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Partnership to Enhance General Aviation Safety, Accessibility, and Sustainability

Project 25: GENERAL AVIATION 2030—GA EXPLORATORY ANALYSIS

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Final Report

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16. Abstract

The primary intent of the *PEGASAS Project 25: General Aviation 2030—GA Exploratory Analysis* team was to generate what the team has called “soft data” that would foster development of a Research and Development plan for General Aviation (GA). The motivation of the project was to provide topics of importance that the Federal Aviation Administration—and the GA community in general—should begin investigating soon so that, as developments are made in smaller, general aviation aircraft, the FAA and the GA community are better prepared to answer questions regarding the safe and efficient operations of GA in 2030.
This report collects data and findings from two phases of effort—with emphasis on the second phase—and attempts to provide specific research objectives, along with additional descriptions of research topics, in a set of seven research areas. To refine the research objectives and to provide the additional descriptions, the team has engaged several Subject Matter Experts (SMEs) from the GA industry, from NASA, and from the FAA via interviews.

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Acronyms

Acronym	Definition
ACS	Airman Certification Standards
ADS-B	Automatic Dependent Surveillance-Broadcast
AGATE	Advanced General Aviation Transport Experiments
AI	Artificial Intelligence
AIC	Airport Improvement Program
ASTM	American Society for Testing and Materials
ATC	Air Traffic Control
API	Application Programming Interface
COA	Certificate of Waiver or Authorization
COE	Center of Excellence
COTS	Commercial-off-the-Shelf
FAA	Federal Aviation Administration
FADEC	Full Authority Digital Engine Control
GA	General Aviation
GAMA	General Aviation Manufacturers Association
IC	Internal Combustion
IFR	Instrument Flight Rules
IoT	Internet of Things
NAS	National Airspace System
NASA	National Air and Space Administration
NTSB	National Transportation Safety Board
ODM	On-Demand Mobility
PED	Personal Electronic Device
PEGASAS	Partnership to Enhance General Aviation Safety, Accessibility and Sustainability
PHMD	Personal Health Monitoring Devices
R&D	Research and Development
RNAV	Area navigation
RTO	Remote Tower Operations
SME	Subject Matter Expert
S/VTOL	Short or Vertical Takeoff and Landing
UAM	Urban Air Mobility
UAS	Unmanned Aerial Systems
VFR	Visual Flight Rules

Executive Summary

The primary intent of the *PEGASAS Project 25: General Aviation 2030—GA Exploratory Analysis* team was to generate what the team has called "soft data" that would foster development of a Research and Development plan for General Aviation (GA). The motivation of the project was to provide topics of importance that the Federal Aviation Administration—and the GA community in general—should begin investigating soon so that, as developments are made in smaller, general aviation aircraft, the FAA and the GA community are better prepared to answer questions regarding the safe and efficient operations of GA in 2030.

This report collects data and findings from two phases of effort—with emphasis on the second phase—and attempts to provide specific research objectives, along with additional descriptions of research topics, in a set of seven research areas. To refine the research objectives and to provide the additional descriptions, the team has engaged several Subject Matter Experts (SMEs) from the GA industry, from NASA, and from the FAA via interviews.

The seven research areas are as follows:

1. *Airports & Infrastructure* discusses important topics to help GA airports adapt to envisioned future changes in general aviation.
2. *Aspects of Connectivity* concentrates on data and information transferred to and from a GA aircraft for use in a variety of ways to support operations.
3. *Automation & Autonomy* considers application- or context-agnostic issues about the software, hardware, and implementation of automation and autonomy to allow its use to provide benefits in the other research areas.
4. *Future Airspace* recognizes a potential future that includes a higher number of Unmanned Aerial Systems (UAS) operations alongside a higher number of GA aircraft operations, based upon several scenarios that involve new aircraft enabling new business models.
5. *Future Propulsion Systems* recognizes issues about providing energy from different sources (e.g., electric and other alternatives to 100-LL AvGas) for propulsion of GA aircraft in the future.
6. *Passenger Safety & Crashworthiness* maintains focus on this important area for GA where the potential visibility of safety and crashworthiness increases under scenarios where GA provides a more common means of transportation through more frequent operations

7. *Pilot Training & Proficiency* considers issues around the current pilot shortage, the envisioned need for many more pilots to support increased future operations, and the technology needed to provide the training and simplified vehicle operations that could facilitate having more pilots or operators available for GA aircraft.

This final report covers efforts conducted between January 2017 and September 2020, with a few interruptions over this time period. As a result, many of the interviews with SMEs took place before the COVID-19 pandemic and before the well-publicized Boeing 737 MAX accidents that highlighted issues with automating flight control inputs.

1 Introduction

The *General Aviation 2030—GA Exploratory Analysis* is Project No. 25 within the Partnership to Enhance General Aviation Safety, Accessibility and Sustainability (PEGASAS), the Federal Aviation Administration's (FAA) Center of Excellence (COE) for General Aviation (GA). The objective of this project is to analyze and explore future GA topics that warrant research efforts so that various stakeholders in the GA community may be better prepared to address needs in the next 10 to 15 years. The research documented in this report builds upon the results from the previous research phase to provide the data necessary for a strategic roadmap for GA research and development (R&D).

1.1 Motivation

The role of GA in the United States transportation system complements the many functions provided by scheduled commercial airlines, and GA has its own mature community. Recent progress in several technological areas and the potential of new GA market opportunities, perhaps enabled by the technological progress, has generated interest in the future of GA. There is a consensus among stakeholders in the GA community that, to address the future needs and realize the potential benefits of GA, both industry and government entities must start researching now to better understand the needs and challenges that are expected to arise in the 2030-to-2040 time frame.

2 Scope of Project and Tasks

The objective of the research documented within this report is to build upon, refine, and streamline the results from the initial research phase (Federal Aviation Administration, 2018; Gao, et al., 2018) and ultimately provide the data necessary for a strategic roadmap for GA R&D. The identified research should facilitate ever-increasing safety in GA operations, support continued and expanding accessibility (particularly with the current interest in new vehicle concepts and technologies that may enable entirely GA-aircraft-enabled business models that have not traditionally been part of GA) and sustain GA as an important part of aviation. The scope of this project is not to develop a comprehensive plan for GA safety R&D, but to collect what the team refers to as the “soft data” which the FAA can utilize as valuable input to a broader strategic planning initiative of the FAA’s aviation safety R&D program. Although the FAA supported this study, the resulting research needs and challenges affect the broad aviation community and all its stakeholders. The FAA may not need, or be in a position, to address all the research identified here; other GA community members can also pursue the identified research.

The Project 25 team completed Phase 1—subject area benchmarking and Subject Matter Expert (SME) workshops—which led to the identification of themes deemed important for the future of GA using the year 2030 as a notional target of the future. The team further developed the input from benchmarking and the workshops into eight themes, as described by Gao et al. (2018).

This report covers the progress of Phase 2, which the team approached as two major tasks: (1) streamlining of Phase 1 content into questions and scenarios for the future GA themes and topics identified, and (2) SME dialogue preparation and execution using generated questionnaires. The main outcomes of the streamlining task, expert elicitations, and post-processing of the collected discussions are documented in this report.

In preparing the questions for use during the SME discussions, the team critically assessed the content of the original eight themes with the intent of making them into "research areas" to align with an R&D plan more closely. The team used the FAA Cybersecurity R&D Plan (Federal Aviation Administration, 2017) as a template when developing these research areas. As a result of this assessment, the team made a few important decisions. Many of the themes from Phase 1 contain overlapping content. In particular, the theme titled "Automation & Autonomy" seemed to have an impact across several different themes; therefore, as the themes were transitioned into areas, the team placed autonomy and automation as a topic in nearly all the research areas. The research area that remained with the standalone title of “Automation & Autonomy” now addresses only issues that are related to the software and hardware needed to implement automation and autonomy and not its potential applications. Also, the team considered that the themes previously titled “Airframes, Legacy Fleet, and Maintenance” and “Advanced Design & Manufacturing” to be of a lower priority for consideration in this phase of the research. While each represents important directions for the future of GA, these themes were not developed in the same fashion as the other themes due to the time and resources available for this study.

As a result, seven research areas were defined to group the outcomes from this phase. These research areas are summarized in General Aviation 2030 Research Areas. Each area has two parts: an overview and description, and findings and proposed recommendations.

2.1 Research Area Development and Expert Outreach

The product of the in-depth exploratory analyses of each research area was a set of mixed-level questions that helped clarify the potential state of GA in 2030. Each research area “questionnaire” contained the context of what the PEGASAS team believed future FAA research actions ought to include for various topics within the research area. Questions were generated using information collected in Phase 1 benchmarking and additional exploratory analyses in

Phase 2. The questionnaires allowed the PEGASAS team to facilitate discussions with SMEs and to collect feedback from the SMEs about actions the FAA could or should take to prepare for GA needs in 2030. The PEGASAS team produced questionnaires for the following research areas:

1. Airports & Infrastructure
2. Aspects of Connectivity
3. Automation & Autonomy
4. Future Airspace
5. Future Propulsion Systems
6. Passenger Safety & Crashworthiness
7. Pilot Training & Proficiency

Each questionnaire included topics and impact areas that the PEGASAS team believed impact or affect the corresponding research area for GA 2030 operations. The questionnaires appear in Appendix B. The questionnaires were not strict scripts for each discussion; rather, these were provided to the SMEs before the discussion and provided a framework for the discussion, while the PEGASAS team allowed deviations from the questionnaire based on the SME interaction during the discussion.

Discussions with experts from the aviation industry and the government provided opportunity for feedback from different stakeholders in aviation. The purpose of eliciting feedback was to iterate and improve upon findings from Phase 1 and develop recommendations for future actions by the FAA and others in the GA community to prepare for GA in 2030. The PEGASAS team intended to have open discussions facilitated by the research area questionnaires. The team documented the discussions with SMEs and subsequently analyzed and distilled the SME feedback into recommended future actions and supporting details. The team interacted with multiple SMEs for each research area to gain a holistic perspective for each area. Overall, there were 27 different interviews. Some interviews involved more than one SME in the same discussion. Because the research areas are not completely independent from each other, a few SMEs provided their thoughts about more than one research area.

Because of the nature of the interactions with the SMEs qualifies as human-subjects research, the Project 25 team needed to apply for and obtain "Exempt, Category (2)" status for the project from the Institutional Review Boards at Purdue and at Georgia Tech. With this approval in place, the team began scheduling telephone or web-meeting interviews or discussions with the SMEs.

The team informed the SMEs that their names would be included in the report, but none of their comments will be attributed to the specific individual.

The Project 25 team prepared this final report at the end of calendar year 2020, and it covers activities from January 2017 through September 2020. Most of SME interviews took place before the COVID-19 pandemic that took hold in the US in March 2020, and many SME interviews took place before the two Boeing 737 MAX crashes in October 2018 and March 2019. Where appropriate, the authors have made notes in the text to point out where the reader may be surprised to not have references to either of these important issues that have had a major impact on aviation broadly.

3 General Aviation 2030 Research Areas

This section contains the outcomes and findings for each of the seven research areas (in alphabetical order of the title the team assigned to each area). Each research area has its own sub-section containing two parts: (1) an overview and description, and (2) findings and proposed recommendations. The research areas are defined and scoped based upon the results from the exploratory analysis and are formulated in a way that helps facilitate the discussions with experts. The results from the interactions with experts are presented and actionable recommendations are provided.

3.1 Research Area: Airports & Infrastructure

3.1.1 Overview and Description

Due in part to the great variety in GA operations, there is also variety in the types of airports and infrastructure supporting GA. From a regulatory standpoint, the FAA and relevant law define an airport as "any area of land or water used or intended for landing or takeoff of aircraft including appurtenant area used or intended for airport buildings, facilities, as well as rights of way together with the buildings and facilities" (United States Code, 2012; FAA, 2012). With further clarification, this general airport definition applies to GA airports, which are "public-use airports that do not have scheduled service or have less than 2,500 annual passenger boardings" (U.S. Department of Transportation Federal Aviation Administration, 2016; United States Code, 2012). While the term "airport" often suggests fixed-wing vehicle operations, it is important to note that existing U.S. regulations consider heliports as included in its definition of airports (U.S. Department of Transportation Federal Aviation Administration, 2016). Some significant differences in usage and operations have been observed among various GA airports. This observation has led to the definition of five GA airport categories, defined by the FAA (FAA, 2012).

1. *National*: "Supports the national and state system by providing communities with access to national and international markets in multiple states and throughout the United States."
2. *Regional*: "Supports regional economies by connecting communities to statewide and interstate markets"
3. *Local*: "Supplements communities by providing access to primarily intrastate and some interstate markets"
4. *Basic*: "Links the community with the national airport system and supports general aviation activities (e.g., emergency services, charter or critical passenger service, cargo operations, flight training and personal flying)"
5. *Unclassified*: "Provides access to the aviation system."

In addition to the runway access available at GA airports, most also offer other physical or organizational structures that support GA operations. These facilities often include terminal space, hangars for vehicle storage or maintenance, and access to fuel or energy.

As with any infrastructure, there are many ongoing maintenance and improvement requirements for GA airports that result from current GA operations. As GA operations change in the future, new disruptors will likely arise and require focus on GA airports and infrastructure. These disrupters would not only include new technologies, but also novel concepts of operations, among others. Electric propulsion, autonomous air vehicle concepts, and alternate fuels are examples of technologies that are likely to disrupt the current usage of airports and ground infrastructure, while some novel ideas of operations—like on-demand mobility (ODM) and the potential proliferation of personal air vehicles—can lead to disruption in the whole paradigm of GA airports, along with the infrastructure associated with them. Upon review of the expected changes to GA by 2030, the PEGASAS team identified three relevant topics of airport requirements for additional investigation.

1. Facilities maintenance and improvements
2. Airspace management around airports
3. Airport security

Perhaps the broadest topic of airport and infrastructure requirements is related to facilities maintenance and improvements. Trends in GA operations suggest that the expected newer generation of aircraft will require newer maintenance and storage infrastructure (UBER, 2017). In addition, with forecasted increases in the number of flight hours flown (FAA, 2017a), a greater number of larger ground-service stations will be required, which may increase the stress placed upon existing facilities and infrastructure. These shifting operational needs will contribute to some direct infrastructure requirements, such as ongoing pavement inspection and maintenance, facility improvement to account for increased terminal capacity (e.g., facilities for passengers, parking, hangar space, etc.), and new infrastructure investments to enable shifting operational use. Several aspects of GA airports and infrastructure which are anticipated to be most impacted by these requirements, and sample questions from the related portions of the questionnaire, are listed here.

- **Runway and terminal facilities**, which includes the basic infrastructure required for existing and future GA operations, particularly the runways and terminal facilities present at airports with GA operations.
    - What new infrastructure requirements will be created by future GA operations?
    - Are these needs met by existing infrastructure?
- **Environmental management**, which includes wildlife issues—most notably ongoing mitigation of bird strikes and other forms of wildlife incursion at airport facilities—and the environmental impact of the airport on the surrounding community and environment.
    - What methods and strategies can be used to mitigate the risk of wildlife incursion for GA operations?
- **Energy management for future GA aircraft**, which includes the infrastructure considerations related to future GA aircraft energy needs—such as the coordination between local power supply companies and airports—and new facility requirements to account for shifting GA aircraft energy needs.
    - How will the introduction of future energy sources for GA aircraft impact GA infrastructure?

A second topic related to airports and infrastructure is that of airspace management around airports. In potential scenarios of GA operations in 2030, there are often significant changes to the number and types of GA operations. Common changes seen in these scenarios include high density GA operations (FAA, 2017a), the inclusion of more autonomous vehicles, and the integration or coordination of Unmanned Aerial Systems (UAS) in the airspace typically occupied by GA (FAA, 2017b; Prevot, et al., 2016). While the research needs for airspace management relevant to GA constitute a separate research area in this report, changes in the supporting GA airports and infrastructure will facilitate many of the envisioned changes in the airspace management paradigm. Given this, the two areas identified within airspace management infrastructure relevant to airports appear below, along with relevant sample questions from the questionnaire.

- **Accounting for increased capacity** refers to shifting airport requirements, regarding both the capability to safely coordinate a higher traffic density in and around the airport and the potential increase in the number of airport patrons.
    - How will increases in GA usage be distributed amongst existing infrastructure?
- **UAS integration** requirements with ongoing—and potentially increased—crewed GA operations.
    - What changes, if any, must be made to GA infrastructure to support the safe GA operation alongside UAS?

The final topic of interest for future GA airport and infrastructure is airport security, which refers both to the physical security of airport facilities and patrons, and cybersecurity concerns. Some trends in GA indicate a potential increase in the volume of GA usage, including an increase in the number of passengers utilizing GA as a mode of regular transportation. For example, recent FAA forecasts for GA utilization—in terms of hours flown—predict a yearly 2.2% increase between 2019 and 2040, driven largely by business passenger usage (Federal Aviation Administration, 2020). While airport site security exists for many airports that support GA operation, a surge in GA usage could potentially create new or increased demands for airport site security. In addition, as GA—and society in general—becomes more connected, there is a similar increase in concern for ensuring cybersecurity at GA airports. In striving to provide the appropriate level of cybersecurity for GA airports, it is anticipated that some physical infrastructure requirements will be generated, prompting further investigation into these requirements and their impact on GA airports and infrastructure. The following impact areas reflect these two concerns, airport site security and cybersecurity. These summary statements also include a sample of relevant questions drawn from the full SME discussion questionnaire.

- **Site Security**, which refers to the on-site security of airports which cater to GA operations.
    - How will passenger safety needs and expectations change in the future, and what infrastructure will be required to meet these needs?

    - What level of monitoring will be needed for future GA operations?

- **Cybersecurity**, which refers to the digital security of connected GA airports and facilities.
    - With the increasing connectivity of GA and the world in general, what infrastructure is required to provide cybersecurity for GA operations?

3.1.2 Findings and Proposed Recommendations

SME feedback on the *Airports & Infrastructure* research area highlighted several key points. Overall, the SMEs believed the FAA should consider devoting resources to analyze potential outcomes by exploring several scenarios of GA in 2030. The emergence of disruptors mentioned earlier would lead to important scenarios that can have far-reaching effects on GA airports and infrastructure. There have been instances in the past when products and research findings intended for large, commercial airport operation have translated to GA airports as the economics made these translations viable. For instance, an SME mentioned a case where a GA airport-oriented lighting handbook was generated based on research for large airports in collaboration with the Illuminating Engineering Society (IES) Lighting Committee. Similar exercises can be used for porting knowledge and experience gained from commercial airport operation to GA airports to minimize the disruption caused by novel technologies and concepts, if analogs have first appeared at larger airports. An interesting point raised looked at how "industrial aviation" (e.g., operations of large airplanes into the airport, perhaps for maintenance or interior conversion, but not operating under Part 121 operations) falls under the domain of GA even though the scale of infrastructure involved is much larger than the typical perceived GA airport. Due to the peculiar nature of its classification, industrial aviation is often left out of the conversation when the future scenarios in GA are considered. SME feedback suggested looking at metrics like economic impact and job creation, in addition to the traditional number of landings, when studying the effect of future scenarios on industrial aviation, especially considering its high economic impact despite having a much lower frequency of operations.

The SMEs involved in the airports and infrastructure discussions widely considered UAS and autonomous vehicle concepts and operations as the most important change that GA airports will face by 2030. General feedback in this area highlighted the need to conduct more research to determine how future short or vertical takeoff and landing (S/VTOL) traffic of unmanned and autonomous vehicles will be managed for high density operations in areas that already are densely populated today. Autonomous ground vehicles, in addition to autonomous air vehicles, are expected to be prevalent at GA airports by 2030 for purposes such as perimeter security, runway inspections, firefighting, and wildlife control, where the unmanned vehicles allow these important functions at lower cost. A marked difference between autonomy in ground-based vehicles and aircraft is that aircraft may rely on more sources external to the vehicle (e.g., Automatic Dependent Surveillance-Broadcast [ADS-B]), while autonomous ground vehicles tend to use internal sensors for operation. Because data requirements, communications interfacing, and data processing needs for air and ground vehicles are expected to vary, SME consensus pointed towards needing more research to determine appropriate systems and infrastructure requirements at GA airports.

SMEs expected On-Demand Mobility (ODM) concepts to cause a paradigm change at GA airports by 2030 through the potential increase in traffic. More research will be needed to find the best way to resolve the air-traffic issues that will be caused by ODM. Even if the traditional GA and new ODM concepts are segregated in terms of airspace—which a few SMEs believed might be a viable option, even though it is contrary to the stated desire to avoid segregated airspace—SMEs expected that additional take-off, landing, pavement, and storage facilities will be needed at GA airports to manage the increased traffic, especially since the traditional GA aircraft are not expected to go away by 2030. ODM concepts will also potentially cause additional traffic at larger commercial airports, where there is an expectation that people will use these to connect with commercial flights. SMEs expected high-density operations to have a waterfall effect, where large busy airports reach capacity, resulting in an overflow into smaller airports, which will then require upgraded infrastructure to deal with the additional traffic as nearby major airports reach saturation.

Available SME feedback on the impact of proliferation of alternate energy for aircraft (e.g., non-100LL AvGas or electric propulsion) and for airport infrastructure requirements focused on changes to firefighting needs and airport lighting considerations. With the advent of alternate energy for GA aircraft, additional research will be needed to determine capabilities needed to effectively control alternate energy fires, such as alternative fuels with flammability considerations that are different from current aviation fuels, or batteries with very different needs for flame suppression, etc. This may result in additional training and equipment requirements for GA airports, particularly if these alternate aircraft energy sources come to fruition in GA aircraft first. SME feedback also pointed towards existing research for developing commercial airport lighting systems that run on alternate energy, such as solar, that could also reduce the operating costs for GA airports in the future.

SMEs suggested the Information Systems of airports may be an additional disruptor not considered in the previous discussions or in the questionnaire. Information sharing, such as navigation aids and weather information, will require new software and hardware at GA airports. In the case of industrial GA airports, networking infrastructure to support autonomous operations is expected to follow trends followed by industrial service providers.

Based upon the data collected in this research area, the following proposed recommendations are provided for this research area and its key topics.

> *Develop a strategy for the ongoing maintenance and improvement of airports and supporting infrastructure to promote increased safety and improve efficiency in GA operations.*

Additionally, the airports and infrastructure research area has been further sub-divided into three subcategories.

3.1.2.1 Facility Maintenance and Improvement

SME consensus noted that any facility improvement will result in additional maintenance requirements not only for the new infrastructure but also to maintain existing facilities. A large amount of feedback focused on requirements generated due to autonomous operations and ODM concepts. Operations that require navigating the airport while taxiing were recognized as areas of big concern. SMEs pointed out that the current airport markings are intended for human use and may be inappropriate for autonomous or remotely-operated aircraft concepts—like some of those envisioned for ODM operations—that rely on camera-based vision systems. SMEs acknowledged that humans can be flexible while interacting with airport markings, while cameras that may be used on autonomous and ODM concepts may have a limited field of vision, low image quality, and may not discern colors well. In the case of remote operators that fly drones from the ground, vision may be restricted by the quality of the network transmitting the signal. As a result, SME feedback pointed towards a need to further research what appropriate airport markings should be in these future scenarios. One expectation was that GA airports might require two sets of markings: one for the existing GA operations, and another for the new concepts. To support autonomous landing and taxi, systems like the Ground-Based Augmentation System (GBAS) can play a critical role and may have to be deployed on a larger scale. The interviewed SMEs who discussed this felt that this requires additional research of the appropriate approach, landing, take-off, and taxi procedures for future ODM, UAS, and autonomous concepts, especially since these procedures can result in additional requirements on facility improvements.

An interesting idea looked at the creation of what one SME calls “drone-ports.” In a future scenario, where passengers require access to ODM concepts similar to today’s ground taxis, research will be needed to understand the best ways to keep ODM vehicles accessible while maintaining security of operations. In such a scenario, research will be needed to establish “drone-port” standards that may be analogous to airport standards of today. To explore this topic fully, there should be a collaborative effort that includes the cybersecurity and UAS research teams.

While anticipating the changes to GA airport facility maintenance and improvements due to the advent of alternate energy, SME feedback pointed towards a need to research appropriate methods to store and handle alternative energy, including the right equipment to manage hazards, as well as training personnel, such as fire-fighters and the handlers who would dispense such energy options to aircraft or ground vehicles. An interesting point was brought forward that looked at powering GA airports themselves using alternate energy sources such as solar powered lighting. At least one SME pointed out that the reduced lighting power consumption due to LEDs may offset the increased energy demand that may occur due to electric GA aircraft. Additionally, infrastructure—such as charging stations or ports—would be needed and may have to be standardized for GA 2030.

The increasingly digital landscape of GA 2030 is also expected to result in physical infrastructure requirements. Inputs from SMEs suggested that real-time data about what aircraft need from a maintenance perspective will allow more aircraft-specific, proactive maintenance. Thus, access to real-time data from the aircraft at the airport may allow for redistribution and reallocation of maintenance requirements and activities, which can lead to reallocation of infrastructure demand.

One SME observed that industrial aviation has a large economic impact despite having a low frequency of operations. These operations are also sensitive to migration of jobs out of the country, such as jobs relating to aircraft maintenance. In such a scenario, there was a recommendation that the FAA should, in conjunction with the aviation industry, go beyond traditional airport metrics and research appropriate metrics for industrial GA, in terms of economic impact and job creation, to provide support for these different, but important, GA airports.

Based upon the data collected in this research area, the following proposed recommendation is provided for this key topic:

Develop and implement a strategy for GA runway and terminal facility improvements, environmental management at GA airports, and energy management for future GA vehicles.

3.1.2.2 Airport Security

While commercial airport security is designed to prevent threats to commercial flights, GA security is designed to prevent threats from GA to GA and commercial systems and infrastructure. It is understood that GA airport security is not treated as comprehensively as commercial security at the airport level. No major change is expected in this treatment after discussion with SMEs. On the other hand, considering the waterfall effect discussed under high-density operations, it is expected that high-traffic GA airports will become the weak link in the safety of the National Airspace System (NAS) and may need additional protection. SMEs suggest that GA security can be improved by adopting commercial airport sensor technology at the GA level. This may be accomplished by focusing some effort of the National Safe Skies Alliance to develop technology for GA airports. However, it is acknowledged that stronger directives from the government may be needed, followed by additional funding.

SME consensus opinion points towards airport perimeter security as a low-hanging fruit in terms of utility of drones in GA airports. However, these come with concerns for airspace violations which would need to be addressed. In the context of industrial GA airports, solutions to concerns about using drones could lie in de-conflicting their operations from traditional industrial operations.

With an increase in networked systems expected in the future, cybersecurity was acknowledged as a major concern for GA airport security. SME inputs provided the example of the simple act of charging a battery, and the number of network handshakes that are needed to ensure safe charging, suggesting that a security compromise of this small process can potentially cause battery overheating and fires. Solutions for securing all such cyber-dependent systems may be found by looking at how commercial aircraft are protected against cybersecurity concerns.

A big concern with autonomous air vehicles lies with their likelihood of being compromised. Additional research may be needed to develop technologies to counteract against future threats, such as dealing with system failure or compromised security. SME inputs suggest it may be necessary to ensure such vehicles can take autonomous action to continue safe operations by ensuring they can safely land without harm to humans or infrastructure under adverse scenarios.

Based upon the data collected in this research area, the following proposed recommendation is provided for this key topic:

> *Identify infrastructure requirements which improve airport site security and cybersecurity for GA stakeholders.*

3.1.2.3 Airspace Management

In future scenarios where UAS share airspace with GA, the three biggest research questions generated from SME input are: (1) How do we track the vehicles? (2) How do we make their locations accessible to any manned or unmanned aircraft in the vicinity? (3) What broadcast information is necessary to ensure manned GA operations are not interfered with?

SME feedback points towards avoiding a situation where any aircraft, GA or commercial, is deprived of the knowledge of an autonomous vehicle in operation in its vicinity. Addressing issues regarding the responsibility of participating agents—operators of manned and autonomous vehicles, and even the air traffic controllers—in advance of entering the airport area is important to prevent mishaps. In the same vein, SME consensus suggests there is no difference between commercial and GA airports, because GA aircraft and larger commercial aircraft require the same information about autonomous and UAS operations. Thus, the solutions for such problems would have to address a similar use case in both GA airports and commercial airports. Possible solutions suggested require traditional and future GA aircraft to have equipment to receive information from drones for improved visibility. Additional ground stations may also be needed for proper coverage with advanced vehicles. Research into development of low-cost ADS-B–like systems and collision avoidance systems may be needed to enable technology-driven solutions. Simultaneously, it may be prudent to require autonomous vehicles to broadcast information on their current location, speed, and heading.

Another scenario generated from SME inputs looks at segregating operations based on landing surfaces needed, thus autonomous S/VTOL flights need not share the same airport infrastructure as traditional GA aircraft. As with any high-density operation, it is anticipated that some form of air traffic control (ATC) function would be needed to control and monitor flow at airports where a high density of GA and autonomous operations occur. In such situations, research on remote ATC concepts may be useful and may need to be extended to incorporate UAS in the same airspace. At the same time, it may be necessary to ensure UAS have the capabilities to communicate and coordinate effectively with remote ATCs.

Once again, industrial GA operations offer a unique perspective on future GA airspace management. SME inputs suggest that automation and autonomy can show up first in industrial GA operations and could translate into small GA operations later. Since industrial GA operations tend to be low frequency, they might be good candidates to test remote ATCs along with autonomous operations early. While SMEs do not see industrial GA operations being impacted by high density operations, they do take place in densely populated areas, simply because every such industrial GA operation employs—directly or indirectly—tens of thousands of people. Therefore, while segregation of airspace for take-offs or landings may be required for automation in future industrial GA, SMEs do not see the potential for ODM-like concepts to transport people in these areas. This is primarily because these operations are already congested with warehouses, hangars, and large parking areas, and there would not be enough space to create separate infrastructure for ODM concepts.

Based upon the data collected in this research area, the following proposed recommendation is provided for this key topic:

> *Identify infrastructure requirements for future airport airspace management scenarios which enable future GA operational scenarios.*

3.2 Research Area: Aspects of Connectivity

3.2.1 Overview and Description

As with many aspects of modern society, where numerous wireless devices have improved connectivity, a likely key change for GA in the near future is an increased level of connectivity between the pilot, the aircraft, and other sources of information. In current operations, GA pilots typically obtain flight-relevant information—including but not limited to weather data, obstacle data, and clearances—from a variety of sources. The increased usage of personal electronic devices (PEDs) by GA pilots that allow for increased levels of connectivity has augmented this proliferation of data. In addition, there is a similar increase in aviation-specific technology, such as ADS-B, which provides an increased level of situational awareness, in part through the transfer of data between GA participants.

While this increased level of connectivity is often an integral component of future GA scenarios, there remain several important topics of research. In future GA scenarios that envision higher connectivity between pilots, GA vehicles, ATC, and other sources of information, there is also an associated increase in the additional infrastructure necessary to support and enable these capabilities. Such infrastructure would likely be required to provide power, maintenance, and security to sustain continuous operations with vast numbers of users. To determine what infrastructure will be required in such future scenarios, two important impact areas warrant closer examination.

- **Aviation "Internet" or Data Link**, referring to a network which facilitates the transfer of data between GA participants.
    - What network or means of data transfer will best enable increased connectivity in future GA operations?
- **Connectivity Profile**, which clearly defines the types of data which are likely to be transmitted between GA participants and the appropriate usage of this data.
    - What types of information are likely to be transmitted and received during future GA operations?

In current GA operations, pilots utilize information from a variety of sources, which are often gathered from a myriad of displays, each with varying means of presenting the supplied information. As the access to information potentially increases due to increased GA connectivity, a lack of uniformity will inhibit the usefulness of the information to GA pilots. The definition of information interface standards, such as through an Application Programming Interface (API), was identified as a possible means of alleviating this potential stumbling block (Gao et al., 2018). More specifically, defining a set of data interface standards would allow for more uniform transmission of information and enable more seamless integration of information for GA operators. In researching this topic more thoroughly, two impact areas were defined as follows:

- **Interface Protocol Development**, which includes background research required to formulate an appropriate set of interface protocols and the process by which these protocols are defined for the GA community
    - What types of standards should be included in a future information interface protocol?
    - Who should be responsible for defining these standards?
- **Interface Regulation**
    - If an interface standard is developed, how should it be regulated and enforced?

Finally, with an increase in connectivity comes an associated increase in cybersecurity risk. Thus, it is understood that for connectivity to exist among users, security protocols are necessary to safeguard transmitted information from users with malicious intent. Recently, there has been a significant increase in the consideration of cybersecurity, as displayed by the recently published FAA Cybersecurity R&D Plan (Federal Aviation Administration, 2017c). While many future cybersecurity changes in GA are likely to be derived from this existing R&D plan, it may also be anticipated that some additional requirements will arise upon consideration of the needs of future GA connectivity.

3.2.2 Findings and Recommendations

SME feedback on *Aspects of Connectivity* emphasized five key areas and the associated implications on connectivity infrastructure, information interfacing, and cybersecurity. The SME discussions collated content for transformative technologies and challenges, human operator and data interaction and interface, collaboration, and data protection and control. The insight provides a basis to evaluate objectives and disruptors in this emerging research area of GA. The SME feedback insists that the FAA and GA stakeholders benefit from intentional research efforts and collaborations within the telecommunication community to develop standardized procedures for data exchange. The increase in connectivity capabilities and technologies provide opportunities for GA manufacturers, suppliers, and operators to develop simplified operations, effective connectivity measures, and data security for safe GA operations.

Based on the feedback and data collected in this research area, the PEGASAS Project 25 team believes the *Aspects of Connectivity* research area objective is to:

> *Develop capabilities for enhanced and secure data sharing among GA stakeholders and standardization of information interfaces.*

3.2.2.1 Connectivity Infrastructure

The FAA and GA community must improve how to manage and communicate within the airspace for pilots and operators in 2030. Connectivity is a technology area that emerged as an enabler for GA operations based on expectations of improvements in telecommunication and inclusion of transformative technologies. The challenges associated with these expectations are related to the data exchanged in the communication, data links, and services that use the data and data links. Connectivity may improve with the inclusion of transformative technology like 5G and satellite communication or cabin intranet, but only with collaboration among the FAA, GA community, and the “connectivity” (i.e., telecommunications) community. GA operations stand to benefit greatly from connectivity, and these stakeholders are vital to providing this benefit. SMEs believe that, given the expected surge in GA aircraft, it is important to better understand the limits of the current systems—such as bandwidth limits on ADS-B that could limit the number of users or could limit additional information provided along with the current ADS-B information—and explore options to adapt capabilities for the future of GA. The SMEs also suggested that third-party entities will provide data management and connectivity services and less of an internet-like structure for most of the connectivity infrastructure required.

For GA, three categories of connectivity emerged from the SME discussion: operational, “concierge,” and entertainment. One SME used these categories to describe current and anticipated operations. Operational connectivity includes the data, data links, and services necessary to operate an aircraft. The data described in operational connectivity includes weather data, traffic data, and pilot reports, etc. Weather and traffic data packets are currently managed with ADS-B. Pilot reports are currently filed manually with ATC; however, with GA operations and traffic expecting to increase by 2030, there are opportunities for digital pilot reports and digital voice to impact GA. “Concierge” connectivity speaks to the data exchange, data links, and services necessary to enable support ground services such as scheduling ground transportation, locating aircraft fuel services, identifying food options, etc. Entertainment connectivity refers to the data, data links, and services necessary to provide in-flight entertainment.

