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General Aviation 2030: GA Exploratory Analysis

December 2018

Final Report

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16. Abstract

"General Aviation 2030 - GA Exploratory Analysis" is Project 25 within the Partnership to Enhance General Aviation Safety, Accessibility and Sustainability (PEGASAS), the Federal Aviation Administration Center of Excellence for General Aviation. The purpose of the project was to document strategic general aviation research topics that, when addressed in the near term, could help the FAA and other GA stakeholders better prepare for issues that general aviation may face in 2030.

This report documents the approach taken during and outcomes resulting from a benchmarking activity to search available literature and other discussions of the future of general aviation and from two workshops that engaged participants from industry and government to gather the view of the future of general aviation from these subject matter experts. This project also leveraged a workshop conducted with participants from academia conducted in May 2016, before the start of Project 25.

The benchmarking exercise identified six major topical areas for GA in 2030: new energy, infrastructure, advanced design & manufacturing, automation, airspace management, and certification. The workshops developed several themes. Workshop 1 participants identified and described themes of pilot training and proficiency, autonomy and automation, airport and infrastructure, GA in the future airspace, airframes, legacy fleet & maintenance, future propulsion systems, and passenger safety. Work- shop 2 participants identified one new theme—aircraft/aviation connectivity—and then provided their own discussion of the themes: autonomy and automation, pilot training and proficiency, airport and infrastructure, GA in the future airspace, and passenger safety. By combining the benchmarking and workshop outputs, there appear to be ten themes that give organization to categorize GA research topics and efforts needed to better prepare for issues that GA may face in 2030.

Based upon the commonality of topics across the benchmarking and workshops, along with the energy the participants in the workshops used to develop the themes, the project team summarizes that the four themes with the highest apparent priority are airspace management, airport infrastructure, automation and connectivity.

The team recommends that all ten themes, perhaps with an emphasis on the four high-priority themes mentioned above, guide work to allow the development of a true general aviation research and development plan. Although the workshop participants represented a broad spectrum of the general aviation community, input from additional sectors of GA would also ensure that as many of the GA stakeholders as possible feel engaged in the research plan.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS

ADS-B	Automatic Dependent Surveillance-Broadcast
AM	Additive manufacturing
API	Application programming interface
ATC	Air traffic control
ATM	Air traffic management
COTS	Commercial off-the-shelf
CPDLC	Controller-pilot data link communications
EASA	European Aviation Safety
ETA	Estimated technology adoption
EVS	Enhanced vision system
GA	General aviation
GAMA	General Aviation Manufacturers Association
GPWS	Ground Proximity Warning System
IAOPA	International Council of Aircraft Owner and Pilot Associations
IFR	Instrument flight rules
IoT	Internet of Things
LOC	Loss of control
ODM	On-demand mobility
PBN	Performance-based navigation
PCAS	Portable Collision Avoidance System
PEGASAS	Partnership to Enhance General Aviation Safety, Accessibility and Sustainability
RNP	Required navigation performance
SVS	Synthetic vision system
SWIM	System Wide Information Management
TCAS	Traffic Collision Avoidance System
TRL	Technology readiness level
UAS	Unmanned aerial system
UAV	Unmanned aerial vehicle
VFR	Visual flight rules
VTOL	Vertical takeoff and landing

EXECUTIVE SUMMARY

"General Aviation 2030—GA Exploratory Analysis" is Project 25 within the Partnership to Enhance General Aviation Safety, Accessibility and Sustainability, the FAA Center of Excellence for General Aviation. The purpose of the project was to document strategic general aviation (GA) research topics that, when addressed in the near term, could help the FAA and other GA stakeholders better prepare for issues that GA may face in 2030.

This report documents the approach taken during, and outcomes resulting from, a benchmarking activity to search available literature and other discussions of the future of GA, and from two workshops that engaged participants from industry and government to gather the view of the future of GA from these subject matter experts. This project also leveraged a May 2016 workshop conducted with participants from academia before the start of Project 25.

The benchmarking exercise identified six major topical areas for GA in 2030: new energy, infrastructure, advanced design and manufacturing, automation, airspace management, and certification. The workshops developed several themes. Workshop 1 participants identified and described themes of pilot training and proficiency, autonomy and automation, airport and infrastructure, GA in the future airspace, airframes, legacy fleet and maintenance, future propulsion systems, and passenger safety. Workshop 2 participants identified one new theme— aircraft/aviation connectivity—and then provided their own discussion of the themes: autonomy and automation, pilot training and proficiency, airport and infrastructure, GA in the future airspace, and passenger safety. By combining the benchmarking and workshop outputs, there appear to be ten themes that give organization to categorize GA research topics and efforts needed to better prepare for issues that GA may face in 2030.

Based on the commonality of topics across the benchmarking and workshops, and the energy the participants in the workshops used to develop the themes, the project team summarizes that the four themes with the highest apparent priority are: airspace management, airport infrastructure, automation, and connectivity.

The team recommends that all ten themes, perhaps with an emphasis on the four high-priority themes mentioned above, guide work to allow the development of a true GA research and development plan. Whereas the workshop participants represented a broad spectrum of the GA community, input from additional sectors of GA would ensure that as many GA stakeholders as possible feel engaged in the research plan.

1. INTRODUCTION

This report documents the efforts of a team from Partnership to Enhance General Aviation Safety, Accessibility and Sustainability (PEGASAS), the FAA's Center of Excellence for General Aviation, to capture important ideas, themes, and needs for research related to the future of general aviation (GA). The team conducted this work as part of PEGASAS Project 25: "General Aviation 2030: GA Exploratory Analysis."

1.1 MOTIVATION

The role of GA in the U.S. 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 ought to be better prepared by starting research now to understand the needs and challenges that are expected to arise from GA in the 2030–2040 time frame.

1.2 SCOPE OF PROJECT

The objective of this study is to analyze and explore future GA topics that might warrant further research in an effort to understand the underlying technological needs and challenges associated with future GA concepts. The approach taken by the PEGASAS team includes a benchmarking task and a series of subject matter expert-driven workshops to collect and analyze GA challenges, technologies, and trends impacting GA in 2030. Although this study was commissioned by the FAA, the resulting research needs and challenges affect the broad aviation community and all its stakeholders.

2. BENCHMARKING TASK

Project 25 included a benchmarking task that asked the team to conduct a survey of literature and discussions (including online web pages, popular aviation magazines, professional society conference papers, and peer-reviewed articles). This broad literature review about the future of GA provided some assurance that the project would capture a range of issues, some of which might not be possible to cover in the shorter, more focused workshops. The major findings of the benchmarking tasks appear in this chapter.

