Analyses guided optimization of wide range and high efficiency turbocharger compressor

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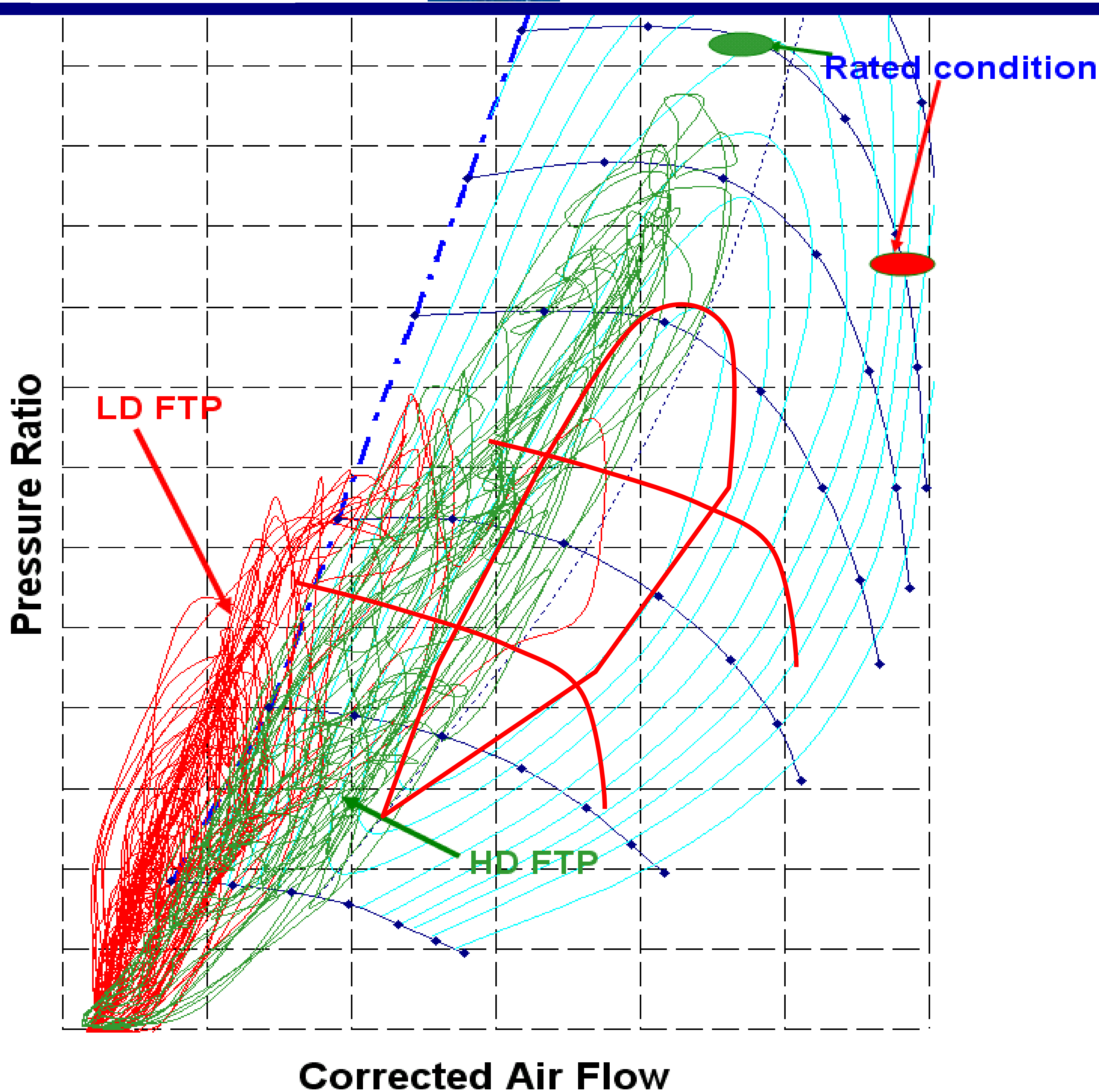
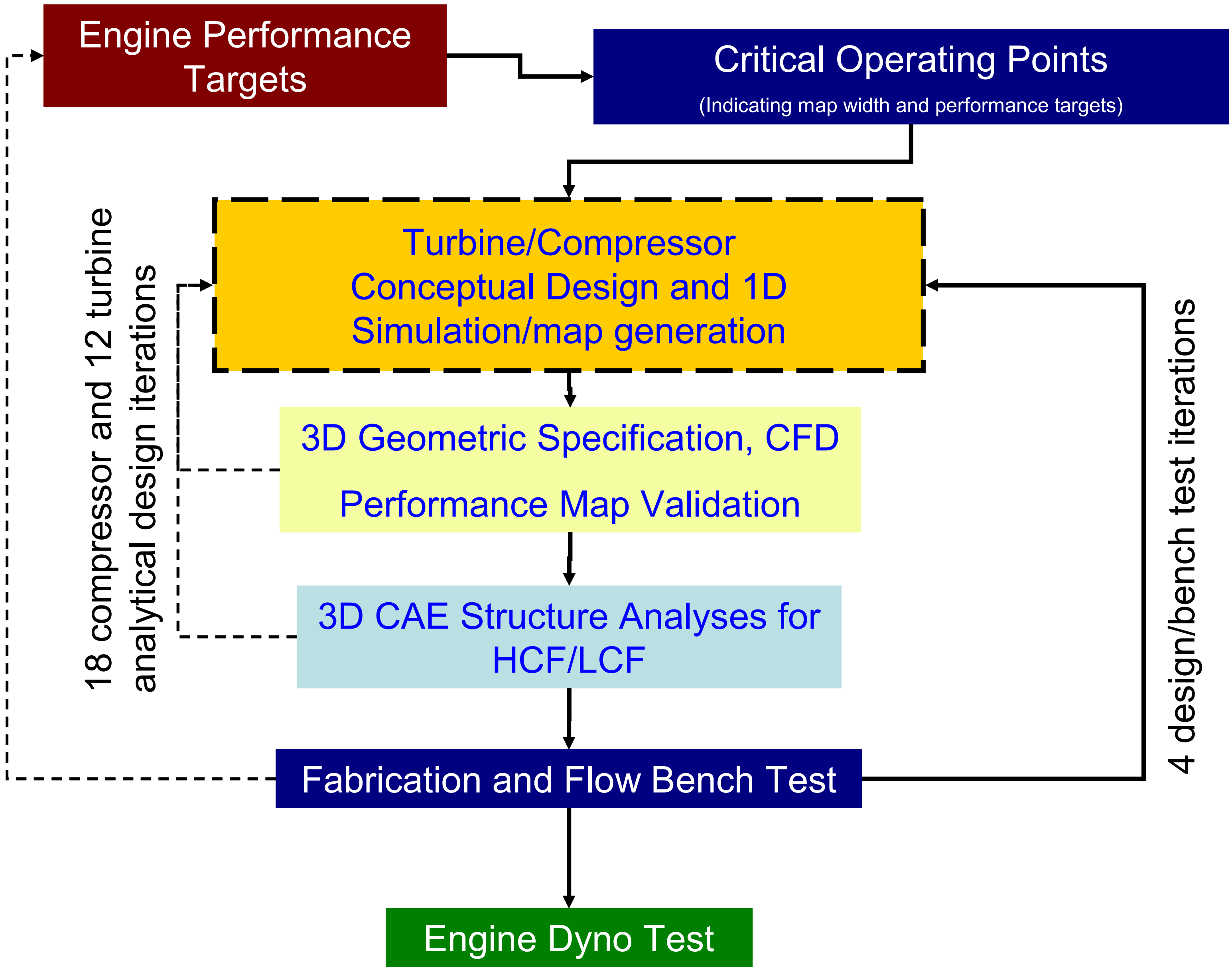
Single turbo?