For each of these categories, the data and data links are the most critical. Data composition and volume are important for the FAA to investigate because composition and volume requirements can help determine what bandwidth and frequency guidelines are necessary to support high volume GA operations in 2030. The infrastructure to support connectivity must function with high reliability and robustness to support GA operations. The infrastructure necessary for each connectivity category depends on what data, data links, and services are involved. SMEs agree that varying levels of connectivity are necessary to provide support to GA operators. Additional research is needed, however, to provide guidance on (1) what degree of connectivity is appropriate for pilots/operators, (2) identification and classification of data links used to provide data, (3) standardized data packets, and (4) appropriate telecommunication frequency for connectivity categories. Operational connectivity, as defined by an SME, would require the highest level of connectivity. The highest level of connectivity equates to large amounts of data packets exchanged, increased measures of redundancy and control, and high bandwidth and transfer rates. The remaining categories of connectivity would require lower levels of connectivity, but must remain robust and reliable for GA operations.

As automation and autonomy become part of general aviation, it may be possible to fly—or operate—the aircraft without the skills and training currently associated with obtaining and maintaining a pilot's license; hence, the SMEs distinguished between pilot and operator. To enable GA pilots/operators to fully utilize future connectivity technologies, the GA operations infrastructure must be evaluated. Updates in pilot/operator training curriculum must accompany any changes in connectivity infrastructure to ensure the pilot/operator's understanding of the additional information received in the cockpit. To address infrastructure improvements to enable connectivity, the FAA must collaborate with telecommunication companies, suppliers, and manufacturers. The assistance from this "connectivity community" can provide guidance to encourage innovation, ensure reliability, and maintain safety.

Based upon the feedback and data collected in this research area, the following proposed recommendation is provided for this key topic:

> *Identify gaps in existing connectivity infrastructure and develop a development strategy for meeting the requirements of future enhanced connectivity scenarios.*

3.2.2.2 Information Interfacing

The SME discussions emphasized the need for additional research efforts and policy guidance on information and how it is transferred between entities. Both data and the data transfer process must have standardized procedures and protocols for the GA community to utilize connectivity. Among the SMEs, there were diverse perspectives about how, and on what aspects, the FAA should provide guidance for connectivity. The consensus across all SMEs was that the information within data packets communicated from pilot/operator to pilot/operator should provide increased situational awareness for both parties. How the information is communicated between the provider and the receiver is safety critical, because pilot/operators are making decisions based on this information. While the infrastructure providing connectivity must identify what data types and volumes are transmitted, it is important for the FAA to use that information to develop guidance on how data types and volumes should be handled (i.e., sent, received, and interpreted). The SMEs believe the FAA should not stipulate which data types are used, but should direct research efforts to understand what standardized data and interface formats are necessary and provide guidance on standardized data processing to ensure safe operations. The FAA could develop and improve guidance through collaboration with the connectivity and GA communities. Each community holds information and knowledge that could inform what data types are necessary for safe GA operations. The insight gained from the connectivity and GA communities can help determine the appropriate standardized protocols for the safe usage and control of the interfaces for such data types.

Redundancy and control measures for the data links and nodes is important to consider. Again, because the information traversing the network is used to make flight decisions, protocols are required to ensure the technology operates nominally with high reliable and the users do not misuse or compromise the data. The redundancy measures could involve a “cabin intranet” or internet of things (IoT) to ensure that the data from sources can be corroborated. Source data in abundance may not improve the network because data saturation can increase processing time, hence the need for data verification processes. There is an opportunity for the FAA to provide guidance on the data source limits to minimize network saturation. In addition to source data accuracy, the data packets themselves must be accurate. For GA operations to utilize “Big Data” to improve connectivity between pilot/operators, the FAA should direct research efforts to develop protocols to ensure data accuracy and mitigate errors, faults, and other degradations of data, data links (i.e., interfaces), and data sources. Communication will evolve, and so should the protocols and standards necessary to enable connectivity among the vast number of GA vehicles in 2030.

Some SMEs believe the volume of information currently presented to pilots in the cockpit has reached a saturation point and suggest a better understanding of how to efficiently include added information in the cockpit. Suggestions included protocols where data is processed and evaluated by autonomous systems before reaching the cockpit to help streamline the flow of information to the pilots. This is necessary to prevent high priority information from becoming lost amongst large amounts of low priority information. The data processing protocols can also help turn raw data into actionable information, reducing the amount of time the pilot spends doing this processing themselves. For these automation systems to be effective, they must have industry-wide trust and high levels of reliability and robustness. Research in the areas of human-automation interaction could provide valuable insights into building confidence in future automation systems with which pilots and operators interact. The SMEs did agree that the FAA should refrain from imposing mandatory human-computer interface standards for systems, as they believed it could reduce innovation in this area, where fresh ideas are needed to keep pace as other connective technologies go mainstream.

Based upon the feedback and data collected in this research area, the following proposed recommendation is provided for this key topic:

> *Develop a set of standards to enable a consistent protocol for the transfer of data between GA participants.*

3.2.2.3 Cybersecurity

Cybersecurity is an important factor when considering GA operations that depend on connectivity to perform safe and reliable operations. The SME consensus is that the FAA will need to collaborate with the connectivity community to develop cybersecurity guidance for the 2030 GA operations. Some SMEs suggested that security standards from other areas, such as commercial aviation and the automotive industries, may help inform GA standards for data and communication security. The SMEs agreed that, while the FAA should set standards to help ensure data and communication integrity, the standards should not restrict how industry meets them. Some of the SMEs believe that the future of GA is moving away from mandated standards, but that the FAA can work to identify a minimum level of requirements for future connective technology systems. The experts provided some perspective on processes and protocols that could benefit GA and ensure the safety of the data, data links, and the network as a whole.

Protections against cyber-attacks can extend beyond restriction control and firewall protection protocols. One alternative that was identified as a sub-optimal alternative was encryption. Encryption services, as described by multiple SMEs, are not necessary for GA operations. Encryption services would require real-time maintenance to update and keep nominal. In addition, the existence of encryption could increase the desire to overcome the encryption from malicious parties. SMEs also mentioned that the services needed to execute and maintain the encryption could overload the connectivity network and cause degradation in other areas. Antivirus software was mentioned as an alternative to protect the connectivity infrastructure, but no other comments were made. SMEs also believe that validating data received by an aircraft will be the responsibility of the vehicle receiving the data. Due to liability concerns, the FAA should not validate sources of broadcast data. Cybersecurity is a subtopic of connectivity that requires additional investigation; however, the SMEs are sure the FAA would benefit from leveraging the knowledge from the industry leaders to generate guidance for securing a connectivity network that is expected to provide service to vast numbers of GA pilots/operators in 2030.

Based upon the feedback and data collected in this research area, the following proposed recommendation is provided for this key topic:

Identify and implement a strategy for ensuring the digital safety of GA participants and their data that reflects the diverse nature of GA operators and operations.

3.3 Research Area: Automation & Autonomy

3.3.1 Overview and Description

Participants in the future of GA workshops in 2016 and 2017 during Phase I of Project 25 mentioned automation and autonomy frequently. These were arguably the most discussed concepts. There have been big advances in automation technologies made in the last two decades, and GA is poised to benefit from them. However, the PEGASAS Project 25 team recognized that, in many ways, the use or implementation of automation and autonomy serves as an enabling aspect of other aspects of GA. Indeed, most research questions about autonomy and automation will require the context of the implementation. As a result, the research area of *Automation & Autonomy* appears as a topic in almost all the other research areas described within this report, so key insights relating to *Automation & Autonomy* will be examined in relation to the contexts afforded by the other research areas.

With the context-dependent issues of automation and autonomy addressed in other GA research areas, this research area considers application-agnostic aspects that must be addressed to enable implementation of automation and autonomy in other research areas. Because of this, the research considerations here focus on software feasibility, reliability, testability, and certification, with an emphasis on aspects that may be specific to GA.

- **Software Reliability** is important to consider. For the autonomy or automation to be successfully integrated into GA, it must be trusted by GA participants. This leads to the need for some level of assurance regarding the safe operations of these technologies. The FAA would likely be concerned with ensuring the reliability of both the software and hardware of the automation system. Furthermore, while processes such as DO-170B (RTCA, 1992) are available for performing this type software reliability assessment, their cost of implementation currently poses an additional hurdle for successful integration into GA.
    - *Will the standards (Level A, B, C, D, and E) for safety-critical software change in the future?*

- *How can the FAA help make software verification quicker and still maintain reliability (e.g., run-time assurance of software)?*
- *Can scenario-based testing reduce test cases and thereby time and cost?*

- **Hardware Reliability** is equally as prominent as software reliability within automation and autonomy. In integrating automation or autonomy into GA, it is anticipated that additional hardware will be necessary on-board the aircraft. Additional hardware impacts the aircraft electrical system, airframe design, cockpit layout, and ultimately the weight of the aircraft. In addition, this hardware will have to function reliably for various environmental and operational conditions, consistent with the safety standards which exist for current hardware implementations.
  - *What does the FAA need to know to ensure reliability of a hardware system of new technologies being introduced into GA?*
  - *What tools and data does the FAA require? How can this be processed quicker than it is done today?*
  - *What technologies should be developed to ensure safe operating conditions for automation hardware?*

3.3.2 Findings and Proposed Recommendations

SME feedback about *Automation & Autonomy* emphasized five key areas and the associated implications on software reliability and on electrical and avionics hardware. The SME discussions provided content for design assurance practices, human operator and automation interaction, automation protection and validation, certification, and enabling technology content. The insight provides a basis to evaluate objectives and disruptors in this emerging research area of GA. The SME feedback insists that the FAA and GA stakeholders benefit from intentional research efforts and collaborations within the automation and autonomy subject area and community. The increase in automation and autonomy capabilities and technologies provide opportunities for GA manufacturers, suppliers, and operators to develop simplified vehicle operations, effective automation, and robust autonomy for safe GA operations.

Based on the feedback and data collected in this research area, the PEGASAS Project 25 team believes the *Automation & Autonomy* research area objective is to:

Develop methodologies to evaluate and ensure software and hardware reliability for automation systems onboard future GA aircraft and external systems enabling GA in future.

3.3.2.1 Software Reliability

Software for avionics and flight control must provide adequate levels of safety, integrity, and robustness for GA pilots and operators in 2030. GA operations in 2030 will require pilots and operators to fly in a denser airspace shared with both piloted and unmanned vehicles; hence the need for improvements in software reliability to maintain adequate levels of safety, integrity, and robustness. Software can leverage automation and autonomy to provide favorable improvements in software capability, flight envelope protection, and operation automation. The flight augmentation provided by variant levels of automation and autonomy can lead to higher functioning software, reduced pilot/operator load, and safer operations.

Software reliability recommendations for GA 2030 extend beyond increased functionality and capability. The SMEs suggested that future software research investigate software design assurance, dissimilar redundancy mitigation strategies, alternative validation and verification strategies, and trade studies for the appropriate division of responsibility in human-automation and human-autonomy interactions to identify improvements in software reliability. Research questions about design assurance aims to improve the design intent and execution of the software itself. Software used for aviation operations must demonstrate high reliability because of certification standards; however, software developed with poor design intent can introduce latency and unintended failure modes when operated by an automation-and-autonomy system. An ill-designed software can be certified and reliable, but still reduce the reliability of the automation and autonomy onboard. Because software used for automation and autonomy may control both critical and non-critical flight processes, the design of the automation-and-autonomy system must ensure system safety and integrity. Design execution and design intent for software vary for a given designer and design methodology; however, additional design reviews used in the development of software can provide adequate oversight to mitigate unintended design flaws and failures.

Automation and autonomy can augment critical and non-critical flight tasks and functions. The versatility of automation and autonomy enables reductions in pilot/operator task load and simplified vehicle operations. Given the aircraft size and onboard avionics, a GA aircraft can house various automation-and-autonomy software packages. The software packages can operate independently or operate as an integrated software package. Commercial-off-the-shelf (COTS) software packages are viable alternatives for both individual and integrated automation-and-autonomy software packages based on cost and functionality. A challenge of automation-and-autonomy COTS alternatives is installation and integration. SMEs believe the installation and integration process can introduce unintended risk of system failure during operations. The reliability of onboard avionics systems may fail or become susceptible to compromise because of failure modes—both known and unknown—in the COTS software, which can take tremendous effort to remedy. The cost savings in design and development from installing COTS automation-and-autonomy software from vendors provides a benefit for pilots, operators, and manufacturers; however, the inability to mitigate known and unknown failures inhibits usage. COTS automation-and-autonomy software implemented for GA must include risk assessments and validation efforts to interrogate software integrity and reliability. Across the SMEs, COTS automation-and-autonomy software validation concerns were consistent. Two recurring concerns were (1) to what extent can the GA community accept COTS service history for automation-and-autonomy software as proof for validation; and (2) to what extent can COTS service history for automation-and-autonomy software serve as a measure of technology readiness? The guidance in documents RTCA DO-178B (RTCA, 1992), FAA AR-01-26 (FAA, 2001), and FAA AR-03-77 (FAA, 2004) provide a basis to address the concerns above, but additional research in both theoretical and practical verification is necessary to expand the use of service history for DO-178B compliance.

Software robustness is important when considering automation and autonomy for GA operations. SMEs believe automation-and-autonomy software must contain robust features to maintain safe GA operations. Automation and autonomy rely on fault detection and mitigation strategies to maintain acceptable levels of robustness and safety. Fault detection and fault mitigation strategies require separate software implementations. A common fault detection implementation strategy mentioned by SMEs during the interviews is the incorporation of software labeled as "run-time assurance wrappers" to monitor the system during run-time and provide assurance that the system responses remain within bounds. Run-time assurance for automation and autonomy for GA operations includes high-integrity monitoring to ensure robust software functionality and safety. High-integrity monitoring can lead to reduced pilot/operator intervention, enabling pilots/operators to focus on more critical tasks in flight. Run-time assurance wrappers can monitor multiple flight and non-flight functions. Flight functions like stability, control, and throttle setting, for example, affect the flight envelope of the aircraft. If GA aircraft use high-integrity monitoring within run-time assurance wrappers, then the automation and autonomy can provide flight envelope protection. Fault mitigation strategies for automation and autonomy in

GA operations depend on pilot/operator intervention, hence the need for tradeoff studies for appropriate human-technology interaction during flight operations. Automation-and-autonomy software functionality is inherently limited compared to the human pilot/operator, so for the software to augment pilot/operator tasks, there must be guidance on the interaction between the human pilot/operator and the technology.

To ensure robustness in automation-and-autonomy software, extensive validation is required on all components and processes. To comply with DO-178B, the automation-and-autonomy software must undergo numerous test case scenarios to validate. The challenge for automation-and-autonomy software validation is developing rigorous test case scenarios that prove compliance. Compliance may be possible if validation can prove the automation-and-autonomy software is unlikely to exceed the test case scenarios. Because all conceivable test case scenarios will not be tested, there is a need for additional guidance to define a basis of automation and autonomy test case scenarios to satisfy DO-178B compliance.

Based upon the feedback and data collected in this research area, the following proposed recommendation is provided for this key topic:

> *Recommend tools and technologies to the FAA that can help evaluate and ensure safe and reliable execution of software code quickly and effectively for given operating scenario.*

3.3.2.2 Hardware Reliability

Avionics hardware, like avionics software, must provide adequate levels of safety, integrity, and robustness for GA pilots/operators in 2030. Because GA operations in 2030 may require pilots and operators to fly in a denser airspace shared with both piloted and unmanned vehicles, avionics hardware must perform with high reliability to ensure safe operations. GA aircraft avionics hardware vary from steam gauges (which are technically not "avionics" but simply flight instrumentation) to glass cockpits; however, each configuration must perform with high reliability to provide automation and autonomy functionality. SMEs believe automation and autonomy can extend to devices brought onto the aircraft as well as technology integrated into the vehicle. The advent of Portable Electronic Devices (PEDs) enables pilot/operators to leverage high-computing portable devices to augment communication and increase situational awareness. PED devices include, but are not limited to, COTS devices like smart phones and tablets. PEDs expand functionality in the cockpit, but such devices must also perform with high reliability to enable and augment automation and autonomy capabilities. The FAA provides guidance on acceptable hardware for use in the cockpit and the appropriate reliability; however, with avionics hardware technology expanding, some SMEs believe the FAA guidance must also evolve. The FAA can remain current by expanding collaboration with hardware developers and suppliers in the "automation and autonomy" community. Collaboration among the FAA and "automation and autonomy" community can encourage knowledge exchange to help address shortcomings in both the technology and guidance governing the technology. The SMEs believe a short-coming of automation and autonomy technology for GA is cost. The FAA cannot set the market for automation and autonomy technology, but the FAA can provide guidance to regulate the performance and use of such technology in a manner that incentivizes developers and suppliers. Such incentives could include streamlining (i.e., making more cost-effective) the certification process or access to flight data for validation. For GA operations, avionics cost plays a vital role, and both the FAA and the "automation and autonomy" community can leverage each other to benefit the GA community.

Automation- and autonomy-enabled hardware aims to reduce pilot/operator task load and increase situational awareness in flight. SMEs believe flight functions that automation and autonomy could improve include collision avoidance, communications, and state monitoring.

Collision avoidance requires vast amounts of data from different sources to operate effectively. The hardware necessary to operate collision avoidance functions requires reliable automation to aggregate the data and reliable autonomy to synthesize trajectories for safe operations. Collision avoidance relies on data links and positioning data from ATC and other aircraft to operate. For automation and autonomy to improve this function, research is necessary to identify and prioritize data link nodes and sources necessary for safe operations.

Communication and state monitoring are pilot functions that improve with automation and autonomy. Communication is a critical task in GA operations, because it affects all aspects of operation: without communications, safe operations cannot exist. SMEs contend that communication is critical for flight operations, but establishing, maintaining, and executing communication can be difficult. Given that pilots develop effective communication skills as the number of flight hours gained increases, there is a need to address pilot proficiency. One alternative discussed by SMEs is using automation and autonomy via pilot augmentation technology to reduce the experience gap. Pilot augmentation technologies allow pilots to use automation to simplify vehicle operations. The automation required in pilot augmentation hardware must operate with high reliability because the pilot/operator needs to trust that the tasks allocated to the "virtual co-pilot" will be completed with minimal failure. "Virtual co-pilot" technology, as described by one SME, can leverage automation via onboard decision-making to augment pilot operations for low-level tasks. Pilot augmentation technologies like "virtual co-pilot" also include state monitoring for both the aircraft health and flight states. State monitoring benefits greatly from automation because state monitoring requires multiple passes of several data sources (e.g., engine fuel, pressure sensors, angle of attack indicator, altimeter, etc.), which may be taxing for a pilot/operator in-flight. The hardware housing the automation must operate with high reliability to ensure safe operations. Hardware designers must integrate reliability through extensive product design and rigorous evaluation and validation to ensure nominal operation. Research questions in automation and autonomy for hardware reliability must address validation, certification, and data link prioritization to ensure the hardware reliability is maintained. Aircraft operations rely on avionics hardware to enable flight and communication, so to maintain safe operations, the avionics hardware devices must be reliable and robust.

Based upon the feedback and data collected in this research area, the following proposed recommendation is provided for this key topic:

> *Recommend tools and technologies to the FAA that can help evaluate and ensure safe and reliable operation of electrical hardware quickly and effectively for given operating scenario.*

3.4 Research Area: Future Airspace

3.4.1 Overview and Description

The "GA in Future Airspace" research area emerged as one of four frequently discussed topics within each PEGASAS Project 25 workshop. Upcoming operational scenarios, such as urban taxi, and new aircraft types, such as electric VTOL, will increase airspace density in which GA operates. Larger numbers of aircraft can lead to problems in the supporting infrastructure for air traffic management, such as overload of communication channels, controlling authority, and security measures. If such a scenario were to become reality by 2030, the FAA needs to be prepared by leveraging automation technologies to help prevent in-air collisions, manage airspace, and control larger numbers of aircraft than is done today. Furthermore, the automation technologies must be safe, reliable, and impenetrable to external attacks. The FAA will likely be driven to investigate airspace design due to the larger variety of aircraft with different levels of technology operating in the same volume of air.

"GA in Future Airspace" aims to provide information about how the airspace may be regulated, alongside an assessment of new technologies that may be integrated and managed in the future. "Future" is defined as the projected 2030 time frame of operation and service. The airspace is defined as the charted airways within which aircraft have authorization to operate. To achieve this objective, the following topics were developed to represent aspects of Future Airspace that are affected:

- **Air Traffic Control and Management** operations directly affect the way GA interact with the airspace and other operators. Additional information and feedback from industry partners, academia, and government entities enables the PEGASAS Project 25 team to identify needs and recommendations for GA operation in 2030.
  - *What aspects of GA Air Traffic Control and Management will be impacted the most in the future?*
  - *What resources, technologies, and capabilities will be necessary to manage increased numbers of diverse GA aircraft in the airspace?*
  - *What additional skills are required by ATC controllers to provide air traffic services to pilots of varying proficiency?*
- **Airspace Evolution** occurs with advancements in technology, capability, and regulation at the aircraft and operator levels. The airspace is expected to house and operation increasing numbers of diverse aircraft in 2030. The modernization of the airspace and potential airspace class reformat attribute to the evolution of the airspace from its current state. The needs and recommendations elicited by SMEs enable the PEGASAS Project 25 team to understand what aspects of the airspace require attention and resources from the FAA.
  - *What lies beyond NextGen airspace? With growing GA traffic will we need a version 2 of NextGen for GA?*
  - *Will current airspace restrictions require revision to accommodate diverse GA aircraft?*
  - *What additional features/capabilities/technologies are required for GA aircraft and or pilots to comply with NextGen (i.e., tablet/iPad functionality)?*
- **Automation & Autonomy in Airspace Control and Management** involves accepting varying degrees of autonomy and augmentation in air traffic control and management tasks and operations. The areas impacted the most are traffic detection and avoidance;

airspace management and aircraft-airspace compliance; pilot-controller communications and pilot connectivity; and accessibility to airspace conditions (e.g., weather, aircraft volume) information. The level of usage and acceptance, safety, and utility are recommendations the PEGASAS Project 25 team wish to provide to the FAA.

- *What tasks of detect-and-avoid need to be automated (or have existing automation improved) and why? What controls do humans still need to retain?*
- *How will new and old aircraft technology integrate in the same airspace?*
- *What tasks of airspace management and compliance can be automated and why? What controls do humans still need to retain?*

3.4.2 Findings and Proposed Recommendations

SME feedback about *Future Airspace* emphasized three key areas and the associated implications on air traffic control and management, airspace evolution, and autonomy and automation of air traffic control and management. The insight provides a basis to evaluate objectives and disruptors in this emerging research area of GA. SMEs believe there will be a wider spectrum of certifications and experience levels among pilots and operators operating vehicles in the NAS. SMEs cite the expected advent of decision support tools as standard equipment in future GA vehicles as a significant reason to continue to develop a pilot certification hierarchy. SMEs use the example of glass cockpit aircraft versus traditional six-pack equipped aircraft. A pilot trained to fly an aircraft equipped with glass cockpit technology may need additional training to fly a six-pack equipped aircraft and vice versa. The SMEs suggest that one option is for the FAA to establish which vehicles a pilot/operator can, and cannot, operate under a given certification. The SMEs also suggest that it will be important for the FAA to understand the difference in skill sets between less experienced pilots using vehicles with some level of automation and pilots flying legacy aircraft that do not have automation to ensure the differing skill sets are reflected in the pilot and operator certifications. SMEs suggest that operator and pilot certifications may be driven by the technology onboard the aircraft, the types of displays, or the information that is displayed within the cockpit. In some cases, certifications to bridge the gap between aircraft of a similar physical architecture with different pilot interfaces and levels of automation may be needed.

One SME acknowledged two potential futures for GA: the possibility that GA could continue to decline in the near-term or the potential for GA to become a dominant fill-in between commercial aviation and road transportation.[1] All SMEs in the airspace interviews spoke about the research needed to facilitate the second future. The SMEs discussed the potential for air carrier operations using small, propeller-driven aircraft on important routes with low passenger volume to disrupt the future GA airspace. SME feedback suggests that these "thin-haul" operations could be made commercially viable if emerging technologies, like electrification and automation, enable lower-cost operations. Many of the airports that currently support GA operations may see thin-haul operations, and the airspace between these airports—at altitudes common to GA operations—may also become busier. SMEs believe thin-haul could increase overall demand in the commercial aviation industry and shift the distribution of that demand. Thin-haul could shift demand to what are currently secondary airports, and potentially change what are the currently dominant routes in the NAS. While SMEs believe Urban Air Mobility (UAM) operations will have a larger impact on the restructuring of the airspace than thin-haul, they suggest that thin-haul operations will cause a significant redistribution of smaller operations to different locations and routes than those in use today.

Remote Tower Operations (RTO) is another idea the SMEs believe may disrupt the future GA airspace. RTO does not have to be a government function; this could be a privately contracted service that could allow smaller airports to handle more traffic and provide better services to its users. By enabling smaller airports to provide on-demand air traffic control services, RTO can expand the available runways to a wide spectrum of future aircraft and operations. RTO could bring controlled airspace into areas that have more traditionally been uncontrolled. The SMEs acknowledge that some work may be required to determine the way RTO—and current and future GA operations, possibly including small recreational UASs—will mesh in these areas.

Based on the feedback and data collected in this research area, the PEGASAS Project 25 team believes the Future Airspace research area objective is to:

> *Develop methods and capabilities for the FAA to design and manage future GA airspace considering future GA aircraft density, technologies, and operations.*

[1] Most of the interviews in this topic were completed before the full effects of the COVID-19 pandemic had set in across the world. There has been discussion that perhaps GA may eventually see an uptick in activity if a sizable number of travelers wish to avoid flying in higher-capacity commercial aircraft.

3.4.2.1 *Air Traffic Control and Management*

Air traffic control and management operations are subject to change given future operations and vehicles in 2030. Because ATC acts as a conduit that connects and coordinates pilots of various certification and vehicle operation, the need to ensure ATC is well-equipped to manage an increased number of operations and vehicles becomes more significant. For GA, interactions with ATC range from clearance requests and routine check-ins to mid-flight interventions. Pilots and ATC currently communicate verbally over radio. SMEs contend that ATC communication in 2030 requires data communication to sustain air traffic services for the increased number of operations and vehicles. Discussions arose involving data communication as a possible alternative to verbal communication, allowing ATC controllers to expand services to more pilots and reduce non-critical communication. Data communication technology can improve ATC communications with GA pilots such that routine check-ins and clearance requests over uncontrolled airfields impose a smaller impact on ATC controller workload. Because GA pilots share the airspace with commercial (and military) operations, and ATC prioritizes the latter, data communication could streamline GA communications in the denser airspace projected in 2030. To service all pilots in the airspace, including GA, data communication technology may require an ADS-B–like mandate to ensure adoption in the aviation community. Industry-wide adoption is necessary to ensure safe operations. To address industry-wide adoption, the FAA, industry partners, and telecommunication companies must collaborate to develop cost-effective solutions and redundancies such that GA pilots are able to integrate the technology in their aircraft.

SMEs believed UAM operations will influence a change in the way ATC operates. This change may cause a redistribution of roles between humans and automated systems and affect how the airspace is designed and managed in the future. Today, airspace is designed to help pilots build and maintain situational awareness and form predictions of an aircraft's future behavior. SME feedback suggests, however, that automation will be a necessary component of future ATC schemes, which may lessen the need for some of the current structure. SME feedback suggests that ADS-B, or similar technologies, could play an important part in future air traffic management schemes. SMEs suggested that with the expected increase in airspace density, self-separation and dynamic airspace classifications are two concepts that could reduce ATC’s workload, improve flight efficiency, and increase airport throughput in future high-density airspaces. The potential increase in communication workload between ATC and UAM operations near airports could be reduced using dynamic airspace classifications. SMEs believe that dynamic airspace classifications could also improve ATC operations, especially in urban environments. SME feedback also suggested that the foundation for a self-separation system for aircraft could be built upon current technologies, like ADS-B, and, with some additional modification and development, could be ready for real-world testing relatively soon.

SMEs discussed two competing ideas about how controlled airspace should be managed in the future. One idea leans toward allowing operators more latitude in determining their routes and the use of a traffic management system that considers 4D-trajectories. SMEs suggested this method has benefits over the current system, such as reducing the workload on controllers and more efficient operations, both of which SMEs believed could be important with the expected increase in the number of operations in controlled airspace. SMEs believed a more dynamic airspace would cause controllers' current role to change and require the use of an automated system to inform controllers as to whether a flight is behaving correctly or not. SMEs also suggest that this concept of air traffic management may improve commercial operations but make it more difficult for GA aircraft to operate in controlled airspace, as there may be equipment requirements for interacting with the automated system and other aircraft. The other traffic management concept discussed centers around using restrictive and tighter tolerance routes, like area navigation (RNAV), for traversing controlled airspace. While this idea is more structured than the other, SMEs suggest this method of control could also have human factor implications for controllers. SMEs asked the question, "If aircraft are flying tight tolerance routes, with a low error rate, and are separated by an automated system, what is the job of the controller in this scenario?" No matter the method chosen, SMEs suggest that the roles of air traffic controllers will change.

SMEs suggest automation plays a role in both traffic control scenarios. Whether monitoring aircraft on many different routes or controlling the separation between aircraft along the same route, automation is considered a part of both systems. In addition, in both scenarios, human factors need to be considered to determine what functions a controller is reasonably able to perform, and what tools and training are needed to help controllers maintain an acceptable understanding of the air traffic they manage.

The advent of data communication potentially opens the market for third-party data service providers (e.g., Google, Amazon, IBM, etc.) to provide air traffic services. The third-party data service providers may be useful for augmenting data provided to avionics. SMEs believe weather and traffic data could benefit from the use of third-party data service providers. Because many GA pilots currently use portable personal electronic devices in the cockpit, the use of third-party services is already present; however, industry-wide adoption can standardize the data available and ensure data accuracy and redundancy. The air traffic services outsourced to third-party data service providers may possess managerial independence from the FAA, but the FAA must still impose oversight policies such that air traffic services are protected and secured.

Based upon the feedback and data collected in this research area, the following proposed recommendation is provided for this key topic:

> *Provide guidelines and recommendations on Services, Workforce management, and Operation classification that can help the FAA control future GA air traffic effectively and with desired safety.*

3.4.2.2 Airspace Evolution

The airspace is projected to service large numbers of operations and vehicles in 2030. To achieve safe and reliable operations, the airspace must adapt to service the aviation community. Discussions among the SMEs revealed inconclusive findings that the airspace requires re-classification to service the pilots/operators, operations, and vehicles in 2030. Some SMEs contended that airspace re-classification should be driven by equipage and certification requirements to traverse the airspace. For example, for an operation to travel though Class "X" airspace, the vehicle must possess <insert capability/technology> and the pilot/operator must possess <insert rating/certification>. If equipage and certification requirements are present, the FAA, NASA, and the aviation community must collaborate to determine suitable requirements for future airspace. Other SMEs expected the airspace to evolve using dynamic and static airspace designations to accommodate increasing UAS operations. For GA operations, the use of dynamic and static airspace designations may affect how pilots/operators use the airspace, but the hope is that GA operations and services may expand with the increased use of dynamic airspace designation.

SMEs unanimously agreed on the notion that airspace re-classification efforts pose a difficult challenge and will take time. A transition is likely, given the future operations and vehicles to enter service by 2030; however, the FAA, NASA, and the aviation community must continue developing a roadmap for the future airspace. This roadmap should include content about airspace structure, advanced technology usage, airspace "sandbox campaigns," and pilot/operator definitions. Among the roadmap content, potential sandbox campaigns piqued interest among SMEs during discussions. The sandbox would represent portions of the airspace used to investigate advanced technologies and operational scenarios. SMEs mentioned government test sites and interested cities could be leveraged to execute research Certificates of Waiver or Authorization (COAs) in a similar manner to the NASA UAM Grand Challenge.

Given the expected equipage requirements, SMEs also suggest that retrofitting legacy GA fleets may be required. The retrofitting process will take time, but if new technologies are used for ATC communication, then it will be important to develop a transition plan for legacy craft to remain current. SMEs noted that the FAA must prepare for a future of mixed equipage aircraft given that, historically, fleet wide upgrades have been a very slow process, even when mandated. SMEs believed that determining critical upgrades to the fleet and incentivizing retrofitting efforts could help speed up the process.

When discussing the evolution of the airspace, SMEs did not believe major changes are needed. They focused mainly on refinements to the current structure to allow more flexibility and continued efficiency as the number of operations increases. SMEs believed UAM operations—and in a broader context, UAS operations—will be a significant disruption to the current airspace. Research is needed to determine how large and small UAS, traditional commercial aviation, and GA will interact within the airspace. The SMEs believed there is a division between larger, human-carrying, UAS and smaller UAS. SMEs believed larger UAS, associated with UAM-type operations, will likely integrate into the airspace similarly to a manned GA vehicle with respect to ATC, but the smaller UAS may not. SMEs suggest that airport operations will be critical to the successful integration of UAM operations, as one of the concepts of operations for UAM is airport shuttle missions. Such missions include larger airports, as they are likely to be the desired destination for many customers, and smaller airports, as they could experience a significant change in demand and in types of operations. SMEs also discussed the need to develop reserve requirements, and standard operating procedures (in case of emergency) for UAM.

Dynamic airspace change is another concept the SMEs believed could help improve the utility of the current airspace. SMEs suggested that factoring in weather conditions, traffic levels, and other important factors to dynamically update the boundaries of controlled airspace could be beneficial, because dealing with many urban air mobility operations under Class B or C rules could be difficult. SMEs also noted that with this concept, it would again require aircraft to have equipment to receive and communicate these changes in real-time to the operator/pilot. The SMEs discussed the concept of self-separation in the airspace, enabled through an ADS-B–like system. For this system to work, either transponders would have to be mandatory equipment for aircraft or there would have to be another way for this system to handle aircraft without transponders.

One SME mentioned personal health monitoring devices (PHMD) and sensory enhancement technologies pose unique opportunities for aviation. PHMD (e.g., smartwatches) offer the potential to monitor pilots' physiological states and create safety systems to switch to an autopilot, or notify emergency services, if the pilot is rendered unable to pilot the aircraft. The SMEs also advised that the FAA and the aviation community need to begin discussing how to handle pilots/operators using wearable or implantable devices that correct or extend the users sensory capabilities.

Another application of automation discussed by the SMEs are decision support tools. SMEs believe decision support tools have potential to increase the number of GA pilots by lowering the cost of entry to GA in terms of training and required experience. Performance-based navigation, weather, and decision support tools were identified as technologies that GA could benefit from. SMEs believed one of the current obstacles to the deployment of decision support tools is the question of liability, and they believe the FAA could play a role in setting guidelines and requirements, so companies will not shoulder all the liability.

SME feedback also suggests that flight operation classifications need to be considered when discussing future operations. While some revision may be needed, SMEs suggested most operations, both old and new, are variations on a theme, and the FAA will need to understand how to leverage existing regulatory structures, but also consider changes in the long term for efficiency.

