The In-time Aviation Safety Management System Concept for Part 135 Operators

Kyle K. Ellis
NASA Langley Research Center
Hampton, VA USA

Lawrence J. Prinzel
NASA Langley Research Center
Hampton, VA USA

Misty D. Davies
NASA Ames Reserch Center
Moffett Field, CA USA

Paul A. Krois
Crown Consulting, Inc
Aurora, CO USA

Robert W. Mah
NASA Ames Reserch Center
Moffett Field, CA USA

Nikunj C. Oza
NASA Ames Reserch Center
Moffett Field, CA USA

Chad L. Stephens
NASA Langley Research Center
Hampton, VA USA

Michael J. Vincent
NASA Langley Research Center
Hampton, VA USA

James R. Ackerson
Flight Research Aerospace
Louisville, KY USA

Samantha Indre Infeld
Analytical Mechanics Associates
Hampton, VA USA

***Abstract*—Transformations of the National Airspace System, such as envisioned with Advanced Air Mobility, will enable improvements for managing and assuring safety for Part 135 transportation of passengers and cargo. The purpose of this paper is to describe the In-time Aviation Safety Management System (IASMS) Concept of Operations (ConOps) and how its innovations such as using predictive analytics could benefit operators for risk management and safety assurance. The National Academies recommended development of an IASMS ConOps to secure a safe future NAS. Part 135 operators are currently not required to have a formal safety management system.**

Keywords— in-time safety, safety management system, Part 135, Part 121

I. Introduction

Transformations of the National Airspace System, such as envisioned with Advanced Air Mobility (AAM), will enable improvements for managing and assuring safety across the National Airspace System (NAS) including the Part 135 domain for both today's traditional operations and new entrants [1]. New entrants include innovations with aircraft using electric Vertical Take-off and Landing (eVTOL) for regional and local (e.g., urban) transportation.

The Federal Aviation Administration (FAA) has established two sets of operating rules for air carriers under 14 CFR Part 135 and 14 CFR Part 121 [2]. Part 135 carriers, which are the focus of this paper, are limited in the number of passenger seats and amount of cargo which can be carried. Part 135 also includes all rotorcraft. Part 121 commercial air carriers have no limits on the size and type of aircraft operated. The current FAA database lists 1,889 Part 135 carriers and 58 Part 121 carriers (6 carriers operate under both rules) [3]. Despite fewer numbers, Part 121 carriers operate almost five times the flight hours of Part 135.

Due to the increased risk of Part 121 operations, carriers are required by regulation to have an FAA approved Safety Management System (SMS) (14 CFR § 5.1). Part 135 operators have the option of joining the FAA SMS Voluntary Program (SMSVP), yet data from the NTSB indicate that currently less than 1.5% of registered Part 135 operators have an FAA approved SMS program [4]. That is, NTSB data showed 30 Part 135 operators participate in the SMSVP relative to 1,940 operators. One would expect the percentage of Part 135 flights that are operated by SMSVP participants to be higher than 1.5% since these would include larger Part 135 operators. Another 165 Part 135 operators have applied for SMSVP acceptance.

Part 135 operators are foreseen to grow in numbers, size, and complexity with transitions involving Advanced Air Mobility involving novel vehicles, new airspace concepts, emerging operations such as Beyond Visual Line of Sight (BVLOS) for unmanned aircraft systems (UAS), and increasingly automated systems [5, 6, 7]. There are three Part 135 certificated UAS cargo airlines with many more applications.

The purpose of this paper is to describe the In-time Aviation Safety Management System (IASMS) Concept of Operations (ConOps) and how its innovations could benefit Part 135 operators for risk management and safety assurance [8]. The IASMS provides an approach to the future SMS for Part 121 operators [9]. The National Academies recommended development of an IASMS ConOps as part of a blueprint to secure a safe future NAS [10, 11]. The overall flow of the paper describes current Part 135 safety management, assesses the needs of Part 135 for in-time safety, and describes the IASMS with use cases.

The NAS-wide transformation envisioned for future operations with critical challenges for in-time safety includes evolving the Safety Management Systems (SMS) for Part 121 commercial air carriers. However, key challenges are that today's NAS does not scale with rapidly evolving aviation markets and envisioned new concepts of operations, combined with the NAS being workload-intensive and the public having a low tolerance for aviation accidents. Addressing these challenges, the IASMS concept of operations provides responsive risk management and safety assurance utilizing system-wide data to provide timely alerting and mitigation strategies much more effective and responsive to resolving known and unknown risks than possible with today's SMS. Of course, the human is still expected to have critical safety roles with air carrier operations as well as data analyst and review board roles in future commercial aviation SMS.

Today's commercial air carriers ensure safety through use of SMS although traditional SMS has difficulty scaling with the increasing volume and complexity of operational data. Sophisticated data mining tools supporting predictive analytics and machine learning are required to properly analyze such data. This innovative perspective enables proactive and predictive safety using data analytics for improved actionable safety intelligence and risk visualization [8]. Reflecting the success of SMS with Part 121, advancing the IASMS for Part 135 would provide for in-time risk identification and mitigation for the safe transportation of passengers and cargo.

Collaboration between the National Business Aviation Association (NBAA) with its Emerging Technologies Committee and NASA identified questions important to structuring an IASMS [12]. One question was how to tailor the requirements and desired level of monitoring and assessment to achieve safety given the breadth of possible operations and the associated risk of those operations? Another question was how to aid innovation by rapidly evaluating the safety of novel operations without losing associated rigor? Considerations important to adapting IASMS for Part 135 included systematically evaluating the risk inherent to both current and novel operations in terms of the public's acceptance of aviation risk, tracing the existing and developing functions to address these risks in-time, and defining the minimum data requirements for monitoring safety performance.

