Research Landscape

for the

National Airspace System

2020 – 2030

Contents

Introduction

The mission of the Federal Aviation Administration (FAA) is to provide the safest, most efficient aerospace system in the world. The FAA continually strives to make aviation safer and more efficient through global leadership while delivering user benefits through technology and innovation. Innovations such as autonomous vehicles, space travel, urban air mobility, and other emerging technologies require the FAA to continually explore industry goals and objectives to remain vigilant of the continual changes and growth possible in the NAS.

Therefore, research and development (R&D) must be an ongoing part of FAA's core responsibilities as it helps the FAA understand how to respond to new technologies, new business models, and the changing needs of system users. This research will help the FAA to understand and prepare for the regulatory, safety, and traffic management impacts that will accompany the integration of these new technologies into the NAS.

The *National Aviation Research Plan* (NARP) is the FAA's performance-based plan addressing near, mid, and far term research needs of the aviation community. In order to appropriately develop that plan, the FAA needs to look beyond today's challenges to prepare for those of tomorrow. The FAA has developed this research landscape to illustrate industry objectives and operational drivers in the next 10 years and highlight industry initiatives that the FAA should be aware of. The intent of this report is to describe emerging technologies and the challenges that they may present to the aviation industry over the next decade, from a high-level perspective, which may then be used later to identify specific research questions or priorities. The descriptions of the drivers are shaded to indicate the expected time to maturity: dark blue for near-term (0-3 years), medium blue for mid-term (3-5 years), and light blue for far-term (5-10 years).

This landscape will inform the research planning discussion by taking a strategic look at what will be driving the research needs facing the FAA and the larger community. This will prepare the FAA for how the industry may evolve over the coming decade. This landscape should not be interpreted as a static set of research drivers, but rather as an evolving list that will continue to grow and adapt as future technologies and research needs are refined. By creating this landscape of research drivers, the FAA can identify areas requiring engagement with industry and facilitate early involvement to ensure that the FAA is prepared to support progress at the pace of industry and respond as an equal partner in furthering innovation.

Identifying and Vetting Research Drivers

A "research driver" is defined as any external force or motivation that stimulates R&D investment. Drivers describe broad concepts encompassing multiple characteristics or potential impact areas but are also specific enough to describe a tangible concept with a unique definition. The drivers in this list are not mutually exclusive, but instead are intended to cover a breadth of technologies, emerging issues, and global political or societal influences that could potentially require the FAA to respond with research.

A preliminary list of research drivers was compiled by talking with subject matter experts, and by reviewing a number of source documents describing future aviation or technical trends and strategies. These source documents included such publications as the *FAA Strategic Initiatives* [1], the *U.S. Department of*

Transportation Strategic Plan for FY 2018-2022 [2], and the FAA's 2016 *The Future of the NAS* [3]. A complete list of sources used may be found in the References section of this document.

In an effort to determine the industry perspective of future research areas related to these drivers, the FAA sought input from the Research, Engineering and Development Advisory Committee (REDAC), an advisory group established in 1989 to provide advice and recommendations on the needs, objectives, and content of the FAA's aviation research portfolio. Through its five subcommittees, the REDAC considers aviation research needs in the following areas:

- Airport Technology
- Aviation Safety
- Environment and Energy
- Human Factors
- NAS Operations

Each REDAC subcommittee was requested to review the initial list of research drivers, focusing on them through the perspective of their particular area of expertise. Members provided their assessment of what the expected impacts would be on the FAA's mission, and the time frame in which these impacts would most-likely occur. Committee members were also encouraged to add to the initial list of research drivers, or to suggest modifications where needed. Inputs from the REDAC were collected and synthesized to determine the challenges each driver may pose as well as their predicted time to maturity from the industry's perspective.

Viewing the Research Landscape

The following pages contain descriptions of each identified research driver and a list of anticipated challenges that may be addressed through R&D in the future. The drivers have been grouped into the following categories:

- Advances in New Vehicles and New Missions
  - Non-Traditional NAS Access Points
  - Routine Small Unmanned Aircraft Systems (UAS) Operations Beyond Visual Line of Sight (BVLOS)
  - Space Operations
  - Autonomous Ground Service Equipment at Airports
  - Growth of Mixed Operations (Piloted, Autonomous, Unmanned)
  - New Mission Types
  - Supersonic Flight
  - Urban Air Mobility
- Advances in Technology and Materials
  - Aircraft Command and Control Using Automation and Remote Sensing Technologies
  - Certification using New Technologies, Standards, or Processes
  - Future Fuel Technologies
  - Infrastructure Resiliency and Continuity of Operations
  - New Medical Technologies and New Medications
  - New Vehicles or Components Which Make Use of New Technologies, Software, or Materials
  - Position, Navigation, & Timing (PNT) Technologies
  - Remote and Virtual Technologies
  - New Technologies for Airport Pavement Infrastructure and Design
  - Advances in Electric or Hybrid Electric Propulsion
- Advances in Data and Processing Power
  - Big Data Analytics and Techniques
  - Crowd Sourcing Weather Data
  - Increased Connectivity by Cyber-Physical Systems (Internet of Things [IoT])
  - Information Assurance and Cybersecurity for All Operations
  - Risk-Based Decision-Making Techniques and Analytics
  - Artificial Intelligence (AI)
  - Human-Machine Teaming and New Technology Interfaces
- System Wide Advancements and Improvements
  - New Methods and Technologies (Air Traffic Safety, Efficiency, Noise, Emissions, Fuel Use, and Airport Surface Movements)
  - Methods for Increased Flexibility of Operators
  - Performance-Based Capabilities
  - Advancement of Global Standards or Requirements
  - Human Response to Traffic and Congestion Management
  - Development of the Workforce of the Future
  - Advances in Aeromedical Certification
  - Changing Public Demographics and Requirements

