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Modelling of the SUNSPOT Cycle: Some Foundational Work

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Research Background

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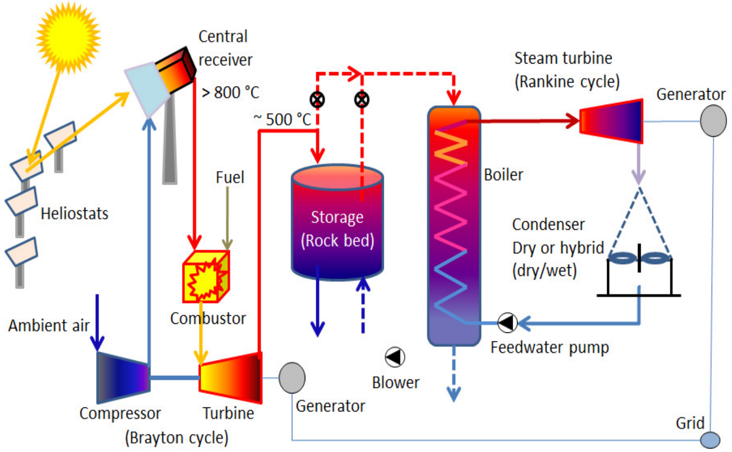
- Overall project objective:
  Comprehensive assessment of the performance characteristics of the SUNSPOT cycle on the basis of high-fidelity thermodynamic modelling
- Assessment framework: software tools to facilitate design-point, off-design, parametric & economic modelling
- Modelling considerations: meteorological data, working fluid property models, component models, system integration models, control strategy, cooling strategy, dispatch strategy, etc.



Research Background

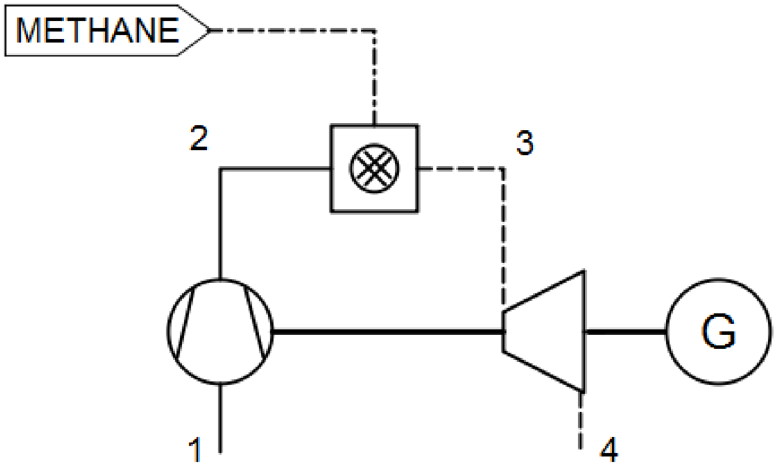
- The performance of most SUNSPOT components can be represented fairly simply with well-established models
- Certain components are more complex to model: e.g. compressor, rock bed thermal storage
- The impact of model complexity is compounded in long-duration calculations, where computational efficiency is of importance
- In addition, a lack of clarity exists regarding best-practice working fluid property models for air & combustion gases
- This presentation outlines two foundational activities related to resolving the above issues:
    1. Part 1: Thermodynamic property modelling of SUNSPOT’s working fluids
    2. Part 2: A generic compressor model for parametric studies

Part 1: Thermodynamic Property Modelling

- SUNSPOT cycle working fluids: (moist) air, combustion gases, water/steam
- Internationally recognised model for water/steam: IAPWS-IF97 formulation
- Internationally recognised model for air & combustion gases: none
- A multitude of contemporary data sources exist for air & combustion gas properties (models, data tables, software)
- Data sources vary substantially in complexity
- Real gas effects (high pressures) & species dissociation (high temperatures) complicate matters further
- How significantly does data source sophistication impact on plant performance predictions?
- Is a state-of-the art ideal gas model sufficiently accurate?