2.1 FUTURE TRENDS FOR GA

2.1.1 Overview of the Current Status

GA plays an important role in the national air transportation system. According to the FAA, three of four takeoffs and landings at airports in the U.S. are conducted by GA aircraft. Nationwide, there are 3300 airports and other landing facilities in the FAA's National Plan of Integrated Airport Systems, supporting main aeronautical functions such as emergency, critical community access, commercial activities, and destination services. [1]. In FAA's "Plane Sense—General Aviation Information" (FAA-H-8083-19A) [2], GA flights are described as flights conducted by operators

other than Title 14 of the Code of Federal Regulations (CFR) Part 121 or Part 135 certificate holders. The General Aviation Manufacturers Association (GAMA) databook shows that there are currently more than 210,000 GA aircraft based in the U.S., with more than 24 million flight hours every year. As for the contribution to economics and job creation, GA activities support $219 billion in economic output and 1.1 million jobs in the U.S. Another aspect worth mentioning is that GA flights use more than 5000 U.S. public airports, compared to fewer than 400 airports served by scheduled airlines [3].

2.1.2 GA Forecasts for 2017–2037

Among the numbers projected by the FAA, changes in three characteristics are worth mentioning here: the number of active GA aircraft, active pilots, and GA hours flown.

According to these forecasts, no large changes in fleet, pilot population, or flight hours are expected. The active GA fleet is projected to increase at an annual rate of 0.1% because of the general increases in fixed-wing turbine, rotorcraft, and light sports fleet. This increase is expected to offset a decline in the fixed-wing piston fleet. The pilot population is projected to decrease at an annual rate of 0.1%, for a foreseeable decline in the number of private and commercial pilots because of new certificate rules. The number of GA flight hours is projected to increase at an annual rate of 0.9% as the utilization rates for new business jets are expected to increase [4]. Details of the breakdown per category are shown in figure 1.
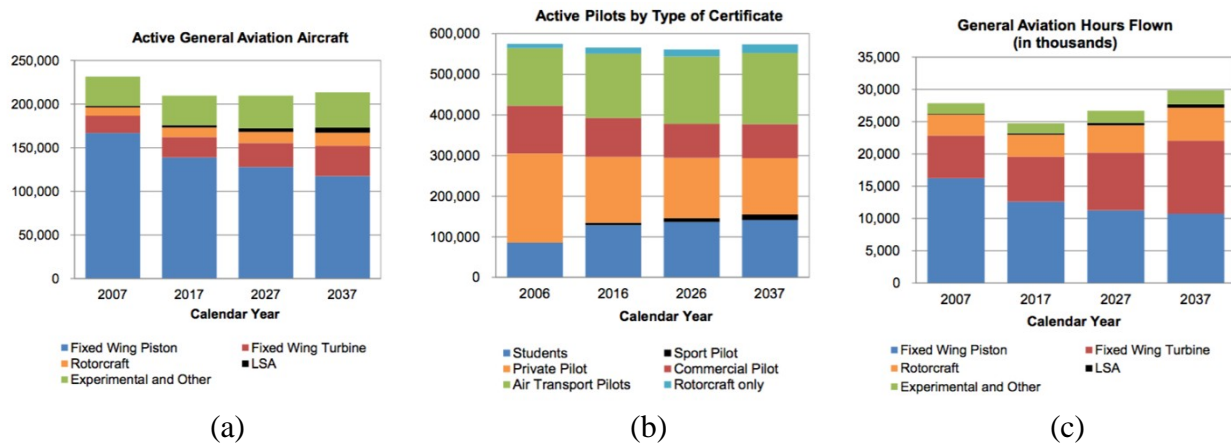
Figure 1. GA forecasts in (a) fleet, (b) pilots, and (c) flight hours; source: FAA [5]

Despite these relatively slow growth projections, expected advancements in technologies, regulations, and economic activities will profoundly transform the future of GA. With the advancement of electric propulsion technologies and technologies aimed at improving safety, urban mobility using GA aircraft may emerge as a major transformational concept [6]. The use of autonomous technologies is likely to increase in areas such as trajectory planning to further simplify the role of human pilots and enhance safety. Furthermore, issues in predicted congested airspace, which had normally been the domain of GA aircraft, brought about by the increasing Unmanned Aerial System (UAS) activities, remain to be solved. The rewrite of 14 CFR Part 23 in 2017, an action that reduced the number of regulations in Part 23 from 377 to 71, will potentially

make it easier to introduce novel technologies that can also improve safety and reduce the cost to acquire, own, and operate GA aircraft.

2.1.3 Top Challenges in Future GA

Although the predicted volume of GA may stay at the same level up to the year 2030, the composition of GA is expected to change. In transitioning from its current state to the expected state in 2030, GA may face many challenges. With newer forms of technology, innovative operation, larger data volume available into and out of the aircraft, and cross-domain technology, the challenges for a safe, efficient, profitable, and environmentally friendly GA ecosystem are enormous.

The recent Uber Elevate summit report [7] described key challenges: the certification process, battery technology, vehicle efficiency, vehicle performance and reliability, air traffic control, cost and affordability, safety, aircraft noise, emissions, infrastructure, and pilot training. The Uber report primarily refers to on-demand vertical takeoff and landing (VTOL) concept aircraft, but it does highlight four key challenging areas identified for GA as well: certification, airspace management, infrastructure, and cost.

- Certification: The new 14 CFR 23 has been effective since August 2017 [5]. Certification is evolving toward a performance- and risk-based approach with complex processes being modelled and results obtained through analysis (computationally) rather than the conventional prescribed tests. Even though these approaches help in the introduction of newer technologies and accelerate the certification process for existing technologies, large challenges lie ahead. With vast technological changes anticipated, processes and methods would need to be developed and identified to quickly and efficiently certify these new technologies while maintaining the same level of safety. Many technologies are not aviation specific but trans-domain (i.e., initially developed for automotive or consumer electronic applications), and their operability and airworthiness would have to be quickly determined.

- Airspace Management: With the advent of UAS and their growing popularity, the number of aerial vehicles operating in the common airspace will be unprecedented [8]. Proper control and management of this increasingly congested airspace is of primary concern for the safe operation of all aircraft [9]. GA aircraft—both conventional airplanes and the proposed new generation air vehicles—are the most likely to share the airspace with UAS. Another concern for the airspace is the variation in levels of operational control of the aircraft. Piloted, remotely piloted, and autonomous aircraft will soon have to share the same airspace. The growing numbers and types of aircraft and varying levels of control make airspace management a key challenge for the future of GA and aviation more broadly.

- Infrastructure: The expected newer generation of aircraft will require newer maintenance and storage infrastructure. With growing numbers of new aircraft, a greater number of larger ground service stations will be required. The safe operation of these ground facilities is also important. The aviation infrastructure of the future will also be as varied as the technology it would need to support; for instance, if the GA fleet uses a mix of

future unleaded fuel(s) and electric power, the airports and ground facilities must address this. Fixed-based operators will have to account for different types of technologies present on similar types of aircraft, different aircraft configurations, and different operating conditions.

- Cost: In overcoming all the challenges, it will also be essential to keep costs down, making cost another major challenge for the future. Cost and safety are two of the primary factors influencing public perception and, thereby, limiting or increasing the number of customers of GA. Keeping costs to reasonable levels for researching, developing, and finally introducing new technologies while overcoming the challenges to assure safe operations will be important in determining the success of future GA and accompanying novel technologies.