The Landscape

I. Advances in New Vehicles and New Missions

Based on private-sector development work that is already underway, the NAS could be challenged to safely accommodate a number of new vehicle types, or existing vehicles operating in non-traditional ways. These drivers will lead to regulatory and operational impacts such as changes to existing rules to enable and certify these operations, or to manage public and stakeholder trust of shifting certification responsibility to operators or manufacturers. New vehicles and missions will also have operational impacts such as incompatibility with incumbent operations or current airspace, route structures and airport designs. Increases in these operations could also lead to increases in noise including "visual noise" from operations like small UAS at lower altitudes near the general public.

The following are the research drivers identified in this category:

- Non-Traditional NAS Access Points (near-term)
- Routine Small UAS Operations BVLOS (near-term)
- Space Operations (near-term)
- Autonomous Ground Service Equipment at Airports (mid-term)
- Growth of Mixed Operations
  (Piloted, Autonomous, Unmanned) (mid-term)
- New Mission Types (mid-term)
- Supersonic Flight (mid-term)
- Urban Air Mobility (mid-term)

Non-Traditional NAS Access Points

Current air vehicles typically enter the NAS through airports, heliports, or more recently spaceports. However, as new entrants operations increase, vehicles such as urban air taxis, balloons, or space vehicles may be entering and exiting the airspace from locations other than conventional airport environments, such as vertiports, new spaceport locations, or even commercial buildings and offices.

Near Term

AIRPORT AND GROUND OPERATION CHALLENGES

- Interference with existing and traditional airport operations
- Integration and equitability of NAS resources
- Recovery of space launch vehicles or reusable launch vehicles

OPERATIONAL AND SAFETY CHALLENGES

- Air traffic management (ATM) monitoring of airspace capacity and demand
- Suitability of access points including emergency or contingency considerations
- Security risks associated with various access points
- Determining regulatory and oversight responsibilities

Routine Small UAS Operations BVLOS

Many future applications for UAS will require routine operations BVLOS. Enabling BVLOS operations creates a number of challenges to ensure safe operations, such as detecting and avoiding obstacles and other traffic and ensuring that control links are maintained over long distances.

Near Term

AIRPORT AND GROUND OPERATION CHALLENGES

- Impacts or conflicts with traditional airport operations
- Understanding on-airport applications

OPERATIONAL AND SAFETY CHALLENGES

- Standards for safe and efficient operations, including operations over people
- Understanding collision risk and impact
- Detect and avoid (DAA) technologies and standards
- Regulatory questions regarding the safety of cargo and package delivery operations
- Certification, standardization, and regulation of UAS traffic management (UTM) providers and UAS service suppliers (USS)
- Adequacy of spectrum and communication links

Space Operations

Industry and literature indicate that the number and type of space launches and reentries are expected to increase and may utilize new types of launch and reentry systems. Current research pertaining to separation standards between aircraft and space vehicles are focused mainly on non explosive phases of space vehicle operations, however, more advanced concepts could examine separation on launch and reentry vehicles from other aircraft based on separation standards as opposed to pure airspace restrictions [3]. Additionally, space tourism will present new mission types that may bring unique challenges affecting both passenger and crew.

Near Term

AIRPORT AND GROUND OPERATION CHALLENGES

- Spaceport design standards
- Standards for assessing the safety and efficiency impacts of proposed launch sites
- Standards and equipage requirements to ensure safe operations at spaceports co-located with airports, including airport rescue and firefighting (ARFF) requirements
- Airspace impacts on airport operations and airport design

OPERATIONAL AND SAFETY CHALLENGES

- Determining size and duration of launch or reentry hazard areas for efficient airspace utilization
- Traffic flow management strategies to ensure shared and equitable airspace use with increased launch frequency
- Aeromedical issues unique to space operations such as radiation impacts
- Impact analysis of increasing the number of commercial space operations
- Integrating orbital traffic management with launch management (i.e., ensuring the launch and reentry operations are not negatively impacted by objects already in orbit)

ENVIRONMENTAL CHALLENGES

- Standards to assess environmental impacts of space operations and proposed launch sites, such as noise, hazardous materials, and community impacts

Autonomous Ground Service Equipment at Airports

Autonomous or highly-automated vehicles are being developed for use on the airport surface to perform tasks such as aircraft tug operations and perimeter security. Understanding the implications of these new, driverless surface vehicles could require further research.