Part 1: Thermodynamic Property Modelling

- To evaluate this, seven contemporary data sources were used to rigorously predict the performance of a gas turbine plant
- Models: McBride et al. ‘93 (IG), McBride et al. ‘02 (IG), Lanzafame & Messina (IG), VDI Guideline 4760 (IG/D)
- Software: NASA CEA v2 (IG/D), REFPROP (RG), FluidEXL Graphics LibHuFlueGas (RG+D)



Parameter Ranges:

T_1: -20°C to 40°C (15°C)

Φ_1: 20% to 100% (60%)

PR_c: 5 to 35 (15)

T_3: 800°C to 1300°C (1000°C)

Part 1: Thermodynamic Property Modelling

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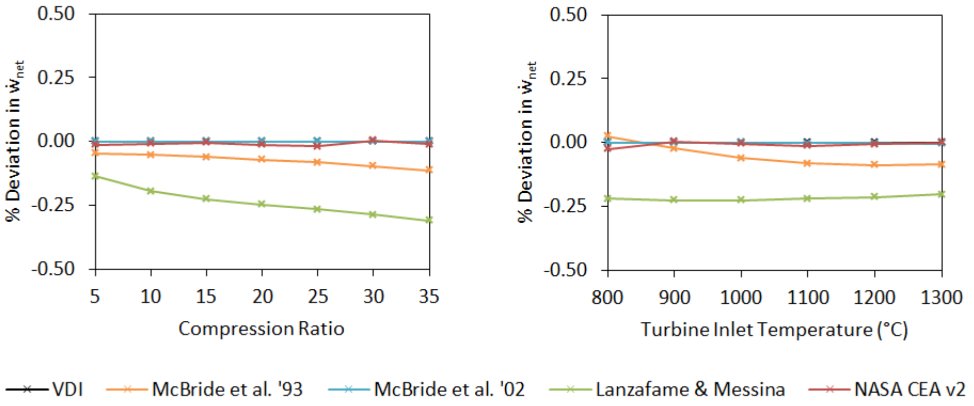
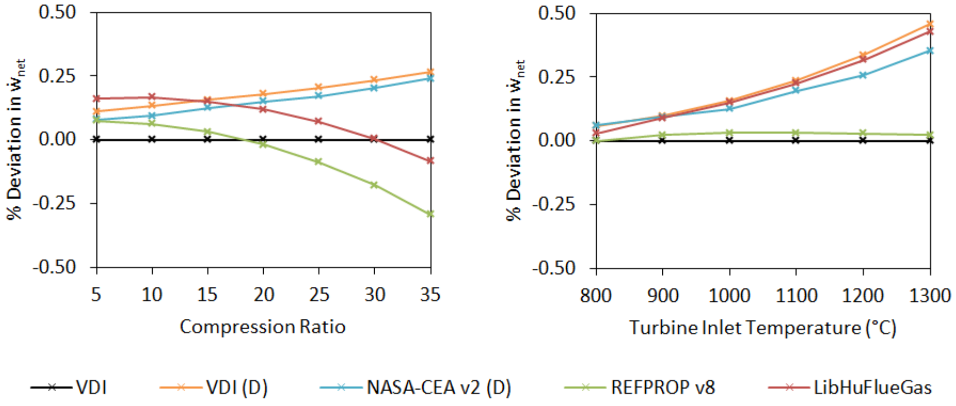
Deviations in net specific power output predictions (w.r.t VDI data)



