ESTABLISHMENT OF A STEAM TURBINE FLUTTER TEST CASE

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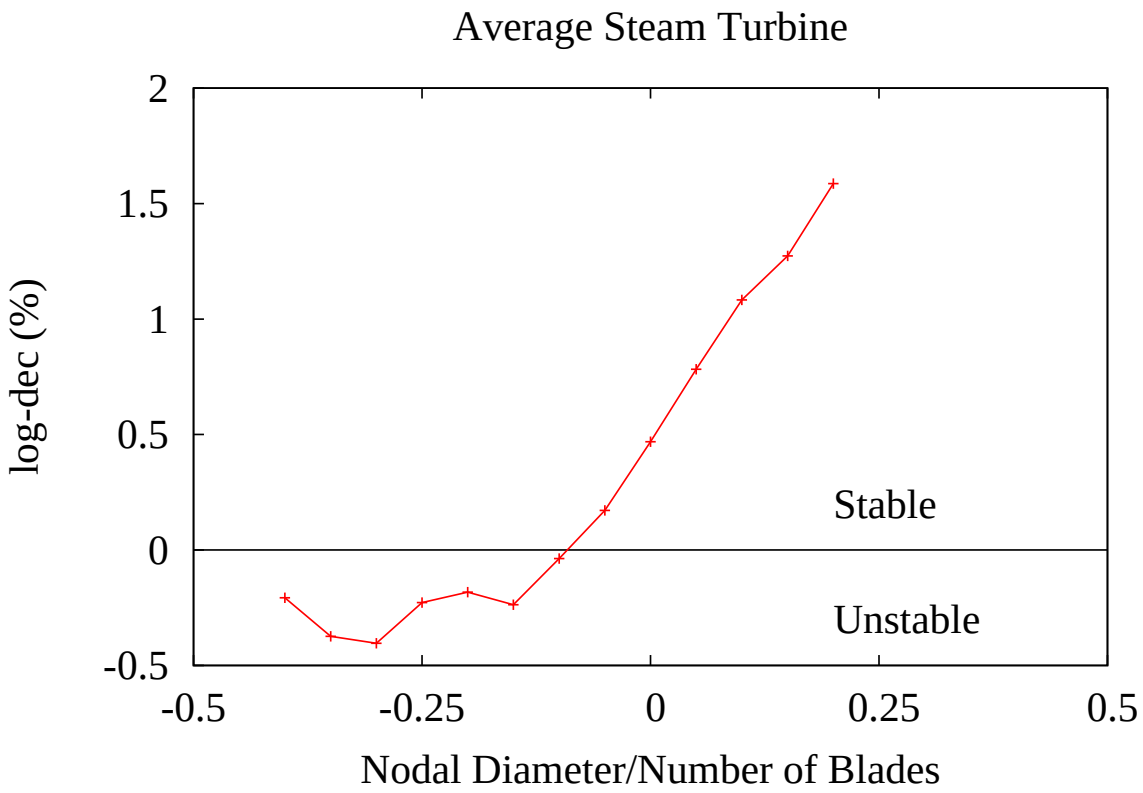
Outline of Presentation

Outline

- Motivation - steam turbine flutter - wet steam effects
- Wet Steam Model in RPMTurbo LUFT® code
- Define Test Case: Standard Configuration 11
- Results: Wet Steam Flow Modelling
- Conclusions and Future Work

Motivation - Steam Turbine Flutter



- Flutter is a problem for steam turbines
- Need to predict minimum log.-dec value as accurately as possible

Motivation - Steam Turbine Flutter

Log.-Dec Calculation

$$\delta = \frac{W_{\text{aero}}}{4\ KE_{\text{aver}}}$$

Unsteady Aerodynamics Modelling

- 3D flow
- Viscous turbulent flow (off-design)
- Far-field boundary conditions (non-reflecting) RPMTurbo 2010
- Complex mode shapes
- Tip clearance flow for non-shrouded blades (Glodic 2012)
- Multi-row effects (Li He 2006)
- Wet steam effects (no published results)

Wet Steam Flow Modelling

Wet Steam Equation of State

- assume equilibrium and treat as single gaseous phase
- remove all perfect gas assumptions and use equation of state
- conserved variables: density, momentum and total energy
- formulae from IAPWS-IF97: International Association for the Properties of Water and Steam - Industrial Formulation 1997 used to calculate pressure, temperature, speed of sound, entropy and enthalpy

RPMTurbo - LUFT® **L**inearised **U**nsteady **F**low for **T**urbomachinery

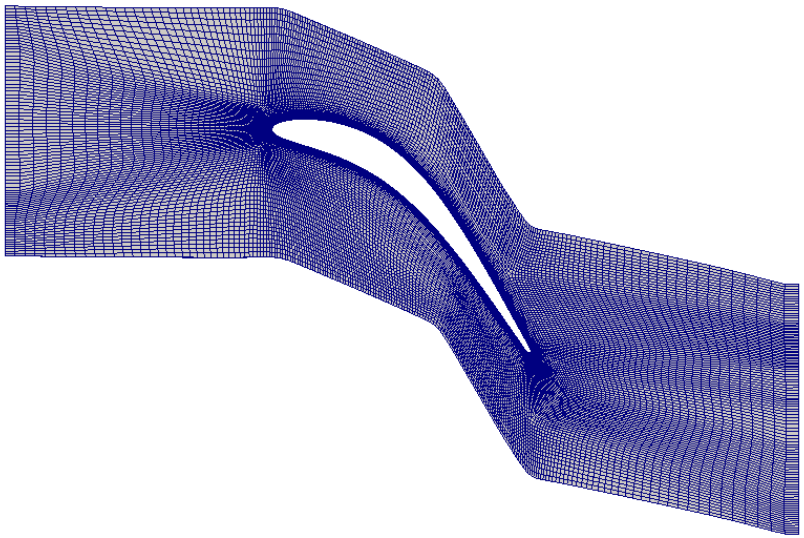
- 3D viscous flow -turbulence model fully linearised
- 3D non-reflecting boundary conditions
- fast - 1.1 millions cells in 1 hour (1D NRBC) or 5 hours (3D NRBC)

