Optimization of a turbocharger for high EGR applications

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<u>*Emission regulation:*</u>

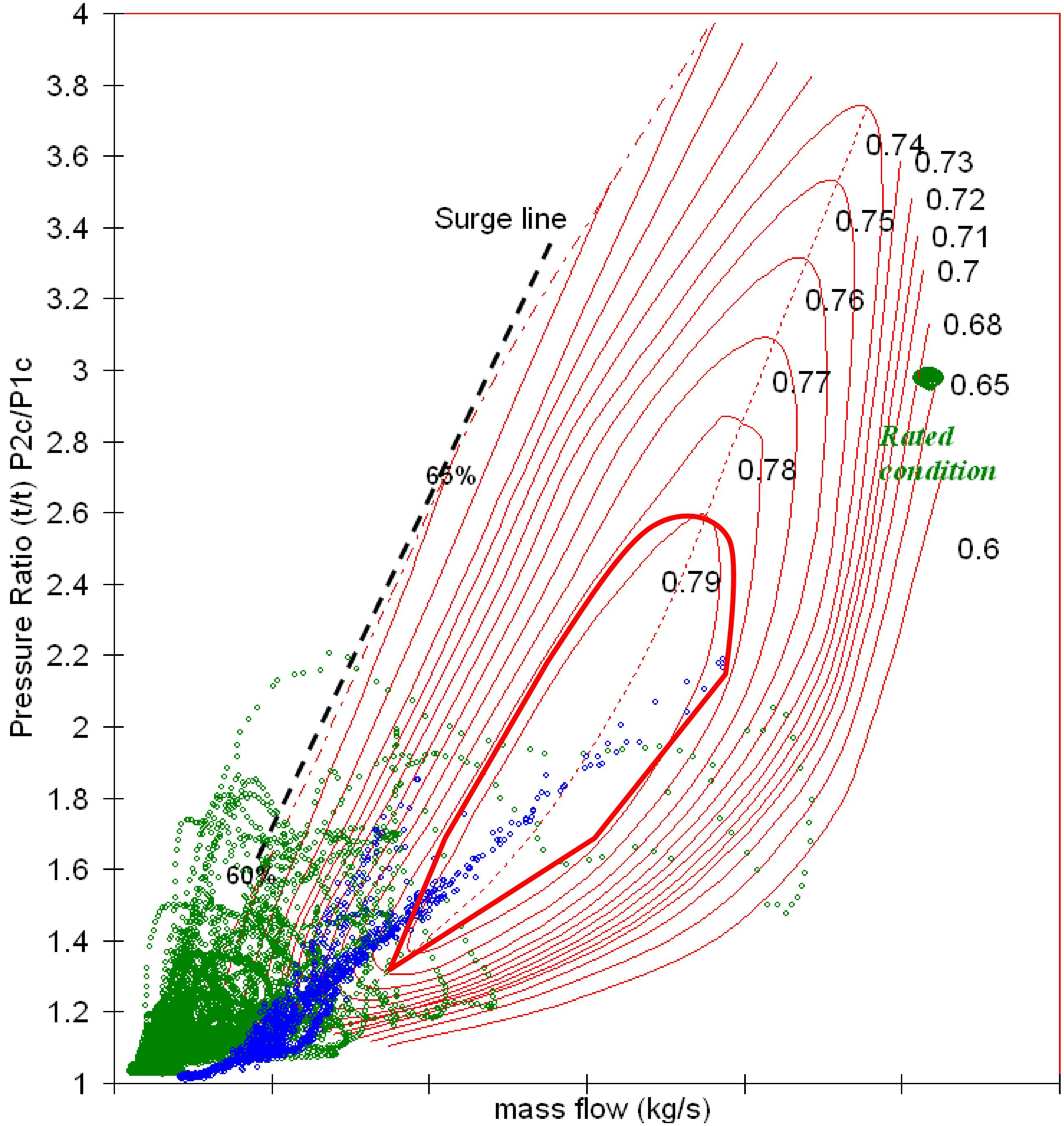
Heavy EGR needed for LTC pushes the operation points into less efficient or even surge area

