



Faculty of Mechanical Engineering  
Brno University of Technology

## Review of Doctoral Thesis

<b>1. PhD candidate</b>
Ing. Josef Pouzar/ Josef.Pouzar@vut.cz
<b>2. Name of PhD programme</b>
Design and Process Engineering
<b>3. Title of PhD thesis</b>
Liquid lubricant evaporation in space applications

<b>4. Principal supervisor</b>
prof. Ing. Ivan Krupka, Ph.D./ Ivan.Krupka@vut.cz
<b>5. Co-supervisor</b>
Ing. David Košťál, Ph.D./ David.Kostal@vut.cz

<b>6. Reviewer</b>
Dr. Achilleas Vortselas / achilleas.vortselas@esrtechnology.com
ESTL, ESR Technology

<b>7. Overview of the scope of PhD thesis<sup>1</sup></b>
<b>Very good</b>
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.

<sup>1</sup> 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**

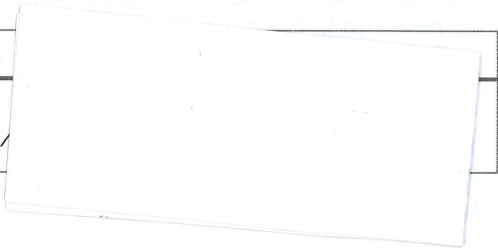
1. The mass of fluid on the ETR balance (10-100g) is large compared to usual amounts on space mechanisms. If the evaporation rate is affected by mass in some way (e.g. diffusion, mass/surface ratio, thermal gradients) can the measured rates be considered representative? How much does this matter for 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?



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<b>15. Conclusion</b>
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.
<b>YES</b>

<b>16. Date and signature</b>	
<b>11/02/2026</b>	<b>Achilleas Vortselas</b>



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](mailto:Klara.Javorcekova@vut.cz)



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## Review of Doctoral Thesis

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Ing. David Košťál, Ph.D./ David.Kostal@vut.cz

<b>6. Reviewer</b>
Prof. Roland Larsson / roland.larsson@ltu.se
Luleå University of Technology

<b>7. Overview of the scope of PhD thesis<sup>1</sup></b>
<b>Very good</b>
This thesis is about evaporation, or loss, of lubricants from critical machine elements in space. A particular focus is places on labyrinth seals or, more correctly, different simplifications (representations) of labyrinth seals. The scope of combining experiments with simulations and analytical modelling is clearly defined. The work has a focus on simplified geometries to avoid too many effects at the same time and thus makes it possible to better understand differences between experiments and simulations.

<b>8. Significance of the topic and clarity of problem statement</b>
<b>Excellent</b>
The topic is highly significant since space missions are strongly dependent on well-functioning machine elements such as bearings. Bearings are, in turn, dependent on lubrication and with fluid lubricants it is a challenge to keep the lubricant in place in a vacuum condition. The problem is excellently described in the thesis, explaining the challenges in detail. Furthermore, the research is well planned by identifying well-formulated research questions based on the needs from space applications and on the state-of the art research.

<sup>1</sup> 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.



**9. Knowledge of existing literature**

**Very good**

The literature review covers liquid lubricants for space, evaporation modelling, molecular flow theory, surface migration, contamination control, and labyrinth sealing. Important models such as Langmuir, ESTL models, Clausius–Clapeyron are described, experimental methods (Knudsen effusion, QCM), and Monte Carlo molecular flow approaches are presented. The review demonstrates very good familiarity with space tribology standards (ECSS) and ESTL contributions. The candidate shows good understanding of both tribological and vacuum-physics aspects of the problem. The references are relevant and up to date, particularly in relation to seal modelling and molecular flow simulation.

**10. Choice of methods and technical soundness**

**Excellent**

The choice of methods is one of the strengths of the thesis. The choice of the ETR and later developed into a LTR are examples of excellent engineering science. Probably built on the traditions and experiences in the group of developing high-class experimental devices. The modelling follows the same pattern of very sound choice of theories and models.

**11. Quality, originality and significance of the results**

**Very good**

The quality of the studies is very good. And, as far as I can judge, these results possess high originality. It is a systematic study showing the effects (on evaporation) of roughness, corners, steps etc. Correction factors are derived to make simulation results more in line with experiments. The inclusion of rotational dynamics and electrostatic field effects adds originality, even if the electrostatic influence is small. It is impressive that model results and experimental results are very close in many cases.

**12. Quality of attached papers**

**Very good**

The thesis comprises four papers. Three are published in well-recognised journals and the fourth is from an international, high-level, space engineering conference. I don't see any reason to question the quality assessment made by the reviewers of the attached papers.