Wet Steam Flutter Test Case

2D Turbine - Standard Configuration 11 - Fransson et al. (1999)

Chord length	77.8 mm
Stagger angle	40.85
Blade Mode	torsion
Mode frequency	212.0 Hz

2D mesh – 23790 cells



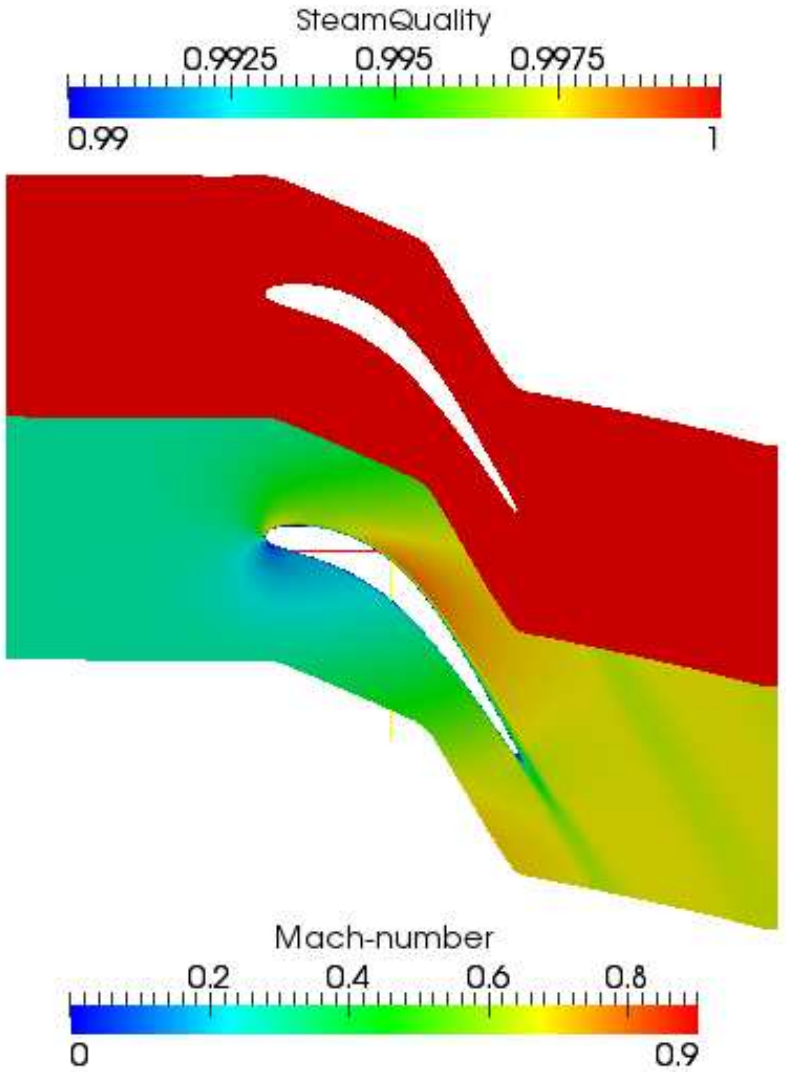
New wet steam flow conditions

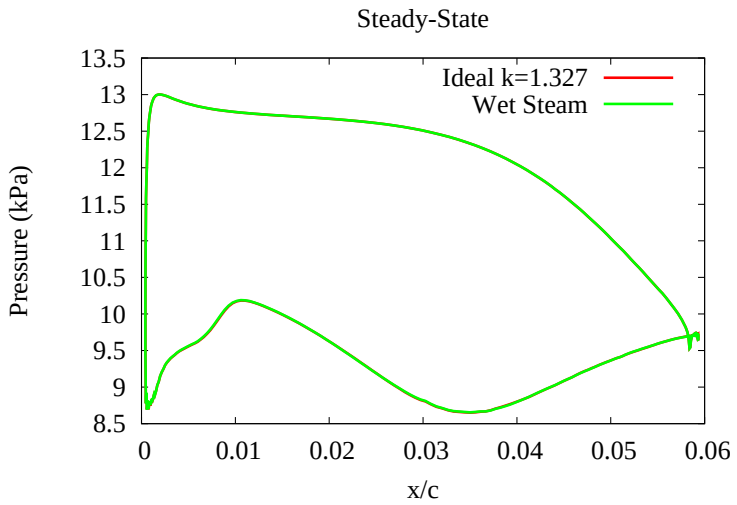
1 – subsonic dry steam
2 – subsonic wet steam
3 – transonic wet steam