Mid-Term

AIRPORT AND GROUND OPERATION CHALLENGES

- Infrastructure or methods to support autonomous ground vehicle operations (e.g., navigation, charging, or fueling)
- Impact of weather conditions on ground service equipment
- Integrating autonomous ground vehicles with aircraft operating on or near the surface
- Foreign object debris (FOD) detection and abatement
- Communication and notifications to flight crews, air traffic control (ATC), ground handlers, and other ground vehicles of information such as destination or intent of vehicle movement
- Security and identification of autonomous vehicles
- Training and procedures for flight crews, including emergency or contingency situations
- Policy frameworks to manage liability, accountability, and responsibility in the event of accidents or incidents (e.g., runway incursions)

Growth of Mixed Operations (Piloted, Autonomous, Unmanned)

The integration challenges of mixed operations are expected to increase as operations by commercial space vehicles, UAS of various sizes, and high-altitude balloons continue to grow. Ensuring safe and efficient separation of air traffic becomes more challenging as vehicle operating profiles become more diverse beyond just aircraft equipage performance. The challenge of sharing the airspace will likely grow with the introduction of urban air taxis, autonomous passenger and cargo flights, and supersonic transports (SSTs).

Mid-Term

OPERATIONAL AND SAFETY CHALLENGES

- Integration of unmanned (e.g., remote-piloted, semi-autonomous, autonomous) and manned traffic, and accommodation of varying performance characteristics
- DAA criteria for all types of operations, including airport, terminal and low-altitude operations
- Defining or developing an appropriate NAS architecture to accommodate mixed operations
- Appropriate pilot training for the mixed operating environment
- Safety and security of information systems, both airborne and ground based
- Touch points and interoperability where unmanned traffic management and traditional ATM meet
- Procedures for off-nominal or contingency events

New Mission Types

Airspace above 60,000 feet creates a new frontier for air operations. New mission types in this airspace could include operations of longer or higher duration by traditional or non-traditional air vehicles. High Altitude Long Endurance (HALE) operations may create unique challenges when integrating with legacy traffic or other new entrants.

Mid-Term

AIRPORT AND GROUND OPERATION CHALLENGES

- Ensure that ARFF is adequate for new mission types
- Impact of air vehicle size and dimensions on airport design or launch platform design and certification standards

OPERATIONAL AND SAFETY CHALLENGES

- Changing/evolving pilot responsibility (e.g., single pilot or remotely piloted operations)
- Potential modifications to NAS infrastructure
- Determining how information is exchanged, collected and distributed with users and/or third parties
- ATM and space traffic management (STM) methods
- Human factors concerns for passengers or crew, including reduced redundancies and alternative contingency mitigation options

Supersonic Flight

Historically, supersonic aircraft were retired due to the costs of maintaining operations that met environmental noise restrictions as well as inefficient fuel consumption. However, more recently, a number of companies are actively working to develop quieter and more efficient Supersonic Transports (SSTs) for commercial use, which could become operational within the next several years. [6]

Mid-Term

AIRPORT AND GROUND OPERATION CHALLENGES

- Noise impacts (particularly during takeoff and landing)
- Airspace and airfield capacity due to special procedures or in-trail separations
- Compatibility with existing airfield facilities
  - Runway and taxiway dimensional requirements
  - Ground handling characteristics
  - Gate and parking position dimensional requirements
  - Compatibility with passenger loading bridges
  - Fueling requirements

OPERATIONAL AND SAFETY CHALLENGES

- Wake vortices and interactions with subsonic aircraft
- Performance characteristics of the proposed delta wing design
- New or modified certification standards for new technologies utilized on SSTs or with their operations
- Safety and medical issues related to:
  - Maintaining cabin pressurization at high altitudes
  - Potential impact of radiation on passengers and crew
  - Use of enhanced or synthetic vision for some phases of flight
- Human factors issues of how pilots will manage new control systems

ENVIRONMENTAL CHALLENGES

- Emissions impact during take-off and landing, but particularly at cruise at altitudes where emissions impact may be magnified
- Noise concerns in the airport, terminal, and en route environments
    - Design for quiet airport operations is contrary to the propulsion needs of supersonic aircraft
    - Sonic boom and flight noise mitigation, particularly in the transition between subsonic and supersonic flight and supersonic climb/cruise

Urban Air Mobility

A number of companies and their partners are currently performing research and prototyping concepts of "flying taxis", also referred to as on-demand aviation [7]. The concepts vary but overall characteristics are generally seen as vertically deployed vehicles with multi-rotor or tilt-rotor designs. The propulsion envisioned is a hybrid or all-electric motor that is designed to operate in urban settings. These operations are expected to be autonomous or highly-automated and operate from vertiports located in strategic urban transfer hubs under a multimodal approach.

Mid-Term

AIRPORT AND GROUND OPERATION CHALLENGES

- Vertiport design standards
- Impacts on traditional airport operations
- Vertiport rescue and ARFF requirements

OPERATIONAL AND SAFETY CHALLENGES

- New vehicle certification and their performance standards
- Electric or other alternative means of propulsion
- Spectrum requirements for control and reliability of commercial communications
- Pilot certification standards (in cases of human pilotage)
- Urban environment "micro-weather" prediction (localized weather caused by buildings)
- Changes to traffic management automation and procedures and non-applicability of the current FAA NAS architecture
- Human factors considerations around a reduced crew environment, decision support aids or technologies, distributed responsibility, human machine teaming, and passenger contingencies

ENVIRONMENTAL CHALLENGES

- Battery disposal from hybrid gas-electric propulsion systems
- Noise concerns including cumulative noise, "visual" noise, and perceived noise as well as defining effective noise metrics for noise measurement
- Electric and hybrid-electric energy use, amount of required reserves, and life-cycle cleanliness of power generation

II. Advances in Technology and Materials

In addition to new vehicles or new operational profiles, industry is also experimenting with cutting edge materials, manufacturing techniques, communications, fuels and propulsion systems. Integration of these technologies and materials into the NAS will require new criteria for validation, acceptance, or compliance with existing certification standards or regulations. Operationally, advancements to fuel technologies and electric propulsion create the potential to reduce emissions, which could ultimately allow increased operations while maintaining or reducing net carbon dioxide (CO_2) output.

