Laboratory of Sustainability Robotics

Department of Engineering Sciences
Laboratory of Sustainability Robotics
Empa, Überlandstrasse 129
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Student Project Task Agreement

Student:	**Name:** ______________	
	Student ID: ______________	**Department:** ______________
	University: ______________	
Thesis:	**Title:** Design and Characterisation of a Lightweight Air-Assisted Impinging Nozzle for Aerial Polyurethane Foam Deposition	
	Kind of thesis: Semester	**Semester:** HS 2026
Supervisor:	Prof. Dr. Mirko Kovac	
Advisor:	Yusuf Furkan Kaya	
Co-Advisor:	Visnusuthan Vairavipillai	

Start of the project:	TBD
Final report deadline:	TBD

1 Introduction

Polyurethane (PU) foam is the material of choice for aerial additive manufacturing: light, curing in seconds, and self-supporting while still attached to the substrate, hence its use in every drone-based deposition demonstration to date [1, 2, 3]. Because it is two-component and reactive, its isocyanate and polyol streams must combine at the correct ratio and mix to homogeneity within milliseconds of leaving the nozzle.

An air-assisted nozzle shifts the energy source to gas: in an HVLP architecture, a high-volume, sub-bar air stream atomises both low-pressure liquid streams and drives them together, mixing two droplet clouds instead of liquid jets in a chamber. The governing variable becomes the air-to-liquid mass ratio, with gas-cap geometry and aerodynamic Weber number setting droplet size [4, 5].

Air-assisted guns are routine for paint, and impingement guns for foam, but a head that both mixes and atomises reactive two-component foam at drone scale is undemonstrated; existing aerial systems sidestep this with pre-mixed or single-component chemistry.

This project designs, builds and characterises such a nozzle: deriving the operating window analytically before CAD, manufacturing variants, and characterising mixing and layer properties on a hand-held rig emulating the payload, to produce a validated geometry ready for integration.

2 Objectives

This project aims to:

- Derive, analytically and before any CAD work, an operating window for impingement mixing at payload scale (orifice diameter, chamber-to-nozzle ratio, jet velocity, Reynolds number, feed pressure, pump force), documented as a reusable sizing calculation.

- Design and manufacture an impinging-jet mixing head below 500 g with an anti-clog strategy (purge, mechanical shut-off or sacrificial element) that survives repeated start–stop cycles without a solvent flush.
- Quantify mixing quality against jet velocity, flow ratio and stand-off using measurable proxies (cream/rise time, density uniformity, closed-cell fraction, striation) rather than qualitative judgement.
- Demonstrate controlled thin-layer deposition on a vertical substrate with the hand-held rig, and report the window in which layer thickness, adhesion and rebound stay within target.

3 Work breakdown

Structured into the following tasks:

1. **Literature review and state of the art:** Survey two-component PU spray chemistry, impinging-jet mixer design [6, 7] and aerial deposition systems [1, 2, 3]; identify what transfers to a payload-scale head.
2. **Requirements and pre-design sizing:** From the target deposition rate, derive flow, jet velocity, orifice and chamber diameters, feed pressure, pump force, and mass/power budget, plus the required Reynolds number and flow-ratio tolerance. Output: a sizing note and chosen geometry family.
3. **Nozzle design and manufacture:** Translate the sizing into CAD, manufacture two to three nozzle variants, and integrate the head with the lab's spray payload (feed lines, valves, ROS 2 stack).
4. **Bench characterisation of mixing quality:** Sweep jet velocity, flow ratio and stand-off, measuring cream/rise time, density uniformity, closed-cell fraction and spray cone geometry; cross-check against the Reynolds number predicted in Task 2.
5. **Vertical deposition trials and reporting:** Deposit thin layers on vertical substrates, measuring thickness, adhesion and rebound versus traverse speed and stand-off; consolidate the validated window, document clog behaviour, and compile the final report.

The work can take place at the Laboratory of Sustainability Robotics, Empa (Dübendorf), or at EPFL (depending on the agreement with the student), over one semester (start date to be agreed). All trials use a hand-held rig emulating the payload, so no flight time is required.

4 Deliverables and assessment

The student is expected to deliver:

- A written report following the host university's guidelines, submitted by the deadline stated above.
- A final presentation to the laboratory (20 min plus questions).

- The nozzle CAD package and manufacturing files, the sizing calculation in reusable form, and the raw characterisation data.

Assessment follows the host university's regulations, with weight on the scientific quality of the work, the independence shown during the project, the quality of the documentation and the reproducibility of the results.

5 Bibliography

[1] G. Hunt, F. Mitzalis, T. Alhinai, P. A. Hooper, and M. Kovac. "3D printing with flying robots". In: *IEEE International Conference on Robotics and Automation (ICRA)*. 2014, pp. 4493–4499.

[2] K. Zhang, P. Chermprayong, F. Xiao, et al. "Aerial additive manufacturing with multiple autonomous robots". In: *Nature* 609.7928 (2022), pp. 709–717.

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[5] M. Diamantopoulos and C. Hochenauer. "Optimised Twin Fluid Atomiser Design for High-Viscosity, Shear-Thinning Fluids". In: *Applied Sciences* 15.14 (2025), p. 7992.

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[7] P. Kolodziej, W. P. Yang, C. W. Macosko, and S. T. Wellinghoff. "Impingement mixing and its effect on the microstructure of RIM polyurethanes". In: *Journal of Polymer Science Part B: Polymer Physics* 24.10 (1986), pp. 2359–2377.

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