Automotive Turbocharging: Industrial Requirements and Technology Developments

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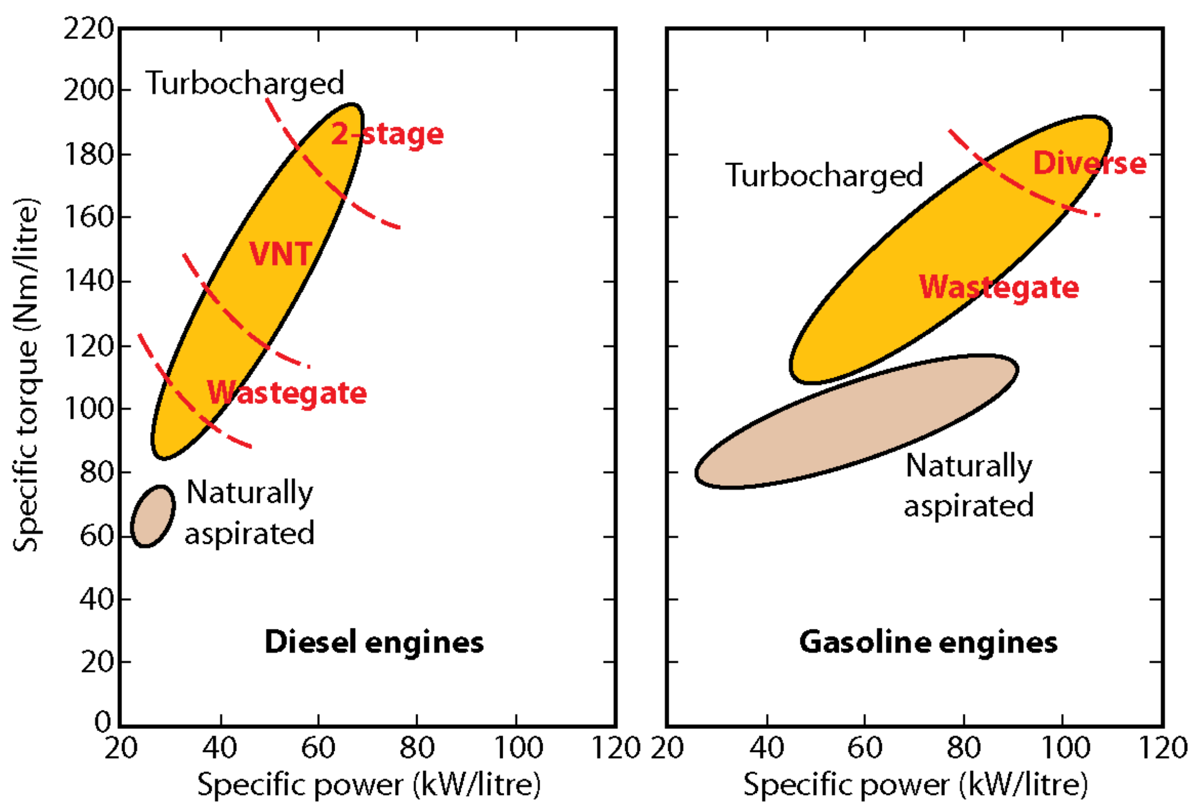
Turbocharging requirement

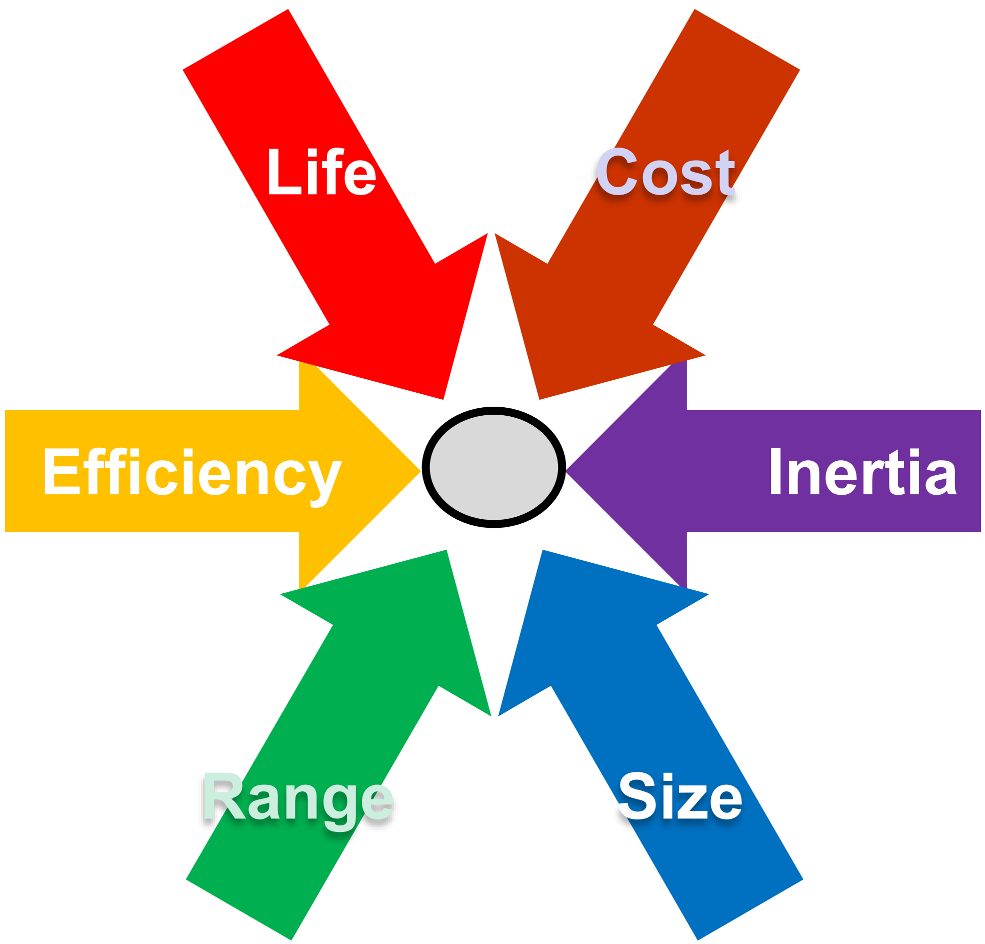


- Turbocharging is essential for modern diesel engines, and is becoming so for gasoline engines