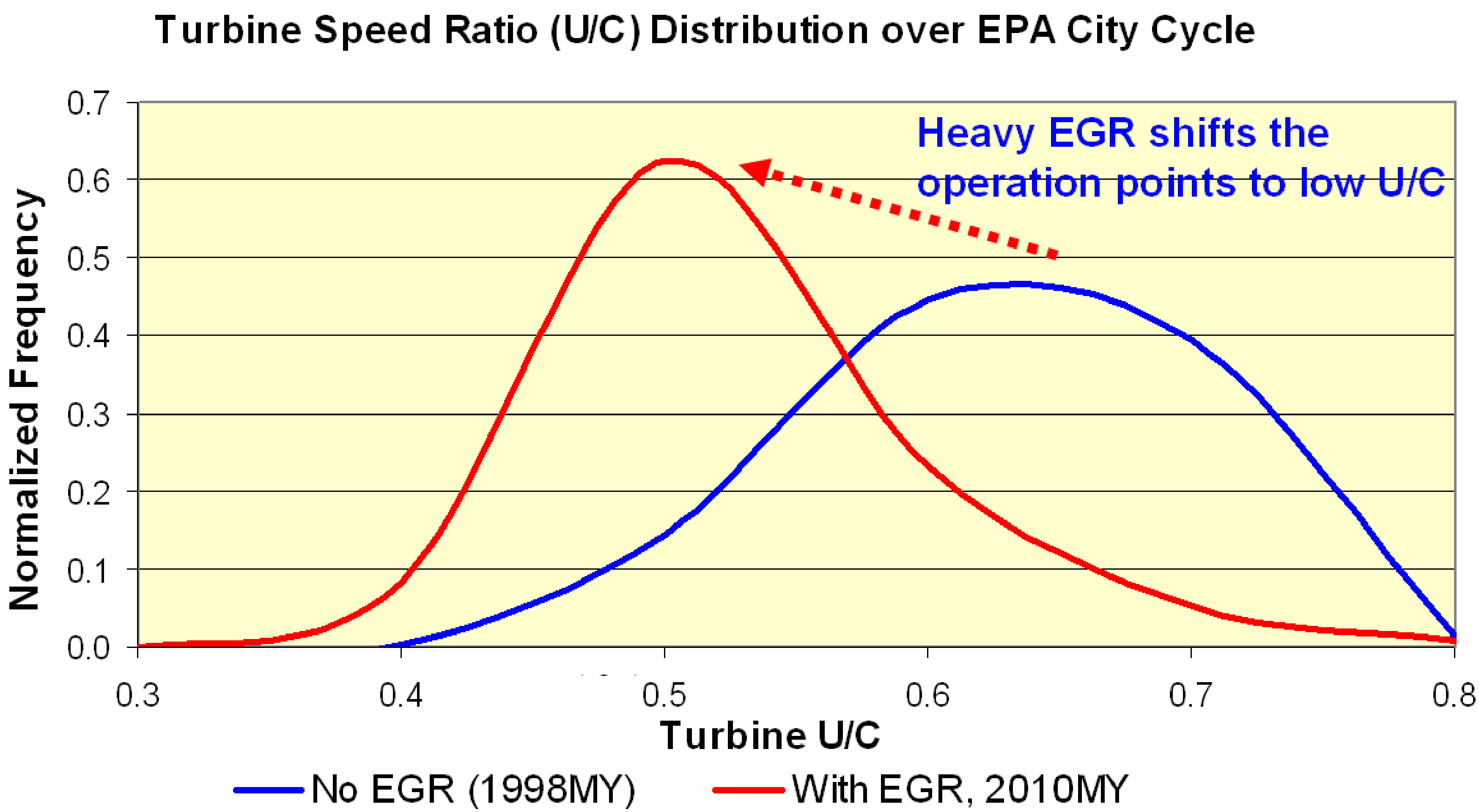
<u>*Market competitiveness:*</u>

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

<u>*Objectives:*</u>

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

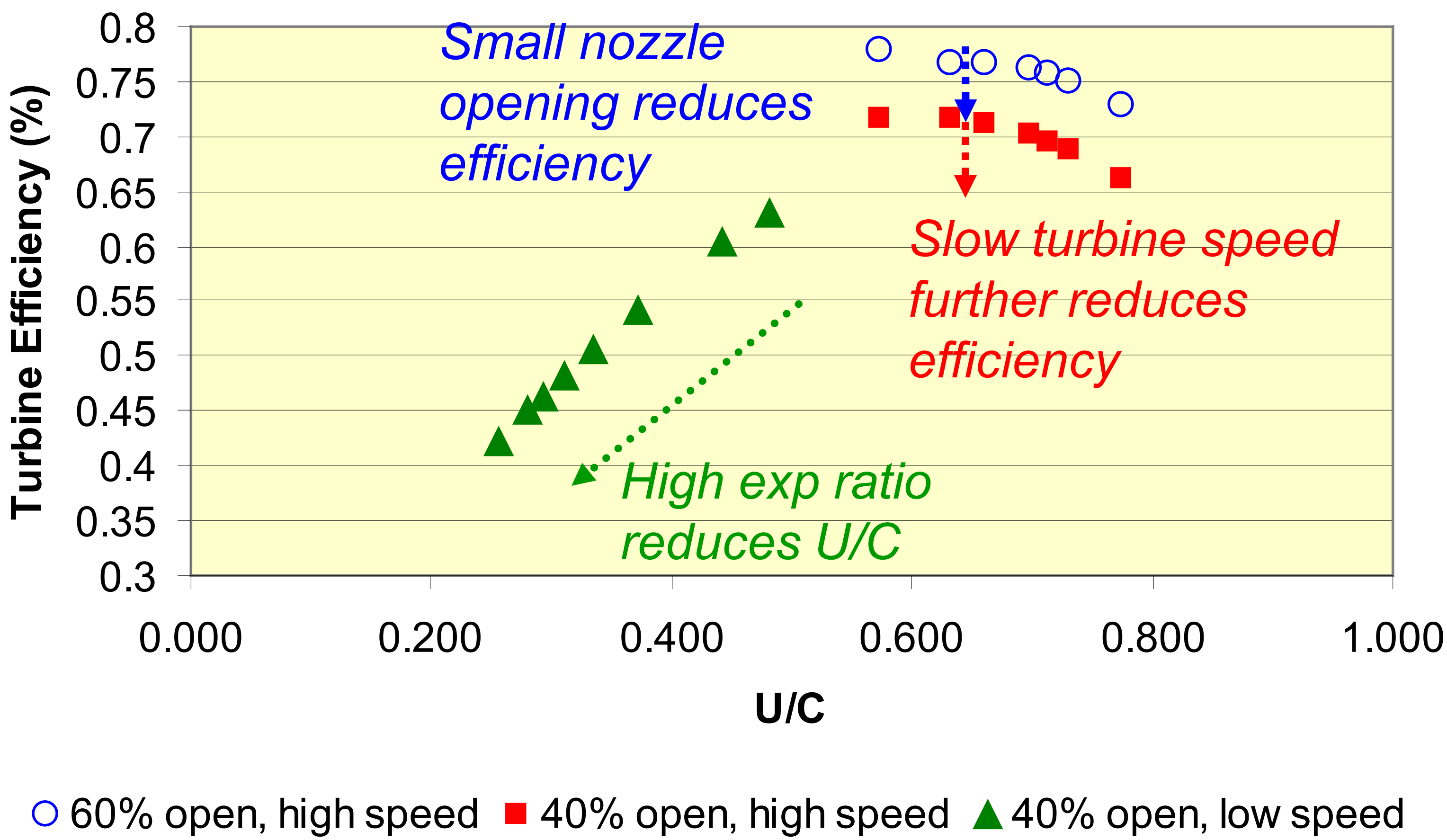




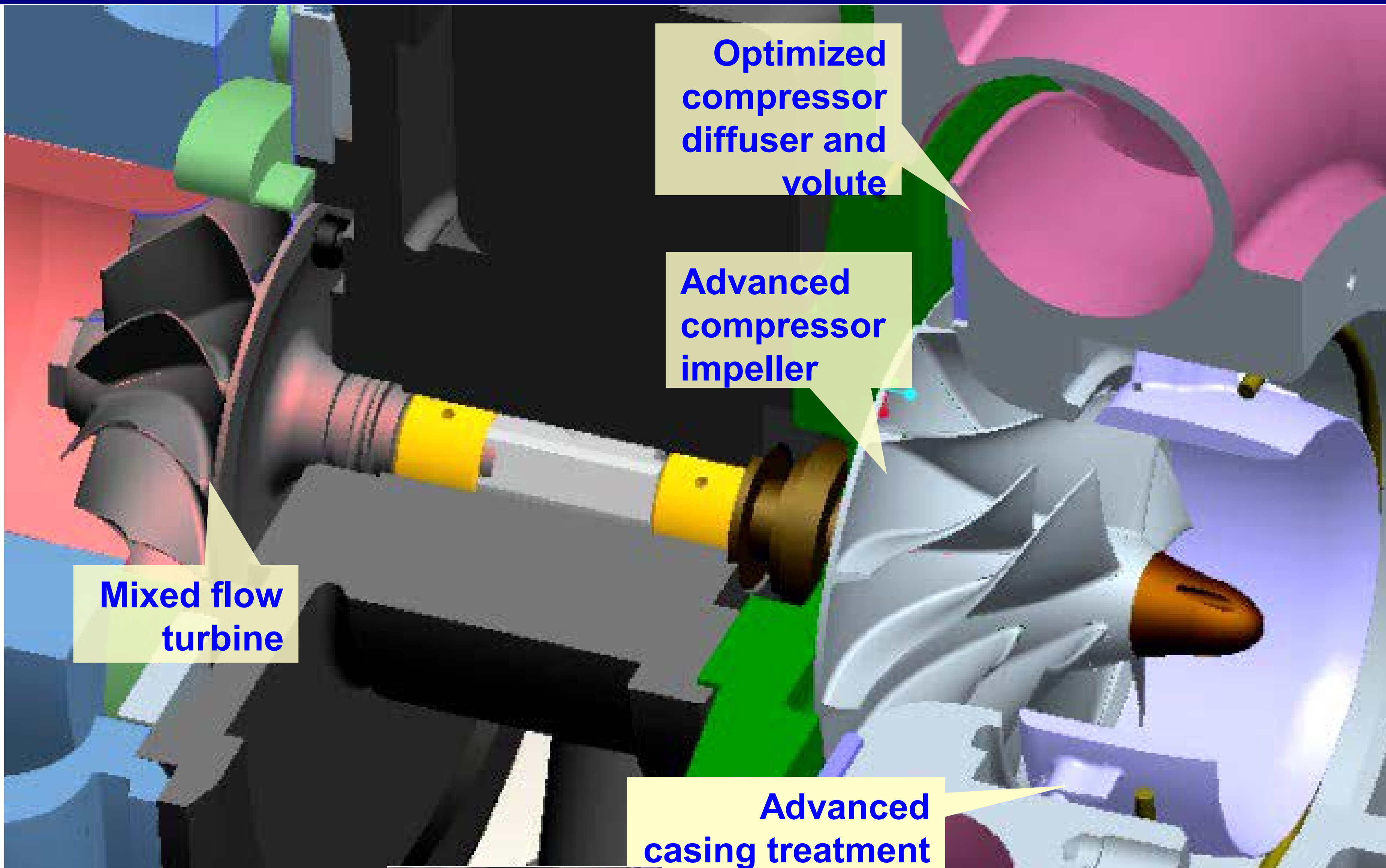
As more EGR is used for NOx reduction, turbine spends more time in low U/C area. Conventional turbine blade, optimized for low/none EGR applications 10-15 years ago, performs well at high U/C but not at low U/C. Therefore future diesel