The System-Wide Safety project has begun an approach to the systematic evaluation of risks and the evolving development and application of IASMS functionality within the context of the SMS steps and the broader AAM system architecture development effort [13]. System modeling and analysis will give the ability to effectively assess to what extent today's SMS can be automated to meet the needs of the future NAS as the presence of increasingly autonomous systems continues to rise.

II. Part 135 Operations

With 1,889 carriers certified under Part 135 using over 11,200 total aircraft (fixed-wing and rotorcraft), there is a wide disparity in the scope of operations under Part 135. For example, approximately 30% of Part 135 operators are categorized as Single Pilot and are limited to using only one pilot for all operations. By contrast, a Standard Part 135 operator can have an unlimited number of pilots and the largest has over 2,000 pilots. Also, over 700 Part 135 operators have a single aircraft on their certificate and the top 1% of Part 135 operators have 24.6% of all aircraft [3].

NTSB aviation accident statistics provide an important perspective on accident rates and accident and fatality counts as shown in Table I [14]. An aviation accident according to the NTSB Form 6120.1 definition "means an occurrence associated with the operation of an aircraft that takes place between the time any person boards the aircraft with the intention of flight and all such persons have disembarked, and in which any person suffers death, or serious injury, or in which the aircraft receives substantial damage. For purposes of this form, the definition of "aircraft accident" includes "unmanned aircraft accident," as defined at 49 CFR 830.2" [15]. Using NTSB data that are averages per year and converting that to averages across 2001 through 2020, Part 135 commuter and on-demand operators had similar accident rates per 100,000 flight hours and both were higher than Part 121 operators having scheduled and nonscheduled service. NTSB data for Part 121 excluded 2001 for this comparison since that data included the September 11, 2001, terrorist acts which skew that data. Also, NTSB did not report total flight hours for Part 135 on-demand operators for 2011 and so the accident rate per 100,000 flight hours was not provided, and those averages exclude missing data. Together these data pose that while there are fewer flight hours for commuter and on-demand flights, with these flights involving aircraft and helicopters having fewer seats to carry passengers, there is a higher risk of an accident.

TABLE I. Average Accident Statistics for Parts 135 and 121

Operator	Accidents per 100,000 Flight Hours	Average Flight Hours	Average of All Accidents (Min/Max)	Average of All Fatalities (Min/Max)
Part 135 Commuter (Table 8)	1.53	325,481	4.9 (2/9)	1.9 (0/13)
Part 135 On-Demand (Table 9)	1.46	3,403,277	48.9 (29/73)	30.5 (12/69)
Part 121 (Table 5)	0.18	17,911,713	32.0 (14/54)	9.5 (0/52)

III. Part 135 Safety Challenges

The SMSVP is predicated on the FAA SMS guidance for Part 121 commercial air carriers [16]. FAA is developing proposed rulemaking requiring SMS for Part 135 operators and industry. Concerns include that the new regulation could disrupt existing safety measures and cultures, and how the regulation would scale for different operators. FAA guidance for Part 121 SMS addresses scalability to allow operators to integrate safety management practices into their individual business models. Scalability corresponds with the size and complexity of the operations to be covered, volume of data available, the size of the employee workforce, and the resources needed to manage the organization. This guidance tailors SMS for small, medium, and large carriers for each of the four SMS pillars of Safety Policy, Safety Risk Management, Safety Assurance, and Safety Promotion.

NTSB identified two aviation safety challenges applicable to Part 135 in its 2021-2022 Most Wanted List [4]. First, NTSB recommended FAA require and verify the effectiveness of SMS in all revenue passenger-carrying operations and creating a safety culture making safety a top priority. Second, NTSB recommended that passenger-carrying commercial aircraft, such as charter planes and air tours, should be equipped with data, audio, and video recording devices noting that Part 121 commercial airliners are already required to have digital flight data recorders (DFDR) and cockpit voice recorders (CVR). Part 135 operators should analyze the data derived from these devices to evaluate crew actions and prevent crashes.

Although exceptions exist for older aircraft, in general Part 135 aircraft with 20 or more passenger seats are required to be equipped with DFDR (14 CFR § 135.152 Flight data recorders). In addition, aircraft with 6 or more passenger seats that require 2 pilots are required to be equipped with CVR systems (14 CFR § 135.151 Cockpit voice recorders). Helicopter Air Ambulance operators are required to have Flight Data Monitoring Systems (FDMS) (14 CFR § 135.607 Flight Data Monitoring System) but there is no requirement to analyze the data nor is there a requirement that the FDMS be built to withstand a crash as is the case with DFDR and CVR. DFDR and CVR data could be analyzed as part of the FAA Part 135 SMSVP such as through the Flight Operational Quality Assurance (FOQA) program.

Part 135 operators are supported by different industry groups that promote safety and provide safety services. The Flight Safety Foundation supports development of safety standards and dissemination of safety information including to the business aviation community.

NBAA identified top safety focus areas, grouped into three areas, to facilitate safety-enhancing communications and activities within flight departments and among owner-flown operations [17]. The areas and risks consisted of the following.

- Address preventable accidents involving risks of loss of control in-flight, runway excursions, controlled flight into terrain (CFIT), and ground operations and maintenance accidents.
- Engage unique operational concerns involving flight crew and maintenance operations proficiency, single-pilot accident rate, procedural non-compliance, and fitness for duty.
- Identify and implement mitigation strategies involving SMS implementation, safety manager qualification and training, increase the use and sharing of human-reported and automated safety data, and foundations for safety including professionalism, safety leadership, technical excellence, and daily risk management.