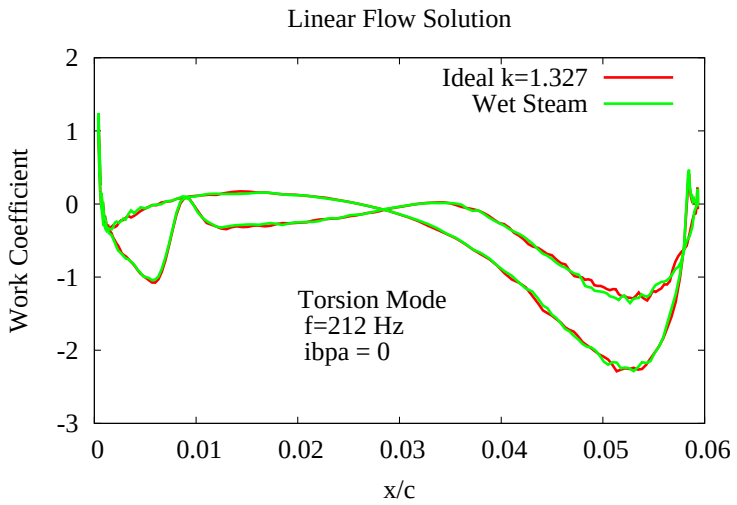
Flow condition	1	2	3
Inlet total pressure (kPa)	13.0	13.0	13.0
Inlet total temperature (K)	400.0	324.0	324.0
Inlet total quality	1.0	0.9	0.9
Exit pressure (kPa)	9.75	9.75	7.5
y^+ first grid line on profile	0.08	0.11	0.11
Outlet Mach number	0.661	0.656	0.913
Reynolds number (millions)	0.126	0.143	0.156
Polytropic index	1.31	1.11	1.11
Reduced frequency (full chord)	0.329	0.381	0.277

