Supplementary Materials for

The Evolution and Taxonomy of Deep Learning Models for Aircraft Trajectory Prediction: A Review of Performance and Future Directions

This supplementary file provides supporting information for the systematic literature review on deep learning-based aircraft trajectory prediction. The materials include categorized lists of reviewed studies, search strategies, dataset sources, and extended performance comparisons. All tables are labeled with the prefix "S" to distinguish them from those in the main text.

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Table S1-1. List of reviewed studies classified as RNN-based models for aircraft trajectory prediction (2020–June 2025).

Ref.	Authors	Title/Source	Year	DOI/Link
[15]	Silvestre, J.; Mielgo, P.; Bregon, A.; Martínez-Prieto, M.A.; Álvarez-Esteban, P.C.	Towards aircraft trajectory prediction using LSTM networks, *Proc. 39th ACM/SIGAPP Symposium on Applied Computing (SAC '24)*	2024	https://doi.org/10.1145/3605098.3636195
[34]	Zeng, W.; Quan, Z.; Zhao, Z.; Xie, C.; Lu, X.	A Deep Learning Approach for Aircraft Trajectory Prediction in Terminal Airspace, *IEEE Access*	2020	https://doi.org/10.1109/ACCESS.2020.3016289
[35]	Xu, Z.; Zeng, W.; Chu, X.; Cao, P.	Multi-Aircraft Trajectory Collaborative Prediction Based on Social-LSTM, *Aerospace*	2024	https://doi.org/10.3390/aerospace8040115
[36]	Wu, J.	Aircraft Trajectory Prediction Based on Long and Short-Term Memory Structural Models, *Proc. ICDCOT*	2024	https://doi.org/10.1109/ICDCOT61034.2024.10516095
[37]	Shi, Z.; Xu, M.; Pan, Q.	4-D Flight Trajectory Prediction With Constrained LSTM Network, *IEEE Trans. Intell. Transp. Syst.*	2021	https://doi.org/10.1109/TITS.2020.3004807
[38]	Wang, B.; Zhai, Z.; Xiong, R.; Gao, B.	Flight Trajectory Prediction of General Aviation Aircraft	2021	https://doi.org/10.1109/ICISCAE52414.2021.9590656

		Based on LSTM Model, *Proc. IEEE ICISCAE*		
[39]	Yang, Z.; Kang, X.; Gong, Y.; Wang, J.	Aircraft trajectory prediction and aviation safety in ADS-B failure conditions based on neural network, *Sci. Rep.*	2023	https://doi.org/10.1038/s41598-023-46914-2

Table S1-2. List of reviewed studies classified as attention-based models for aircraft trajectory prediction (2020–June 2025).

