Integrating Neurosymbolic AI in Advanced Air Mobility: A Comprehensive Survey

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Introduction

Neurosymbolic AI integrates neural adaptability with symbolic reasoning, offering a promising approach to tackle Advanced Air Mobility (AAM)'s safety, regulatory, and operational challenges. This survey bridges the research gap by analyzing Neurosymbolic AI applications across demand forecasting, aircraft design, autonomy, and air traffic management. We classify current advances, review case studies, and outline future directions for creating reliable, explainable, and regulation compliant AAM systems.

Contributions of This Survey

- **Unified mapping:** First cross-domain review of Neurosymbolic AI across different areas of AAM (design, operations, safety, demand).
- **Method synthesis:** Taxonomy of Neurosymbolic patterns for *compliance*, *explainability*, and *robustness*.
- **Regulatory alignment:** Across to FAA/EASA AI safety frameworks with actionable integration patterns.

Neurosymbolic AI

Definition: A hybrid AI paradigm combining:

- **Symbolic AI:** structured reasoning, explainability, knowledge representation.
- **Neural AI:** data-driven learning, pattern recognition.

Advantages:

- Integrates reasoning and learning for **interpretability** and **adaptability**.
- Requires less training data than pure deep learning.
- Enables error correction, logical inference, and transparency.

Applications in Transportation & AAM:

- Real-time sensor fusion with predefined traffic/flight rules.
- Adaptive, regulation compliant decision-making in ITS and AAM.
- Enhances demand forecasting, safety, and autonomous navigation.
- Improves reliability in AAM operations.