NBAA's Small Flight Department Safety Guide, "Pathway to Improving Safety Guide" provides guidance for small flight departments identifying steps for improving the safety of their operation and this guidance is seen as a way toward establishing a fully operational SMS [18]. The NBAA links with the International Standard for Business Aircraft Operations (IS-BAO™) zto help operators apply industry best practices for safety-related policies, processes and procedures [19].

The Air Charter Safety Foundation (ACSF), comprised of air ambulance companies, air tour operators, and others, provides SMS information and tools including serving as a third-party manager of Aviation Safety Action Programs (ASAP) used by members [20]. ASAP provides for pilots and other employees to voluntarily report safety issues and events with the data managed by the company itself such as by a safety department. Analysis of patterns in the reports could identify systemic problems for which corrective action is needed.

At one point in time, the ACSF ASAP program held 7,000 safety reports and more than 90 percent were considered sole source meaning the safety events would not have been disclosed without ASAP [21]. Sharing ASAP information among members enables learning from the experiences of other members without incurring the operational costs associated with the safety events. The Foundation also supports members in conducting safety risk assessments, monitoring fatigue, and evaluating safety culture.

FAA developed AC 120-66, "Aviation Safety Action Program," to provide guidance for ASAP development, implementation, acceptance, and operation [22]. This guidance addresses use of ASAP safety data, much of which would otherwise be unobtainable, to develop corrective actions for identified safety concerns, and to educate the appropriate parties to prevent a recurrence of the same type of safety event. The guidance identifies third-party facilitators including ACSF, the Medallion Foundation, the Web-Based Analytical Technology for Aviation Safety, Inc. (WBAT-FAS), and Universal Technical Resource Services, Inc. (UTRS).

Similar to ASAP, the Aviation Safety Reporting System (ASRS) developed by NASA is for pilots and other aviation professionals to voluntarily submit confidential aviation safety reports [23]. ASRS data are de-identified to protect confidentiality and analysis identifies global systemic issues since the level of detail constrains analysis of specific systems and processes. ASRS was developed and continues to be managed by NASA as an outside third-party.

One example of an ASRS report set from pilots operating under Part 135 involved inflight weather encounters [24]:

- First Officer of a Beechjet 400 air taxi reported the aircraft weather radar failed in heavy weather involving extreme precipitation and severe turbulence and the flight crew elected to divert to a precautionary landing.
- Flight crew reported a loss of aircraft control involving an immediate 4000+ ft. per minute drop in altitude in severe turbulence after being vectored into a cloud.

An ASRS report set on Cockpit Resource Management (CRM) issues by pilots operating under Part 135 included the following [25]:

- Flight crew operating an Embraer ERJ 135 ER/LR reported that during arrival into Burbank airport they had experienced a Traffic Alert and Collision Avoidance System (TCAS) Resolution Advisory (RA) to descend, followed by an air traffic control (ATC) instruction to climb that they could not comply with, and later had a terrain warning caused by passing over a mountain peak at a high rate of descent.
- First Officer of a Learjet 60 air taxi flying into Aspen reported receiving multiple ATC altitude alerts during a cleared instrument approach and having full visual contact with all terrain but lost visual with the airport due to a cloud layer. This is considered a communication breakdown with ATC and in part, CRM regarding the intentions to execute a visual approach.
- Captain of a Learjet 60 corporate operator reported a critical ground conflict during takeoff roll with a runway incursion aircraft taxiing across the far end of the departure runway.

An ASRS report set on CFIT issues reported by pilots operating under Part 135 included a flight crew report of a CFIT event during approach to Chattanooga airport involving the crew selecting 3,100 rather than the cleared altitude of 3,600 feet. ATC announced the terrain alert, and the crew took evasive action by climbing [26].

An ASRS report set on commuter and corporate flight crew fatigue issues by pilots operating under Part 135 identified a range of human factors concerns including flying at the end of a long duty day (preceded by multiple long duty days), reduced staffing due to the Covid crisis, dehydration, and lack of nutrition [27]. Operational considerations included planning an aggressive landing while fatigued, flying an area navigation (RNAV) approach that was not authorized at night, and entering instrument meteorological conditions IMC) while on a visual flight rules (VFR) flight plan.

IV. Safety Intelligence

Safety Intelligence represent the goals, policy, procedures, and processes used by an organization to ensure safety management and continuous learning are part of everyday operations. Safety intelligence is construed to be comprised of three areas of safety emphasis, as shown in Figure 1.

The traditional safety management approach can be characterized as reactive safety that focuses on the absence of safety [28, 29]. The organization through forensic investigation identifies the causal factors leading up to an accident and ensures controls are present to prevent their reoccurrence. The organization learns what went wrong but this learning is limited to the number of accidents that occur.

While it is important to continue to learn from what goes wrong, it is increasingly important to learn from what goes right as proactive safety, which reflects an organizational goal of continuous learning. In other words, data from everyday operations are needed for analytics to assess what goes right such as in terms of a flight crew mitigating a risk that might otherwise would have evolved into a critical safety problem or accident. Analytics could diagnose precursors and provide prognosis based on leading indicators. For example, analytics could identify potential drift in operational practices away from nominal procedures and training. Proactive safety contributes to safety intelligence through a safety culture that recognizes the professional work and operational effectiveness for ensuring safety of flight.