The following are the research drivers identified in this category:

- Aircraft Command and Control Using Automation and Remote Sensing Technologies (near-term)
- Certification using New Technologies, Standards, or Processes (near-term)
- Future Fuel Technologies (near-term)
- Infrastructure Resiliency and Continuity of Operations (near-term)
- New Medical Technologies and New Medications (near-term)
- New Vehicles or Components Which Make Use of New Technologies, Software, or Materials (near-term)
- Position, Navigation, and Timing Technologies (near-term)
- Remote and Virtual Technologies (near-term)
- New Technologies for Airport Pavement Infrastructure and Design (mid-term)
- Advances in Electric or Hybrid Electric Propulsion (far-term)

Aircraft Command and Control Using Automation and Remote Sensing Technologies

Aircraft operations are relying more and more on automation or remote sensing technologies, such as satellite based information. These technologies could lead to fully autonomous flight to control and maneuver the aircraft and include UAS operations as well as traditional passenger and cargo operations.

Near Term

OPERATIONAL AND SAFETY CHALLENGES

- System impacts and human response (e.g., pilots, ATC) of manned or unmanned aircraft autonomously executing an avoid maneuver
- Automated system response to off-nominal or unforeseen situations
    - Fault tolerance to in-range and out-of-range sensor failures
- Autonomous system response to traditional aircraft operations
- Communication with non-autonomous systems
- Cyber and non-cyber threats related to automation and remote operations
- Sensor reliability and certification
- Understanding how humans interact with autonomous systems
- Training methods for human response (e.g., pilots, ATC)

Certification using New Technologies, Standards, or Processes

New techniques may be used for the purposes of testing or certification. This might include techniques such as non destructive testing or computer simulations. These new technologies could add robustness to inspection or certification standards or improve the efficiency of existing processes.

Near Term

OPERATIONAL AND SAFETY CHALLENGES

- Validation criteria for model-based certification
- International harmonization of certification standards
    - Ensuring that harmonization does not lead to competitive advantage for one original equipment manufacturer (OEM) over another
    - Ensuring that harmonization does not reduce level of safety and rigor required for certification
- Leveraging other government agencies' certification criteria (e.g., for cybersecurity)
- Combining related certifications (e.g., cross agency)
- Updating outdated guidance to keep pace with the predictive and performance-based nature of new certification standards
- Moving from fail safe to damage-tolerant design methodology
- Training and increasing the technical knowledge of individuals tasked oversight of these types of certifications

Future Fuel Technologies

> This driver encompasses efforts to modify existing aircraft fuels, such as biofuels, fuel cells, or unleaded Avgas. Future fuel technologies could impact aircraft system performance or lead to new environmental considerations and may require modifications to current emergency or fire prevention procedures.
>
> **Near Term**

AIRPORT AND GROUND OPERATION CHALLENGES

- Safe handling issues and impacts to humans
- Future facility requirements and emergency event response

OPERATIONAL AND SAFETY CHALLENGES

- Compatibility with existing aircraft and fuel delivery systems
  - Impact to aircraft structures, engines, and operation, such as cold soak properties, corrosive properties, weight, or deposits
- Changes in reserve fuel requirements or other aircraft performance requirements
- Fuel stability and icing potential
- Impact on piston engine performance of removing lead from Avgas
- Test methods and certification
- Impacts to aircraft performance
- Unique issues related to fuel cells

ENVIRONMENTAL CHALLENGES

- Improving efficiency of engines and combustion systems
- Fuel production
- Bi-product of combustion
- Fuel dumping
- Cabin air quality
- Supply, sustainability, and economic impacts
- Effects on emissions

Infrastructure Resiliency and Continuity of Operations

Critical ATM services are required on a 24 X 7 basis with continuity and resiliency. In the near future, this requirement may become more challenging as the NAS evolves and expands with new missions, new vehicles, and new technologies. The critical components of ATM automation, surveillance, weather data service, and data and voice communications must provide continuous operations, particularly given the challenges posed by natural or man made disasters.

Near Term

AIRPORT AND GROUND OPERATION CHALLENGES

- Novel techniques for protecting and maintaining airport infrastructure
- Detecting and mitigating unauthorized UAS or other new types of vehicles
- Potential uses and limitations for remote facilities to serve as a backup

OPERATIONAL AND SAFETY CHALLENGES

- Techniques for protecting and maintaining ATM infrastructure
- Detecting and mitigating unauthorized UAS or other new types of vehicles
- Potential uses and limitations for remote facilities to serve as a backup

New Medical Technologies and New Medications

> The pharmaceutical and medical industries are developing new medications and new medical devices, and their impact on pilot or controller performance must be fully understood.
>
> **Near Term**

OPERATIONAL AND SAFETY CHALLENGES

- Applying new medical technologies and techniques to speed up medical certification
- Evaluation of what medications are appropriate or inappropriate for flight crew use to ensure medical evaluations are keeping up with modern medical advancements
- Recognition and detection of fatigue biomarkers for pilots, controllers, and other safety critical job functions

New Vehicles or Components Which Make Use of New Technologies, Software, or Materials

New manufacturing techniques, such as 3D printing, and new materials, such as carbon fiber, are being incorporated into aircraft design. These techniques and materials must be certified as safe for their intended application and may have other implications that need to be understood.