2.1.4 Key Transformational Changes

^In addition to the four main challenges for future GA, five key transformational changes have also been identified and listed below:

- Urban mobility: This may emerge as a major transformational concept. Urban air taxi service is most likely to happen first in the Dallas-Ft. Worth area and the San Francisco Bay area based on current investments and discussions.
- New propulsion architectures: More aircraft will be powered by alternate energy sources, such as electric, hybrid-electric, fuel cell, and distributed propulsion architectures.
- Enabling technologies: Many new technologies will be used to enhance GA safety, including Ballistic Recovery Systems, NextGen, pilot aids, runway incursion prevention systems, and real-time weather.
- Automation: The level of automation in air transportation, plausibly first in GA, will increase. Some examples are increased autonomous operations and trajectory planning.
- UAS activity: UAS will be used more extensively for the purposes of package delivery, agriculture, civil engineering, and surveillance. The substantial increase of UAS will impact the shared airspace.

2.2 IDENTIFICATION OF THE SIX MAIN AREAS

To identify the main topics in GA for further studies, a text-mining task was conducted using detailed notes from an academia workshop conducted in May 2016, prior to the start of Project 25. The notes from that workshop included all the previous year's outputs regarding GA topics, issues, and themes. In particular, topics or themes that occurred frequently in these proceedings were identified. Conclusions from the data-mining process, combined with a brainstorming process, finally generated six main topics for further in-depth studies in GA, as shown in figure 2. Under each main area, some secondary and tertiary topics were developed, many of which overlap with more than one of the main areas. These relationships and interdependencies are shown in figure 3 using a Sankey diagram, a flow diagram that visualizes the proportion of the major components within the system and locates the dominant contributions.
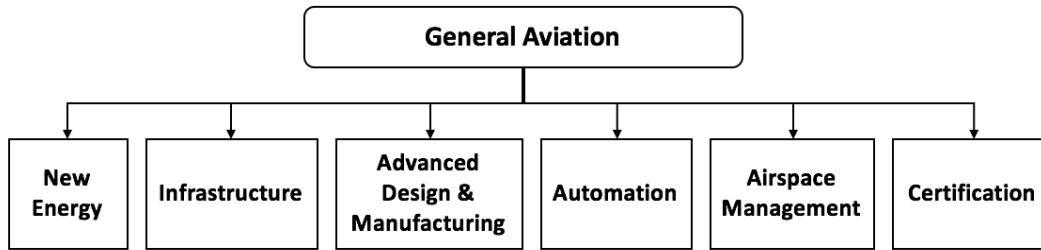
Figure 2. Down-selection of six major topic areas for future GA

The researchers at Georgia Tech and Purdue undertook a more in-depth literature review of the six main identified areas: New Energy, Infrastructure, Advanced Design and Manufacturing, Automation, Airspace Management, and Certification.
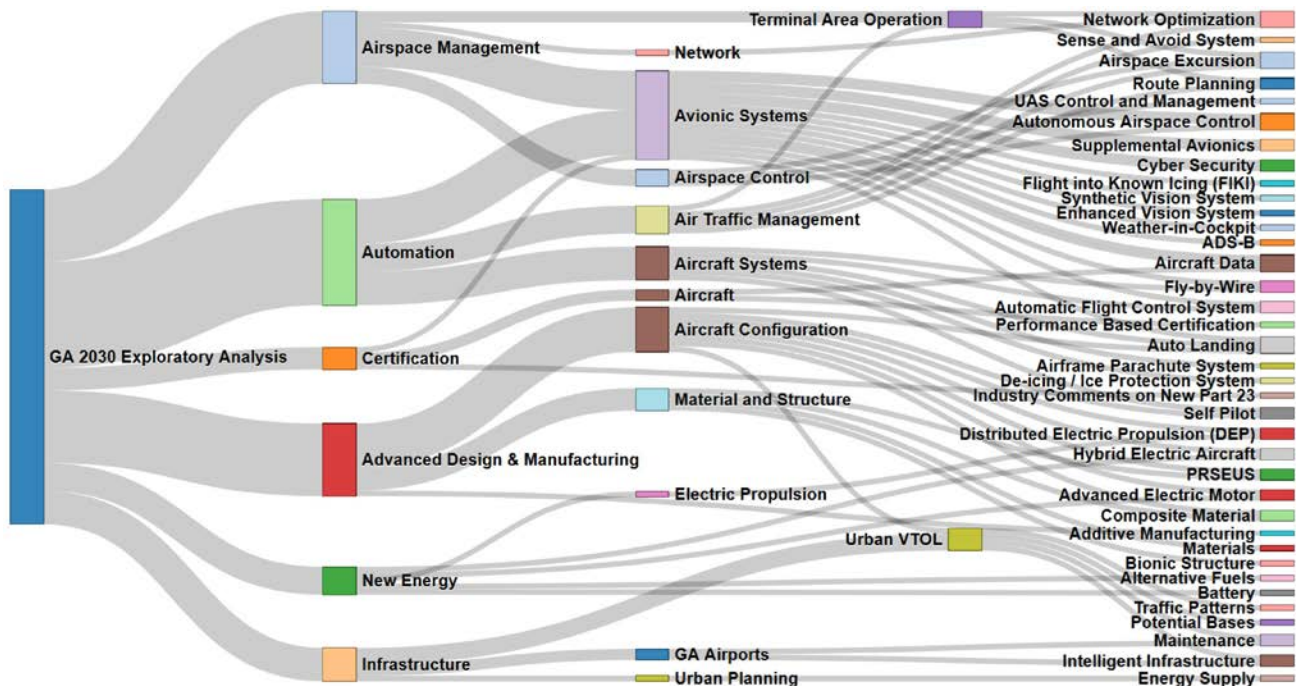
Figure 3. Topic taxonomy with secondary and tertiary topics

2.3 NEW TECHNOLOGIES AND TECHNOLOGY METRICS

2.3.1 The Full List of New Technologies

The team identified representative new technologies in each of the six areas to investigate further. A full list of new technologies studied is presented in table 1. A combination of two metrics—technology readiness level (TRL) and estimated technology adoption (ETA)—was used to assess the feasibility and the potential influence of each new technology on GA in the 2030 time frame.