Turbocharging impacts

- 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

Design compromises

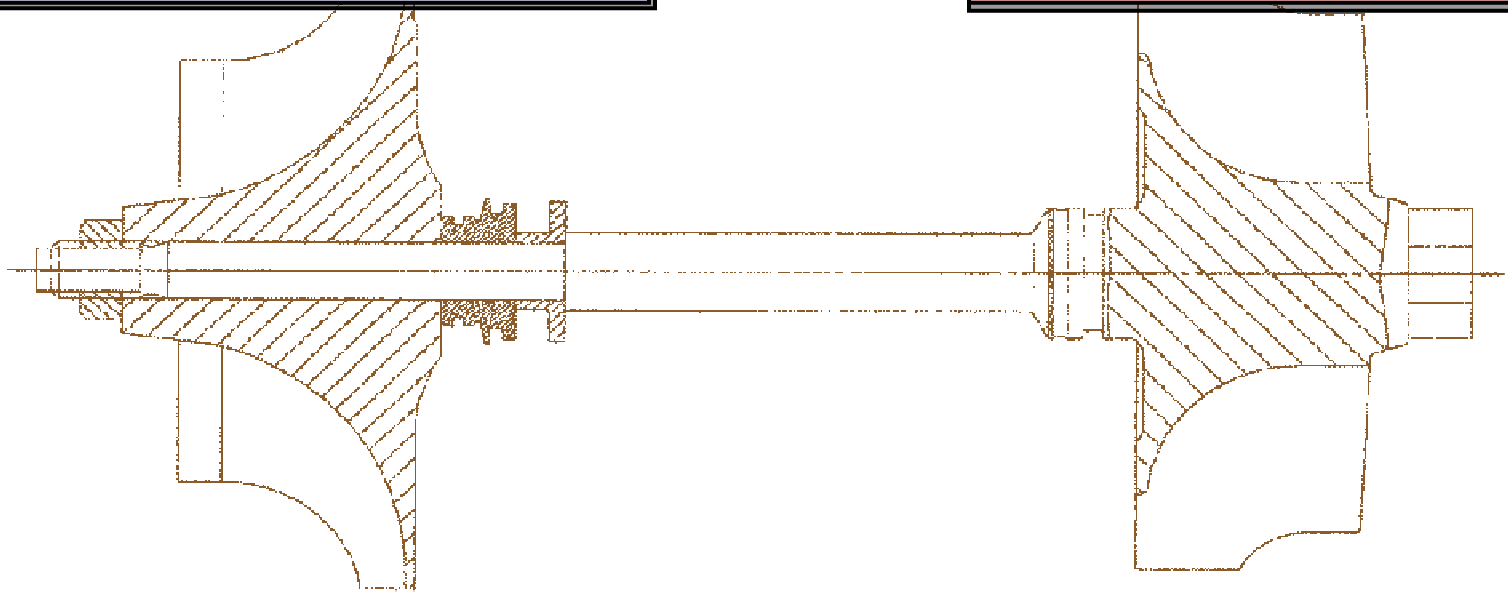


- The design space for the turbocharger has become very small
- Turbocharging is a mature technology – developments will be incremental
- Proper understanding of the trade-offs require collaboration between engine and turbocharger design