The focus is to move high efficiency island on a compressor map to cover customer driving cycles





Numerical simulation is the key to guide the design iterations !!

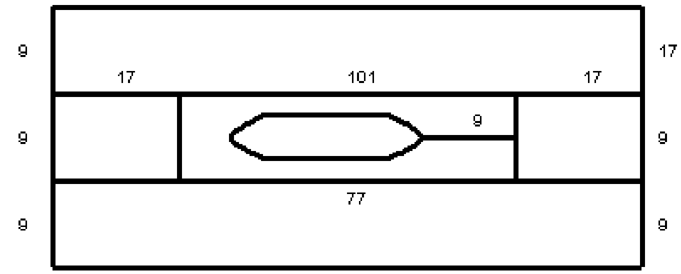
Validation of compressor model

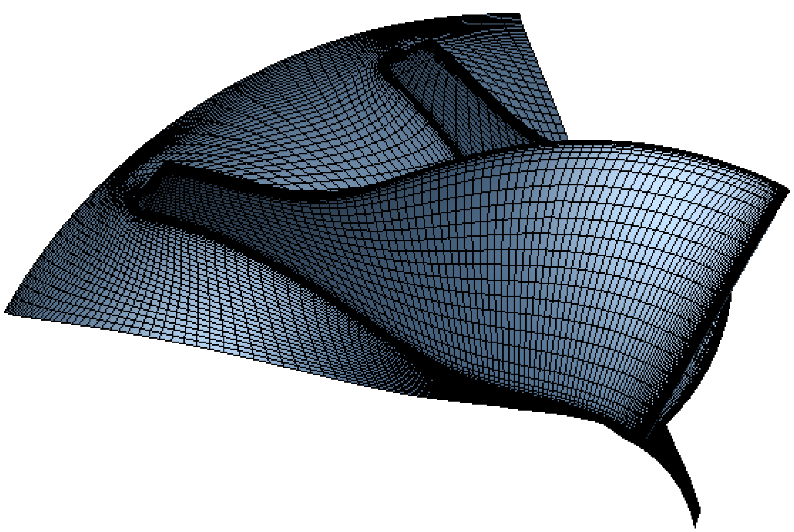
- Compressor with arbitrary blades;
  - ✓ 6 main/splitter blades
- Low solidity vaned diffuser with different setting angle
  - ✓ Solidity=0.7 with 7 vanes

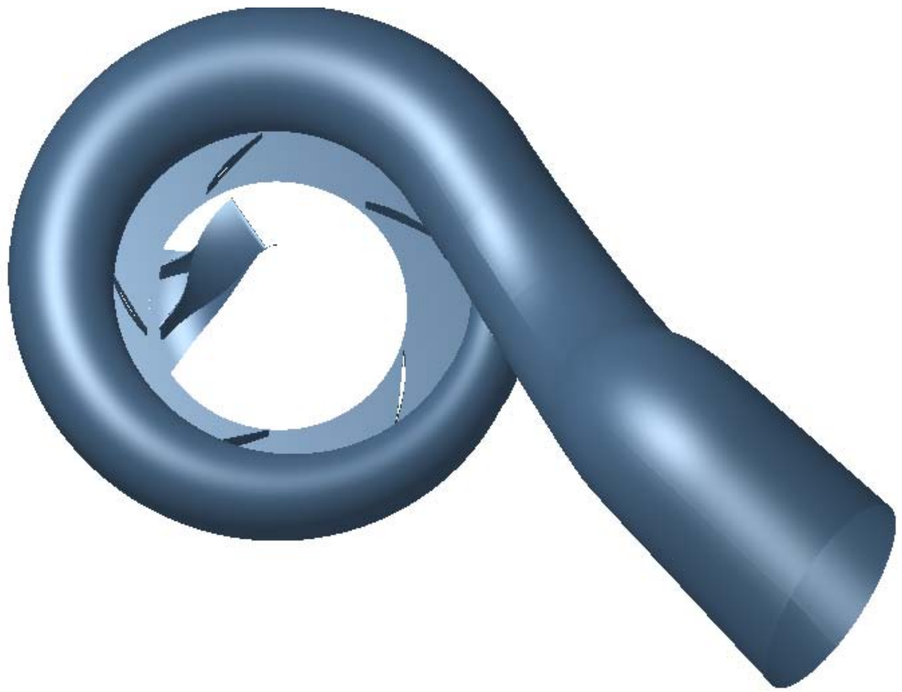
- Test at 108krpm, vaneless diffuser also tested.