Predictive safety is another key part of safety intelligence. Using machine learning with data analytics, underlying relationships can be uncovered such as from being hidden due to complexity, masked by other factors, or emergent as a new risk. Continuous learning can leverage analytics including modeling human performance. The intent from predictive analytics is to provide actionable safety data for use by organization safety boards and executives.

Learning from all operations involves different methods and practices including systematic observation of work activities, event investigations, and employee surveys [30]. Learning from all operations ties together information and data coming from SMS operational safety assurance to identify potential changes in design necessary for ensuring effective controls as part of safety risk management. Notionally there is a space between the safety control envelope (e.g., operational or engineering design limit) and the safety prevention envelope (e.g., procedural limit) [31]. This space can be used for recovery from a situation trending away from nominal operation. Learning from all operations would be integrated as part of a continuous learning organization.

V. SMS Methods for Part 121

SMS guidance for Part 121 commercial air carriers is provided in FAA Advisory Circular (AC) 120-92B and a carrier

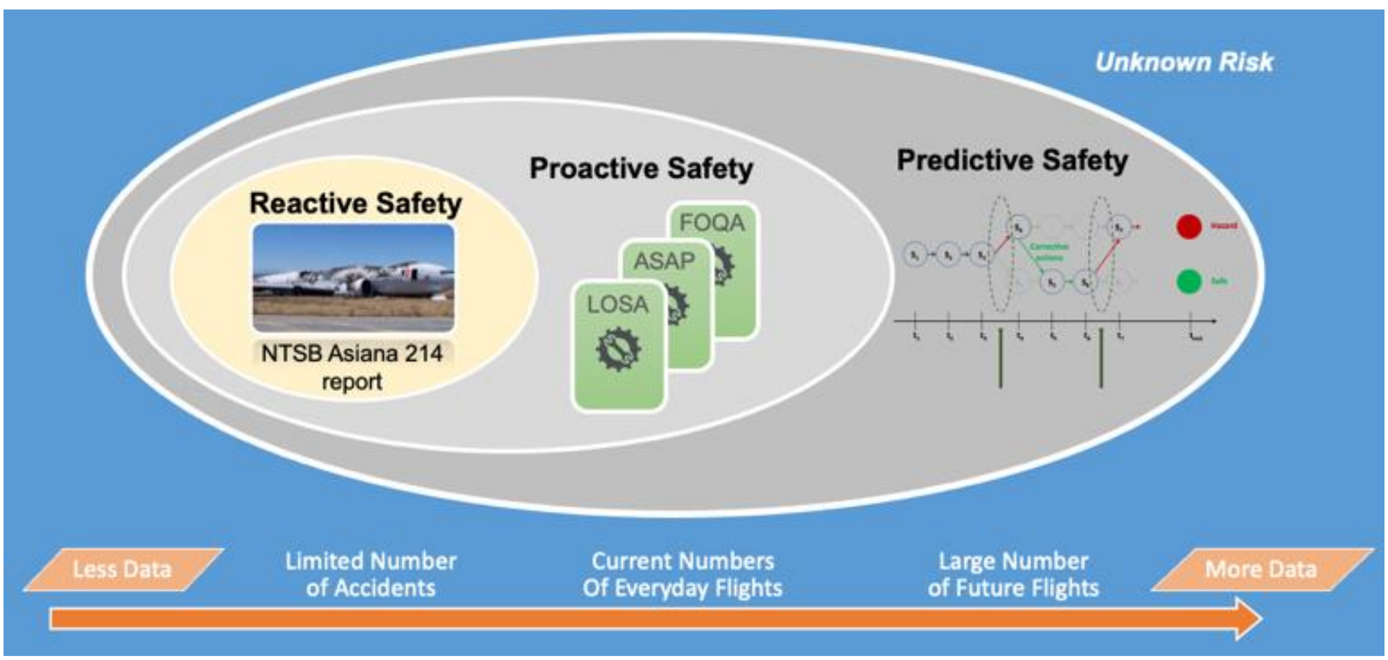

Fig. 1. Areas of Safety Intelligence.

can devise other method(s) to show means of compliance [16]. In addition to ASAP and ASRS previously described, other SMS methods are as follows.

- Line Operations Safety Audit (LOSA) involves pilots, as qualified observers, who ride in the flight deck or cockpit, to observe and record safety-related data such as pilot performance, airspace complexities, ATC communications, and weather and visibility conditions. LOSA uses the Threat and Error Management (TEM) taxonomy to classify observations and safety issues about flight operations, human errors, and unsafe conditions and how they were handled.
- Advanced Qualification Program (AQP) is used by the pilot training department and involves a data-driven quality control process for validating and maintaining the effectiveness of training curriculum content for pilots and dispatchers.
- Flight Operational Quality Assurance (FOQA) is another data-driven program involving collection of digital flight data. The data are downloaded from the aircraft post-flight for analysis. FAA AC 120-82, "Flight Operational Quality Assurance," provides guidance for FOQA program development, acceptance, and operation [32].
- Internal Evaluation Program (IEP) is a safety process comprised of inspections and audits of managerial controls. The IEP promotes increased awareness by managers and employees for following company safety practices and regulatory requirements.
- Continuing Analysis and Surveillance System (CASS) is a quality assurance system for the company's Continuous Airworthiness Maintenance Program (CAMP).