Wet Steam Flutter Test Case - Condition 1

Condition 1 - Subsonic Dry Steam

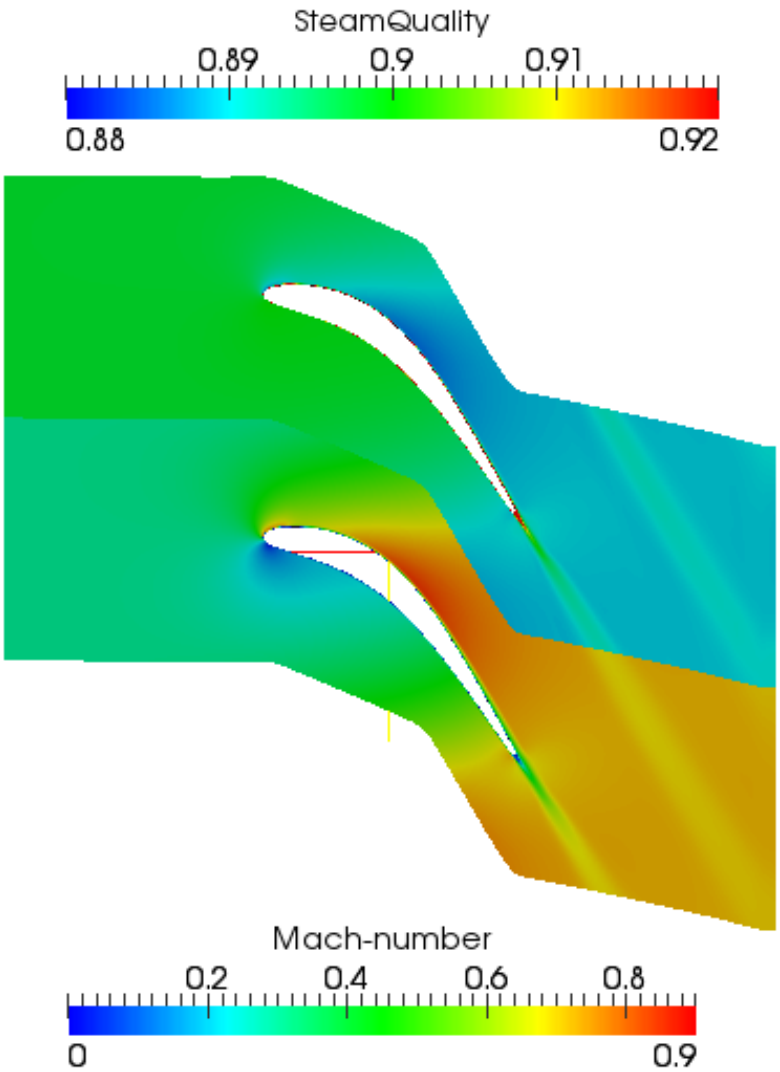


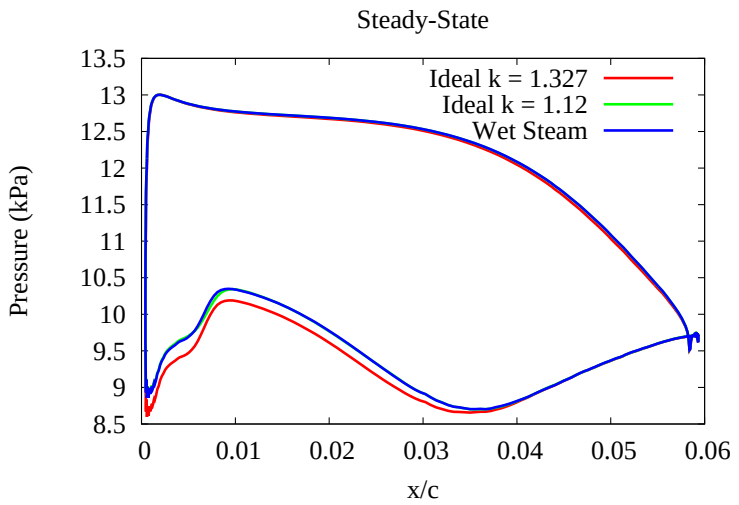


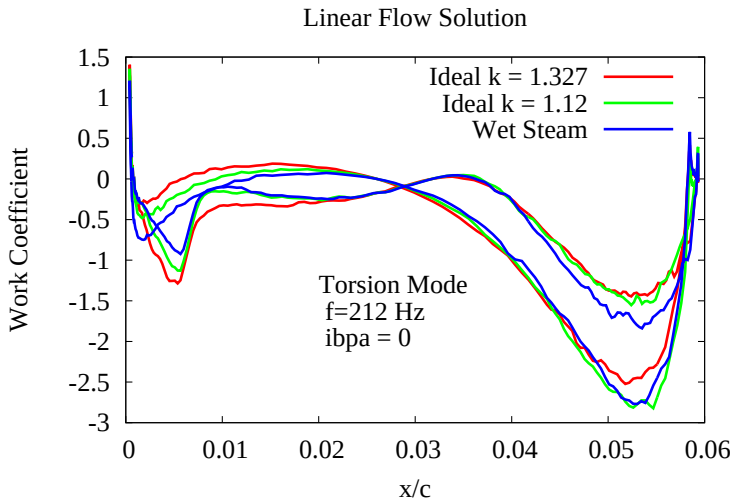


Wet Steam Flutter Test Case - Condition 2

Condition 2 - Subsonic Wet Steam