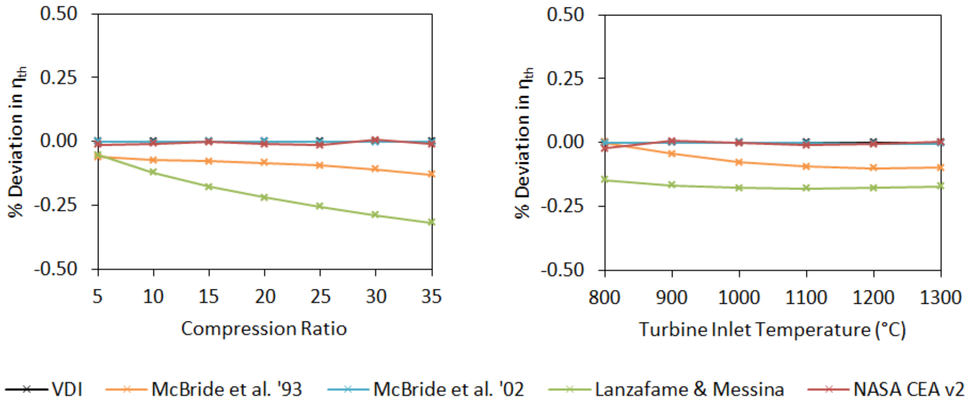
Ideal gas data sources



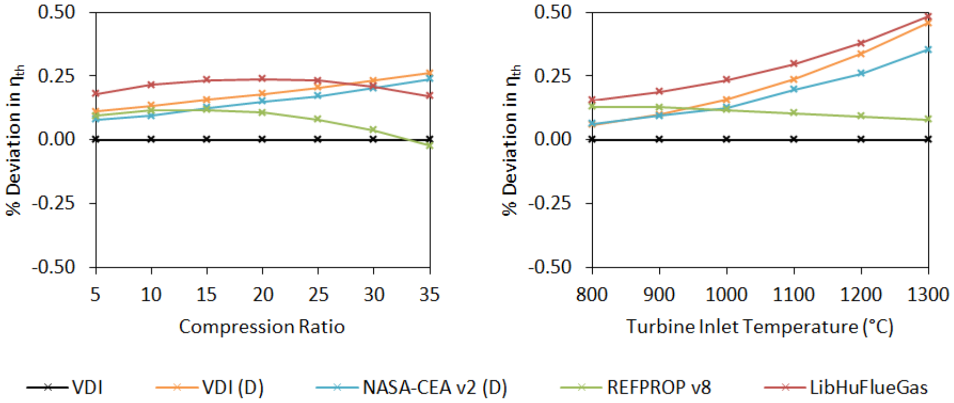
Advanced data sources

Part 1: Thermodynamic Property Modelling

Deviations in thermal efficiency predictions (w.r.t VDI data)



Ideal gas data sources



Advanced data sources

Part 1: Thermodynamic Property Modelling

Some conclusions:

- Appreciable deviations in performance predictions exist, especially for high PRs & TITs
- Ideally, both real gas effects & species dissociation should be accounted for; even at moderate PRs & TITs (i.e. SUNSPOT)
- Air & combustion gases: high-fidelity simulations – LibHuFlueGas software, lower-fidelity simulations – VDI Guideline 4760
- An alternative, more flexible approach: employ REFPROP software with chemical equilibrium routine
- Water/steam: IAPWS-IF97

Part 2: Generic Compressor Model for Parametric Studies

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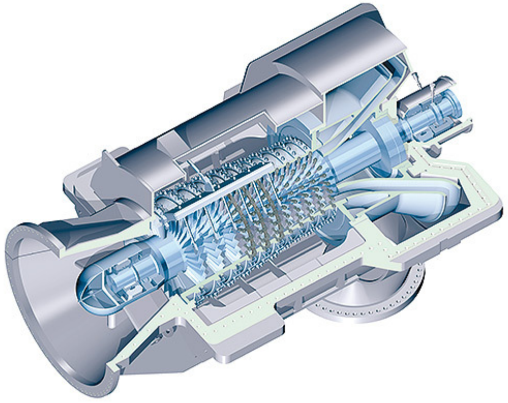
- Prediction of compressor performance complex but crucial
- Maps: pressure ratio & isentropic efficiency vs. parametric mass flow rate at varying parametric speeds
- Approaches: experimental, scaling, analytical/numerical, CFD, etc.
- These typically require detailed design information
- When conducting parametric/optimisation studies, this is problematic
- A generic, representative performance model scaled to design-point parameters would thus be useful
- Proposed method: data from a wide range of axial compressors & simple fitting functions to develop averaged, normalised characteristics



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Part 2: Generic Compressor Model for Parametric Studies