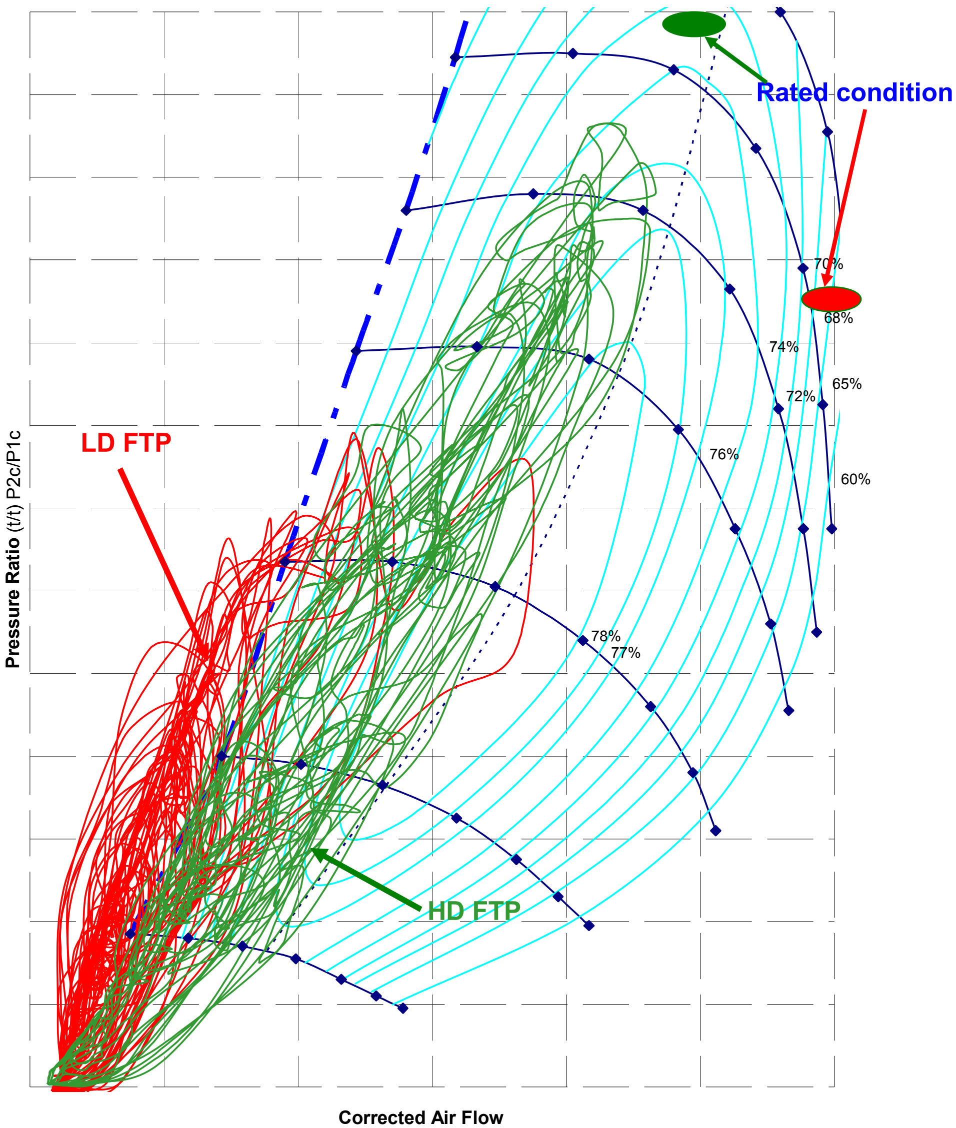
Turbocharger technology focus items

Compressor
Increased range without sacrifice of efficiency

Turbine
Better use of exhaust pulse energy

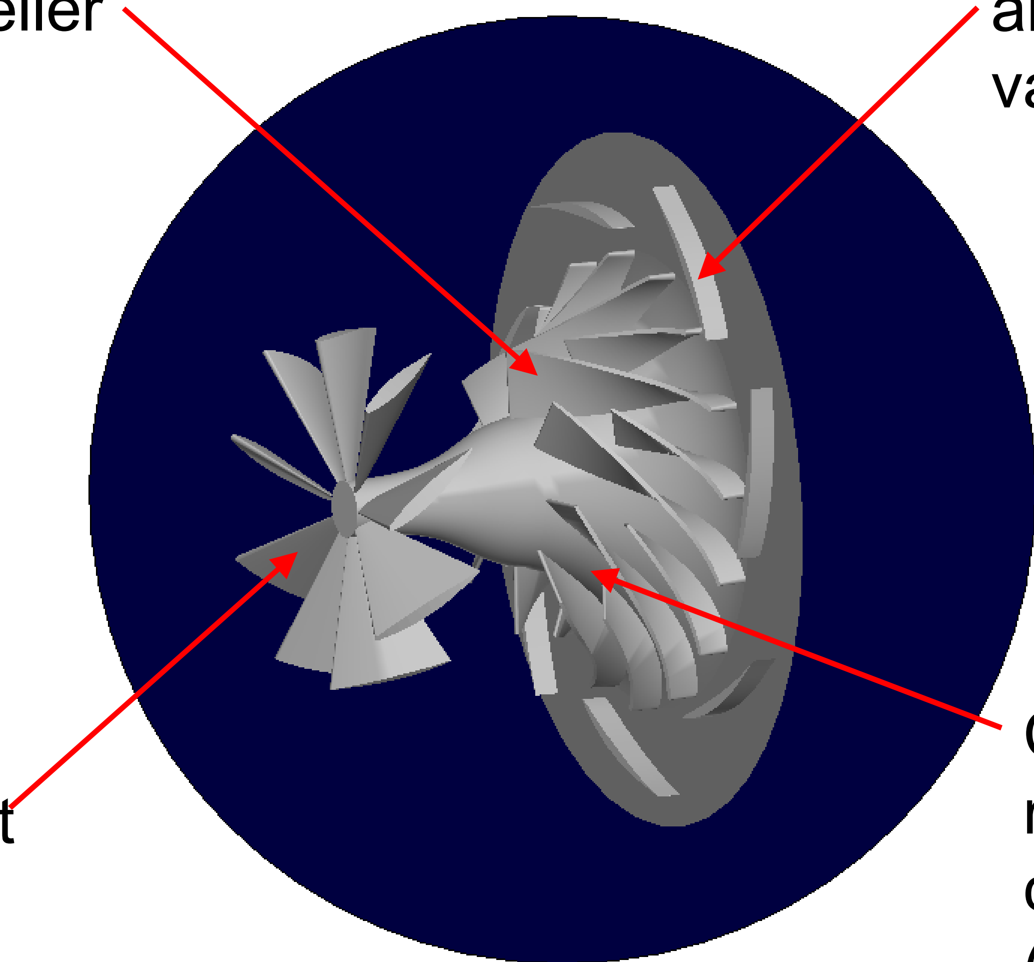


Compressor development



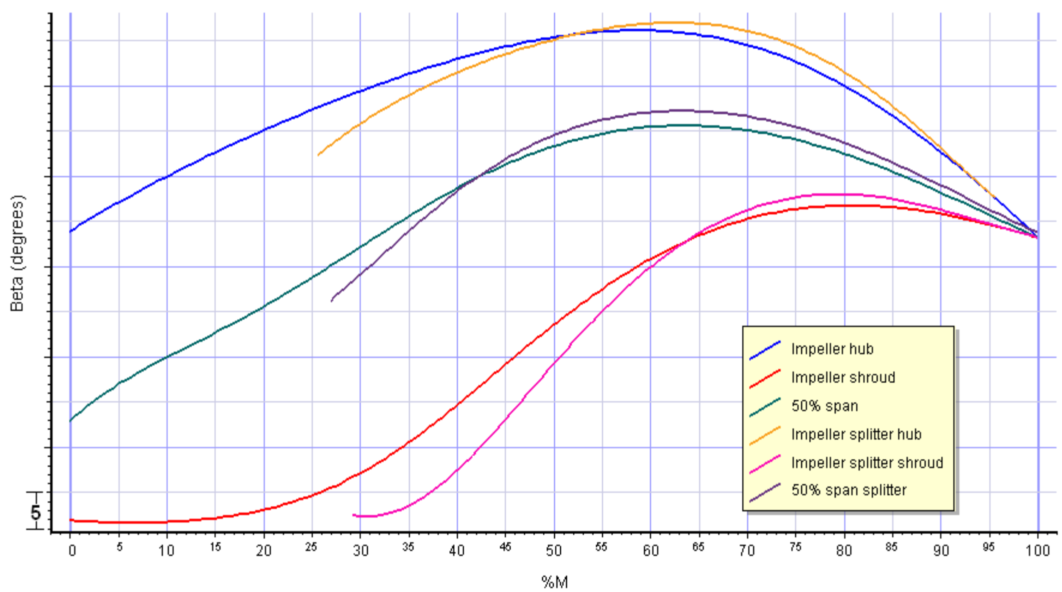
- Customer driving cycle and emission cycles for light duty diesels are focused on the areas where compressors are **not efficient** and are close to or into **surge**

Technology options for efficient wide flow range compressor