Numerical model

- Mesh : Auto/Grid, Structure O-4H mesh, $Y^{+}\approx 3$
- Solver: Fine/Turbo Euranus
- Turbulence Model: Spalart-Allmaras
- R/S interface: non reflecting BC
- Boundary Condition
  - Inlet: Tt, Pt, flow direction
  - Outlet: Ps/ target mass flow

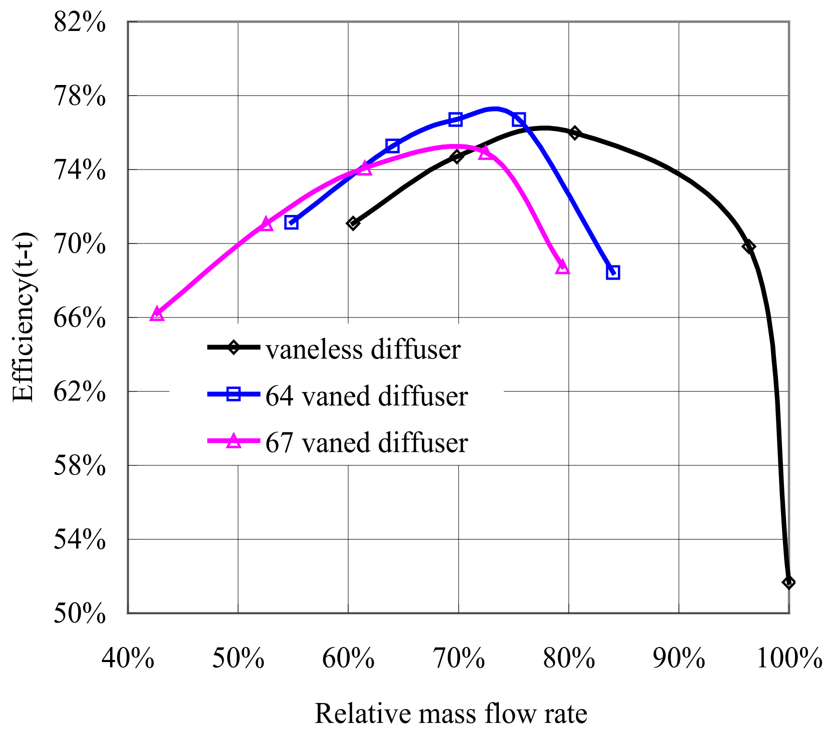


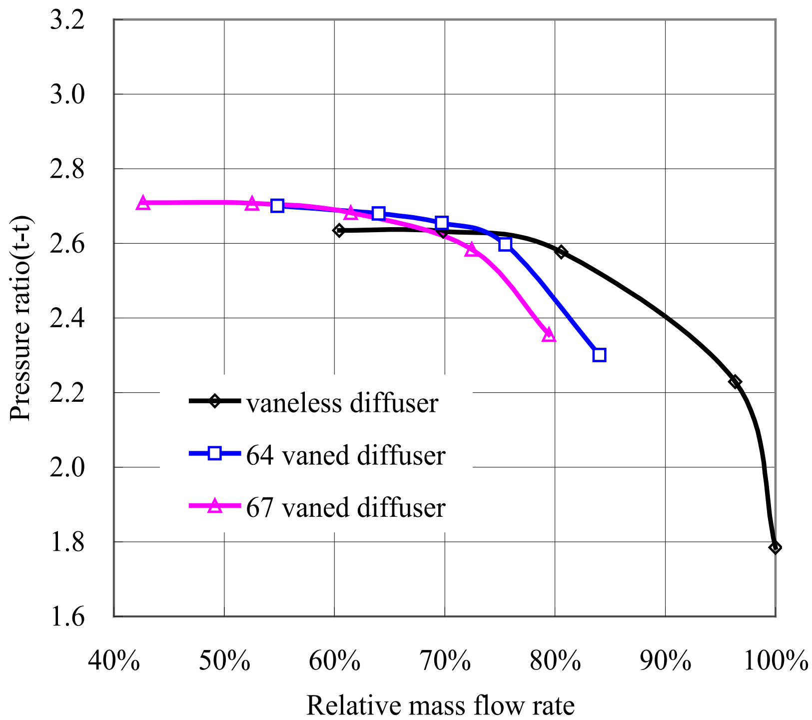




Test of Compressor Performance

- Two setting angle of diffuser vane and vaneless diffuser

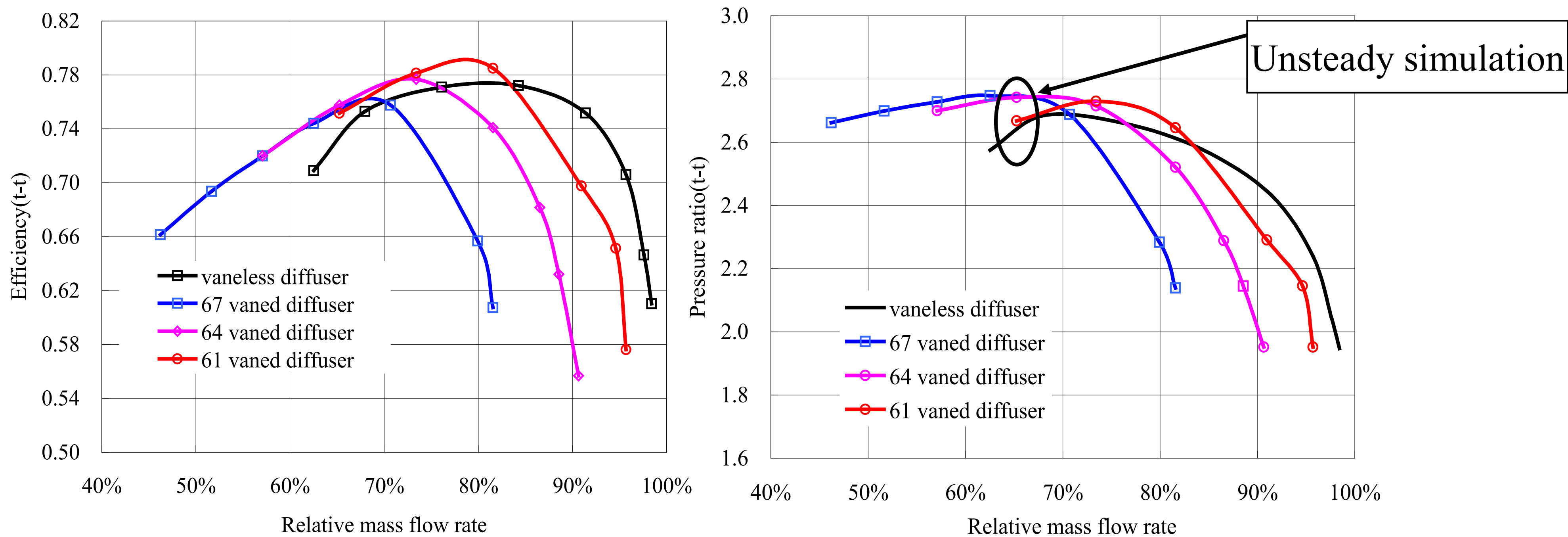




- Improved efficiency at low end;
- Surge extension with increase of setting angle;