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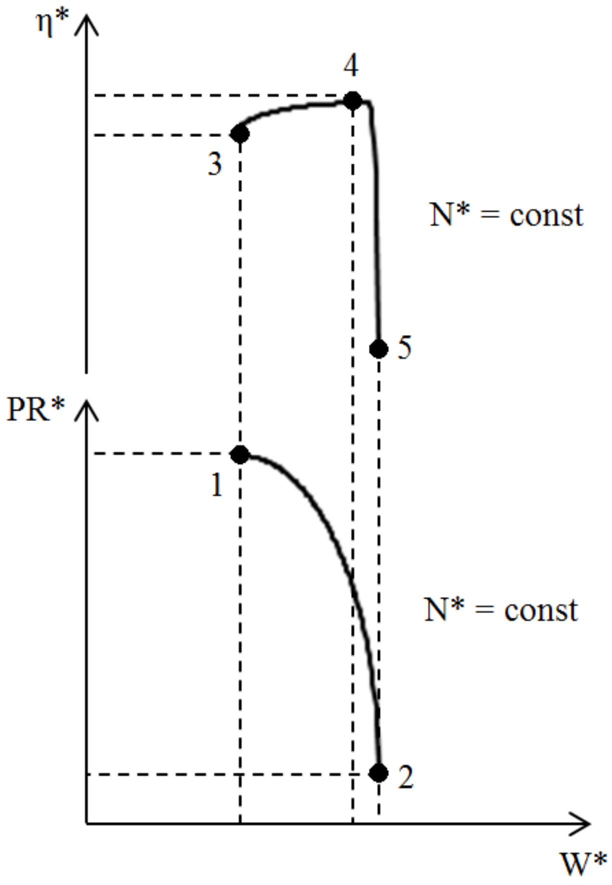
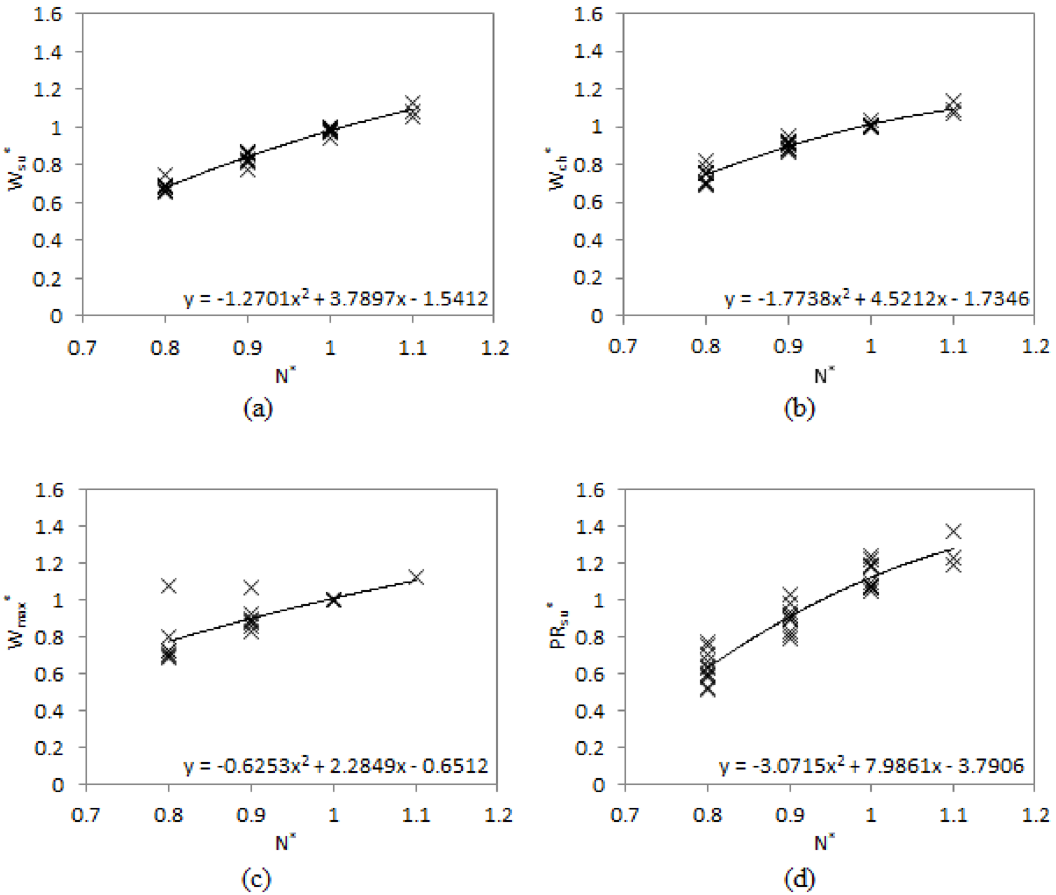
Characteristic points on the constant speed lines



Point coordinates:

1. (mass flow, pressure ratio) @ surge
2. (mass flow, pressure ratio) @ choke
3. (mass flow, efficiency) @ surge
4. (mass flow, efficiency) @ maximum efficiency
5. (mass flow, efficiency) @ choke