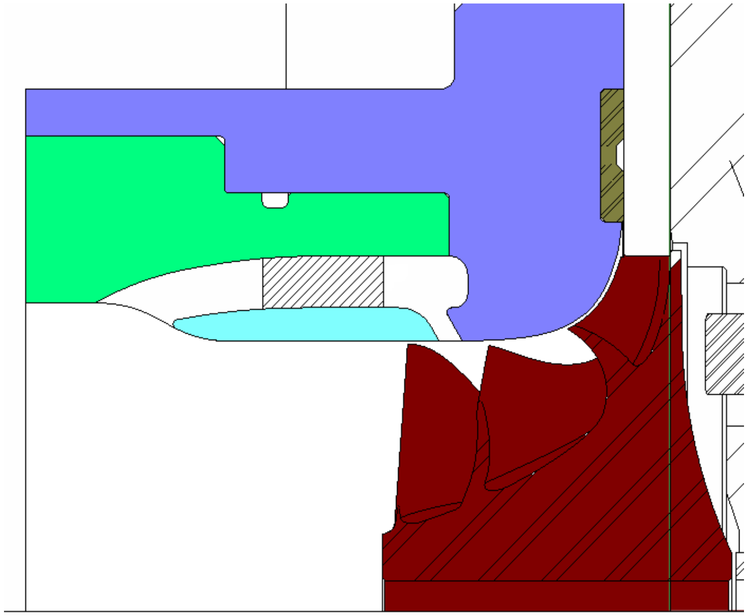
Application specific impeller design

- ‘Arbitrary’ blading provides ability to fine tune aero performance and structural response
- Bowed blading is utilized to influence secondary flow development and interaction with the recirculating casing treatment

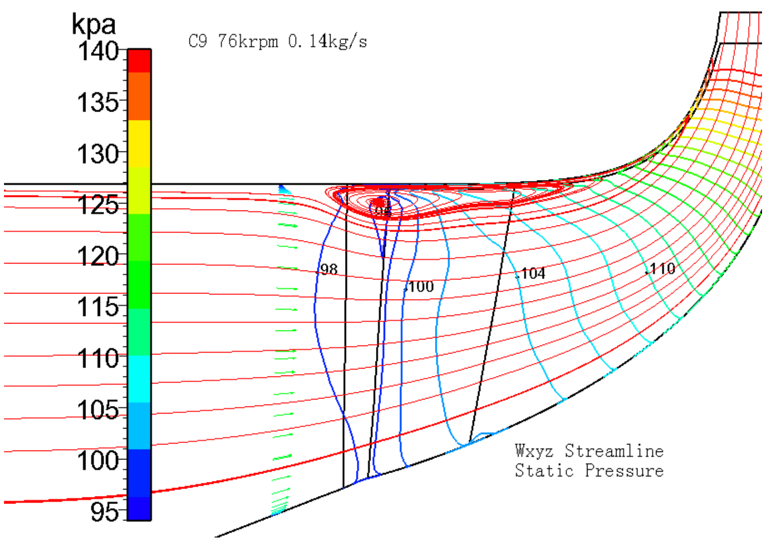


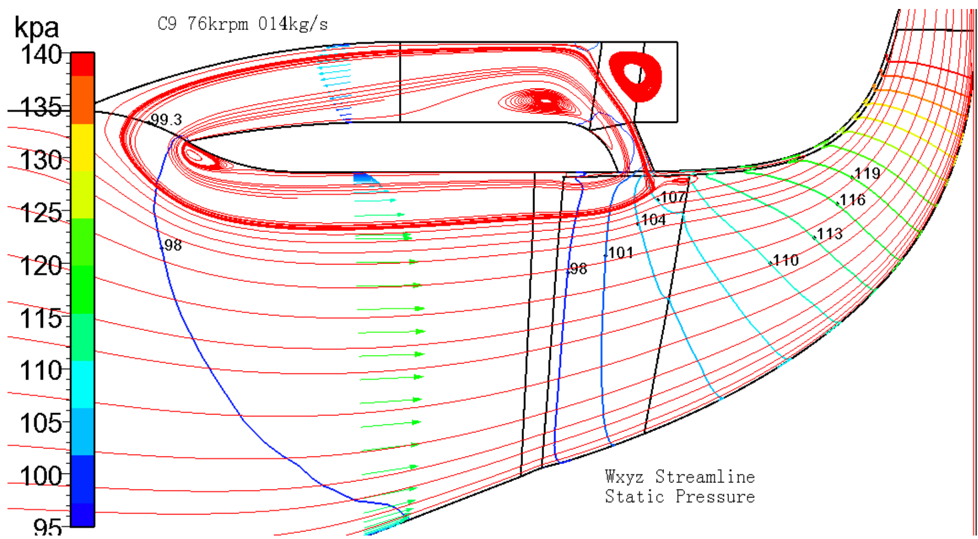
- Blended features of transonic and subsonic blading provide high performance capability across a wide range

