SKYGRID

Operational Risk Assessment for Advanced Air Mobility Third-Party Service Providers

White Paper

Introduction

Aviation technology is advancing rapidly and changing the operational landscape of the air transportation system. The emergence of the Advanced Air Mobility (AAM) aviation ecosystem promises to normalize the operations of remotely piloted and increasingly autonomous vehicles, large and small, in the global airspace. These new vehicles may be engineered differently than existing aircraft: flight-essential systems, digital services, and data[1] may be hosted on or off-board the aircraft and operating on a connected and decentralized model.

A new decentralized AAM environment will expand the stakeholder community of real-time flight operations by including the additional technologies necessary to support off-board flight operation functions. Part of this technological infrastructure includes new third-party service providers (TSPs) responsible for certain decentralized flight operations and airspace integration functions.

One example of a TSP system, albeit at lower levels of assurance and designed to support low-risk operations, is the Unmanned Traffic Management (UTM) system designed to enable small UAS operations. TSPs that support safety-of-life operations, like large UAS in integrated airspace and air taxis, will have to meet additional assurance and safety requirements. For these assured TSPs, industry-accepted system safety engineering practices will likely be embedded into the development and operational processes. However, current aerospace industry-standard Society of Automotive Engineers (SAE) Aerospace Recommended Practices (ARPs) do not reference distributed digital systems provided by TSPs, so it must be questioned whether the ARPs can be used as-is to guide the safety assessment of TSP systems. Since following incomplete specifications may leave safety assessment gaps, the safety stakeholders in the AAM ecosystem must work together to understand and close the gaps to ensure comprehensive safety is achieved for all users of the airspace.

[1] Systems that perform flight operation functions like flight controls, flight management, traffic surveillance, and receiving, processing, and monitoring any relevant data to support flight operations: weather, airspace and aerodrome, etc.

This paper aims to advance the conversation on safely integrating TSPs to support AAM operations and focuses on the safety impacts of introducing TSPs into the National Airspace System (NAS) via AAM flight operations in the United States. More specifically, this paper outlines the position of AAM TSPs in the advanced airspace operations framework, describes the potential AAM TSP safety assessment gap, and proposes the adoption of an Operational Risk Assessment (ORA) as a complementary assessment method to close the safety case to demonstrate acceptable levels of safety for approved TSP systems.

This paper asserts that while current industry-standard and safety assessment methods provide a solid foundation for TSP systems, they cannot fully address the complexities of autonomous and AAM operations. Additional complementary safety assessment methods are essential to ensure comprehensive and reliable safety for TSP integration. This paper calls on industry leaders and regulators to recognize the critical role of TSPs within the AAM safety paradigm and to establish clear, robust safety standards for the approval and operation of TSP systems.

1

Advanced Air Mobility and Third-Party Service Providers

Advanced Air Mobility (AAM)

The FAA AAM Integration Plan introduces AAM as "an emerging aviation ecosystem that leverages new aircraft and an array of innovative technologies to provide the opportunity for more efficient, more sustainable, and more equitable options for transportation" ("Advanced Air Mobility Implementation Plan" 2023, p. 1). AAM intends to transform the landscape of the NAS by introducing new classes of aircraft with varying levels of autonomy, such as electric vertical take-off and landing (eVTOL) vehicles, delivery drones, and autonomous middle-mile cargo aircraft. These vehicles are designed to move people and goods more efficiently across urban and rural areas, potentially reducing road traffic and offering faster, more accessible, and sustainable mobility options.

Integrating AAM into the NAS means accommodating a variety of new, highly automated, and in some cases, autonomous aircraft at lower operating altitudes than conventional aircraft. The increasing levels of autonomy in aircraft systems and faster operating cadence mean greater reliance on data, algorithms, and networks for flight planning, management, control, and operation. This accommodation will require significant updates to the current air traffic management systems, including new operational protocols, airspace restructuring, and real-time data-sharing platforms that can handle the increased complexity of tracking and directing traditional and novel air traffic types in the integrated NAS.

Table 1 summarizes the FAA's perspectives on the evolution of the AAM ecosystem with levels of vehicle autonomy in a "crawl-walk-run" model ("Advanced Air Mobility Implementation Plan" 2023, p. 33).

Level	Description	Trigger Events (for reaching level)
0	Late-stage certification testing in limited environments, aircraft certification testing, and operational evaluations with conforming prototypes and existing rules/procedures, and early industry development and prototyping.	
1	Exploratory operations of minimal density and complexity, type certified aircraft, early FAA procedures development, and initial Provider of Services for UAM (PSU) services.	Completion of relevant NPRMs and rulemaking to allow for vehicle type certification, initial public standards to support data exchanges between industry participants and the FAA.
2	Low-density scheduled commercial operations in urban areas and around airports, as well as an established federated service network* with several PSUs and Supplementary Data Service Providers (SDSPs). Designated cooperative airspace is limited (see UAM ConOps, Version 2.0). *A federated service network is one that is provided and supported by the operators and third-party service providers to exchange the information and agreements needed for FAA-approved cooperative operating practices.	Increased operational density, new operational modes (e.g., remotely piloted), and the evaluation of cooperative airspace and a federated service network with multiple operating PSUs.
3	Medium-density scheduled and unscheduled commercial operations using an increased number of vertiports and routes in specific geographical areas that make continued use of limited, designated cooperative airspace. Established PSUs and federated service networks support increased levels of automation and instances of remotely piloted aircraft with a safety pilot on board.	Continued evolution of the modes of operations, implementation of designated cooperative airspace in more geographical areas, and the establishment of certification standards for automated and remotely operated large aircraft.
4	Medium-density scheduled and unscheduled commercial operations in an AAM network that make widespread use of cooperative airspace. Fully remotely-piloted operations are supported.	Certification of fully remote piloted aircraft and the availability of enhanced CNS capabilities that can support long distance and fully remote operations, complete implementation of new regulatory frameworks, widespread implementation of cooperative airspace and vertiports, and the ability to support operations in instrument meteorological conditions (IMC).
5	Mature AAM ecosystem, characterized by high density scheduled, unscheduled, and on-demand operations that are geographically dispersed and served by aircraft able to operate autonomously.	Certification of fully autonomous aircraft and the satisfactory performance of highly integrated automation within the federated service network.

