ÚSTAV TERMOMECHANIKY AV ČR
INSTITUTE OF THERMOMECHANICS OF THE CAS

Referee report for the dissertation thesis

Thesis author: Mgr inż. Sima Shabani, Silesian University of Technology, Gliwice, Poland

Supervisor: Dr hab. inż., Mirosław Majkut, prof. PŚ, Silesian University of Technology, Gliwice, Poland

Title of thesis: Analysis of the blade geometries for a highly efficient wet steam turbine stage

Referee: Prof. Ing. Václav Uruba, CSc., Institute of Thermomechanics, Czech Academy of Sciences, Prague, Czechia; University of West Bohemia in Pilsen, Czechia

The dissertation "Analysis of the blade geometries for a highly efficient wet steam turbine stage" is an impressive and thoroughly executed piece of research that, in my view, fully meets, and in many respects surpasses, the standards expected for the award of the doctoral degree.

Below, I offer an extended, holistic appraisal of its merits.

Relevance and ambition of the research problem

Wet-steam phenomena in the low-pressure (LP) stages of large powerplant turbines remain a long-standing source of efficiency loss, mechanical degradation, and design uncertainty. By directing its efforts toward (i) identifying condensation and droplet-growth models that yield reliable CFD predictions and (ii) using those models to optimize last-stage stator geometry, the thesis tackles both a fundamental knowledge gap and a challenge of direct industrial significance. The author's decision to combine in-house experiments with extensive three-dimensional CFD gives the work an immediately practical orientation and positions the results for rapid uptake by turbine manufacturers and operators.

Clarity of aims and scope

The thesis articulates a clear four-fold objective set—model selection, experimental validation, full-stage 3-D simulation, and blade-shape optimization—and then adheres to it with admirable discipline. The logical flow from fundamentals (Chapter 1) through experimental set-up (Chapter 2), model benchmarking (Chapter 3), full-scale simulation (Chapter 4), and optimization studies (Chapter 5) makes the document easy to navigate and ensures that each technical advance is properly contextualized.

Depth and currency of the literature review

Chapter 1 provides an authoritative survey of condensation-modelling literature, ranging from Classical Nucleation Theory variants to contemporary commercial CFD implementations. Particularly valuable is the critique of earlier small-scale or purely two-dimensional studies, which motivates the move to realistic 3-D blade passages and emphasizes the novelty of the present contribution. The review is balanced—crediting seminal work while candidly identifying persisting shortcomings—and is fully referenced to the international state of the art.

Experimental rigor and originality

A significant strength of the dissertation is the custom steam tunnel and its sophisticated Light-Extinction Method (LEM) instrumentation. The author not only employs LEM but also undertakes an exhaustive calibration campaign—including cross-checks against laser-diffraction (Spraytec) measurements—achieving ±6 % accuracy in droplet size and ±12 % in number density. Few published studies offer such meticulous validation of their diagnostic tools, and this effort greatly enhances confidence in the subsequent numerical comparisons.

Methodological breadth in CFD benchmarking

Seven alternative model combinations—mixing Gyarmathy, Fuchs-Sutugin, and Young growth laws with virial, NIST, and IAPWS equations of state—are scrutinized against nozzle and rotor-cascade experiments. The analysis reveals that Gyarmathy- or Fuchs-Sutugin-based cases (3, 4, 6) reproduce static-pressure distributions most faithfully, whereas Young-based cases yield unrealistic efficiencies and are justifiably rejected. This systematic screening constitutes an important, publishable finding in itself and will be of immediate use to CFD practitioners.

Insightful full-stage simulations

The subsequent low-pressure turbine study leverages the validated models to quantify how condensation alters flow physics: shock-wave migration, Mach-number suppression, and entropy generation. The author shows that condensation reduces stage efficiency by ≈1.3 % and power by ≈15 % under representative operating conditions and that losses concentrate chiefly on the stator (≈10 % of total) rather than the rotor (≈1 %). These well-argued insights advance our understanding of where design effort should be focused and are supported by clear visualizations and quantitative tables.