Tailored casing treatment development

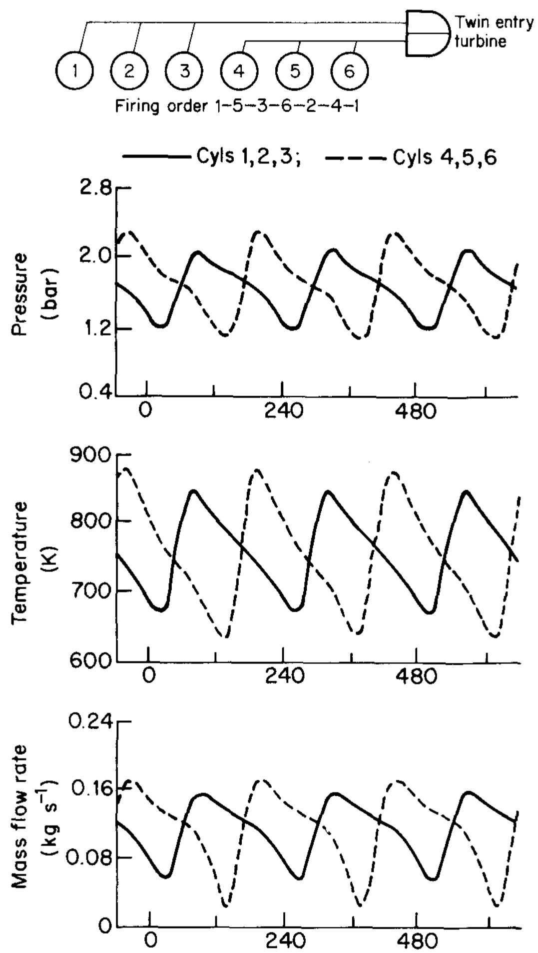


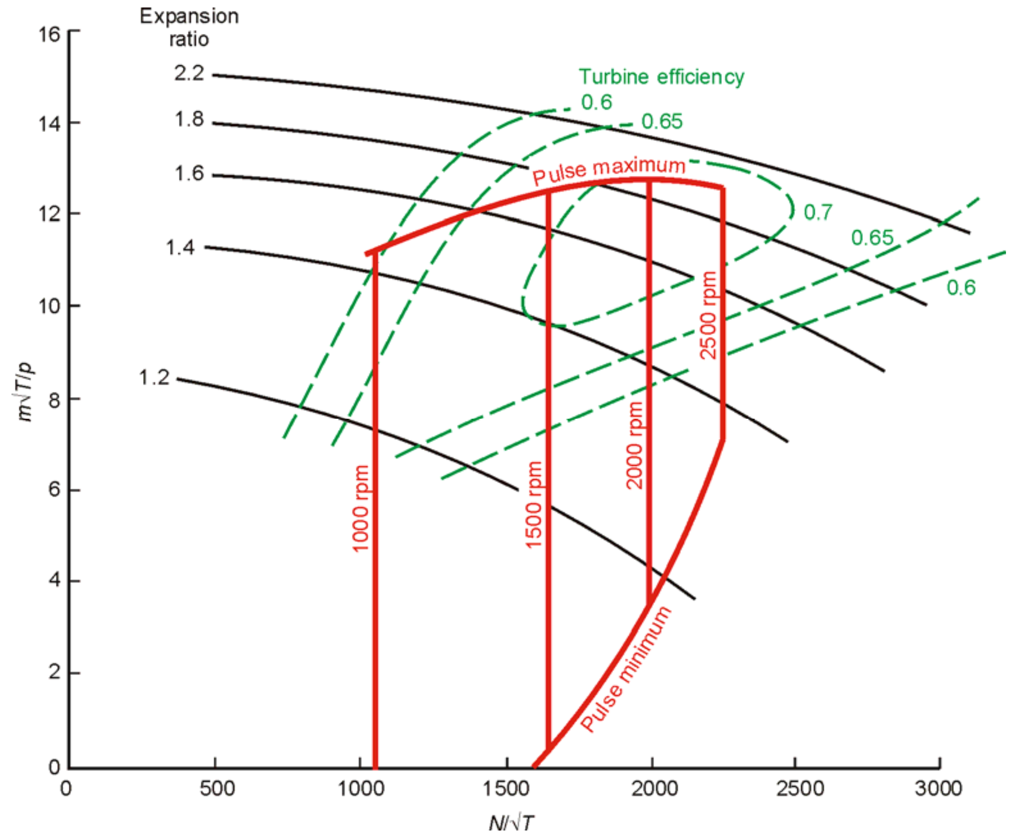
- Tailored casing treatment for range enhancement based on comparative CFD analysis
- Minimal impact on efficiency