Ref.	Authors	Title/Source	Year	DOI/Link
[21]	Youyou, Y.; Fang, Y.; Long, T.	Noise Robust Autoregressive Transformer for Aircraft Trajectory Prediction, *Sci. Rep.*	2025	https://doi.org/10.1038/s41598-025-96512-7
[40]	Jia, P.; Chen, H.; Zhang, L.; Han, D.	Attention-LSTM based prediction model for aircraft 4-D trajectory, *Sci. Rep.*	2022	https://doi.org/10.1038/s41598-022-19794-1
[41]	Tong, Q.; Hu, J.; Chen, Y.; Guo, D.; Liu, X.	Long-Term Trajectory Prediction Model Based on Transformer, *IEEE Access*	2023	https://doi.org/10.1109/ACCESS.2023.3343800
[42]	Luo, S.; Zhao, M.; Zhao, Z.; Li, L.; Zhang, S.; Zhang, X.	FT-TF: A 4D Long-Term Flight Trajectory Prediction Method Based on Transformer, *Proc. Chinese Control Conference (CCC)*	2023	https://doi.org/10.23919/CCC58697.2023.10239944
[43]	Lu, G.; Wang, H.; Song, Z.; Cui, P.	An improved transformer-based model for long-term 4D trajectory prediction in civil aviation, *Int. J. Intell. Syst.*	2024	https://doi.org/10.1049/itr2.12530
[44]	Sun, Y.; Wang, D.; Wang, W.; Xiong, L.; Yang, X.	Confrontational flight trajectory prediction based on attention mechanism, *Proc. ICBASE*	2020	https://doi.org/10.1109/ICBASE51474.2020.00052
[45]	Hao, H.; Si, X.; Li, M.; Liang, J.	Flight Trajectory Change Prediction Via Patched Spatial-Temporal Transformer, *Proc. IGARSS 2024*	2024	https://doi.org/10.1109/IGARSS53475.2024.10641236
[46]	Guo, D.; Zhang, Z.; Yan, Z.; Zhang, J.; Lin, Y.	FlightBERT++: A Non-autoregressive Multi-Horizon Flight Trajectory Prediction Framework, *Proc. AAAI Conf. on AI*	2024	https://doi.org/10.1609/aaai.v38i1.27763
[47]	Silvestre, J.; Mielgo, P.; Bregon, A.; Martínez-Prieto, M.A.; Álvarez-Esteban, P.C.	Multi-Route Aircraft Trajectory Prediction Using Temporal Fusion Transformers, *IEEE Access*	2024	https://doi.org/10.1109/ACCESS.2024.3415419
[48]	Lu, G.; Long, L.; Zhang, Y.; Zheng, Y.	An Inverted Transformer Framework for Aviation Trajectory Prediction with	2025	https://doi.org/10.3390/aerospace12040319

		Multi-Flight Mode Fusion, *Aerospace*		

Table S1-3. List of reviewed studies classified as generative models for aircraft trajectory prediction (2020–June 2025).

Ref.	Authors	Title/Source	Year	DOI/Link
[28]	Zhang, H.; Liu, Z.	Four-Dimensional Aircraft Trajectory Prediction Based on Generative Deep Learning, *J. Aerosp. Inf. Syst.*	2024	https://doi.org/10.2514/1.I011333
[50]	Hu, Q.; Huang, G.; Shi, H.; Lin, Y.; Guo, D.	A Short-term Aircraft Trajectory Prediction Framework Using Conditional GAN, *Proc. IEEE ICCASIT*	2022	hhttps://doi.org/10.1109/ICCASIT55263.2022.9986799
[54]	Yin, Y.; Zhang, S.; Zhang, Y.; Zhang, Y.; Xiang, S.	Context-aware Aircraft Trajectory Prediction with Diffusion Models, *Proc. IEEE ITSC*	2023	https://doi.org/10.1109/ITSC57777.2023.10422124
[55]	Yang, S.; Liu, L.; Chen, B.; Cheng, S.; Shi, Z.; Zou, Z.	GooDFlight: Goal-Oriented Diffusion Model for Flight Trajectory Prediction, *IEEE Trans. Aerosp. Electron. Syst.*	2025	https://doi.org/10.1109/TAES.2025.3536436

Table S1-4. List of reviewed studies classified as graph-based models for aircraft trajectory prediction (2020–June 2025).

Ref.	Authors	Title/Source	Year	DOI/Link
[25]	Sun, Y.; Zhou, X.; Yang, Z.; Wang, W.; Shi, Q.	Flight Trajectory Prediction Method Based on Attentional Graph Convolutional Network, *Proc. ISCTIS*	2023	https://doi.org/10.1109/ISCTIS58954.2023.10213104
[26]	Sun, Y.; Jing, T.; Wang, J.; Wang, W.	Fighter flight trajectory prediction based on spatio-temporal graphical attention network, *arXiv*	2024	https://doi.org/10.48550/arXiv.2405.08034
[59]	Fan, Y.; Tan, Y.; Wu, L.; Ye, H.; Lyu, Z.	Global and Local Inter-attribute Relationships-Based Graph Convolutional Network for Flight Trajectory Prediction, *IEEE Trans. Aerosp. Electron. Syst.*	2024	https://doi.org/10.1109/TAES.2024.3357668
[60]	Kuang, Y.; Wang, Z.; Zhang, J.; Shi, Z.; Zhang, Y.	DA-STGCN: 4D Trajectory Prediction Based on Spatiotemporal Graph Convolution, *arXiv*	2025	https://doi.org/10.48550/arXiv.2503.04823

Table S1-5. List of reviewed studies classified as hybrid and integrated models for aircraft trajectory prediction (2020–June 2025).

