



The design of radial turbines for automotive turbochargers

PCA's radial turbine design system makes best use of advanced CFD

- PCA's radial turbine design system takes a new design from initial 1D design and performance prediction right through to full stage CFD and comprehensive structural analysis.
- PCA's Vista codes handle the 1D design and performance prediction.
- ANSYS® CFX® software is used to create the 3D geometry of the impeller, and initial vane shape optimisation is conducted by multiple CFD runs using ANSYS® CFX®.
- The scroll 3D geometry is set up with the assistance of Unigraphics, and a full-stage CFD mesh is then created with a mixing plane between scroll and impeller. The full stage flowfield is analysed with ANSYS® CFX® software.
- Structural analysis is conducted in parallel either with proprietary codes or PCA's own FENELLA.

The usual starting point for a new radial turbine design is the 1D optimisation process where the effect of changing the basic geometry parameters on the design and off-design performance can be explored quickly. PCA's Vista RTD and RITA, respectively design point and performance codes, allow first-pass values of wheel diameters and scroll A/R to be established.

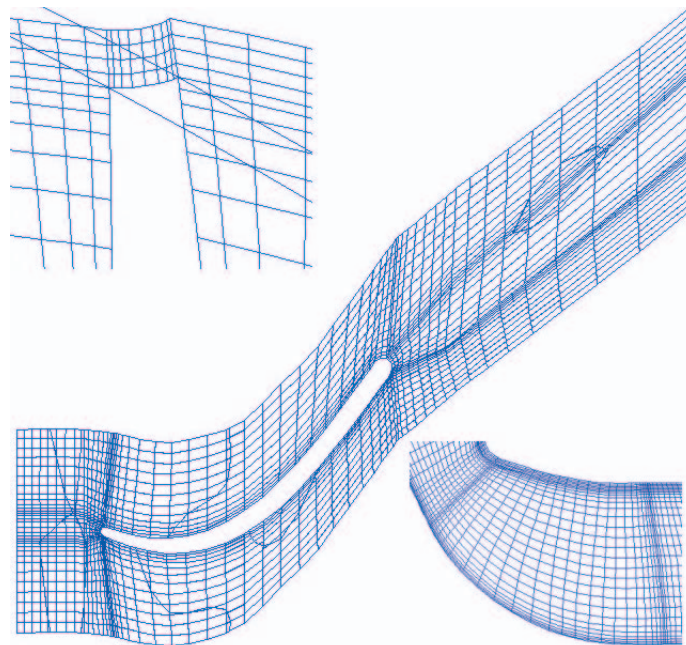


Figure 1 - Impeller passage mesh

Detailed development of the impeller vane shape is carried out using ANSYS CFX software. A structured mesh (Figure 1) is generated around a vane shape defined by its meridional envelope, vane number, a wrap angle and a thickness description. The turbine aerodynamic boundary conditions are applied and a CFD solution generated, the important outputs of which are the flow capacity and the efficiency. The A/R of the scroll is modelled as an inlet swirl angle. The target flow capacity is achieved either by modifying the vane wrap angle distribution or the inlet swirl angle. Single-passage CFD calculations of this type are quick, allowing many geometries to be considered before freezing a first pass design.

The scroll internal geometry is developed using UNIGRAPHICS. The scroll channel area and A/R circumferential variation are set, initially, from 1D principles, but are subject to revision following CFD analysis incorporating the scroll plus a single vane passage, connected using a stage mixing plane. The scroll is meshed using predominantly unstructured elements (Figure 2) but with prismatic elements in proximity to the walls for better capture of the boundary layer. Flow bypass to a waste-gate valve may be modelled if necessary.



Figure 2 - Stage model and scroll mesh

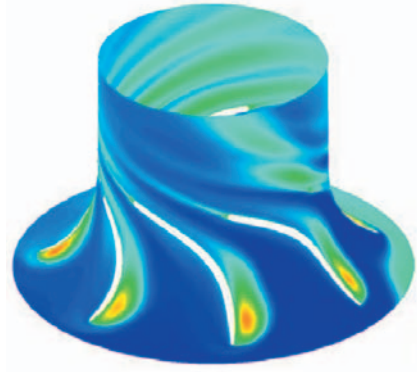


Figure 3 - Entropy field at pulse peak

Basic FE analysis on the first pass design is carried out in parallel with the development of the scroll; ANSYS, ABAQUS or PCA's own FENELLA may be used. Calculations are made, typically, of peak stresses, burst margin, vibration characteristics and creep life. The latter, which is often the limiting feature, is assessed based on the extreme combination of stress and temperature and the material's Larson-Miller parameter.

Gasoline engine turbocharger duty is often extremely demanding resulting in a balancing act between efficiency, inertia and robustness. More advanced analyses may be carried out where prevailing guidelines, on vane flap frequencies say, are transgressed, or creep life appears marginal. Transient

CFD may be carried out (Figure 3) to provide boundary conditions for a dynamic forced response calculation (Figure 4). Provided constitutive equations are available for creep strain rates, a non-linear time-integral assessment of accumulated creep strain can be undertaken.

In general, once the above aerodynamic and structural calculations (or a reduced set) are complete a number of weaknesses will have been revealed in the first pass design. The vane design may be revised and a number of analyses repeated. The final step for PCA is to release a CAD model of the impeller (Figure 5). This will have the appropriate fillet radii and, for automotive applications, will generally have inertia-reducing back-face scallops.

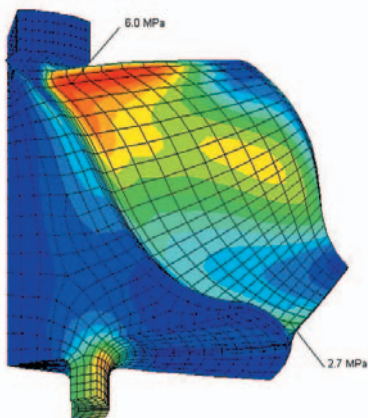


Figure 4 - Dynamic stress from forced response

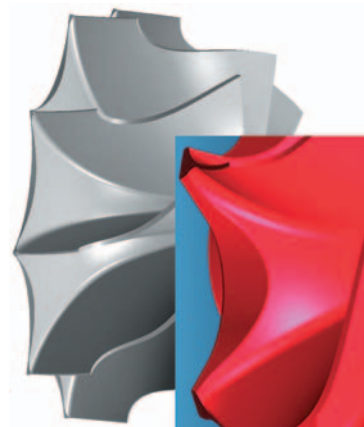


Figure 5 - CAD models