Near Term

OPERATIONAL AND SAFETY CHALLENGES

- Test and evaluation of parts made by additive manufacturing, such as 3D "parts on demand", carbon fiber, composites, and ceramics, including manufacturing in the field and at the maintenance, repair, and operations (MRO) facility
- Moving towards a process and material standardization similar to metallic materials properties development and standardization (MMPDS[1])
- Understanding the physics (e.g., durability, fracture) of new materials such as anisotropic material
- Technology to detect damage and impending failure of components
- Uses and risks of morphing wings or self-healing materials
- Standardized repair procedures for composite structures for both temporary and permanent repairs

ENVIRONMENTAL CHALLENGES

- Ensuring that new materials and new technologies continue to be applied in ways that reduce the noise and emissions of aircraft

[1] MMPDS is the primary source of statistically-based design allowable properties for metallic materials and fasteners used in many different commercial and military aerospace applications around the world. (www.mmpds.org)

Position, Navigation, and Timing Technologies

The NAS reliance on Global Positioning System (GPS) for navigation (position, velocity, time) is increasing and will become the standard method for aircraft navigation and with the transition to Automatic Dependent Surveillance Broadcast (ADS B) surveillance. Improving GPS robustness and the availability of alternative forms of PNT will ensure the safety and reliability of this vital NAS infrastructure.

Near Term

<u>OPERATIONAL AND SAFETY CHALLENGES</u>

- Safety, reliability, and certification of future PNT technologies
    - Optical air data systems using lasers
    - Machine-based visual navigation
- Navigation data safety and security (e.g., data validity so that valid position and navigation data is being used)
- Understanding and mitigating human performance issues during a partial or total system failure

Remote and Virtual Technologies

The emerging potential of cameras, sensors and telecommunications is starting to allow operations to take place at a distance. Examples would include remote ATC towers, remotely piloted aircraft, or remote inspection technology. In addition, future augmented reality technologies can be applied to operations and training.

Near Term

AIRPORT AND GROUND OPERATION CHALLENGES

- Remote airport traffic control tower concepts and safety risks
- Criteria and specifications enabling deployment and implementation of remote towers

OPERATIONAL AND SAFETY CHALLENGES

- Use of augmented and virtual reality for training purposes (e.g., pilots, maintenance personnel)
- Use of augmented reality for maintenance and operations functions
- Minimum performance standards for operations using augmented reality
- Human factors issues with remote or virtual technologies
- Increased risk of cyber attack with remote operations
- Data integrity and timeliness of remote operations
- Using remote technologies to enable single-pilot operations

New Technologies for Airport Pavement Infrastructure and Design

New materials, techniques and designs are being developed to improve the performance and sustainability of airport pavement. These technologies could impact testing and evaluation protocols, maintenance processes, or relationships with surface operations and data.

Mid-Term

AIRPORT AND GROUND OPERATION CHALLENGES

- Development of new materials and techniques, such as:
    - Low-viscosity penetrating sealers for concrete to prevent freeze thaw damage, chloride intrusion, and potentially alkali-silica reaction
    - Biomass concrete made from agricultural by-products
    - Nano particles, electrically conductive concrete or phase change materials to inhibit or melt snow and ice
    - Internal curing of concrete to improve concrete quality
- Standards and minimum qualifications for new materials, while fostering continued innovation and development
- Impact of new materials, particularly surface sealers, on runway friction
- Determination of toxicity or other hazards to airport and airline personnel
- Impact of new materials on aircraft performance on the surface
- Impact of transition between surface types on aircraft performance

Advances in Electric or Hybrid Electric Propulsion

Although electric or hybrid propulsion systems may be a feature of some of the new vehicle types discussed earlier, this driver is meant to capture the challenges and opportunities specific to these engine and battery systems, regardless of what types of vehicles they are powering. For example, hybrid and fully-electric conventional aircraft are already under development.

Far-Term

AIRPORT AND GROUND OPERATION CHALLENGES

- Assessing the needs for ARFF
- Charging infrastructure and siting requirements on airports

OPERATIONAL AND SAFETY CHALLENGES

- Safety of fast-charging high-energy-density batteries
- Safety of efficient high-power electric motors
- New propulsion system impacts to aircraft designs and architectures
- Reserve power requirements
- Standards for certification and continuing airworthiness
  - Failure detection and accommodation
  - Ensuring engine robustness to bird strikes, icing, fatigue
  - Damage tolerance and failure containment
  - Potential removal of redundant components (e.g., ram air turbine)
- Requirements for auxiliary power unit (APU) availability
- High-voltage distribution requirements

ENVIRONMENTAL CHALLENGES

- Noise and emissions standards
- Ensuring efficient power extraction (from turbines) and efficient transmission systems

III. Advances in Data and Processing Power

Information technology has played a role in aircraft development, flight control, and ATM for several decades. However, recent advances continue to push the envelope in new ways. Advances to data and information management will impact the roles and responsibilities of stakeholders and require data sharing agreements and governance from data stewards. As operations make use of these technologies, increased automation may create interoperability challenges between vehicles and systems. Similarly, incidents or accidents involving autonomous or highly automated vehicles may also create uncertainties in liability or other legal considerations.