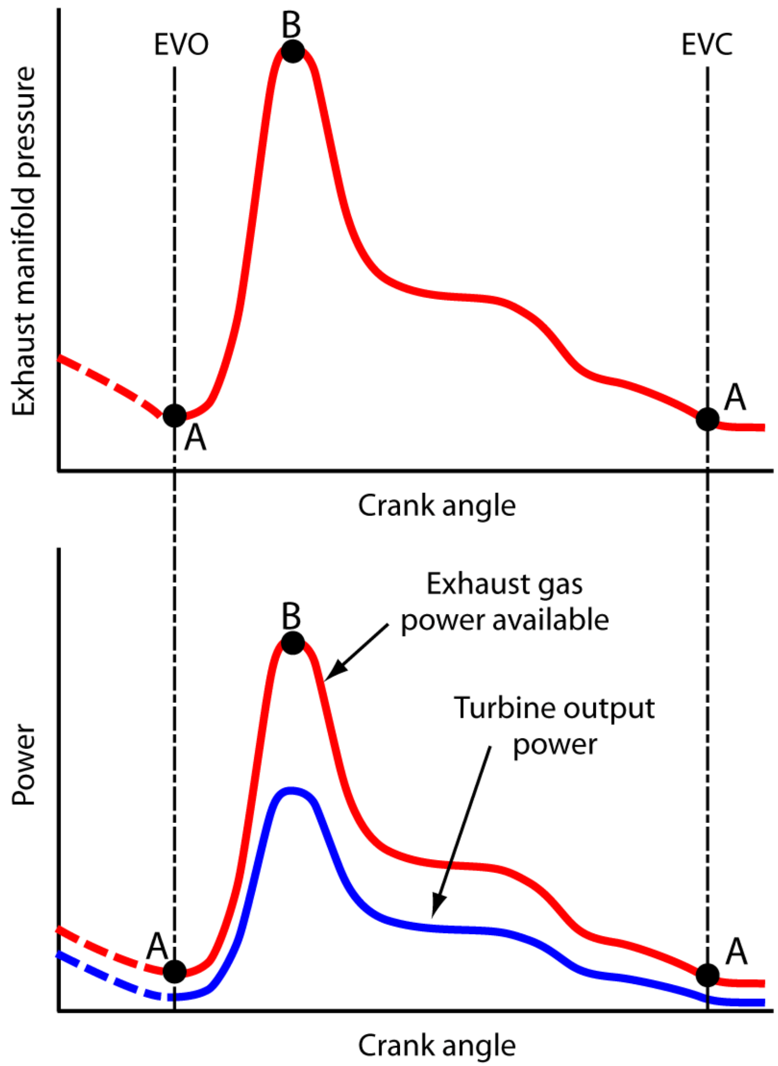
Pulse flow in turbines

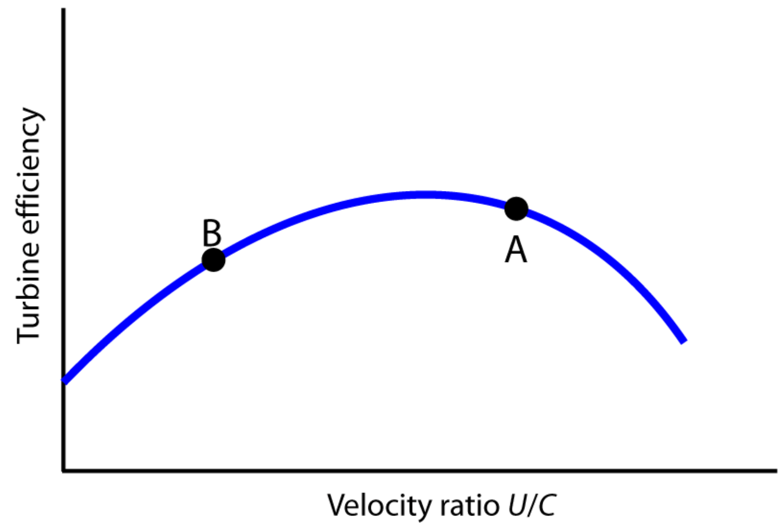




- Turbine spends little time at or near its maximum efficiency during the pulse cycle