- Penalty of choke flow rate: further reduction of setting angle would possibly improve the choke flow.
- Variable vaned diffuser is the best.

Numerical simulation of compressor performance

- Reduction of setting angle is included: 61˚ setting angle

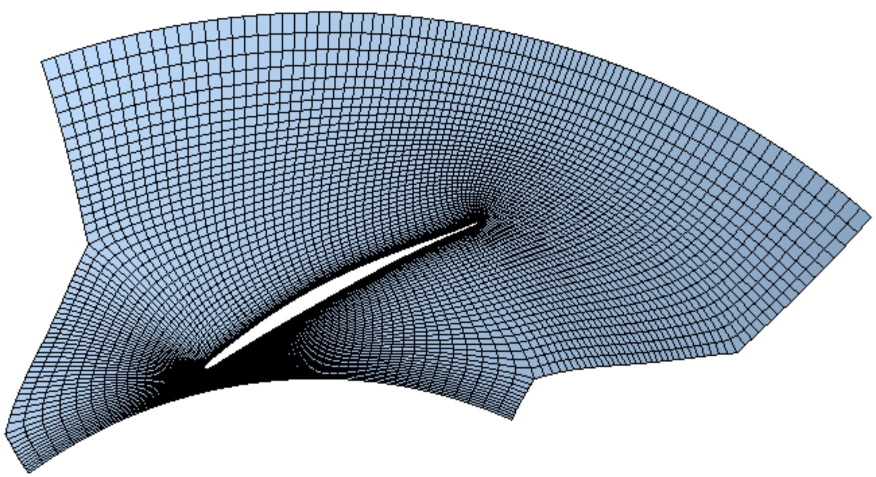


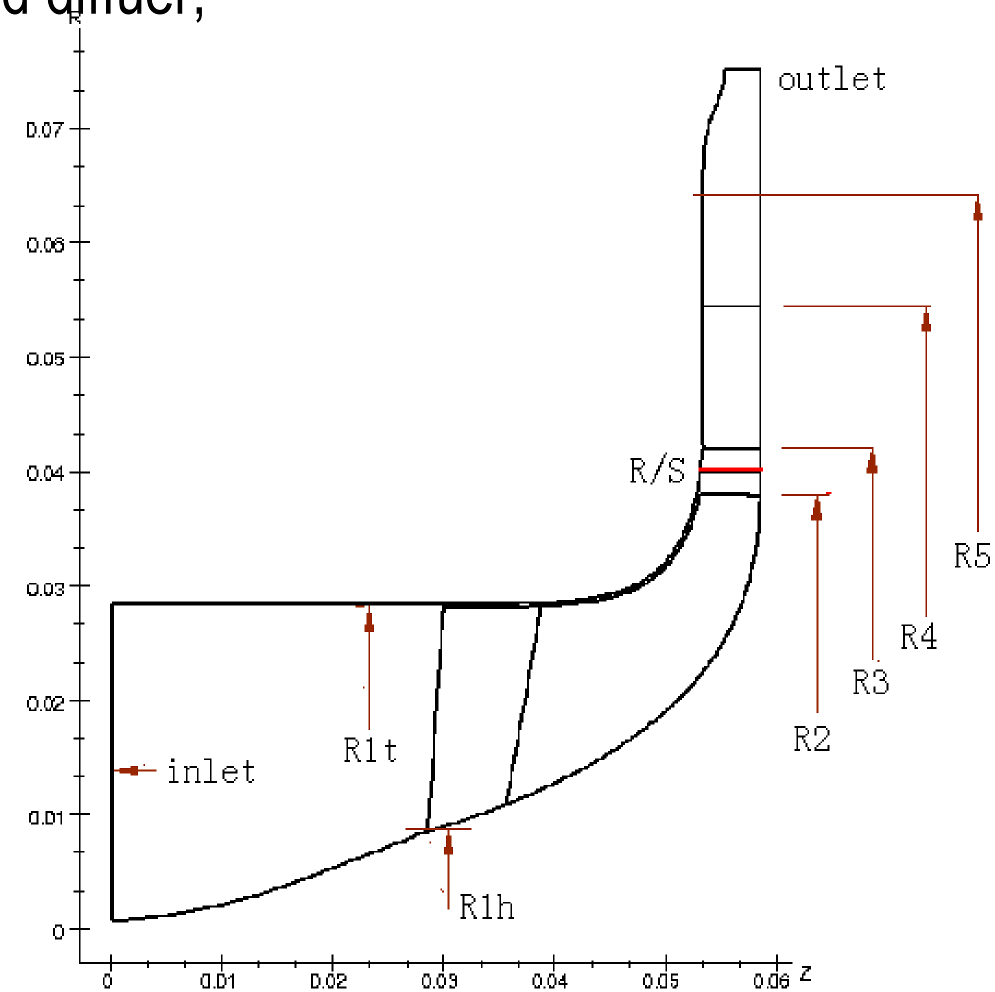
- Increase of setting angle, compressor surge could be extended;
- Improved efficiency especially at low end;
- Reduction of setting angle could improve performance near choke;

Compared with test data, CFD prediction matches well with the test data except the near surge areas.