application requires that turbine should have high efficiency in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

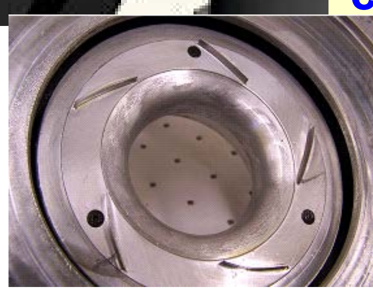
Turbine Efficiency vs. U/C

$$\frac{U}{C} = \frac{U}{\sqrt{2C_pT_0\left[1-(\pi_T)^{-0.285}\right]}}$$



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


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



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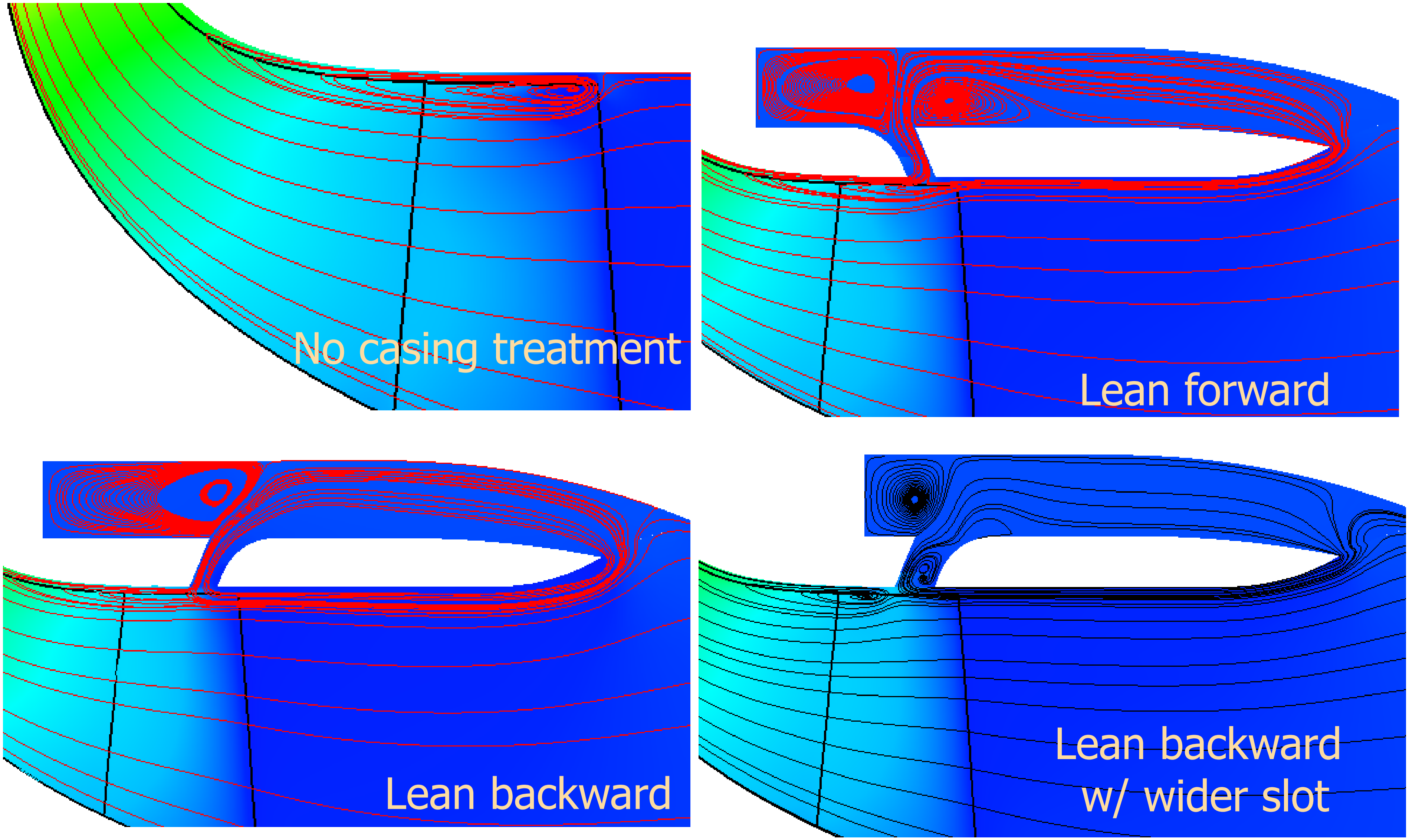
CFD Simulation to optimize casing treatment design