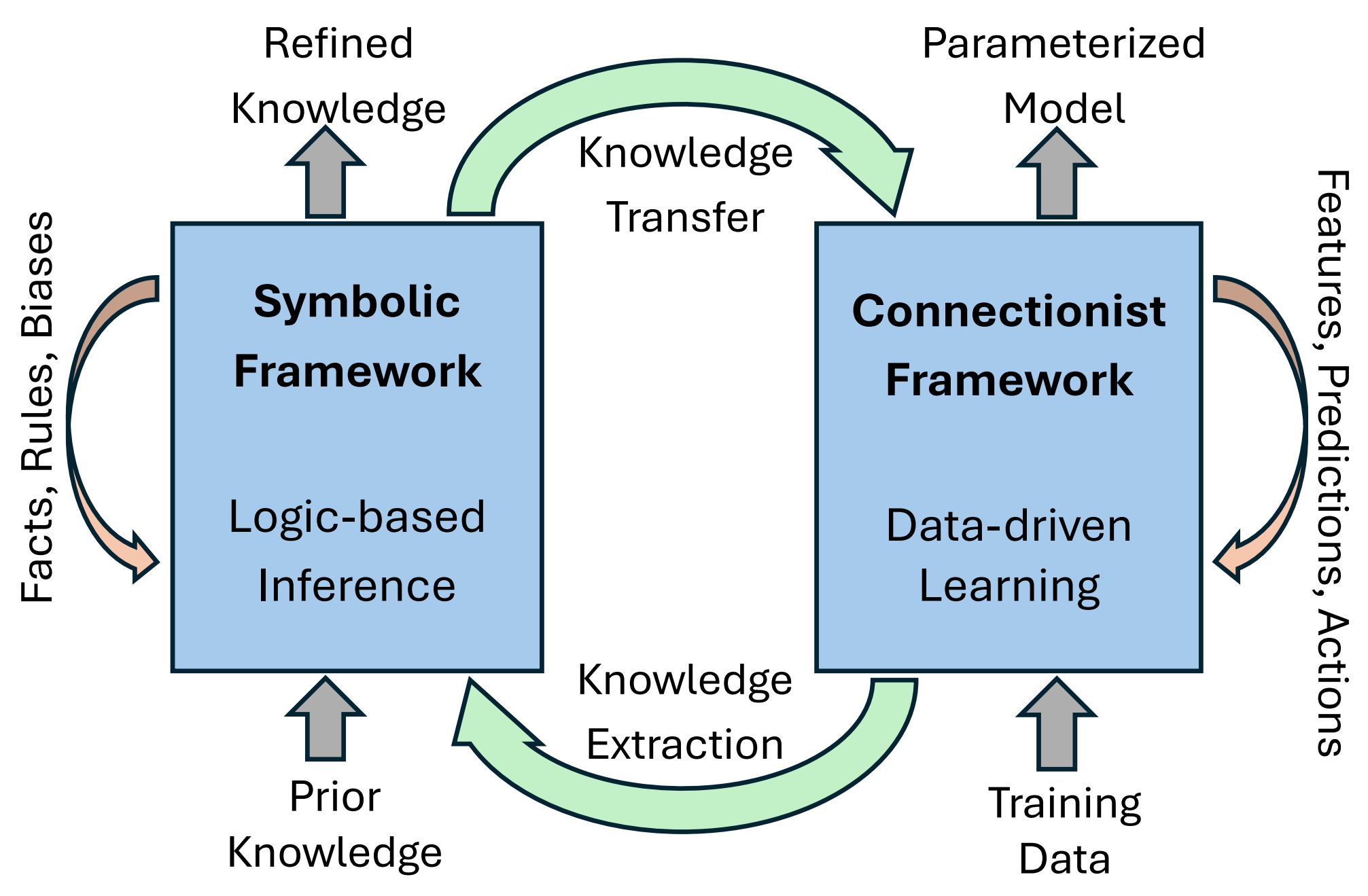

Figure 1. General interactions between symbolic and connectionist frameworks in Neurosymbolic AI

Advanced Air Mobility

Definition: A paradigm shift in transporting people and goods in urban & regional contexts.

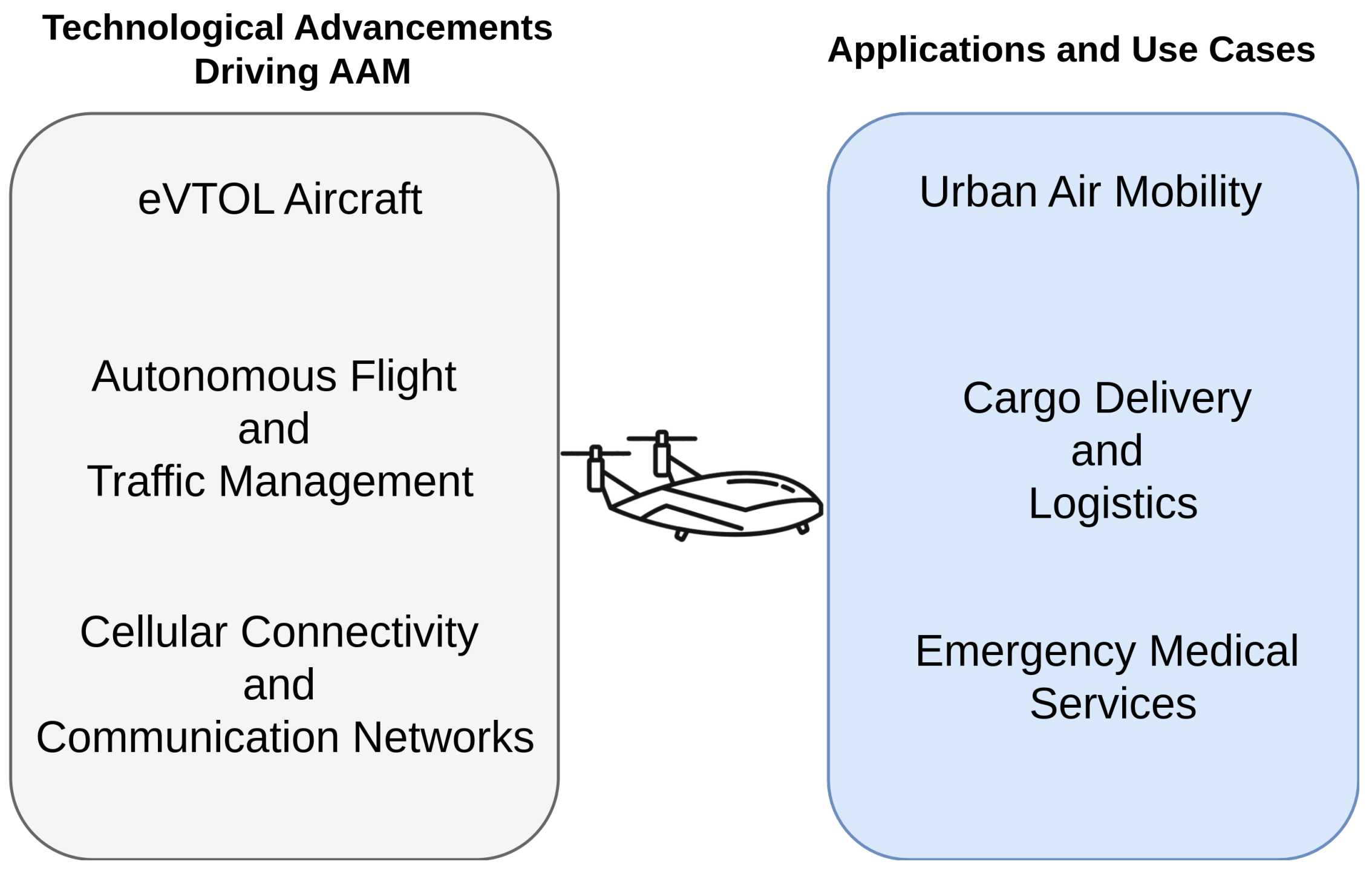

Figure 2. Advanced Air Mobility Overview

Key Technological Drivers:

- **eVTOL Aircraft:** Low-noise, low-emission electric propulsion; autonomous potential; battery density and safety are critical challenges.
- **Autonomous Flight & UTM:** Centralized vs. decentralized architectures for collision avoidance and airspace management; ML-enhanced decision-making; advanced sensors (lidar, radar).
- **Connectivity & Networks:** 5G/6G, satellite, and V2V communications for real-time monitoring, traffic control, and coordination.

Applications & Use Cases:

- **UAM:** Reduce congestion and travel times; integrate with ground transport; address noise, safety, and public acceptance.
- **Cargo Delivery:** Serve remote/underserved areas; medical supply transport; integrate with logistics and warehousing.
- **EMS:** Rapid patient transport; improved access to care; strategic vertiport placement near hospitals.

Application Areas of Neurosymbolic AI in Advanced Air Mobility

- **Electrification:** Predictive energy optimization, battery lifecycle management.
- **Aircraft Design:** AI driven aerodynamics, propulsion efficiency, ride comfort optimization.
- **Training & Simulation:** Digital twins, multi-agent scenarios, safety-critical environment modeling.
- **Predictive Maintenance:** Fault detection via hybrid Bayesian & case-based reasoning.
- **Safety:** Symbolic safety shields in reinforcement learning for hazard avoidance.
- **Autonomy:** Real-time, rule-compliant navigation in dense airspace.
- **Cybersecurity:** Logic-augmented anomaly detection, GPS spoofing mitigation.
- **Demand Modeling:** Merging travel behavior data with regulatory constraints for accurate forecasting.