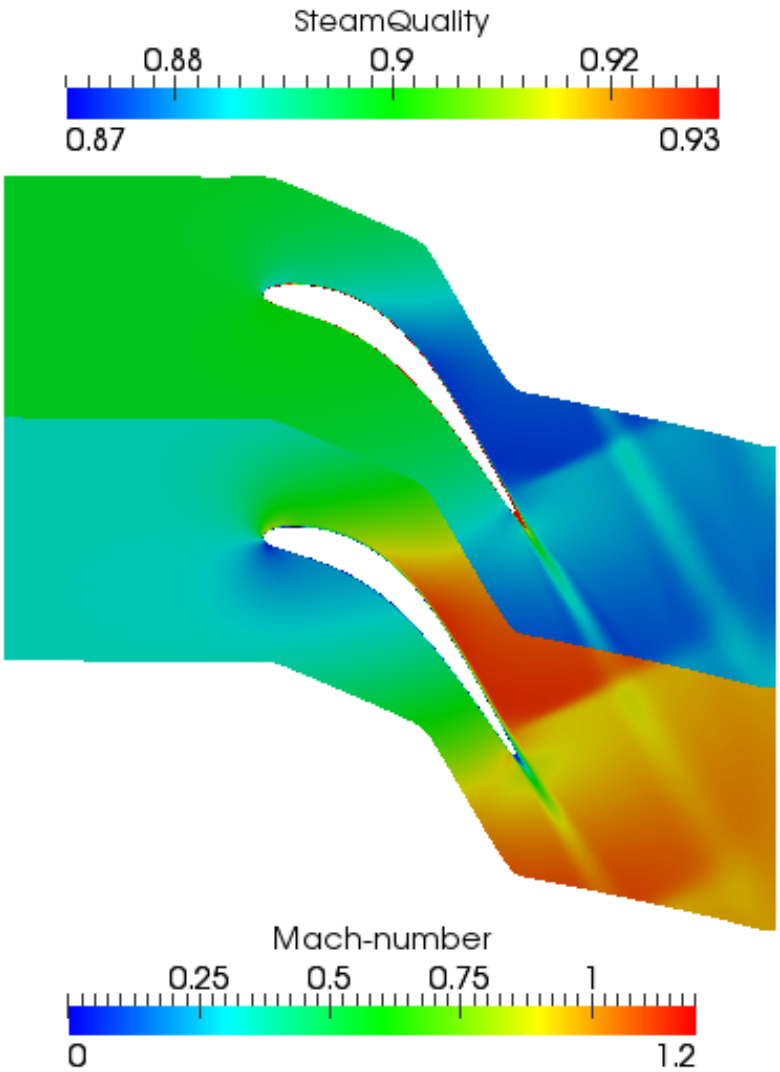


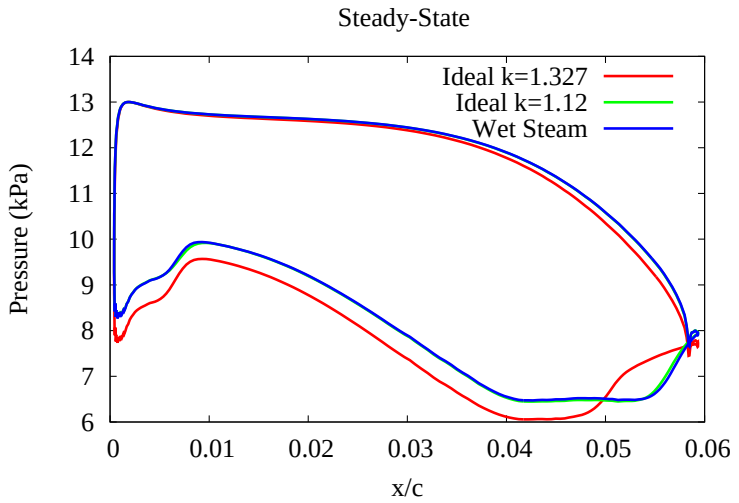


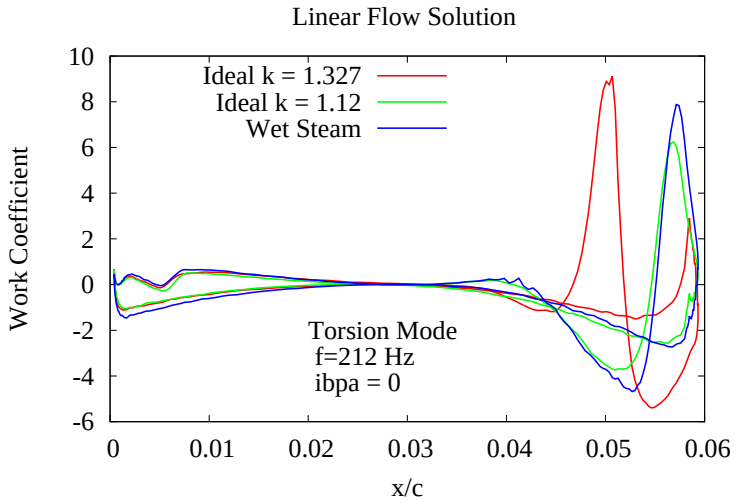


Wet Steam Flutter Test Case - Condition 3

Condition 3 - Transonic Wet Steam







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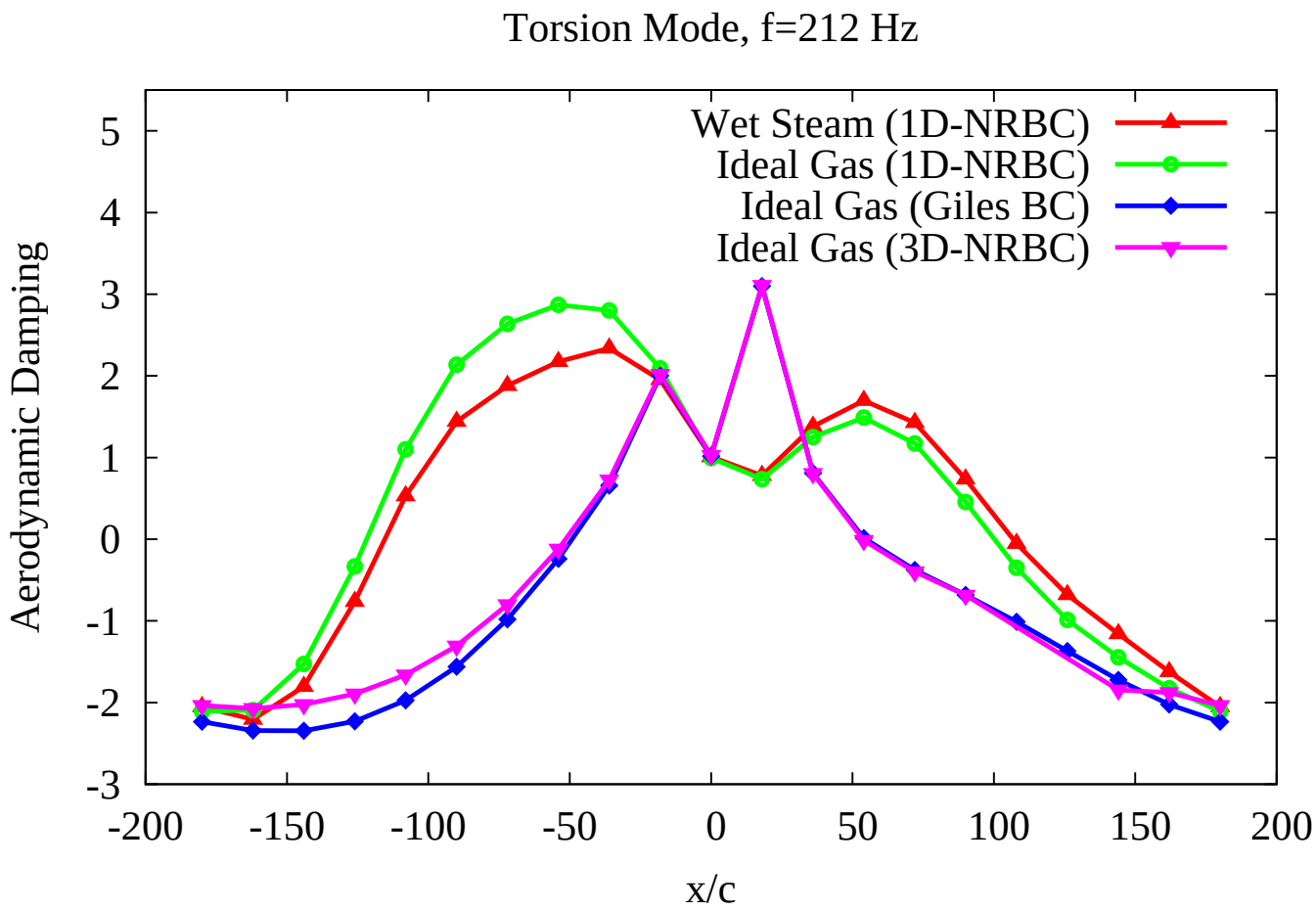

