PROPOSITION DE SUJET DE THESE

Intitulé : Transfer Learning in Generative Methods for Aircraft Collision Risk Assessment and Sustainable Air Traffic Management

Référence : **TIS-DTIS-2026-26** *(à rappeler dans toute correspondance)*	
Début de la thèse : October 2026	**Date limite de candidature : May 2026**

Mots clés

mid-air collision, risk estimation, environmental sustainability, trajectory clustering, trajectory generation, transfer learning

Profil et compétences recherchées

MSc in Data Science, Statistics, Engineering

Présentation du projet doctoral, contexte et objectif

Aircraft collision risk assessment is a critical aspect of air traffic management. With the continuous growth of air traffic, future systems must not only ensure safety and capacity but also contribute to environmental sustainability. Optimizing aircraft trajectories is directly linked to fuel efficiency, CO_2 and NOx emissions reduction, and noise abatement around airports. These concerns are central to European initiatives such as the Single European Sky, SESAR, and Clean Aviation. Generative models, including variational autoencoders (VAEs) [1], have been used to generate realistic aircraft trajectories for probabilistic collision risk estimation. However, these models face challenges such as balancing physical and statistical realism, handling temporal dependencies between trajectories, and interpreting the latent space used for trajectory generation. This thesis aims to address these challenges through transfer learning, using pre-trained generative models to adapt to different geographical zones. Moreover, collision risk assessment cannot be decoupled from environmental considerations. Poorly calibrated safety margins may result in unnecessarily long or fuel-intensive routes, while better compromises between safety and efficiency could foster more eco-friendly air traffic management.

The assessment of aircraft collision risk relies on generating plausible aircraft trajectories that balance both statistical validity and physical realism. In previous research, we developed generative models based on VAEs, which have been successfully applied to generate plausible aircraft trajectories and estimate collision probabilities, as seen in recent work [2,3,4]. These models depend on the structure of the latent space to generate new trajectories, where we also seek to improve explainability [5].

Additionally, current models often struggle to capture the complex spatio-temporal dependencies between multiple trajectories. Generating realistic trajectories requires modelling both individual trajectories and their relationships over time, which presents a significant challenge for risk estimation. The models developed so far, including those based on VampPrior [6], have laid a solid foundation for trajectory generation but are not yet fully equipped to handle temporal dependencies. Furthermore, they have not addressed the generalization to new geographic zones without requiring complete retraining.

The primary goal of this PhD proposal is to explore how transfer learning can be applied to generative models for aircraft collision risk estimation while incorporating environmental performance criteria. Specifically, we aim to develop methods that enable the reusability of learned weights and latent structures from one airspace (geographical region) to another, thereby accelerating model adaptation and specialization to new environments. We can notably draw on recent work on transfer learning for trajectory predictions [7,8] to achieve this objective. This transferability will also focus on minimizing computational overhead while maintaining interpretability in the latent space and accuracy in collision risk prediction. Moreover some environmental indicators could be integrated into trajectory generation, including fuel consumption, CO_2 and NOx emissions. We thus aim to contribute to eco-efficient air traffic management strategies, where minimizing collision risks and reducing environmental impacts are jointly addressed, in line with the sustainability goals set by SESAR and Horizon Europe's Clean Aviation program. By embedding ecological considerations into advanced generative modeling of aircraft trajectories, this project aims to strengthen the link between air safety and environmental sustainability, providing innovative tools for the future of aviation.

[1] Diederik P. Kingma, Auto-encoding variational Bayes. arXiv preprint arXiv:1312.6114 (2013).

[2] Timothé Krauth, Adrien Lafage, Jérôme Morio, Xavier Olive, and Manuel Waltert. Deep Generative Modelling of Aircraft Trajectories in Terminal Maneuvering Areas. *Machine Learning with Applications*, 11, 2022.

[3] Timothé Krauth, Benoit Figuet, Xavier Olive, and Jérôme Morio. Collision Risk Assessment in Terminal Manoeuvring Areas Based on Trajectory Generation Methods. *Proc. of the 15th USA/Europe Air Traffic Management Research and Development Seminar*, 2023.

[4] Timothé Krauth, Jérôme Morio, Xavier Olive and Benoit Figuet. Advanced collision risk estimation in terminal manoeuvring areas using a disentangled variational autoencoder for uncertainty quantification. *Engineering Applications of Artificial Intelligence*, 133, 2024, 108137.

[5] Zakaria Ezzahed, Antoine Chevrot, Christophe Hurter, and Xavier Olive. Bringing Explainability to Autoencoding Neural Networks Encoding Aircraft Trajectories. *Proceedings of the 13th SESAR Innovation Days, 2023.*

[6] Jakub Tomczak and Max Welling. VAE with a VampPrior. *International conference on artificial intelligence and statistics*. PMLR, 2018.

[7] Theocharis Kravaris and George A. Vouros. "Transferable aircraft trajectory prediction with generative deep imitation learning." *International Journal of Data Science and Analytics* (2024): 1-23.

[8] Yulin Liu and Mark Hansen. "Predicting aircraft trajectories: A deep generative convolutional recurrent neural networks approach." *arXiv preprint* arXiv:1812.11670 (2018)

Collaborations envisagées

Fédération de recherche ONERA ISAE ENAC

Université technique de Delft

Université des sciences appliquées de Zurich (ZHAW)

Laboratoire d'accueil à l'ONERA
Département : DTIS
Lieu (centre ONERA) : Toulouse
Contact : Jérôme Morio
Tél. : 05 62 25 26 63 Email : jerome.morio@onera.fr

Directeur de thèse
Nom : Xavier Olive
Laboratoire : DTIS/RIME
Tél. : 05 62 25 26 75
Email : xavier.olive@onera.fr

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