Based upon the feedback and data collected in this research area, the following proposed recommendation is provided for this key topic:

> *Develop methodology for the FAA to evolve the current state and shape of the airspace to accommodate the future needs of General Aviation.*

3.4.2.3 Automation and Autonomy in Airspace Control and Management

According to SMEs, the airspace in 2030 must leverage automation and autonomy to manage the projected increase of operations. SMEs do not expect future automation and autonomy technologies to replace human interaction in air traffic services or airspace management; however, future automation and autonomy technologies may help streamline operations and reduce ATC controller workloads. SMEs believed the transition from tactical controllers to "control managers" would require a revision of controller responsibilities and objectives. The perception of ATC controllers could transition from stick/rudder and geolocation guidance to system-level airspace constraints management. The system-level airspace constraints include operational guidelines and limits to manage the airspace. Because the airspace is projected to facilitate large numbers of operations and vehicles, ATC may operate more effectively using an automated, system-level management protocol. SMEs believed future automation technologies can impact and improve detect-and-avoid or see-and-avoid protocols, data communication protocols, and weather observation tools.

Autonomy within the airspace may only become feasible beyond 2030 as guidance is limited-to-nonexistent regarding non-deterministic system certification, according to the SMEs. Autonomy-enabling technologies (e.g., machine learning, artificial intelligence) will be available by 2030 and many are in use now in non-aviation applications, but the FAA and the aviation community must collaborate to define certification requirements before the technology can be adopted and utilized. SMEs agree that automation and autonomy has potential to improve and expand GA operations and airspace control and management. The most discussed concern regarding automation and autonomy is cost and legacy vehicle compatibility. To deliver cost-effective automation and autonomy technologies to GA operations within the airspace, the FAA and the aviation community must collaborate to reduce the cost point for reliable systems and provide guidance on legacy vehicle compatibility such that pilots/operators and legacy vehicles can communicate and remain safe in the airspace.

Communications, piloting, and ground services are three of the many tasks and functions that SMEs identified as potential beneficiaries of automation. SME feedback suggests that while there are potential benefits to automation, ensuring the reliability and safety of any automated system will be a significant undertaking. The SMEs believe that ATC in general is shifting towards giving pilots and operators more freedom to determine their routes, and automation will play a significant role in enabling this shift. The SMEs believe the FAA should work to determine what are acceptable re-allocations of roles between automation and humans on the ATC side, and how to ensure automated tasks are performed in a safe and reliable way that does not negatively impact the airspace. The SMEs also suggest the FAA consider how automation gets included into new regulations, and in the interpretation of existing regulations.

SMEs suggest that communications between entities in the airspace could be automated to improve efficiency and reliability. SMEs use the examples of Artificial Intelligence (AI) computing a reroute that both pilot and controller can then review and act on, an autonomous system managing frequency changes for an aircraft, and automated detect-and-avoid as illustrations of the numerous tasks that could be shifted off of the pilots and controllers using automation. SMEs believe that automated decision support tools and automated weather information systems could be beneficial, but may lead to an increase in less experienced pilots operating in the airspace. The SMEs recommend rigorous vetting for any decision support tool, and believe feedback from experienced pilots could be key to refining the tools and building trust in them. SMEs suggest that smaller airports that are not staffed 24 hours per day, 7 days per week could use autonomous traffic management systems to provide better airspace management as airspace density increases. SMEs also mentioned that voice-to-text technologies should be explored and evaluated by the FAA as data communications may improve efficiency and reliability of communications, depending on the accuracy of the technology. Determining the appropriate accuracy is a potential research topic.

The SMEs also discussed many obstacles to bringing automation into aviation. SMEs noted that air traffic controllers are wary of UAS because there is not a strict protocol for how UAS will react to a given scenario. Air traffic controllers have been trained to impose a structure on the airspace based on rules and regulations which dictate what actions are to be taken in a situation, and have lots of experience with manned aircraft and what actions pilots will take in different scenarios. However, manufacturers and operators of UAS may find many different solutions to the same scenario, which adds a level of unpredictability for the controllers. SMEs suggest that the controllers will still want to feel confident when predicting what actions an aircraft might take, so it will be critical for the integration of UAS systems to determine what information or tools are needed for controllers to feel comfortable doing their jobs. SMEs believe this same unpredictability will also occur if pilots are given more control over routes and resolving conflicts between aircraft. The SMEs believe that automated systems will be needed to assist controllers in maintaining an acceptable level of understanding and vigilance of the airspace.

Based upon the feedback and data collected in this research area, the following proposed recommendation is provided for this key topic:

> *Recommend how the FAA can leverage automation and autonomy technology to reduce in-air collision, airspace excursion/incursion, and improve GA pilots' communication.*

3.5 Research Area: Future Propulsion Systems

3.5.1 Overview and Description

The Phase 1 effort identified propulsion as one of the five key transformational areas for GA. Survey data collected by the FAA in 2015 shows that of the 19,200 fixed-wing aircraft considered as “General Aviation and Air Taxi,” 12,825 used one or more piston engines, 2,538 used one or more turboprop engines, and 3,837 used a turbojet engine. There has been a reluctance to develop a completely new engine specifically for the GA, and most of the current engines are based on designs from the 1930s era. While the existing fleet of GA vehicles almost exclusively utilize internal combustion engines, future GA vehicles are expected to adopt a wider range of powerplants, potentially including turbofan, turbo-electric, electric, and fuel cell. In fact, with concepts like the urban e-VTOL and urban air-taxi being developed by the industry, the question should be “when” rather than “if” these newer propulsion systems will be introduced into the GA world. With these changes anticipated in the future, three relevant topics have been identified for further investigation.

The first topic requiring further investigation relates to identification of a portfolio of powerplant options that will be available to GA by 2030. Several nearer-term propulsion system challenges that may need to be addressed first include electric, hybrid-electric propulsion, and very small turbine engines. Options such as turbo-electric, fuel cell-powered powerplants are anticipated in the longer term. There are two prominent impact areas that need to be considered under this topic and can lead to changes in requirements at the powerplant and aircraft level:

- **Energy Source Considerations** refer to the proliferation of future alternative energy options such as alternate fuels, electric propulsion, fuel-cells, etc.
    - *How does the storage and usage of future energy sources impact the safety and performance of future GA vehicles?*
- **Life Cycle Management**: The potential growth of improved propulsive systems may inspire both the production of new airframes equipped with these systems and an increase in the number of propulsive retrofits on existing airframes. This growth must be matched with effective strategies for managing the full life cycle of propulsion systems due to potential economic and environmental risks.
    - *Does the production, installation, or disposition of future propulsion systems present negative economic or environmental risks?*

The second topic pertains to certification and the impact these future propulsion systems will have on the regulatory environment. An examination and potential adjustment of the existing regulatory framework should be performed alongside the development and introduction of new propulsion systems to maintain acceptable safety standards. Many of the technologies being considered for future GA propulsion have existed in ground operations for a longer duration than they have been considered for GA, e.g., electric motors and fuel cells. As a result, standards for their ground operation exist and can be referenced when considering the future standards for GA. This way, research done in UAS, automobiles, and power-generation industries can be advantageously utilized. Apart from these references, data gathering and expertise development necessary to support certification of future GA propulsion via industry-based standards can be considered. The above-stated arguments lead to two impact areas for this research topic:

- **Airworthiness Standards** as they are currently defined may not capture all the possible architectural solutions that can be envisioned for GA propulsion systems of the future.
    - *Are the existing certification requirements of Part 23 Subpart E sufficient to ensure the airworthiness of future GA propulsion systems?*
- **Type Certification,** as stated in 14 CFR Part 33, do not apply entirely to GA propulsion. A cursory glance at the requirements shows that they are not pertinent to the GA powerplant options of 2030.
    - *Part 33 currently provides general guidelines for all engines and specific guidelines for existing propulsion systems. What information would be needed to develop specific engine certification requirements for future propulsion systems?*

Automation and autonomy form the third topic in this research area. Advances in automation and autonomy will likely impact the ways in which propulsive systems are operated and managed. There is uncertainty in the types of automation and autonomy that will emerge in the future as well as in their impact on the current state of the GA propulsive autonomy and automation. These considerations can be summarized in the following impact area:

- **Standards of Propulsive Automation**
    - *Are the certification requirements of "Part 33.28: Engine Control Systems" sufficient for the certification of future GA propulsive automation and autonomy?*

3.5.2 Findings and Proposed Recommendations

SME feedback about Future Propulsion emphasized three key areas and the associated implications on identifying future powerplant portfolios, certification, and autonomy and automation. The insight provides a basis to evaluate objectives and disruptors in this emerging research area of GA. Electrification and automation are two of the main disruptors SMEs brought up during interviews. Electrification has the potential to significantly impact operational costs by reducing fuel costs, as well as improving maintainability and reliability as electric propulsions systems tend to have fewer moving parts. Electrification could be viewed as an enabler as well as a disruptor to the current aviation community. Becoming a pilot is an expensive and time-consuming process, but SMEs believed electrification could greatly reduce the cost of entry, leading to an increase in the number of GA pilots.

SMEs also believed that certification of electric propulsion systems will need to be further developed to make the process more efficient and cost-effective. Electrification will have an impact on the design of every aspect of an aircraft, and new aircraft may be uniquely designed to exploit the strengths of electric propulsion that cannot be achieved retrofitting electric propulsion systems into traditionally internal combustion engine (ICE) aircraft. Another consideration SMEs brought up was life-cycle management for aircraft with newer propulsion systems. There is the likelihood that battery cells would need to be replaced before the airframe has reached retirement and, at some point, an electric aircraft will be retired and there will need to be a plan for how to handle toxic and chemically sensitive components in the batteries.

In the area of automation, SMEs believed that health monitoring may quickly become a common feature on propulsion systems. With newer architectures, such as hybrid or all-electric propulsion systems, there is yet a need for research to determine what conditions are reliable indicators of the overall health of the system. SMEs also believe that future propulsion systems may be utilized more for overall aircraft control and not just as a propulsive force, and with this shift in function will come more autonomous control algorithms that manage propulsions system in conjunction with the attitude of the aircraft and inputs from the pilot.

SMEs are also aware of the work being completed as part of the ASTM (formerly known as the American Society for Testing and Materials) committee F44 to consider standards for Aircraft Electric Propulsion Systems and recognized the continuing need for support of those efforts.

Based on the feedback and data collected in this research area, the PEGASAS Project 25 team believes the Future Propulsion Systems research area objective is to:

> *Identify future GA propulsion systems to identify new standards for fleet integration and type certification.*

3.5.2.1 Powerplant Portfolio Identification

According to SMEs, the projected powerplant portfolio of 2030 consists of the exploration of greener engine architectures, novel vehicle and system integration, and guidance from the FAA. The FAA enables progress in the industry by indicating areas of research for the industry to develop and address with technology. The guidance developed by the FAA and industry partners can lead to a roadmap document that outlines current progress and projects future milestones for technology development. This roadmap document would include specific goals and objectives, within each research area, that may enable propulsive technologies by or beyond 2030.

In 2030, SMEs expected hybridization, electrification, and cleaner internal combustion (IC) propulsive technologies to appear as viable powerplant option architectures. SMEs believe the transition to greener technology begins with hybridization and smaller IC engines. The consensus in the SME discussion suggests that IC engines will remain in service up to and beyond 2030. SMEs expected manufacturers to continue improving the IC engine since the technology has a Technology Readiness Level (TRL) level of nine with years of testing, validation, and service history. To maintain range demands with greener propulsion, hybridization is expected to impact GA aviation the most. SMEs believed hybridization is the next step to address environment constraints and maintain feasible operations, and because GA flights have smaller ranges than commercial flights, they are well suited to adopt this technology. The step beyond hybridization includes the incorporation of full electric engine architectures. SMEs expected fully electric propulsion to service trainer and short flight missions, and they see current examples of this under development and some—particularly in Europe—in early production phases now. Given the range demand and expected battery energy density, full electric propulsive technologies still must improve to service GA aviation. If electric propulsion becomes more prevalent and there is a need for increased access to electric power at airports, SMEs believed that airports are ideal candidates for solar farms. If batteries are to be used in future propulsion systems, understanding the fluctuation of output voltage with state of charge—and whether this relationship remains constant or changes with use cycles—will be important. These phenomena will need to be effectively communicated to operators and reflected in the protective margins which are included in future flight standards.

Alternative fuels and hybrid technologies were discussed among the SMEs; this included biofuels and fuel cells. These propulsive technologies, however, are not expected to provide utility in 2030 for GA. Biofuels and fuel cells are greener technologies (relative to CO2 and other emissions) than IC and hybridization, while they are comparable to electrification; however, system cost, energy density, and fuel/energy storage remain concerns when considering GA in 2030. SMEs believed that for alternative fuels and hybrid systems to impact GA in 2030, the system cost and fuel/energy storage must be reasonable, and the energy density must be comparable to hybridization and electrification.

SME feedback suggested that the current challenges of creating an electric storage device with energy density on par with petroleum fuels restrict all-electric propulsion system applications to smaller aircraft with short ranges; however, some SMEs believed that, long-term, electric storage devices could reach a level of energy density not too far below that of petroleum-based fuels. SMEs believed that, while the use of 100LL will continue, there is a need for continuing research to determine requirements for unleaded fuel options beyond the current efforts, like the Piston Aviation Fuels Initiative. Unleaded fuels have environmental benefits over 100LL, but may cause performance degradations or other negative impacts to current engines and fuel systems. For unleaded fuels to effectively replace 100LL, SMEs believed research needs to continue to determine what modifications limit performance degradation as well as how they interact with fuel wetted surfaces, like gaskets and seals. Verifying both material compatibility as well as detonation profiles to ensure as seamless a transition as possible will be important for future adoption of unleaded fuels.

SMEs also discussed the potential of fuel cells in future propulsion systems. Currently, there is some interest and activity in fuel cell research, but SMEs believed there are significant challenges to overcome. A relatively long start up time, and the crashworthiness concerns of compressed gas (for hydrogen or natural gas fuel cells) are just two obstacles that SMEs suggest will need to be researched and developed to make fuel cells a feasible option for aircraft.

SMEs believe that, when considering any potential transition between fuels in the GA community, considering the effect on, and goals of, both owner/operators and airports will be critical. Additional infrastructure will be required at airports to support fuel source transitions. This infrastructure will be a significant investment and SMEs believed that incentives, potentially Airport Improvement Program (AIP) funds, may help push adoption in the early phases of transition. SMEs also believed there may be one or two alternative fuel sources that will win out amongst the field and become widely used enough to merit the infrastructure modifications needed to supply the future GA fleet, and without these modifications to support the use of alternative fuels, owners will be less likely to buy aircraft that use them.

Improved propulsive technologies bring innovation to vehicle capabilities and design. Expected propulsive technologies in 2030 suggest that with hybridization and electrification, the airframe design will include the electrical system. SMEs believed that if hybridization and electrification were to replace modern IC engines in 2030, vehicle design and operation will be impacted most. Because of hybridization and electrification, the electrical system is no longer isolated from the airframe and control. Both the airframe and the control laws necessary to control and stabilize the vehicle shift from the use of mechanical linkages and circuit breakers to solid state and digital actuation. It was unclear to SMEs as to whether vehicles with future propulsion will be classified under Part 23 or Part 27, because STOL or VTOL aircraft development may push this for GA. Though innovation is helpful, some SMEs believed the GA industry is not equipped to deliver and certify eccentric concepts. This notion suggests that legacy vehicles will remain in service because of acquisition cost challenges.

Based upon the feedback and data collected in this research area, the following proposed recommendation is provided for this key topic:

> *In coordination with industry, identify likely future GA powerplant architectures, detailing their operational limitations, energy source considerations, and lifecycle management strategies.*

3.5.2.2 Certification

SME feedback suggests that there is currently no standardized certification path for alternative-fuel-based propulsion systems and the aircraft that use them. SMEs believed the FAA should continue to work with ASTM to develop standards for future propulsion systems. SMEs also suggested that system analysis should shift from a traditionally siloed approach to a more holistic approach, focusing not just on each individual propulsion subsystem's fault tolerance, but on the whole propulsion system's fault tolerance. Holistic analysis that includes system interfaces and overall integration is thought to allow more robust evaluation of future propulsion systems. Model-based analysis will be important for handling the large combinatorial spaces being evaluated. Current assumptions made for evaluation may have to change as well, SMEs discussed the example of moving from "one engine out" failure for multi-engine aircraft to a "critical loss of thrust" evaluation assumption. Standards relating to required fuel level will also need to be re-thought. Visual Flight Rules (VFR) and Instrument Flight Rules (IFR) standards require enough fuel to fly a specified amount of time beyond what is calculated to reach the landing point, but these may need to be modified to consider any degradations in energy storage or battery performance that could occur as the aircraft approaches an empty state.

The challenges for enabling future propulsion are: the separation of the engine from the airframe when hybridization or electrification is used, enabling part swap without certification re-evaluation, and in which format to write certification guidance. It was uncertain among the SMEs which certification format best suits propulsion technologies in 2030. SMEs contended on whether prescriptive or performance-based guidance best enable future propulsion through certification. For example, some SMEs believed that performance-based certification policy enables the industry to innovate beyond the status quo; whereas others believe performance-based policy introduces negotiations of processes and terms for certification to be awarded. The latter perspective requires the FAA to become experts in wide-spread technologies to facilitate certification, whereas the former requires a general knowledge and acceptance that the standards and performance are clearly stated and met.

When considering hybridization and electrification, multiple vendors may exist that can provide this capability at various cost points. Given that GA encompasses aircraft ranging from home-built aircraft to business jets, some SMEs believed a market could exist for owners who would want to “swap” out an IC engine for hybridization or electrification with minimal difficulty with the potential for reduced cost. SMEs believed updates to the certification process and a Part 33 re-write may enable this capability such that there is an incentive to update legacy fleets without the purchase of a new vehicle. There is no current certification pathway for this. For future propulsion in 2030, SMEs believed that additional metrics may be required to certify hybrid-electric and full-electric systems. For electrification specifically, SMEs believed the certification process can have fewer critical failure points because of the simplified propulsive mechanisms. Additional concerns arise when considering hybridization and electrification, such as power storage and metrics to define safety and reliability. Because IC engines have extensive service history and testing that provides the basis for current certification, SMEs believed that the hybridization and electrification technologies for GA powerplants must continue to develop and have a well-established database to demonstrate reliability, safety, repeatability of performance, etc.

Based upon the feedback and data collected in this research area, the following proposed recommendation is provided for this key topic:

> *Develop a set of performance-based standards for the certification of novel GA powerplant architectures.*

3.5.2.3 Automation and Autonomy

Automation and autonomy discussions regarding future propulsion focused mainly on simplified vehicle operations and engine management. The use of automation provides a means to allow solid-state power systems to execute flight tasks to reduce pilot load. Automation capabilities, like simplified vehicle operations that include engine management systems, can provide the pilot with essential engine health metrics that enable safe operation of the vehicle. On the propulsion control side, Full Authority Digital Engine Control (FADEC) was given as an example of how engine performance is improved and pilot workload reduced though this automatic system, and SMEs believed this type of technology will become more common in GA, particularly with electric powerplants, and the need for a propulsion integration package only increases as the number of propulsive units on an aircraft increase. SMEs also believed that propulsion may be used in more of a control capacity as opposed to a purely motive force. Adaptive control and other decision-making algorithms may be required to enable this shift in function. Integration systems, like FADEC, also enable health monitoring of the propulsion system on an aircraft. Expertise that was traditionally required to operate aircraft can be transferred to the monitoring system and alert the pilot only when needed. Within the aviation community, there is a good understanding of what signals must be monitored within a piston or turbine engine, but with newer propulsive systems, there may not be as great an understanding of what signals are the best indicators of the health and performance of the system. This will require additional research to ensure health monitoring systems can properly identify and respond to abnormal health conditions in the engine. The autonomy within the engine management system appears when engine health requires mitigation. For non-critical faults (e.g., loss of engine communication, inconsistent measurements, etc.), SMEs expected the autonomy to rectify the fault or inform the pilot/operator if unsuccessful. Whereas for critical faults, the pilot/operator must be notified for mitigation. Engine management systems are prevalent in commercial and military technology, but GA aircraft may or may not be equipped with such technology. SMEs believed widespread automation and autonomy adoption in GA is necessary for safe operations, but the technology must be reliable. SMEs believed that to achieve the desired reliability, manufacturers should use the reduction in GA accident rates as a metric to drive technology development.

SMEs also asserted that propulsion systems may be used for vehicle articulation and not just as a propulsive force. This will most likely include control algorithms that have some level of autonomy and simplified interface between pilot and the propulsion system. Ensuring the safety and reliability of software, especially decision-making algorithms, will be a significant undertaking. SMEs also believed the decision-making algorithm certification process will be dependent on whether an algorithm is deterministic or stochastic. SME feedback suggests that it would be prohibitive to certify decision-making algorithms, both deterministic and stochastic, under current certification processes, but that some insights could be drawn from the pilot certification process. Pilots are non-deterministic systems that are certified using a “continued learning” approach versus a “once and done” approach, and SMEs suggest the continued learning philosophy could be applied to non-deterministic algorithms, but research will be needed to identify what tests should be run, and what is an acceptable threshold at which to stop testing.

Based upon the feedback and data collected in this research area, the following proposed recommendation is provided for this key topic:

> *Develop a set of standards for the safe incorporation of automation into GA powerplant architectures.*

3.6 Research Area: Passenger Safety & Crashworthiness

3.6.1 Overview and Description

The research area of *Passenger Safety & Crashworthiness* emerged often during workshops held in 2016 and 2017. The research area investigates the increasing passenger safety on GA aircraft as well as survivability of pilots and passengers in a GA aircraft accident. If personal vehicles are to be accepted into society, crash survivability and passenger safety is critical and needs to improve. Technologies from several sources can enable GA to improve crashworthiness. During our benchmarking phase, we identified airframe parachute systems, seat belt airbags, de-icing protection systems, and angle of attack indicators as some technologies that may help improve passenger safety and improve crashworthiness of a GA aircraft. Workshop attendants felt that aircraft design strategies must account for passenger safety and crashworthiness. Lightning strike crashes can be improved upon with current technology. The FAA can improve accident and incident reporting infrastructure and processes to collect better data which can lead to fruitful analysis and safer recommendations.

- **Re-definition of Conditions in Accidents and Incidents and Crashworthiness certification**: Utilizing up-coming concepts of urban air mobility, the definition of accidents and incidents will have to be revisited for various operation and aircraft type. The different type of aircraft and operation will also impact the crashworthiness requirements. Data, information, and new technology can help the FAA evaluate crashworthiness quickly and lead to faster certification.
    - *What kind of data is required to make these decisions? How can FAA collect such data?*
    - *Are there current technologies out there (e.g., transferable automobile crash technologies and processes) that can be incorporated into GA aircraft?*

- *Can new manufacturing techniques and materials help improve crashworthiness? If so, what does the FAA need to know about these materials and techniques to evaluate the required crashworthiness?*

- **Fatalities in Aircraft crash**: For faster integration of new concepts and small aircraft into operations accepted by the public as a common mode of transportation, the fatalities resulting from GA aircraft crashes must improve. There were over 1,900 GA accidents from FY 2010 to FY 2017 that led to fatalities; this data corresponded to the time when the first "GA 2030" workshops were held. Avoiding accidents is clearly important. Minimizing the likelihood of fatalities if an accident occurs is also important. Future aircraft will have to be safe to operate in adverse weather conditions, which can be a contributor to accidents, if they are to see more widespread use as a means of transportation.
  - *We know the top reasons for fatal accidents. Work is currently being done to reduce the accidents because of these causes. However, what is the research in preventing fatality even if an accident occurs?*
  - *For urban mobility and air taxi to be viable, aircraft operational performance in adverse weather conditions will have to improve. Is this a feasible goal? Can future aircraft operate more safely in bad weather conditions?*
  - *What tools and technologies currently exist that can help reduce fatalities in accidents? What additional research is required?*

- **Automation and Autonomy in Safety**: Onboard automation can help prevent accidents and improve crashworthiness. We must leverage automation technologies that save the passengers' and pilots' lives in the event of a crash. Current technologies—such as TCAS, terrain warning systems, and auto-pilots—do help in improving safety, but have not been integrated into all GA.
  - *Is safety a by-product of automation and autonomy in the aircraft? Or is it the main driver? What is the current state of automation that increase GA safety?*
  - *What new automation and autonomy technology should we expect to see in future aircraft that will improve safety?*
  - *How will the FAA relate the impact of the technology to risk and crashworthiness?*

3.6.2 Findings and Proposed Recommendations

SME feedback about *Passenger Safety & Crashworthiness* emphasized three key areas and the associated implications on: (1) guidance and technology to improve passenger survivability, (2) designing for crashworthiness, (3) and leveraging accident and incident data to improve safety. The insight provides a basis to evaluate objectives and disruptors in this emerging research area of GA. The SME feedback insisted that the FAA and GA stakeholders benefit from intentional research efforts and collaborations within *Passenger Safety and Crashworthiness* subject area and community. GA accident rates are among the highest in aviation; therefore, GA stakeholders must develop research objectives to develop, test, and certify processes and technologies that increase survivability. A few SMEs went further and suggested the FAA, NASA, aviation industry partners, and academia initiate a second rendition of the crashworthiness efforts in the Advanced General Aviation Transport Experiments (AGATE) program to address modern-day materials, advanced manufacturing, and crashworthiness topics.

Among the SME discussions, the *Passenger Safety & Crashworthiness* disruptors identified by the Project 25 team were evaluated. Most SMEs agreed that automation and autonomous control, alternative energy, wider spectrum of pilot/operator certification, and additive manufacturing will impact how GA stakeholders approach and deliver safety and crashworthiness measures.

Based on the feedback and data collected in this research area, the PEGASAS Project 25 team believes the *Passenger Safety & Crashworthiness* research area objective is to:

> *Develop policies and methods for FAA to increase aircraft crashworthiness and passenger safety for future GA aircraft operations in all weather conditions.*

3.6.2.1 Re-definition of Conditions in Accidents and Incidents and Crashworthiness certification

SMEs believed passenger safety and crashworthiness for GA must be addressed using technology, Part 23 certification re-writes, and the use of accident and incident data. The FAA can leverage findings and records from additional regulatory bodies, such as the National Transportation Safety Board (NTSB), to improve guidance for crashworthiness and, perhaps, to redefine the conditions experienced in a general aviation accident or incident. SMEs suggested that the findings and records the NTSB gathers from GA accidents are often not as comprehensive as the findings and records for commercial airliner accidents; however, SMEs suggest that the FAA develop second-order metrics using the findings and records to better define crash dynamics and provide information to improve guidance for crashworthiness so loading and accelerations, for instance, closely reflect conditions in GA accidents or incidents.

SMEs contended that the current guidance for crashworthiness certification may require an extension or revisit of the Part 23 rewrite to investigate and develop crashworthiness criteria and to avoid tests that are not reflective of actual crash conditions. This effort impacts GA manufacturing and airframe stakeholders. SMEs agreed that a Part 23 rewrite should enable the use of certification by analysis, given appropriate validation testing to support the analysis. SMEs believed certification by analysis may enable technology usage for crashworthiness at lower cost and less time. Certification by analysis is a promising certification method, but still requires additional work to streamline and validate the process.

Based upon the feedback and data collected in this research area, the following proposed recommendation is provided for this key topic:

> *Recommend processes for the FAA to evaluate the definition of conditions in Accidents and Incidents for future GA aircraft.*

3.6.2.2 Passenger and Pilot Fatality in GA Accidents

The notion that GA accident rates are too high is consistent among all SMEs. SMEs believed airframe improvements, the use of additive manufacturing to facilitate improved crashworthy features, and recurring pilot training to avoid accidents may increase survivability and reduce the GA accident rates over time. SMEs believed designing the airframe for crashworthiness improves the vehicles durability and passenger and pilot survivability. Airframe improvements include, but are not limited to, rerouting fuel lines and structural members, improving seating design and configuration, incorporating reinforced and crushable structures, and incorporating emergency landing aides. Because the FAA does not mandate specific design features in crashworthiness certification, the airframe companies have autonomy to produce a vehicle for certification and airworthiness. However, the FAA can provide guidance to better define accident scenarios so that airframe companies can map accident scenarios to causes, then design to mitigate or lessen the severity of the accident. The FAA can leverage the findings and records from additional agencies, such as NTSB, to develop second-order metrics to define GA accidents such that airframe companies have a better reference to develop improved airframe design characteristics. The SMEs suggested that, in addition to developing a GA accident database with the same capabilities and same level of detail as commercial aviation databases, the FAA revisit the testing conditions needed for certification to ensure that these conditions are more accurately reflective of accident conditions for the GA aircraft.

SMEs believed additive manufacturing can improve airframe crashworthiness characteristics and performance. Using additive manufacturing may reduce component weights, enable design of components for energy absorption, and enable the use of energy-absorbing materials. SMEs acknowledged that, if the aircraft structure can absorb more energy during impact, the chances of survivability are improved. The difficulty for GA airframe companies is the testing, certification, and cost to incorporate advanced technology in airframe designs. Because cost impacts GA more than commercial and military aviation, most decisions for GA airframes are decided based on cost and weight savings. One SME contends that the life cycle of an airframe can impede the ability to incorporate added safety measures as well. Because the airframe may last decades and production is low, companies must incur large cost to update the design when certifiable technology becomes available. Because designing for crashworthiness may increase weight and increase cost, there must be external support and incentive to utilize available technology. External support may consist of standardization of components such that the cost reduces as units rise; one example suggested was, if possible, to have a standard occupant seat.

SMEs working in crashworthiness also remained constant about the need for adequate and recurrent training for pilots/operators such that accidents might be avoided in the first place. SMEs believe that pilots/operators that stay current on training for both nominal and contingency flight tasks can reduce GA accident risk. The FAA does provide guidance about recurrent training for GA under Part 135 and Part 91 (for fractional ownership); however, the FAA should consider how to recommend an increase in the frequency of recurrent training for GA pilots to mitigate pilot error, lack of situational awareness, and an over-reliance on automation and autonomy.

Based upon the feedback and data collected in this research area, the following proposed recommendation is provided for this key topic:

> *Develop methodology for the FAA, such that tools to improve crashworthiness of aircraft can be certified.*

3.6.2.3 Automation and Autonomy in Safety

SMEs attested that automation and autonomy in safety manifests in envelope protection technologies, situational awareness technologies, and mitigations to address degradations in emergency scenarios. SMEs believed envelope protection systems and related technologies are available to incorporate into GA aircraft, but cost of the equipment and cost to have the equipment certified can impede adoption. GA can benefit from envelope protection through automation and autonomy. The GA community requires assistance from the FAA, industry partners, and academia to research and develop software certification methods to enable technology. SMEs expected automation and autonomy to reach multiple systems that may impact situational awareness and accident mitigation such as collision-avoidance, communication, engine management, and system-level management. These systems house automation and autonomy tasks that can reduce pilot load in critical flight scenarios (e.g., loss of power, loss of control, loss of communications, etc.). The reduction in pilot load, but increase in situational awareness, can reduce the risk of accidents. SMEs believed automation and autonomy are good for situational awareness, but not directly for crashworthiness because the automation is built to protect against scenarios that may lead to accidents. The use of autonomy or automation to protect occupants in a crash was unclear. Among the discussion, SMEs also stated that in critical scenarios where the aircraft is compromised, the degradation of automation and autonomy could compound the difficulty of mitigating accidents. Because the degradation of automation and autonomy affects situational awareness, additional research is necessary to provide guidance about how to safeguard automation and autonomy in critical flight scenarios when the state of the aircraft is suboptimal. One SME believed automation and autonomy technology should provide a metric to define an increase in level of safety by some degree, given the technology developed. There is no such notion for technology today; however, the FAA, industry partners, and academia could develop guidance for such a metric to exist.

The interface of automation and autonomy is the pilot/operator. SMEs believe automation and autonomy will enable pilots/operators to perform more flight tasks with less training. Some SMEs believe that the usage of automation and autonomy technologies such as auto-throttle and auto-land encourages over-reliance on automation instead of remaining current in training. Another SME added that an over-reliance on automation, especially in cases where the automation and autonomy is suboptimal or compromised, can cause accidents that one expected the automation to protect against. When considering future operations, one SME projected that the expectation is that automation and autonomy will perform all flight tasks such that the passenger is only required to input or upload destination markers and press a “fly/go” button. Though this level of simplified operations may not be feasible in 2030, this level of automation and autonomy may provide utility for urban mobility service providers in far-term operations with extensive research and development.

Based upon the feedback and data collected in this research area from SMEs in crashworthiness, the following proposed recommendation is provided for this key topic:

> *Recognizing that automation and autonomy are not direct crashworthiness technologies, recommend how the FAA can use Automation and Autonomy to increase pilot and passenger safety of future aircraft to avoid scenarios that result in accidents or incidents.*

3.7 Research Area: Pilot Training & Proficiency

3.7.1 Overview and Description

The *Pilot Training & Proficiency* research area emerged as an important research area for GA in 2030. With decreasing pilot population, growing automation, and expected growth in aircraft density in 2030 due to UAS operations and the potential for urban air mobility service, there is a potential need to revisit the pilot training procedures and standards. Simulator technology has progressed by orders of magnitude in the recent past. These improved technologies could be leveraged to reduce pilot training time and cost while maintaining or improving the quality of the training. There appears to be a need to review the Airmen Certification Standards for redundancies or what some believe to be unnecessary content (e.g., specific aerobatic-like maneuvers) and to incorporate training that recognizes new technologies onboard the aircraft. Automation technologies can help simplify flying and provide data (e.g., automated and/or self-paced training, envelope monitoring, and protection) that flight schools can use for training analysis. Such practices can lead to faster and cheaper certification of pilots while maintaining safety. New ideas of functional certification could also be investigated, where a pilot has partial certification based on the assisting technology onboard the aircraft at a reduced time and cost to certify.

Our team elicited SME feedback on the topic areas within the research area to assist the FAA provide guidance to the aviation industry for GA aircraft, infrastructure, operations, pilots, and emergent services and technologies.

- **Automation and Autonomy in GA aircraft operation (Simplified Vehicle Operations)**: This involves incorporating technologies onboard the aircraft that simplify the pilot's tasks during operations. The impacted areas would include pilot training time, cost, and currency and proficiency requirements.

- *How would increasing automation and autonomy in the cockpit impact the time required to achieve proficiency?*
- *Should there be levels of pilot certification that represent proficiency in specific augmented technologies?*
- *What resources are necessary for ground and flight schools to incorporate augmentation?*

- **Pilot Training Procedure and Methodology**: Pilot training procedure and methodology involves the standards of Airmen Certification and the processes followed to achieve those standards. The primary impact area are pilot training time, cost, and proficiency and currency requirements.
  - *What would the curricula for GA pilots consist of in relation to incorporating automation and autonomy?*
  - *Growing cockpit technology may increase workload and training. How will we circumvent this in the future?*
  - *Currently, the initial pilot licenses are based on flight rules such as VFR and IFR? Will there need to be a change for GA in 2030?*

3.7.2 Findings and Proposed Recommendations

With regards to pilot training procedures and overall pilot proficiency in the 2030 timeframe, discussions with SMEs generally highlighted the influence of the new technologies and possible future operational paradigms on the anticipated requirements for pilot proficiency, how this proficiency will be acquired, and the impact these changes may have on the number of pilots operating GA aircraft. Somewhat paradoxically, the team noted during the SME discussions that, while there is certainly a shortage of pilots with the aviation system generally and GA particularly, current technology trends suggest future scenarios in which more vehicles with the NAS will be unmanned. Their potential presence presents new challenges and opportunities to both GA pilots and to regulatory agencies.