Table 1: AAM Maturity Levels (Source: FAA)

AAM Third-Party Service Provider (TSP) Systems

In this context, TSPs are ground-based digital service providers in the federated network expected to support AAM operations[2]. The term "third-party" refers to the fact that TSPs can be independent entities separate from AAM operators or Air Navigation Service Providers (ANSPs)[3]. Figure 1 illustrates an example integrated AAM operational ecosystem, including stakeholders like operators, aircraft, Air Traffic Control (ATC), TSPs[4], and flight operation infrastructure.

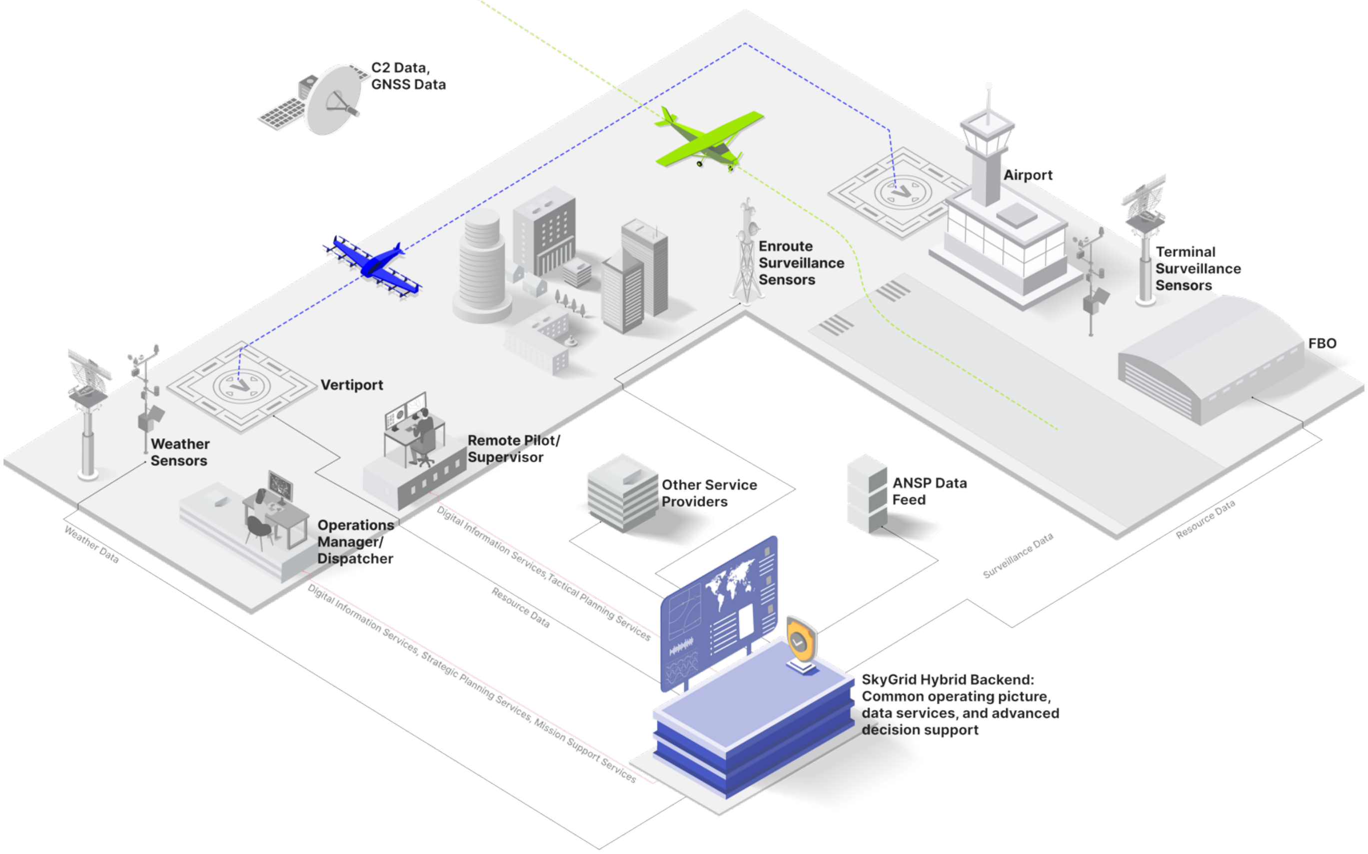

Figure 1: An example AAM operational ecosystem

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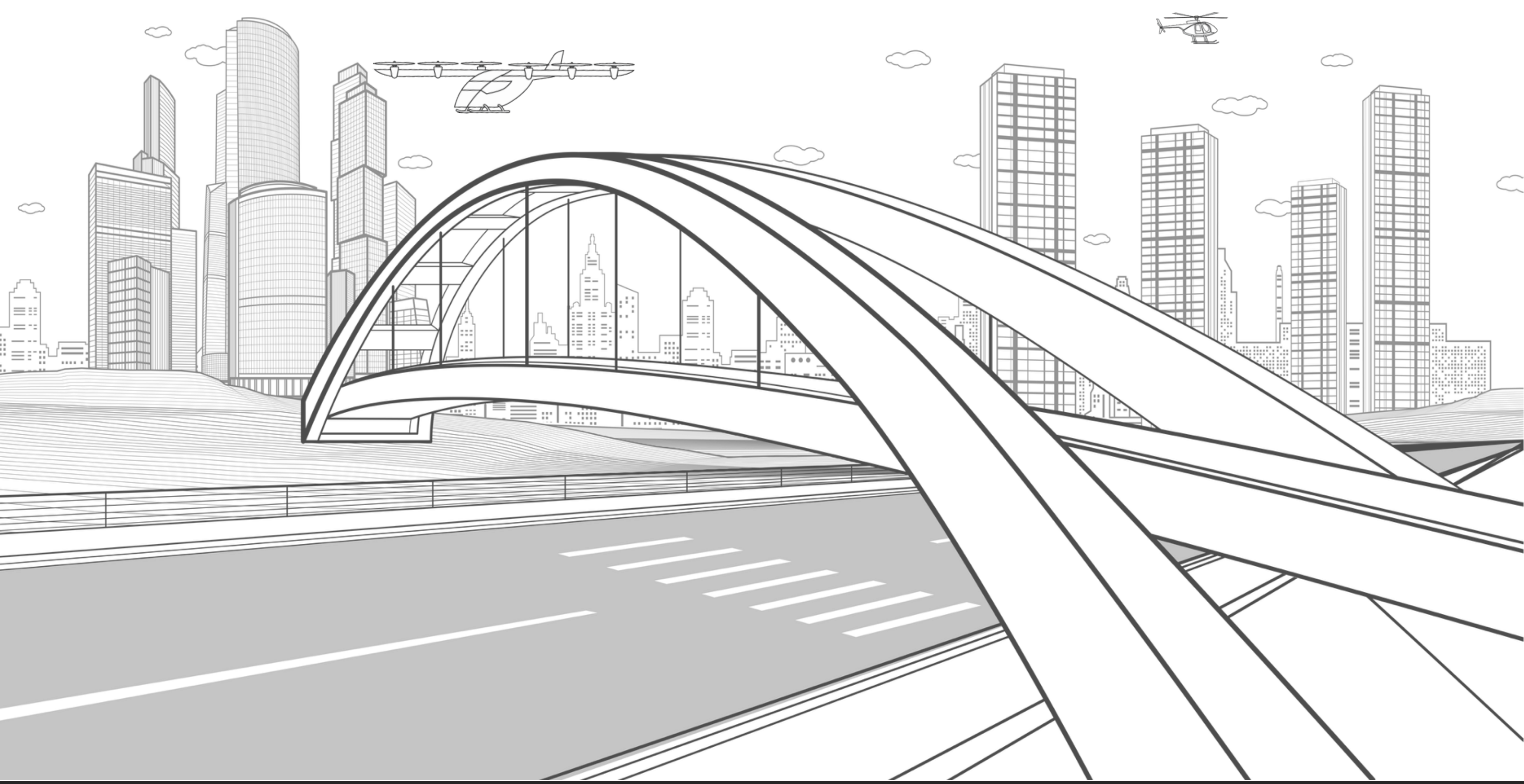
[2] As defined in Figure 1 FAA AAM Maturity Levels
[3] Third-Party Service Provider (TSP): A commercial entity that integrates a variety of data from the operating environment to provide actionable information and decision support services to AAM operators and Air Navigation Service Providers (ANSP) to facilitate the airspace integration of novel operations (SkyGrid Concept of Operations for Third-Party Services)
[4] For example, the SkyGrid System (SkyGrid Concept of Operations for Third-Party Services)

An example of a near-term AAM TSP solution is a system that provides high-fidelity, real-time weather data to plug into an AAM aircraft ground control station for use during flight operations to monitor and avoid weather hazards. An example of a longer-term AAM TSP system is a ground-based traffic avoidance system, which acts as a decentralized system that monitors all air traffic in an operational volume, computes collision risks and provides resolution advisories directly to AAM vehicles while notifying ATC. The latter example may require evolutions in the Rule of Air and partial delegation of cooperative air traffic management responsibilities to TSPs.

The advantages of TSPs are their ability to serve as federated players in the AAM aircraft ecosystem and to respond quickly to market signals to address the needs of emerging vehicles and operations. Just as the FAA has released a "crawl-walk-run" model for AAM evolution, TSPs can also provide support at increasing levels of responsibility over time, which sets an expectation that the safety impact of a TSP will likely increase over time. At a steady operating state, TSPs may remotely provide functionality to multiple operations within the same airspace or across multiple operational volumes. These characteristics of TSPs potentially introduce unique safety assessment challenges.