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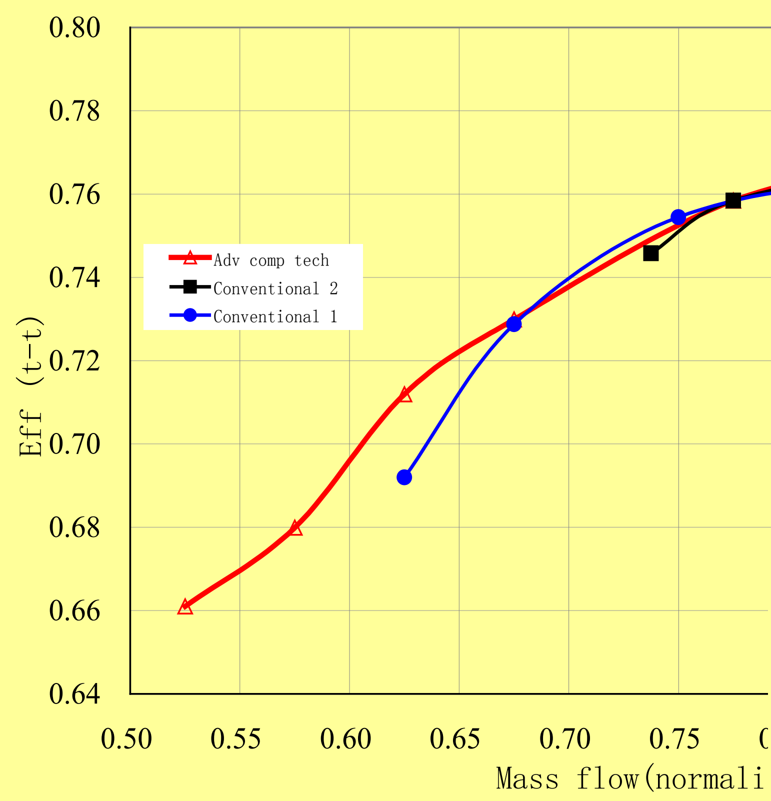
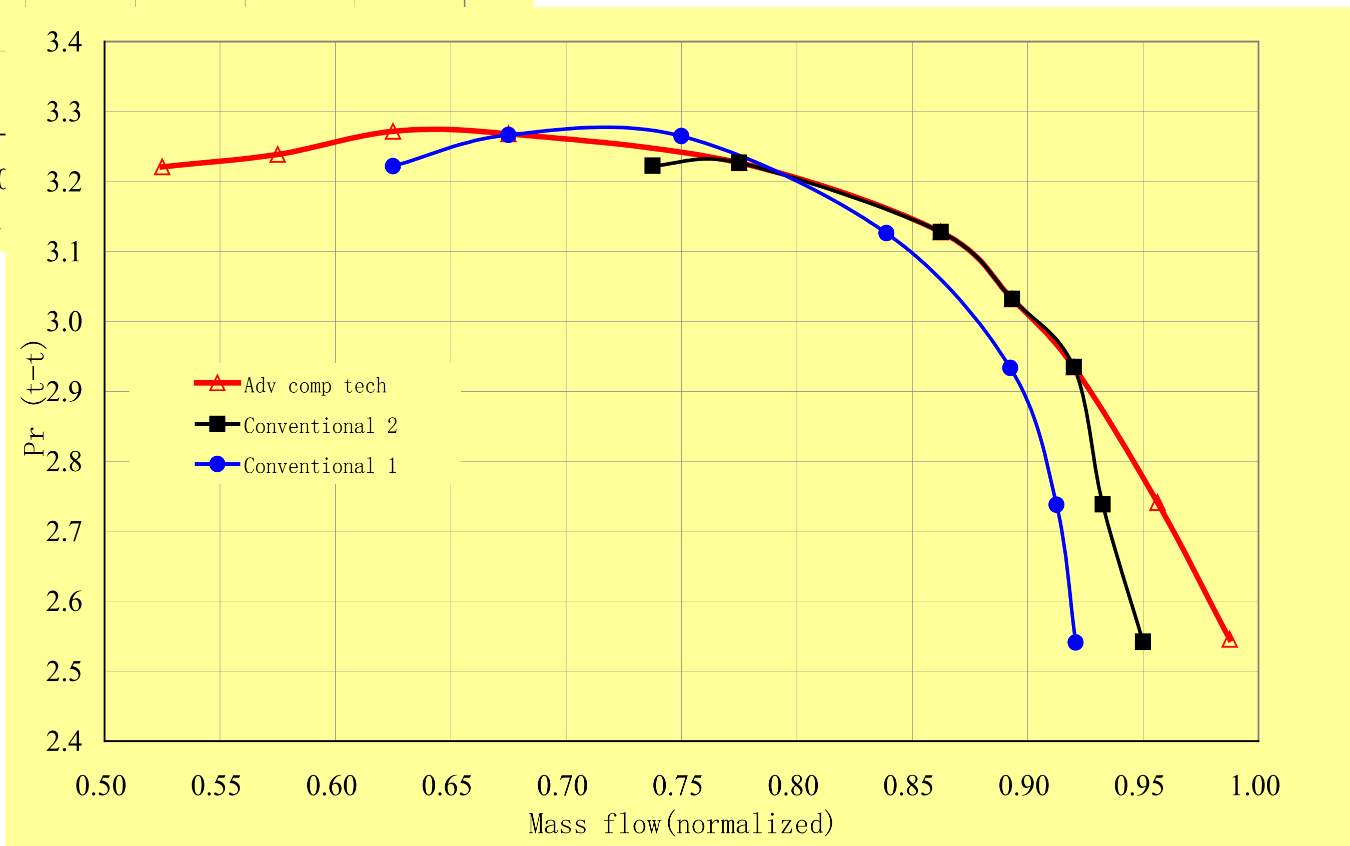
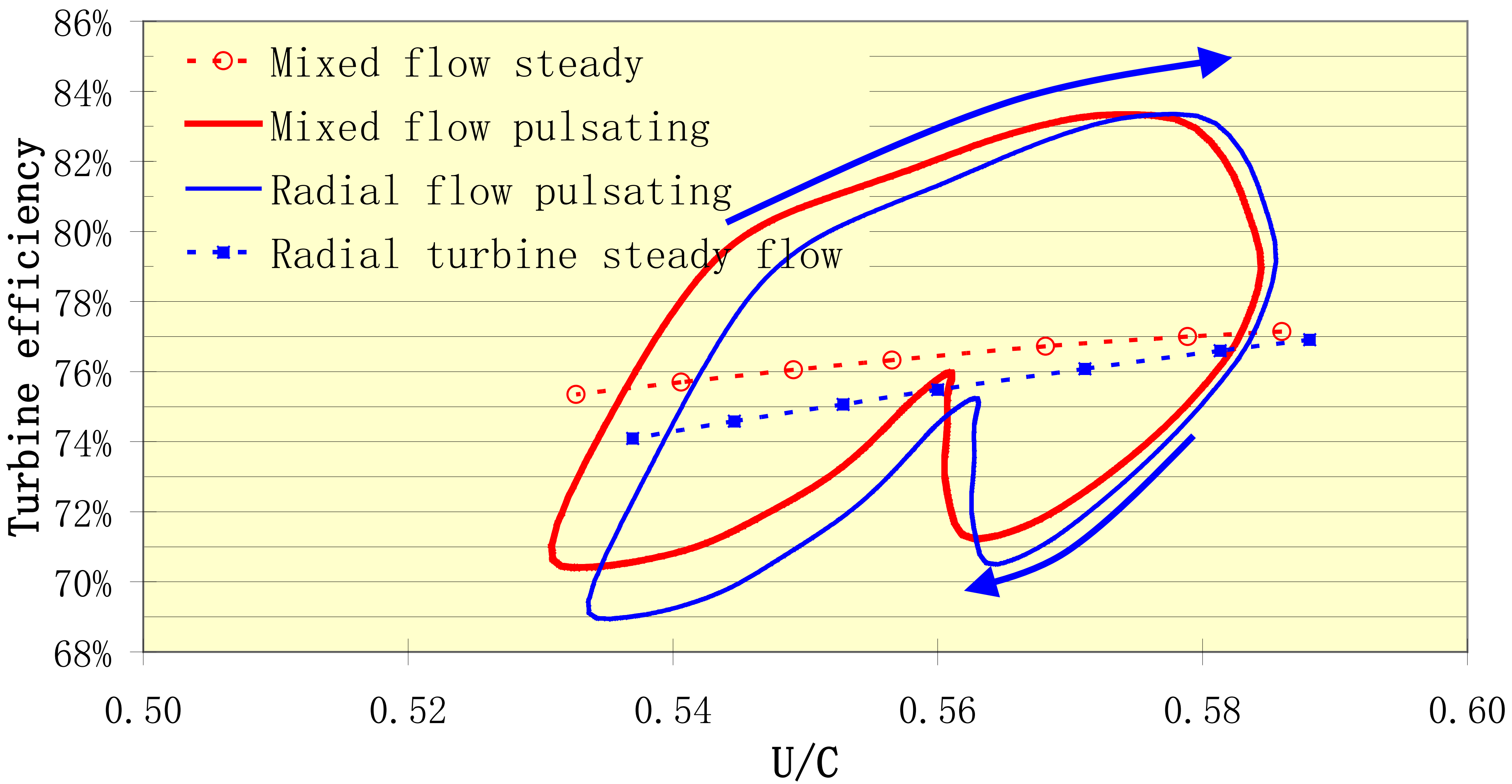
Simulation @ 120krpm (with volute)