Alongside this potential influx of unmanned systems is a potential increase in the level of automation or autonomy within the vehicle which overall simplifies or re-allocates pilot responsibilities. Further, it is anticipated that the infusion of vehicle automation is likely to be non-uniform, such that various categories of automated vehicles emerge, each requiring different levels of pilot skill for safe operation. As these new vehicles emerge and potentially begin to proliferate within the GA fleet, it is anticipated that shifts in the regulatory framework will likewise be needed. In general, this shift was likened to the shift from the tail-dragger landing gear on small aircraft—up until around 1950—to the tricycle landing gear as the predominant small aircraft configuration today being the assumed regulatory norm. Likewise, new GA vehicles equipped with modern equipment such as glass cockpits and future technology innovations such as automation or autonomy will eventually be viewed as the new normal.

With this potential shift in the types of vehicles, both manned and unmanned, operating in the future NAS, the SMEs also suggested various emerging scenarios relating to new methods of pilot training. These future scenarios typically leverage simulation as a tool for pilot instruction. In addition, SMEs noted that the current pilot shortage is likely to be exacerbated, because there are likely to be fewer available flight instructors in the future given that there are fewer pilots overall at present. This potential gap of available flight instructors may be addressed through emerging technology solutions, including increased simulation flight time, autonomous or AI-augmented flight instruction, and envelope protection systems onboard training vehicles.

At present, the SME discussions saw many of these technological shifts, with regards to pilot training and proficiency, as facing restrictions from the existing regulatory framework. Some potential solutions were identified through comparison of existing pilot standards to recent changes made to Part 23 of the FAR regulations, particularly with regards to a task- or competency-based standard for pilot certification. SMEs acknowledged that, given the time required for rulemaking, if some shift in the pertinent regulations is to take place, then the FAA would need to begin collecting data related to the potential impacts of future technology disruptors on pilot proficiency and pilot training.

Given these findings, the PEGASAS Project 25 team believes that the *Pilot Training and Proficiency* research area objective is to:

> *Recommend guidelines to the FAA to develop policies that can help increase pilot base for GA in the future, given new aircraft design and technologies.*

In addition to this general objective, two key topics also appear to clarify further key aspects of the *Pilot Training & Proficiency* research area.

3.7.2.1 Automation & Autonomy in GA aircraft operation (Simplified Vehicle Operations)

One of the most anticipated technologies to emerge within the 2030 timeframe is automation and autonomy, which allows for simplification of—or perhaps reallocation of some responsibilities within—the piloting task. With respect to this technology, SMEs noted that, because there are likely to be various degrees of automation in future vehicles, from existing non-autonomous vehicles up to full automation or autonomy of the vehicle, a spectrum of piloting requirements are likely to emerge. This range of pilot requirements would then correspond to an expansion of pilot certification requirements that are inherently tied to the underlying levels of automation onboard a given vehicle.

In general, it was recognized that the pilot certification requirements, and by extension pilot training requirements, need to change with respect to increased automation. Following the existing safety paradigm, SMEs envisioned that new automated systems would be required to exhibit levels of safety that are comparable to, or better than, existing vehicles. In the event of automation failure, it is expected that the pilot must be capable of taking over flight in a manner that provides for a safe transition and a high likelihood of safely landing the vehicle.[2] These needs imply that further research is required in the field of vehicle automation and associated pilot training requirements, including risk analysis of the various levels of automation, means of identifying off-nominal automation behavior, human factors issues with how the pilot interfaces with the automation and takes over when needed, and new methods of pilot training in light of these factors.

The SME discussions also included the concept that new training requirements are likely to emerge from increased automation, but the discussions also reflected some concern that these new requirements may further increase both the duration and cost of pilot training. It was noted that within commercial aviation, while there has already been an influx of automation within various systems onboard the vehicle, the training workload and cost has continued to increase. These rises were largely attributed to the tendency to add on to existing training requirements. For example, commercial pilot training requires training in steam gauges, viewed as entirely obsolete from a commercial perspective, as well as modern glass cockpit displays. Given this precedent under existing regulation, the SME discussion suggested that increases in automation within GA may similarly lead to increases in pilot training time and cost, thereby standing in opposition to general goal of simplifying pilot training.

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[2] Note that these SME interviews took place before the highly-publicized 737 MAX accidents. Clearly, lessons learned from those accidents, in which an automated system provided flight control inputs without full awareness of the pilots, should also be used to improve how automation is introduced for general aviation.

Given these findings, the PEGASAS Project 25 team additionally recommends the following objective:

> *Provide guidance and recommendations to the FAA on automation and autonomy technology that can reduce pilot training time and cost.*

3.7.2.2 Pilot training procedure and methodology

Alongside potential shifts in the required piloting skills due to potential technological changes, findings from SME discussions indicated some potential shifts in the methods and procedures by which GA pilots will be trained. While the problem of pilot shortage was noted to be largely a business problem, there is some potential cause for concern given the secondary effect on the number of future flight instructors. If there are currently few pilots, then it is likely that in the future there will be few qualified flight instructors, given that flight instructors themselves must also be pilots. Considering such a scenario, some technological solutions were suggested which aid in overcoming this reduction in capability.

One potential solution is some capability that enables a single instructor to train multiple students simultaneously. For example, an aircraft equipped with appropriate envelope protection systems could allow for a student pilot to operate a vehicle safely by "nudging" the student pilot to remain within the safe envelope without an instructor onboard. Following such a flight, an instructor could review data collected from the flight and assess the data with the student to aid in further training. Another technological solution that could be investigated in a scenario, where the number of available instructors is insufficient for current training approaches, is the increased usage of flight simulators for pilot training. Such usage could additionally be augmented with automated flight lessons that allow for individualized training regimens.

While it is likely that technology will impact some methods by which pilots receive training, some SMEs noted that another shift in the pilot training procedure could be changes in the type and degree of required training. Should future aircraft incorporate more automation, the expected responsibilities of the pilot will be reduced. This reduction of responsibility could, therefore, allow for lower training requirements, under the assumption that the assumed level of automation is shown first to be a robust solution. The increase in technology, such as automation within future aircraft, additionally presents the potential to define narrower classes of vehicles, defined relative to the installed technological capability. These new vehicle classes could be associated with various pilot certification levels that are more specifically tailored to the specific vehicle class and type of automation; perhaps today's Sport Pilot license provides an analogy. Such separation of license types or categories could allow for refinement or reduction in the training required for specific license categories.

In these scenarios, the SMEs noted that a key challenge to be addressed in these or other potential changes is the lag between when changes in the training program are made and the time when they may be effectively assessed. Ultimately, any gaps or shortfalls in training are likely only to emerge once a pilot has completed their training and has begun to fly regularly. Thus, any potential changes to pilot training procedure or methods would require a greater degree of research to confirm that new methods or procedures provide the same levels of pilot competency. In addition, research is likely also required to ascertain the degree to which any proposed new training method conveys not only basic pilot competency, but also the efficacy with which other pilot capability, such as traditional wisdom regarding effective decision making, is transferred to new pilots.

With these findings in mind, the PEGASAS team additionally recommends the following objective with respect to pilot training procedure and methodology:

> *Given future technologies, provide recommendations as to how the FAA should revise training procedures and develop methodologies for the procedures.*

4 Conclusions

This report summarizes the activities conducted under Phase 2 of the Partnership to Enhance General Aviation Safety, Accessibility and Sustainability Project 25. The research documented in this report builds upon the results from the previous research phase (Federal Aviation Administration, 2018) with the intent to provide the data necessary for a strategic roadmap for GA R&D.

This report covered the progress of Phase 2, which the team approached in two major tasks: (1) Streamlining of Phase 1 content into questions and scenarios for the future GA themes and topics identified, and (2) preparing for and conducting SME interviews.

The Project 25 team conducted 27 SME interviews. Each interview focused on one of the seven research areas, and the team interviewed multiple SMEs for each area. In some cases, the team interviewed more than one SME at a time in each area. Because of the overlapping nature of the seven research areas, a few SMEs provided input for more than one area. The report included findings and proposed recommendations for *Airports & Infrastructure*, *Aspects of Connectivity*, *Automation & Autonomy*, *Future Airspace*, *Future Propulsion Systems*, *Passenger Safety & Crashworthiness*, and *Pilot Training & Proficiency*. A summary of the full set of proposed research recommendations for all the addressed research areas is provided in Table 1.

Since the recommendations listed in Table 1 could affect the entire aviation community and all its stakeholders, FAA resources may be limited, so FAA decision makers would need to evaluate the research topics in context of a broader strategic planning initiative. Thus, the outcome of this study is expected to be valuable input into a FAA strategic planning initiative of its entire aviation safety R&D program.

Table 1. Summary of Proposed Recommendations for GA 2030 Research Areas

Research Area	***Proposed Recommendations***
Airports & Infrastructure	• Develop a strategy for the ongoing maintenance and improvement of airports and supporting infrastructure to promote increased safety and improve efficiency in GA operations. • Develop and implement a strategy for GA runway and terminal facility improvements, environmental management at GA airports, and energy management for future GA vehicles. • Identify infrastructure requirements which improve airport site security and cybersecurity for GA stakeholders. • Identify infrastructure requirements for future airport airspace management scenarios which enables future GA operational scenarios.
Aspects of Connectivity	• Develop capabilities for enhanced and secure data sharing among GA stakeholders and standardization of information interfaces. • Identify gaps in existing connectivity infrastructure and develop a development strategy for meeting the requirements of future enhanced connectivity scenarios. • Develop a set of standards to enable a consistent protocol for the transfer of data between GA participants. • Identify and implement a strategy for ensuring the digital safety of GA participants and their data that reflects the diverse nature of GA operators and operations.
Automation & Autonomy	• Develop methodologies to evaluate and ensure software and hardware reliability for automation systems onboard future GA aircraft and external systems enabling GA in future. • Recommend tools and technologies to the FAA that can help evaluate and ensure safe and reliable execution of software code quickly and effectively for given operating scenario. • Recommend tools and technologies to the FAA that can help evaluate and ensure safe and reliable operation of electrical hardware quickly and effectively for given operating scenario.
Future Airspace	• Develop methods and capabilities for the FAA to design and manage future GA airspace considering future GA aircraft density, technologies, and operations. • Provide guidelines and recommendations on Services, Workforce management, and Operation classification that can help the FAA control future GA air traffic effectively and with desired safety. • Develop methodology for the FAA to evolve the current state and shape of the airspace to accommodate the future needs of General Aviation. • Recommend how the FAA can leverage automation and autonomy technology to reduce in-air collision, airspace excursion/incursion, and improve GA pilots' communication.
Future Propulsion Systems	• Identify future GA propulsion systems to identify new standards for fleet integration and type certification. • In coordination with industry, identify likely future GA powerplant architectures, detailing their operational limitations, energy source considerations, and lifecycle management strategies. • Develop a set of performance-based standards for the certification of novel GA powerplant architectures. • Develop a set of standards for the safe incorporation of automation into GA powerplant architectures.
Passenger Safety & Crashworthiness	• Develop policies and methods for FAA to increase aircraft crashworthiness and passenger safety for future GA aircraft operations in all weather conditions. • Recommend processes for the FAA to evaluate the definition of Accidents and Incidents for future GA aircraft. • Develop methodology for the FAA, such that tools to improve crashworthiness of aircraft can be certified. • Recognizing that Automation and Autonomy are not direct crashworthiness technologies, recommend how the FAA can use Automation and Autonomy to avoid scenarios that result in accidents or incidents.
Pilot Training & Proficiency	• Recommend guidelines to the FAA to develop policies that can help increase pilot base for GA in the future, given new aircraft design and technologies. • Provide guidance and recommendations to the FAA on automation and autonomy technology that can reduce pilot training time and cost. • Given future technologies, provide recommendations as to how the FAA should revise training procedures and develop methodologies for the procedures.

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A 2018 PEGASAS Annual Meeting

At the 2018 PEGASAS Annual meeting, the Project 25 team presented a summary of the key results from the first year of the project and planned work for the coming year. During this presentation, the team summarized the findings of the workshops conducted in the first year of the project, which culminated in the definition of the seven key research areas presented in Section 3. Further, the team presented preliminary results regarding the prioritization of these research areas with regards to which areas would first be investigated further.

From a consensus of the Project 25 team and those present at the 2018 PEGASAS Annual Meeting, all seven research areas reflected important research and warranted further investigation and study. Practically, however, the time and resources available to the Project 25 team prevented the simultaneous study of all seven research areas. Rather, the team first focused their efforts on a subset of the research areas before proceeding to investigate the remaining research areas in turn. As a result of preliminary prioritization efforts by the Project 25 team and feedback collected at the 2018 PEGASAS Annual Meeting, it was decided that the team would first focus on the *Airports and Infrastructure* and *Pilot Training and Proficiency* research areas. Subsequently, the team pursued the remaining research topics over the course of the project.

B Research Area Questionnaires

This appendix contains the full research area questionnaires that were generated by the Project 25 team. These questionnaires were generated to facilitate discussions and interviews with SMEs in each research area. In general, each questionnaire first begins with a set of questions which seek to clarify the context of the given research area as it relates to GA in 2030, followed by questions relating to key topics within each research area. While each questionnaire was developed such that direct usage would yield useful information pertaining to the research area, these questionnaires served in practice to facilitate discussion rather than as a script. As such, these questions often provided a reliable source from which to introduce or clarify a given topic. Therefore, it was likely that, during a given SME discussion, questions or ideas beyond those presented in the questionnaires would be discussed. Despite this, the seven developed questionnaires have been included here in full to provide more complete context to the findings presented in Section 3 and the interview notes which are provided in an additional Appendix.

1. Research Area: Airports & Infrastructure

Description of GA Airports and Infrastructure

Q1. What is the current guidance provided by the FAA for GAAI?

- **a.** Who is currently responsible for overseeing existing GAAI?

Q2. How well does existing GAAI meet the requirements of current GA?

- **a.** How will these requirements change for GA in 2030?

Q3. Are existing GAAI sufficient to meet the demands of GA in 2030?

- **a.** If not, what improvements must be made and how soon should these changes be implemented?

Q4. What are the GAAI topics impacted by the changes to GA by 2030?

- **a.** Airport Security
- **b.** Facility Maintenance and Improvements
- **c.** Airspace Management

Q5. How does this research and its findings assist the FAA in providing guidance for GAAI in preparation for GA in 2030?

Topic 1: Facilities Maintenance and Improvements

Q1.1. What is the current state of GA infrastructure maintenance and improvements?

Q1.2. What are the primary drivers of GA infrastructure maintenance and improvements?

- **a.** What new drivers will emerge in the future?

Q1.3. Is the current approach to GA infrastructure maintenance and improvements sufficient to meet these future demands?

Q1.4. What aspects of GA infrastructure maintenance and improvements will be most impacted in the future?
  - **a.** Runway and Terminal Facilities
  - **b.** Environmental Management
  - **c.** Energy management for Future GA Aircraft

Q1.5. How will research in this area help the FAA provide guidance to maintain GA infrastructure maintenance and improvements more effectively or with an improved level of security?

Impact Area 2.1: Runway and Terminal Facilities

Q1.6. What new infrastructure requirements will be created by future GA operations?
  - **a.** Are these needs met by existing infrastructure?

Q1.7. What new techniques and methods will be used to improve future runway and facility maintenance?

Q1.8. Are existing funding channels sufficient to meet the needs of future runway and terminal facility maintenance and improvements?

Impact Area 2.2: Environmental Management

Q1.9. What methods and strategies can be used to mitigate the risk of wildlife incursion for GA operations?

Q1.10. What methods and strategies can be used to mitigate the risks of GA operations and facilities on the surrounding environment?

Impact Area 2.3: Energy Management for Future GA Aircraft

Q1.11. How will the introduction of future energy sources for GA aircraft impact GA infrastructure?

Topic 2: Airspace Management

Q2.1 What is the current state of GA airspace management infrastructure?

Q2.2 What are the primary drivers of GA airspace management infrastructure?
  - **a.** What new drivers will emerge in the future?

Q2.3 Is the current approach to GA airspace management infrastructure sufficient to meet these future demands?

Q2.4 What aspects of GA airspace management infrastructure will be most impacted in the future?
  - **a.** Accounting for Increased Capacity
  - **b.** UAS Integration

Q2.5 How will research in this area help the FAA provide guidance to maintain GA airspace management infrastructure more effectively or with an improved level of security?

Impact Area 3.1: Accounting for Increased Capacity

Q2.6 How does a potential increase in the usage of GA airports impact infrastructure requirements?

Q2.7 How will increases in GA usage be distributed amongst existing infrastructure?

Q2.8 What aspects of the existing infrastructure are sufficient to meet the needs of increasing demand? What aspects are lacking?

Impact Area 3.2: UAS Integration

Q2.9 What changes, if any, must be made to GA infrastructure to support the safe GA operation alongside UAS?

Q2.10 In the future, would GA and UAS share infrastructure such as airports, runways, helipads, or terminal space?

- **a.** If yes, what additional considerations must be made to ensure safe GA operation?

Topic 3: Airport Security

Q3.1 What is the current state of GA airport security?

Q3.2 What are the primary drivers of GA airport security?

- **a.** What new drivers will emerge in the future?

Q3.3 Is the current approach to GA airport security sufficient to meet these future demands?

Q3.4 What aspects of GA airport security will be most impacted in the future?

- **a.** Site Security
- **b.** Cybersecurity

Q3.5 How will research in this area help the FAA provide guidance to maintain GA airport security more effectively or with an improved level of security?

Impact Area 1.1: Site Security

Q3.6 How well does existing infrastructure provide safety to GA operators and passengers?

Q3.7 How will passenger safety needs and expectations change in the future, and what infrastructure will be required to meet these needs?

Q3.8 What level of monitoring will be needed for future GA operations?

- **a.** How will the level of security for various types of airports with GA operations be decided in the future?

Q3.9 What special requirements for airport site security do GA operations present?

Impact Area 1.2: Cybersecurity

Q3.10 With the increasing connectivity of GA and the world in general, what infrastructure is required to provide cybersecurity for GA operations?

Critical Milestones & Task Outputs

Q1. What are the outputs from the tasks of this research area and what other tasks rely on tasks completed from this research area?

Q2. How urgent is this research to GA in 2030?

Q3. Who are the primary stakeholders of the research outside of FAA?

Q4. With whom should the FAA collaborate?

Summary & Outcomes

Q1. What potential outcomes are required for this topic area?

Q2. How do the research initiatives / tasks from the fill the gap between current and future GA?

2. Research Area: Aspects of Connectivity

Description of the Aspect of Connectivity

Q1. What is the current guidance provided by the FAA for GA connectivity?

- **a.** Who is currently responsible for overseeing existing GA connectivity?

Q2. How well does existing GA connectivity meet the requirements of current GA?

- **a.** How will these requirements change for GA in 2030?

Q3. Is existing GA connectivity sufficient to meet the demands of GA in 2030?

- **a.** If not, what improvements must be made and how soon should these changes be implemented?

Q4. What are the GA connectivity topics impacted by the changes to GA by 2030?

- **a.** Connectivity Infrastructure
- **b.** Information Interfacing
- **c.** Cybersecurity

Q5. How does this research and its findings assist the FAA in providing guidance for GA connectivity in preparation for GA in 2030?

Topic 1: Connectivity Infrastructure

Q1.1. What is the current state of GA connectivity infrastructure?

Q1.2. What are the primary drivers of GA connectivity infrastructure?

- **a.** What new drivers will emerge in the future?

Q1.3. Is the current approach to GA connectivity infrastructure sufficient to meet these future demands?

Q1.4. What aspects of GA connectivity infrastructure will be most impacted in the future?

- **a.** Aviation "Internet" or Data Link
- **b.** Connectivity Profile

Q1.5. How will research in this area help the FAA provide guidance to maintain GA connectivity infrastructure more effectively or with an improved level of security?

Impact Area 1.1: Aviation "Internet" or Data Link

Q1.6. What types of standards should be included in a future information interface protocol?

Q1.7. Who should be responsible for defining standards?

Impact Area 1.2: Connectivity Profile

Q1.8. With What types of information are likely to be transmitted and received during future GA operations?

a. How do these types of information differ from information exchanged in existing GA operations?

Topic 2: Information Interfacing

Q2.1 What is the current state of GA information interfaces?
Q2.2 What are the primary drivers of GA information interfaces?
  a. What new drivers will emerge in the future?
Q2.3 Is the current approach to GA information interfaces sufficient to meet these future demands?
Q2.4 What aspects of GA information interfaces will be most impacted in the future?
  a. Interface Protocol Development
  b. Interface Regulation
Q2.5 How will research in this area help the FAA provide guidance to maintain information interfaces more effectively or with an improved level of security?

Impact Area 2.1: Interface Protocol Development

Q2.1 What types of standards should be including in a future information interface protocol?
Q2.2 Who should be responsible for defining these standards?

Impact Area 2.2: Interface Regulation

Q2.3 If an interface standard is developed, how should it be regulated and enforced?

Topic 3: Cybersecurity

Q3.1 In association with existing cybersecurity R&D efforts, what additional requirements does increased GA connectivity pose in terms of cybersecurity?
Q3.2 Are these requirements sufficiently expressed in the existing cybersecurity R&D plan or is additional development warranted?

Critical Milestones & Task Outputs

Q1. What are the outputs from the tasks of this research area and what other tasks rely on tasks completed from this topic?
Q2. How urgent is this research to GA in 2030?
Q3. Who are the primary stakeholders of the research outside of FAA?
Q4. With whom should the FAA collaborate?

Summary & Outcomes

Q1. What potential outcomes are required for this research area?
Q2. How do the research initiatives / tasks fill the gap between current and future GA?

3. Research Area: Automation & Autonomy

Description of GA Automation and Autonomy

Q1. What are the topics impacted by the changes to GA by 2030?
  - **a.** Software reliability
  - **b.** Hardware reliability

Q2. How does this research and its findings assist the FAA in providing guidance for Automation and Autonomy in preparation for GA in 2030?

Topic 1: Software Reliability

Q1.1. Why will the current state of Software Reliability test/certification not be good enough for GA in the future?
  - **a.** Will the standards (Level A, B, C, D and E) for safety critical software change in the future?

Q1.2. What does the FAA need to know about a software product to prove it is reliable?
  - **a.** Does the FAA have to certify 100% of the product before it goes on the aircraft? Or can be done dynamically over time?
  - **b.** How can the FAA make software verification quicker and still maintain reliability? E.g.: Run time assurance of software.
  - **c.** What is the feasibility of artificial intelligence in the cockpit? How can the FAA certify a 'learning' software?
  - **d.** The increasing use of Commercial Off-The-Shelf (COTS) software in aviation - currently in UAS - has led to a need for strategies to benchmark reliability on such COTS software. Can COTS be feasible for GA in the future? What are the roadblocks?

Q1.3. Can scenario-based testing reduce test cases and thereby time and cost?
  - **a.** Evolution of DO-178 standards and process for aircraft operation and type? There has been research into risk-based alternatives to DO-178.

Q1.4. What does the FAA need to know to retrofit old aircraft with new software? What is the change from current scenario to the future in 2030?

Topic 2: Hardware Reliability

Q2.1. Will the current methodology of verifying reliability of the electrical systems be valid for 2030? If not, why?

Q2.2. What does the FAA need to know to ensure reliability of a hardware system of new technologies being introduced into GA?
  - **a.** Currently, pilots use a large number of personal electronic devices. With growing automation, how will on-board equipment interact (directly or indirectly) with PEDs?

Q2.3. What tools and data does the FAA require? How can the processes of certifying electrical hardware be quicker than it is done today?
  - **a.** Are there new methods by which the FAA can improve electrical hardware requirements and tests procedures, to reduce costs?

Q2.4. What technologies should be developed to ensure safe operating conditions for automation hardware? For example, cooling mechanism or fire resistant materials?

Q2.5. What impact does new manufacturing methods have on avionics hardware? How will the FAA ensure required reliability of product?

Critical Milestones & Task Outputs

Q1. What are the outputs from the tasks of this research area and what other tasks rely on tasks completed from this research area?

Q2. How urgent is this research to GA in 2030?

Q3. Who are the primary stakeholders of the research outside of FAA?

Q4. With whom should the FAA collaborate?

Summary & Outcomes

Q1. What potential outcomes are required for this topic area?

4. **Research Area: Future Airspace**

Description of GA in Future Airspace

Q1. What is the current state of Air Traffic Control (ATC) in relation to GA operations and management?

Q2. What aspects of ATC are necessary for GA in future and will be impacted the most?

- **a.** Air traffic services
- **b.** Flight Operations Classification
- **c.** Workforce

Q3. How will research in this topic area help the FAA provide guidance to manage airspace for GA more efficiently with equivalent or improved level of safety?

Topic 1: Air Traffic Services

Q1.1. With the increase in air traffic, what will the ATC need to manage the increase in demand of services?

- **a.** What resources/technologies/capabilities will be necessary to manage increased numbers of diverse GA aircraft in the airspace?
- **b.** How will additional data from aircrafts through ADS-B affect how ATC controllers perform air traffic services and mitigate in-flight incidents?
  - i. Will additional bandwidth and filtering software be necessary to assist ATC controllers manage the increased flight data?
- **c.** What is the current state of remote controlled airports? What are the additional requirement for remote controlled airports in future?

Q1.2. What additional technologies are required to for ATC to continue providing air traffic services in the future not previously mentioned?

Impact Area 1.1: Flight Operations Classification

Q1.3. Flight operations of PVTOL, autonomous, electrically driven, and or hybrid propulsion vehicles belong to which part (e.g., 91, 103, 107, 125, 133, 135, 136 137, etc.) operation

- **a.** Should there be a part revision or insertion to incorporate future operations not describe with current part operations?

Q1.4. What GA flight operation within the Airspace could be considered commercial flight operations (e.g., Uber Elevate, Amazon Prime Air)?

Impact Area 1.2: Workforce

Q1.1. With the increase in air traffic services required to manage the increase in air traffic, will additional ATC controllers be required?

   a. Should ATC consider hiring additional ATC controllers or provide multi-tasking technologies to ATC to provide air traffic services?

Q1.2. What additional skills are required by ATC controllers to provide air traffic services to pilots of varying proficiency?

   a. What flight services/support is necessary to aid pilots flying different vehicle types and pilot proficiency (e.g., conventional single-engine, electric VTOL, Manned UAS)?

   b. What recruitment efforts are required to address increased demands of ATC controllers?

Topic 2: Airspace Evolution

Q2.1 What is the current state of the Airspace in relation to GA operations?

Q2.2 What aspects of the Airspace are necessary for GA in future and will be impacted the most?

   a. Modernization of Airspace

   b. Airspace Class Distinction

Q2.3 How will research in this topic area help the FAA provide guidance to manage airspace for GA more efficiently with equivalent or improved level of safety?

Impact Area 2.1: Modernization of Airspace

Q2.4 The FAA Next Generation Air Transportation System (NextGen) seeks to improve how NAS users see, navigate, and communicate, what does NextGen provide for GA pilots and flight operations?

   a. What steps need to be taken so that the GA manufacturers incorporate NextGen technologies?

      i. Automatic Dependent Surveillance-Broadcast (ADS-B)
      ii. Automation
      iii. Data Communication (Data Comm)
      iv. Decision Support Systems (DSS)
      v. NAS Voice System (NVS)
      vi. Performance Based Navigation (PBN)
      vii. System Wide Information Management (SWIM)
      viii. Weather

Q2.5 What additional features/capabilities/technologies are required for GA aircraft and or pilots to comply with NextGen (i.e., tablet/iPad functionality)?

Q2.6 What lies beyond NextGen airspace? With growing traffic will we need a version 2 of NextGen?

Q2.7 Impact Area 2: Airspace Class Distinction

Q2.8 With increasing number of diverse GA aircraft (e.g., personal air vehicle with electric vertical takeoff and landing (PAV-EVTOL), autonomous, electrically driven, and or hybrid propulsion vehicles) projected in 2030, would the airspace require a redesign?

   a. Will current airspace restrictions require revision to accommodate diverse GA aircraft?

- **b.** What additional airspace restrictions exist to accommodate diverse GA aircraft?
- **c.** Will additional airspace classes be necessary?
  - i. Urban Operations (e.g., deliveries, urban mobility)
  - ii. Others not mentioned

Q2.9 How will the airspace be shared between commercial, GA, and UAS in high density airspace?

Topic 3: Automation & Autonomy in Airspace Management and Control

Q3.1 What is the current role of Automation and Autonomy in Airspace management and control?

Q3.2 Why do we need Autonomy in Airspace Management and Control in the future?

Q3.3 What areas of the Airspace Management and control will Autonomy and Automation impact the most?

- **a.** Traffic detection and avoidance
- **b.** Airspace management & Aircraft-Airspace compliance
- **c.** Airspace Control: Pilot-Controller Communications & Pilot Connectivity
- **d.** Airspace Weather Information

Q3.4 What other areas of airspace can automation and autonomy influence/impact?

Q3.5 How will this research help the FAA provide guidance to manage airspace for GA more efficiently with equivalent or improved level of safety?

Impact Area 3.1: Traffic detection and avoidance (UAS- Detect & Avoid)

Q3.6 Why is this area going to be impacted? What is the research need?

- **a.** Example: Why is TCAS not sufficient for GA in 2030?
- **b.** How does NASA's UAS airspace integration research help overall GA in2030?

Q3.7 What tasks of detect & avoid need to be automated (or improved automation) and why? What controls do humans still need to retain?

Q3.8 How can the tasks (in Q2) be automated? Are there technologies currently present that can enable it, or do we need further development?

Q3.9 What other topics are related? What activities/tasks, including efforts from other tasks, are necessary prior to this topic?

- **a.** Evaluation of approaches can be in the Certification and Compliance Research Areas.

Q3.10 Who is responsible for detect and avoid in future?

- **a.** Currently, the onus lies with the pilot. How will this apply to UAS?

Q3.11 Will the technology for detect and avoid need to be aircraft type specific or span all aircraft in the airspace?

- **a.** For example TCAS is aircraft specific. The technology only needs to be on board the aircraft.

Q3.12 Any other tasks or comments?

Impact Area 3.2: Airspace management & Aircraft-Airspace compliance

Q3.13 Why is this area going to be impacted? What is the research need?

- **a.** Example: More than the need for airspace redesign, we want to know the need for automation in airspace redesign.

   - **b.** Example: Q] How will airspace excursion and incursion be handled in the future?

Q3.14 How will new and old aircraft technology/integrate in the same airspace?

   - **a.** What low cost technology development is required for safe operations?
   - **b.** How can FAA define what aircraft types requires ADS-B (or similar traffic information system)? Example: Will it be mandatory for all UAS to have ADS-B?
   - **c.** Will the technology on-board the aircraft decide future airspace design?
   - **d.** How will GA and UAS aircraft achieve Performance Based Navigation?

Q3.15 What tasks of airspace management and compliance can be automated and why? What controls do humans still need to retain?

   - **a.** Example: Airspace classification to Class D, C or B.
   - **b.** Example: Flight Plan approvals. Intent of flight known in spite of no flight plan being filed.

Q3.16 How can the tasks (in Q3) be automated? Are there technologies currently present that can enable it, or do we need further development?

   - **a.** What other topics are related? What activities/tasks, including efforts from other tasks, are necessary prior to this topic?
   - **b.** Can artificial intelligence dynamically define airspace based on traffic density? If so, what technologies are currently in place and what needs to be developed?

Q3.17 Based on airspace, can the 'intent' of an aircraft without a flight plan still be known?

Q3.18 Who owns the automation of airspace management? Does the FAA develop the technology, acquire the technology, or provide compliance and certification to the technology used?

Q3.19 Any other tasks?

Impact Area 3.3: Airspace Control: Pilot-Controller Communications & Pilot Connectivity

Q3.20 Why is this area going to be impacted? What is the research need?

   - **a.** Example: Q] How can we have low cost CPDLC options for UAS and GA aircraft?

Q3.21 What tasks of airspace control need to be automated (or improved automation) and why? What controls do humans still need to retain?

   - **a.** Example: Several levels of communication with center/approach/departure/tower.
   - **b.** How can text or audio communication be automated?

Q3.22 How can the tasks (in Q2) be automated? Are there technologies currently present that can enable it, or do we need further development?

   - **a.** What other topics are related? What activities/tasks, including efforts from other tasks, are necessary to complete prior to this topic?
   - **b.** Can some communications and control be automated between aircraft and control tower?
   - **c.** Do personal devices play a role in this communication? What about cyber security in such cases (Section 3.2 of Cyber Security R&D plan)?

Q3.23 What is the extent of human intervention required in all communications?

a. Human (aircraft) – AI (controller) interaction
b. AI(aircraft-UAS) – AI(controller) interaction
c. AI (aircraft-UAS) – Human (Controller) interaction

Q3.24 Any other tasks?

Impact Area 3.4: Airspace Weather Information

Q3.25 Why is this area going to be impacted? What is the research need?
- **a.** What does the research being done today (Weather in cockpit) not fulfill for GA in 2030?
- **b.** Example: Q] How would weather integrate into autonomous UAS systems?

Q3.26 What tasks of weather information required for flight need to be automated (or improved automation) and why? How will this information vary depending on airspace operations?
- **a.** What other topics are related? What activities/tasks, including efforts from other tasks, are necessary to complete prior to this topic?

Q3.27 Who is responsible for providing weather information autonomously? What does the 'providing' involve: assimilating, processing, communicating?

Q3.28 'How' or 'What' can help future GA make 'Go/No-go' decisions based on weather information?
- **a.** Can AI play a part? If so, do we have the technology and what do we need to know?
- **b.** Example: How can achieve autonomous dynamic flight planning? Currently it involves various areas: level of pilot certification, communication, airspace control.

Q3.29 Any other tasks?

Critical Milestones & Task Outputs

Q1. What are the outputs from the tasks of this topic and what other tasks rely on tasks completed from this topic?
Q2. How urgent is this research to GA in 2030?
Q3. Who are the primary stakeholders of the research outside of FAA?
Q4. With whom should the FAA collaborate?

Summary & Outcomes

Q1. What potential outcomes are required for this topic area?
Q2. How do the research initiatives / tasks from the fill the gap between current and future GA airspace?

5. Research Area: Future Propulsion Systems

Description of Future GA Propulsion Systems

Q1. What is the current guidance provided by the FAA for GA propulsion systems?
Q2. How well do existing GA propulsion systems meet the requirements of current GA?
- **a.** How will these requirements change for GA in the future?

Q3. Are existing GA propulsion systems sufficient to meet the demands of GA in the future?

- **a.** If not, what improvements must be made and how soon should these changes be implemented?

Q4. What are the key topics pertaining to future GA propulsion?

- **a.** Powerplant Portfolio Identification
- **b.** Certification
- **c.** Automation and Autonomy

Q5. How does this research and its findings assist the FAA in providing guidance for GA propulsion systems in preparation for GA in the future?