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Third-Party Service Provider Safety Assessment Gap

Current Aviation Safety Resources

The aviation industry adheres to rigorous safety standards overseen by regulatory bodies like the Federal Aviation Administration (FAA) and the International Civil Aviation Organization (ICAO). Existing industry standards and regulatory requirements for safety assessment and airworthiness compliance have successfully established an acceptable level of safety for the industry. The following safety standards and regulations are generally applicable in the development of certifiable aircraft or aircraft systems:

- **Demonstrating Safety Compliance:** AC-23.1309 and AC-23.1301 set acceptable means of compliance for aircraft safety.

- **Safety Recommended Practices:** SAE ARP4761 and ARP4754 provide recommended practices for performing lifecycle safety assessments on an aircraft and its installed systems.

- **Development Assurance Standards:** RTCA DO-178, DO-254, and DO-278 provide standards that must be met to ensure the safe development of aircraft software and electronic systems.

- **AAM Policy Development:** FAA policy work is advancing the definition of the safety continuum for AAM vehicles via draft FAA Policy Statements on the Safety Continuum for Powered-Lift, PS-AIR-21.17-01, and FAA Engagement on Highly Automated Aircraft Projects, PS-AIR-21.17.03. These policy documents focus on the vehicle and do not provide guidance on TSP systems.

Gaps in TSP Safety Assessment Methods

AAM TSP systems represent a new paradigm for distributed ground systems to support flight operations and have no direct precedence in comprehensive safety assessment. In the absence of a specific ARP for AAM TSP systems, existing industry-accepted recommended practices for aircraft safety assessment may be used as the starting point for demonstrating TSP system airworthiness. ARP4761 provides the lifecycle safety assessment process illustrated in Figure 2.

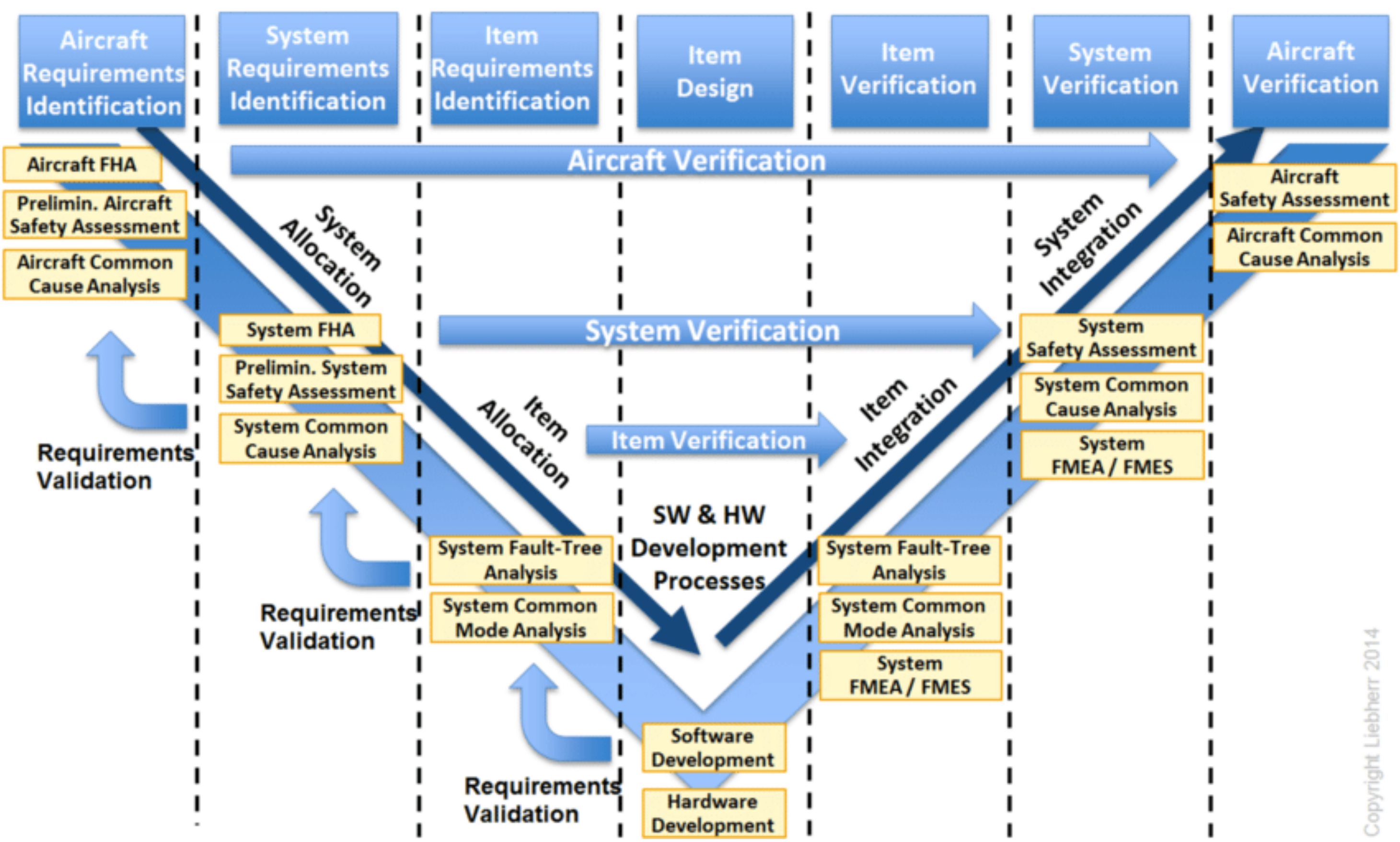


Figure 2: ARP4761 Safety Assessment Process

This detailed assessment process provides a sound foundation for a top-down understanding of the internal safety risks inherent in the system. It begins with two levels of functional safety assessment of the system: aircraft and system functions. Then, it digs deeper into subsystem component-level failure analysis to substantiate how those aircraft and system-level functional failures may occur. Additional analyses determine what common risks exist within the system and which external particular risks may impact the system. At different stages of the design process, these analyses are collected with safety assessments to provide iterative stages for risk management, deriving safety requirements to levy upon system design.