Many of the SMS methods described in AC 120-92B are labor intensive and rely heavily on humans to implement. These methods must adapt to scale with the increasing complexity foreseen with transformation of the NAS in coming years. As NAS operations are projected to exponentially grow from today's 45,000 daily operations to over a million daily by 2041, the need to automate and move towards a more proactive and predictive SMS becomes increasingly necessary [33, 34]. The challenge, however, is to find the appropriate levels of SMS automation for various operational scenarios. Research to model the SMS and augment it with new capabilities that leverage increasing levels of automation is currently underway. (See Section VII for more.)

VI. Aviation Safety Information Analysis and Sharing (ASIAS) Program

The ASIAS program involves the sharing of safety data and information collected by SMS methods used by Part 121 commercial air carriers and voluntarily by some Part 135 stakeholders. ASIAS has a governance structure and processes necessary to establish and maintain collaborative relationships with the aviation community [35]. The ASIAS infrastructure and its data mining tools enable deep dives in analyzing targeted risks based on multiple data sources. The data sources currently provided by airlines consist of FOQA and ASAP. Aircraft operators provide digital flight data sourced from flight data monitoring (FDM) and General Aviation Airborne Recording Device (GAARD). The FAA ATC organization provides voluntary ATC safety reports that are part of the Air Traffic Safety Action Program (ATSAP), Mandatory Occurrence Reports (MOR) from controllers, ATC voice data from controller/pilot communications, surveillance digital flight data, weather (including from the National Oceanic and Atmospheric Administration) involving Meteorological Aerodrome Reports (METARs), and NAS aeronautical information from the National Flight Data Center (NFDC).

ASIAS intends to evolve from a reactive, forensic investigation approach assessing causal factors associated with identified risks of incidents and concerns necessary for understanding and preventing their reoccurrence to a diagnostic/prognostic approach for predicting and mitigating risk occurrence. ASIAS accomplishes this by aggregating and fusing data across carriers. Trends can be assessed over time to see how certain rare events when combined could be indicative of systemic problems and identify emerging safety issues that may otherwise be undetectable based on data from sources at individual carriers.

While ASIAS collects and analyzes pilot ASAP and air traffic controller ATSAP data, the FAA ATC organization directly shares safety information through the Confidential Information Sharing Program (CISP) [36]. CISP has agreements with 29 partners including cargo operators, air carriers, charter companies, and dispatchers. Results from CISP take different forms. ATSAP publishes CISP Discussion Sheets providing information for controllers such as when the flight crew is experiencing task saturation during critical stages of flight so that nonessential communications and instructions should be minimized, and the miscommunication when a flight crew does not include their call sign as part of their read back to the controller. CISP information is used for national formal Corrective Action Requests to resolve an identified concern when it becomes unlikely that identified safety issues will (or should) be resolved informally, as well as many informal corrections accomplished through sharing of information such as chart publication changes and Notice to Airmen (NOTAM) information and dissemination.

VII. Part 135 In-time Safety Needs Analysis

Beyond the previously discussed FAA proposed rulemaking requiring SMS for Part 135 operators and industry, there remains the need for in-time safety risk mitigation across the NAS. To provide sustainability for the NAS with its increasing diversity, complexity, density and volume of operations, higher levels of automation will be required to support the system goals of safety, efficiency, throughput, capacity, and individual operator business goals.

The need for in-time safety risk mitigation necessitates proactive and predictive SMS with adopting machine learning for predictive analytics and advanced data mining. In-time safety can build upon existing information technology architectures for increased access to data and tools to improve system agility and responsiveness.

Barriers to today's safety management are that it is not quickly responsive to identifying and mitigating operational risk in-time; labor-intensive for operators, pilots, data analysts, safety managers/executives, and others; and does not readily scale relative to the complexity of operations such as considering the volume of air traffic, airspace and weather, aircraft capabilities, and contingency management.

In addition, the public historically has had a low tolerance for aviation accidents and fatalities even though aviation is one of the safest modes of transportation. For example, in 2020, the Bureau of Transportation Statistics showed 349 aviation fatalities (Part 121 none, Part 135 commuter air carriers had 5 fatalities, Part 135 on-demand air taxis had 21, and all operations other than those operating under Parts 121 and 135 had 332) compared with 38,824 highway fatalities and 902 railroad fatalities [37].

Part of the public's low tolerance of aviation accidents and fatalities is based on the cost of human life. This cost is factored into analysis for rule-making and regulatory decisions. The United States Department of Transportation estimated the economic value of statistical life (VSL) for 2020 to be $11.6 million [38, 39].

The importance of overcoming these barriers is highlighted by analysis of Part 135 accidents that demonstrate the need for improved safety management in design safety risk management and operational safety assurance.

For example, the 2020 helicopter crash near Calabasas, California resulted in nine fatalities including basketball star Kobe Bryant, his daughter, and the pilot. According to the NTSB, the pilot made a "poor decision" to fly at "excessive airspeed" into an area of poor visibility and lost visual contact with the ground. The NTSB said the charter company could use better risk management tools to make decisions about whether to fly, better train pilots on how to get out of disorienting conditions when there is a sudden loss of visibility, and improve its safety culture [40].

IASMS would provide better pre-flight planning tools and in-flight modeling predicting adverse flight conditions, trajectory advisories to the pilot and air traffic controller based on predictive modeling (e.g., safety margin), and identify charter company changes to training and safety culture to use this new safety intelligence.