The following are the research drivers identified in this category:

- Big Data Analytics and Techniques (near-term)
- Crowd Sourcing Weather Data (near-term)
- Increased Connectivity by Cyber-Physical Systems (Internet of Things [IoT]) (near-term)
- Information Assurance and Cybersecurity for All Operations (near-term)
- Risk-Based Decision-Making Techniques and Analytics (near-term)
- Artificial Intelligence (AI) (mid-term)
- Human-Machine Teaming and New Technology Interfaces (far-term)

Big Data Analytics and Techniques

Big data refers to the massive quantities of data that is now being collected or could be collected from a multitude of sources, using sensor networks and inexpensive storage. Big data analytics refers to the mining of this data for useful information that may help to improve operations.

Near Term

AIRPORT AND GROUND OPERATION CHALLENGES

- Use of data on aircraft movements and pavement conditions (e.g., to improve surface maintenance, estimating construction costs)
- Using real time data on aircraft movements and passenger flows through the terminal to improve airport landside and airside operations
- Airport data applications to airport safety management systems (SMS) improvements

OPERATIONAL AND SAFETY CHALLENGES

- Data governance, including ownership, privacy and attribution
- Data integrity and pedigree when data is stored in the cloud
- Certification impact of in-time safety assurance (e.g., “digital twinning”) [4]
- Using data to transition from life-limited parts (LLP) to condition-based maintenance (CBM) methodology
- Data protection and security (e.g., ensuring proprietary data does not become compromised or released to the public)

Crowd Sourcing Weather Data

Improved weather data, improved aviation forecasts, and reduced weather uncertainty is a goal for pilots and ATM personnel. With the advent of greater network connectivity and the proliferation of individual weather reporting stations, can big data analytics and crowd sourcing techniques be used to further this goal? [3]

Near Term

OPERATIONAL AND SAFETY CHALLENGES

- Methods to collect, store, and share new weather data, such as data on winds aloft, eddy dissipation rates, etc.
- Methods to obtain more granular weather and environmental data, particularly for new users flying in non-traditional airspace
- Translating weather data for use in ATM systems
- Potential uses and limitations of using real-time weather data to make information-based decisions

Increased Connectivity by Cyber-Physical Systems (Internet of Things [IoT])

More and more systems are sharing information with other systems, often over the Internet or private networks. This driver refers to the potential benefits and challenges involved in this information sharing, which may include data such as weather conditions, the health of infrastructure or mechanical systems, or the location and state of vehicles in the system.

Near Term

AIRPORT AND GROUND OPERATION CHALLENGES

- Uses and limits of internet of things (IoT) capabilities in areas such as airport facility management, airport maintenance, and airport operations, such as "smart" airport operations, maintenance, and work order management solutions
- Data storage and transport infrastructure required to implement IoT solutions, including bandwidth and spectrum needs

OPERATIONAL AND SAFETY CHALLENGES

- Interconnectivity and interoperability standards for IoT systems, particularly those owned or provided by different entities
- Cybersecurity and privacy standards for IoT systems associated with critical infrastructure
- Reliability standards to determine if systems are delivering bad data, especially for safety critical applications
- Understanding any emergent behavior from systems of systems
- Certification required for providers of non-aviation intermediate services (e.g., communications networks)

Information Assurance and Cybersecurity for All Operations

As information technology advances and becomes more ubiquitous, there is both an increased need for cybersecurity and data protection, as well as new techniques for providing it. This includes aspects such as user identification and prevention of "spoofing," secure data transmission, and system performance and secure backup standards.

Near Term

<u>OPERATIONAL AND SAFETY CHALLENGES</u>

- Access, control, transfer and location of data
- Data security and redundancy requirements
- System recovery and resilience to a cyber-attack or other system failure
- Understanding electromagnetic system vulnerability and criticality
- Determining the pedigree and integrity of data
- Ensuring the integrity of data used for MRO
- Ensuring that all aircraft systems are secure from cyber attack [5]

Risk-Based Decision-Making Techniques and Analytics

Safety Policy, Safety Risk Management, Safety Assurance, and Safety Promotion are the cornerstones of the FAA's SMS. Innovations in proactive safety data management, data analytics (big data) and integration of safety risk into decision making would advance safety and efficiency in the NAS as it continues to evolve and expand in new and unique dimensions. [1]

Near Term

OPERATIONAL AND SAFETY CHALLENGES

- Tools to help decision-makers improve risk estimates
- Potential uses and limitations of in-time SMS [4]
- Training and guidance for effective risk-based oversight
- Applications of risk-based decision-making to fault isolation and troubleshooting
- Applications of risk-based decision-making to MRO
- Risk-management tools for flight crews

Artifical Intelligence (AI)

AI refers to techniques that allow computers to "learn from experience" and adjust their behavior. This technology has great promise for improving automation, but it can be difficult or nearly impossible to decompose why an AI system made a certain decision, or how it might respond to a future situation that it has not yet encountered.