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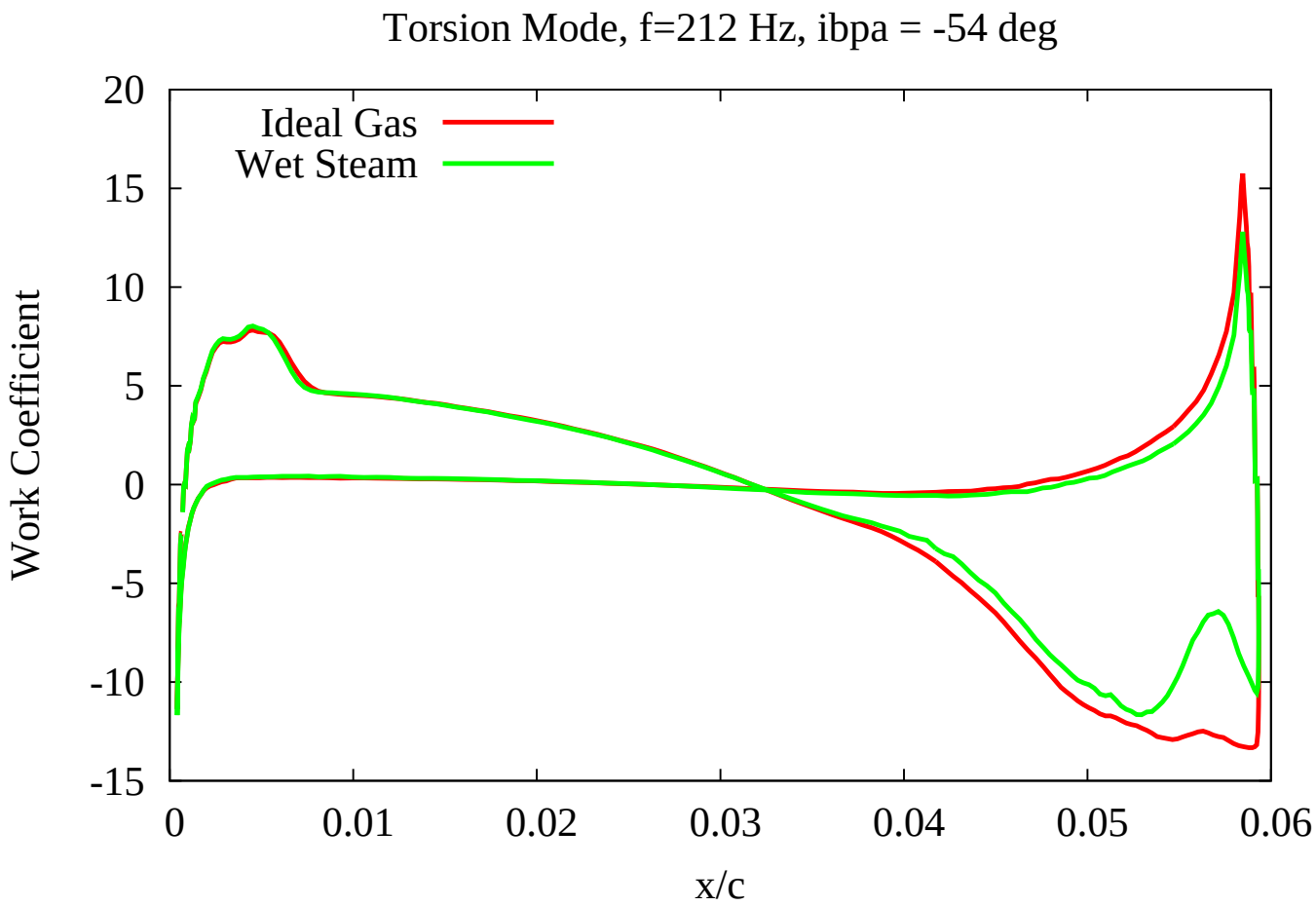