The ARP guides the safety assessment of a risk object: the aircraft system being built, which is directly related to the safety assessment subject, the aircraft/occupants. TSP systems indirectly impact the safety assessment subject, the aircraft/occupants, via a digital linkage to the aircraft, and may simultaneously impact several independent subjects. The safety concern is that the system-of-systems (SoS) has grown to include more stakeholders, and the boundaries of design and operational safety responsibility are harder to distinguish. Table 2 compares the two classes of safety cases and highlights the changes.

	Traditional Safety Case	**TSP Safety Case**	**What Changed**
System Configuration	Monolithic vehicle	Distributed systems	Distributed architecture and remote connectivity introduce new safety considerations
System Scale / Unit of Analysis	A single vehicle	Distributed ground systems interacting with multiple vehicles	An aircraft, integrated avionics suite, or TSP-aircraft system are all examples of complex system-of-systems (SoS). What is new here is that the highest unit of SoS for analysis now extends beyond a single aircraft
Risk and System Boundary	Operational risks are not explicitly analyzed. They are assumed to be mitigated through onboard pilot and Air Traffic Control (ATC).	Vehicle operational risks are conflated with TSP design risks. The removal of onboard pilot and allocation of some of their functions to the TSP further conflate operational and design risks	What is traditionally considered aircraft operations is now within the TSP system design perimeter

Table 2: A comparison of the scope, boundaries, and components of TSP and traditional aircraft and aircraft systems safety cases

The ARPs enable the assessment of the system and its direct safety impacts but lack guidance for comprehensively assessing the three distinguishing features that characterize the TSP safety case:

1. **System Configuration – Distributed Systems:** TSP systems have a remote connection to aircraft systems. ARP4761 provides a robust framework for assessing the safety of onboard aircraft systems; however, it may prove insufficient for evaluating safety risks associated with remotely delivering safety-critical information to multiple aircraft in the airspace. Moreover, ARP4761 is tailored to airborne systems under the direct control of the aircraft manufacturer or operator. It does not explicitly address systemic and operational risks associated with external service providers, including issues like data and service infrastructure[5], integrity, availability, timeliness, and consistency across multiple users. Additionally, TSP systems may eventually implement or interface with novel technologies like advanced algorithms and machine learning, which are not yet adequately covered by the development assurance process in ARP4754[6]. The increasing responsibility and distributed nature of digital systems in flight operations put pressure on the current software safety practices to ensure evaluation methods scrutinize the risks of unexpected system interaction.

2. **System Scale – Multiple Vehicles:** Digitally linked TSP systems may provide services to multiple aircraft simultaneously, expanding the SoS boundaries of the TSP safety case. Current analysis methods lack the sophistication to model the dynamic nature of real-time, simultaneous digital operations with multiple safety stakeholders. Instead, they primarily focus on hazard identification and risk assessment within the bounds of individual aircraft systems where the assessor has design control over the entire system. While the ARP guides employ rigorous techniques such as Functional Hazard Assessments (FHA) and Fault Tree Analysis (FTA), these methods are typically constrained to internal system interactions and do not extend to complex, interconnected TSP operations. For example, when a service provider disseminates erroneous safety-critical information, the cascading effects across multiple aircraft cannot be adequately captured using the ARP4761 framework. Such scenarios require a broader approach to safety assessment whose highest unit of analysis extends beyond the monolithic aircraft or line replaceable unit (LRU).

[5] *For data warehousing, sharding, and remote connection*
[6] *As identified and reported by SAE AIR7209*

3. **Risk and System Boundary – Conflated Design and Operational Risks:** Safety risks may be realized after the system is put into operation. A top-down ARP-guided internal safety assessment of the TSP system may sufficiently derive the system design risks but will not derive the full suite of operational safety risks that a TSP system poses to simultaneous aircraft operations. Following ARP methods, TSP system safety assessments depend on the assumption and generalization of end effects to aircraft outside of the TSP system's control. In scenarios with multiple user entities, the aircraft may utilize the TSP system data differently, posing various safety risks dependent on the operation. Operational risks and mitigation strategies become conflated. In fact, the necessity to consider operational risks within the design process at all is novel – conventional aircraft system safety cases and design assurance are separated from operational risks and approval. This more compartmentalized approach is backstopped in part by the assumption that the operational safety of conventional aircraft is assured through compliance with regulations like Part 91, 135, etc.

These gaps motivate the need for complementary frameworks or standards to address the limitations of following ARP4761 for TSP system safety assessment. Since the outstanding risk identification is operational, an additional operational safety analysis, henceforth referred to as an Operational Risk Assessment (ORA), may be value-added to capture and mitigate potential emergent risks from these unique TSP system features. Illustrated in Figure 3, the ARP4761 safety assessment process plus an ORA may close the TSP safety assessment gap.