Mid-Term

OPERATIONAL AND SAFETY CHALLENGES

- Use of AI as a strategic decision-support system in the cockpit or the airline operations center (AOC)
- Issues of reliability and liability, such as levels of control given to operating state monitoring taking over for pilots or OEM liability for AI decisions
- Certification of non-deterministic algorithms
- Best practices, requirements, and validation for "training" the algorithms
- Exploring the potential and the limits of using AI for:
    - Autonomous aircraft operation
    - Fault isolation and trouble-shooting
    - Maintenance and repair decisions
- Safety and security issues
- Human factors issues around operator and public trust of AI systems

Human-Machine Teaming and New Technology Interfaces

This driver refers to new and improved interfaces between operators and machines, perhaps using such things as augmented reality or wearable technology. These technologies could include advances to speech recognition and natural language processing, gaze or gesture recognition, and physiological monitoring.

Far-Term

OPERATIONAL AND SAFETY CHALLENGES

- Certification standards for virtual technologies:
  - Synthetic vision, Head-up Displays (HUDs), etc.
  - Wearable technology
  - Gesture technology
  - How to certify non-aviation equipment for use in aircraft?
- Roles and responsibilities between humans and machines
- Human factors considerations around the potential for information overload

IV. System Wide Advancements and Improvements

The drivers presented in this landscape describe the anticipated challenges and research areas that may come to the FAA from industry. It is important to note that these drivers are not comprehensive of all future FAA research areas, but rather just those that reflect potential industry, academia, and other government agency needs. There are many additional drivers that describe system wide advancements and improvements that are more focused on agency priorities or continued FAA enhancements. Further research is expected to support these drivers based on continued and future objectives. These research needs would be spearheaded by FAA and coordinated with industry partners as needed. These additional drivers are:

- **New Methods and Technologies for Air Traffic Safety:** efforts to continuously improve the safety of commercial, general aviation, and all other operations; including a reduction in incidents or accidents due to loss-of-control, controlled flight into terrain, unstable approaches, wrong surface landings, and other hazards or obstacles that may impede operational safety.
- **New Methods and Technologies for Air Traffic Efficiency:** research to support efficiency improvements could include efforts to reduce aircraft separation standards, runway occupancy times, and the exploration of methods to reduce the impact of adverse weather on traffic flows.
- **New Methods and Technologies for Noise, Emissions, and Fuel Use:** this driver includes methods to better understand the impact of noise and emissions on communities that could entail advanced capabilities for noise mitigation measures, improved utilization of data to influence fuel-saving, noise-reducing procedures, or mitigation of hazardous run-off.
- **New Technologies for Airport Surface Movements:** future technologies could affect operations on taxiways, such as taxiway design or separation standards, lighting and signage, or better understanding jet blast risks.
- **Methods for Increased Flexibility of Operators:** this driver may require continued or further research to support trajectory-based operations (TBO), customized routes, tailored arrivals, and optimized profile descent.
- **Performance-Based Capabilities:** future operations may require enhancements to current performance-based standards such as area navigation (RNAV) and required navigation performance (RNP) routes or other equipage-based procedures.
- **Advancement of Global standards or requirements:** to retain the U.S. as a Global Aviation Leader future research may be needed to support U.S. guidance to international governing entities establishing global standards or requirements.

- **Human Response to Traffic and Congestion Management:** this driver explores the human factors aspect of future advances to air traffic management, such as the use of new delay mitigation tools or other types of automation.
- **Development of the Workforce of the Future:** continued efforts to support the future workforce could explore agency hiring and selection methods, as well as technologies to improve job performance, increase employment longevity, and improve training programs for existing employees and potential recruits.
- **Advances in Aeromedical Certification:** the current requirements for medical certification may need to be revisited as future technologies and medical advancements may impact areas such as allowable medical conditions for pilots and crew, appropriate time between certification exams/renewal, and mandatory retirement age.
- **Changing Public Demographics and Requirements:** changes to physical characteristics and pathologies of human populations over time will create a need for research to understand its impact, such as average human height and aircraft seat configurations or potential impacts of performance altering pathologies on pilots or passengers.

Summary by Time Frame

The drivers presented in this landscape describe the potential areas for future research in the near, mid, and far-term time frames. While many of the drivers will not be fully realized until many years from now, current industry initiatives to support incremental milestones and phased development goals will begin operational implementation in the near-term. A summary of the industry-led drivers by time frame is below.

Near-term Drivers:

<table>
<tr><th>Driver Category</th><th>Driver</th></tr>
<tr><td rowspan="3">Advances to New Vehicles and New Missions</td><td>Non-Traditional NAS Access Points</td></tr>
<tr><td>Routine Small UAS Operations BVLOS</td></tr>
<tr><td>Space Operations</td></tr>
<tr><td rowspan="8">Advances in Technology and Materials</td><td>Aircraft Command and Control Using Automation and Remote Sensing Technologies</td></tr>
<tr><td>Certification using New Technologies, Standards, or Processes</td></tr>
<tr><td>Future Fuel Technologies</td></tr>
<tr><td>Infrastructure Resiliency and Continuity of Operations</td></tr>
<tr><td>New Medical Technologies and New Medications</td></tr>
<tr><td>New Vehicles or Components Which Make Use of New Technologies, Software, or Materials</td></tr>
<tr><td>Position, Navigation, and Timing Technologies</td></tr>
<tr><td>Remote and Virtual Technologies</td></tr>
<tr><td rowspan="5">Advances in Data and Processing Power</td><td>Big Data Analytics and Techniques</td></tr>
<tr><td>Crowd Sourcing Weather Data</td></tr>
<tr><td>Increased Connectivity by Cyber-Physical Systems (Internet of Things [IoT])</td></tr>
<tr><td>Information Assurance and Cybersecurity for All Operations</td></tr>
<tr><td>Risk-Based Decision-Making Techniques and Analytics</td></tr>
</table>