Ref.	**Authors**	**Title/Source**	**Year**	**DOI/Link**

[17]	Nia, H.S.; Regan, A.C.	4D Flight Trajectory Prediction Using a Hybrid Deep Learning Prediction Method Based on ADS-B Technology: A Case Study of Hartsfield Jackson Atlanta Int'l Airport. *Transp. Res. Part C*	2022	https://doi.org/10.1016/j.trc.2022.103878
[18]	Hao, Q.; Zhang, J.; Jing, T.; Wang, W.	Flight Trajectory Prediction Using an Enhanced CNN-LSTM Network. *arXiv*	2024	https://doi.org/10.48550/arXiv.2404.19218
[19]	Li, F.; Xu, X.; Wang, R.; Ma, M.; Dong, Z.	Flight Trajectory Prediction Based on ADS-B Data Fusion with Interacting Multiple Model and Informer Framework. *Sensors*	2025	https://doi.org/10.3390/s25082531
[20]	Dong, X.; Tian, Y.; Dai, L.; Li, J.; Wan, L.	A New Accurate Aircraft Trajectory Prediction in Terminal Airspace Based on Spatio-Temporal Attention Mechanism. *Aerospace*	2024	https://doi.org/10.3390/aerospace11090718
[61]	Ma, L.; Tian, S.	A Hybrid CNN-LSTM Model for Aircraft 4D Trajectory Prediction. *IEEE Access*	2020	https://doi.org/10.1109/ACCESS.2020.3010963
[63]	Zhang, K.; Chen, B.	Phased Flight Trajectory Prediction with Deep Learning. *arXiv*	2022	https://doi.org/10.48550/arXiv.2203.09033
[64]	Zhang, L.; Chen, H.; Jia, P.; Tian, Z.; Du, X.	WGAN and LSTM Based Prediction Model for Aircraft 4-D Trajectory. *IWCMC*	2022	https://doi.org/10.1109/IWCMC55113.2022.9824928
[66]	Wang, S.; Wang, Y.; Xu, L.; Shi, J.; Hu, Z.	SATF: A Flight Trajectory Prediction Method Incorporating Spatial Awareness and Time Frequency Transformation. *Aerosp. Sci. Technol.*	2025	https://doi.org/10.1080/17538947.2025.2512592
[67]	Liu, B.; Shi, Q.; Han, P.	Short-Term 4D Trajectory Prediction Method Based on LSTM-IMM. *DASC*	2022	https://doi.org/10.1109/DASC55683.2022.9925832
[68]	Ding, W.; Huang, J.; Shang, G.; Wang, X.; Li, B.; Li, Y.; Liu, H.	Short-Term Trajectory Prediction Based on Hyperparametric Optimisation and a Dual Attention Mechanism. *Aerospace*	2022	https://doi.org/10.3390/aerospace9080464
[69]	Wu, Y.; Yu, H.; Du, J.; Liu, B.; Yu, W.	An Aircraft Trajectory Prediction Method Based on Trajectory Clustering and a Spatiotemporal Feature Network. *Electronics*	2022	https://doi.org/10.3390/electronics11213453
[70]	Wu, H.; Liang, Y.; Zhou, B.; Su	A Bi-LSTM and AutoEncoder Based Framework for Multi-step Flight	2023	https://doi.org/10.1109/ICCRE57112.2023.101556

