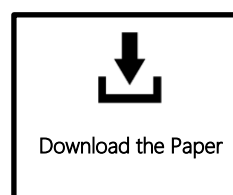




ACCURATE STAGE-BY-STAGE AXIAL TURBINE MODELLING WITH MINIMAL GEOMETRY

This case study describes how Flownex was used to model axial turbines stage-by-stage using a nozzle-based approach that reproduces turbine behaviour accurately even when limited geometric data is available.



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CHALLENGE:

Turbine operators and engineers often need accurate predictions of off-design turbine behaviour, yet real machines are difficult to characterise because detailed blade-passage geometry is seldom available. Classical methods such as velocity triangle analysis or full CFD either require extensive geometric input or are too computationally expensive for rapid system-level studies.

BENEFITS:

Flownex was used because it can represent each turbine stage using the expanded nozzle-analogy method, allowing precise modelling of impulse, reaction and 2-row governing stages while requiring only basic information such as design mass flow, mean blade speed and inter-stage pressures. The approach enables rapid scenario testing, excellent execution speed and accurate reproduction of off-design conditions.

SOLUTION:

A turbine stage was represented as two nozzles followed by a work-extraction element and a carry-over section. Using Flownex restrictor components with correct contraction and loss coefficients, custom components were created for impulse, reaction and governing stages. These components were used to model real turbines, including a four-stage air turbine and multi-stage steam turbines, and the results showed close agreement with validation data.

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INTRODUCTION

Accurately predicting the performance of axial turbines at off-design and abnormal conditions is a long-standing engineering challenge. Traditional tools either rely on simplified empirical laws or require detailed geometric data that is typically unavailable for real power-plant turbines. The method described in the attached document expands classical nozzle theory so that each stage of an axial turbine can be represented entirely through nozzle behaviour, bypassing the need for detailed blade geometry. This expanded approach was implemented in Flownex and tested on several real turbine configurations.

MODELLING A TURBINE STAGE USING NOZZLE ANALOGY

Representing Stator and Rotor as Nozzles

Classical turbine theory describes stator passages as nozzles, but the paper shows that rotor passages can be treated the same way by applying relative inlet conditions. The moving-nozzle concept (Figure 1) demonstrates that the rotor can be modelled as a nozzle with relative velocity inputs, followed by a work-extraction "bucket" element. This allows a full stage to be represented as:

1. Stator nozzle
2. Rotor nozzle
3. Work extraction
4. Carry-over channel

This structure is compatible with Flownex restrictor components, which can be assigned appropriate loss and contraction coefficients.

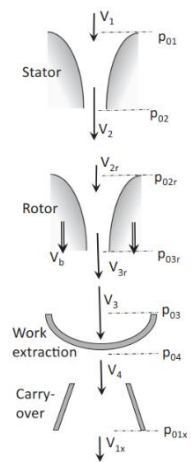


Figure 1: Moving nozzle analogy

Incorporating Losses and Efficiency

The paper presents relationships for:

- Nozzle losses using enthalpy loss coefficients
- Nozzle efficiency relationships
- Carry-over effects between stages
- Conditions for supersonic (choked) nozzles

These relationships allowed Flownex to calculate realistic velocity, pressure and enthalpy distributions for each turbine stage.

BUILDING CUSTOM TURBINE STAGE COMPONENTS IN FLOWNEX

Using the Compound Component feature in Flownex (Figure 2), custom 50% reaction, impulse and 2-row governing stage components were assembled. Each used:

- A stator restrictor component
- A rotor restrictor component
- A pipe component to represent carry-over
- A script to apply the correct coefficients, throat-pressure iterations and heat removal (work extraction)

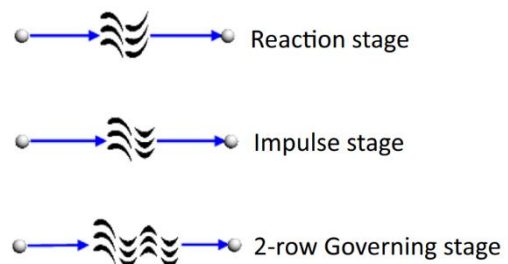


Figure 2: Three custom compound components built in Flownex employing the nozzle analogy

The approach was verified by comparing Flownex predictions with analytical data, showing near-identical behaviour for three representative stage types.

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APPLYING THE METHOD TO REAL TURBINES

Test Case: AGARD Four-Stage Turbine

The method was applied to the well-documented AGARD turbine (Figure 3), which includes detailed measurements of inter-stage pressure, temperature and velocity. Model calibration involved adjusting only throat areas and loss coefficients.