Transient simulation is needed for surge prediction

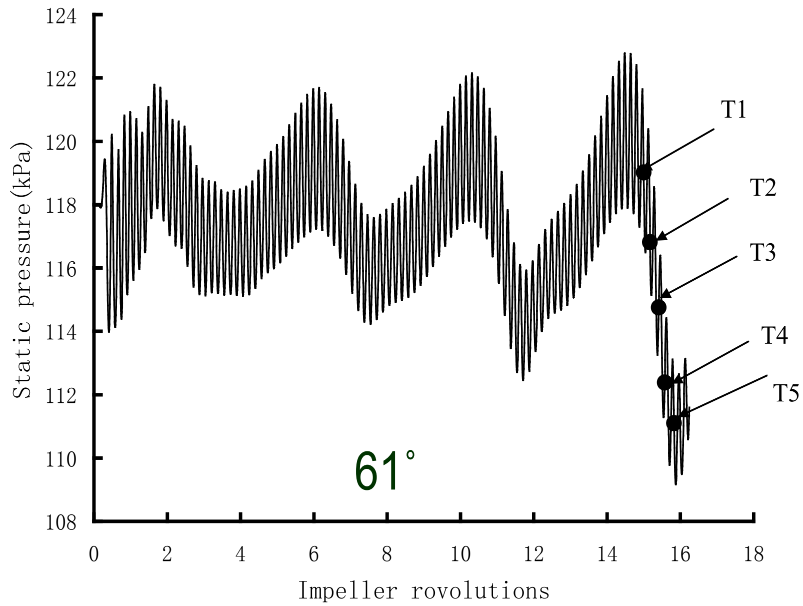
- Unsteady simulation: investigate how the vaned diffuser affects the compressor surge flow rate;
- Sliding mesh-diffuser vane was scaled to 6 vanes;
- Same BC, mesh applied @ 61˚,67 ˚vaned diffuer;
- Impeller+diffuser simulated.

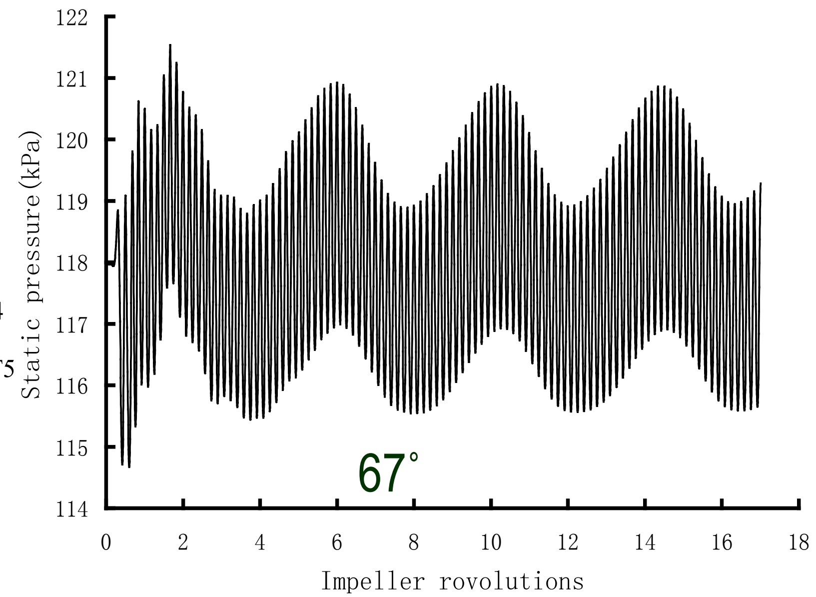




Unsteady CFD analysis -pressure oscillation

- Fluctuation of Ps at leading edge of impeller:

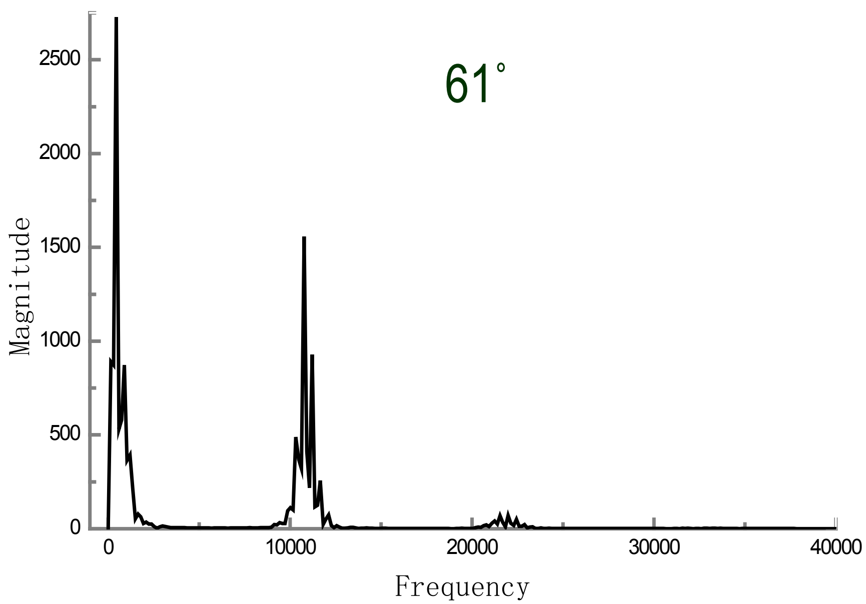


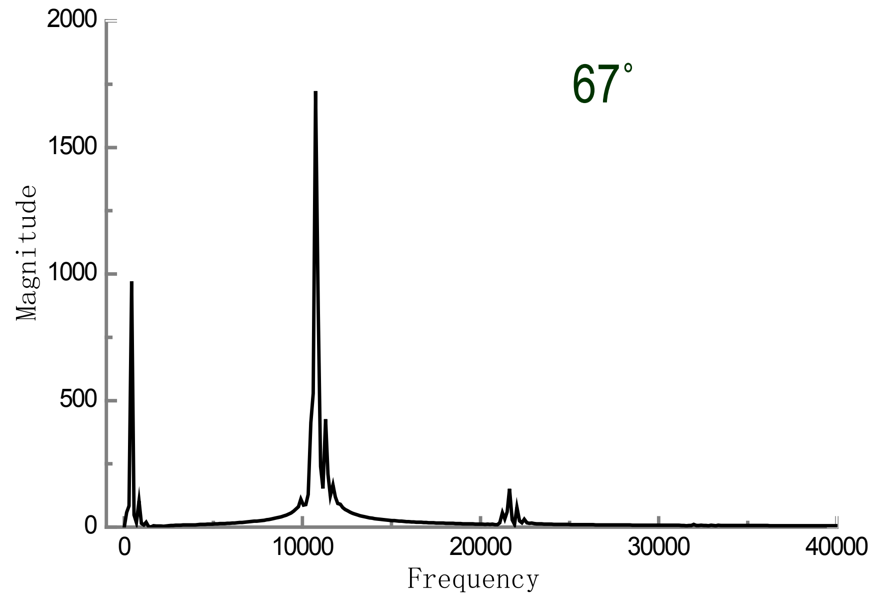


- Both Ps oscillations are visible;
- With 61° vaned diffuser, more fluctuation in Ps
- ➢ The impeller with 61° vaned diffuser is less stable