Quadratic regression of characteristic point locus equations as f(N*)



(a) (b)

(c) (d)

Part 2: Generic Compressor Model for Parametric Studies

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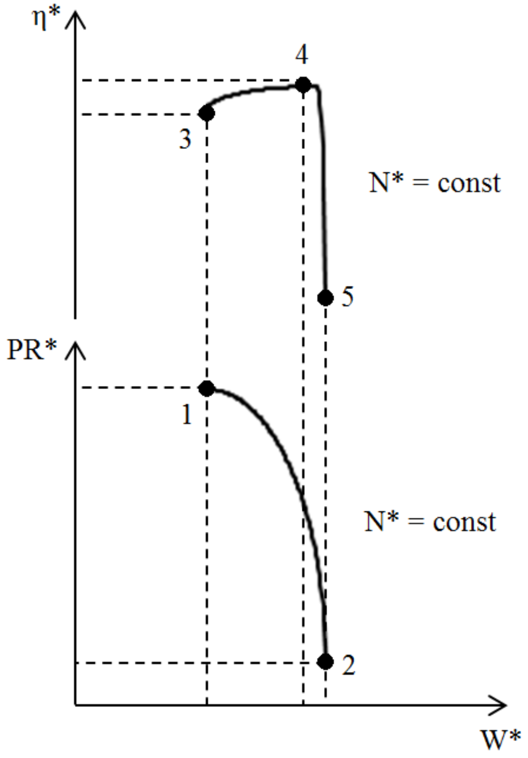
- Locus equations provide normalised coordinates for each characteristic point as f(N*)
- Locus equation coefficients and constants vary according to source data set
- Lines of constant N* are then defined between the characteristic point sets by elliptical functions
- For a known mass flow rate and speed (@ design-point and off-design conditions), the pressure ratio and isentropic efficiency can be found



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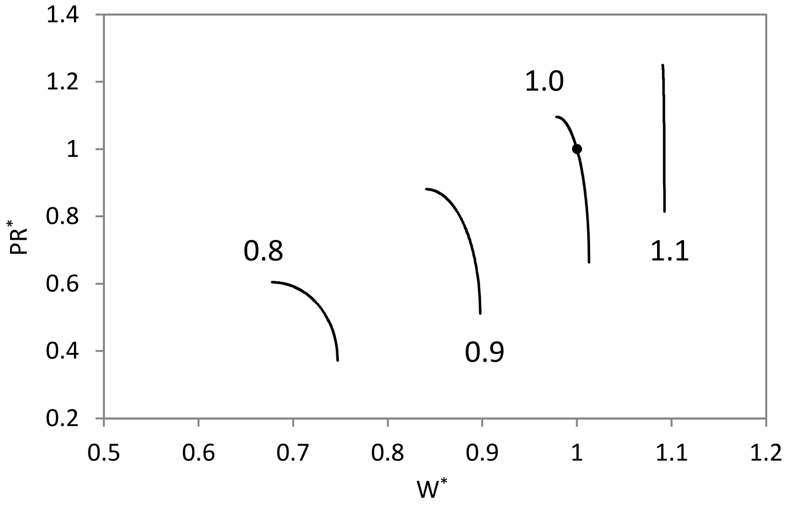
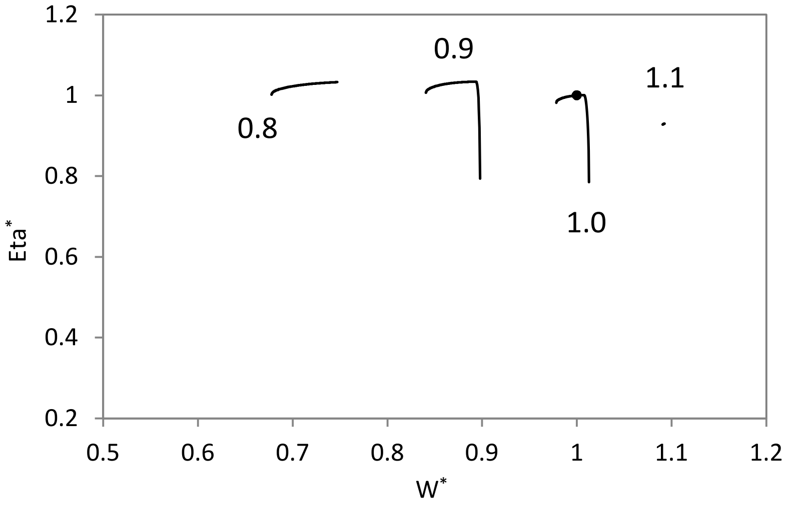
Averaged compressor maps derived from data associated with 11 sources