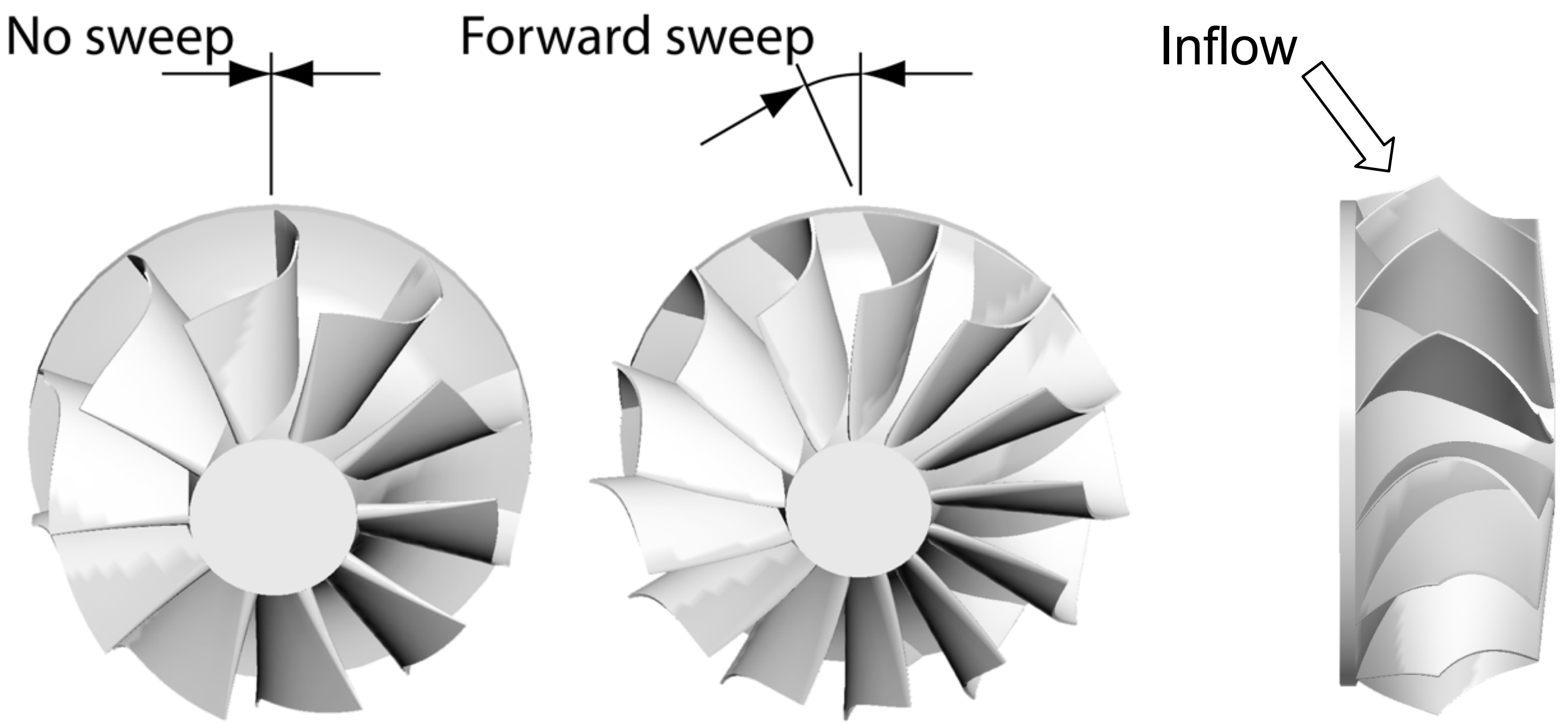
Turbine operation during pulse cycle





- The greatest exhaust energy availability occurs at point B (high pressure ratio → low *U*/*C*)
- But the turbine efficiency is poor in this range
- How to modify the turbine characteristics?

Modifying the turbine characteristics

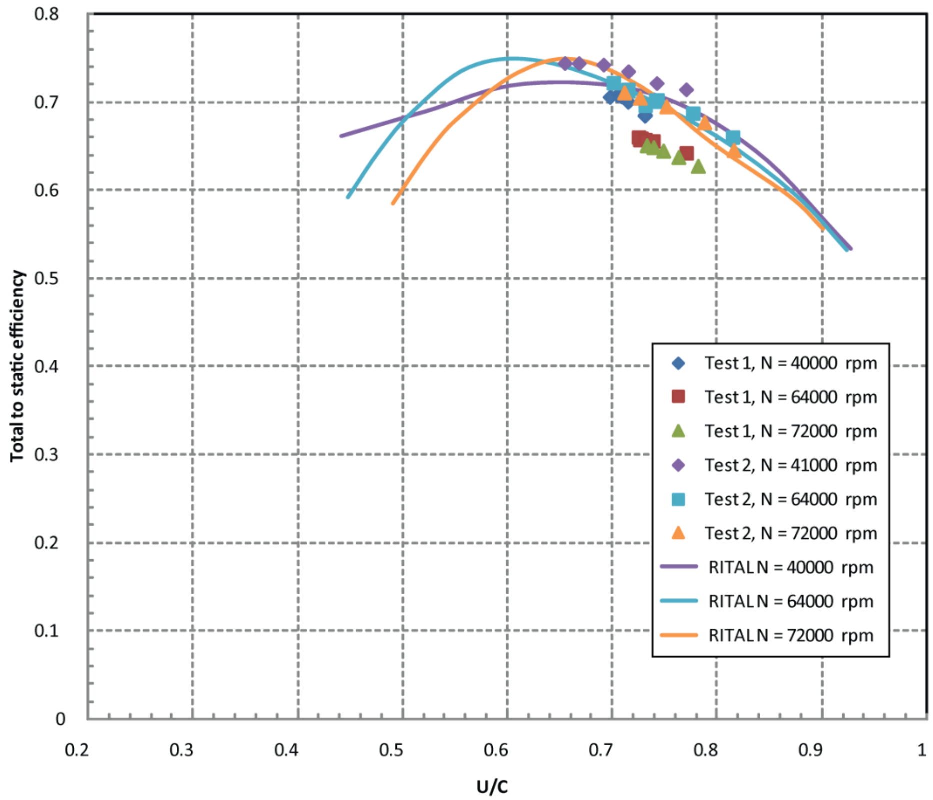


- Forward sweep moves peak efficiency to lower *U*/*C*
- Cannot be achieved in a radial turbine without increased stress – requires a mixed flow geometry
- Greater flow turning in rotor leads to increased secondary flow loss – must be minimized by careful design

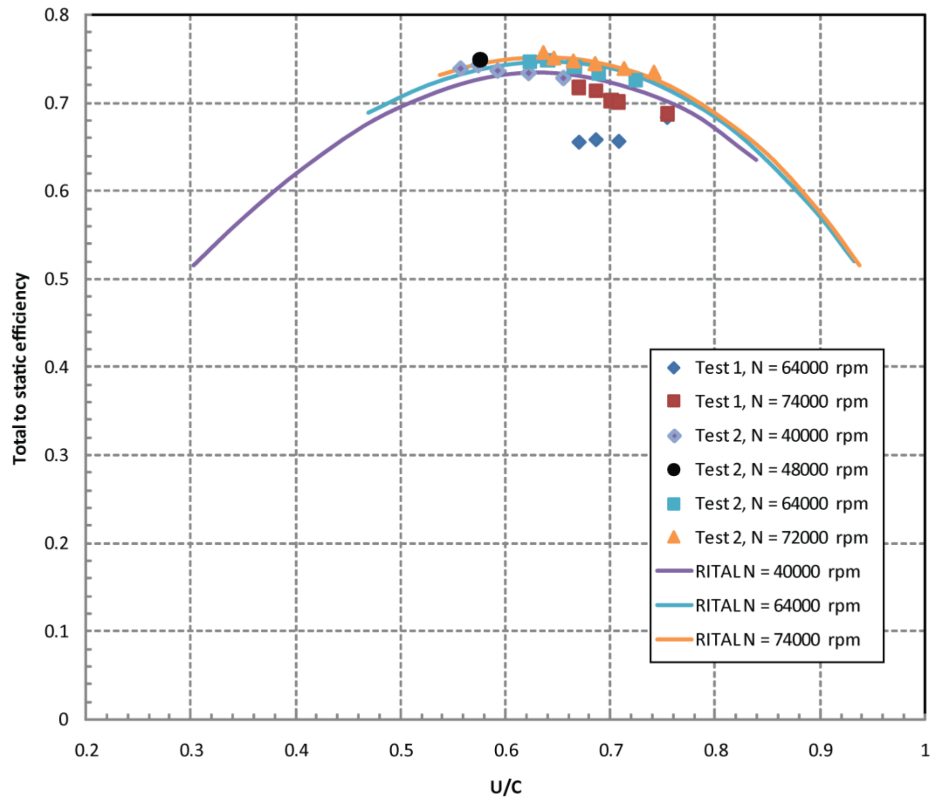
Progress with forward swept turbine design