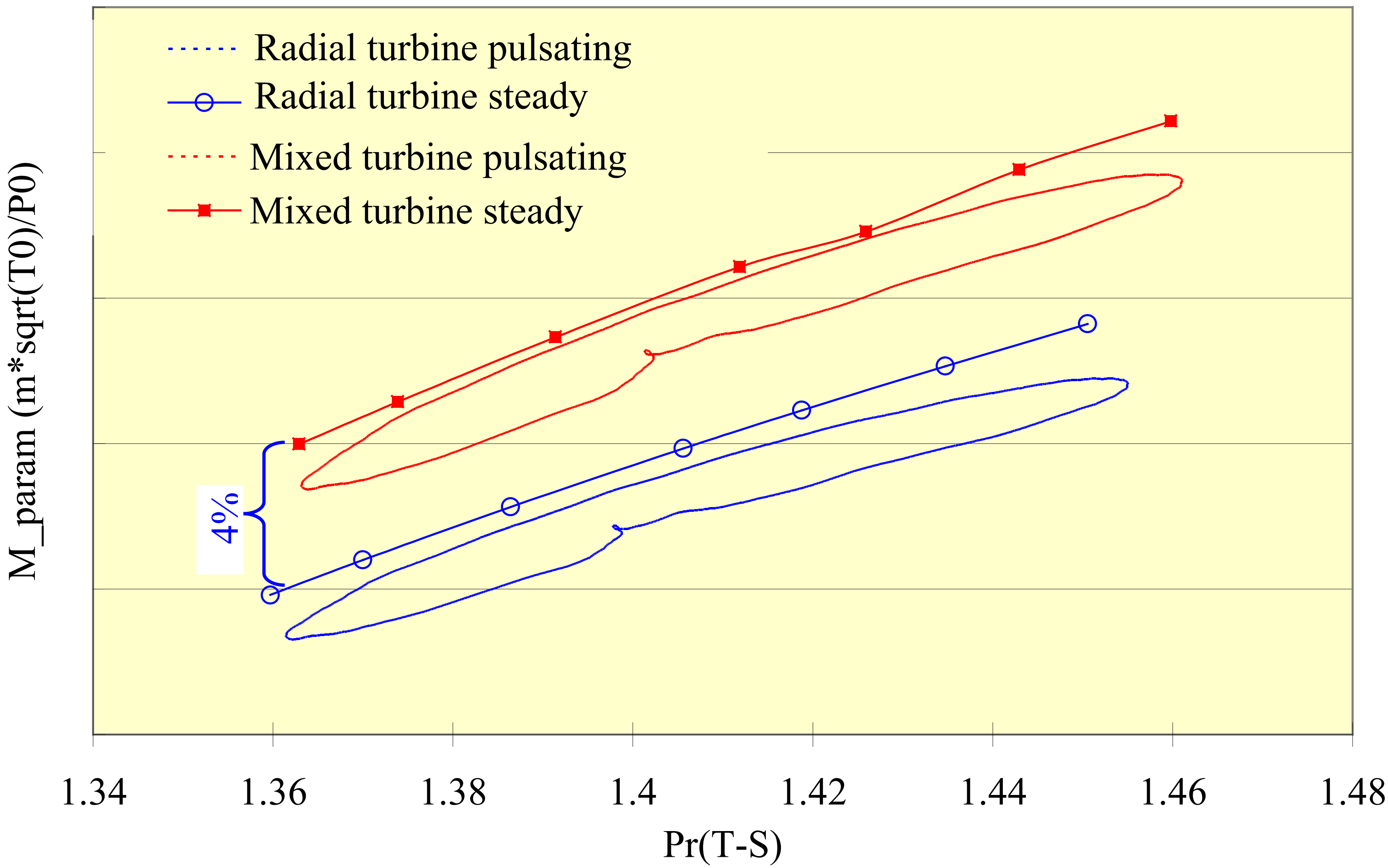
Optimization of casing treatment can extend flow range/surge margin without compromising efficiency