Table 1. List of new technologies investigated for GA

Distributed Electric Propulsion	Hybrid-Electric Propulsion System	Hydrogen-Powered Aircraft
Diesel Aircraft Engine	Advanced Battery	ADS-B Related
Solar-Powered Aircraft	Efficient Electric Aircraft Charging Station	Fly-by-Wire Tech
Autopilot System	Auto Landing (hands-off)	Flight Data Monitor
SVS	EVS	Weather-in-Cockpit
ADS-B out	ADS-B in	ABS-B Self-Separation Application (Sense-and-Avoid)
CPDLC	Required Navigation Performance (PBN): RNP and RNAV	TCAS and GPWS
SWIM (ATM Perspective)	ATM Tech: ATD-1 (TSAS & FIM) and ATD-2	UAS Traffic Management
AM Process and Methods	AM Materials	AM Applications
Electric Aircraft Design	Hybrid Aircraft Design	VTOL Aircraft in GA
Pultruded Rod Stitched Efficient Unitized Structure	Bionic Structure (AM + Design Optimization)	Airframe Parachute System
Ice Protection System on GA	Seatbelt Airbag System	Angle of Attack System

ADS-B = Automatic Dependent Surveillance-Broadcast
AM = Additive manufacturing
ATM = Air traffic management
CPDLC = Controller-pilot data link communications
EVS = Enhanced vision system
GPWS = Ground Proximity Warning System
PBN = Performance-based navigation
RNP = Required navigation performance
SVS = Synthetic vision system
SWIM = System Wide Information Management
TCAS = Traffic Collision Avoidance System

2.3.2 Technology Metrics and TRL

TRL characterizes the maturity level of a new technology. A widely used version defined by NASA has nine TRLs ranging from TRL 1 (basic principles observed) to TRL 9 (actual system flight proven). Detailed definitions of the nine TRLs are shown in table 2 [10]. During the investigation process, the TRL for each GA-relevant technology was assigned by evaluating its current development against definitions and descriptions for each TRL. Technologies with a current TRL level of at least 5–6 have the potential to be developed to TRL 9 in 10 years.

Table 2. Technology readiness level definitions; source: NASA [10]

TRL	Definition
1	Basic principles observed and reported
2	Technology concept and/or application formulated
3	Analytical and experimental critical function and/or characteristic proof of concept
4	Component and/or breadboard validation in laboratory environment
5	Component and/or breadboard validation in relevant environment
6	System/subsystem model or prototype demonstration in an operational environment
7	System prototype demonstration in an operational environment
8	Actual system completed and flight qualified through test and demonstration
9	Actual system flight proven through successful mission operations

2.3.3 Estimated Technology Adoption

The PEGASAS Project 25 team developed the ETA metric to provide another dimension in the technology evaluation process. The motivation for an ETA is that technology readiness and its adoption into the market do not necessarily go together. The successful development of a technological innovation depends on the availability and performance of the technology, which depends ultimately on the mastery of the science and engineering embedded in the technology. The adoption of innovative technologies and solutions, however, also depends on non-technological factors [11]. Some high TRL technologies are not adopted in GA today. Similarly, many technologies under development today show great promise, but the GA industry and community may not actually adopt them for use. A large discrepancy between TRL and ETA might point out that there is a need for additional research to make the well-developed technology readily accepted and used by the GA community. As part of the exploratory analysis for GA 2030, this metric helps drive discussion toward why a technology expected to have a high TRL by 2030 may not be widely adopted. The ETA scale has three levels, as shown in table 3.

Table 3. ETA level definitions

ETA	Definition
Low	A less than 30% technology adoption by applicable GA fleet of aircraft in 2030.
Medium	A technology adoption of 30% to 60% by applicable GA fleet of aircraft in 2030
High	A more than 60% technology adoption by applicable GA fleet in 2030.

There are numerous stakeholders in GA for whom the factors affecting technology adoption may vary. One of the key stakeholders is the aircraft customer/pilot. From the benchmarking and literature survey, it was possible to infer that the factors that influence the adoption of technology to this stakeholder are cost, downtime, human factor, safety, reliability, and privacy:

1. Cost: Amount of money required to install a new technology into an existing aircraft or the additional increase in price of new aircraft as a result of integrating a new technology.
2. Downtime: Time required installing, upgrading, and maintaining the new technology.
3. Human Factor: The ease of use and the amount of training required. It also includes the aesthetic component of the new technology.
4. Safety: Does the stakeholder believe that the new technology will increase flight safety? Does the new technology make flying safer? Is the new technology safe to use?
5. Reliability: How often does the new technology operate at required and acceptable levels of performance?
6. Privacy: User perception regarding ability and use of technologies to gather and disseminate information regarding the user to other entities or to objectionable extents.

Such factors and many more can be used as lenses during this project while exploring possible new types of technologies entering GA and deciphering why a technology appears to have a particular adoption state. The schematic diagram for the usage of the ETA metric in "exploratory" analysis of GA in 2030 for a notional "New Technology A" is shown in figure 4.
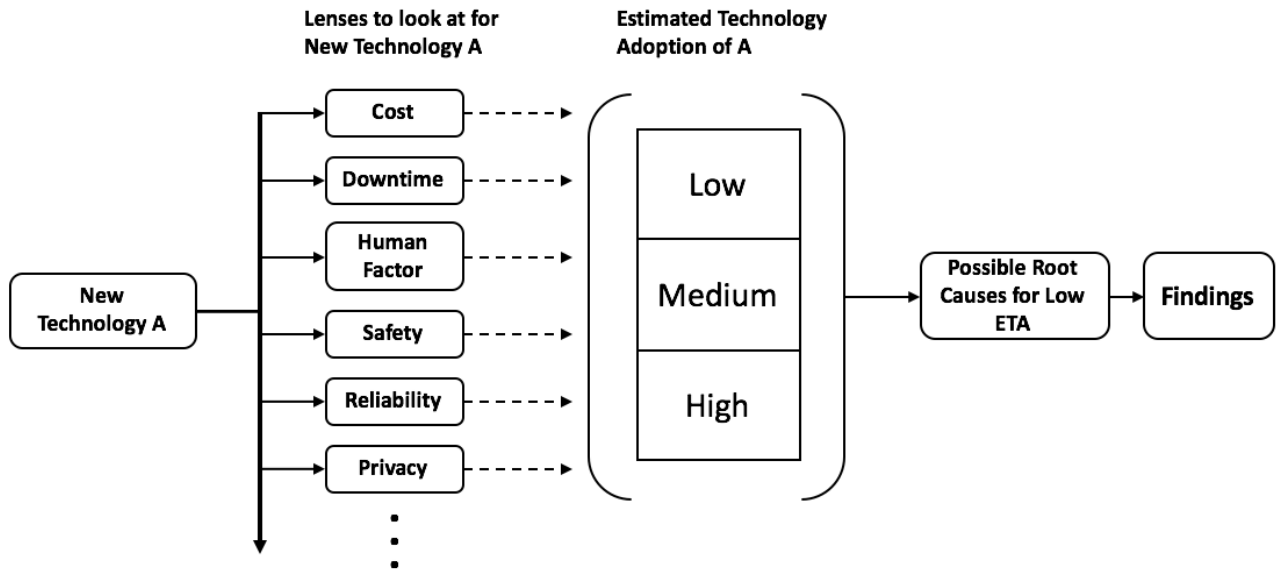
Figure 4. Schematic diagram for the usage of ETA

2.3.4 Technology Evaluation Table

For each new technology, the team assigned a TRL value between 1 and 9 and an ETA value of low, medium, or high, as shown in figure 5. In this figure, TRL values were assigned based on the information in the 2017 timeframe, and ETA values were assigned for both the 2017 and 2030 timeframes based on currently available information and expectations. If subsequent workshops or other efforts seek to develop specific research plans around a given technology or set of technologies, the opportunity to survey GA subject matter experts could lead to ETA ratings with a broader consensus. This table is used to assess if a technology has the potential to be part of GA operations in 2030. A good candidate should have a high TRL value and a medium-to-high ETA value by 2030. A complete version of the technology evaluation table can be found in appendix A.