	n, H.	Trajectory Prediction. *ICCRE*		14
[71]	Ma, T.-Y.; Meng, X.; Wu, Z.	A Novel Trajectory Prediction Method Based on CNN, BiLSTM, and Attention Mechanism. *Aerospace*	2024	https://doi.org/10.3390/aerospace11100822
[72]	Huang, J.; Ding, W.	Aircraft Trajectory Prediction Based on Bayesian Optimised TCN–BiGRU Hybrid Neural Network. *Int. J. Aerosp. Eng.*	2022	https://doi.org/10.1155/2022/2086904
[73]	Tran, P.N.; Nguyen, H.Q.V.; Pham, D.-T.; Alam, S.	Aircraft Trajectory Prediction With Enriched Intent Using Encoder–Decoder Architecture. *IEEE Access*	2022	https://doi.org/10.1109/ACCESS.2022.3149231
[74]	Dong, Z.; Fan, B.; Li, F.; Xu, X.; Sun, H.; Cao, W.	TCN-Informer-Based Flight Trajectory Prediction for Aircraft in the Approach Phase. *Sustainability*	2023	https://doi.org/10.3390/su152316344
[75]	Ma, L.; Meng, X.; Wu, Z.	Data-Driven 4D Trajectory Prediction Model Using Attention-TCN-GRU. *Aerospace*	2024	https://doi.org/10.3390/aerospace11040313
[76]	Fang, J.; Liu, Y.; Xu, T.; Wang, Y.; Li, J.	GCTrajectory: A CNN-Transformer Adversarial Learning Framework for Flight Trajectory Prediction. *ICAACE*	2025	https://doi.org/10.1109/ICAACE65325.2025.11020282
[79]	Schimpf, N.; Wang, Z.; Li, S.; Knoblock, E.J.; Li, H.; Apaza, R.D.	A Generalized Approach to Aircraft Trajectory Prediction via Supervised Deep Learning. *IEEE Access*	2023	https://doi.org/10.1109/ACCESS.2023.3325053
[80]	Phisannupawong, T.; Damanik, J.J.; Choi, H.-L.	Aircraft Trajectory Segmentation-based Contrastive Coding: A Framework for Self-supervised Trajectory Representation. *IEEE Open J. Intell. Transp. Syst.*	2025	https://doi.org/10.48550/arXiv.2407.20028
[81]	Liu, S.; Sun, Y.; Jing, T.; Li, Z.; Wang, W.	Effective and Efficient Representation Learning for Flight Trajectories. *AAAI Conf. on AI*	2025	https://doi.org/10.1609/aaai.v39i12.33330

Table S2. Search strings and query parameters used for the systematic literature review (PRISMA protocol).

Database / Source	**Coverage Period**	**Search String (Keywords, Boolean Operators)**	**Notes (Filters Applied)**
IEEE Xplore	Jan 2020–Jun 2025	("aircraft trajectory prediction" OR "flight path prediction") AND	Filtered for journals and conferences in aerospace and AI

		("deep learning" OR "neural network")	
MDPI	Jan 2020–Jun 2025	("aircraft trajectory" AND "deep learning")	Applied to journals *Sensors, Aerospace, Electronics*
ScienceDirect/ Elsevier/ACM	Jan 2020–Jun 2025	("flight trajectory prediction") AND ("deep learning" OR "neural network" OR "LSTM" OR "Transformer")	Journals only; excluded unrelated disciplines
arXiv	Jan 2020–Jun 2025	("aircraft trajectory prediction" OR "flight trajectory prediction") AND ("deep learning" OR "machine learning")	Preprints reviewed manually for relevance
SpringerLink	Jan 2020–Jun 2025	("aircraft trajectory prediction") AND ("deep learning" OR "neural network")	Excluded book chapters; peer-reviewed papers only
AIAA Aerospace Research Central	Jan 2020–Jun 2025	("aircraft trajectory" AND "prediction" AND "deep learning")	Filtered AIAA conference and journal publications
Hindawi (Wiley)	Jan 2020–Jun 2025	("aircraft trajectory prediction") AND ("deep learning")	Applied to engineering and computer science journals
Other (manual search)	Jan 2020–Jun 2025	Citation chasing and cross-references from key studies	Included if peer-reviewed and directly relevant

Table S3. Dataset identifiers, sources, and access links.