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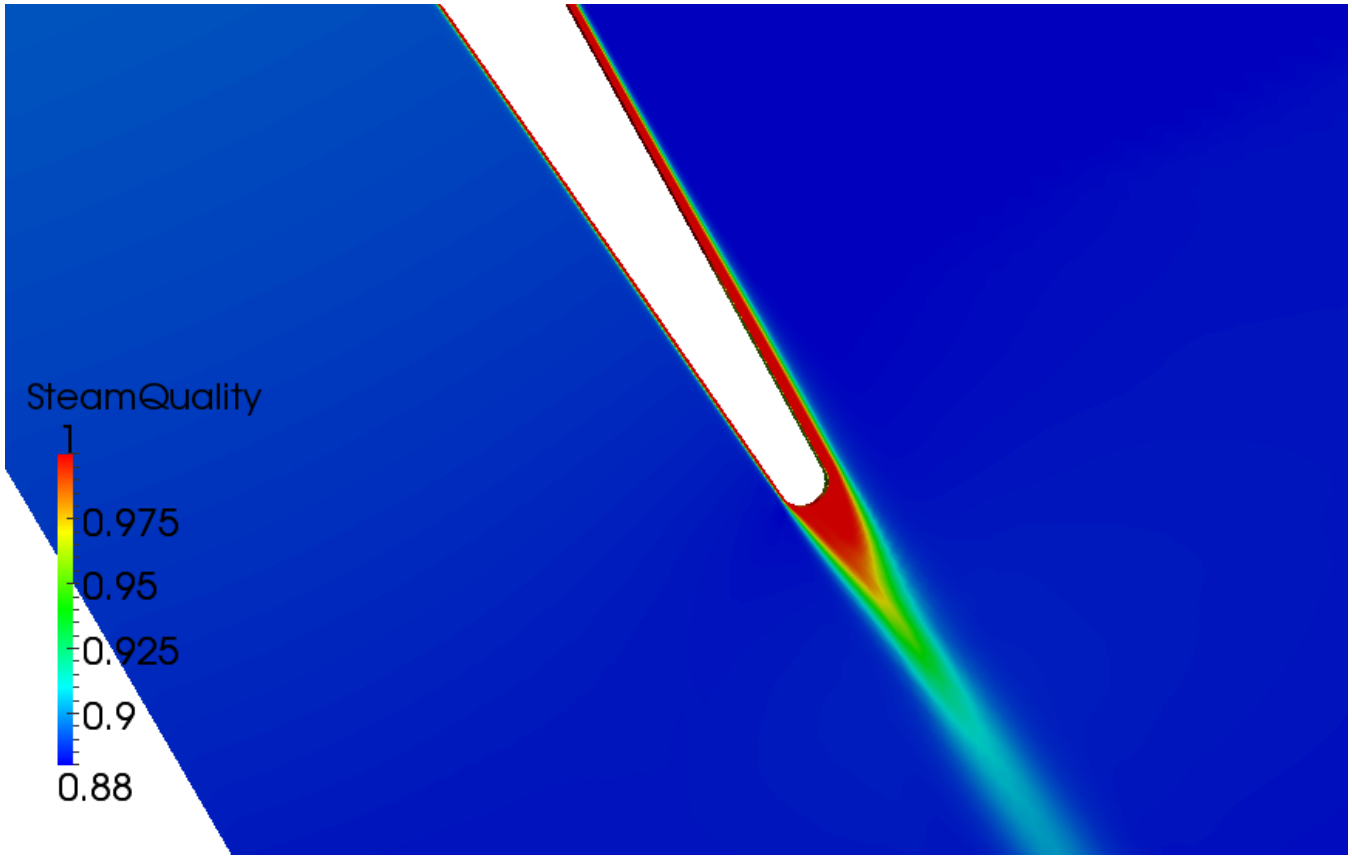
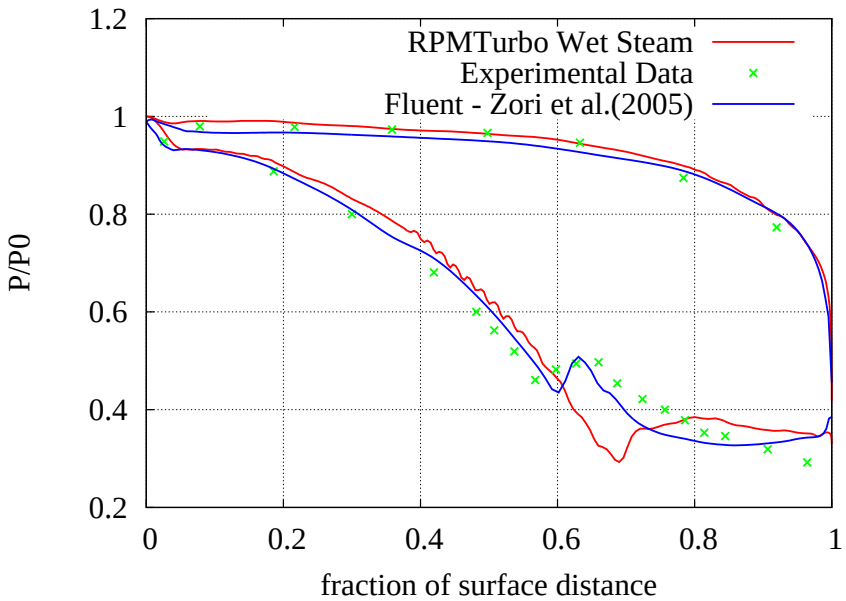
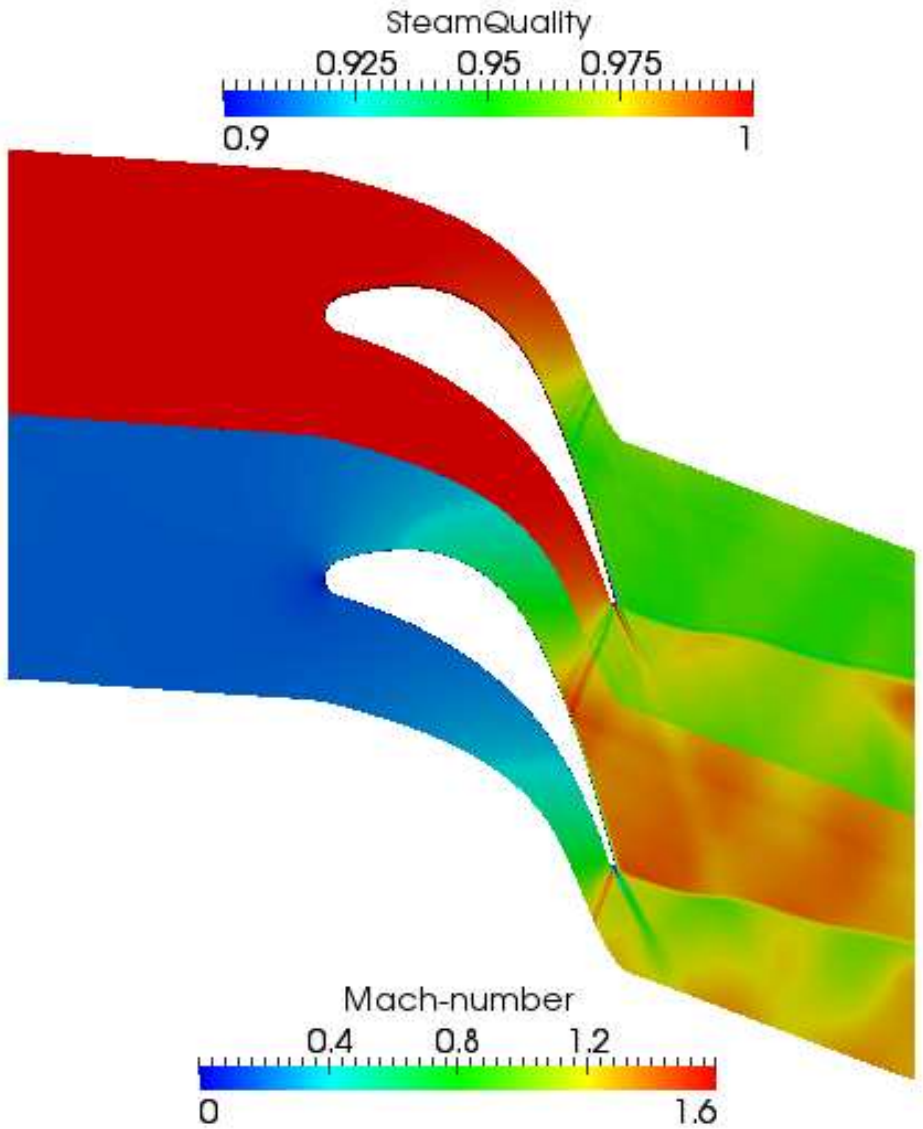


Steam Turbine Test Case - Case L1

5th stage stator of 6-stage LPT
White, Young & Walters (1996)

Chord Length	137.51 mm
Stagger Angle	45.32^o
Inlet P_0	40.3 kPa
Inlet T_0	354.0 K
Exit p	16.3 kPa
Re	712 000

