

Review of Doctoral Thesis

1. PhD candidate
Ing. Josef Pouzar/ Josef.Pouzar@vut.cz
2. Name of PhD programme
Design and Process Engineering
3. Title of PhD thesis
Liquid lubricant evaporation in space applications
4. Principal supervisor
prof. Ing. Ivan Křupka, Ph.D./ Ivan.Krupka@vut.cz
5. Co-supervisor
Ing. David Košťál, Ph.D./ David.Kostal@vut.cz
6. Reviewer
Dr. Achilleas Vortselas / achilleas.vortselas@esrtechnology.com
ESTL, ESR Technology
7. Overview of the scope of PhD thesis¹
Very good
Justification for evaluation: The PhD thesis consists of a systematic attempt to advance the state of the art in fluid lubricant evaporation and molecular flow through labyrinth seals, a long-standing problem in space mechanism engineering. It combines three different aspects: First, extensive experimental studies, involving the development, validation, and use of 4 different experimental assemblies, for in-vacuo measurement of evaporation rates, with or without a labyrinth seal of various shapes and surface conditions, and the presence of an electric field or a moving rotor. Second, application of numerical models of molecular flow, in two state-of-the art software environments, proving the benefits of the numerical approach. Third, the critical application of the experimental and numerical results and existing theoretical modelling, improving the theoretical models and to explore the design space towards optimisation of labyrinth seal design. The research quantified the known discrepancy between theoretical and observed lubricant loss rates. It affirmed the importance of the main known parameters defining the efficiency of a labyrinth seal (length, gap, path complexity) and provided direct evidence of the significance of others (roughness, wall speed), whilst also documenting for the first time the minor impact of an electric field, even in the case of Ionic Liquids.

¹ Overview of the scope of PhD thesis is a short description of objectives of PhD thesis's research and summary of main findings and scientific achievements.

8. Significance of the topic and clarity of problem statement

Very good

Justification for evaluation: The problem of accurate estimation of lubricant evaporation rate in vacuum and through labyrinth seal systems has been impacting space mechanism design and lubricant selection for a long time. Insufficient trust in sealing solutions leads to overengineering or choosing less performant lubricants with lower vapour pressure. Progress on this field can only be achieved through systematic all-aspect engineering research (measurement, modelling, design) that can work on a level of abstraction just above the application. This is exactly what this research proposed, with work broken down in a set of 4 precise scientific questions.

9. Knowledge of existing literature

Very good

Justification for evaluation: Literature on the topic consists of a physics background (evaporation and molecular flow), a background on space tribology (typology, performance, and heritage of fluid lubricants for vacuum) and space mechanism design, and a state-of-the-art on labyrinth seal testing, flow modelling, and design. All the above have been well presented and concisely summarised in the Literature Review Analysis section. There are no major omissions, as far as I am aware.

10. Choice of methods and technical soundness

Very good

Justification for evaluation: Measurement of the evaporation rate requires a balance that is sensitive enough to capture minute mass changes from very low vapour pressure fluids. The ETR has the sensitivity to fulfil this, although the choice of tested fluid mass and vapour pressure has been conservatively high. The design choices for both the rig variants and the labyrinth seal designs are proven to be efficient for the testing purposes. The DLTR and ELTR variants are designed in such way that the effect is isolated to the seal section and can be measured without confounding factors. The main findings were not affected by random errors. The test matrices were adequate for the planned purpose. The choice of numerical models and their implementation is fit for the purpose they were utilised.

11. Quality, originality and significance of the results

Very good

Justification for evaluation: The results are very clear and unambiguous and serve well in support of the main conclusions. Although the scope of the relevant parameters could have been explored more widely (e.g. wall material, gap width in relation to roughness, evaporation rate vs fluid mass and temperature), the results are significant in relation to the main scientific questions proposed. The known discrepancy between experimental and theoretical evaporation rates has been quantified and the capability of numerical modelling to math experiments and help improve theoretical modelling has been demonstrated. The research has steered clear of exploring how the physics of evaporation at the source may affect the observed rates and proposes empirical correction factors, focusing instead on the parameters of the labyrinth seal, which is a practical engineering approach. The originality of the research stems from the novel exploration of parameters affecting seal efficiency (roughness, wall speed, electric field).

12. Quality of attached papers

Good

Justification for evaluation: The attached papers cover the full extent of the thesis topics. They are well written, and clearly describe the research. The writing quality matches the quality of the thesis. The relevant data is also made publicly available. Although unfortunately one of the papers required a correction, which could have been prevented with more thorough validation of calculations against literature, the correction has been handled professionally. The papers could have benefitted from more comparison to literature, in general. The most impactful of the papers was presented and well received by an audience consisting of the vast majority of European experts in space mechanisms (ESMATS 2025).

13. Overall assessment, strengths and weaknesses (based upon the above evaluation categories 8–12)

Very good

Justification for evaluation: The research has managed to make a significant contribution on a topic that is important to the space mechanism research community, although it is daunting and difficult to examine. This was managed through a good balance of experimental and modelling work and a systematic approach into answering the proposed scientific questions. Practical labyrinth seal design recommendations have been produced. Its strengths are in rig design and testing and the use of numerical modelling to overcome the shortcomings of theoretical modelling. There are some weaknesses in terms of conservative parameter space exploration and comparison to literature results.

14. Questions and comments

1. The mass of fluid on the ETR balance (10-100g) is large compared to usual amounts on space mechanisms. If the evaporation rate is affected by mass in some way (e.g. diffusion, mass/surface ratio, thermal gradients) can the measured rates be considered representative? How much does this matter for lubrication choice at the space mechanism level?
2. Have fluids of lower vapour pressure (e.g. Z-PFPEs) been tested? What are the limitations in terms of test duration?
3. Is the discrepancy with theoretical evaporation rates (the correction factor) dependent on temperature?
4. Do the numerical models reproduce the shape of the theoretical model's dependence of mass loss rate on gap width b_m and on L_m/b_m ? (Figs. 38, 43)
4. Would the effect of roughness on TP be dependent on the gap width?
5. It seems like the speed effect is related to the ratio of linear wall velocity to the average thermodynamic molecular velocity (which is a function of temperature and molecular weight). Do the simulations show by how much the molecular velocity is altered and what effect that has to the mean total path and number of wall collisions?
6. Both experimental and numerical evaporation rates are steady-state. Is any nonlinearity or transient effect recorded at the start of the tests?
7. What is the testing sequence for the electric field tests? Only aggregate results are shown, but are these on back-to-back testing periods on the same cell, without break of vacuum? Were the 4 lubricants tested in parallel on 4 different cells? Were there multiple repeats of field-on/off measurements?
8. Nye 2001 is formulated with an anti-wear additive. How can it be ascertained that the additive evaporation rate does not affect the evaporation rate measurement of the base oil?

15. Conclusion
PhD thesis is an independent scientific work that presents a novel solution to a significant problem in the research area and demonstrates the candidate's ability to conduct independent research.
YES

16. Date and signature	
11/02/2026	Achilleas Vortselas

Please note

- A. Evaluate categories 7 to 13 using the following scale: unacceptable, acceptable, satisfactory, good, very good, excellent. The qualification of 'excellent' should only be given for a PhD Thesis in the top 3% of the research in your field of expertise.
- B. E-mail the completed form to: Klara.Javorcekova@vut.cz