- First turbine has been designed and tested using a variable geometry nozzle from a commercial donor turbine
- Cold testing only so range of *U*/*C* is restricted, but initial results are encouraging
- Performance improvement at low *U*/*C* is also shown by CFD simulations
- Second turbine has been designed and will be hot tested

Turbine test results

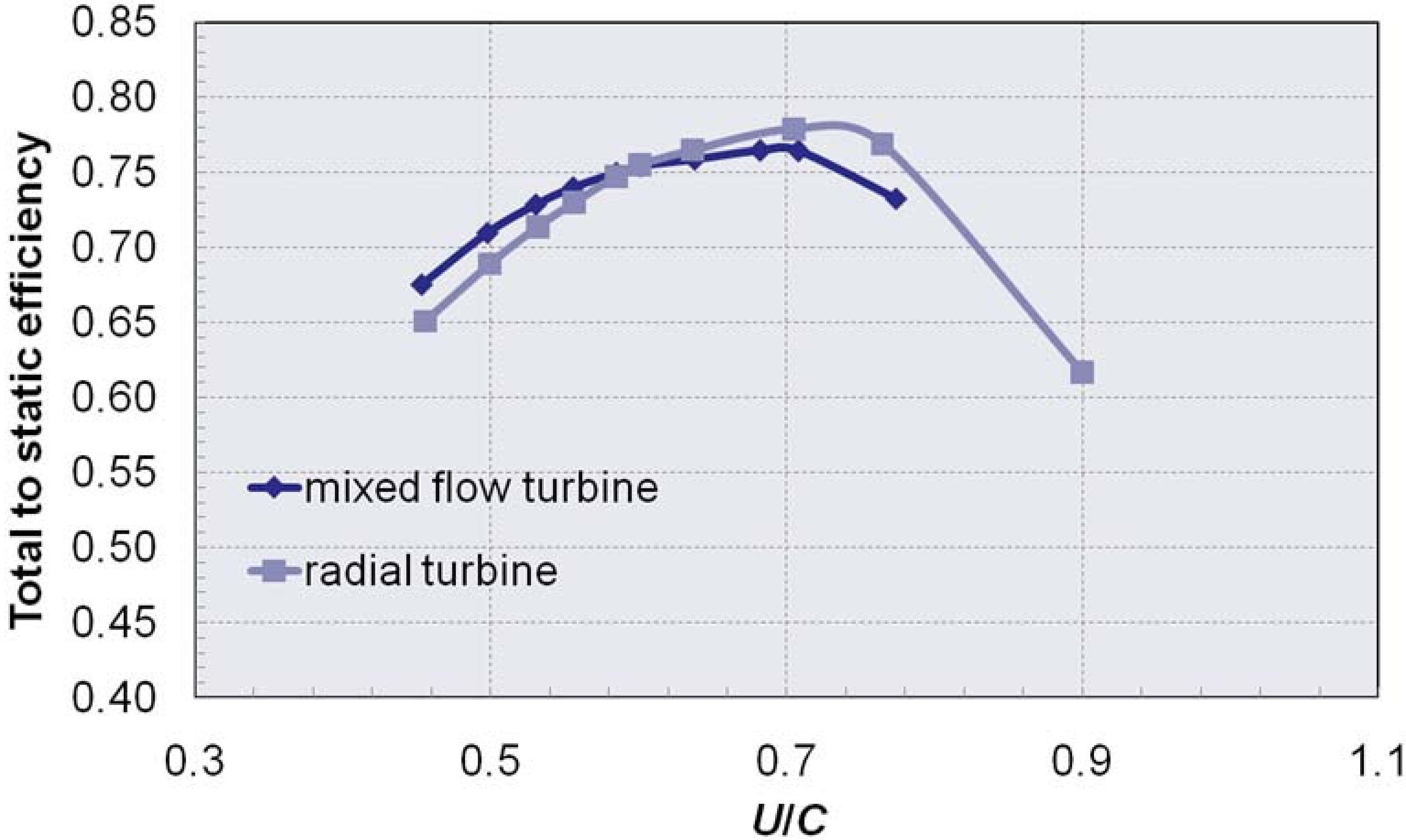


100% open



50% open

CFD predictions



Conclusions

- Significant improvements in turbocharger performance will be difficult to achieve
  - Requires a proper understanding of the trade-offs
  - Engine effects and impacts must be part of turbocharger development
- Compressor range/efficiency trade-off is a focus technology, that will require some combination of
  - Application-specific impeller development
  - Tailored casing treatment
  - Variable inlet guide vanes
  - Advanced diffuser developments
- Turbine focus is on pulse flow performance
  - Requires new rotor design for the necessary efficiency characteristic
  - Stress, life, and inertia are limitations to performance development