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

**Very good**

This thesis is a strong contribution to the field of space tribology. The strength are primarily the innovative experiments and the parallel, validating modelling. When the model is validated it is later used for parameter variations in order to learn about the influence of various input parameters. It is a classical and successful way to tackle problems in mechanics. The weakness may lie in the need of correction factors instead of finding “exact” models based on physics. The candidate has, however, identified a number of ways to make the models better in the Future work chapter.



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<b>14. Questions and comments</b>

<b>15. Conclusion</b>
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<b>YES</b>

<b>16. Date and signature</b>	
<b>15/02/2026</b>	

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- 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.Javorceková@vut.cz](mailto:Klara.Javorceкова@vut.cz)

## Principal supervisor's final report on the PhD study

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Josef Pouzar / josef.pouzar@vut.cz
<b>2. Name of PhD programme</b>
Design and Process Engineering
<b>3. Title of PhD thesis</b>
LIQUID LUBRICANT EVAPORATION IN SPACE APPLICATIONS
<b>4. Principal supervisor</b>
Prof. Ing. Ivan Křupka, Ph.D. / krupka@fme.vutbr.cz
<b>5. Co-supervisor</b>
Ing. David Košťál, Ph.D. / david.kostal@vut.cz
<b>6. Stays at other institutions (min. 7 days)</b>
Lulea University of Technology / Sweden / 07/05/2023 / 27/05/2023
Daresbury Laboratory / GB / 22/04/2024 / 22/05/2024
<b>7. Teaching activities</b>
Course name / Total number of hours
3CC CAD – Advanced
1K Engineering Drawing Fundamentals
<b>8. List of main publications</b>
Bibliography references cited according to the norm ISO 690. If appropriate, impact factor must be specified. [1] Pouzar J, Kostal D, Sperka P, Krupka I, Hartl M. Experimental study of space lubricant evaporation in a high vacuum environment. Vacuum 2024; Volume 219, 112758. <a href="https://doi.org/10.1016/j.vacuum.2023.112758">https://doi.org/10.1016/j.vacuum.2023.112758</a> . [2] Pouzar J, Kostal D, Westerberg L-G, Nyberg E, Krupka I. Labyrinth seal design for space applications. Vacuum 2025; Volume 232, 113882. <a href="https://doi.org/10.1016/j.vacuum.2024.113882">https://doi.org/10.1016/j.vacuum.2024.113882</a> . [3] Pouzar J, Kostal D, Westerberg L-G, Nyberg E, Polacek T, Jurik K, et al. Influence of Surface Roughness on Molecular Flow Through Labyrinth Seals for Space Applications. Results in Engineering 2025; Volume 28, 107905. <a href="https://doi.org/10.1016/j.rineng.2025.107905">https://doi.org/10.1016/j.rineng.2025.107905</a> . [4] Pouzar J, Kostal D, Westerberg LG, Krupka I. Labyrinth seal design for enhanced sealing of evaporated lubricant molecules in space mechanisms, 21st European Space Mechanisms and Tribology Symposium (ESMATS); 2025.



**9. Assessment of the supervision process**

**Excellent**

Justification for evaluation: During the course of his studies, the student demonstrated the ability to work independently. Based on his study of literature, he identified problems that he subsequently addressed in his dissertation. During his studies, he mastered the experimental methods needed to solve the given problem. He was able to design the experimental test rig and plan required experiments based on the discussion with colleagues at the Institute and other laboratories. He passed all required exams and fulfilled other requirements for PhD study. He has demonstrated the skills needed to successfully complete a PhD study.

**10. Assessment of the candidate's ability to work independently**

**Excellent**

Justification for evaluation: He was able not only to find the problems and solve them but also to submit the PhD project to ESA. It was based on his ideas and proved his ability to work independently. He solved it successfully and obtained new findings and presented and published them. He was able to both implement his own experiments and plan collaboration with other colleagues. This was also reflected in the successful publication of the obtained results.

**11. Assessment of the contribution that the research makes to knowledge in the field**

**Excellent**

Justification for evaluation: The dissertation logically summarizes the results achieved by the doctoral student during his studies. These results are his original and were obtained on the basis of a critical assessment of the current state of knowledge and the definition of scientific questions and hypotheses. During the doctoral studies, the doctoral student managed to find answers to the scientific question and confirm/deny hypotheses. The doctoral student approached the solution independently and proactively, and his approach can be assessed as exemplary. He obtained original results that contributed to the expansion of knowledge in the given area. He published articles in IF journals and also presented the results at prestigious scientific conferences. He simultaneously addressed the topic of the dissertation with the support of a project of the European Space Agency, where he successfully defended this project.

**12. Other comments**

**13. 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**

**14. Date and signature**

**26/02/2026**