On May 13, 2019, two aircraft collided in midair while on sightseeing flights near Ketchikan, Alaska. The accident resulted in 6 fatalities, 9 serious injuries, and 1 minor injury. Both aircraft were operated as on-demand charters under the FAA's Part 135 rule. One of the operators was classified as Single-pilot operation while the other was classified as a Standard Part 135 operation. The NTSB determined the probable cause as "the inherent limitations of the see-and-avoid concept, which prevented the two pilots from seeing the other airplane before the collision, and the absence of visual and aural alerts from both airplanes' traffic display systems, while operating in a geographic area with a high concentration of air tour activity." Although both aircraft were equipped with ADS-B transceivers which could have alerted the pilots to the other aircraft's proximity, the systems were not configured properly to provide visual and aural alerts. The surviving pilot stated that he did not understand the functioning of the ADS-B avionics which had been modified in 2015 [41].

Neither operator had implemented a Safety Management System (SMS) at the time of the accident. A key component of safety risk management includes a system analysis when new systems or procedures are introduced. According to the NTSB "it is possible that a system analysis of the new equipment would have identified the loss of the traffic alerting capability in the flight manual supplement. If this change had been identified, the company could have evaluated the potential increase in risk associated with the removal of this safety protection and considered strategies for mitigating the increased risk of a midair collision introduced by this change."

On January 29, 2019, an air ambulance helicopter collided with the ground near Zaleski, OH resulting in 3 fatalities. The helicopter was operated as an on-demand air ambulance under the FAA's Part 135 rule and classified as a Standard Part 135 operation. The NTSB determined the probable cause as "inadequate management of safety, which normalized pilots' and operations control specialists' noncompliance with risk analysis procedures and resulted in the initiation of the flight without a comprehensive preflight weather evaluation, leading to the pilot's inadvertent encounter with instrument meteorological conditions, failure to maintain altitude, and subsequent collision with terrain." The pilot of the helicopter failed to complete a pre-flight risk assessment as required by the regulations and the helicopter operator had no SMS in place [42].

Current and former employees of the air ambulance operator confirmed during the investigation that pilots were not comfortable reporting safety issues. The NTSB emphasized that actions such as completion of the pre-flight checklist are inadequate without a positive safety culture and an SMS program is an effective way to establish and reinforce a positive safety culture and to identify deviations from established procedures.

Safety Culture is a foundational element of an SMS. An effective safety culture is "the product of actions of the organizations leadership as well as the results of the organization learning." Developing a positive safety culture "takes time, practice and repetition, the appropriate attitude, a cohesive approach, and constant coaching from involved mentors." [16] Despite the effort involved, developing a positive safety culture is, according to ICAO's Safety Management Manual Document 9859, "arguably the single most important influence on the management of safety" [43]. This time commitment often creates hesitancy among small operators to develop an SMS. However, small operators are better able to create a positive safety culture as they are less likely to have bureaucratic management layers. "What costs money is not safety, but bad safety management" [44].

Part 135 operations in Alaska face unique safety management challenges due to uncontrolled airspace and adverse weather conditions and underscored by a high accident rate. With 303 Part 135 certificate holders in Alaska, just 8 (3%) participate in the FAA voluntary SMS program. ADS-B provides significant benefits including traffic avoidance, terrain awareness, and weather monitoring [45].

VIII. IASMS for Part 135 Operators

The IASMS ConOps provides for the timely and assured means of monitoring, assessing, and mitigating operational risk and is intended to scale between small and large operators. The IASMS ConOps bridges risk management and safety assurance to quickly manage known operational risks, identify unknown risks, and inform design for system improvements. IASMS accomplishes risk management and safety assurance through key functions of monitoring different data sources to identify risk, assess that data to understand known and emergent patterns, and determine appropriate risk mitigations, as shown in Figure 2. Just as use of SMS methods scales with the size of the operator, the IASMS would scale with increasing complexity of the operation to provide in-time risk mitigation and safety assurance.

The three IASMS functions of Monitor, Assess, and Mitigate correspond to FAA SMS guidance for safety risk management and safety assurance, as shown in Figure 3 [16].

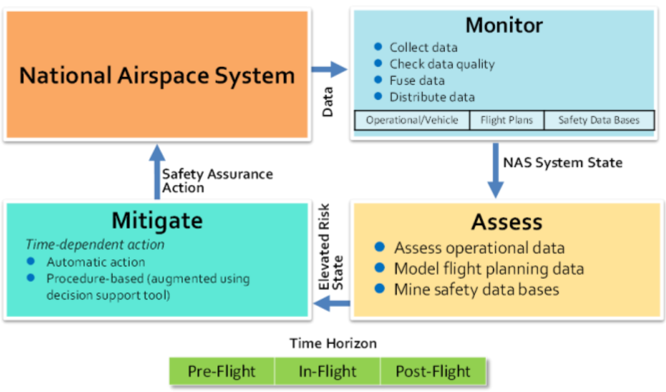

Fig 2. Relationships of IASMS functions.

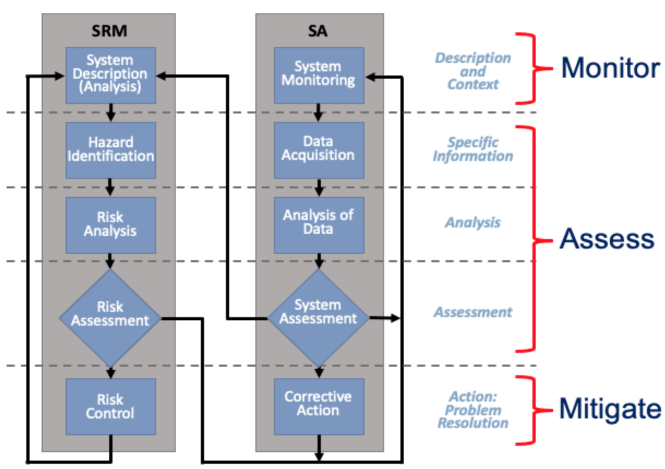

Fig 3. IASMS functions related to FAA SMS guidance (adapted from (from AC 120-92B, Figure 2.1).