Convincing blade-geometry optimization

Perhaps the most tangible engineering dividend emerges in Chapter 5, where a suite of 2-D and 3-D stator modifications—including twist, pitch, profile substitution and combined axial-sweep / circumferential-lean—is assessed. The recommended Bakhtar profile with circumferential lean in the direction of rotor rotation (Bakhtar-CL1) lifts stage efficiency by 3.2 % without unacceptable wetness penalties. The study also explains why apparently minor geometric tweaks can influence stage performance markedly, especially near the hub, and it provides an ordered matrix of design trade-offs that will guide future industrial retrofits.

Scientific contribution and originality

Collectively, the thesis delivers:

- A validated selection protocol for condensation models applicable to commercial CFD solvers.
- First-of-its-kind 3-D entropy and loss budgets for a 200 MW steam turbine LP stage operating in wet conditions.
- Quantified, geometry-specific design recommendations that demonstrably improve efficiency.
- An experimentally benchmarked measurement methodology transferable to other two-phase-flow laboratories.

These contributions, in my opinion, amount to a substantial advance in the field of wet-steam turbine research.

Quality of exposition

The dissertation is written in clear, fluent English, with only minor typographical lapses that do not impede comprehension. Figures are plentiful, well captioned, and reproduced at a resolution appropriate for detailed scrutiny. Extensive tables—for example, the side-by-side comparison of modelling cases and the summary entropy-generation budgets—allow the reader to verify every major claim. Appendices and nomenclature lists are comprehensive, aiding quick reference.

Critical reflection and future work

The author does not shy away from the residual limitations of the work—most notably, the need to refine droplet-diameter predictions and to corroborate findings with alternative

CFD platforms—and sets out a sensible roadmap for subsequent research. Such self-criticism underscores the scientific maturity of the candidate.

Overall verdict

In summary, the thesis is technically rigorous, methodologically innovative, and industrially relevant. It stands out for its rare blend of carefully calibrated experimentation, exhaustive model benchmarking, and pragmatic turbine-blade optimization. The scholarly apparatus—literature review, argument structure, data presentation—is of high quality, and the conclusions are both defensible and insightful.

I therefore strongly recommend that the dissertation be accepted as it stands, and that the candidate be awarded the doctorate without reservation. The work would also make an excellent basis for journal publications and industrial design guidelines, and I anticipate it will attract widespread citation within the turbomachinery community.

Prague, August 11, 2025

Prof. Ing. Václav Uruba, CSc.

ÚSTAV TERMOMECHANIKY AV ČR
INSTITUTE OF THERMOMECHANICS OF THE CAS

Notes and questions for discussion

1. Choice of condensation model vs. droplet-diameter error

The thesis shows that Gyarmathy- and Fuchs-Sutugin–based cases (3, 4, 6) closely track static-pressure data, yet they under-predict Sauter diameters, whereas Young-based cases behave in the opposite way.

Question: Can you quantify how the conflicting accuracy metrics (pressure vs. diameter) propagate into stage-efficiency predictions, and why you opted to carry the Gyarmathy variant forward into the 3-D turbine study without recalibration?

2. Equation-of-state (EOS) extrapolation into the metastable zone

The manuscript concedes that all commercial EOS options were developed for equilibrium steam and must be extrapolated into super-cooled regions, a step for which "further research is needed".

Question: Did you perform a sensitivity analysis showing how strongly Wilson predicted points and wetness fractions shift when the virial versus IAPWS-IF97 formulations are perturbed within plausible uncertainty bands?

3. Experimental uncertainty in the Light-Extinction Method (LEM)

The calibrated LEM system achieves ±6 % in droplet size under ideal conditions, yet the thesis later adopts ±10 % when operating in real flow and acknowledges probe-induced disturbances.

Question: Given that the model-selection exercise hinges on these droplet data, what is the cumulative measurement-plus-inverse-algorithm uncertainty, and how might it bias model ranking?

4. Absence of a documented grid-independence study

While solver-order and discretization schemes are described, no mesh-refinement curve is presented.