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

Mass flow of mixed flow turbine vs. radial flow turbine



Mixed flow turbine has better flow capacity that may help downsizing

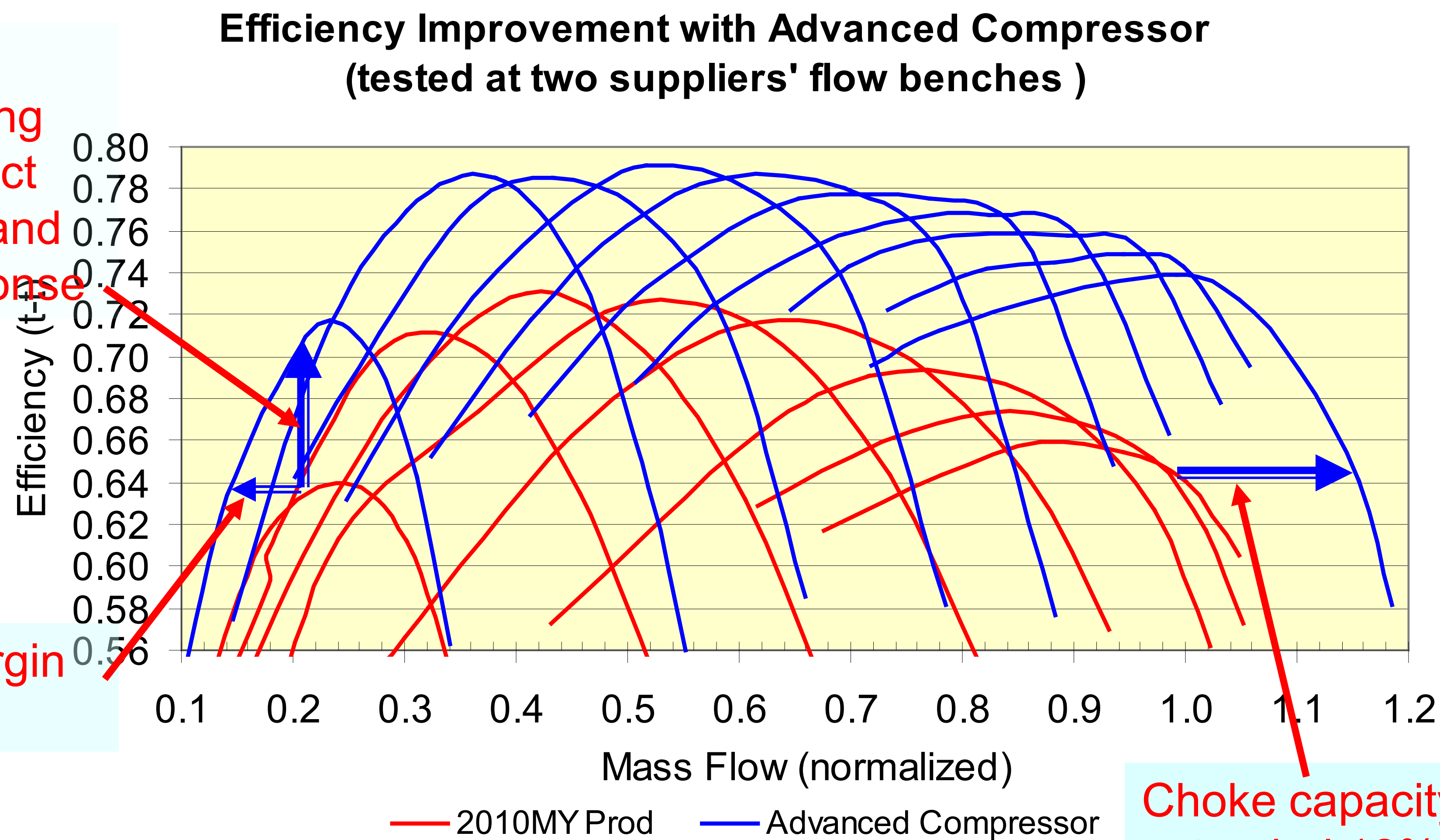
Major design changes:

•Arbitrary surface compressor impeller blades to improve compressor efficiency at light load conditions; optimal casing treatment to improve efficiency at high load

•Mixed flow turbine for better performance at high EGR (or low U/C) conditions

Flow bench test of compressor

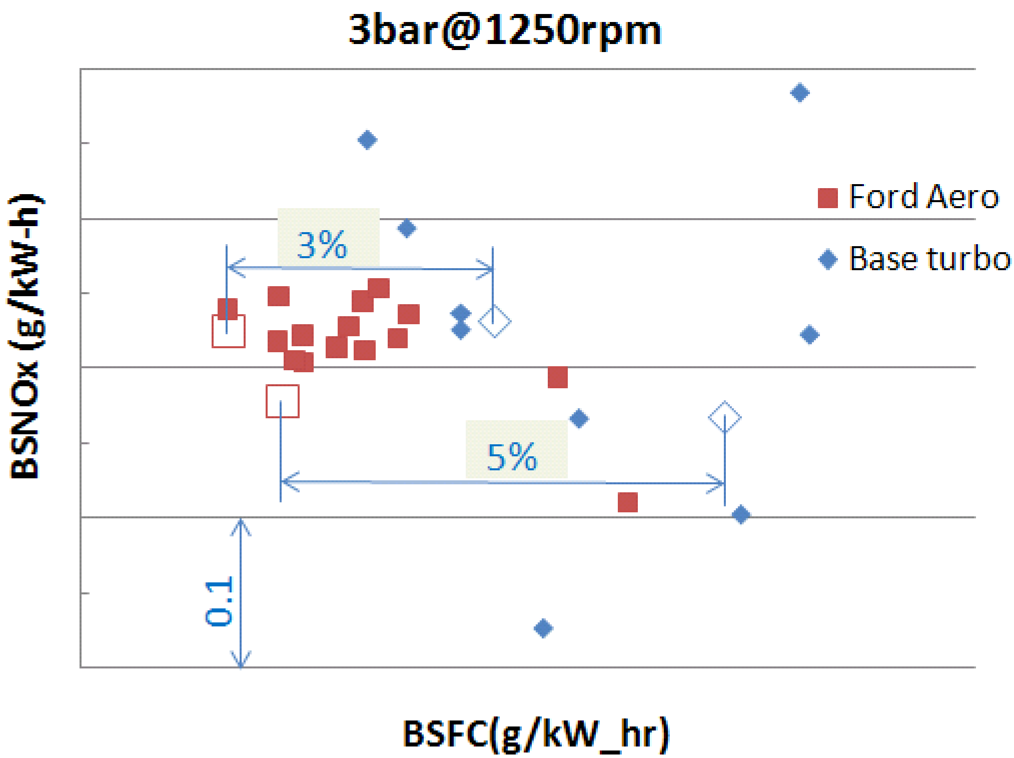
Efficiency on customer driving cycle will impact FE, emission and transient response



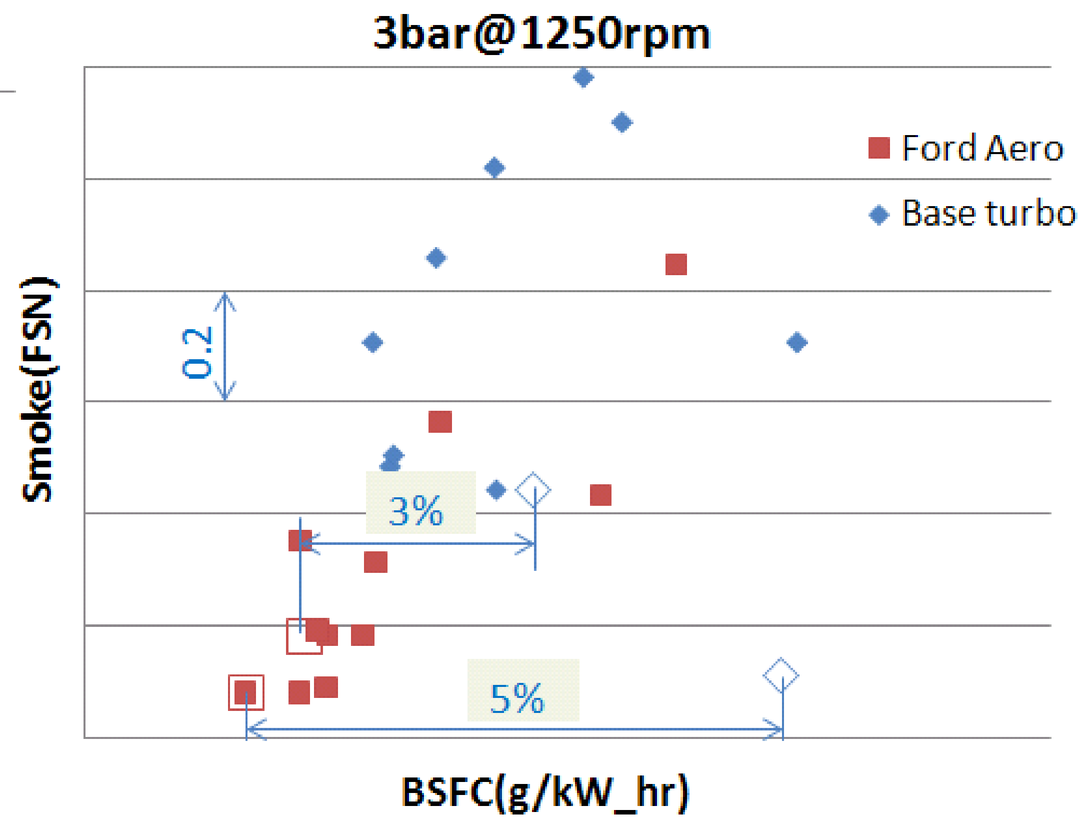
Surge margin enhanced

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



The advanced turbo demonstrated better FE at light load conditions



The advanced turbo gained more BSFC advantages at lower NOx or higher EGR (thus low U/C) conditions