Technologies	TRL	Status in 2017	ETA	Status in 2030	ETA
Distributed Electric Propulsion (DEP)	5-6	First NASA DEP manned flight demonstrator will be achieved in 2017.	Low	No forecast yet.	Medium
Hybrid-Electric Propulsion System (HEPS)	2-3	Airbus's plan initialed back in 2013.	Low	Regional hybrid electric flight demo before 2021, practical airliners in 2030 - 2035.	Medium
Hydrogen-Powered Aircraft	6-7	First passenger aircraft prototype took off in Germany in 2016. The HY4.	Low	May enter service later than 2030 due to the change to new energy infrastructure.	Medium
Diesel Aircraft Engine	9	Many diesel aircraft engines already in operations.	High	May be chosen as retrofit and in new aircraft following the high price of AVGas and possible fuel transition.	High
Advanced Battery	4	Current battery density at 250-300 Whr/kg. Latest outcomes in lab can already reach more than 400 (even more).	Low	Need more than 400 Whr/kg for DEP for electric propulsion market. Highly possible.	High
ADS-B Related	9	Technologies for ADS-B in/out units and ground stations are mature.	Medium	Will require most GA aircraft to equip ADS-B out by 2020. Need investigate ground stations.	High
Solar-powered Aircraft	7	Already have a few successful prototypes.	Low	Not a practical solution for future GA aircraft because of the aerodynamics design, efficiency and operational limits.	Medium
Efficient Electric Aircraft Charging Station	3	First EA charging station in 2011. Two cities in California installing the first network of charging infrastructure.	Low	Expect to form charging station networks in some areas (like SF bay area).	Medium
Continued for all the 30+ technologies	:	:	:	:	:

Figure 5. TRL and ETA table for new technologies [12–15]

2.3.5 Conclusion of the Technology Metrics Analysis

With the criteria described above (with a TRL of at least 5–6 and an ETA of medium to high), a set of new technologies was identified as having the potential to shape the future of GA in the 2030 time frame. A list of such technologies is provided below:

- Propulsion System: Distributed Electric Propulsion, Diesel Aircraft Engine, Advanced Battery
- Avionics: ADS-B related (ADS-B in/out, sense-and-avoid applications), Flight Data Monitor, Synthetic Vision System, Enhanced Vision System, Weather-in-Cockpit, and CPDLC
- Flight Control and Automation: Fly-by-Wire and Autopilot System (navigation, takeoff and landing-hands off)
- Air Traffic Control/Management: Performance-Based Navigation (PBN): RNP and RNAV, TCAS/Portable Collision Avoidance System/GPWS, and SWIM for Air Traffic Management
- Airframe Safety Measurements: Airframe Parachute System, Ice Protection System, Seatbelt Airbag System, and Angle of Attack System (ranging from pilot displays to envelope protection)

2.4 TECHNOLOGY PORTFOLIO STUDY

2.4.1 Overview

The formulation of six topic areas allowed the team to focus on research areas that have a major influence on GA 2030. Subsequently, state-of-the-art technology was researched in each area to identify barriers/challenges and understand their development status and GA impact using the TRL and ETA metrics. However, another interesting exploratory exercise involved analyzing how these technologies could be adopted on specific aircraft models. This was carried out by mapping these advanced technologies to current and future aircraft models. The aircraft technology portfolio in this section describes this approach to investigate the pattern between technologies and aircraft systems.

2.4.2 Technology Portfolio Analysis Formulation

The first step in analyzing the technology portfolio was to identify the group of aircraft models. The proposed aircraft technology portfolio includes 128 aircraft models that are available in 2017, and 18 additional models that have been proposed (some prototyped/tested) with an entry into service of approximately 2030. The next step was to categorize the technologies into five areas: propulsion system, airframe material, advanced avionics/control systems, aircraft configuration, and airframe safety measures. Within each area, detailed methods, subsystems, or equipment were further divided into more specific subareas accordingly. Information on aircraft models and aviation technologies were sourced from aircraft technical information sheets, news reported in multiple media, and journal papers. The aircraft technology portfolio table structure is shown in figure 6.

GA Aircraft Technology	Manufacturer	Manufacturer #1		
	Aircraft	Model #1	Model #2	Model #3
Airframe Safety Measures	Airframe Parachute System	Y	N	Y
	Seat belt Airbags	Y	Y	Y
	De-icing/Ice Protection system	N	O	N
	Angle of Attack System	N	N	N
	Flight into Known Icing Conditions (FIKI)	N	Y	Y
Propulsion System	Turbo Based/piston/ Electric / Hybrid	Piston	Turbofan	Electric
Avionics / Control Systems	SVS	O	Y	Y
	EVS	N	Y	O
	Weather-in-cockpit	N	Y	N
	Autopilot / Automatic Flight Control Sys	N	Y	O
Airframe Material	Composite Material for Airframe	N	Y	Y
Airframe Configuration		Fixed-Wing	Fixed-Wing	Multicopter

Figure 6. Structure of aircraft technology portfolio table

Figure 7 shows an example portfolio table for a single engine fixed-wing aircraft.

GA Aircraft Technology		Manufacturer	Cirrus			Cessna							
		Aircraft	SR20	SR22	SR22T	Skyhawk	Skyhawk JT-A	Skylane	Turbo Stationair HD	TTˣ	Caravan	Caravan EX	Denali
Airframe Safety Measures		Airframe Parachute System	Y	Y	Y	O	O	O	N	N	N	N	N
		Seat belt Airbags	Y	Y	Y	O	O	O	O	O	O	O	O
		De-icing/Ice Protection system	N	O	O	N	N	N	Y	Y	Y	Y	N
		Angle of Attack System	N	N	N	Y	Y	N	N	N	N	N	N
		Flight into Known Icing Conditions (FIKI)	N	O	O	N	N	N	Y	Y	Y	Y	N
Propulsion System		Traditional (turbo-/piston)	piston	piston	piston	piston	piston	piston	piston	piston	turboprop	turboprop	turboprop
Avionics / Control Systems		SVS	O	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
		EVS	O	O	O	N	N	N	N	N	N	N	O
		Weather-in-cockpit	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
		Autopilot / Automatic Flight Control Sys	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Airframe Material		Composite Material for Airframe	Y	Y	Y	N	N	N	Y	Y	N	N	N
Airframe Configuration			Fixed Wing	Fixed Wing	Fixed Wing	Fixed Wing	Fixed Wing	Fixed Wing	Fixed Wing	Fixed Wing	Fixed Wing	Fixed Wing	Fixed Wing

Figure 7. A snapshot of the portfolio table

In both tables, Y indicates that the technology or equipment is present in the investigated aircraft model; O indicates that it is an optional component or function; and N indicates that it is not an option. Additional aircraft technology portfolio tables were created for business jet propeller-driven fixed-wing twin-engine aircraft, rotorcraft, multi-copters, VTOL concepts, and electric aircraft.