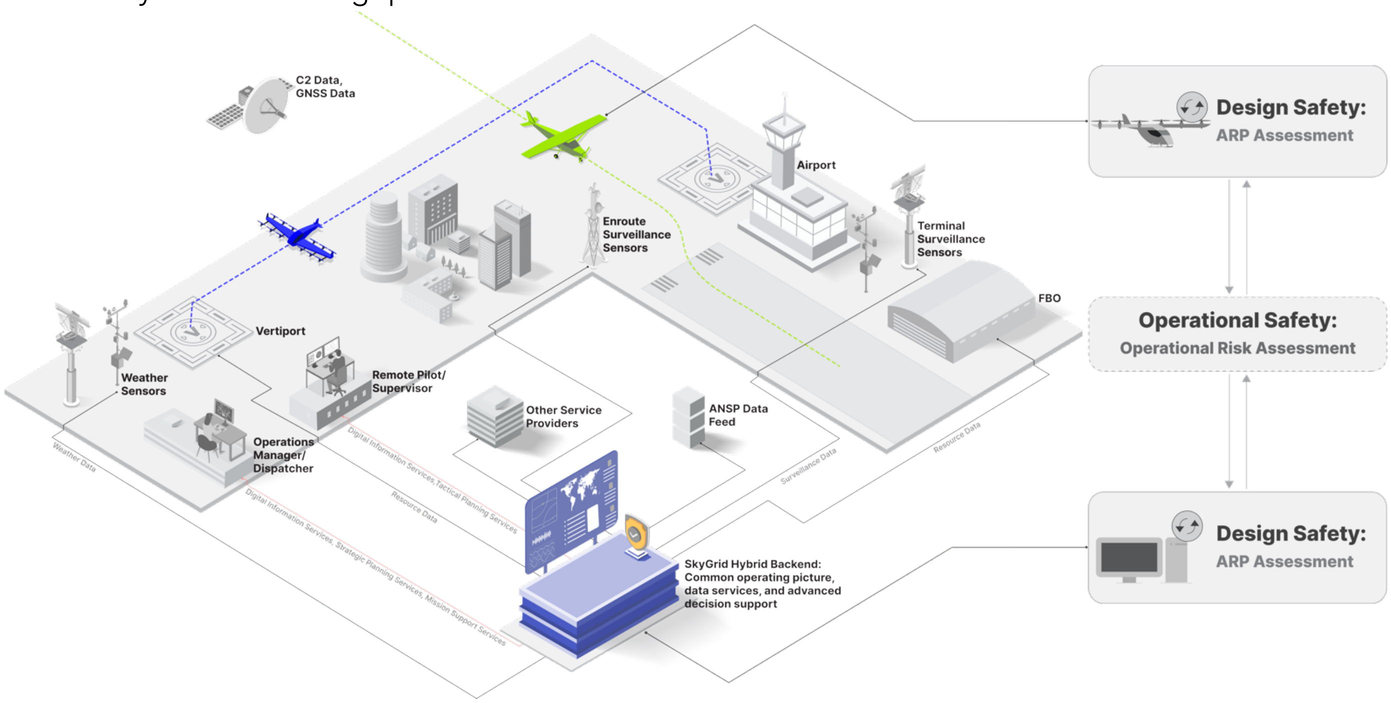


Figure 3: Operational Risk Assessment covers an expanded safety case scope

3

Proposed Operational Risk Assessment

Trade Study for Candidate TSP Safety Assessment

The intention of the ORA is to provide a comprehensive framework for evaluating and mitigating emergent operational safety risks associated with integrating TSPs into the NAS. Its purpose is to address the unique challenges posed by distributed architecture, integration across multiple vehicles, and conflated risk categories by identifying and assessing operational risks. The ORA aims to complement existing safety assessment methodologies, ensuring that the approval and operational safety of TSP systems meet acceptable levels.