Topic 1: Powerplant Portfolio Identification

Q1.1. What is the current GA powerplant portfolio?

- **a.** Survey data collected by FAA in 2015 show that of the 19,200 fixed wing aircraft considered as "General Aviation and Air Taxi", 12,825 used one or more piston engines, 2,538 used 1 or more turboprop engines, and 3,837 used a turbojet engine

Q1.2. What new powerplants are likely to be introduced to GA in the future? How soon are these new propulsion systems expected to enter the market?

- **a.** Currently expect the introduction of very small turbine engines and high power-to-weight ratio electric engines?

Q1.3. How will the portfolio of propulsion systems change between the current state of GA and GA in the future as new propulsion systems are introduced, considering both the inclusion of new airframes with new propulsion systems and the retrofit of new propulsion systems on existing airframes?

Q1.4. What aspects of GA powerplant portfolio will be most impacted in the future?

- **a.** Energy Source Considerations
- **b.** Life-cycle management

Q1.5. How will research in this area help the FAA provide guidance to maintain GA airport security more effectively or with an improved level of security?

Impact Area 1.1: Energy Source Considerations

Q1.6. How does the storage and usage of future energy sources impact the safety of future GA vehicles?

- **a.** Performance considerations (range, endurance, etc.)
- **b.** Energy management (distribution of power between aircraft systems)
- **c.** "Fuel" systems of future propulsion systems

Q1.7. What additional considerations are needed for the safe usage of future propulsive energy sources?

Impact Area 1.2: Life-Cycle Management

Q1.8. Does the production or installation of future propulsion systems present negative economic or environmental risks?

Q1.9. Does the disposition of legacy or future propulsion systems present negative economic or environmental risks?

Q1.10. How can these risks be mitigated?

Topic 2: Certification

Q2.1 What is the current state of GA propulsive certification?

Q2.2 What are the primary drivers of GA propulsive certification?

- **a.** What new drivers will emerge in the future?

Q2.3 Is the current approach to GA propulsive certification sufficient to meet these future demands?

Q2.4 What aspects of GA infrastructure maintenance and improvements will be most impacted in the future?

- **a.** Type Certification
- **b.** Airworthiness Standards

Q2.5 How will research in this area help the FAA provide guidance to maintain GA propulsive certification more effectively or with an improved level of security?

Impact Area 2.1: Type Certification

Q2.6 Part 33 currently provides general guidelines for all engines and specific guidelines for existing propulsion systems.

- **a.** How well does the existing framework for general engine type certification requirements (i.e. Part 33, Subpart A) allow for the certification of future propulsion systems?
- **b.** What information would be needed to develop specific engine certification requirements for future propulsion systems?

Q2.7 What improvements could be made to Part 33 to allow for more efficient type certification of future GA propulsion systems while maintaining the current level of safety?

Impact Area 2.2: Airworthiness Standards

Q2.8 Are the existing certification requirements of Part 23 Subpart E sufficient to ensure the airworthiness of future GA propulsion systems?

Q2.9 What new considerations, or changes to existing considerations, should be incorporated in Part 23 Subpart E when considering the certification of future GA propulsion systems?

Topic 3: Automation and Autonomy

Q3.1 What is the current state of GA propulsive automation and autonomy?

Q3.2 What are the primary drivers of GA propulsive automation and autonomy?

- **a.** What new drivers will emerge in the future?

Q3.3 Is the current approach to GA propulsive automation and autonomy sufficient to meet these future demands?

Q3.4 What types of propulsive automation and autonomy are most likely to emerge in the future?

Q3.5 What aspects of GA propulsive automation and autonomy will be most impacted in the future?

- **a.** Standards of Automation

Q3.6 How will research in this area help the FAA provide guidance to maintain GA propulsive automation and autonomy more effectively or with an improved level of security?

Impact Area 3.1: Standards of Propulsive Automation

Q3.7 Are the certification requirements of Part 33.28: Engine Control Systems sufficient for the certification of future GA propulsive automation and autonomy?

Critical Milestones & Task Outputs

Q1. What are the outputs from the tasks of this topic and what other tasks rely on tasks completed from this topic?
Q2. How urgent is this research to GA in 2030?
Q3. Who are the primary stakeholders of the research outside of FAA?
Q4. With whom should the FAA collaborate?

Summary & Outcomes

Q1. What potential outcomes are required for this topic area?
Q2. How do the research initiatives / tasks from the fill the gap between current and future GA?

6. Research Area: Passenger Safety & Crashworthiness

Topic 1: Re-definition of Conditions in Accidents and Incidents and Crashworthiness certification in the future

Q1.1. Why will accidents and incidents need to be redefined for future general aviation aircraft?
Q1.2. What needs to be known to redefine accidents and incidents?
- **a.** What kind of data is required to make these decisions?

Q1.3. How will airworthiness certification vary based on aircraft type?
- **a.** What technologies play a critical role in that decision making? What are some technologies that will make it safer to fly in the future?
- **b.** Are there current technologies out there (Transferable automobile crash technology/process) that can be incorporated into GA aircraft?

Q1.4. Can new manufacturing techniques and material help improve crashworthiness? If so, what does the FAA need to know about these materials to reach the required crashworthiness?

Topic 2: Fatalities in Aircraft crash

Q2.1 What is the current probability of survival in a GA aircraft crash?
- **a.** We know the top reason for fatal accidents. Work is currently being done to reduce the accidents because of these causes. However, what is the research in preventing fatality even if an accident occurs?

Q2.2 (WHY question) For urban mobility and air taxi to be viable, aircraft operational performance in adverse weather conditions will have to improve. Is this a feasible goal? Can future aircraft operate more 'safely' in bad weather conditions?

- **a.** What will be the future operational requirements in bad weather?
- **b.** What technologies do we need to achieve required capabilities?

Q2.3 To ensure success of future technology concepts, human in aircraft has to survive the crash. Irrespective of the cause of crash. How can we achieve this?

Q2.4 What are the current tools/technology present that can help reach reduce fatalities in accidents? What additional research is required?

Q2.5 How can the FAA certify such technology or add certification requirements without adding a big burden on aircraft manufacturers?

Topic 3: Automation and Autonomy in Safety

Q3.1 Is Safety a by-product of Automation and Autonomy in the aircraft? Or is it the main driver?

- **a.** What is the current state of automation that increase GA safety? E.g.: Autopilot, UAS auto-landing, TCAS?
- **b.** What new automation and autonomy technology should we expect to see in future aircraft that will improve safety?

Q3.2 How will the FAA relate the impact of the technology to Risk and crashworthiness?

Q3.3 Can automation in the future increase crashworthiness?

Critical Milestones & Task Outputs

Q1. What are the outputs from the tasks of this topic and what other tasks rely on tasks completed from this topic?

Q2. How urgent is this research to GA in 2030?

Q3. Who are the primary stakeholders of the research outside of FAA?

Q4. With whom should the FAA collaborate?

Summary & Outcomes

Q1.1. What potential outcomes are required for this topic area?

Q1.2. How do the research initiatives / tasks from the fill the gap between current and future GA?

7. Research Area: Pilot Training & Proficiency

Topic 1: Automation & Autonomy in GA aircraft operation (Simplified Vehicle Operations)

Q1.1. What is current on-going work in automation and autonomy for GA aircraft flight control operations?

- **a.** NASA’s simplified vehicle operation. Road map defined by NASA in 2015.

Q1.2. Why is there a need to improve automation in the cockpit to ‘make flying easier’ for GA 2030?

Q1.3. How would increasing automation and autonomy in the cockpit impact the time required to achieve proficiency?

Q1.4. What types of automation and autonomy in the cockpit help to augment pilot training along with simplified operations?

  - **a.** What limitations exist for such augmentations?
  - **b.** What type of fail-safe practices accompany such augmentation

Q1.5. Will training augmentations provide satisfactory pilot proficiency for certifications?

  - **a.** What methods and technologies are necessary to validate augmentation

Q1.6. Any other comments on automation and autonomy in aircraft that may impact pilot training & proficiency?

Topic 2: Revising Airman Certification Standards

Q2.1 Are there any on-going work for an 'outlook' ACS in 2030?

Q2.2 What are the steps involved in building new ACS?

  - **a.** How will the FAA accesses new aircraft type and cockpit automation with respect to required amount of proficiency?
  - **b.** Example: Q] Should the revisions to the Airman Certification Standards (ACS) regarding demonstrating stall recovery procedures necessitate changes to stall characteristics of new aircraft certified under Part 23? If so, of what nature?

Q2.3 What are the impact areas for changing the ACS?

  - **a.** Curriculum for Pilot Training
  - **b.** Training methodology and procedure
  - **c.** Pilot Certification Levels

Impact Area 2.1: Curriculum for Pilot Training

Q2.4 What is the research needed to the change curriculum for pilot training?

  - **a.** Example: Q] Growing cockpit technology may increase workload and training. How will we circumvent this in the future

Q2.5 What are the tasks involved in streamlining and simplifying the current VFR and IFR training curriculum?

Q2.6 What are the steps involved in building new curriculum?

  - **a.** What needs to be done to build the curriculum from the new ACS?
  - **b.** How will the FAA make sure that the curriculum reduces cost and time of training?

Q2.7 Will training data be used in formulating the curriculum?

  - **a.** What are possible data sources for collecting training data?

Q2.8 (Who and How) do we determine the degrees of automation and autonomy in pilot training?

Q2.9 Any other tasks or comments?

Impact Area 2.2: Training Methodology and Procedure

Q2.10 Why is there a need to improve the pilot training methodology and procedure?

  - **a.** Why will the current methodology and procedure not be sufficing for new curriculum of the ACS?

Q2.11 What are the different methodologies that can be applicable for training in the future?

   - **a.** Simulator technology is growing, but has not seen a wide acceptance in pilot training yet. Should simulators be used in training in the future? If so, what needs to change/improve?
   - **b.** A possibility provided in the workshop was that of a remote trainer with remote monitoring with full situational awareness in addition to pilot (trainee) on board.

Q2.12 What resources are necessary for ground and flight schools to incorporate inflight training augmentation?

   - **a.** What cost-incentives should be available for ground and flight schools to leverage in case budget restrictions exist?

Q2.13 Who would determine when recommended proficiency is achieved using inflight augmentation?

   - **a.** What is the road map to in-flight AI determining that the student has reached a level of proficiency?

Q2.14 Any other tasks or comments?

Impact Area 2.3: Pilot certification

Q2.15 How will the Airmen Certification Standards impact pilot certification in the future?

   - **a.** Currently, the initial pilot licenses are based on flight rules such as VFR and IFR? Will there need to be a change for GA in 2030?
   - **b.** Will Part 61 and Part 141 be sufficient in capturing different levels of pilots operating differently capable aircraft?

Q2.16 Should there be levels of pilot certification that represent proficiency in specific in-flight augmented technologies?

Q2.17 What processes should exist for pilots to maintain certification for flight with degrees of automation and autonomy?

Q2.18 What tasks would need to be performed to help answer Q2? Are there current technologies that can help or do we need additional development?

Q2.19 Who are the stake holders for the change in pilot certification?

Q2.20 Any other tasks or comments?

Critical Milestones & Task Outputs

Q1. What are the outputs from the tasks of this topic and what other tasks rely on tasks completed from this topic?

Q2. How urgent is this research to GA in 2030?

Q3. Who are the primary stakeholders of the research outside of FAA?

Q4. With whom should the FAA collaborate?

Summary & Outcomes

Q1. What potential outcomes are required for this topic area?

Q2. How do the research initiatives / tasks from the fill the gap between current and future GA?

C SME Interviewee Listing

The following is a listing of all SME interviewees that contributed to the development of this report. The listing includes the name and affiliation of each interviewee and is organized in alphabetical order by affiliation and then by SME first name.

Keith Hoffler	Adaptive Aerospace Group
John Uzcekaj	Aspen Avionics
Todd Hurley	Cirrus
Aimee McCormick	Federal Aviation Administration (FAA)
Bryan Barmore	FAA
Gary Pokodner	FAA
Ian Johnson	FAA
Jim Patterson	FAA
Ken Knopp	FAA
Kenneth Allendoerfer	FAA
Michael Walz	FAA
Robert McGuire	FAA
Tom Glista	FAA
Wes Ryan	FAA
Jeremy Brown	Frasca International
John Frasca	Frasca International
Randy Gawenda	Frasca International
Greg Bowles	General Aviation Manufacturers Association (GAMA)
Jonathan Archer	GAMA
Husni Idris	National Air and Space Administration (NASA)
Justin Littell	NASA
Ken Goodrich	NASA
Matt Underwood	NASA
Michael Patterson	NASA
Nick Borer	NASA
Tom Haueter	National Transportation Safety Board (NTSB) – Retired
Rod Borden	Port Columbus Airport Authority
Rick Crider	San Antonio Airport Authority
Bruce Holmes	SmartSky Networks

Neal Willford	Textron Aviation
Mark Voss	Thermodynamic Sciences LLC
Christabelle Bosson	Uber

D SME Interview Notes

In this appendix, the collection of SME interview notes is organized and consolidated. Each section includes SME interview notes that correspond to the seven research areas and subsequent impact areas discussed in this report. In general, the SME interviews deviated from the interview questionnaires and thus do not chronicle the interviews specifically. The SME interview notes serve as a source reference to develop content for the report.

1. Research Area: Airports & Infrastructure

Disruptors

UAS, Autonomous Air Vehicle Concepts

- UAS is one of the things that the FAA need to catch up. UAS growth will outpace FAA's capability to manage and accommodate UAS in Airspace.
- Personal air vehicles (‘flying car”) – autonomous vehicle equivalent to autonomous car
- UAS is a component of a larger section of technology. Automation and Autonomous operations. Personal vehicle that are capable of flying autonomously (including flying car). Transition from traditional vehicles to VTOL and high density traffic. Specifically in areas of population.
- UAS poses enormous threat to airport aviation operations
- High density operations at an airport
- Major concern on how FAA is going to manage S/VTOL traffic in high density operation in areas that already have high density today
- “Outpace” FAA
- More density where density is already focused
- Lots of current FAA work looks at intentional use of drones/autonomous vehicles at GA and part 139 airports locally
- Useful for firefighting, security, pavement inspections, wildlife, clear approach path
- Include autonomous ground vehicles in the list of disruptors_to do some of the above tasks
- Building new airports will only be helpful if people want to go there. Need to figure out where people want to go – and then decide what the routes look like in the airspace. May need to consider designated routes through waypoints, and how to mark them, especially in urban airspace with high-rises / obstacles.

VSTOL/STOL Concepts that will Facilitate Novel Operations like On-Demand Mobility

- STOL/VTOL/eVTOL
- FAA has briefings within agency, see it as something that is coming, and are very interested in it

- May need dedicated landing/take off facilities, and can be just as disruptive as UAS

Alternative Energy – Alternative fuels, Electric Propulsion

- We generally see cross checking fail, not necessarily system fail. How do we do it so it's not pushed back to humans is a question. When done appropriately, we get something like FADEC.
- We don't design [automation and autonomy systems] to fail in a degraded way currently. It's all or nothing.
- Glass cockpit – for two decades, we kept the steam gauges before removing them. Similar may happen [for automation and autonomy systems]. However, for flight control automation is not as easy to transition. Trying to build ourselves to a level of comfort in flight controls to go to a basic level of operation of cross-check fails
- Envelop protection – this is becoming available – an excursion from envelop managed by equipment
- It may be completely inappropriate to hand back the control back to the pilot – particularly in a high stress environment
- Two aspects – Firefighting and airport lighting:
    - Firefighting: Big airports have advisory circulars for firetrucks etc., but GA airports may not have dedicated firefighting facilities. Research is needed to determine capabilities needed to effectively control alternate energy fires like alternate fuels, batteries etc. Additional training and equipment requirements for GA airports might be needed
    - Airport Lighting: Looking at solar airport lighting – standalone- where light fixtures have battery and solar panel, or modular- where solar array and storage powers multiple lights
- FAA has worked on / are promoters / funders of operational vehicles (that move people etc.) that are partially / fully electrified. The program has been slow in adoption at commercial airports. There is a large difference in funding between commercial and GA airports, and convincing FAA to invest in alternative energy options for GA will need good justification.

High Density Operations

- Anticipate waterfall effect – where big airports get saturated to capacity, leading to more traffic at smaller airports.
- UAS – may not operate out of existing airports. Use of airspace does not mix well, and may require separate ground space too. Use of each - UAS, fixed wing, rotor wing is unique and they may need to operate separately. May be somewhere else because they don't always mix well, airspace / ground space can be different.
- New vehicle operations may not be easily integrated into the current, somewhat antiquated systems due to the disparity between technology, operations, and infrastructure needed. A big question that can be asked is "How do you share airspace with someone who need not have any training (UAS operators) and does not understand airspace in the same way as trained pilots do?"

SME Defined

- Automation - difference in ground-based vehicles and air. Ground transportation and air transportation.
- Are we going to have separate systems in the air from on the ground?
- Ground and aircraft are very different. Aircraft depend on ADSB, weather etc. - external inputs. Autonomous ground use sensors exclusively.
- If ground and air vehicles converge (flying cars), need to figure out system(s) for gathering and processing information from both external sources and sensors. A/C rely on external data, but autonomous vehicles gather and use their own data with an array of sensors
- Cyber (-security) disruptor missing- navigational aids. E.g. Physical infrastructure on ground has changed with GPS. Maintenance, weather information systems. Cyber/ IT changes data exchange between aircraft and ground which can be used for maintenance. Newer equipment is 'smart' equipment
- Physical – infrastructure to support autonomous, alternative etc. providers of industrial services will follow the trend that developments follow, therefore infrastructure will have to catch up.

Topic 1: Airport Security

Site Security

- Security less stringent at GA than commercial airport
    - A need today isn't being fully met. Security at GA airport is much less stringent than commercial airport/aircraft. Security in commercial mainly to stop weapons, baggage and employee sabotage in commercial aircraft
- GA, prevent someone from damaging the infrastructure than people
    - GA airport, mainly to prevent people from jeopardizing the system. Stakes are lower numerically in GA airports. Probably, need in future but does not see relative change of impact from current scenario. Will rely more and more vetting people than assessing physical security at GA airport.
- Physically securing isn't going to increase security if individuals have more access to vehicles outside airports
- May need to have technology to intercept vehicles
    - Opportunity to rely on technology to secure individual / property/ etc.
    - Opportunity to look at technology to command an aircraft that won't allow it to collide with other aircraft and force it to take a direction and land where it's not a danger.
- Focus for future aircraft not expected to change from current paradigm -> do not let GA flights harm commercial airports / system / buildings etc.
- As security gets tighter at large airports, GA airports become weaker link. Need to protect the weakest link for safety of NAS.
- One way can be by readopting sensor technology to GA level. It might need stronger directives from government along with funding to support smaller airports.
- [Regarding how digital landscape affects physical infrastructure requirements] Prime example is ASD-B. Traditional maintenance – go to base. Will ASD-B operators will make changes not at hub necessarily. Real time data on what aircraft needs will allow more aircraft specific proactive maintenance. Access to real time

data allows for redistribution/reallocation of maintenance requirements/activities which will lead to reallocation of infrastructure demand.

Cybersecurity

- "Can't prevent anything from being hacked... can only make it difficult"
    - We cannot prevent anything from being hacked. We can make it difficult. Might need to research technologies in individual aircraft, where if the control system is hacked, then the vehicle can safely land without causing damage to people, infrastructure and other aircraft.
- Incorporate technology to counteract against system failure/hacking/compromise and mitigate situation
- The denser the traffic becomes, the more we need technology to safeguard safe operations.
- Incorporate technology to each vehicle that ensures the vehicle are capable of taking action autonomously in a manner that ensures they'll be able to take a route that doesn't endanger other aircraft, buildings, etc.
- Focus on technology driven solutions
- A mere act of charging a battery involves communication between the charger's computer and the battery circuit. Will need to look into issues like possibility of hacking the charger station remotely to overcharge a battery which can cause fires etc. Similarly, big aircraft have 5+ systems connecting to gate via WIFI to transfer information. Future UAS may need to be protected to a similar extent as current large aircraft. Need to make sure they are not any more vulnerable than commercial.

Topic 2: Facilities Management & Improvements

Runway & Terminal Facilities

- Pavement T/O, landing, and vehicle storage
    - What is the pavement and vehicle storage area look like? When newer aircraft are similar in number to traditional aircraft, additional infrastructure will be required on top of what is there currently to accommodate takeoff and landing of new aircraft type.
    - What does the pavement (takeoff and landing) and vehicle storage area look like when PAVs/UASs arrive?
    - Need same infrastructure we have now and new demand for infrastructure for new type of vehicle.
- Existing aircraft and operations are not going away - so additional demand for infrastructure will be felt
- Will be interesting to see how FAA plans to resolve traffic issue - Do they keep conventional GA traffic separate? If so, separate parking and TO/Landing areas will be required
- Do fixed wing aircraft begin to become minority vehicle in hanger?
    - How FAA regulates traffic for vehicle operations
    - Different approaches to different aircraft type/operations.

    - Different infrastructure required for different approaches for new aircraft. This may define how new aircraft types will land, park and also separation of aircraft types/operations in terminal areas.
- If VTOL is emerging than the small GA airports may be unaffected
    - More impact on commercial airports since people may use these vehicles for connections
    - Land in backyard? Are airports used?
    - Greater impact for commercial airport due to connection to commercial flights
    - STOL will affect the small GA airports
- Markings may/may not need improvements.
    - With autonomous operations there may be a need for other markings for pilots
    - Runway and taxi way will need to be maintained. Markings may not be as important in the future if vehicles are autonomous.
- Renewed and enhanced efforts to update and improve GA airport infrastructure
    - Who will pay for it?
- Inclusion of E-VTOL charging stations, power management
    - Question is how do you hook electric aircraft up? Research in dedicated parking areas for electric aircraft.
    - Look at infrastructure requirements that puts charging stations in parking stations.
- Reduced power requirements due to LEDs might help airports set up charging under original capacity - might not need additional electric capacity
- How do you hook them up
    - May need standards for universal plug for electric vehicles (may utilize vehicle charging port from auto)
    - Need power standards to regulate actions
    - Need to standardize connectors and power.
    - Tradeoff between demand and energy capacity
- Who controls that standard (FAA, DOE)
    - First able to implement could dictate the market?
- Do something that's uncharacteristic of FAA and execute plan of action to address new tech / demand / capacity of airways/airports/operations/etc.
    - Must get ahead of the curve o Look at Europe for examples
    - Every improvement comes with corresponding maintenance
- Ground based guidance systems are critical
    - More precise ground navigation
        - Similar to GBAS - ground based augmentation systems
        - GBAS enhances the ADS-B and GPS which enables the aircraft to taxi runway<-> ramp. Next level of navigation on ground. For the level of activity we expect to see, we would need higher precision systems. More of an improvement.
        - Ground based guidance systems like GBAS (ground based augmentation system) will potentially be critical to help with autonomous landing and taxi

    - System: array of antennas and black boxes at the airport (runway)
    - Several installed across US, many in Europe.
        - Newark, Houston,
        - Privately installed through United Airlines
        - FAA working on Gov't Install in SF
        - Europe has active systems
    - Need to be deployed to manage
        - A system like GBAS will need to be deployed more broadly.
    - For personal vehicles of the future, expect these to be deployed in larger scale – e.g. GA airports
- Current systems will remain in place anyway to help current operations that continue in future
- Foresee navigation around airports as a big concern for UAS/ODM/Autonomous:
    - Current airport markings are intended for human use – where humans are flexible with respect to interacting with markings. Humans can change field of vision to interact with different markings that may be located at different locations, be colored differently.
    - UAS camera systems currently have a very limited field of vision (difficult to mimic human head movement) and may have low image quality. Determining what markings, lighting, and color coding will work best with UAS is a big unsolved research question.
    - For remotely piloted aircraft, we do not know if pilots may have to deal with low quality, black and white, narrow image to decipher markings. There will also be bandwidth concerns to maintain data link with ground operator.
    - Earlier autonomous air concepts will likely have a human pilot for redundancy and safety assurance even if computer does all the flying.
    - Unsolved research question on what is needed to define appropriate approach, take off, landing, and taxi procedures for ODM, UAS, autonomous concepts. This will depend on the concept and the way it addresses visibility problems. FAA is watching technologies but is not sure what it will be in the future.
- Passenger access to air-vehicles is another research concern – Air taxi access is supposed to be as easy as regular taxis, unlike commercial operations. There is a need to greatly reduce access time
- Foresees creation of what he calls 'Drone-ports'. Maybe we are looking at drone-port standards – different than heliport/airports. Cannot say if we will have separate markings for ODM/drones or new markings for everybody (including GA). Gave example of ILS not at every airport, and zipper centerline at busy airports to mention certain changes may be made only to certain airports depending on how future scenario builds up. Cannot say with certainty what future holds.
- [Regarding automation & autonomy impacting infrastructure] Could translate to infrastructure. Do (?) see impact on cargo operations etc. don't see VTOL type vehicles replacing long distance cargo etc. commercial derivatives of autonomous

aviation will be first in RC's opinion (cargo operators). Will translate into smaller GA later.

- Not sure [if autonomous systems will impact infrastructure] – assuming autonomous aircraft will be more useful in populated areas. In industrial context – industrial operations also happen in populated areas. Simply because industrial airport areas already have 10s of thousands of employees working near them. E.g. Seattle has 70-80k, savannah 10k people etc. So industrial operations have highly populous areas nearby [contrary to popular belief that they are in sparsely populated areas].
- [Regarding requirements changes for airport facilities] Technically GA requirements are very few, recommendations are numerous. Do not expect a change in the requirements. Even if new requirements show up or airports ask for funding to upgrade facilities, FAA will evaluate if the funding is justified in terms of air traffic.

Environmental Management

Energy Management for Future GA Aircraft

- Another change can be anticipated in alternative energy storage safety and logistics:
  - There is a need to research proper training to ensure ground personnel and pilot safety during charging process/refueling with alternative energy
  - Research also needed to develop right equipment to mitigate hazards to ensure safe storage – airports may need to store spare batteries, fire prevention and containment for alternate energy storage, environmentally friendly ways of achieving all of above.
  - For biofuels – FAA is currently trying to understand molecular structure of biofuels and the additives that are added. Bio-fuels do not seem to have different fire-fighting needs based on past experience, but that may change depending on what comes up in future.
- It's a scale issue. 2 vs 200 aircraft per day – will affect transition period for aircraft infrastructure.
- In GA, many airports would like to try alternate energy, however, they will expect someone to pay for infrastructure upgrades. Most GA airports are barely hanging on economically. While some may want to be a part of program to upgrade infrastructure, but people may not want to go there. The 'National' category of GA airports are generally in economically healthy areas may be the first ones where programs to invest in alternate energy succeed and should be considered first.

Topic 3: Airspace Management

Accounting for Increased Capacity

- One idea can look at segregating operations based on landing surface needed
- Autonomous flights need not be at airports – they can be out of parking lots or many other places.

- Looking at GA, it may be necessary to bring some kind of air traffic function, some control mechanism to monitor flow etc.
    - An example of a high-volume GA airport in West Las Vegas - This airport has ATC facility 7am-7pm. It would be impossible to fly in/out safely without ATC there.
    - Thus, SME doesn't see a way to transition to high volume operation without some form of ATC present. The remote ATC concept is being tested; an airport can have ATC functions provided remotely by having cameras, radars, and other sensors to remotely provide information to ATC to do its job. With UAS, it will be important to make sure they are visible and have sensors/equipment to communicate with remote ATC.
- [Regarding high density operations] see that as airspace segregation issue apart from near landing etc. Do not see much impact on industrial operations
- Not so much airspace issue in industrial. Remote towers are interesting. One characteristic of industrial airports is that operations are based on industrial activities. Smaller frequency of takeoffs and landing, but massive economic activity. Might be a good scenario for remote towers.
- [Regarding more people flying into airports instead of driving for work] Not sure. San Antonio – about 13000 people, about quarter is aerospace. Bus, highway systems make a lot of sense. Parking 12000 people in addition to hangars and warehouses becomes a big problem for cars. There is a case for mass transit, not so sure about air taxi etc. option.
- Operations are going up in certain areas. In case of smaller airports, there are no towers, so pilots have to self-report safety incidents – as a result, data collection is less. New facilities that come up will likely be in the form of new technologies. Small airport footprint is really shrinking because a lot of world war era airports can no longer be maintained.
  For airports at higher end of GA classification, land use is changing. Eg. Self-check reduces no. of kiosks in commercial airports and Uber replaces taxi stations. Similarly in GA, land use change doesn't necessarily mean we will need additional space despite needing increase in security.
- [Regarding measures to ensure GA airspace remains safe given increased capacity in the future] Anything – cell towers etc. that are added to an airspace are reviewed by FAA to determine if they are a deterrent to safety or capacity. At larger commercial airports, it is easier because they control a lot of the surrounding land, space.
  It is seldom the case that airports suddenly become busy. Generally, airports that were already busy get busier. FAA needs to consider whether it is wiser to invest in added infrastructure at existing facilities or add new airports/facilities. These requests need to be solicited by airports, FAA cannot force them. All requests for capacity are evaluated, but it is rare that major new infrastructure (like new airports) are built anymore.

UAS Integration

- Within the UAS world, the important questions are 1) how do we track the vehicles? 2) How do we make their location accessible to manned aircraft in the vicinity? 3) What broadcasted information is necessary to ensure manned GA operations are not interfered with?
- Development of low-cost ADS-B like system and collision avoidance system might be needed. UAS needs to have access to data to be aware of airspace. Likewise, need to make sure UAS broadcast information on their location, speed, and flight maneuver like taxi etc.
- GA may be required to have equipment to receive info from drones in order to see them. Additional ground stations may be needed for proper coverage with the advanced vehicles.
- It would be unfortunate to have a situation where any aircraft is deprived knowledge of an autonomous vehicle in operation in its vicinity (e.g. Drone running inspection at GA airport). Questions on who is responsible in such situations should be answered early.
- As a result, SME doesn't see how we can differentiate between small and large airports. There would be no reason to deprive small GA aircraft information about autonomous/UAS compared to large aircraft. Maybe use case for small airports would be same as large airports.
- Drones – concerns about airspace violations. Commercial drone operators – do have use in industrial operations. Will probably see more of them. Perimeter security, aircraft inspection use cases. Matter of de-conflicting those operations from traditional operations around industrial airspace. Similar thing happened with ultralights few years ago. Army UASs operate sometimes in commercial corridors, but they have figured out how to share airspace?
    - Serve as perimeter security – low hanging fruit.
- On one end, we are working to reduce the problems caused by birds, while on the other, we are planning to introduce UAS that are similar. There needs to be a categorization based on usage, size, aircraft type, and operation. It may be wiser to determine and designate 'lanes' for different vehicles within airspace so different vehicles can stick to their 'lanes'.
- [Regarding measures to ensure safe integration of UAS into existing infrastructure] Need to start with the end in mind and back out requirements. There may be alternate sites that suit certain UAS operations. This will also depend on whether they are STOL/VTOL capable. One idea would be to establish how the airspace looks like and then back out infrastructure requirements from there. Compatibility with GA needs to be established. Examples of how helicopters (VTOL) has worked can be considered. E.g., Skydiving has designated areas in 3D airspace that can be identified on a map by fixed wing pilots. Something similar can be used to sort out UAS airspace.

FAA's Role:

Airport Security

- FAA, TSA interact through the avenue available due to National Safe Skies Alliance – which looks into developing scanning technology etc.

Facilities Management & Improvements

- Should FAA bet on a technology?
    - FAA might need to predict a range of possibilities and plan for a basket of them
    - Cannot wait for technologies to mature to work towards regulations
    - At the same time, cannot afford to be overly restrictive so as to handicap tech development
- What is the share of FAA's responsibility for GA airport regulations vs state/local government?
    - Allocation of responsibility between FAA and state, but majority of regulation is determined by FAA. States don't play much of a role on how small airports operate or technology, FAA is primary stake holder. FAA calls the shots on that. States do some funding and administer grants for smaller airports.
- Most important deliverable: Provide the basis for convincing the FAA what areas they need to focus on for future needs.
- Early on deliverable - paper to make the point that the US needs to be a leader in this area.
- Someone at FAA needs to be convinced to act on these questions now before it is too late.
- Hope this happens: more consideration given to investing in infrastructure that supports an ecosystem of aviation. FAA and government should also focus on looking broader metrics including economic impact, job creation apart from just number of landings. Shift towards consideration beyond traditional metrics – consider broader implications and rational for investment and infrastructure to include job creation etc. Translating to industrial airports – sensitive to migration of jobs outside especially due to moving maintenance etc. outside.
- Economic impact in terms of jobs, products etc. instead of just number of operations etc. need to look at FAAs role to promote aviation. Summarizing: Trying to map not just how busy an airport is but also utility it is providing, economic impact, jobs created etc.
- [Regarding partnership between aviation and automotive sectors for charging stations] GA airports that get federal funding have to be compliant with all the rules and regulations – which are often times restrictive for good reasons. Thus, it would be imperative that a FAA group meets with non-FAA / industry for talking about what can/cannot be done. Need to have partners from every side to ensure airports are still compliant after forming such partnerships and do not lose entitlements / standing with the FAA. There is no requirement for FAA to fund such initiatives right now, and don’t see that happening unless there is a national initiative / program with dedicated staff and potential funding.
- Can help them improve safety by requiring more training. We can improve markings, signs, lights, as well as layout and geometry of the airports. Sometimes that can mean making taxiways skinnier, so pilots don’t confuse them with runways.

- FAA would like to work together and partner better with airports. Sometimes it is a matter of putting right folks in a room and seek innovative solutions while being aware of policy and rules in place to ensure safety. Need to have outside the box thinking.

Airspace Management

- [Regarding installation of navigational aids that facilitate IFR/ precision approaches to manage increased traffic at GA airports] FAA is a fan of these navigational aids. However, they do require certain cleared surfaces near the airport runways. In case of GA airports, these tend to go way beyond airport property, and therefore cannot be controlled to maintain said cleared surfaces. For GA airports to ensure they obtain and maintain navigational aids, owning those cleared surfaces seems like the only feasible long-term option. If they cannot invest that money, it can be difficult. This can also be difficult to do in populated areas / near cell towers / near mountains etc. FAA should try to experiment and figure these out.

General Comments:

- Look ahead for FAA to find emerging issues in GA to be prepared for changing environment and technology in 10 years or so.
- A marked difference between ground-based vehicle and aircraft. Aircraft rely on sources external to them (ADS-B), but autonomous ground vehicles use internal sensors to avoid [obstacles/people]. Is there one system that we can use on ground and air to avoid other vehicles or do we need separate systems? Ripe for research and collaboration. Assumption: In future ground and air personal vehicles will/can be the same.
- FAA tends to look at system and problems of today; Are not as focused on future, especially since there is no data to support anything
- FAA tends to be "myopic" – tend to look at current issues
- Without solid information on technology, don't think of future
- Blue statement under airport security – not necessarily "improve", but "maintain" current level of safety
- Other blue statements are fine the way they are
- Backstory context about successfully answering a GA airport operation need:
    - 15-20 years ago, there was a need to develop lighting recommendations for GA airports since large airport lighting requirements were expensive for them
    - The development of a GA lighting handbook after collaborating with IES Aviation Lighting Committee which got endorsed by National, State, and Regional Airports appeared useful
    - It provides guidance and support for implementing technologies at GA level without breaking the bank
- Thus, there is a successful precursor to porting some large airport research into GA economically, and similar studies can be carried out for future problems
- Big missing research question: what are appropriate metrics for industrial aviation? There should be economic metrics/ job creation etc. as mentioned above.