Mid-term Drivers:

<table>
<tr><th>Driver Category</th><th>Driver</th></tr>
<tr><td rowspan="5">Advances to New Vehicles and New Missions</td><td>Autonomous Ground Service Equipment at Airports</td></tr>
<tr><td>Growth of Mixed Operations (Piloted, Autonomous, Unmanned)</td></tr>
<tr><td>New Mission Types</td></tr>
<tr><td>Supersonic Flight</td></tr>
<tr><td>Urban Air Mobility</td></tr>
<tr><td>Advances in Technology and Materials</td><td>New Technologies for Airport Pavement Infrastructure and Design</td></tr>
<tr><td>Advances in Data and Processing Power</td><td>Artificial Intelligence (AI)</td></tr>
</table>

Far-term Drivers:

Driver Category	Driver
Advances in Technology and Materials	Advances in Electric or Hybrid Electric Propulsion
Advances in Data and Processing Power	Human-Machine Teaming and New Technology Interfaces

Conclusion

The collection of research drivers provided in this landscape describe forward-looking industry objectives and how they could impact aspects of the FAA; including airport and ground challenges, operational and safety challenges, and environmental challenges. In addition to the drivers presented in this landscape, there are other drivers from industry that could result in research needs that may impact the FAA as a secondary stakeholder. For example, future security technologies are expected to alter current Department of Homeland Security (DHS) or Transportation Security Administration (TSA) functions, such as passenger or cargo screening or counter-UAS capabilities. These technologies could create research needs that may tangentially impact the FAA.

Additionally, there are drivers that are broader in nature and may have impacts to multiple aspects of the FAA. Aviation system sustainability, for example, is a consideration that could impact maintenance of facilities and aging infrastructure, oversight of aircraft fleets and growing passenger demand, as well as sustainability of resources such as energy consumption and CO_2 emissions standards. Another example is human factors considerations, which could have impacts such as the evolving complexity of the NAS with integration of UAS and other new entrants, advances in information management, training and qualification methods, and passenger and crew impacts of increased automation and autonomy, and cybersecurity.

Moving forward, this landscape will be used to identify areas where the FAA should be preparing to address industry advances. The drivers presented here can serve as the starting point to inform FAA research plans like the NARP, and will play a role in the overall research cycle as specific questions are explored and the findings are used to update and refine future drivers and their expected impacts.

References

[1] FAA, "Federal Aviation Administration Strategic Initiatives: 2014 - 2018," U.S. Department of Transportation, Washington, DC, 2014.

[2] U.S. Department of Transportation (DOT), *Strategic Plan for FY 2018-2022,* Washington DC, 2018.

[3] FAA, "The Future of the NAS -2030, draft v2.1," U.S. Department of Transportation, Washington, DC., 20591, 2018.

[4] National Academies of Sciences, Engineering and Medicine, "In-Time Aviation Safety Management: Challenges and Research for an Evolving Aviation System," The National Academies Press, Washington, DC, 2018.

[5] Airline Pilots Association (ALPA), "Aircraft Cybersecurity: The Pilot's Perspective," Airline Pilots Association (ALPA), Washington, DC, 2017.

[6] NASA, "NASA Strategic Plan 2018," National Aeronautics and Space Administration, Washington, DC, 20546, 2018.

[7] UBER - Elevate, "Fast-Forwarding to a Future of On-Demand Urban Air Transportation," UBER, 2016.

[8] FAA, "NAS Horizons," U.S. Department of Transportation, Washington, DC, 2018.

[9] REDAC, "Emerging Issues Report," FAA's Research, Engineering and Development Advisory Committee, Washington, DC, 2014.

List of Acronyms

Acronym	Definition
ADS-B	Automatic Dependent Surveillance – Broadcast
AI	Artificial Intelligence
AOC	Airline Operations Center
APU	Auxiliary Power Unit
ARFF	Airport Rescue and Firefighting
ATC	Air Traffic Control
ATM	Air Traffic Management
BVLOS	Beyond Visual Line of Sight
CBM	Condition-based Maintenance
DAA	Detect and Avoid
DHS	Department of Homeland Security
DOT	Department of Transportation
FAA	Federal Aviation Administration
FOD	Foreign Object Debris
GPS	Global Positioning System
HALE	High Altitude Long Endurance
HUDs	Head-up Displays
IoT	Internet of Things
LLP	Life-limited Parts
MMPDS	Metallic Materials Properties Development and Standardization
MRO	Maintenance, Repair, and Operations

NARP	National Aviation Research Plan
NAS	National Airspace System
OEM	Original Equipment Manufacturers
PNT	Position, Navigation, and Timing
R&D	Research and Development
REDAC	Research, Engineering, and Development Advisory Committee
RNAV	Area Navigation
RNP	Required Navigation Performance
SMS	Safety Management Systems
SSTs	Supersonic Transports
STM	Space Traffic Management
TBO	Trajectory Based Operations
TSA	Transportation Security Administration
UAS	Unmanned Aircraft Systems
USS	Unmanned Aircraft Systems (UAS) Service Suppliers
UTM	Unmanned Aircraft Systems (UAS) Traffic Management