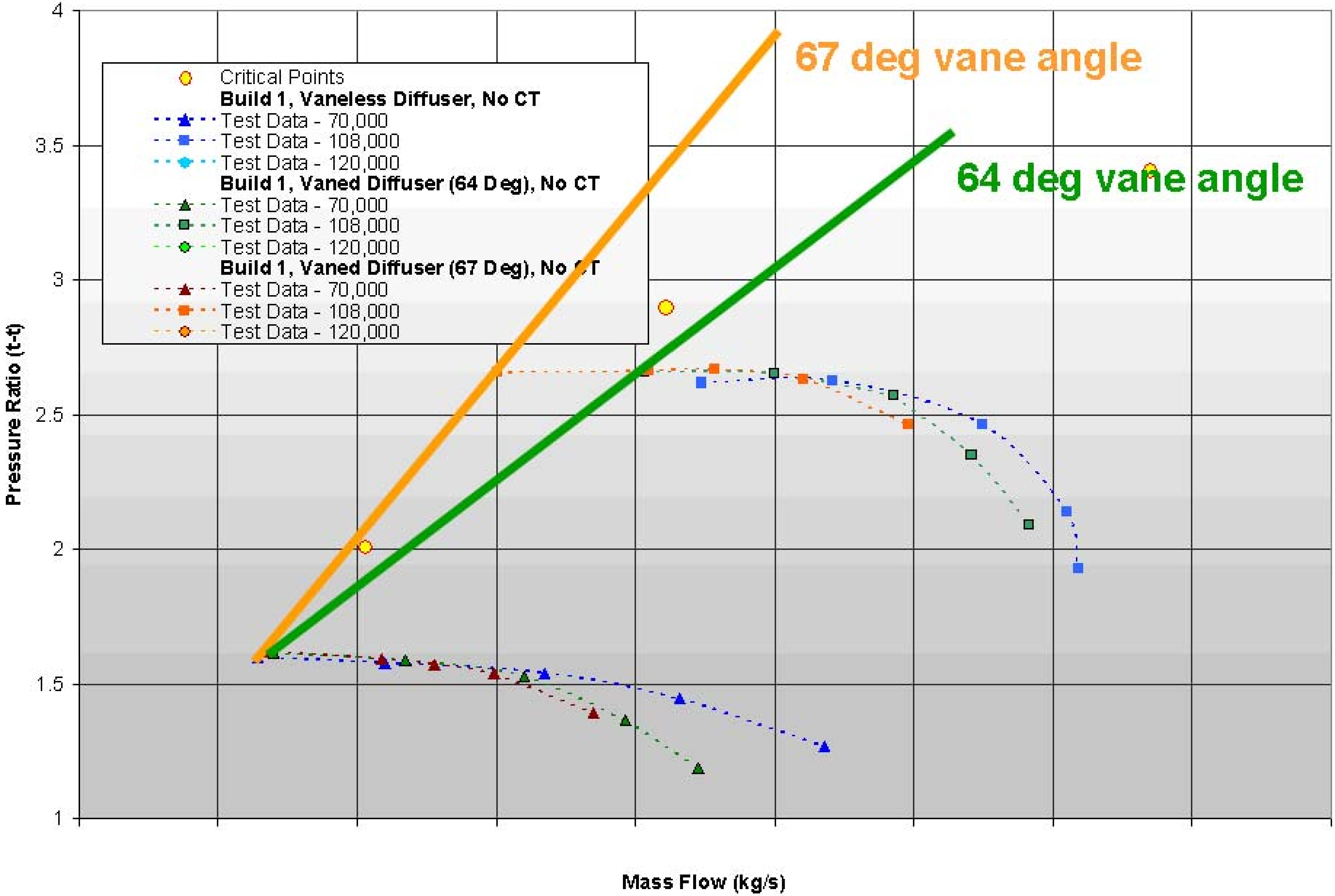
Optimal casing treatment enhanced operation range