Normalised pressure ratio vs. normalised parametric mass flow rate



Normalised isentropic efficiency vs. normalised parametric mass flow rate

Part 2: Generic Compressor Model for Parametric Studies

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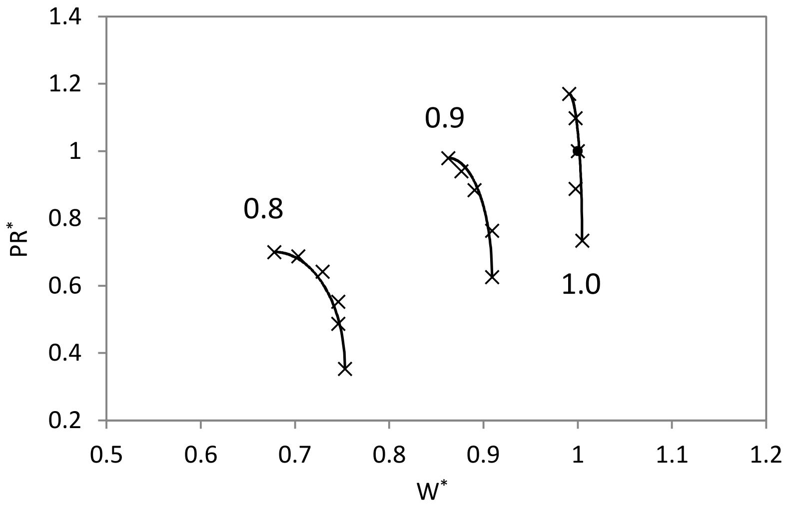
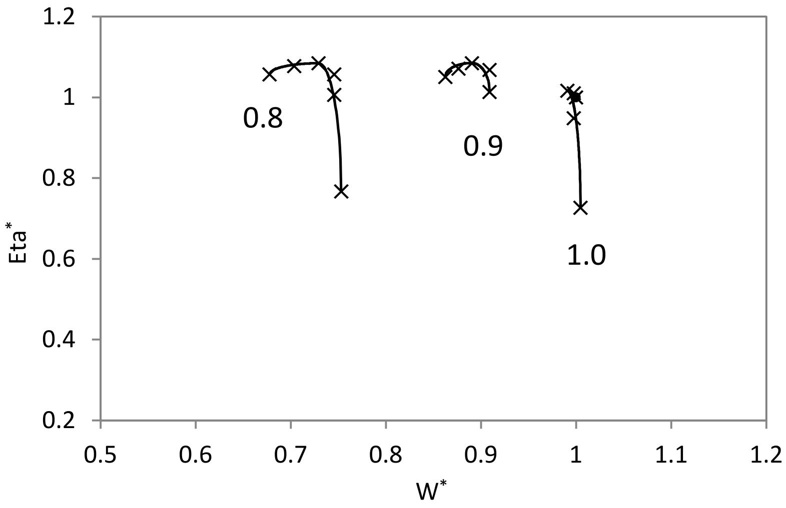
How well do the elliptical functions describe the constant speed lines?



Normalised pressure ratio vs. normalised parametric mass flow rate



Normalised isentropic efficiency vs. normalised parametric mass flow rate

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Some conclusions:

- The proposed model provides a simple, generalised representation of axial compressor behaviour for use in parametric/optimisation studies
- It also provides a useful performance map digitisation technique
- The model's continuous, algebraic nature enables efficient simulation, especially over long time periods
- Future improvements: incorporation of more data sources, categorisation of data sources & alternative constant speed functions for isentropic efficiency

In Conclusion

As part of the foundational phase of the project:

- Thermodynamic property models for SUNSPOT's working fluids have been selected
- Development of a computationally-efficient generic compressor model for use in parametric studies

Concurrently:

- Component models have been assigned to most cycle components
- Design-point modelling of the gas turbine and water/steam cycles
- Initial software development activities

In the near future:

- Finalise outstanding component models
- Complete first-phase of software development
- First round of pseudo-transient modelling