Unsteady CFD analysis -pressure oscillation

- They differ in the frequency domain:





- Two frequencies: 10.8kHz(blade passing frequency)
- 450Hz- related to the stall phenomenon.
- 61˚ vaned diffuser: the magnitude at 450Hz is ~3 times that of 67˚ vaned diffuser, i.e. impeller matched with 61˚ vaned diffuser is less stable.

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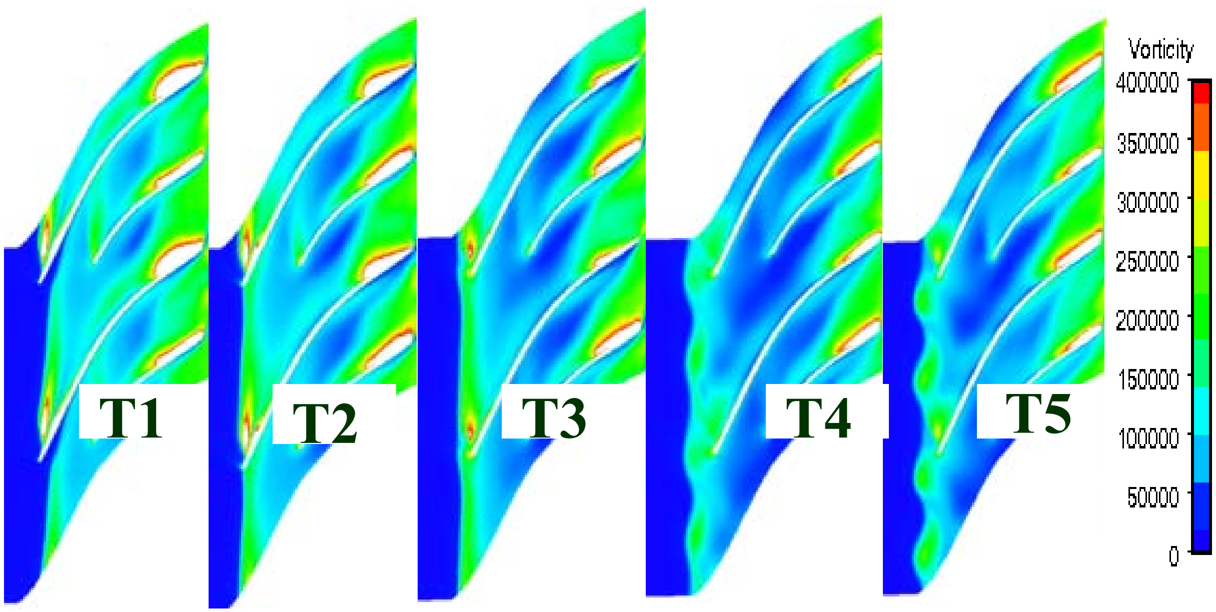
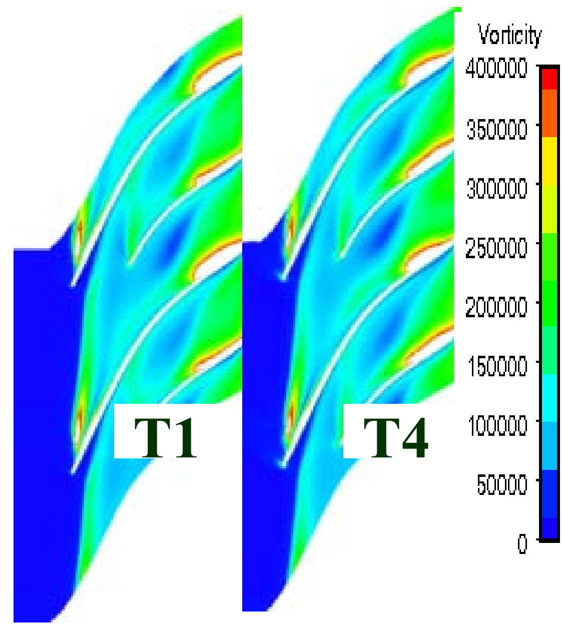
Unsteady CFD analysis - vorticity

- Flow field investigation@5 time instants, 95% Spanwise:



61˚

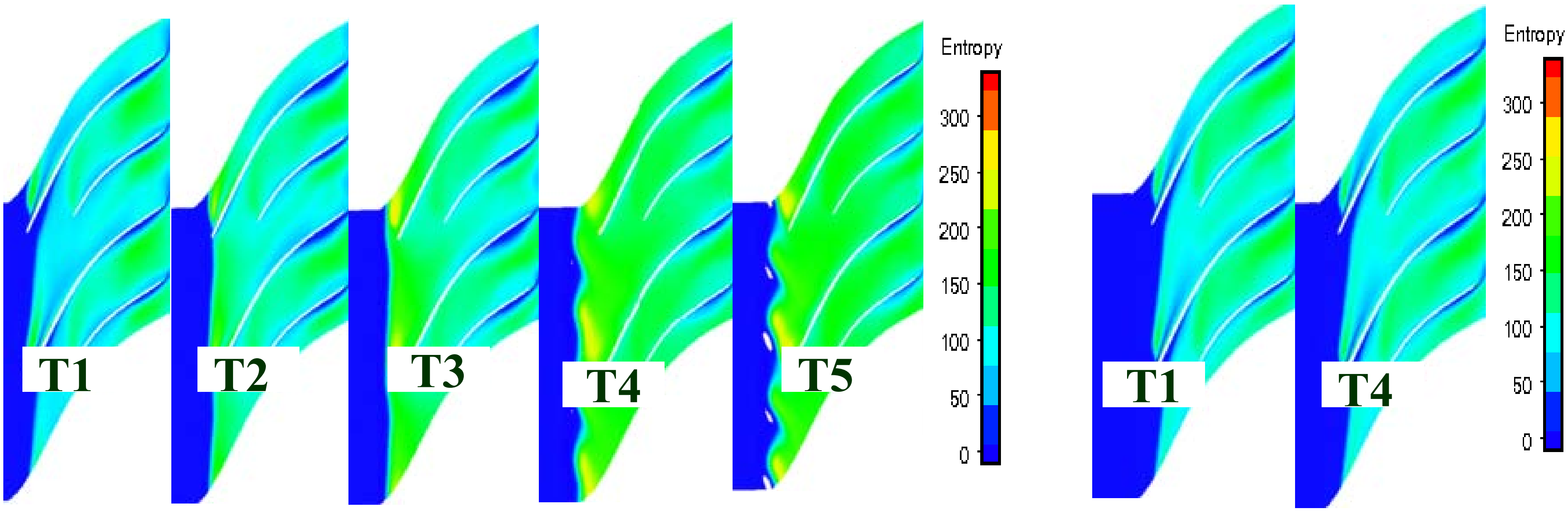


67˚

- 61˚ vaned diffuser: the high vorticity gradually spills out of the impeller passage, unstable-indicating impeller stall;
- 67˚ vaned diffuser: the high vorticity stays inside the impeller passage, relatively stable.
- ➢ Compressor with 67 ˚ vaned diffuser is more stable.

Unsteady CFD analysis - entropy

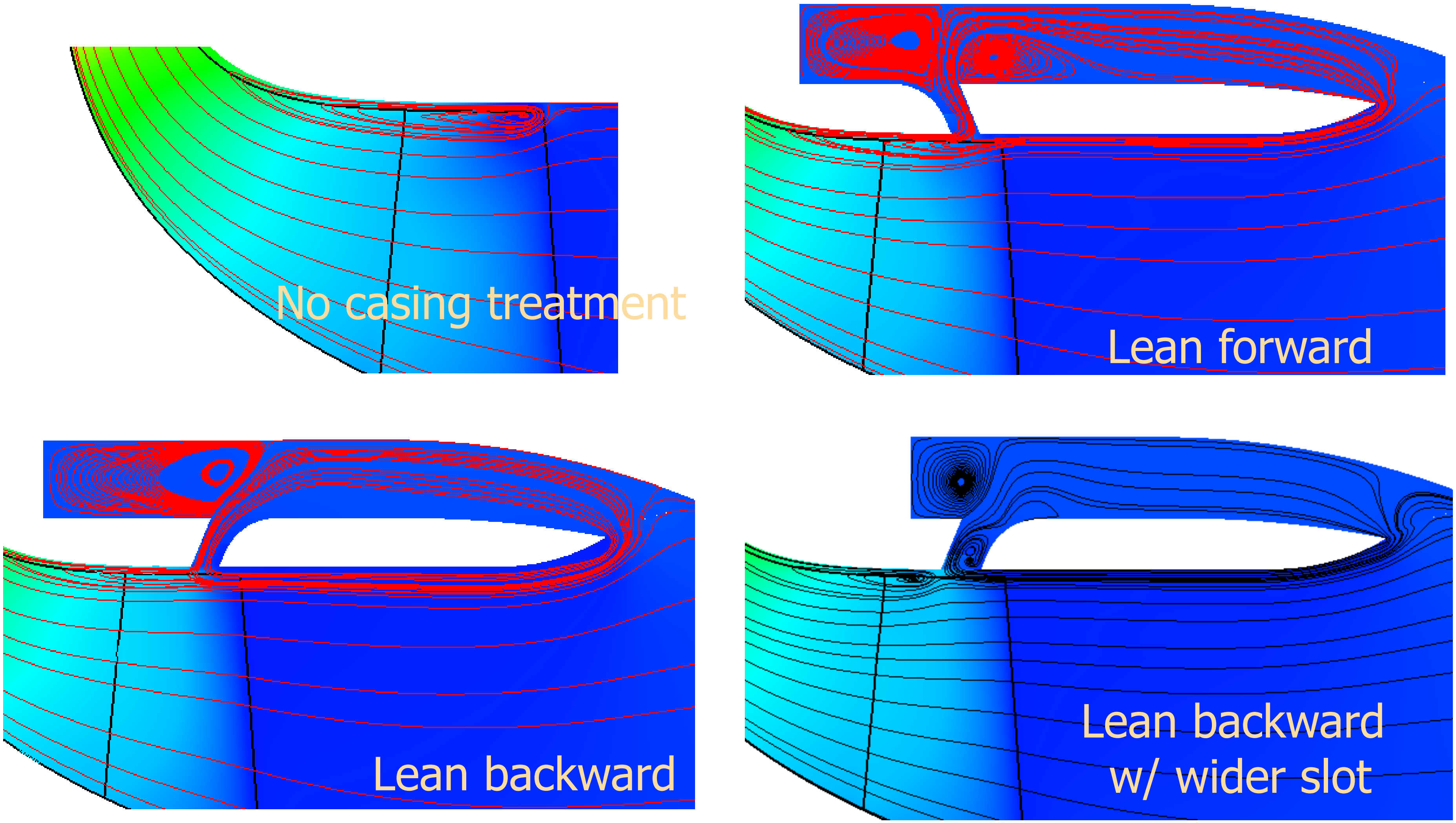
- Flow field investigation@5 time instants, 95% Spanwise:



61˚ 67˚

- Entropy distribution:
- 61˚ vaned diffuser: high entropy area gradually spills out of the impeller passage, entropy increased – impeller unstable;
- 67 ˚ vaned diffuser: more stable – increased diffuser vane angle is able to stabilize impeller flow.