Technical accomplishment in 2008



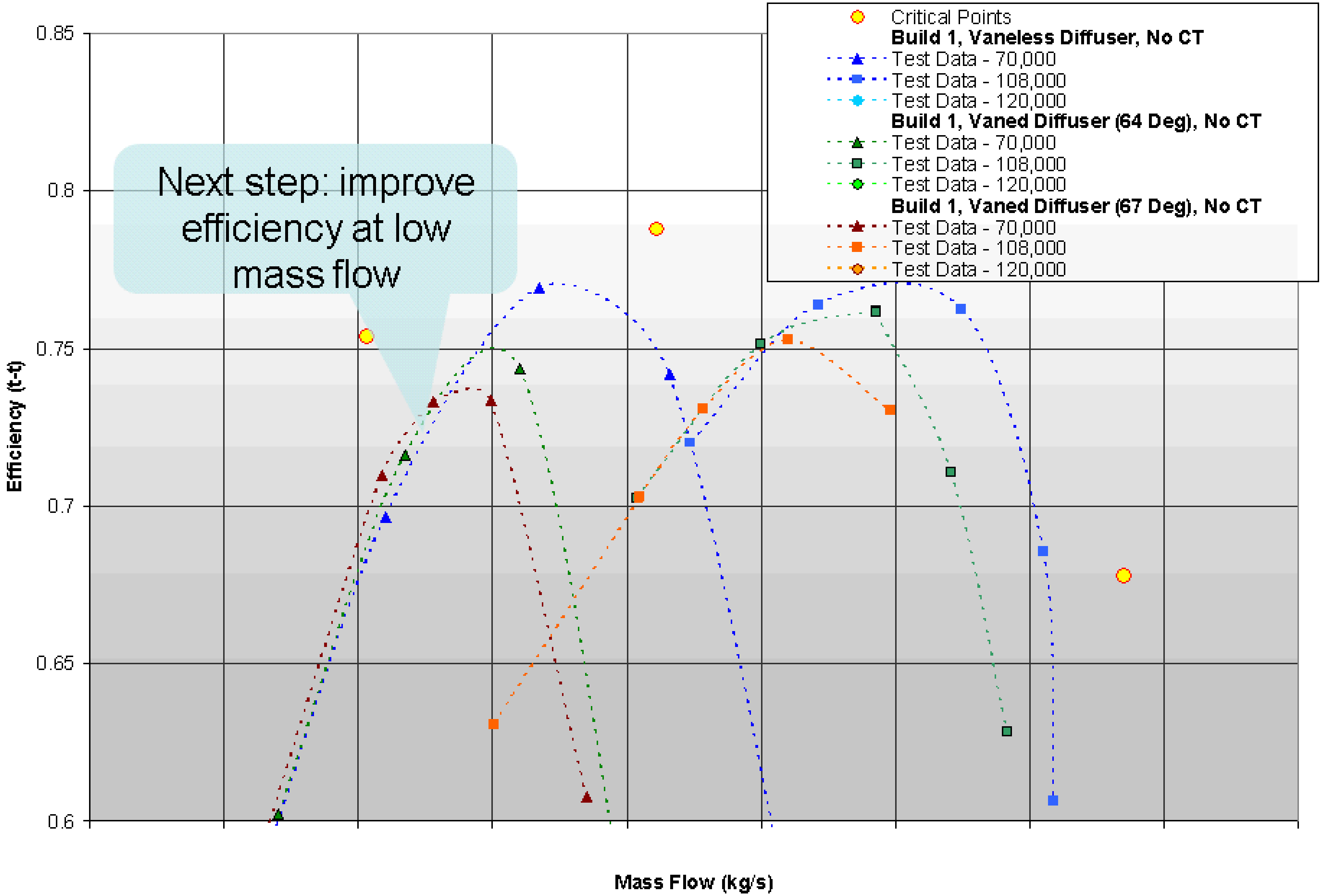
Optimal casing treatment improved efficiency at low end