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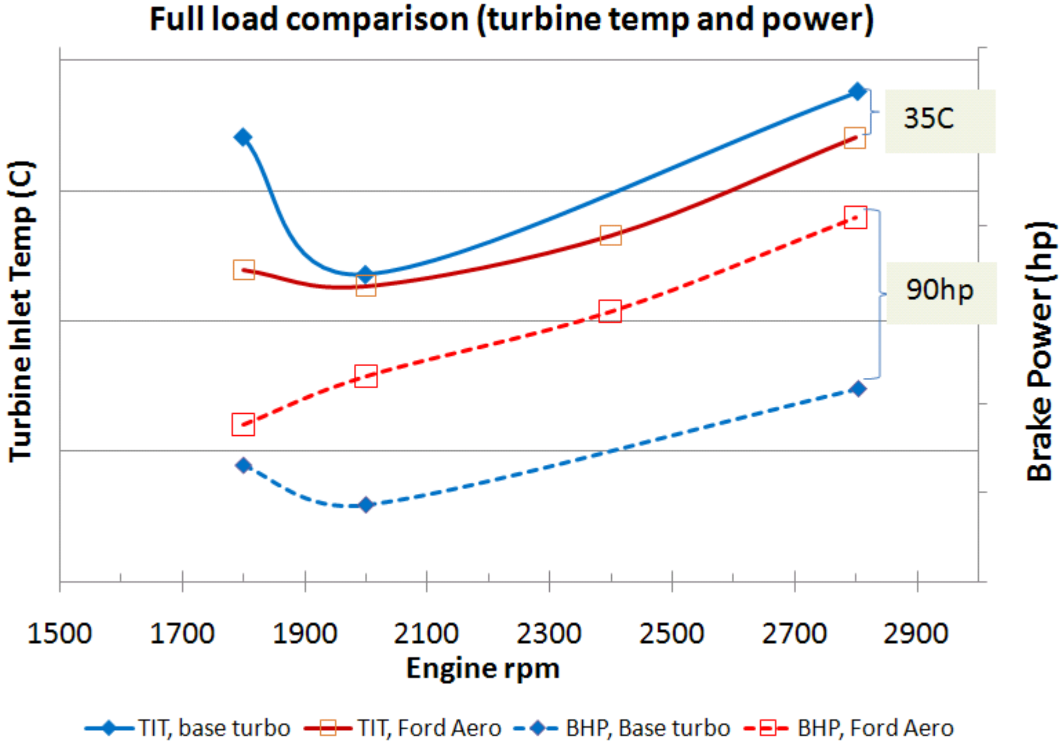
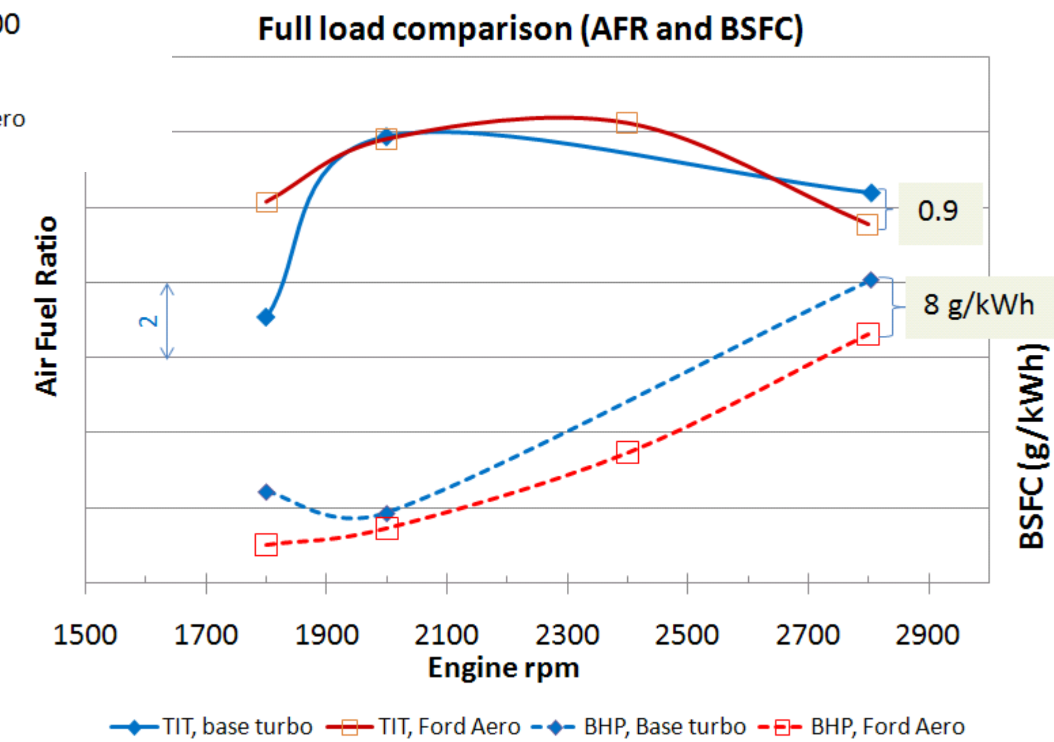


Performances at full load conditions were improved as well



The mixed flow turbine gained better efficiency at low EGR or high U/C conditions

Conclusions

- *EGR based NOx control pushes operation points into less efficient area on compressor and turbine maps, which has to be addressed with advanced turbocharger technologies*
- *Optimal design of compressor impeller, combined with advanced casing treatment improved compressor efficiency over wide operation range*
- *Mixed flow turbine has demonstrated improved efficiency at low U/C area, which is relevant to high EGR applications and pulsating exhaust environment*
- *The engine dyno test has demonstrated BSFC improved 3-5% at light load and 3% improvement at full load with wider operation range due to design optimization on compressor impeller, advanced casing treatment and mixed flow turbine*