After the portfolio tables were created, mathematical interpretations were generated using portfolio vectors assigned to each aircraft model to record the number of available technologies. There are five components in each portfolio vector: S for airframe safety measurement, P for propulsion system, A for avionics/control systems, M for airframe material, and C for airframe configuration. Some examples of the portfolio vectors and these components are shown in equations 1–3.

$$(S_1, P_1, A_1, M_1, C_1)_{model\#1} = (2, 1, 1, 1, 1) \tag{1}$$

$$(S_2, P_2, A_2, M_2, C_2)_{model\#2} = (3, 1, 4, 1, 1) \tag{2}$$

$$(S_3, P_3, A_3, M_3, C_3)_{model\#3} = (3, 1, 3, 1, 1) \tag{3}$$

The number of each component in the vector indicates the number of technologies available to the aircraft model being studied. The way to interpret these numbers is as follows: In figure 7, using Cirrus SR20 as an example, it has 2 Y in safety measures, 1 propulsion architecture, 2 Y and 2 O in avionics/control system (4 in total), 1 Y in structure material, and 1 airframe configuration. With this information, the portfolio vector for Cirrus SR20 can be constructed as:

$$(S_{SR20}, P_{SR20}, A_{SR20}, M_{SR20}, C_{SR20})_{CirrusSR20} = (2, 1, 4, 1, 1) \tag{4}$$

Then, by using the portfolio vectors, a cumulative technology count can be calculated by using equation 5, in which N is the number of aircraft models reported in 2017 or the number of models expected in 2030.

$$T = \sum_{i=1}^{N} S_i + \sum_{i=1}^{N} P_i + \sum_{i=1}^{N} A_i + \sum_{i=1}^{N} M_i + \sum_{i=1}^{N} C_i \tag{5}$$

Ratios between T and the summation of S, P, A, M, and C describe ratios of the five aircraft technology portfolio areas. For example, with the table shown in figure 8, the ratios (in percentages) of airframe safety measurement, propulsion system, avionics/control systems, airframe material, and airframe configuration are: 33.5%, 12.5%, 33.5%, 8.0%, and 12.5%, respectively, with T = 24.

Similarly, each aircraft technology portfolio can be further broken down into many subareas. For example, avionics/controls system is comprised of SVS, EVS, weather-in-cockpit technology, and autopilot/automatic flight control system. Therefore, A_1, A_2, and A_3 in equations 1–3 can be further broken down into the following vectors:

$$A1 = (1, 0, 0, 0) \tag{6}$$

$$A2 = (1, 1, 1, 1) \tag{7}$$

$$A3 = (1, 1, 0, 1) \tag{8}$$

The components in equations 6–8 represent the availability of each avionics/control system technology (from left to right: SVS, EVS, weather-in-cockpit, autopilot, and automatic flight control system) for the aircraft models under study. Similarly, the ratio between T and each specific technology or equipment can be computed. For example, in the case of figure 6, the overall ratios are 12.5% (3/24) for SVS, 8.33% (2/24) for EVS, 4.17% (1/24) for weather-in-cockpit, and 8.33% (2/24) for autopilot and automatic flight control system.

2.4.3 The Sankey Diagram

Once the area and subarea vectors for the actual portfolio tables of new aircraft models in 2017 and expected models in 2030 were established, Sankey diagrams were used to visualize the shifting trends in aircraft-technology implementation during the next 10–20 years. Figures 8 and 9 show the Sankey diagrams for the aircraft technology portfolio for the new aircraft models in 2017 and the expected models in 2030, respectively.

The use of Sankey diagrams revealed some interesting trends. In the 2017 list of models, the aircraft models are manufactured primarily from metal, are equipped with traditional piston or turbine-based engines, and their configurations are either fixed-wing or rotary-wing. In the list of projected 2030 models, however, there are more diverse developments in aircraft configurations. There are many new proposed configurations in addition to fixed and rotary-wing configurations, such as multi-copters and V/STOL aircraft; this reflects much of the current discussion about new vehicles being proposed or under development.
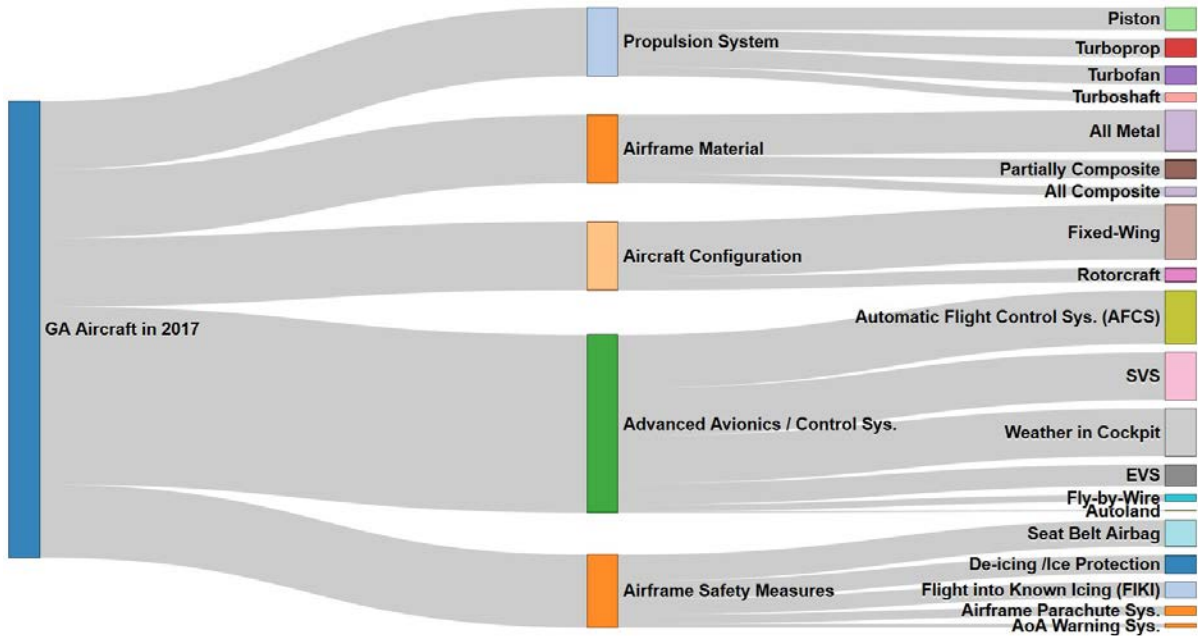
Figure 8. Sankey diagram of aircraft technology portfolio for new aircraft models in 2017
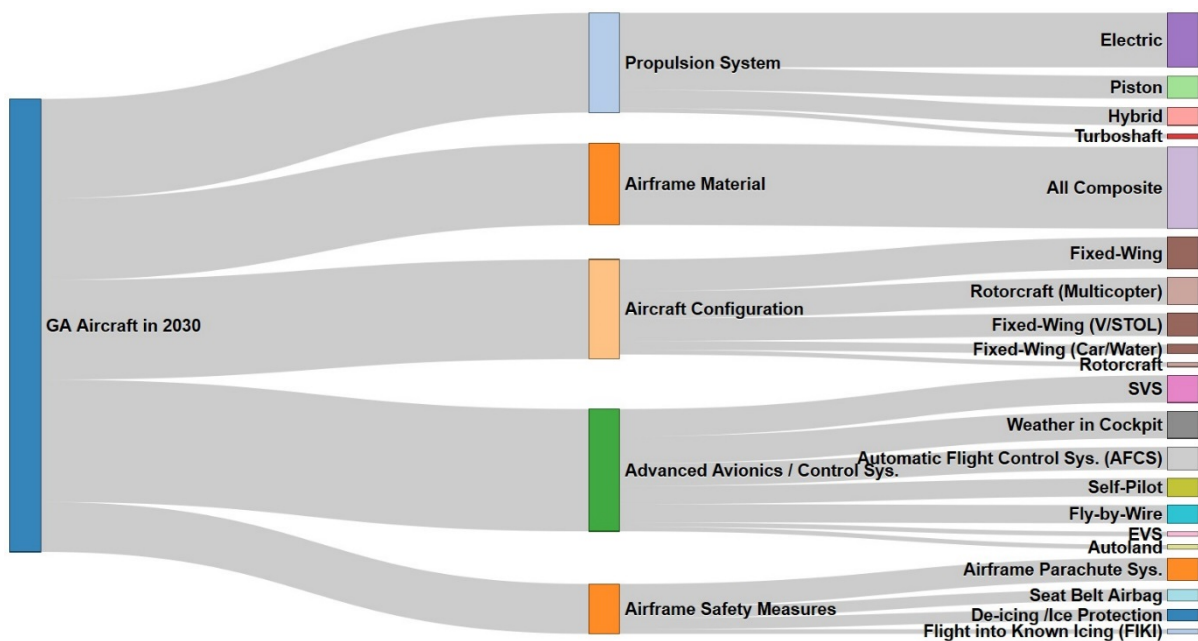
Figure 9. Sankey diagram of aircraft technology portfolio for expected aircraft models in 2030