Dataset/ Source	Identifier/ Citation	Access Link	Notes (Coverage, Access Policy)
ADS-B Exchange	ADS-B Exchange Project	https://www.adsbexchange.com	Global coverage; community-based; open access
OpenSky Network	Schäfer et al., 2014 (OpenSky Network)	https://opensky-network.org	Strongest coverage in Europe and North America; free API
FAA SWIM/ Radar Data	FAA System Wide Information Management (SWIM)	https://www.faa.gov/nextgen/programs/swim	Restricted access; requires institutional agreement
EUROCONTROL DDR2	EUROCONTROL Demand Data Repository (DDR2)	https://www.eurocontrol.int/ddr	Restricted academic access; covers European flights
CAAC Radar /ADS-B	Civil Aviation Administration of China (CAAC)	http://www.caac.gov.cn	Restricted; often available through institutional projects
NATS (UK)	National Air Traffic Services	https://www.nats.aero	Restricted access; UK-focused coverage
Flightradar24	Commercial Platform	https://www.flightradar24.com	Global commercial dataset; free (limited) + premium tiers
FlightAware	Commercial Platform	https://flightaware.com	Global coverage; API access subscription required
Synthetic: DCS World	Eagle Dynamics, DCS Simulation	https://www.digitalcombatsimulator.com	High-fidelity simulation; combat/rare scenarios
Synthetic: TacView	TacView Flight Analysis Tool	https://tacview.net	Training and scenario replay; widely used in simulation

Synthetic: Air Combat Simulation	Research Simulation Data	(no stable URL—project-based)	Used in academic studies; scenario-specific availability

Table S4. Extended comparison tables of model performance across datasets, computational cost, and robustness.

Model Category	Performance (Representative Results)	Computational Cost	Robustness
RNN-based (LSTM, GRU, Bi-LSTM, ConvLSTM)	Stable in short-/mid-term prediction; RMSE ≈ 0.012–0.025 km; MAE ≈ 0.015–0.030 km on ADS-B datasets [15][34][36]. Performance degrades in long-horizon forecasting due to error accumulation.	Low-to-moderate; efficient for training/inference, suitable for real-time prediction with small-to-medium datasets.	Sensitive to noise and missing values; limited scalability in dense airspace; instability in altitude prediction.
Attention-based (Transformer, Informer, TFT, Dual Attention)	Best long-horizon performance; ADE/FDE improved by 15–30% compared with RNN baselines [40][41][47]. Demonstrated stability in 150–300 sec forecasts.	High GPU/memory demand; training time scales with dataset size; requires complex hyperparameter tuning.	Strong generalization when large-scale datasets available; scalable to parallel training but limited in resource-constrained environments.
Generative (GAN, Diffusion, VAE, TimeGAN)	Competitive ADE/FDE; CTGAN/diffusion reduced MED by 10–80% vs. LSTM [28][54][55]. Effective in rare/extreme scenarios and data augmentation.	High training cost; GAN suffers from instability; diffusion introduces significant inference latency.	Useful for small or imbalanced datasets; robust for rare events; generalization to real-world operations limited.
Graph-based (GCN, GAT, ST-GCN, DA-STGCN)	ADE/FDE improvement of 10–20% in dense terminal airspaces [25][26][59]. Explicitly models multi-aircraft interactions, outperforming sequence models in crowded traffic.	High cost of graph construction; scalability issues for large-scale or real-time applications.	Sensitive to noisy or incomplete graphs; robustness decreases in sparse airspaces; effective in dense traffic scenarios.
Hybrid and Integrated (CNN-LSTM, Attention-LSTM, IMM+Informer, etc.)	Achieves best overall perfomance; RMSE/MAE as low as ≈ 0.011–0.012 km [19][61][70]. Combines multiple architectures for enhanced stability and accuracy; strong in long-horizon prediction and uncertainty quantification.	Highest structural complexity; greater computational overhead; long training times.	Strongest robustness across tasks; representation learning improves generalization; effective with multimodal inputs (ADS-B + Weather + ATC).