- Sometimes we put things together because they look the same, but they are not related in reality. Eg. Intermodal transportation – trains and airports. Cargo for two is different, use for each is unique and need not belong in the same place.

2. Research Area: Aspects of Connectivity

Disruptors

Application Programming Interface (API)

- A lot of challenges relate to what is the data that we are expecting? Do we have any idea of Volume/complexity– does that inform the kind of links we need to provide these services?
- Whether info is purely autonomous or requires pilot – info between aircrafts/ a/c pilots / aircraft operators? Do we have links to provide those services or do we need to look at something else?
- Some way to define what does connectivity mean? Do we have sufficient capacity for ACARS etc links? Do we deploy it over Satellite links? 5g could be lower altitude, and high altitude could be serviced by satellites.
- These are a huge deal. Two options – can be open (like Apple), or closed (similar to Garmin). Benefit with open is that anyone can develop applications etc, while closed APIs don't allow interfacing with avionics and flight. Right now, everyone is going in different directions. One place where this was standardized is in the GDL90 protocol in Alaska under the ADS-B capstone project. A big strategic question for the FAA is whether they want to dictate any API that goes into the cockpit. However, they cannot do that with PEDs like IPads – so it is both a business and regulatory issue that needs to be resolved.

Personal Electronic Devices (PEDs)

- Everybody uses PEDs to an extent in GA. In airlines, this is regulated, not so far in GA.

ADS-B

- ADS-B is good example of that – traffic, weather relevant for GA
- Flight data: ADS-B / similar tools related to TCAS for situational awareness of traffic. Traffic intentions - allowing better dynamic pic of what other people intend to do rather than what they do now
- Opportunity for top down regulatory changes. Industry doesn't always like this, but it is important sometimes. Problem with top down development is that it is slow, while industry likes to move faster to gain business advantage.

SME Defined

- Commercially one of the discussions have been the provision of high altitude weather to aircraft behind you – aircraft to aircraft info (turbulence/microbursts etc), to be helpful to others flying in same airspace.
- Flight plan perspective – submitting and acknowledging flight instructions from controller – is that passed from vehicles to vehicles? Dynamic management of

closely flying traffic can be anticipated – how do we apply data links to those? Can we use 5-g services as they come online?

- Automation plays a role – human-machine interaction, artificial intelligence
- Add Pipelines of Connectivity
    - Satellites, proliferation of nano-satellites, project loon etc. A lot of money is being invested in trying to create for-profit networks, ACARS. How these connectivity choices will be used in the cockpit will be important.

Topic 1: Connectivity Infrastructure

Aviation "Internet" or Data Link

- Don't see infrastructure where you would have aviation internet. You would have aviation service -Data management service for aviation purposes can be needed. May have requirement/restriction on amount of data in/out that is allowed of it that may be different from ground infrastructure. Can be a contract service. Another vision can be aircraft having hot-spots, pull info from national weather service, aviation services etc. different services for ground and air. Certain security needed. Some non-critical flight data can use ground internet. Don't need separate aviation link. Need to manage inputs/outputs though.

Connectivity Profile

- [Necessary Infrastructure should be] something similar to SLIM today. Lay out the service parameters – basically the internet of the future. Quality checks through authorized providers. Will need lots of cloud memory, processors, distribution needed. Love to get away from hard data link. Aviation internet – can have IP on aircraft, data management service. See info on your avionics / interfaces.
- Everything they can [transmit]. Icing, particles, winds, temperature, surface winds for takeoff/landing etc. If [Part] 121 has radar data, why not send it to GA. Turbulence data from ADS-B by backing out from acceleration data from ADSB – FAA is looking into this for GA.
- With ADSB/TSBs, method remains same. With more a/c, UAS etc. size increases. Don't know what the current limit is. They know already from a spectrum study that they will be inundated with no. of new players. Already thinking about moving TCAS to another spectrum. Don't know where spectrum, bandwidth, display saturation (space available on display) will come from for connectivity and avoidance etc. People need to believe in automation, for automatic avoidance etc. to work or for pilotless a/c.
- We do not understand what info is traded between A/C and controller or between A/Cs. Understanding that may help what links are needed – needs research. Whatever capacity we have, we fill it with noise right now – e.g., Pax wi-fi services. Less need for voice over IP services, we transitioned to satellite linked that is close to giving broadband connectivity. The more connectivity we have, the more we use it. For GA we are moving towards more need. Split it into two – what is needed to fly the aircraft, and second is commercial data links for internet and voice over IP communications etc.

- FAA would be right in establishing standards for data that is provided/ interacts with navigation system of the aircraft so only 'good quality' data is passed into the automated system. Don't think FAA should control app itself. Can establish standards for apps and industry required to comply. Similar to what we have in cockpit today. Third party data provided now is advisory, but one should use approved sources for flight critical data.
- [Uses of data in the cockpit] dynamic weather (current picture, locally or further out, more consistent). Experience of weather as it occurs, you can share it with folks in future (esp. to centralized system to rebroadcast). Allow people to change their routes/speed/altitude etc. dynamically. Can be provided depending on bandwidth. A lot of future programs rely on bandwidth and appropriate data being available.
- Going forward, cockpit connectivity can be broadly classified into three categories:
    - First - Operational connectivity: Necessary to operate an aircraft. Will include communications, ATC, weather, traffic, pilot reports etc. Today we have good connectivity regarding weather and traffic due to ADS-B. Challenges in future will include density of data and how you present it to pilot.
        - FAA is heavy in regulating this type. It is regulated on glass panels in cockpit, but there would be no way to regulate this information if obtained via PEDs like iPads. A lot of research needs to go into how to solve this problem. E.g. using an iPad for synthetic vision can be extremely dangerous, since there is no way to control the orientation of this device with respect to the aircraft – an error of 5 degrees can be fatal. Utilizing an artificial horizon, or GPS data on PEDs can be extremely dangerous and should not be considered even for a backup. In a scenario of flying through clouds while shifting focus between iPad and looking outside can cause disorientation. Therefore, research is needed regarding how these devices are used, when it would be allowable to use them etc. while including human factor elements in the research. This is especially true since there is no way to control how PEDs will be used in a cockpit.
    - Second – 'Concierge' connectivity: Aspects like trip planning, booking a rental car at the airport where landing, fuel availability at night etc. These are primarily taken care by PEDs while in the air, and have the potential to affect operational decisions.
    - Third – Entertainment connectivity: Music, news etc. in flight.
- Don't think the concept or bandwidth exists today to support all 3, one device cannot possibly support all 3 today. How you do that in the future is important question. How do you regulate what kind of connectivity user uses when all 3 are supported by same system? E.g. Cockpit avionics can be regulated by saying that at no time should concierge or entertainment connectivity interfaces ever interfere with operational systems. There is no way currently of doing that with PEDs like the iPad. An iPad freezing up due to multiple open connectivity apps is a real

possibility. Priority of bandwidth is important, but how that can be de-conflicted or regulated is a big question.

- [Performance standards for connectivity] would be good. Would allow room for innovation. That requires FAA to define what performance means in connectivity – research question. Need to have some standardization of issues. Maybe standardize interface W/O standardizing or prescribing APIs

Topic 2: Information Interfacing

Interface Protocol Development

- Doing some of that in the WHITT program. Identify a minimum level of requirements – eg. State something has changed and research with human factors to ensure pilots notice the change. GA can't make money to justify standardizing stuff because that will reduce competitive advantage – prices will get high if that is done
- If you transfer data, you have ownership as broadcaster, consumer has ownership as user to capture and store. Right now, FAA captures all data it needs among the transmitted data, while aircraft captures whatever it needs. Each participant can maintain their own record and share when needed just as it is right now. We need to determine what data is appropriate to be captured to provide investigators sufficient picture to figure out what happened in case of an incident. Research question: What is the right data, and how is it best captured?

Interface Regulation

- We have some standardization already. Don't think you can increase the amount of information in front of pilots any more. They are already saturated. Need autonomous systems. If you replace a pilot, what kind of sensors do you need? Equivalent level of safety as pilot -> toughest choice. Eg. Looking out of a window for making decisions, don't know how you are going to replace that and have an equivalent level of safety there. We are moving away from standards, especially in the GA world - mandated standards are going out. Are not going to happen. Information saturation - maybe AI can help process data. Can have algorithms to do integrity checks and identify bad data points, lots of ways to do that.
- Interface may be via an industry standard. Currently we use primary/secondary surveillance to determine where and who shall manage airspace. At one point, that was done in conjunction with voice. We have now replaced some voice with data links– ADSB, or a specialist CPLB link (?). If vehicle to vehicle interface is required, it may use ADSB type link, may require special bandwidth. May need to work with FCC to provide that frequency and bandwidth. FAA will potentially provide structure and environment of use, while industry can determine how it is implemented assuming a standard interface can be developed and understood. Don't think it is in FAA's benefit to stipulate details. E.g. – messaging that passes between aircraft – how can FAA stipulate beyond basic parameters. Let industry figure it out, develop standard since they are developing equipment so long as it meets FAA parameters.

- To an extent yes. FAA can work with industry to determine appropriate info guidelines. May not necessarily standardize it but can provide what best practices are to present the data and level of data. Do not need to prescribe anything. What is correct environment to make sure pilot is proficient and competent? Pilot training is going to change as pilot has less control on what is happening as automation comes along. Simplified vehicle operations committee looking at what future cockpit is going to look like etc. FAA sets standards to expectation of safety, and work with industry to ensure safety ensured.
- Broad set. if air traffic intent, or data links for a/c to a/c, ultimately it is to improve safety. So it will be authorities- FAA, with academia, avionics companies as participants. Cannot just be FAA, need a broader community to discuss what is possible and practical and cost effective.
    - No. of concepts and ideas have never been adopted e.g., -some landing system to replace ILS – never made it. Some early concepts behind ADS-B never made it. Need to ensure ideas/concepts we put forward meet broader stakeholder adoption rather than just a niche group of folks.
- Right now, it is reassuring to talk to a person along with the ability to double check and confirm a request. Automatic conversation between ATC and pilots will be difficult due to lack of contextual information. Listening to other pilots report/communicate with the ATC provides additional awareness. This looks difficult to replace in the next 10 years.

Topic 3: Cybersecurity

Cybersecurity Risk

- FAA is not getting into cybersecurity, even in the [Part] 121 world. Suggest looking at the automotive industry for industry standard for internet of things, and what they are doing in protecting vehicle to vehicle communications etc.
- Boxes inside cockpit have responsibility to validate data. Much easier to get the box to get redundancy to get to level A than validating sources where data is coming in. e.g., Flight controls has to verify data. Difficult to do that at the source. Don't want to move away from that since it increases FAAs liability. So stick to validating inside cockpit. Things FAA sends out will have a level of security – that will be continued. Whoever receives it – manufacturer will have responsibility to validate info they receive.
- [Current infrastructure support for cybersecurity] in general terms, reasonably well. Easy to discuss hacking a control link etc. is easy to discuss in a classroom, but not easy practically. Industry has an awareness of data integrity, access, error/redundancy checking. These things are being considered and implemented in relatively simple ways. Being able to break into systems physically is one way, as we move into more automated systems, those measures need to be improved (physical site security).
- Goes back to OEM, FAA makes sure info being broadcast is appropriate, within a set of standards, that inappropriate data is not being released by equipment that is issuing it. ADS-B is e.g., – broadcasted, consumed by A/C, FAA, even flightaware.

As long as it is not being misused/misrepresented, all is good. When it is inappropriate and unsafe, need to take direct action.

- Encryption is an ever-increasing workload. Have to be changed daily/weekly etc. Increases people's desires to break the system. It's better to control data that is broadcast and ensure error checking etc. to ensure what you receive is expected. Goes into how we determine quality, appropriateness, and it is used appropriately.

FAA's Role:

Connectivity Infrastructure

- FAA should establish standards for how the data interacts with the flight instruments and automation.
  - Should also establish standards on app development for flight operations
  - Additional studies and future standards in the quality data.
- FAA's role in data robustness and collaboration
  - All long as you crowd-source, you have a lot of data points you can validate against one another. You can validate data points thru volume.
  - [The Part] 121 world already has cybersecurity committee for standards. Maybe GA can reuse a little. Not sure where cybersecurity falls under FAA's responsibility. GA gets a lot of services from 3rd party and private industry.
  - FAA helps provide infrastructure/connectivity. Regulation as it relates to flight and safety.
- Whatever is needed for management of airspace, that is FAA's responsibility. For ADSB, certain no. of comm. etc. – there is FAA responsibility to maintain. For cabin perspective, when internet needed, maybe not as critical (?). Boils down to what connectivity is required between vehicle to vehicle and a/c to ground/ controller etc. We use surveillance, navigation. See the same moving forward, but it will be more of a data link between computers to ensure safe passage between airspace.
- FAA has done a good job with the part 23 rewrite, and is on the right track to provide leeway for innovative companies to bring the product to the market – with less prescriptive and more performance-based regulations. A strategic approach towards connectivity is recommended to maintain safety in connectivity – cybersecurity, software and hardware reliability, user interface etc. Can allow companies to bring ideas to FAA in a way that doesn't stifle innovation. Need to have some level of standardization for issues. Maybe standardize interface W/O standardizing or prescribing APIs. Limiting what APIs can do will slow and limit innovation, while improving technology can be utilized to improve safety.
- [In relation to API interfacing] Not regulating the interface will allow innovation and safety enhancing technologies to the cockpit. Research will be needed to look at how information is presented in the cockpit and to the pilot. FAA can determine what data is considered flight critical and the redundancy needed to ensure validity of data presented – how does pilot know screen is refreshed? Software/ hardware reliability, robustness, refresh rate needed, and how data can be better represented in cockpit are all questions that FAA can answer. Weather is a good example of

where presenting the data is critically important. FAA should not regulate the pipeline.

- [To enable performance-based connectivity the FAA should collaborate with] a mixture of academia/NASA, government (regulatory), and industry. Industry cannot lead because of IP considerations. Academic / public research through organizations is the only way to get ahead of this problem because it is more free flowing – with industry and FAA participation.

Information Interfacing

- FAA is not fully appropriate to solely advise what pilot data is necessary and how its communicated. This feat is a collaborative effort among operators, advisory orgs., and the FAA

Cybersecurity

- FAA should oversee setting a set of expectations/standards/set procedures etc. to make it difficult to hack. Necessary controls put in place to restrict access to people that can interact. Can ensure system is partitioned correctly, necessary site security controls, access is monitored. How – that is more of industry implementation, but FAA can work with industry to establish best practice and what information needs safeguarding. Similar to now but need to be more forward looking. Industry does necessary data checks right now, can continue.

General Comments:

- Connectivity will be driven by other aspects of aviation, like the need for better and more real time information. Addition hardware and sensors will be required.
- GA owners probably won't pay for these upgrades, may have to find a way to have organizations that want the flight data, pay for the additional sensors and hardware added to GA aircraft.
- Connectivity is going to boom. Pilots don't want to deal with forecast data (e.g., 50% chance of rain). Instead, put it out there when route data changes (actionable info). Don't want to deal with uncertainty in real-time. More real time data etc. is good, but pilots don't want to be overwhelmed with less-useful data. GA pilots will not pay for improving system security. Someone has to pay for improving data collection and for establishing downlink capabilities in GA aircraft for the benefit of everyone.
- Who owns the data: Broadcasters
  - Need to understand what data is appropriate to capture
  - General consensus is that more data is good, but we should look at what data is required
- How data can be used in the cockpit besides weather and traffic
  - Dynamic weather for local and beyond
  - Since there is a time delay for NWS sources, it's helpful to have dynamic sources for current conditions
- How does data saturation affect the pilot and flight operations?

    - Need to use human factors to assess how much data is necessary for a given action/event
    - Should we consider adopting the level of simplified operations as that of cars with sharing warnings/events in a concise manner
- Concept applies mostly to weather – national weather service provides consistent weather. Can be consumed in a reasonably consistent way. Different people using it come to reasonably same conclusion. Cannot be the case that different people use the same data to come to different interpretations. Should have a similar response from different parties. Should be used predictably (units of data etc.) to ensure no conflicts.
- Training needs reflect technology coming along. Providing more complex information due to automation to pilots is going to be overwhelming. Therefore, using human factors to assess what info is appropriate at any given point of time. Not to overwhelm pilot with data. If automated system is failing in degraded way, need to inform pilot. Need to inform pilots what action s/he needs to take. Just providing information is not helpful – instead provide pilots with suggestions. Look at cars. Only provide ultimately relevant info – speed, rpm, warning lights etc. Drivers can do little to influence anything. E.g. – tells how many miles before you need to refuel etc. Pilot interface may follow same – simplify pilot interface to advice when particular action or decision needs to be taken. When things go wrong, decision making process to fly, or control aircraft becomes pilot's future role.
- Pilot training will probably move to a glass cockpit certification first, with all others – like steam gauges, tail wheel operation requiring certain permits. We can then look at a combined glass cockpit + PED certification somehow. This is currently a controversial topic, but it should be noted that a glass cockpit just provides information differently, and is unlike a fly-by-wire system.
- With respect to GA, low level communications like 5G will be provided by telecom companies – what 5G is, benefits, how does it interact with a/c? How is it going to be consumed? What does it mean to pilot/ passengers? All needs to be researched – whether satellite / ground providers.
- In terms of regulations on connectivity, FAA has improved tremendously. However, there is room to make the process faster still. It is understood that there will be challenges when there is little tolerance for safety risk.
- In 10 years, GA will use connectivity for tactical information. Up to date, tactical information for traffic and weather, automatic PIREPS, including information whether nearby aircraft are flying by themselves, by remote operators, or guided by ATC. We will also have 5G connectivity or satellites to link aircraft or drones.
- Autonomy and connectivity are highly inter-related. For unmanned air taxis etc., infrastructure for communication should be highly regulated. Not so for manned. Drones and autonomous cargo aircraft should be able to communicate with each other and ground, should be able to avoid buildings or obstacles etc. – therefore need high regulation. With a manned system with a human in the loop capable of making operational decisions, less regulation is fine. Maybe segregating these systems in operation may be needed. Autonomous world needs a lot more research, while in a human operator/ pilot world – there should be more room for innovation.

3. Research Area: Automation & Autonomy

Disruptors

Artificial Intelligence

- [Regarding AI capability to adapt/learn between flights] In between flights we can look at data and see what we can learn but not real time. Next time it flies it can be smarter. Just like you can't upgrade your car software while it's driving.

Block-chain Technology

Runtime Assurance of Software

- We generally see cross checking fail, not necessarily system fail. How do we do it so it's not pushed back to humans is a question. When done appropriately, we get something like FADEC.
- We don't design [automation and autonomy systems] to fail in a degraded way currently. It's all or nothing.
- Glass cockpit – for two decades, we kept the steam gauges before removing them. Similar may happen [for automation and autonomy systems]. However, for flight control automation is not as easy to transition. Trying to build ourselves to a level of comfort in flight controls to go to a basic level of operation of cross-check fails
- Envelop protection – this is becoming available – an excursion from envelop managed by equipment
- It may be completely inappropriate to hand back the control back to the pilot – particularly in a high stress environment

COTS Software & Hardware

- Commercial Off the Shelf software could fill the gap for GA but it depends on how much credit you can take for the operational history of the system. Can also include other equipment to protect against the failure modes of COTS.

Open source Application of EFBs & PEDs

- Everybody uses PEDs to an extent in GA. In airlines, this is regulated, not so far in GA.
- Pilots are continually determining what to do with new data. Right now, info used from PEDs is secondary, can be integrated into a/c. Optimal state is aircraft processes data itself like radio frequency of airport etc.
  - The pilot is the processor now. The less processing the pilot needs to do, the better

High Number of NORSEE Equipment

- Need avionics devices to provide / receive right data and data checks

SME Defined

- All of these are high level concepts and very general – like AI. Suggest adding autonomous situational awareness to the list.
    - Can be a virtual copilot – constantly monitoring the situation, highlighting unusual trends and bringing it to the attention of pilots
- Removal of humans as backup for Automation and Autonomy (A&A) and system criticality under such assumptions. As we get to higher levels of A&A, this question is bound to arise.
- Appropriate metrics for characterizing human performance vs A&A performance.
- Human machine interfaces. Cross cutting system integrity and decision making.
- Clear characterization of functionality is needed – how do you 'deconstruct' functions? We have thought about pilot - but not as much as controllers (locate, communicate, separate) and other human functions (eg. Dispatcher). Training automation to do those functions. Do you require autopilot to fly like a human, or should it be more precise?
- Criticality of connectivity – important for an internet of things. Transferring critical flight data- Procedures for losing communication today involve humans in loop. Under automation, criticality of such failures can be greater. FAA would have a role in considering criticality of data and then severity of loss
- Traditional automation works well. At a juncture where we do not want to step across the line by fully automating GA. We're not there yet. Partially automate flight controls, we have cross checking that shuts down automation if cross check fails and hands over to pilot. This is where most issues lie. Solution is to raise the integrity level of those systems.
- Redundancy [is] good – but they all need to act the same. Need to be transparent to the pilot if there is a failure and continue operations.

Topic 1: Software Reliability

- We typically hold automation to a higher bar during certification than humans. So, it is easy to push things across the barrier from machine to person. Current tendency is to hand things over to the pilot if we are unsure whether system will handle a case correctly. Need a better way to make tradeoffs between humans and automation – do a better job of backstopping one another rather than relying completely on one. Air France 447, A320 variant case is a good example, where all 3 pitot systems iced over. Envelop protection switched off and handed the plane over to the pilot suddenly. What can be done better is to stabilize the aircraft, then alert the pilots.
- For GA, companies are going to try and avoid level A or B software [certification] if they can. They can use architectural diversity to reduce criticality of any system element.
- [Reliability and redundancy are] similar, but it is not like having 3 identical systems in parallel. Instead, have diverse systems provide the same function, so there is no common failure. May not make economic sense, but can improve safety. Can call it dissimilar redundancy – satisfying the same function through different modes.

Run-time assurance is an example. You have a protective element of system that is simple.

- [Regarding software challenges] Prefer safety assurance over design assurance. Garmin says going from level C to A of software is expensive ($ millions) on same hardware. Instead of front end, process heavy software, have backend heavy simulation / hardware in the loop testing, and get credit for V&V by testing. Create enough scenarios to gain confidence. Some SMEs will argue that level A cannot be reached by this method, there can still be a shift to level C with robust validation instead of A.
    - If you have a runtime assurance wrapper, you can achieve high level integrity almost like a level A system Potential research topic to demonstrate that level C might result in similar level A. Power of combined well design system with monitors can work. Research should go into high integrity monitoring for runtime assurance to reduce the need for human intervention during system failure. Some research has been done on this in space and military, not in GA. E.g. In recent cases with AoA failure, can have a derived AoA determined through other sensors. Whenever one or more AoA sensors don't match the derived value, notify pilot. A multi-path voting system can be used to replace pilot intervention. Thus, not only having redundancy, but monitoring it too.
- [Regarding non-deterministic software] No matter what goes inside an AI (deterministic or not), there are certain top-level principles it can be tested against – e.g. g-limits, preventing air/ground collisions, envelop protection etc. It is then a matter of defining and executing routines / scenarios for testing and monitoring. One way can be through a hardware in loop simulation environment - we throw everything we could at these algorithms to make sure they could handle extreme cases. What type of credit can you get for these HILS cases? Test edges of barrier to show it works there and assume the rest of the flight envelope works fine.
- [Regarding verification of corner case testing] One way can be to generate boundary case scenarios (need not be realistic). Need to look into what credit one can get for HILS testing. Also, instead of extra/interpolating, show you can never exceed these test cases, therefore the executive monitor will protect the vehicle. Hardest will be if you have reconfigurable architectures that can change itself in flight and potentially change safety.
- [Regarding automation that's capable of performing cross-checking/diagnosis tasks] effectively propose envelop protection – don't let aircraft to get into an unsafe situation no matter if piloted by human or automation. Make sure pilot doesn't do anything stupid, but don't hand the pilot an impossible situation to handle – that will be inappropriate.
    - We're seeing the cross-checking of systems highlight issues, that's where we shutdown.
- Don't want to fully automate everything in GA. Discomfort in automating flight controls. Safety issues are emerging when we shut down automation

Topic 2: Hardware Reliability

- Do not think advance automation changes much. If you want full credit for automation during hazard analysis, need to stop assuming pilot will be a backstop if something fails. Will drive up required design assurance levels for hardware as well as software. One of the reasons companies are hesitant to go down this path, apart from the safety benefit, is that they don't get much credit. E.g. There is no provision to reduce pilot training requirement. It is like paying the cost without getting any benefit for it. Reconsideration of human operator requirements will be needed. Ramifications on pilot side need to be considered – e.g. Potential restrictions on license. Challenges to implement this will need to be thought of.
- [Regarding certification challenges on legacy vehicles] we are already going down that path. Need to start taking credit for operational history during experimentation. While intent of such automation advances is good, one needs to be careful. Frequent usage of non-required equipment may cause a behavioral change in pilots over time – they will adapt to the expectation of said equipment working. There needs to be a study to consider complacency that may build up or skill loss that may occur due to such adaptations. E.g., Synthetic vision can be useful, but need to consider how pilot habits change.
- If you look at leading causes of fatalities in GA – loss of control etc., they are all independent of ground. Certainly, GA can therefore be upgraded independent of ground infrastructure. Also, helping pilots need not be in real time – we can have tools and automation highlight things after a flight to educate pilots on bad habits or behavior.
- Traffic and ground avoidance to autonomy – can you get some integrity with multiple COTS products? This brings affordability to the function.
- Advisory functions, flight planning functions can be brought onto aircraft with PEDs. Onboard devices could provide functionality and automation for pilots - still need certification and standards to regulate apps, devices, and update protocol. There is a research effort for ground collision avoidance – where entire globe's data is compressed and can fit in a PED. Algorithms developed to leverage this in high profile GA accidents have shown promising results. There is also an idea of using PEDs towards word association and data gathering to provide weather information etc. ahead on the flight route. PEDs can bring critical connectivity in the cockpit one day, but maybe not for 2030. The biggest challenge so far is developing flight critical software for PEDs. This problem is multi-faceted, with one aspect including study on human interaction with these PEDs.
- [Regarding PED/hardware influence on reliability and certification] more information to pilot is good to a point. Optimal goal will be a clean interface where all comes in one place. Weather, air traffic, etc. info has resulted in safety improvements. Now at a stage where it is installed in PEDs etc. PEDs are helpful to bring tech early, but don't see that as an end-state solution – which will be more integrated.

FAA's Role:

Software

- [Regarding collaboration between the GA and automation & autonomy communities,] most of these conversations take place at a very high level and don't have enough detail to understand certification challenges. Public use cases to demonstrate complex system safety analysis – like AC 23.1309 – deriving design assurance levels etc. Easy to describe at abstract level, but details take long time for FAA and industry to get together. NASA Grand challenge is good start. A public private partnership may be a good. Hopefully X57 will contribute there at least for electric propulsion perspective by not keeping all their data and details of this process proprietary.

- [Regarding FAA's intentions to look into reliability of data in the cockpit] Yes. Hazard analysis including severity and likelihood of failures will generate requirements for certification. Currently, high reliability systems cost too much for GA. Resilient autonomy program with NASA - onboard architecture for decision making. Automating ground and air separation functions. Best practices for this? How to get these things down to GA by making them affordable?
- [Regarding FAA work prioritization] Pilot aircraft interface. How does pilot interact with automation? How does automation degrade? Is maintenance action required when landed? Providing pilots with better situational awareness results in improved safety
- Not in a good position to answer [whether the FAA can aid development while not scarifying safety]. There seems to be some disconnect between those who develop automation and autonomous systems, and those who certify them, since, until recently, these were two different worlds. Need to work to get a common understanding between both. Common set of tools, etc.
- If [dissimilar redundancy is] engineered correctly it will cost some money, but that is unavoidable, especially for safety critical systems. Key for FAA is enabling higher level of functionality that can allow the GA markets to grow, gain in size to reach critical mass – so there is enough market to cover non-recurrent costs.
- FAA has not allowed systems that have the way to really tell pilot something is wrong and to help pilot understand what has happened. How we present information when something has failed
- Pilot-machine interface with automation needs study – what does pilot need to know, when does pilot need to intervene?
- [Figure out] how do we determine the level of goodness/safety [for automation and autonomy]?
- The certification process maybe fixating how to tackle these questions – not letting us think about alternative approaches. We have a federated approach now

Hardware

- [How does FAA encourage technologies that fail/degrade gracefully] FADEC system fails in a graceful way. FADEC is a good example – failure handled in a way that process/product helps handle this. Engine control works the way pilot expects, software manages failure and pilot stress minimize. From a certification and use perspective, that has already been achieved, just haven't allowed that to show up in other aspects of automation.
    - Have a layered control system to allow a degraded failure mode and keep pilot aware. We have the reliability needed (most avionics is 10^-6,8,9), just no layering – binary failure. Need to make sure automation is connected to

other a/c and ground for situational awareness, and to know about failure of one and take smart decisions.
    - Some issues with AI: how do you test system that doesn't operate in predictable ways? How do you demonstrate corner cases? Model based testing – simulation to test in corner cases. We have to be comfortable with simulation. What if humans cannot interact with a system. Train people on a basic operational mode, and in case of failure, revert to said basic mode (safe mode)
    - "give aircraft back to pilot" – can we allow autonomy to function in a degraded way.

General Comments:

- Not so much the case that hardware/ software is unreliable. It is designed as per requirements/specifications and is rarely unreliable in that sense. Sometimes the requirements/specifications are unsuitable.
- [Regarding ATC/ traffic avoidance/ TCAS/ ADS-B type systems look like in the future,] FAA will probably try to drive towards solutions that support automation. It should be easier to support automation in the loop with airspace development. In terms of digital communication between ATC and aircraft, solutions for how this can happen in unmanned settings need to be explored. Since all air to ATC communication today is carried by voice, the first near term hurdle would be automating this communication – one way can be by voice recognition. If pilots need to translate ATC voice commands for automation, this adds a time cost to pilot operation while flying. Potential way to address things in near term from GA standpoint- more operation centric systems that are independent of ATC - using technologies, communications, etc. coming out of unmanned realm.
- [Regarding the future of automation in ATC or A/C] Need to know frequency tuning etc. for aircraft while this is not needed for cell phones etc.; Need to get to a stage where auto-tuning, verbal communication, voice recognition, effort on how to digitize some of this information.
    - magic moment – switchover to future tech, will it be overtime? Build robust solutions in that case. Don't think it's a real challenge from regulatory standpoint – can be easily updated. Challenge is in equipment upgrade needed. 5G is going to bring additional connectivity mechanism.
- There is growing resistance to automation with failures. Everyone points out when it doesn't work. We don't have a good example of automation saving the day. We need more research on cases when automation saved the day for the public eye. Let's use automation in a manner in a way that makes machines better at what they're good at and pilots what they're good at.
- How to digitize information to cut down on voice traffic. Things like auto-tuning. Off load voice – digitize some more information to lower pilot burden
- Humans do not always respond predictably – but our approach is to treat these [software] like predictable system
- What is a model-based testing analogy for automation?
- Just because the A/C is a Cessna 152, there is nothing to say it is much different than G650 with respect to avionics

4. Research Area: Future Airspace

Disruptors

New Aircraft Concepts

- Emergence of thin haul
  - Looking at 9-pax
  - Enabled by newer technologies to bring operating price point down makes this viable
  - Thin-haul market may have more use for adv tech since more ops would help offset the cost of tech instead of the UAM
  - These thin-haul concepts will overlap UAM
  - This thin-haul could change how operations need to be managed
    - No too much work done in this area. Mentioned SATS work to leverage secondary airports
  - Perhaps changing dominant routes
  - Increasing overall traffic in thin-haul takes a bigger role
  - Thin-haul could be an overlay of current operations – growth in different places from today's commercial traffic
- NASA is also considering supersonic – business jet size; how will these integrate? Operations are different, what class airspace look like?
  - Cruise at Class E or "High E"
  - Transition could be from B to A to E
- UASs: hobbyist operating drones – very high numbers influencing airspace
  - There are a large number of UASs registered at FAA. Think there would be a bigger risk of UAS with GA interactions. Push to certify UAS operators. Thinks the individual owned drones could be more impact than commercial UAS
  - Do not think there is something that ATC can really address this. This could need better certification of operators – more regulations about who gets to fly UAS
  - Current efforts to expand current regulations to enable UAS ops – also needs to provide guidance for newer entrants/operators
- Sees autonomous UAS operating in same airspace as other traffic
- UAM: drone delivery, eVTOL will change airspace
- New entrants in near term will not operate outside of VFR (eg UAS)

Internet of Things (IoT)

- Connected cockpit -> more data to the flight deck or dispatch or controller
  - Cyber security concerns
  - HF: right data to right person
  - Data fusion
  - What does all data get used for?
  - Electronic Flight Bag Technology to transmit data/information from source to cockpit
- Public/private partnership to provide air navigation services

    - What impact will this have on GA
- Cloud computing – could airspace be managed by computing anywhere?
- AI/machine learning will allow more automation in airspace
- Connectivity – more travelers will want to access internet in air, what impact does this have on the cockpit <- this needs to be researched – how to get to this bandwidth
- [Connectivity] for entertainment [and] for cockpit
- How to bring cell signal into aircraft
- How to know where the aircraft is
    - Will need to get position and projected position onto ground
- What band is needed to get this comm. between ground and a/c. How do we know this is "safe" because information is available.
- Connectivity gives bandwidth to upload trajectories to aircraft could allow more aircraft to operate – can greatly reduce separation
    - With imposed "accuracy" of flight via improved predictability will lower controller workload

Wider Spectrum of Pilot / Operator Certification

- Thinks that glass cockpit trained pilots might already lead to a different certification from six-pack trained pilots
- If operating in congested airspace where see and avoid is needed, maybe you need to be a pilot
- If flying taxi follows I-5 in given direction, you don't need to do "pilot stuff", the this segregated airspace could facilitate an operator-level experience function
- Like UAS/remote pilots: how do you have one pilot for multiple vehicles? What does a mutli-vehicle operator look like?
- Spectrum of Pilot/operator certification – this affects cost and safety

SME Defined

- Improve propulsion technologies
- Advances in automation/autonomy may not be commercially viable rn, but can be in future
- Autonomy plays a role in both aircraft and in the airspace (control/mgmt.)
- Maybe with increasing activity and larger fleets of thin-haul vehicles may have some autonomous fleet management
- UAM will be huge disruptor, not sure anyone has full understanding of impact
- Simon asked about what research needs to be looked at now – Bryan says there will be several aspects: casual GA pilot is different from high hire pilot
- Thinks we will see this wider range of operations, mentioned a taxonomy for UAM "piloted – not piloted, one pilot-one a/c, one pilot – many aircraft
    - Research needed to develop a taxonomy for the degree of autonomy and human pilot tradeoffs given new vehicle concept entrant.
- Sees operations increasing; no feasible way that every UAM vehicle can have its own pilot

    - As remote piloting expands – one pilot managing multiple vehicles; data come could be clearer / safer
- Decision aids and autonomy will make this differentiation even bigger – like the help of dispatch
- Could GA help self-separate by using on-board equipment, perhaps we could increase operations at airports in IMC
- Commercial space launch could also disrupt more concern during transition to high-E airspace
- More robust launches - affect large sections of airspace – this might impact GA operations (maybe launch from less populated areas)
- Thoughts about airspace access from non-traditional GA – refined “Blackfly” ultralight* Part 130 operations with little training
- Thinks electrification could reduce cost significantly and make GA operations more wide spread
    - Can see this as a means to reduce cost operations and provide proficiency for pilots that have limited time and $ for flights
- Automation can provide a means to streamline proficiency at a lower cost while maintaining safety
- The other part of this airspace story that's worth keeping very visible is noise (acoustics) and safety. How they affect both consumer acceptance and community acceptance. The extent to which the FAA is paying attention to the noise story and the safety considerations

Topic 1: Air Traffic Control

Air Traffic Services

- Remote tower operations for bringing air traffic services to smaller airports. A controller at a remote location can provide traditional towered services. This could be on-demand. This seems like it could expand GA.
    - Growth would be in less populated areas where service is not
    - Does not need to be gov’t could be 3rd party
    - Would impose service, could increase flying. If there are more vehicles. This could provide better air traffic services
    - There is currently a contract tower program company provides the tower function. Use certified equipment. Follow rules, employees not FAA
    - Described that flight services provided much information to GA pilots
        - If flight plans filed with service provider, the service provide would not provide control – but would provide guidance
            - This seems to be in UAS ops n uncontrolled airspace. Say you file to spray field, and another files plan that crosses field, service provider notify – look for some sort of deconflict
            - Imagine that many new vehicles will mostly be in uncontrolled airspace – could allow for filing to cut across controlled airspace -> in non-conflicting way/away from an a* stream the GA pilot does not need to call and file

            - If there are large numbers of eVTOL, these a/c operators will not want to interact with controllers for only a few minutes. If the number of vehicles is high, this would also load up the controllers.
- How different do operators interact in an airspace? Is there a 3rd party service provider for ATM function
- Flying from an uncontrolled field to another - not crossing airline paths – ATC will be happy to not talk with you in GA
    - Not having verbal communication could be an improvement

Flight Operations Classification

- Good work around UAM to allow ops near airports. This has been successful in specific scenarios.
- Will be more difficult in takeoff and descent -> SME seems to think about increased separation of new entrants away from commercial a/c during TO/land
- How to extend authorization to fly for larger aircraft. Potential UAM try to have this permission from the start
    - Maybe to operate outside of VFR
    - Currently segregating UAS from manned ops -> but the ability to move to GA ops where ATC/ATM connections are not needed

Workforce

- There is a pilot/workforce issue. The current GA pilots are aging out – new vehicles might change this, but the operators may be more willing to fly routes, etc, without the same experience base that current pilots have, because of all the autonomy on board
- Technologies applicable to GA: wearable devices on pilots -> a service provider notices heartrate and responds. Could monitor sleep/fatigue of pilot/operator
- SME also wondered about next heath care devices – like Lasik* was several years ago. If GA pilots had "enhanced eye-sight" via implant – what would his mean for piloting?
    - What about AR goggles that would help pilots? A long way from knowing how to certify this. How would you even start the process to certify this?