CFD to guide optimization of compressor casing treatment



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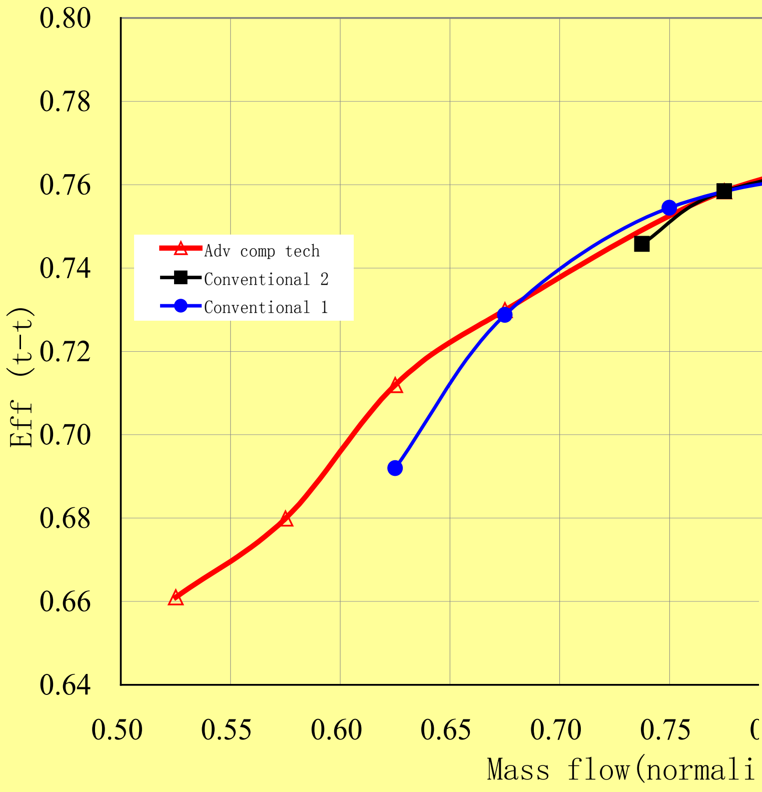
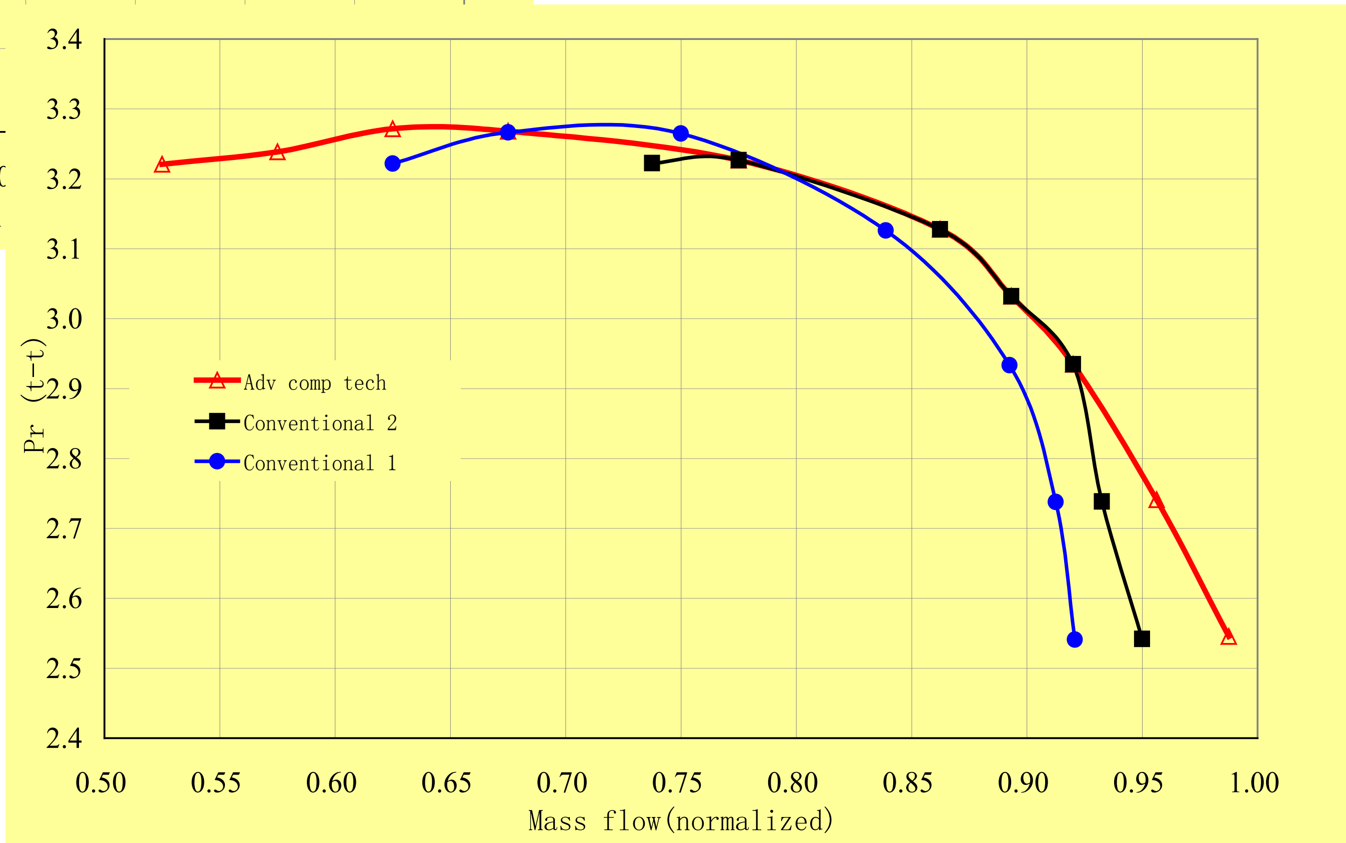


Simulation
@ 120krpm (with volute)



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

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Conclusions

- ✓ CFD simulation tool (Numeca) has been demonstrated to be very effective to guide the compressor optimization (the compressor went through 18 design iterations and only 4 designs went to hardware build/test);
- ✓ The accuracy of CFD tool has been validated in steady state and transient simulations for both vaned and vaneless compressors;
- ✓ Variable geometry compressor can extend the flow range dramatically but may have reduced peak efficiencies;
- ✓ Optimization of compressor casing treatment shows the potential of improvement in both surge margin and flow capacity without compromising of efficiency.