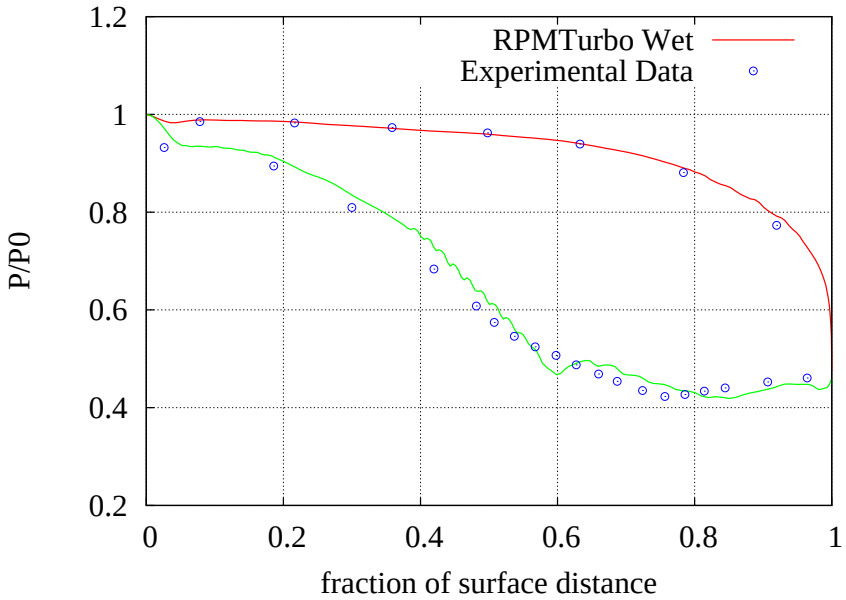


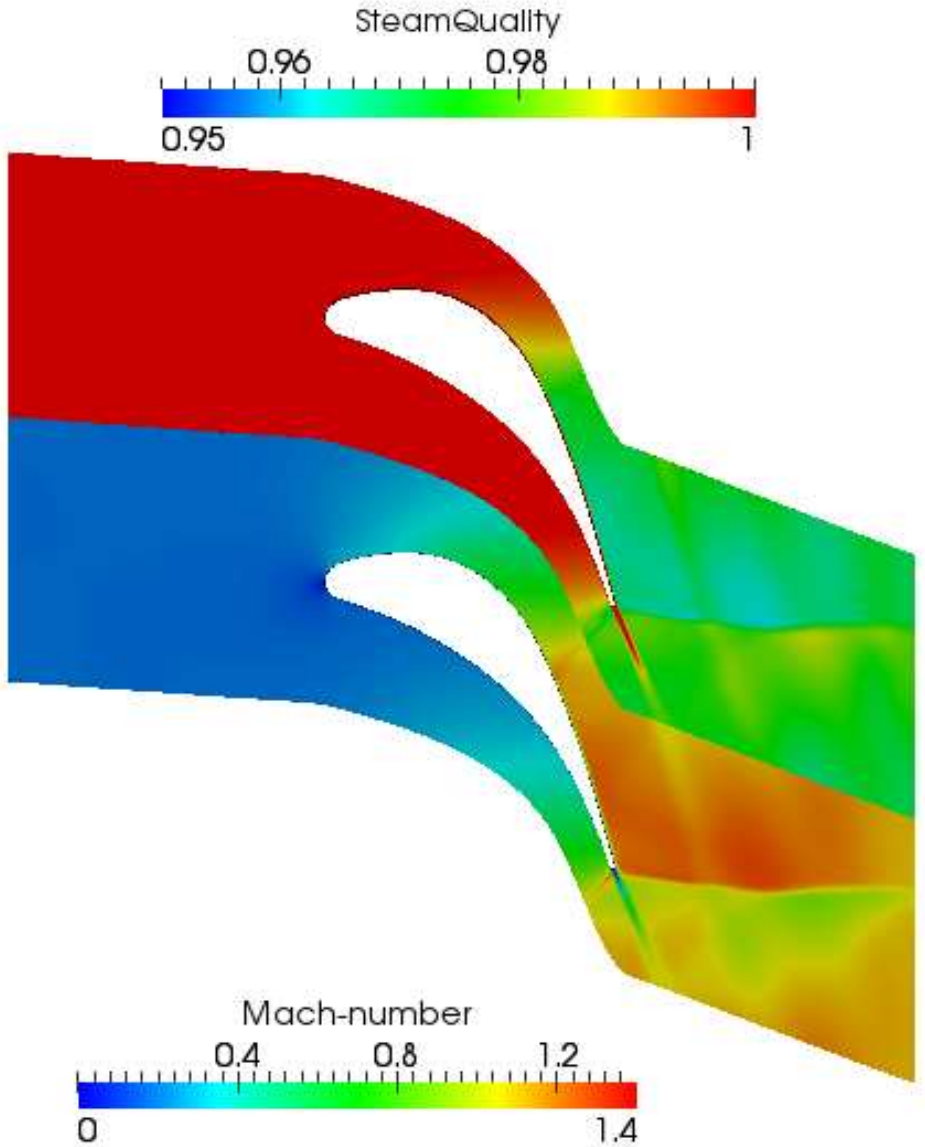


Steam Turbine Test Case - Case L3

5th stage stator of 6-stage LPT
White, Young & Walters (1996)

Chord Length	137.51 mm
Stagger Angle	45.32^o
Inlet P_0	41.7 kPa
Inlet T_0	357.5 K
Exit p	20.6 kPa
Re	779 000





Conclusions

- Wet steam equation of state in RPMTurbo LUFT® code
- Wet steam flutter test case established - initial results published
- Implementation appears to be correct - more testing required
- Differences between ideal steam and wet steam flow models
- Non-equilibrium effects may be important in some cases
- Improve test case - increase chord to match Reynolds number
- Publish results on web: www.rpmturbo.com