Propulsion, electric, or hybrid electric-enabled GA aircraft is a future trend beyond 2030. Almost every newly proposed (or under development) aircraft is made from composite materials, such as fiberglass or carbon-fiber composites. As for airframe safety measures, parachute systems and seatbelt airbags are currently implemented and proposed in several future GA aircraft. Finally,

technologies such as self-pilot (i.e., autonomous flight with passengers aboard), fly-by-wire, and auto landing/takeoff are also expected to be used extensively on future GA aircraft.

The aircraft technology portfolio analysis helps to create a series of technology portfolio tables for the current and the future aircraft models. The technology portfolio tables list the specific technology breakdown of current and proposed aircraft models. The Sankey diagrams show the ratios and linkages between surveyed aviation technologies. All these methods provide additional ways to assess the trends and correlations between aviation technologies and GA aircraft models.

2.4.4 Technology Portfolio Analysis Conclusion

Finally, with the aid of the Sankey diagrams, the percentages for technology subareas in 2017 and 2030 are listed in table 4.

Table 4. Percentages of the subareas in both Sankey diagrams

Subarea of Aircraft Technology	% in 2017	% in 2030
Advanced Avionics/Control Systems	39	27
New Airframe Configuration	15	22
New Airframe Material	15	18
Airframe Safety Measurements	16	11
New Propulsion System	15	22

Some comparisons and takeaways are listed in the following bullet points:

- Advanced Avionics/Control Systems: Reduced from 39% to 27%; despite its importance in the future, the ratio reduction is caused by the increase of ratios in other subareas (airframe configuration, airframe material, and propulsion system). Technologies such as self-pilot, fly-by-wire, and auto landing/takeoff are expected to be widely used for future GA aircraft.
- New Airframe Configuration: Increased from 15% to 22%; new drivers in aircraft design, such as VTOL and multi-copter, could be the potential options for future GA airframe configuration, largely driven by the interest in urban air mobility concepts.
- New Airframe Material: Increased from 15% to 18%; almost all newly proposed aircraft or those still under development are at least partially made of composite materials, fiberglass, or carbon fiber.
- Airframe Safety Measures: Changed from 16% to 11%; airframe parachute systems and seatbelt airbags are currently implemented and proposed for several future GA aircraft.
- New Propulsion System: Changed from 15% to 22%; other than traditional turbine or piston-based engines, electric and hybrid propulsion architectures have the potential to be major game changers for future GA aircraft.

In conclusion, the propulsion system, the airframe material, and the airframe configuration are the subareas that emerge with a higher implementation ratio for future aircraft. This may be an

indication that these key technology areas could influence and drive the research and development work of GA aircraft during the next 10–20 years.

2.5 CERTIFICATION

The new 14 CFR 23 has been in use since August 2017. It removes prescriptive design requirements and replaces them with performance-based airworthiness standards [16]. For the industry and GA community, the rewrite is a big step toward better certification techniques. The new rule is expected to enable the industry to introduce new technology into the GA market at a faster rate than possible under the previous 14 CFR 23. The FAA has introduced a risk-based parts manufacturer approval program, which will enable newer and more cost-effective solutions to be introduced into GA [17]. As discussed in the previous section, GA in the future will consist of an even more diverse set of aircraft types with different operational characteristics, all operating in a complex airspace. Techniques have been developed for UAS certification that will likely be applicable to future GA. System-level tools and argument-based airworthiness assurance have been developed and presented in open literature; these showcase methodology in the certification of UAS based on how they are operated [18–19]. NASA has developed the Aviation System Risk Model, which is a risk-based decision-support system prototype designed to evaluate the impact of new safety technologies/intervention for commercial aviation [20]. Similar, system-level, risk-based tools can be used for certifying new GA aircraft with different operational capabilities.

Automation will play a key role in the future of GA. Software to enable the automation of pilot tasks and provide vehicle autonomy has to demonstrate higher levels of safety and reliability in addition to simplifying vehicle operations. For the near term, risk-based alternatives to DO-178 have been proposed [21]. Run-time assurance techniques have widely been proposed to increase the level of safety in GA aircraft through the use of autopilot and other automation technologies [22–24]. 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 [25]. The level of computational power currently available enables the use of new machine-learning techniques in developing safer GA autopilots and providing more data in proving aircraft assurance levels in critical failure modes, such as icing conditions [26–27]. A summary of the certification techniques and its applicability is shown in Figure 10.