Question: How coarse can the grid be made before the location of the condensation shock or the computed entropy budget changes by, say, 1 %? In other words, what is your grid convergence index?

Institute of Thermomechanics of the Czech Academy of Sciences, Dolejškova 1402/5, 182 00 Prague, Czech Republic
Tel.: +420 266 052 021 (Secretariat), + 420 266 053 122 (Financial Department)
E-mail: secr@it.cas.cz, www.it.cas.cz, VAT No.: CZ61388998

5. Inlet turbulence intensity fixed at 5 %

A uniform value of 5 % is imposed for both nozzle and cascade cases.

Question: On what experimental evidence is this figure based, and how sensitive are nucleation-rate predictions to, for instance, doubling or halving that intensity?

6. Geometric scaling of the rotor cascade by 2.5 ×

The linear cascade used for pressure validation is enlarged relative to the real rotor tip.

Question: How were Reynolds and Mach similarity preserved after scaling, and do you expect droplet-inertia effects (Stokes number) to be identical at full size?

7. Trade-off between efficiency gain and wetness rise

Blade variants such as "st-2 deg" and "Bakhtar-CL1" boost efficiency but also increase wetness, sometimes at the stage outlet.

Question: What operational margin—e.g., erosion limits or separator capacity—defines the acceptable wetness ceiling for an LP stage, and do your recommended geometries stay within it across the load envelope?

8. Loss-budget validation

Chapter 4 derives entropy-generation maps and attributes ≈10 % of total losses to the stator hub region, yet no experimental loss breakdown is offered.

Question: Have you compared simulated pressure-loss coefficients with the cascade rig's total-pressure taps—or, failing that, with existing literature—to corroborate the localization and magnitude of those losses?

9. Generalizability beyond commercial ANSYS solvers

All CFD work relies on Fluent/CFX; the thesis itself notes that academic solvers can behave differently.

Question: Which elements of your workflow (e.g., droplet-growth source terms, real-gas interpolation) are strictly vendor-specific, and how portable is the methodology to open-source platforms like OpenFOAM?

10. Uncertainty propagation to the headline 1.3 % efficiency loss

Institute of Thermomechanics of the Czech Academy of Sciences, Dolejškova 1402/5, 182 00 Prague, Czech Republic
Tel.: +420 266 052 021 (Secretariat), + 420 266 053 122 (Financial Department)
E-mail: secr@it.cas.cz, www.it.cas.cz, VAT No.: CZ61388998

The reported 1.27 % stage-efficiency penalty due to condensation is precise to two decimals.

Question: When the combined numerical (mesh, model, EOS) and experimental uncertainties are propagated, what is the confidence interval on that 1.27 % figure? Could the actual value be, say, anywhere between 0.5 % and 2 %?

Minor remarks and corrections:

- Literature coverage incomplete: Some of key wet-steam CFD validation papers published after 2022 are not cited, weakening the positioning of the work (authors e.g., Zhang, Han, Tabata, Akbarnejad, Hu, ...)
- Spelling/grammar typos: "Mesearement Techniques" → "Measurement Techniques"; "comparision" → "comparison".
- Consistent terminology: American/British forms (e.g. "modeling" vs. "modelling"). Hyphenation consistency (e.g., "wet-steam" vs. "wet steam", "low-pressure" vs. "low pressure", etc.).
- Capitalization: Section headings mix title-case and sentence-case ("3D Simulation of Wet Steam Flows..." vs. "Assessing stage performance sensitivity..."). Choose one style.
- Symbols list: some Greek symbols (e.g., ϑ) lack definitions; check completeness of Subscripts/Abbreviations tables.
- Figures: The Schlieren images need captions indicating flow direction.
- Reference style: ranges should be "[5–8]", not "[5,6,7,8]"; ensure uniform punctuation before years in the bibliography.
- Nomenclature: verify alphabetical order and avoid duplicate entries.
- Chapter cross-referencing: a few forward references point to wrong section numbers after final edits—run LaTeX label check.