The Monitor function continuously collects data from existing and non-traditional data sources across all phases of flight and fuses the data into new and existing safety databases. The Assess function uses multi-risk safety prognostics and predictive risk assessment with machine learning to identify anomalies, precursors, and trends as well as emergent risks. The Mitigate function intends to operationally prevent, trap, or eliminate threats and hazardous states during pre-flight or in-flight, and identifies re-design of risk controls that are ineffective, incomplete, or missing.

The in-time responsiveness provided by IASMS enables timely monitoring and detecting of safety risks. This responsiveness would be enabled by an architecture and SFCs designed to monitor, assess, and mitigate safety critical operations and exceedances such as those associated with the NBAA top safety focus areas. Considerations include provision of digital twin architectures for increased sustainability and reliability during operations. A data exchange architecture involves alignment with the FAA System-Wide Information Management (SWIM) data pipeline. SWIM involves a service-oriented architecture with an enterprise infrastructure necessary for NAS systems to share and reuse information and increase interoperability.

IX. System Architecture for Part 135 Operations With IASMS

The notional integrated system architecture for the current NAS including Part 135 is shown in Figure 4. The architecture represents the integration of IASMS safety services with the vehicle (aircraft) and operations, and with proactive and post-flight services managed by individual operators and with industry sharing data and analysis across multiple operators. IASMS safety services could be scaled for different operators and their safety business cases. FAA System Wide Information Management (SWIM) enables the sharing of information between diverse systems through a service-oriented architecture to publish information of interest to NAS users and request and receive information from other NAS services. The ASIAS 3.0 ConOps identified industry flight data vendors and cloud services as channels for FOQA and ASAP data [35].

In a transformed NAS, IASMS predictive safety services could use sophisticated data mining tools and machine learning to identify exceedances and other indicators of anomalies, precursors, and trends as well as emergent risks previously unknown. Predictive safety services could be scaled at the operator and industry levels to access new and existing data sources.

IASMS safety services use SFCs for monitoring, assessing, and mitigating risk. These SFCs involve classes of information decomposed into different data parameters, such as shown in Table II [46].

TABLE II. Example Information Classes and Data Parameters

Information Class	Parameters
Aircraft State	Position (latitude, longitude, altitude) Attitude (pitch, roll, yaw) Heading Track Airspeed Groundspeed Vertical speed Acceleration (x, y, z) Flight-critical systems states (includes auto-pilot mode)

Air Traffic	Identification and location reports (e.g., ADS-B or radar-based) Intended flight plan Schedule information (e.g., departure/arrival and waypoint slot times) Air traffic-related constraints (e.g., procedures and restrictions) Air traffic-relate warnings (e.g., from ATC)
Airspace Conformance	Authorizations Airspace-related warnings ATC Communications
Flight Plan	Flight plan waypoints (including estimated time of arrival or airspeed at waypoints) Flight plan mode changes Takeoff and landing information (e.g., descent and climb rates)

X. Data Analytics

Some Part 135 operators could obtain and review basic ATC radar, voice, and weather recorded data provided through internet service providers on a routine basis or in association with particular trips when there would be a safety concern. These data could provide important perspective with regard to threats external to the aircraft as well as possible errors made by the pilot in aircraft and airspace operations.

In a study of pilots flying in a Learjet 60 fleet within a FAA aviation system standards office operating under Part 135, a time series analysis of FOQA event rates was used to assess whether quarterly reports providing feedback to pilots, as a cost-effective intervention method, could result in significant safety benefits. Results showed that feedback provided to pilots through quarterly reports produced significant reductions in exceedance rates over the course of the program although pilots showed some ambivalence toward FOQA between the value and risks of the program. While the fleet office monitored approximately 53 unique FOQA events, analysis was limited to two of the most prevalent exceedances consisting of Rate of Descent High (400-1200 feet AGL) and Speed High Below 10,000 feet. [47]. IASMS SFCs could in-time monitor, assess, and mitigate exceedances for Part 135 pilots.

Data analytics will scale corresponding with complexity, accuracy, and amount of available data. Today much of this data analysis occurs in silos based on sourcing constraints. The challenges include integrating data across these silos that would enable better assessment of time series data for trends and building safety intelligence. IASMS innovations with safety intelligence will enable achieving future aerospace visions and accelerate digital transformation with machine learning and artificial intelligence.

Data analytics today reflect both reactive and proactive/prognostic safety. Causal factors of accidents are typically analyzed using different taxonomies to characterize why and how they occurred. Recommendations such as from the NTSB target these causal factors to prevent or reduce their re-occurrence leading to further accidents. Similarly, pilot reports filed with ASRS are analyzed with associated taxonomies. These data are analyzed for higher-level trends although there is no baseline against which to make comparisons.