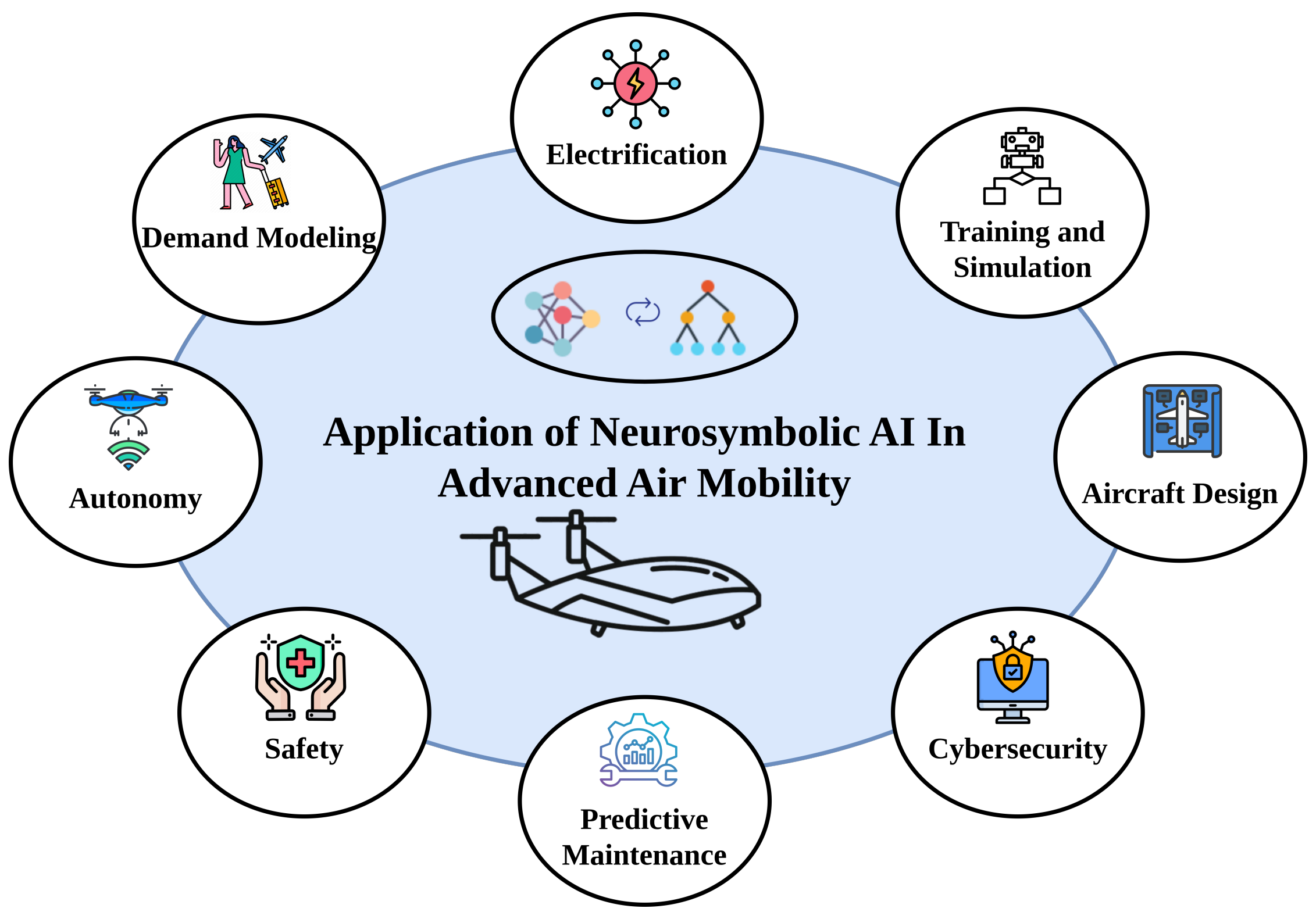

Figure 3. Applications of Neurosymbolic AI in AAM

Potential Case Studies

1. FAA Roadmap for Artificial Intelligence Safety Assurance
    - **Phased, risk-based integration**—start with low-criticality systems, gather operational data, scale to safety-critical applications.
    - Differentiates *learned AI* (static) vs. *learning AI* (adaptive); learning AI raises certification and explainability challenges.
    - Emphasizes **regulatory alignment** and industry collaboration, but lacks robust evolving-AI certification methods.
    - **Neurosymbolic Opportunity:** encode safety rules and reduce unpredictability for certifiable adaptive autonomy.
2. EASA AI Roadmap
    - **1.0:** Trustworthiness, explainability, human-AI collaboration, phased certification.
    - **2.0:** Adds Neurosymbolic AI , predictive maintenance, cybersecurity, and alignment with EU AI Act.
    - Risk-based AI categorization; mandates transparency, explainability, and human oversight.
    - **Neurosymbolic Opportunity:** combine reasoning + learning for interpretable, regulation-compliant AI in aviation.

Risks and Challenges

Neurosymbolic AI can improve efficiency, safety, and scalability in AAM, but it introduces significant risks:

Technological Challenges

- **Data Integration & Interoperability:** Heterogeneous sensors, need for standardized formats, legacy system re-engineering.
- **Cybersecurity:** Vulnerable to adversarial attacks on neural and symbolic components; demands real-time defenses.
- **Lifecycle & Scalability:** Managing version control, verification, and modularity across diverse AAM fleets.

Ethical Challenges

- **Accountability:** Clarifying responsibility in autonomous decision failures; mitigating bias and unfairness.
- **Transparency & Explainability:** Balancing interpretability with performance; ensuring auditability and traceability.
- **Public Trust & Social Acceptance:** Addressing privacy, ethics, and societal concerns for market adoption.

Regulatory & Governance Challenges

- **Certification:** Lack of established standards; need for rigorous testing of hybrid AI systems.
- **Legal & Compliance:** Harmonizing global standards; defining liability for hybrid AI decisions.
- **Data Governance & Privacy:** Adhering to GDPR/CCPA; ensuring secure, transparent data handling.