Topic 2: Airspace Evolution

Modernization of Airspace

- Sees future for larger, human-carrying UAS. Thinks that on larger UAS, flight system will be similar to piloted a/c, so that the air traffic management perspective would not see a difference.
- Small UAS will be more difficult to fold into the airspace
- Operation around airports will be an important use case – said Uber Elevate had talked about 1000 arrivals in an hour, while DFW has a max of 240 operations per hour, for instances
- Vehicles into airport with much less infrastructure will be overwhelmed by change in number of and types of operations

- Some of the "future" operations are not really new – but the future may have a greatly increased number of operations
    - Thinks that current regulatory framework could apply, but we could see bigger changes to gain efficiencies.
- "Airspace Sandbox" has high value, but relatively low practicality. How can we do this without sterilizing airspace? It will be important to fly demonstrations along-side of actual, active airspace. Can help get rest of public on-board with solutions needed for airspace
    - A dedicated section of airspace to collect data 24/7 will be very useful
    - Maybe in a small segregated section of airspace
    - Airspace "carved out" for experiments – where airspace experiment sees increasing levels of automation
    - "Airspace sandbox" – a good idea to examine these concepts. Take a current section of airspace with a GA airport, then assume 100 or 500 aircraft are operating near this airport. Oshkosh is an example of how challenging this can be.
    - What does this look like with 100s of a/c operating in a county sized area? Not sure that we could even simulate this.
        - Can computers/controllers keep track of it.
        - Hard to simulate since little is known about the future state of the airspace
        - Hard to validate model because of uncertainty as well.
        - UAS has good notion with test facilities, maybe this could be a place of interest for growth in that area
    - "Siphon off" airspace under some sort of safety monitoring to see what emerges: a UAM/GA testbed
    - What happens with 100s of operations in a small area? What happens when some are autonomous, different vehicle types
    - There is benefit in having airspace section to test in-flight new concepts – can you cordon off areas to test w/ real aircraft?
        - Set up COAs / restricted airspace for these – there could be cities, etc. interested in supporting this
        - Similar to grand challenge concept. Can us UAS test sites or other DoD test sites
            - There's interest in the broad UAM community
- Having a transition plan, identifying what mix is available of equipage – particularly for GA in airspace. How to find few, really critical upgrades and incentivizing. Those upgrades are really important. Airplanes with automation could provide incentive to upgrade.
- A GA aircraft could fly a trajectory w/o equipage – as long as the uncertainty on that trajectory was included in the prediction, the autonomy may make this better.
- A constant acknowledgement that this is the future state is needed
- Flexibility is critical when considering these advances – be flexible about what the future really will be. "The future is going to look different from what we think the future is going to look like"
- All aircraft should have transponders – manned and unmanned

- Performance based navigation seems like it could be adopted – glass cockpit a/c could handle this
    - Decision support in cockpit: fundamentals, guideline, etc. by FAA seems like this needs to companies shouldering all of the liability
    - GA is not as adept at getting to waypoints “faster”, vehicle performance could limit 4D trajectory based on crossing* waypoints GA aircraft have upper limit on speed
- Interested in dynamic airspace charged – this might not impact typical GA however, UAM could benefit in a changing Class B airspace might make sense
- Commercial GA/UAM or UAS
- Might not need data comm. or time of arrival, but might need an on-board trajectory planning that broadcasts the projected trajectory
    - What would make this minimum set?
- ATC cannot provide control for rate of growth in operations – somehow need to evolve for current paradigm to UAM “without” affecting ATC oversight of other flights
- The airspace can evolve on a faster time-scale than expected. Airspace can be reallocated. NASA and FAA must collaborate on this to identify activities that need to be evaluated
    - Grand challenge connection - what airspace needs, what technologies are needed, companies have access to testbed activities
- Separation in dense operation
    - What to build, how to build it, what to expect from it
- Thinks UTM idea has some promise – NASA allows drones to operate in increasing technology – test out new vehicle and technology in an airspace test to facilitate implementation
    - Maybe creating areas where certain operators can operate
- In controlled airspace, two views:
        - Trajectory based operations, allow more freedom / flexibility
            - Will read autonomy
        - This route is accurately defined. Every flight can follow some path
            - If operator decides how they want to fly the route, this introduces uncertainty to the systems
            - GA might not have enough equipage to “stay away” from other flights - this could discourage GA approaching
            - If RNAV becomes prevalent, then the GA operations could take place “nearby” these operations, knowing that other traffic will follow the RNAV directly
- One theme that's emerged in some conversations is the notion of more unified airspace architecture and procedure space. What unified airspace system means to me is that there is the ability for anyone to use all of the procedures and air traffic services regardless of whether you're big or small, commercial or private.
- Controllers have been skeptical of “tailored” arrivals. This has been contrary to the training they have had and are skeptical about the tools needs to manage these operations.
    - Controllers really like RNAV

    - Possible human factors research question when considering controllers having lighter task load but possess the knowledge of position/trajectory of aircraft to higher precision
    - What tools are needed is a good research question, but the human factors aspect of the scenario is also important.
- If all flights are flying exact RNAV, then there is not a big role for the controllers. This "take the fun away" at present: used for approach at large airports – could be used at higher altitudes to limit the interaction needed, if a/c is following the prescribed path directly.
- There has been work on "free flight" for tools and concepts. Some work in flight deck human factors to help pilots with decisions. There could be some HF work on controller side. Are controllers able to maintain their awareness with increasing traffic. If tools do not help, controllers often bring back structure into the airspace.
- [Regarding new airport-operations concepts] Made point that sectional chart shows circle around airport, but operations tend to be more aligned with runways.

Airspace Class Distinction

- Some hesitation about not separating airspace further, but recognition that issues like IFR radar separation would make UAM nearly impossible in high density
    - Does not want to place restrictions on pilots – VFR and sport pilots – from flying when/where they want
    - Don't want to take away all of the freedom in airspace, but maybe some places where density may preclude having all traffic in same area
- What happens in/near class B or class C airspace? Consider what happens with increased operations near airports. May need to change how we consider these definitions
- If there are eVTOL operations – they may be 10yrs or more out – but they could be doing some things in airspace – so maybe a self-regulated / self-spacing concept could increase efficiency
    - Some of the self-separation tools can be implemented in the cockpit to make it useful – could appear in 5years
- Covering many vehicles in a Class B airspace cannot go to voice-based control. If winds, approach, departure, etc. change; then Class B could be smaller
- "Big slices of the wedding cake" where the UAM could operate without interfering w/ airlines
- Airspace class distinction will be an interesting area/topic -> based on requirements for entering/traveling airspace may require new equipment
    - Aside: Discussion precludes high-end business aircraft are often well equipped
- Interactions between GA and commercial – particularly with UAM
- VFR GA ops might become more stringent because of additional flights
- For near term – How do we accommodate new operations via procedure? Changing rules and airspace classifications is very difficult – but maybe a long-term issue
- How will we carve up airspace - allow corridors?

- Will need dynamic change of airspace to accommodate volume and frequency of operations
- Can we have unstructured airspace?
- Can we have dynamically structured airspace only when needed?
- A dichotomy between VFR and IMC that might get wider in future
- The type of equipage will really limit what types of airspace classes can be accessed
- If there could be less mandates on what is needed, how could airspace classification change?
- Can think about segregated airspace to allow introduction- but this could condition aviation to operate in segregate airspace – Do not want to see a segregated airspace in long term
- Not sure that airspace need to be reclassified – show new tech can work in current airspace
- Reconsidering airspace reclassification could have impact on GA ops
    - Maybe this would open up GA -> traditional or UAM at certain times, perhaps of airspace dynamically re-classified could expand GA ops
    - Want to minimize the amount of updates to airspace as possible, but not opposed to transition
    - May have equipage requirement in addition to airspace restriction to ensure safe operations in a high dense airspace
- Do we want to reclassify airspace for a new vehicle or operator?
    - Super-dense pockets may need new equipage or new rules

Topic 3: Automation & Autonomy in Airspace Management & Control

Traffic Detection & Avoidance (UAS-Detect & Avoid)

- Detect and avoid systems for UAS could be made available for GA
    - Would like to have some of DO-365 from unmanned aircraft apply to GA
    - Some of this may need to be automated
- "Non-traditional avionics" could play a role
    - Google, Amazon providing data services
        - Challenge of pace relative to aviation will be an interesting situation
- Opportunities for automation is voice, automated detect n avoid (identify conflict & mitigate conflict in a tactical time frame - both in flight and on ground), airspace restriction
- Prediction of conflict and maintaining separation could have automation
- Detect and Avoid - this needs to be automated. Current concepts require pilot on board to conduct "see-and-avoid"
    - Technical deconfliction is part of see and avoid
    - Strategic deconfliction could be done on ground but will require automation to do this quickly.
    - Automation could help with observation role: WX cells. What are other a/c prevent access to restricted airspace

- Work done with UAS – see that different manufactures have implemented different solutions to same problem
  - E.g., UAS loses link, continues on path to destination, continuous on current path to destination, or goes into some sort of hold until signal regained.
  - What if flight plan includes much more information – if link is lost, her is what the vehicle will do. Controllers cannot keep track of all of these items, but system should. Then, if link is lost, system can "pull up" the next flight path. Then, controller "knows" what is about to happen.
  - SME suggested controllers can watch a scenario to gain experience about how a vehicle behaves after link loss
  - Giving vehicles their own resolution capabilities could result in a resolution that the controller might disagree with or not understand.
  - Does the resolution make sense? Does controller need to wait to see resolution before making next decision? This could be a challenging situation.
- There are lots of "stuff" that could be automated. One example is managing frequencies as aircraft moves to different sectors. There is a cost in terms of workload for this. A great benefit if frequency management could be automated.
- Self-spacing could be given to automation
  - Frequency management, match speed, maintain distance from other vehicles (his is likely more on approach, I think – maybe less en route?)
- See/detect and avoid -> tow autonomous vehicles might do this, two pilots might. The mix of human and autonomous might not work well either.

Airspace Management & Aircraft-airspace compliance

- Autonomy in air traffic management could be a "touchy" subject
  - Perhaps hand-off tasks could be automated
  - Some flow management details
  - Handout and freq. changes between sectors - very repetitive, low-risk task. Could be opportunity for automation
  - Where does the tradeoff/limitation exist for automation, voice detection etc.
- Details about flight assigned autonomously, where human plays as oversight
  - Operations into un-towered airports could be a research area
- Airport module management concept from SAB/NASA could see aircraft and arrange them, avoids flying a hold pattern – assign airport, tail number, give speed, etc. could come through ADS-B
  - An encoding issue
  - Cockpit integration
  - Would need coverage at airports via this module
- ATC becomes more of an overseers or manger. If UAM proliferates, cannot control all of the vehicles via voice
- Operation autonomy means each actor has responsibility – users are managing their trajectories
  - This is a system architecture issue

    - Lower level flights in uncontrolled airspace that need to pass through controlled airspace -> this interaction between E and B has too many operations for human controllers
- Will need automation to handle increased operations
- Will augment ATC in the short, near terms but never eliminate the human in the loop / will not displace role of human
- Human may never be out of the loop
    - Transition from controller to manager
    - Human controller may transition from tactical controller to controller manager. The change in responsibilities and objectives could allow automation and autonomy to be used to handle airspace with vast numbers of operations and vehicles. Controller manager would set system-level constraints instead of stick/rudder, lat/long inputs
    - Roles and responsibilities change but human still in the loop
    - Analog on controller side to pilot + modern flight management system
    - Machine can make decisions without human
        - Currently system relies on human and is based on human behavior
        - At high density/ high-throughput, functions can be fast; system should not mimic human behavior to handle the volume -> let AI do things the humans cannot, particularly for high-tempo operations
        - Human controller cannot handle large amount of traffic – this is the bottle neck. Automation needed at management level
- Need to reduce controller workload via automation – example: one controller might want to see vehicle (UAS) all time, other just near airport, other not all

Airspace Control: Pilot-Controller Communications & Pilot Connectivity

- Non-verbal communication could be automated – e.g. automated frequency switch during hand off
- Some data comm. tasks – still a role for voice communication, but automated data comm. for more routine and procedural instruction
- How do we distinguish role of human and autonomy? The tasks will still need to be done for airspace operations
    - How can we (FAA) ensure that the role of automation does not negatively influence other parts of airspace?
- Urban Air Mobility will make big changes; a lot of airspace design is intended to help humans do their job. As role of automation increases, airspace design might change
- If we could get data comm. working, this could improve clarity of communication between pilots/controllers/others
- Connected cockpit will receive more data, will help or will make decision for pilot
    - How do you certify a non-deterministic system?
- See more intelligent automation in the sense that the automation will handle larger/denser data sets and programmed to help make flight critical decision. For example, automation dictating its own trajectory

- Wider definition of autonomy vehicles will control themselves as uncontrolled airspace is populated, control is autonomous

Airspace Weather Information

- NextGen does not appear to have major impact on "typical GA" – maybe on biz jets – other than some improved weather info and some traffic/transponder information
- Constant WX monitoring – even w/ IPad or electronic device. Automated notification and "checking" could be automated
- If vehicles are readily available, much automation, pilot/operator may not have sufficient experience to make good WX decisions. 1000s of new GA pilots /operators will need help to deal with thunderstorms or icing. This could be automated.

FAA's Role:

Air Traffic Control

- FAA needs to have oversight role, but may not be able to manage the third-party services
- FAA will maintain comptroller like responsibilities and objectives but will leverage 3rd- party service providers to service airspace. Need of redundancy practices
- Lots of the initial concepts for airspace in future might need to be done outside FAA at first – need to develop operational capability, then ensure safe deployment
- Severe limitations on research efforts based on budget. For research to progress, the academia, NASA, MITR, Gov. Labs need to take over.

Airspace Evolution

- Build a roadmap to future airspace, testing technology in operational aircraft in context of system today, but with concepts that are advanced
- FAA should look into heavier regulation for small UAS to reduce incidents and operations
    - Certification possible without "flight xp"
    - Policy still have opportunity to evolve to encourage UAS commercial ops with parcel services as wingmen

Automation & Autonomy in Airspace Management & Control

- FAA needs to certify non-deterministic decision support tools – this will be critical
- FAA/government needs to determine the necessary back up – what minimum level of operations must be obtained?
- Defining these roles is still an open question and needs attention
- Role of FAA to figure out what can be automated, guiding what technology is needed. Describing how to certify automated systems
- FAA layout the roadmap for this development

General Comments:

- Sees that lots of UAM discussion seems to gloss over VFR/reserves/weather deviation
- Simplified vehicle operations needed to get more people flying
- Second to cost – need lower cost to get more people flying
- Eagles are still 1940s technologies – why are we looking at 100cc replacement vs electric
- Would think we do need a large number of experienced operators flying
    - Something like having an experienced operator, like NetJets, have them fly w/ the decision support tools
    - In the real world for these in-flight tests of automation for airspace
- Multi-modal mobility will be a bigger importance, may be harder to separate aviation from other modes, maybe more partnership across agencies
- To allow more aircraft in airspace, we need to be more precise
- Addressing legacy vehicles with automation development will need to have an approach to allow mix of equipment, but difficult to do outside of typical ATC coverage areas where separation is not strictly
- Legacy aircraft with limited equipage. "Great concept that does not work unless nearly all a/c have this"
    - Used ADS-B mandate as an example
        - Even with well-established safety case
- Lots of equipment and information will be close to free, but is not certified -> how do we do this? Certified version more expansive, who will be able to afford this, who will be willing to pay for something that is nearly free
- Automation will lead/may lead to better outcomes – but there is some resistance to this
- A majority of non-safety related communications will be via data comm. on commercial flights. For GA pilots, this may become expensive for a certified data comm. device. Why not have a better approach to the low-cost leverage of SMS text to fill the function of data comm. for GA
- Why can't aviation have leverage of things like cell phone comm. to assist pilots in GA?

5. Research Area: Future Propulsion Systems

Disruptors

Energy Sources – Alternative Fuels, Electric Batteries, Fuel Cell

- Electrification is a big disrupter because the energy cost is a big cost of the operation
    - All the -illities are impacted
    - Big impact on maintainability & reliability because of fewer moving propulsive arts
- Maybe fuel cells become a disruptor. Unleaded, Av Gas, great but not disruptor
- Alpha electro shows it can be done at a lower operating cost
- Electric grid issues if there is lots of electric aircraft operations – is there enough infrastructure for this.

- New fuels would be interesting but not necessarily a big change unless cost was greatly reduced
- Low Lead would not be as big of a disruptor has intended. Good for the environment, not so much for the bottom dollar
- Certainly, variations of fuel, whether electric or different fuel feedstock coming from different sources, that will continue, the pressure won't be financial but more environmental. In a more developed world, environmental considerations will be a driving factor.
- Range is the big driver for technology
- Should look at alternative fuels/technologies but hybridization may have larger impact
- Short range/short duration have purpose both in training and UAM operations
- Batteries not favorable end state, hybridization is a better near term option
- Looking at an aircraft for reliable and durable, he's "bullish" wrt fuel cells.
    - The energy reduction is too great to outweigh the clean savings
    - Need to find a different hydrogen carrier for fuel
- People ought to have interest in methanol since there is ample supply
- Electric propulsion for all aviation
    - Once you change to electric propulsion, you can change everything about aircraft
        - Distribute electric propulsion to change wing – mentions NASA X-57 and higher wing loading
        - Urban Air Mobility looking at "scaling up" small UAS concepts
        - Use electric motors for high lift, vehicle concept
- We have limited experience with electric propulsion
- Thinks automation is not as big of a disruptor
- Bio gas, 100LL replacement – there are incremental
- Electric brings hydrogen, lithium batteries – this will be more disruptive
- 100 low lead is heavily entrenched due to capability, energy density, storage but research should aim to determine reqs for unleaded fuel options to be implemented and installed in a/c
    - Electrification is a long-term reality
    - Fuel cells not likely to have impact in next 20 years
    - Must have the infrastructure to support fuels/energies
    - Performance implication with unleaded fuel/alternative energy swap
        - System analysis is necessary to identify the interactions between the fuel, fuel systems, a/c sys
- Fuel transition in GA
    - Owner/operator & infrastructure are big contributors to consider to support fuel source transition for GA
        - Since airports are business assets, there needs to be a cost-benefit analysis completed
        - FAA need to subsidize/incentivize the use of alternative fuels
- If I were in the shoes of the manufacturers, I'd electrify the aircraft and put in provisions for autonomy in a step-wise process.

    - NASA and the FAA play a big role to reduce time to market for electric aircraft and autonomy capabilities

Propulsion Systems – Very Small Turbine Engine, Electric Motors, Distributed Electric

- All things electric / hybrid electric will be the big disruptor
- Everyday trainer may be potential for alternative fuel. May change the game for cost but not for the environment
- Promise of lighter maintenance cost for electrification, we'll see if that'll pan out
    - Maintenance man hours per flight hours could also be drastically affected by electrification
- Smaller turbines may not be that valuable, maybe smaller turbine engines due something other than just output shaft power, like provide energy for distributed electric architecture. When I think of small turbine engines I don't think it is the direct drive source of aircraft, but something that converts one form of energy into electric power.
- In the case of distributed propulsion, you could get rid of control surfaces and the distributed propulsion will drive and articulate the vehicle to the attitude and condition desired. That may not happen in 2030 but will continue to be pursued.
- Types of propulsion is mission dependent, electric creates potential for new missions and new markets, energy cost is a large part of cost of mission
- Need to ensure FAA has access to technology progress even though companies have concerns for IP protection
- Fuel Cell safety concerns
    - Leakage problems
    - Certainly there are safety issues, if you run any system above atmospheric pressure and have flammable gases there are issues. There are issues but I haven't seen any show stoppers, to steam reform you need water with that, so in that particular system they weren't running pure methanol but a 50/50 mix of methanol and water, so the flammability was reduced by that and the fuel processor was only running 3 bar. And some of the issues around leakage are mitigated just by dealing with a lower pressure, in the fuel cells themselves have a huge number of leakage sources because of the NEA assemblies, those kinds of sealing problems are typical industrial problems that were solved. If you say those issues can be resolved because they are responsive to detect leaks that are used in aviation and other industries to mitigate leakage and flammability risks, then after that you just have electrons and that is kind of a common mode problem for any electrification system right now.

Automation & Autonomy – Powerplant Control Systems

- Automation and Autonomy comes in for throttle control and engine management
- Autonomy will also be added to the equation, just the ability of what is available today, and our capability to construct architectures, I see it as something that is very positive to aviation and smaller vehicle manufacturing in the future. We will reduce the number of controls for engine or powerplant, just be a single lever or automated into certain positions that come with the commanded setting that

someone wants from the engine, or it could get the automation/autonomy will be so integrated into the whole vehicle and the propulsion becomes one input to it.

- X-57 Maxwell as an example, and it has a lot of low-speed aero conditions driving that, but what I think it will get to is you can get more articulation from the propulsion system and that will replace or displace what we know as flight control systems right now, ailerons, flaps etc, all those conventional flight control surfaces could, could, be thrown away, and something that is primarily a Vertical lift type of vehicle you won't have those devices, and be using propulsive system to command movement of vehicle as you desire, or as computer makes it happen. That is a timeline maybe a little beyond what you are pointing too, but there are lots of companies pursuing this, and it will be revolutionary to a great extent.
- So in the next ten years, there will be lots of automation, but it is hard to give a timeline as to what it will look like, but within the next ten years you could have engine control systems that have an on button, and commanded levels of power output and no other types of controls. Whatever those levels are, in ten years that could be done, and done with electric drive systems.
- I think the one most concerning thing about how this is implemented is the last half of the energy storage system and how that is handled, and how it is denoted to someone and drive the operational requirements. When you are out of fuel today, that is pretty distinguishable, but if you have a slow decay of available electrical power that may have other ramifications, potentially decreasing the number of options someone has, which if you are in a continuing descent you may not have power to stop the descent or climb back up to an altitude. Some of the ways in which you deplete the energy source you have if it is static, then you get to a point, when that decays away you aren't going to have the same power output that you can command in the vehicle. There are lots of nuances that will have to be worked out until it can be handed off to someone that maybe won't appreciate those finer details.
- Non-deterministic systems have been certified before, as pilots, non-deterministic certification system that uses benchmarks, and continuous updates and rechecks, and this philosophy should be expanded and used for non-deterministic systems, like Autonomy
- Can see reduction in complexity and increase in reliability
    - It is a complex system to control. It will require a FADEC just like any other modern propulsion system will, so things don't change, you still need the sensors and the values and the control logic in order to make that system work.
    - The fuel cell was a complex system that was reduced to a start and stop button and a gas pedal, in the automotive industry, the companies didn't stop working on the fuel cell until it resembles the same type of human machine interface you see today.

SME Defined

- Improve propulsion technologies

Topic 1: Powerplant Portfolio Identification

Energy Source Considerations

- You might not be able to fly where you want on batteries. There will be some range anxiety. Possible that there will be a hybrid architecture
    - Maybe IC + electric or small turbine + electric
    - In 10-15 there still will be ICE engines, but a general shift to hybrid electric and full elec.
        - May see urban electric or hybrid electric or even small turbine
            - Trainers would see electrification first then older models will follow
            - B-Jet possibly move to hybrid electric but may need additional revolution of technology
- Hybrid electric needed to provide travel
- Electric for training / short flight
- Legacy still around, perhaps higher performance A/C remain
- Battery swapping ideas will be needed
- Where do you recharge? Do you skip charge batteries?
- Mentioned need to consider heating in electric aircraft because of potential effect on range
- In 10-15 years not sure how revolution elec. batteries will be.
    - Could see elec. batt replace piston if revolution happen for energy density
- Fuel cells especially, given they can be kicked offline and there is a given startup time that must be observed, and if that can't be improved for faster restart, then that becomes critical in an airborne vehicle. Some of the chemically reactive fuel cells, you could have something fail and need to restart it but not have the time, some take upwards of 15 minutes to come on line, and fuel cells have been around for a long time, they could be used on aviation vehicles in the future but that is a concern. There is a lot to be learned from automobiles when it comes to compressed natural gas, but for an aircraft I would be concerned about crashworthiness and containment issues if there was an on/off airport event, and not to harken back to the Hindenburg but other off nominal things that can happen in aviation. If something breaks, can it be contained appropriately.
- In regard to unleaded fuels, it is about making the conversion as seamless as possible and the problems will be with detonation or materials compatibility between chemical additives and how they interact with the fuel wetted surfaces, gaskets, seals, paint. And you would think it would be simple but it isn't that simple, because once you check material compatibility we have to verify detonation profiles and power output of the engine to make sure performance isn't degraded.
- Using -illities as the basis
    - Airports have more utility than corralling aircraft based on energy ports
    - Solar/wind capable
- Depending on the location the energy source could vary based on price
    - No strong believe in hydrogen
- [Regarding eco-friendly efficient hydrogen air carrier] Someone needs to champion the concept and get it out there. Whenever I bring it up I kinda get this

side-ways look of 'what Steam reformers are heavy and large', and the fact of the matter is they are not just no one knows about it. If the technology emerges again and continues to run apace ahead of battery power density I think that some of these things will become self-evident and people will become more interested in commercially developing the technology. There isn't much that needs to be done to rediscover methanol, there is a very large amount of methanol that is produced in the world every day.

- Now incorporating energy storage as part of the airframe when considering electric storage
- As the airframe changes, there are many differences – many differences mean questions for certification – that can make the process more challenging
- The new vehicles will fall into Part 23 or Part 27 – the industry is not ready for these radical concepts
- Ideas where electric is being used to augment thrust*, this has fewer challenges
- Impact Electric propulsion has on the rest of the aircraft?
    - Many smaller motors across wing, so wing surface area doesn't have to be as large, distributed propulsion moves air across wing without having to move aircraft as fast
        - Distributed propulsion allows air to be moved over surfaces without moving aircraft
    - Airplanes will look a lot different because of this
    - The more drastic the airframe is the longer it takes to certify
- With more electric aircraft, propulsion, energy storage, airframe are more tightly linked – harder to address these questions
- The electrical system is no longer isolated from airframe and control
- Will electric really propagate?
    - Pipistrel trainer alpha is working now, maybe short takeoff and landing might be next
    - Missions that a/c actually perform are a mix of typical a/c
    - FAA already into research w/ the 170+ concepts
- FAA has engaged many of these concept developers early – this is new. Big organization may not as fast as some would like
- GA like large a/c, some introduction for hybrid or additional power/thrust is most likely
- Electric propulsion and hybrid propulsion may not much different for Part 23 but higher end GA and Part 25
- Hydrogen fuel cell seems promising but needs their own separate battery
    - Challenge hers is "balance of plant" not always positive
- Lithium batteries – close to 2 tons
    - Danger of thermal runaway at this size
- 3% increase in energy density every five years might not make Li batteries really useful
    - Maybe other battery chemistry needed
- Energy source that makes sense for GA
    - Hydrogen fuel cells vs lipo battery

        - Lipo battery negative is limited range because of energy density, translates to operational penalty and weight to maintain range
        - Hydrogen fuel cell has storage concerns, which translates to a weight penalty
        - Future looking to leverage either of the two
    - Infrastructure interface
        - Current GA airports not equipped to supply energy source for either hydrogen / battery charging/swapping
        - Need to fine tune standardized vehicle battery charging / installation.
            - FAA role: on committees for standards (ASME, SAE, ASEE, ASTM, NASA, Acad.)
                - Make sure standards draws the line where FAA can safely manage/operate GA
                - Takes about 5 years to write a standard
- Moving from mechanical circuit breakers to solid state advantages comes from working around faults, reduction in pilot loading was great – pilot not looking for circuit breakers, etc.
- These will come for GA over time
- Not electric propulsion to enable the better pilot work load
- Sees multiple motors for safety allows for easier switch of one motor out
- The legacy vehicles won't be affected as much by electrification. The vehicles with STOL/VTOL could push GA
    - Most impact on legacy vehicles will be hybridization. Automation has incrementally have impact on legacy vehicles, but when the cost of automation is reasonable, the tech will be adopted

Life-Cycle Management

- Maybe more of the physical area at an airport will be used for renewables – solar, wind, etc.
- We can't bifurcate the energy sources in aviation very much. Every airport has to be universally acceptable for the entire fleet, so if someone is using compressed natural gas, somehow it has to be interchangeable from aircraft to aircraft, you can't have ten different refueling sources in an airport, something has to win out and be the next default energy source and the infrastructure has to be built around that. I don't see airports ever offer five different refueling sources. In aviation we just can bifurcate much beyond what we have. Beyond turbine fuel and ab-gas once we introduce something else, and need lots of coverage to a large number of airports, I don't see that happening. The money and expense to offer all or lots of energy options would be prohibitive. I don't think it will work.
- There probably won't be much retrofit applications, most of this happens on new systems, disposal will go vehicle by vehicle, an old Cessna won't be retrofitted with an electrical system you compromise too much and it would be cost prohibitive. Total vehicle level will be the changeover, no retrofit or backfit market. Single engine general aviation aircraft are on average 40 years old, and lots of those will be retired in the next 20 - 30 years. At some point utility and

operational cost doesn't make sense to maintain, and they will be parked or recycled to new systems. I think we are making a new type of challenge for us in the future

    - I will use an automotive analogy, if you are going to recycle and retire a tesla vehicle, as a larger community I don't think we understand how ugly it is going to be, with some of the rare earth materials that have to go into the pipeline to build them, but when you have to recycle them and isolate certain components out of them, it will be more challenging when on the order of thousands versus handfuls, and when it gets to aviation and you have 10,000 Pipistrel aircraft to retire, that will be difficult to do, you can't just cut stuff up and throw it, there is sensitive chemistry someone will have to work with. With the current generation of aircraft retiring the concern is what fluids are left inside, and the rest of the material could be recycled. And thinking about a cirrus aircraft with a pyrotechnic parachute system, that would have to be carefully handled when it is retired.

- Retrofit market
    - Need to have a slam dunk on energy storage before the concept is successful
    - Better market with clean-sheet than retrofit
    - Bring engine speed up but want to reduce tip speed
    - For the flights UAM/GA would operate, GA airframes have long wings and minimal high lift devices
    - Compact enough and light enough could be a good retrofit
    - Electrification - STOL for noise not for field length
        - Keys to increase utility in a short flight operation environment

Topic 2: Certification

Type Certification

- With different energy system, some of the corner case issues will be very different – may need a Part 33 rewrite
    - Batteries sensitive to temperature for example
- Challenges exist between approach to separating engine from airframe
- Bulk of the effort needs to go into ASTM standards – like effort to certify new propulsion systems
- New engines, new policy on certification must come based on performance-based metrics
    - May need to have a rewrite of Part 33 such that you can maintain part swap without certification re-evaluations.
- Integration standards are missing, and needs to be more developed, can't just swap one power plant for another, but needs more consideration for integrations with the airframe
    - Industry is simply swapping motor technology
        - Impact not as significant until regulation expands integration guidance
- Standards need to move from prescriptive cert to make manufactures identify it

- What sort of interface conditions need to be enforced to have a siloed very of system certification?