Technical accomplishment in 2008



Diffuser vane angle further improves surge margin

Technical accomplishment in 2008

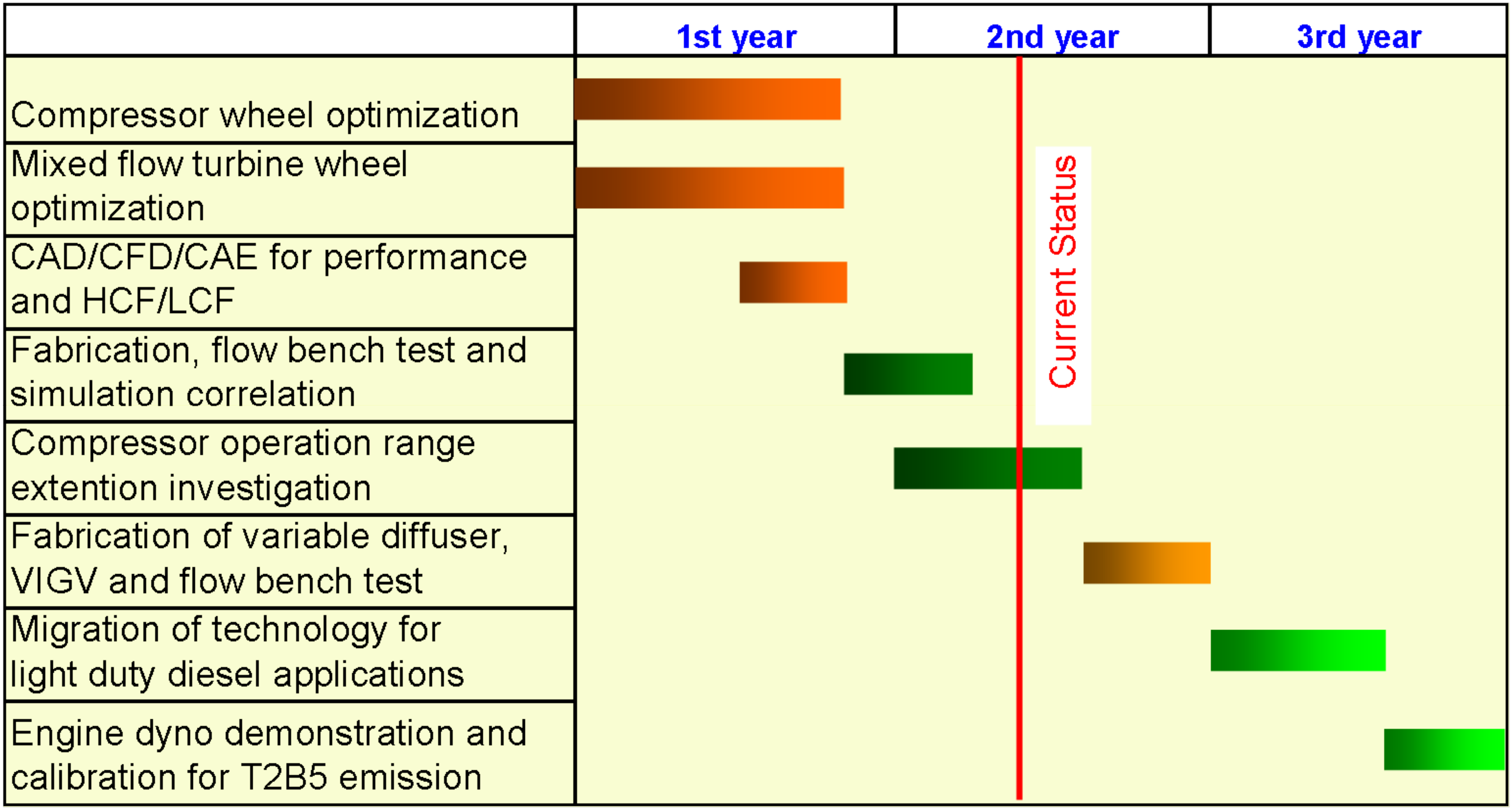


Large diffuser vane angle drops peak efficiency. But off-peak efficiency (e.g. when heavy EGR is used) may be improved

2009 Objectives

- Further improvement in compressor efficiency (5% more), esp. at low mass flow area
  - Impeller refinement
  - Better matching of impeller and diffuser geometry
  - Refinement of casing treatment design
  - Further explore the variable inlet guiding vane
- Test validation of turbine performances in low speed ratio area
- Development and fabrication of compressor control/actuation system
- Flow bench demonstration of fully functional, production feasible wide range turbocharger for midrange diesel application

Milestone


1st year
2nd year
3rd year
Compressor wheel optimization
Mixed flow turbine wheel optimization
CAD/CFD/CAE for performance and HCF/LCF
Fabrication, flow bench test and simulation correlation
Compressor operation range extention investigation
Fabrication of variable diffuser, VIGV and flow bench test
Migration of technology for light duty diesel applications
Engine dyno demonstration and calibration for T2B5 emission
Current Status

Summary

- Turbomachinery overall has a longer history than internal combustion engine. However, the design and analytical tools are NOT as mature as we thought;
- Studies on turbochargers to enable the diesel HCCI/LTC without compromising the fuel economy and aftertreatment efficiency have just started in the industry
- Decision was made during 2008 to pull up one design to build a modulated prototype turbocharger to validate against analyses and confirm design concept.
- Preliminary flow bench test data is encouraging, even though they did not totally achieve the design target. The data will be used to more precisely guide the future improvement on compressor and turbine.

Future works

- Migration of the same technologies to a small turbocharger for light duty diesel application
  - Repeat CAD/CFD/CAE on a small turbocharger for light duty diesel application with well polished analytical techniques and well defined design concepts
  - Fabricate prototype of the designed turbocharger
  - Demonstration on flow bench test
- Demonstration of the turbocharger on engine dynamometer after steady state and transient calibration (optimized for the new boost system) for 3-5% fuel economy improvement on customer driving cycles while meeting Tier II Bin 5 emission