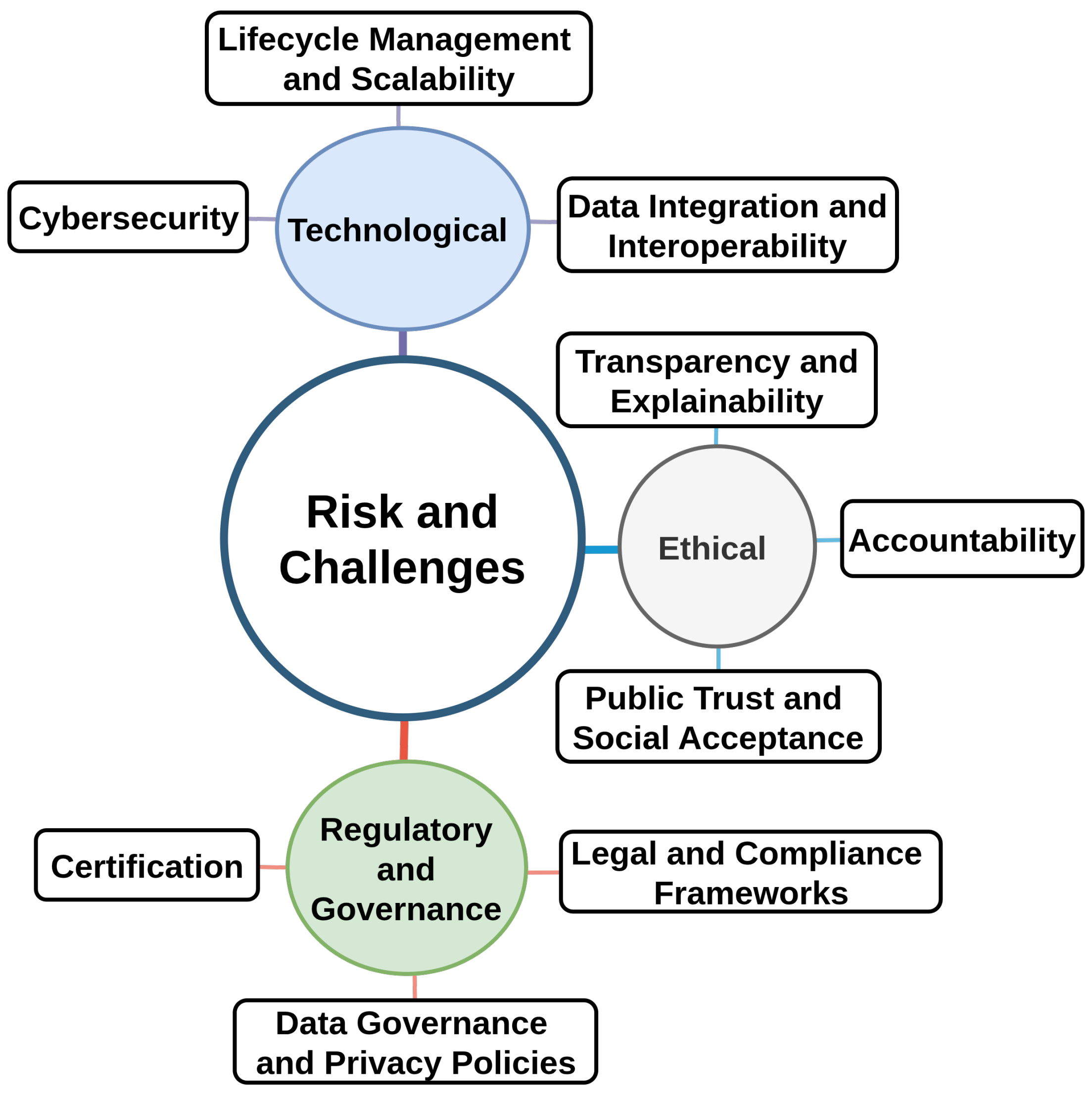

Figure 4. Risks and Challenges

Risks → Neurosymbolic Controls

Black-box decisions	Symbolic constraints; proof obligations; counterfactual checks
Specification drift / updates	Rule versioning; contract-based learning; formal monitors
Data bias / shifts	Knowledge priors; coverage rules; out-of-scope detectors
Certification gaps	Traceable logic; runtime assurances; failure mode libraries

Conclusion

- Neurosymbolic AI offers a viable path to **safe, explainable, and regulation-ready autonomy** in Advanced Air Mobility.
- This survey provides the **first cross-domain mapping** of Neurosymbolic applications across AAM, from design and electrification to safety, demand modeling, and cybersecurity.
- Integrating symbolic reasoning with data-driven learning can **reduce training data needs**, enhance **interpretability**, and improve **trustworthiness**.
- Alignment with **FAA** and **EASA** AI safety frameworks positions NeSy as a strong candidate for future certification standards.
- **Future work:** develop real-world case studies, standardize NeSy evaluation metrics, and test deployment in live AAM environments.

Acknowledgement

This material is based upon work supported by the NASA Aeronautics Research Mission Directorate (ARMD) University Leadership Initiative (ULI) under cooperative agreement number 80NSSC23M0059. This research was also partially supported by the U.S. National Science Foundation through Grant No. 2317117 and Grant No. 2309760.

Read the full paper here

https://arxiv.org/abs/2508.07163

2025 IJCAI, Montreal