Airworthiness Standards

- Remarks on Part 23.
  - FAA is going in the right direction and the FAA is aware of what changes are necessary
- Treating electrical applicants for part 23 like aircraft using
  - F3338: electrification standard that enables manufactures to produce a elec. variant
- No emphasis on integration of electrification onto airframe
  - Need more guidance this
- Biggest changes that have to occur is system safety assessment
  - Assumption with multi-engine a/c of part 23 is that one engine will fail
    - Note that with multi-rotor the assumption does not apply directly
    - Should move to loss of most critical system(s) and the likelihood of the failure to occur
- The traditional approaches are considered cumbersome & difficult to implement when expanding system analysis to different technologies
  - Need a model-based approach
  - Note that subsystem level has 2-fault tolerance protection but in the integration of subsystems single subsystem faults would propagate to other subsystems and such the complete system isn't 2-fault tolerant
- Holistic safety approach instead of traditional approaches
  - Traditional approaches could be useful, but the interface conditions must be addressed
- More electric aircraft will be a tradeoff in terms of safety, reliability, etc.
- Turning a propeller with electric is simple
  - Current experience with IC means this is about as safe as it can be -> lots of infrastructure and experience
  - Electric: No icing (carburetor) concerns
    - Fewer moving parts, but power storage is large and becomes critical
    - This is the tradeoff between IC and Electric - cannot directly safe which is safer
- Part 23 use perform based standards + ASTM standards
  - For alternative fuels, it'll be difficult to certify since FAA has not accepted all industry standards. Would have to iterate/negotiate with manuf. for alternative means of compliance

Topic 3: Automation & Autonomy

Standards of Propulsive Automation

- Health monitoring & response to abnormal health conditions in engine
  - Need to be developed for electric
  - Do we know the things to monitor in the tractor motors. We know what to monitor in ice/piston engines

- May use more adaptive control than automation/autonomy
    - Use propulsion as an input not just motive output
- Sees automation as a piloting issue – learning how to fly with more automation
- Thinks move to solid state power systems that can readily shed tasks to reduce pilot workload in an emergency
- Worse GA aircraft do not have this capability to reduce pilot workload in an emergency – facilitated by more electric aircraft
- FAA does not like mandates
    - GA accident rates will drive tools, introduction into the market
- Automation has two components convenience (automation for engine mgmt) & safety
    - Struggle with AoA, but as tech improves, GA adoption/install pending
- What does FAA need to do for FADEC certification on future vehicle and propulsion concepts
    - Have to work with each applicant to understand the integration & capability

FAA's Role:

Powerplant Portfolio Identification

- [Regarding FAA's role in investigating safe storage/utilization of energy/alternative power] Some things could be done to allow for AIP funds to be spent to look for new energy sources utilized at airports, like solar panels at airports and then harness that energy and supply it to the airport customers via a recharging station paid for AIP funds, and that could start the mass roll out of a new energy source.
    - Some of these aircraft right now are from Pipistrel or other manufacturers, when they deliver their products how is the national supporting infrastructure going to be configured and put in place in order to give those products the same utility of our legacy vehicles. It depends on making the change in the AIP appropriations to actually be utilized by airport sponsors to install these systems that will be necessary. That should definitely happen in the next 10 years. As these companies like Pipistrel and others as they emerge and deliver their products, there will be opportunity for something to happen here, and it doesn't have to be a commercial sold A/C product, could be homebuilt. Until there is more infrastructure support people won't buy products from those companies. I think the funding from AIP would be sustainable to pay for it, and there would have to be policy and supporting grant assurances that would allow FAA to put money in the hands of airport operators to buy, field, and support the equipment.
- Encourage the FAA to identify specific goals and objectives with respect to propulsion technology such that industry/others can understand the progress to be made and dev technology accordingly
    - Set lofty goal and let people sort it out from there.
- When looking at new disruptive technologies, FAA needs to write issue properly to ask questions – if few questions, we can target research to answer these questions

Certification

- [Regarding FAA next steps] A/C certification part would be very important, but it would be something that is downstream, so outside of Part 33 certification requirements to part 91 requirements, so if someone is operating with a VFR or IFR flight plan, what is the required distance they have to be away from quote “an empty state”, an empty state we know what that is with liquid fuels today, but it is going to decay in a different way with these energy storage systems and it will come down to flight standards being the organization that defines that, and give protective margins they put in place, and it may not be repetitive, and I don’t know what the end state is there, because it may not be reproducible, every time you get to 50% remaining point it may not perform the same every time.
    - [With] these electric vehicles there is an impact on the speed of charging, and maybe there will be an improvement to make high rate re-charging possible, but each time a new system is there a fully charged state will give you so much output, but at the thousandth time you’ve done it, it may be different. I don’t think this reduction in power is predictable enough, or reproducible enough that there will have to be a margin of safeguard put over the top of it and it will be very different from today and what people are used to. It won’t be like you put 50 gallons on board and when you burn it your empty no matter how fast or slow you use it.
- Part 133 rescriptive parts became a benchmark for things to not happen again
    - Afraid this policy hinders progress
    - Would want to write fuel cell policy - maybe out of the ASTM group and make prescriptive policy to make them safe and reliable
- Not sure if performance-based certification is effective. For instance prescriptive policy gives guidance where perf based policy introduces negotiations of processes/terms to adhere to the perf certification
- Adaptation of Part 133 is necessary for emerging technology for future propulsion (electrification, multi-rotor operations)
- Electrification of air vehicles is a cool technology looking for an application

Automation & Autonomy

- FAA for health monitoring
    - The FAA should be able to address this using the system analysis
    - For adaptive control: if it’s not deterministic than there are addition cases to consider
        - Though we have been executing non-deterministic certification (pilot training), we still have a ways to go with technology. But the philosophy should be used/possibly expanded for technology - include training/testing/re-evaluation/
        - What tests should be run, what should be evaluated, where is the threshold to stop testing?
- How does the Tech Center enable manufacturers to do more than the motive testing - possibly add adaptive control piece to overall vehicle control?
- Near term would be to invest in automation and develop autonomy in future work

General Comments:

- WX – more granularity in airspace at low-altitudes – maybe more accurate for UAM
- Can pilot file for VFR – the improved resolution would benefit GA
- Hard to think about GA separate from other operations like UAM
  - SVO could benefit "traditional GA" even if needed for Urban Air Mobility
- It is an exciting time for general aviation, maybe there is another big production capacity that is coming in the future with a high demand product. GA is accessible by 1-2 percent of the population, and something may come along that makes it much more accessible.
- Challenge to become pilot. Lots of training, expensive., but GA operations for private pilots have less useful flights.
  - Does not see usage for mode of transport based on cost/maintenance.
  - Place where electrification reducing the operation cost
    - Range is a consideration, but for nominal flights, the design range isn't entirely needed
      - Reasonable cheap, reliable, easy
- Propulsion is the pivot for aerospace. Advances here can evolve the way vehicles are designed, serviced, managed.
- How much emphasis is more of the challenge, FAA is looking at many of these issues already – but the priority is not always lined up
  - The priority is often driven by funding
- Electric propulsion is really disruptive towards broad parts of the FAA, therefore this demands attention
- FAA research mission is to consider technology and disruptions to see how this impacts safety – where are the tradeoffs and where are thy weak points in the technology
- Been able to make leaps and bounds for energy density of fuels but batteries are a long way from supporting aviation. Diesel could be closer, hybridization slowly after.
- Scaling down turbo-prop and turbo-fan engines for GA may be difficult challenge. Cost, efficiencies are among limitations.
- Propulsion advances PR in needed

6. Research Area: Passenger Safety & Crashworthiness

Disruptors

Automation & Autonomous Control

- Automation & Autonomy
  - Energy MGMT
    - Referring to fuel/batt life (availability/life). Thinks output should be displayed with high precision
    - Referring to trajectory recommendations based on energy available
      - Whether mitigation/contingency is necessary

            - Offers example where additional energy is used because of unintended/evasive maneuvers & climbs. Notes that traditional pilots are accustomed to these tasks but new pilots may need assistance
- Two-fold energy management, fuel or battery life (how much is available to pilot at any given time) and must be displayed to pilot in a usable fashion, what are your capabilities with that much (battery or energy) remaining
    - Industry drives design & implementation, whereas the FAA imposes certification standards. FAA may use academic-industry research to provide knowledge base on future and novel displays
    - Unexpected maneuver could make you burn through energy faster than expected
        - How to display as much info to the pilot in a useful manner

Alternative Fuel / Energy

- Battery capacity not quite at a level for tech adoption
    - Li-ion even, how to have them on board and perform well while still being safe

Wider Spectrum of Pilot / Operator Certification

Additive Manufacturing of Light Weight Components

- Want aircraft to absorb more energy during impact, but have difficult reducing the price point
    - CS-22 Regulations
    - Want to use the entire a/c airframe as crashworthiness, but practically isn't financially feasible because of certification and testing and cost
        - Need a better approach such that the process is cost effective for air-framers and testing
            - Certification via analysis
                - Want to understand the load characteristics to determine whether airframe can improve crashworthiness and survivability
                    - Survivable accident: at least 1 survivor per fatality
                        - 30-120 KN
                    - Use automotive approach to design for crash conditions
                        - Found that the minimum available speed should be survivable if an accident occurs
        - Constraint of the airframe life-cycle
            - Since most airframe lives are long, it is difficult to improve/update airframe with "added" safety measures

- Composites structures for eVTOL
  - Should perform to spec both in ops, off-cycle ops, and crashes
  - Material properties are of interest as well given projected service life of aircraft
  - Additive manufacturing may lead to break-through, but airworthy certifications are of concern
  - Not a simple task to implement composite airframe, not simply "swapping" metallic airframe with composite. Without ductile properties, the aircraft will need to be designed to take advantage that the composites do offer (i.e. the strength and stiffness). Composites can certainly be used in load bearing environments, they just need to be designed differently. With metallic airframe structures, extensive testing is available; for composite, test data is not universally available and repeatable.
    - Composites safer approach? Up to designer to figure out, but probably, lighter weight but could be designed
    - Lots of research could be done on how they fail at component and above level, not a lot of data on large structures, crush data etc.
    - Metallic aircraft have 50 years of performance life and history, and we have crash test data on them
  - How do composites perform regularly and in a crash?
  - Aging characteristics - what do the properties look like in 10 years?
- Additive manufacturers is promising technology in terms of cost
  - If something breaks and you 3D print a replacement, how would one certify that the new part is safe?

SME Defined

- Since most GA servicing airports have limited funds
  - Burden of certification & tech integration is difficult for GA
    - Tech is available, but not widely accessible at favorable price point

Topic 1: Re-definition of Conditions in Accidents & Incidents & Crashworthiness Certification

- Remote tower operations for bringing air traffic services to smaller airports. A controller at a remote location can provide traditional towered services. This could be on-demand. This seems like it could expand GA.
- FAA put more safety measure on commercial, than someone who puts together an ultra-lite
- Definition won't change but NTSB only has enough staff to investigate fatal, so lots of them don't get investigated very well
- Insurance companies put more restrictions on GA pilots than what the government does
- FAA can't change the definition of accidents and incidents, comes from ICAO and NTSB
  - NTSB only have enough personnel to investigate/research fatal accidents & not incidents.

  - GA doesn't garner the same news as a commercial airliners
- Technologies and Training
  - New Garmans are built to have black-box type capability
  - Changes GA litigation - instead of debating on what happened based on opinion, the advent of black-box tech allows debates to be rooted in fact/data,
  - Fly your own check ride to benchmark data and refresh-skills.
- Need more context about crashworthiness criteria for certification (14 CFR section 27.562 (rotorcraft) and 14 CFR section 23.562 (general aviation)
  - No equivalent set of numbers to pass for eVTOL (23-562)
  - How do we define a single number (as done for airplanes and helicopters), since they don't look like airplanes or helicopters, and there is a need for these?
  - VTOL Airworthiness Certification & Crashworthiness
    - Currently no way to tell how these vehicles are likely to crash
  - Can observe a/c and rotorcraft criteria, but it is unknown as to what future GA A/C for AAM/ODM/UAM would require
    - The certification criteria is based on extensive testing over time
  - These are based on tests done by NASA
    - criteria are based in part on mishap data and NASA Langley Test
    - refs: mishap data https://www.ntsb.gov/safety/safety-studies/Documents/SR8501.pdf
    - that's only one of many mishap reports. I can provide more
    - NASA LaRC tests - NASA TP 2083 (published 1982)
  - Do we start fresh, or start with what we have and modify them?
  - Large vertical speeds? Large horizontal speeds?
    - Flight profiles will define "crash profiles" - but as of yet these are not yet defined and there seems to be no clear answer
    - Hard to reconcile Part 23 and Part 27 crashworthiness requirements for this class of vehicles
      - Vehicles on a spectrum between fixed-wing and VTOL, so unclear on how to apply existing regulations
- Cost for tech certification, adoption and implementation
  - Biggest thing is the part 23 rewrite that is supposed to cut cost and save time
  - Better answer for a manufacturing since its within their purview
  - May be able to certify
    - Certification by analysis is promising but requires more work
  - Certification by analysis validated by testing is more appropriate.
  - Testing at component level doesn't always reveal issues that may arise at vehicle level

Topic 2: Passenger & Pilot Fatalities in GA Accidents

- Improve crashworthiness

    - Must separate survivable accidents from non-survivable accidents to understand what can be done to improve survivability
    - Airframe
        - There's effort to make GA aircraft more crashworthy but there is a weight and cost tradeoff.
            - Mentions SIRUS SR-22 parachute
        - Role for automation & autonomy to affect crashworthiness may be looped into the envelope protection protocol to deploy chute or flare upon landing
        - Could do a lot more in survivability if design for crashworthiness.
            - Rerouting of fuel lines, move struts
            - Impediment due to perceived over-safety
            - GA can benefit from improved seating and seat arrangement
            - Cost big challenge
                - NASA, GAMA may be good options to sponsor research
        -
    - Below $5000 definitely more likely under $1000 for most GA pilots/operators
    - Restraints or harnesses, that could be done
    - Seats themselves could be more crash resistant, work has been done on commercial, but not sure about GA
- Rectify operator/pilot error
    - Additional training
    - How do you combat against pilot error
- Incorporating tech
    - UAM can help with tech bring the number of units up
    - Standardization can help with increase the safety, but the GA community must agree.
        - Found that each pilot wants its unique setup
    - Airbags are not old tech but took time for a/c
- Crashworthiness features
    - Parachute or employ other tech in airframe (i.e., reinforced structure)
    - Parachute is fairly simple to implement in airframe.
    - C.R.E.E.P.
        - Container, restraint, energy absobsion, environment, post-crash factors
        - Containers:
            - Airbag
        - Restraint
        - Safety belt/helmets
        - Energy absobrsion (interesting research area to investigate)
        - Additive manuf. for energy absorbsion is available, but not currently implemented in aircraft
            - Composite as well

            - Or use other parts of the airframe to protect occupant
        - Environment
        - Post-crash factors
        - Looking at fuel sys
        - Fire
        - Rescue
        - How do you improve the survivability of pax such that the pax can be found?
- Running out of gas is weirdly common
- Crash/incident databases often have limited content. But with the crash database one could map crash scenarios to causes and design to mitigate/lessen severity
    - Technology like a 3d scanner can be used to detect before and after differences in crashes and estimate a cause that can be used to drive research for preventing accidents
    - With better data, designers have a better reference for how to design appropriately
        - Would require accident investigators to collect more detailed data, More detailed investigations
- Training is a valuable way of improving data collected from crashes. i.e. train the investigators to focus on detailed items that could lead to further understanding the crash itself. Which could include new technologies such as 3D scanning at accident site
- Survivability
    - Addition of restraints and other crashworthy aids: Shoulder harness for example
        - Note that shoulder harness is an example of added safety features that have been implemented over the course of using mishap data to increase safety in these vehicles. There are others.
    - Airframe
        - Crushable structures (e.g., Crushable structure underneath cockpit, and crushable engine compartment)
        - Floor structure of composites doesn't absorb energy in the same way that a metallic structure does
            - Composite structure needs to be designed differently than metallic
                - Crumble zones may be an option
        - Some data on components, but still need more analysis for system level
        - Design rules for composite design?
            - Choose materials that are conducive
                - Ex: Kevlar rather than carbon fiber in order to absorb energy on crash
            - Is there an opportunity that us of composite structure make systems safer?
            - Probably - since they are lighter it could be possible that optimized vehicle is safer

        - Aircraft division
            - Engine type, propulsion type, etc.
                - Elec/hybrid engine, wing / blade lift these can impact the way the vehicle needs to be certified for crashworthiness
    - Battery Limitations
        - With limited energy density you can either have large quantities of batteries or very short mission profiles
        - Battery chemistry
            - Li-ion batteries are dangerous when ruptured, which makes testing in crashworthiness context dangerous
        - Need to be a standard drop test for these technologies. Since fore example dropping a li-ion/li-poly batter is inherently unsafe, so additional contingency is required to appropriately assess technology.
            - Conventional test is a 50-foot drop of fuel system, so there needs to be a standard impact test for batteries, and this is inherently unsafe
                - reference is for rotorcraft. 14 CFR 27 section 952
            - This may slow down the certification process
        - Battery crashworthiness
            - Challenges of how to determine/evaluate battery state post-accident to ensure safety of occupant and first responders
            - Fire risk is a concern, esp. in a crash

Topic 3: Automation & Autonomy in Safety

- Envelope protection system
    - Tech is available and tested, but need to be implemented on GA
    - Who has the authority when making decisions: want the pilot to be able to override the system or not, no clear decision as to which is appropriate/acceptable based on the industry & R&D.
        - Notes that for operations that involve varying degrees of pilot training, this automation & autonomy could be essential
    - Tech not specific to GA, but GA can benefit from tech at the right price point
- Software certification is very difficult to achieve. A "sticking point" with the FAA, does require additional research and focus
- There is a lot of concern with flying through cities, there are strange wind patterns, that how does automation handle unexpected events and varying weather conditions and the effect on these lighter aircraft
    - This is a newer issue, you don’t currently have Cessnas flying around downtown Manhattan, but UAM that is what is envisioned
- Big concern is over-reliance on automation, auto throttles are great, auto-landing, people are going to put too much trust in them

- People expect the automation to work, but are they prepared when it doesn't work
- Over-reliance in automation
    - Auto-throttle, auto-land, for examples of automation/autonomy tech
        - But the down-side is that people believe these automation/autonomy will save life despite reckless flying behavior
    - Airfrance, Achiana, 737 max are commercial examples where comm pilots expect aircraft to function nominal but can make
    - Cannot have intermediate degree of autonomy because operators must be aware of both nominal and off-nominal states such that over-reliance does not occur
        - First step could be use of ground operator to intervene when necessary
        - To go to full automation, technology requires huge improvement. To incorporate for GA at a feasible price point will take significant time
        - Must understand which group of operators is the focus.
- Improve crashworthiness
    - Must separate survivable accidents from non-survivable accidents to understand what can be done to improve survivability
        - Airframe
    - Addition of tech a improves level of safety by x
        - But is tech a really improved safety since the pilot/operator can now push beyond nominal operations/conditions given tech a
    - Reduce stall speed, improve structures, update layouts
    - Human factors issues on pilot-load, over-saturated data should be researched to understand how much data/load is appropriate for a nominal pilot
    - Pilots that aren't quite VFR or IFR is the concern
        - Lends itself to research whether different pilot certificates should be used to match vehicle operation
- Automation with all systems: collision-avoidance, comm., engine management, system management
    - Even with these technologies: how can you measure or quantify safety. What accident rate is appropriate delta GA accident rate
- Automation & autonomy may be good for situation awareness, but not so much a proponent in crashworthiness to improve occupant safety
- Seems that automation is built to prevent a crash from occurring in the first place
    - Evidence of existing automated systems makes this seem unlikely to be completely true
    - It should be designed to aircraft as safe as possible and ideally safer than with a pilot
- It should be possible to make automated system as safe as possible, and likely safer than what a human pilot could achieve
    - Certainly would require significant research into the various applications of A&A

- Would the sub-optimal conditions of the aircraft reduce the ability for the automation/autonomy to act/impose

FAA's Role:

Re-definition of Conditions in Accidents & Incidents & Crashworthiness Certification

- Involved in the AGATE work
  - Could use a continuation of AGATE but instead sass took over
  - Money is the main driver for GA research. People are interested and willing to participate but require subsidized assistance
- AGATE developed roughly 10-15years ago
  - Improve the design methods that help improve pax safety & crashworthiness
- AGATE-like research is worth expanding and investigating to address today's research questions to forward GA (Gov-Academia-OEM consortium)

Passenger & Pilot Fatalities in GA Accidents

- 2 factors that impact crashworthiness efforts:
  - Crash test ($17k +/test) for engr. time, test articles)
  - New regulatory methods to get the certification cost down

Automation & Autonomy in Safety

- What is a good accident rate to use for A&A systems?
  - Transport is so close to zero that it might be too restrictive
  - GA rate may be too low
  - Going to need a lot of research, and lots of automation
    - Need to figure out exactly how reliable automated is and compare to some other standard, but also what do we compare to

General Comments:

- Volume can reduce the cost point for technology inclusion and adoption
  - Should be able to go to composite mat manuf. and specify a standard that defines the level of safety deemed acceptable
  - But instead the composite mat manuf. are able to generate material to a spec generated by the buyer and the spec is deemed safety (by the manuf.) if targets are met. Absolves liability
    - Do something similar with additive material manuf.
- Address perceived safety & actual safety
- Newer airplanes contain a black box, Garmin's are popular, they have lots of data in flight data recorder, has changed how GA is litigated
- It's a whole different world trying to reach GA pilots, they don't practice maneuvers
- Cirrus came out with the parachute, and guys started doing stupid stuff
- Advancements in weather gathering/aggregating/relay at local/region level. May need weather network city-wide

    - Weather stations, intersections, everywhere should broadcast weather
    - Don't think eVTOL should operate in IFR conditions, but should be capable

7. **Research Area: Pilot Training & Proficiency**

Disruptors

Simplified Vehicle Operations (SVO)

- [Regarding AI capability to adapt/learn between flights] In between flights we can look at data and see what we can learn but not real time. Next time it flies it can be smarter. Just like you can't upgrade your car software while it's driving.

Automation & Autonomy in New Aircraft (e.g., Urban eVTOL, etc.)

- [Regarding artificial intelligence envelope protection control in training] Envelope protection is becoming more prevalent
    - Cirrus has it now with "magic blue button"
    - Cessna has something similar

Simulator Technology

- Should simulators be used in training in the future? If so, what needs to change/improve?
  Issues with simulators: 1-Initial cost. Those simulation devices that have the fidelity to be approved for flight training (and has proven to be effective in training) are expensive. Many flight schools cannot afford the initial cost. 2-Student wants: Pilots, especially, those taking initial training, prefer to fly an aircraft. Change needed-Appeal to the wallet. If the technology is there (FAA approved for logging of flight time), the cost needs to be low enough that the student will fly it in lieu of the aircraft. Additionally, automated flight lessons should be developed so no instructor is required at the time of the lesson. The lesson can be recorded for review by the instructor and debriefed after.
- FAA today limits simulator credit to 5 hours, but simulators today are already good enough to allow for more – this needs immediate attention
    - They should look at task based, competency-based training instead of current time based – congress mandates hours of training? – unnecessary since no other country does that
    - FAA has rudimentary requirements for AATDs (low fidelity simulators), and high requirements for FTDs (high quality simulators) – however, flight credit is same for both. FAA needs to change 30-year-old paradigm to allow new technology in training
    - Analog to Part 23 rewrite – shift to task-based or competency-based standard possible?
        - Potential for "self-examining authority" alongside special training credits

- Simulators for novel architectures like DEP?
    - Getting the data to build them can be a challenge, but it can be dealt with.

Reducing Pilot Population

- Military has shortage too that bleeds into GA pilot shortage. FAA needs to be smart and vet training technologies thoroughly. One size fits all approach will not work in future.
- Pilot shortage will result in instructor shortage later which will bottleneck future scenarios unless technology allows one instructor to train multiple students (e.g. Via simulators etc)
    - Automated trainer AI
- The problem with attracting new pilots is a business problem. For many years the commuter airlines were not paying first officers what they were worth. You cannot earn $20,000/year and pay off a $100,000 student loan. Today the commuter air carriers have figured that out and starting pay first officers a living wage.

SME Defined

- [Regarding Pilot Training & Proficiency topics impacted by changes to GA by 2030] Air Carrier SIC certification requirements impact GA training. Although most GA aircraft build today have glass cockpits, many legacy aircraft still have steam gages. Transition training will be impacted. New rule on using a TAA in lieu of complex aircraft will also impact transition training. Other issues FADAC and fuel injected aircraft vs. carbureted aircraft.
- [Regarding pilot training] The real question is how do you effectively transfer 30 years of wisdom regarding good decision making
- [Regarding distinction between operator and pilot] Seems like it. Possibly fly within separate classification of airspace
    - Package delivery will likely be lower than GA airspace. Operator environment will likely be very controlled – fixed airspace, fixed routes etc. similar to airport trains. GA will probably remain separate from these
    - Military doesn't train remote controllers same as pilots – some crossover elements exist if environment overlaps. By separating airspace by vehicle classes, you can take stuff out of training
    - Example - Disney – monorail used to have operator, but now is automated
        - The defined tracks aid in automation
        - Similar mindset may aid automation and help clarify what distinct airspaces are
- Challenge – gaps in training won't emerge until after pilot is trained and begins to fly

Topic 1: Automation & Autonomy in GA aircraft operation (Simplified Vehicle Operations)

Pilot Training Time & Cost

- [Regarding need to improve automation in cockpit to "make flying easier"] Efficiency of the operations. Computers fly the aircraft more efficiently using less fuel and producing less pollution. Flight training can be reduced. Technology transfer and steps toward a completely autonomous aircraft.

- As autonomy and automation increases, flight training could decrease in time.
- [Regarding types of automation and autonomy that should be used to augment pilot training] Unknown. Automation technology changes. A risk analysis need to be done on each level of automation to determine what level of training is necessary. From the pilot being able to fly the aircraft if the technology fails, to familiarity with the technology, to (due to the robustness of the technology) no mention of it is needed.
    - [Regarding augmentation limitations] There will be in the foreseeable future that mixed aircraft (those with automation and autonomy technology and those with almost not technology) operate in the NAS. Mixed operations is a challenge since it may be difficult for the automation to interact with aircraft not equipped.
- [Regarding fail-safe practices with augmentation] Pilot training that could take over in case of technology failure. But that defeats the purpose of having SVO in the first place. Multiple technology back-up systems. 10^{-9}, or better reliability.
- [Regarding responsible entities for degrees of automation and autonomy in pilot training] FAA and Industry. The FAA is using industry consensus standards. Industry consensus standards are developed by industry (with FAA input) and approved by the FAA.
- [Regarding the need for technology-specific training] It would make sense. Right now, pilots are taught to fly manually before learning automation.
    - In urban air environments, pilots need to know how to respond if something goes wrong – they need to be trained to identify off-nominal behavior
- Automation and technology also have some risks
    - Recent accidents; automation bias
    - Need to be careful with preventing overreliance
- For optimizing training time:
    - Take some training offline, with a self-paced component
    - Utilize high-fidelity simulator for most of training, while using actual aircraft as validation tool
    - Need to research appropriate ratios of simulation time vs aircraft time with different levels of simulators
- In corporate world there is lots of automation
    - Primary challenges lie in human interfaces of automated systems
    - Problem of safe de-escalation of automation
        - If something goes wrong, how to safely disconnect automation to find out what has gone wrong?
        - Need to define strategies to de-automate one step at a time rather than deactivating all automation completely
        - What is the training for this situation? (e.g. Deactivating autopilot in icing conditions)
- [Regarding other technologies that may be useful for training in the future] VR tools.

    - Currently FAA allows about 5 hours of simulator time credit. Simulators today are much more capable and FAA should look into giving more credit for simulator time
- Envelope Protection doesn't override pilot, but gently nudges the pilot back to the envelope
    - Examples exist with trainers from the ground. Students flying solo, data collected and assessed to determine exceedances and correct training

Pilot Certification

- If a person is dependent on technology to operate the aircraft then aircraft certification reliability standards must be robust. Again, FAA's statutory requirement for safety. There are different levels of automation and autonomy. Determining what is the right mixture will be difficult with, what I expect, will be multiple aircraft manufacturers in this category.
- Depending on the level of automation, pilot certification requirements change. To the point where it is totally autonomous and no pilot certification is required.
- Simulation technology (and other augmentations) can provide satisfactory pilot proficiency.
- Research will be needed to determine if the use of the augmentation technology provides an equal level of training and proficiency then without the use of the augmentation.
- Research will be needed to determine the deterioration of skills over time when a person is certified to operate an SVO aircraft.
- [Regarding levels of pilot certification that represent proficiency in specific augmented technologies] If you mean SVO aircraft, yes.
    - If trained in glass cockpit, need special certification to revert back to steam gauge vehicle?
    - Counter-point – pilot only trained to simplified operation has nothing to fall back on in the event that automation fails

Topic 2: Pilot Training Procedure & Methodology

Training Time & Cost

- As for improving training procedures, on-line training is now available and approved. Consequently, pilots can arrive at the training centers with a lot of base knowledge about the aircraft (systems, limitations, speeds, and procedures.)
- General economic response: Lower costs leads to more people having the ability to use the product or services. This brings more money into the aviation system where it can be used for training and research into training to reduce time and cost.
- [Regarding growing cockpit technology that may increase workload and training] The higher the automation the lower the training requirements. Part 25 aircraft used to have a navigator and flight engineer. Today those positions have been eliminated due to automation. But this is an iterative process. First the navigator was removed, then the FE. The automation needs to be robust.
- [Regarding incorporating automation and autonomy in curricula for GA pilots] Cannot be answered directly. It depends on levels of automation and levels of autonomy. With a completely autonomous system the only training will how the

PASSENGER to tells the system the destination. The less autonomy the more training. For automation, the same is true. Automation may not reduce training. It may just shift what training needs to be performed.

  - Training providers and manufacturers develop the curricula. FAA sets standards and (under Part 141) approves the curricula.
  - Again, it depends on the levels of automation and autonomy. Different levels will require different resources and technologies from just programing a destination, to on-line training, to flight training in a simulation devise, to in-aircraft flight training. Also, if a technology is not available or affordable (i.e. a full flight simulator) then in-aircraft flight training may be required.
- [Regarding steps to improve curricula] Every urban platform may have different requirements
  - Regulation tends to be reactive rather than proactive; FAA is attempting to shift being proactive to anticipate upcoming urban aviation
  - Need to look at upcoming methods (all models) of training, not just regimented ones (and prepare for those)
  - Some examples in European models
- Recently time to certify has increased as there are more things to learn and more things to teach
  - More technology onboard the aircraft would potentially mean more time would be required for training

Pilot Certification

- Standards must be established and consistent between aircraft that allow SVO operations. Without standard, training for SVO would need to be tailored for each aircraft. Possible, yes. But, it may not be practical or cost effective.
- I believe it would not really be a change in pilot certification levels. It would be refining the operational types the pilot would be able to perform. By statute air carrier operations are at the highest level of safety. Other operations are at an appropriate level of safety. Additionally the First Officer Qualification requirement is in Title 49. So without a congressional change air carrier pilots must hold an ATP. We can place conditions and limitations on a pilot certificate and in an aircraft flight manual. Also, 61.31(h) allows the FAA to require type specific training in any aircraft in the interest of safety. If an aircraft is so different we can restrict operations of that aircraft (or only operate that aircraft)
- [Regarding use of Part 61 to capture different levels of pilots operating differently capable aircraft] No. But Modernization of Special Airworthiness Certificates (MOSAIC) is being positioned to handle different aircraft. MOSAIC used to be called Permit to Fly.
  - Implementation of MOSAIC which includes changes/additions to current guidance. Q2.10 is Will there be a need to change the pilot certification levels in the future? I don’t know what technology current technologies can help with changing guidance.
- Multiple types of pilot certificates – fixed wing, glider, lighter-than-air
  - Within fixed wing there are additional variations

    - For urban pilots likely to be new category of pilot certification
        - For weather, someone else may be making go/no-go decisions
    - In Europe, going to simulation certification where simulator needs only to demonstrate desired capability. (Possibly 7 levels of simulators defined already?)

FAA's Role:

Automation & Autonomy in GA aircraft operation (Simplified Vehicle Operations)

- FAA, TSA interact through the avenue available due to National Safe Skies Alliance – which looks into developing scanning technology etc.
- [Regarding resources necessary for ground and flight schools to incorporate augmentation] The FAA, with industry, will need to develop guidance and standards for incorporation of augmentation technology. These guidance and standards will need to reflect an equal level of safety as today in the NAS.
- [Regarding who should the FAA collaborate with] SAFE, NAFI, AOPA, EAA, and COEs
- As automation and autonomy changes so will the rules and guidance (Handbooks, ACs, FSIMS, etc.). The FAA will be required to change the ACS to accommodate aircraft with differing levels of autonomy.

Pilot Training Procedure & Methodology

- [Regarding training procedure and method readiness for GA 2030 demands] As technology continues to evolve and needs shift (requirements for additional pilots) the FAA requirements need to evolve also. i.e., as simulation technology improves, additional credit for simulation time needs to be considered.
    - [Regarding necessary improvements to implement] This is an unknown because we (FAA) does not know what new technologies be created in the future. The only thing that is sure is the FAA does not have the expertise to have all the answers. Recently the FAA has created more partnerships with industry when it comes to training and safety (ARCs, ARACs, USHST, COEs, CAST, GA-JSC, etc.). The industry must be willing to provide data so the FAA can make appropriate changes without violating their statutory requirement for safety.
- [Regarding who should the FAA collaborate with] Manufacturers of these aircraft, Alphabet Groups (AOPA, EAA, SAFE, NAFI, UAA, AABI, etc.), Universities (COEs), Standards Developers (ASTM, SAE, RTCA, etc.)
- [Regarding research outcomes] Research on simulation levels and the effectiveness of training in those flight simulation devices. FAA policy changes. FAA Guidance changes. Determine of training needs based on the level of automation and autonomy.
- FAA has tendency to simply add to existing requirements
    - Pilots still need to learn about steam run/ obsolete instruments
    - FAA needs to remove unnecessary "legacy" requirements
- Limitations of various training tools should be explored (via trial and error if required)

- Shift mindset from hours-based to proficiency-based
    - Train until pilot can demonstrate proficiency
    - Outcome-based training

General Comments:

- [Regarding location of current FAA guidance for pilot training and proficiency] Various handbooks, orders, standards (i.e., PTS ACS), and FSIMS.
- [Regarding who's responsible for overseeing existing pilot training & proficiency] FAA safety inspectors. Policy AFS-800. DPEs, AFS-600.
- [Regarding the impact of guidance on the requirements of current GA] The FAA works hard developing standards, requirements, and guidance to keep up with changing and industry technology and needs. I.e. changes allowing more use of simulation, reducing geographical restrictions on DPEs, allowing additional military experience towards civil certificates, etc.
- [Regarding requirements for GA] I only see additional changes needed in the future. Must accommodate and bring into the NAS unmanned systems as just another aircraft, not a special operation. Technologies continue to evolve.
- [Regarding utility of research outcomes to FAA] Research by industry (COE-Pegasus) allows the FAA to stretch research resources (dollars and people).
- [Regarding urgency of research for GA in 2030] This is dependent on the recommendations of this research. Changes to the regulations normally take 5 or more years (it could be less with a congressional mandate, but we still must adhere to the Administrators Procedures Act). Policy, guidance, and handbook changes take much less time, but still may take over 12 months.
- [Regarding stakeholders for the change in pilot certification] SAFE, AOPA, EAA, and COEs
- [Regarding urgency of research for GA in 2030] If rulemaking is required, it is very urgent. Rulemaking typically takes about 3 years. And that is after it gets approved to move forward. The FAA has only so many resources available to be put on rulemaking projects. All rulemaking requests are evaluated for their urgency and impact on safety. Data is needed to move requests high enough on this list to be approved. So lead time for rulemaking is, typically, 5 or more years. From today that makes starting the request at 2025 for a 2030 implementation. 2025 is only 7 years from now to conduct all the research needed.