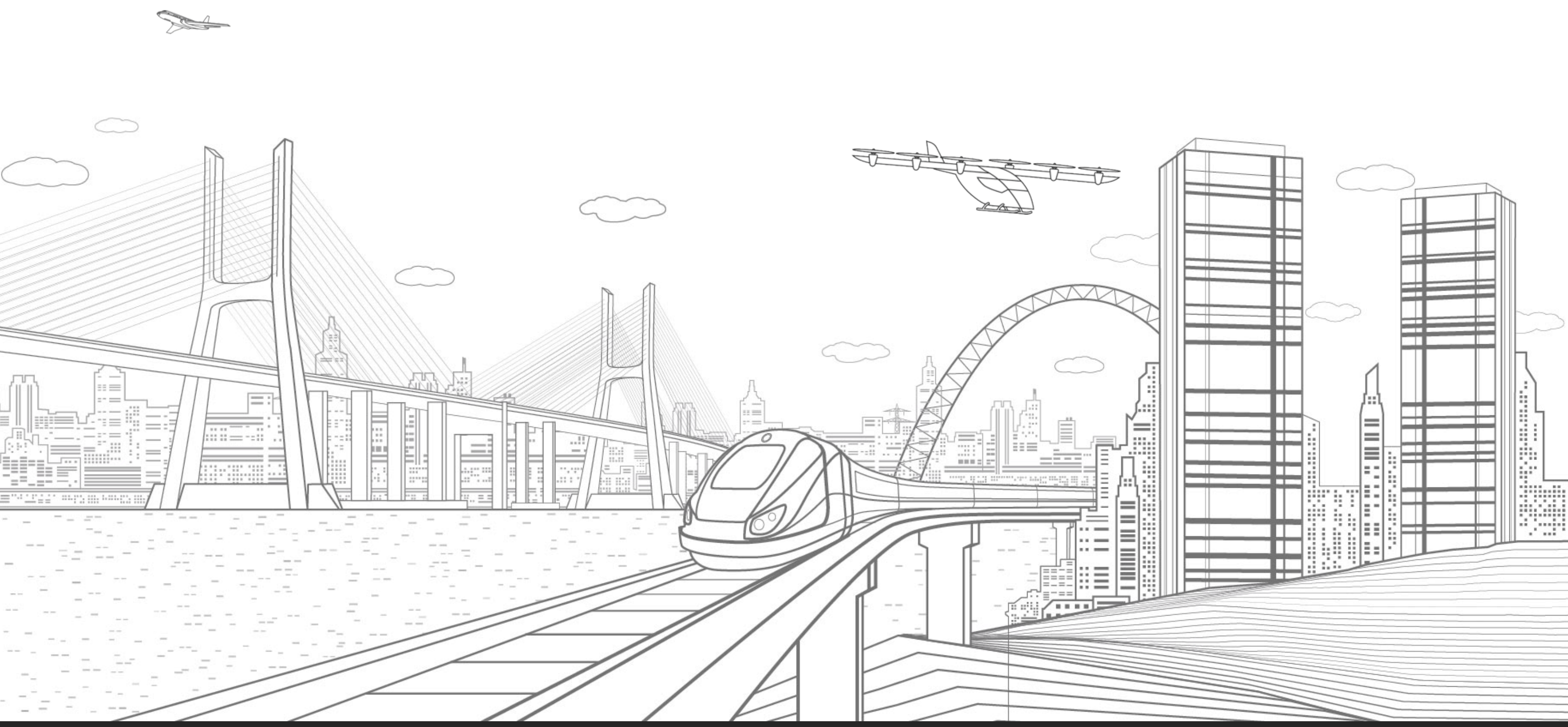
Based on these goals, SkyGrid reviewed established safety analysis methods to see if one or a combination of these existing methods could meet the intent of the ORA. If an existing method met the intent, then it could be recommended as a candidate complementary method to add to the TSP safety assessment suite. Table 3 summarizes the results of a trade study on industry-accepted safety analysis methods that could meet the objectives of this operational safety analysis. Each of these methods is well-regarded and addresses specific facets of safety.

Method	Source	Strengths	Limitations
Systems-Theoretic Process Analysis (STPA)	MIT-STAMP-001	Identifies operational control failures Derives safety requirements by analyzing feedback loops	Lacks structured ways to prioritize and quantify risks
Specific Operations Risk Assessment (SORA)	EASA	Evaluates operational risks in specific flight contexts Provides safety recommendations	Only analyzes specific operations (i.e. single flight path)
Hazard & Operability Method (HAZOP)	IEC 61882	Identifies deviations in standard processes that could lead to hazards	Does not prioritize risks or address interaction hazards
Aviation Risk Management System (ARMS) Operational Risk Assessment (ORA)	ARMS	Supports the development of risk reduction strategies for systems in the deployment phase	Primarily targets deployment-phase risks, leaving gaps in early design assessments
Integrated Safety Assessment Methodology (ISAM)	EC JRC92779	Integrates safety processes across architecture and verification phases	Focuses on deployment-phase risks, with limited applicability in early design assessments
Safety Critical Functional Thread Analysis (SCFTA)	AC-17-01	Analyzes critical hardware and software functions through functional decomposition	Limited to pre-identified safety-critical functions Fails to capture new or emergent hazards

Table 3: Candidate TSP Safety Assessment Trade Study Result Summary

The SORA framework identified in Table 3 has emerged as a leading method in Europe for certifying Unmanned Aircraft Systems (UAS) operations, reflecting the growing recognition among aviation experts of the need for robust operational risk assessments in advanced aviation contexts. SORA embodies many principles that align with an ideal ORA, such as its structured approach to identifying and mitigating operational risks and its emphasis on tailoring safety assessments to specific operations. However, while SORA effectively addresses localized and operation-specific scenarios, it lacks the scalability required to encompass the broader, more dynamic requirements of AAM operations involving multiple vehicles and complex system-of-systems environments. Building on this foundation, our trade study evaluates additional safety analysis methods to determine their potential for meeting ORA requirements within the AAM ecosystem.

Along with SORA, analyses such as STPA and SCFTA, come close to achieving our objective, but no method applied individually fully meets the rigorous demands of a comprehensive operational safety evaluation for AAM TSP systems. The multifaceted nature of TSP operations involves not just isolated risks but also the interplay of multiple systems and external factors that these methods do not fully address. A new analysis approach is needed to integrate operational risk considerations with existing practices to effectively assess and manage the full scope of potential hazards across all stages of a TSP system's lifecycle.



Components of an Operational Risk Assessment

An ORA should evaluate the operational risk of interconnected systems within a larger system-of-systems framework, such as that found in AAM. Unlike traditional assessments that focus on isolated systems, the ORA should consider how a given system's operation affects and is affected by other components within the broader environment. This type of analysis helps to understand the risk profile of any system by examining how it interacts with upstream and downstream systems and the implications of these interactions on overall safety.