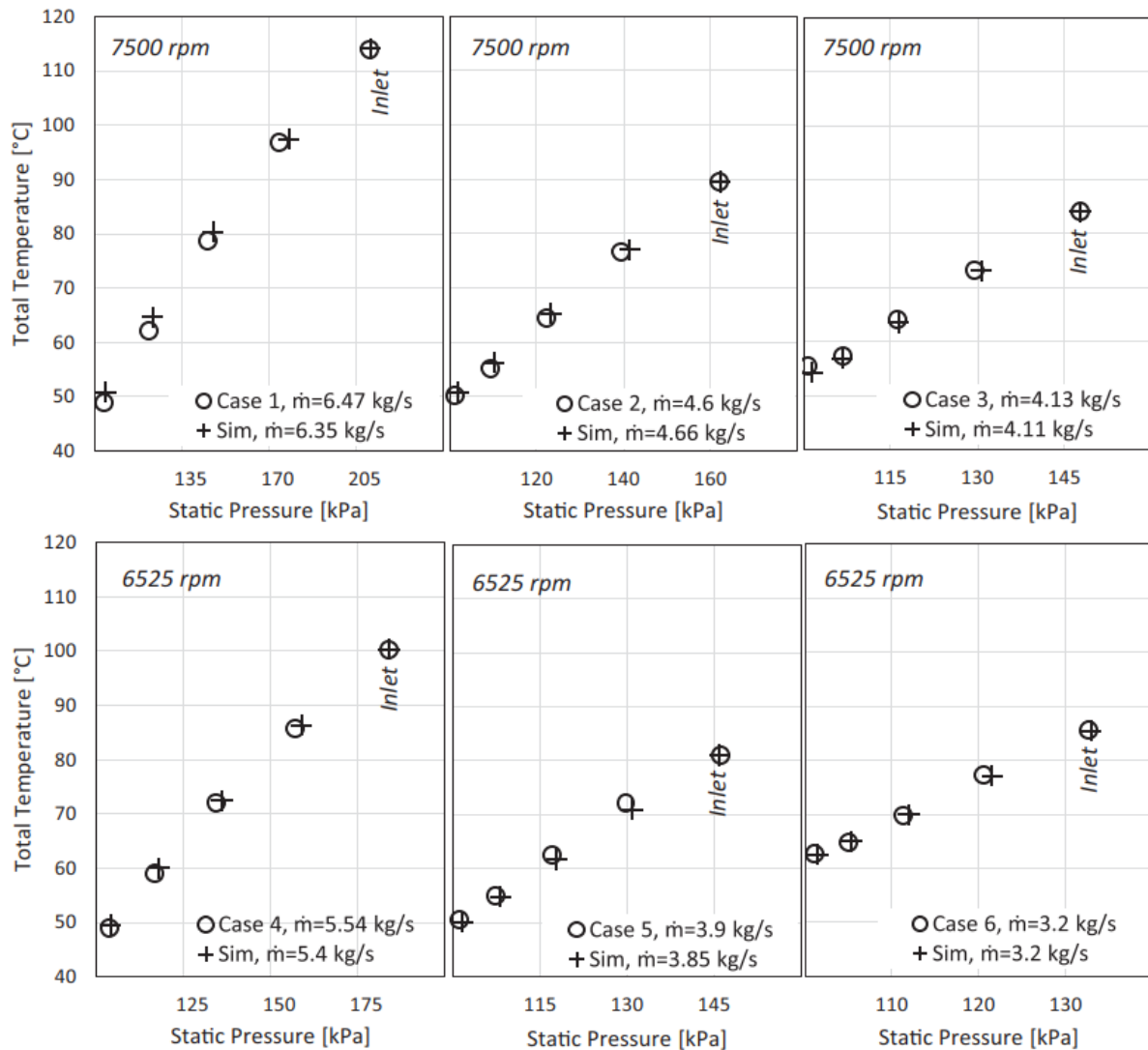


Figure 3: Comparison between the test and simulation results for all 6 test cases of the AGARD turbine

The Flownex model reproduced:

- Off-design mass flow within ~2.5 percent
- Blade efficiency trends
- Inter-stage pressures and temperatures
- Power output within approximately 5 percent

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Steam Turbine Application

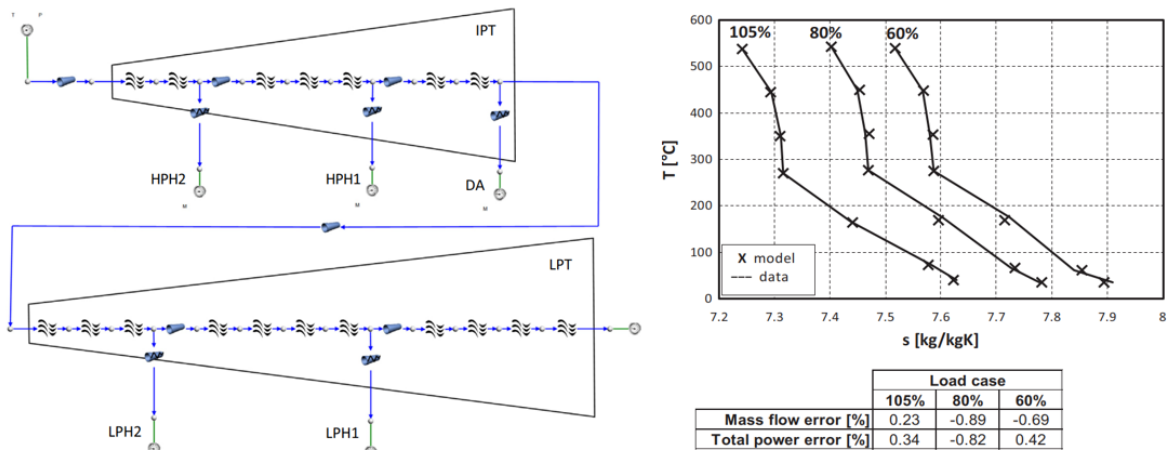


Figure 4: Expansion line results compared with acceptance test data of a 600 MW reheat plant's IP and LP steam turbine

The methodology was further tested on a complex 600 MW steam turbine's intermediate- and low-pressure sections (Figure 4). Using only acceptance test data and without detailed blade geometry, Flownex matched inter-stage T-s paths closely, reproducing load-dependent mass flow and power with very small error.

CONCLUSION

This case study demonstrates that Flownex can accurately model axial turbines stage-by-stage using only limited geometric inputs by applying an expanded nozzle analogy. The method supports impulse, reaction and governing stages and provides excellent predictions of off-design behaviour. Because it avoids heavy CFD requirements while maintaining physical accuracy, this approach is well suited for system-level studies, operator decision-making, and integration into full plant models where turbine performance plays a critical role.