

PhD position in experimental supersonic flows with condensation

Project description

Cooling production represents a significant share of global energy consumption, making it a key lever for improving energy efficiency and supporting the transition toward low-carbon energy systems. In this context, the ATHENA project, coordinated by the CEA and embedded within the French national research program PEPR SPLEEN on energy systems for the energy transition, aims to develop innovative low-carbon cooling technologies through the valorization of industrial waste heat.

Absorption refrigeration systems using the ammonia/water ($\text{NH}_3/\text{H}_2\text{O}$) working pair are a promising solution to improve energy efficiency. The integration of supersonic ejectors (Figure 1) can significantly enhance flow entrainment and system performance [1,2]. However, their operation involves complex and coupled physical phenomena, including highly compressible flows, rapid expansions, and interactions with shock-wave structures.

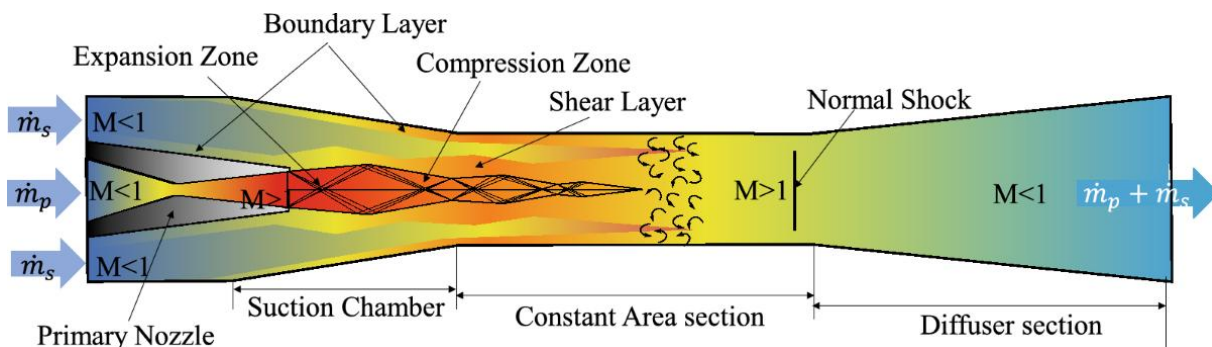


Figure 1: Supersonic ejector schematic

The focus of this PhD is the investigation of condensation phenomena in high-speed compressible flows [3,4]. Such phenomena are directly observable in the condensation trails formed around aircraft during transonic flight conditions (Figure 2), illustrating the strong coupling between rapid expansion, pressure drop, and phase change.



Figure 2: Condensation in transonic/supersonic flow (vapor cone)

Research objectives

The main objective of this PhD is to improve the understanding of condensation mechanisms in supersonic flows and their impact on flow structure and shock-wave dynamics.

More specifically, the work aims to:

- characterize condensation onset in highly expanded supersonic flows,
- analyze interactions between condensed phases and shock-wave structures,
- identify transitions between single-phase and two-phase flow regimes,
- quantify the impact of condensation on flow dynamics,
- contribute to the understanding of compressible two-phase flows for energy applications.

Methodology

The research will be based on an experimental approach using a dedicated supersonic nozzle facility to be designed and developed during the PhD. This setup will allow access to a wide range of flow regimes, from dry gas to fully developed two-phase flows.

Optical diagnostics will be implemented, including Schlieren imaging for density-gradient visualization [5], incoherent light diffraction and light attenuation techniques for condensation detection. Depending on progress, complementary methods such as laser-based diagnostics may be considered.

The work will combine experimental facility development, measurement campaigns, data analysis, and physical interpretation of the observed phenomena.

Expected outcomes

The expected results include a better understanding of condensation processes in supersonic flows and their coupling with shock-wave structures. The PhD will provide new insights into regime transitions and flow modifications induced by phase change, with applications to the design and optimization of advanced cooling systems.

Environment & funding

The PhD is part of the ATHENA project, coordinated by the CEA, within the PEPR SPLEEN national research program (<https://www.pepr-spleen.fr/projet/projet-athena/>). The project involves collaboration with academic and institutional partners working on energy systems and low-carbon technologies.

The PhD candidate will benefit from a collaborative research environment and opportunities for scientific exchanges and international mobility.

Skills/Qualifications

We are looking for a candidate with a Master's degree in fluid mechanics, thermal engineering, energetic systems, or experimental physics. The ideal candidate should have:

- strong interest in experimental work and optical diagnostics
- knowledge of compressible and/or multiphase flows (asset)
- skills in data analysis (Python or MATLAB)
- basic knowledge of CFD for flow analysis or experimental design (considered a plus)
- autonomy, rigor, and strong analytical abilities
- good level of English (required for publications and conferences)

Benefits

The successful candidate will join a dynamic and collaborative research environment within the ATHENA project, part of the French national PEPR SPLEEN program coordinated by the CEA.

This PhD offers:

- the opportunity to design and develop a dedicated experimental setup
- hands-on experience with advanced optical diagnostics
- involvement in cutting-edge research on energy-efficient and low-carbon technologies
- access to a strong academic and institutional network
- opportunities for international collaboration and mobility
- participation in international conferences and high-impact scientific publications

Eligibility criteria

Applicants should hold (or be close to obtaining) a Master's degree in fluid mechanics, thermal engineering, energetic systems, or experimental physics. A strong interest in experimental research, fluid dynamics, and data analysis is expected. Prior experience in experimental work or optical diagnostics will be considered an asset. Candidates should demonstrate autonomy, rigor, and strong analytical skills, along with good communication abilities in English.

Selection process

Applications should include a CV and a cover letter describing the candidate's background and motivation. Shortlisted candidates will be invited to an initial online interview. Final selection will be made after an interview with a committee, including external experts.

Where to apply

E-mails: guillaume.castanet@univ-lorraine.fr; nicolas.rimbert@univ-lorraine.fr

References

- [1] Chunnanond, K., & Aphornratana, S. (2004). *Ejectors: Applications in refrigeration technology*. Renewable and Sustainable Energy Reviews, 8(2), 103–115.
- [2] S. Braccio, N. Guillou, N. Le Pierrès, N. Tauveron, H. Trieu Phan, 2022. Thermodynamic analysis of an ejector-assisted ammonia–water absorption system. Thermal Science and Engineering Progress, 101615.
- [3] Blythe, P. A., & Shih, C. J., 1976. *Condensation shocks in nozzle flows*. Journal of Fluid Mechanics, 76(3), 593–62
- [4] Puzyrewski, R., Gardzilewicz, A., & Baginska, M., 1973. *Shock waves in condensing steam flowing through a Laval nozzle*. Archives of Mechanics, 25(3), 393–409.
- [5] Settles, G. S., 2001. *Schlieren and Shadowgraph Techniques: Visualizing Phenomena in Transparent Media*. Springer.