Aircraft equipage is a key enabler for what data could be collected such as through FDM or FOQA. With such data flowing into a data store like ASIAS, predictive analytics and

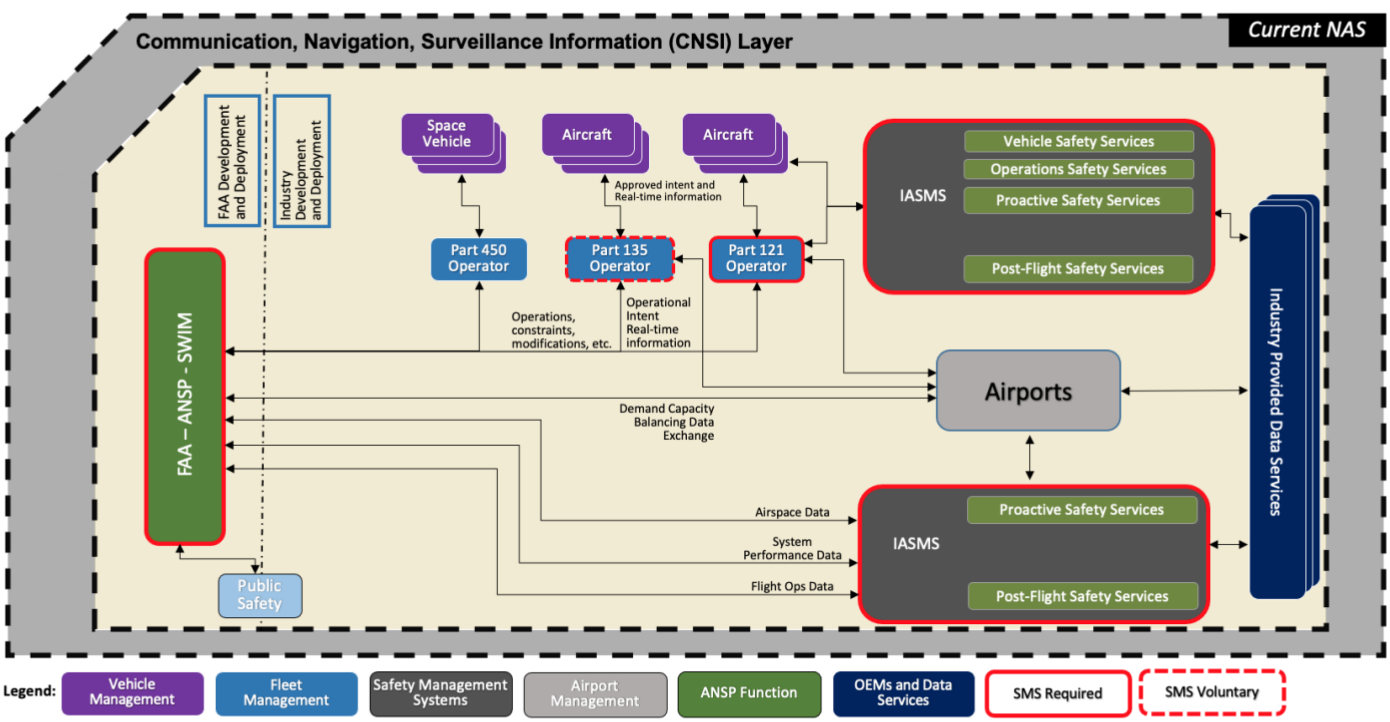

Fig 4. Notional integrated system architecture of the current NAS.

machine learning could provide increased understanding and insight into safety risk management with efficacy of risk controls and safety assurance for identifying hidden or emergent risk.

XI. IASMS Use Cases

Use cases provide a means to assess and gain increased understanding and insight into how an IASMS would be integrated into the design and operation of Part 135 aircraft. Detailed use cases identify information requirements associated with risk management services. These scenarios capture the diversity and complexity in the operational environments that the industry is currently facing and will be challenged with in the future NAS [48].

Use cases could represent pilot, data analyst, and other viewpoints. Use cases would scale with small to large operators, and show that some operators may use third-party providers for SMS services. Use cases would identify IASMS design considerations relative to architecture and SFCs to monitor, assess, and mitigate risk based on reactive, proactive, and predictive safety systems [13]. Use cases could involve different types of data and data sources. Design of data analytics could scale with the volume and complexity of data sets. Aggregation of data sets could enable use of complex algorithms and machine learning to identify and assess known risks, off-nominal conditions, exceedances, and other flights of interest. This proactive and predictive approach could improve safety intelligence beyond identifying causal factors of accidents as done today.

One approach for identifying use cases to drive definition of SFCs reflects categorization of small airplane accidents [49]. Categories included accidents in which excessive speed might have contributed to structural failures, excessive airspeed on final, landing distance performance for wet and contaminated runways, and out-of-limits center of gravity. These categories can be mapped to information classes, previously discussed, to identify requisite SFCs for further specification.

Another approach is to define use cases based on particular future operations missions. For example, an IASMS use case involving an emergency medical drone delivering a defibrillator can be characterized from the information classes previously discussed. Conditions which create an unacceptable risk would require additional services to mitigate [48].

XII. Conclusions

As the NAS transforms with Part 135 and other traditional operations being integrated with AAM, IASMS enables improvements for managing and assuring safety for the transportation of passengers and cargo. The National Academies recommended development of an IASMS ConOps to secure a safe future NAS. The innovations posed by IASMS provide for in-time responsiveness to risk with more efficient use of people in all aspects of safety monitoring, assessment, and risk mitigation as the NAS scales with increasing traffic and airspace complexity. With reactive safety that focuses on determining the causal factors of accidents to prevent reoccurrence, the continuous learning viewpoint adds proactive learning to recognize the important contributions of humans in everyday operations and to understand how risks are mitigated in normal operations with safety culture supporting continuous learning. Predictive analytics and machine learning leverage diverse data types and large datasets provided by multiple operators to identify precursors, anomalies, and trends that may be difficult to discern by a single operator using its own data. While Part 135 operators are currently not required to have a formal SMS, FAA is expected to be issuing new rules mandating SMS for Part 135.

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