In this context, the boundaries of responsibility among stakeholders often become blurred, creating challenges for ensuring safety and accountability. With interconnected components spanning multiple organizations, from TSPs to vehicle operators and regulators, it is increasingly difficult to delineate clear lines of control and responsibility. An ORA must address this complexity by providing structured guidance for navigating these boundaries. This could include defining explicit areas of control for individual stakeholders, fostering collaboration through joint risk assessments, or developing innovative frameworks to distribute responsibility effectively. By offering solutions to these challenges, the ORA ensures that safety considerations are not overlooked due to fragmented accountability, enabling a more cohesive and secure approach to AAM operations.

To address the safety assessment challenges of TSP systems delivering safety-critical information, three analytical approaches stand out: System-Theoretic Process Analysis (STPA), Safety Critical Functional Thread Analysis (SCFTA), and Specific Operational Risk Assessment (SORA). Each method offers distinct advantages from an operational standpoint and collectively can inform the development of a comprehensive Operational Risk Assessment (ORA) framework.

STPA

STPA is particularly effective in identifying hazards that arise from complex interactions within and between systems, including those that span organizational boundaries. From an operational perspective, STPA focuses on unsafe control actions and causal factors, making it well-suited for analyzing how third-party service providers interact with aircraft systems and airspace management. For example, STPA can identify scenarios where delayed or erroneous safety-critical information could lead to conflicting actions by multiple aircraft. By addressing both technical and human factors, STPA offers a holistic approach to hazard identification and ensures that operational risks stemming from system interdependencies are comprehensively understood.

SCFTA

In contrast and complement to STPA, SCFTA zeroes in on specific functional threads—end-to-end processes critical to safety. This method is particularly valuable for analyzing how individual functions, such as the dissemination of traffic advisories or weather updates, perform under different conditions. From an operational perspective, SCFTA helps ensure that each functional thread meets safety and performance requirements, even in degraded or failure states. For instance, by analyzing a thread from data generation at the service provider to its point of use in cockpit decision-making, SCFTA can pinpoint vulnerabilities and propose mitigations for ensuring the reliability and integrity of critical information flows.

SORA

SORA is a risk-based assessment method originally developed for unmanned aircraft systems but is increasingly applicable to broader aviation contexts. It evaluates the operational risks specific to a given environment, including those posed by external factors like traffic density, environmental conditions, and system failures. From an operational standpoint, SORA enables stakeholders to quantify risks associated with third-party services and prioritize mitigations based on their potential impact. By emphasizing contextual factors, such as the complexity of the airspace and the criticality of the information being provided, SORA offers a dynamic and scalable framework for operational risk assessment.

Combining elements from STPA, SCFTA, and SORA can create a robust Operational Risk Assessment (ORA) framework that captures the strengths of each method. STPA can provide a high-level view of systemic interaction hazards, SCFTA can drill down into the performance of individual functional threads, and SORA can contextualize risks within the operational environment. Together, these approaches can deliver a comprehensive understanding of safety-critical risks and inform the development of targeted operational requirements, mitigation strategies, and approval processes. An integrated ORA framework would ensure that TSPs are evaluated not only for the safety of their systems but also for the ability of those systems to operate reliably within the interconnected aviation ecosystem.

While this is one potential approach for developing an ORA framework, we acknowledge that this may not represent the optimal solution. The complexities of integrating TSPs into the aviation safety framework require a nuanced and collaborative effort that goes beyond any single proposed method. We call upon industry leaders, regulators, and stakeholders to engage in the development of a comprehensive and scalable ORA process that effectively addresses the current safety gaps. Such a process should leverage collective expertise to ensure it is robust, adaptable, and capable of supporting the safe integration of TSPs into the global airspace.

4

Conclusion

The emergence of the AAM ecosystem heralds a transformative era in aviation, where the routine operation of remotely piloted and increasingly autonomous vehicles becomes a global norm. As this landscape evolves, the safe integration of TSPs into the global airspace is crucial, especially regarding their influence on AAM operations within the United States.

Central to the discussion is the need for a comprehensive approach to evaluating TSP safety. While existing industry standards and regulatory practices establish a reliable baseline for aviation safety, TSPs introduce complexities that require additional scrutiny. TSP and similar distributed digital systems, by their indirect but impactful role in connecting multiple aircraft systems, necessitate a broader consideration of risk factors, including system configuration, scalability, and the conflation of design and operational risks. To address these challenges, this paper advocates for using an Operational Risk Assessment (ORA) as a complementary method to enhance safety evaluations and close assessment gaps.

Existing safety analysis methods like STPA, SCFTA, and SORA offer valuable insights but do not fully meet ORA requirements. We advocate for building a comprehensive process which uplifts valuable aspects of these methods to complement current safety analyses outlined in the ARP guidelines and strengthen the safety case for TSP systems.

Ultimately, this paper calls upon industry leaders, regulators, and stakeholders to recognize the evolving role of TSPs and prioritize their integration into the AAM safety paradigm. Defining clear safety standards and processes for TSP approval will be essential to realizing the transformative potential of AAM while maintaining the highest safety standards in the aviation industry. More importantly, developing the right tools to build safer distributed ground and cloud-based systems to support more digital and automated operations has implications beyond AAM – to potentially touch all segments of aviation. This collaborative effort will ensure a seamless and secure transition to a future where advanced aerospace infrastructure becomes an integral, safe part of global transportation.

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