Technique		Applicability/ State of Usage	Since
Certification by Analysis	Conventional FEM method	AC No: 20-146. Followed largely in cabin crashworthiness certification.[AC19]	2003
	Argument-goal based	NASA has been developing argument-based airworthiness strategy for UAS.[AC21]	2015
	Reduced-order modeling (Adaptive)	Academia research on aero icing analysis. The above Advisory Circular should cover this. Need to understand if companies are using this form of technology in modeling.[AC18]	2012
	Model checking and simulation	Autonomous UAS operation certification.[AC23]	2012
	Zone-based damage tolerance framework	This methodology is proposed by FAA. FAA also working with industry in developing other strategies with respect to AM.[AC17]	2016
Risk-Based Strategy		FAA's 2016 Philosophy on Compliance talks of risk-based decision making. Part 23 rewrite is also based on risk-based decision making. Research present on using this method to simplify software certification for GA.[AC20][AC26]	2016
System-Level Airworthiness Tool		Tool developed by NCSU to provide a comprehensive approach to sUAS airworthiness.[AC 22]	2010
Run-Time Assurance		The Air Force Research Laboratory proposed this methodology for safety-critical flight control systems.[AC24] Air Force Research Lab, Uni Tulsa, NASA and FAA collaborated in developing certification strategies for Part 23 autopilot using RTA.[AC24]	2016
		NASA also worked on using run-time assurance of advanced propulsion algorithm.[AC25]	2014
Advanced In-Flight Measurement Techniques (AIM^2)		Developed in collaboration of DLR, Goettingen and Cranfield, UK. Optical methods for in-flight flow and structural measurements. Optical measurement techniques can minimize the installation effort and reduce the testing time because they are able to capture a large number of parameters within a short time.[AC27]	2013-2017
Dependable Use of 'Software of Unknown Pedigree' (SOUP)		Establishing an accepted framework for dependable use of SOUP in aviation offers the promise of reducing cost and expediting airworthiness and operational approvals. MITRE working on case studies for sUAS.[AC28]	2015

Figure 10. Certification technologies

Additive manufacturing is currently used in creating small, noncritical aircraft components. The use of additive manufacturing in GA aircraft is expected to grow rapidly in the future. The FAA has created a road map that addresses airworthiness challenges and concerns with additive manufacturing [28]. A methodology for assessing structural integrity of additive manufacturing has also been studied by the FAA [29].

The certification process and required compliance tests are major contributors to the R&D costs of a new vehicle. The high cost of certification is tied to the time required in proving airworthiness through multiple flight tests. Optical methods have been proposed to reduce the time of flight tests of new aircraft and equipment [30].

Key to the efficiencies promised in the 14 CFR 23 rewrite is the use of existing industry standards to establish levels of safety and airworthiness. Research is needed to be sure that these are incorporated into the certification process quickly and are able to capture the levels of safety intended in these standards. Overall, certification plays a key role in the success of GA in the future. The above are examples of ongoing efforts to help demonstrate the level of required aircraft performance, system level airworthiness and risk based assessment, and show the path toward the future certification of new technologies.

2.6 OVERSEAS DEVELOPMENT

The benchmarking efforts were broadened to include the international arena, with priorities on current GA status and future trends in Europe, Australia, Brazil, Japan, and China. Generally, there are a few practical indicators of GA development in a country, including number of GA aircraft, number of GA airports, number of GA operating hours, and number of GA related companies. However, because of the difficulty of collecting data for all the indicators mentioned above, only the number of GA aircraft in different countries during the past 20 years is used to quantitatively compare status in different countries. Using data from GAMA [3] and the International Council of Aircraft Owner and Pilot Associations (IAOPA), figure 11 shows the change in number of GA aircraft in different countries from 1996 to 2016. Other indicators, such as the number of GA airports, number of GA operating hours, and recent policy changes, will be included in the analyses of individual countries.

Figure 11 shows that some countries, including China, Australia, Brazil, and South Africa, have an increasing number of GA aircraft during the past 10 or 20 years. For other countries, such as Germany, Switzerland, the United Kingdom, and Japan, either the number of GA aircraft has remained at approximately the same level or the authors do not have adequate information to comment on the trend. Following are the analyses of individual countries regarding their current GA status and future trends:

- China: As of June 2017, China has 2776 GA aircraft (1808 fixed-wing aircraft, 903 rotorcraft, and 65 airships and balloons), 22 flight academies, 311 GA airports, 2524 GA pilots, 380 GA operators, and 765,000 GA operating hours/year. Since 2010, the number of GA aircraft in China has an average annual growth rate of approximately 15%. In recent years, the role of the GA industry has gradually been recognized by the Chinese government. As a result, relevant policies have been introduced to simplify the approval procedures, deregulate, and improve GA infrastructure [31]. In addition, a guideline published by China's General Office of the State Council stated the development objectives for 2020: more than 500 GA airports, more than 5000 GA aircraft, and more than 2,000,000 GA operating hours. Overall, it can be predicted that GA development in China will be on the rise before 2030. Limiting factors in developing GA in China include market, infrastructure, pilot shortage, and policy.
- Europe: According to GAMA, the current European GA fleet has more than 140,000 aircraft and can access more than 4200 airports [3]. Currently available data are inadequate for a thorough economic analysis for GA in Europe, yet many indicators suggest that GA activities play a significant role for the economy of EU countries [32]. GA is currently a high priority for the European Aviation Safety Agency (EASA), and in 2017, EASA updated their GA roadmap toward simpler, lighter, and better regulations for GA in Europe.

Their latest actions include the new Part-DTO that alleviates the GA training domain, easier access to instrument flight rules (IFR) flight, reorganization of CS-23, and simpler rules for aircraft maintenance. [33] Additionally, new technologies for future GA aircraft are extensively studied in Europe to keep pace with the evolving GA industry in the EU. There are three main bottlenecks in developing GA in Europe: regulation, taxation, and access to services [32].

- Australia: The latest statistical report from the Australian government's Department of Infrastructure and Regional Development shows that, as of 2015, Australia has 8976 GA aircraft and 1,544,400 GA and sports aviation operating hours/year [34]. GA in Australia consists of five sectors: aerial work (40.1%), instructional flying (27.8%), sport and pleasure flying (18.2%), own-use business (12.7%), and other (1.2%). Whereas commercial air transport hours in Australia increased by 4.8% in 2015, GA hours flown by VH- (International Civil Aviation Organization Aircraft Registration Prefix for Australia) registered aircraft decreased by 2.6%. It is worth mentioning that of the hours flown in Australian aircraft activity in 2015 (3,432,100), 45.0% were GA and sports aviation hours, indicating that GA takes up a significant portion of Australia's aviation activities.

- Japan: Information on GA in Japan is limited in general. According to data provided by the Aircraft Owners and Pilots Association Japan official website, back in 1968, there were more than 1000 GA aircraft in Japan. The number of GA aircraft in Japan decreased to less than 700 at the beginning of the 21st century, resulting in a 40% reduction in 40 years. Despite these declines, the number of GA pilots in Japan has been slightly increasing year by year. GA data for 2012 show that Japan currently has fewer than 600 GA aircraft and approximately 30,000 GA pilots. Limitations for further developing GA in Japan include aircraft shortage, regulation, and accessibility [35].

- Brazil: According to the Brazilian National Civil Aviation Agency, Brazil had 15,342 GA/business aircraft and 5,867 experimental aircraft in 2017. The 2014 Brazilian Yearbook of General Aviation by the Brazilian Association for General Aviation shows that since 2007, the GA fleet in Brazil has increased with an annual rate of at least 3.2% [36]. During the past 15 years, there has been an increase in the GA fleet from approximately 10,000 aircraft to 15,342 aircraft [37]. Challenges for developing GA in Brazil include infrastructure, competition with scheduled commercial aviation, development of skilled labor force, and regulations [38].
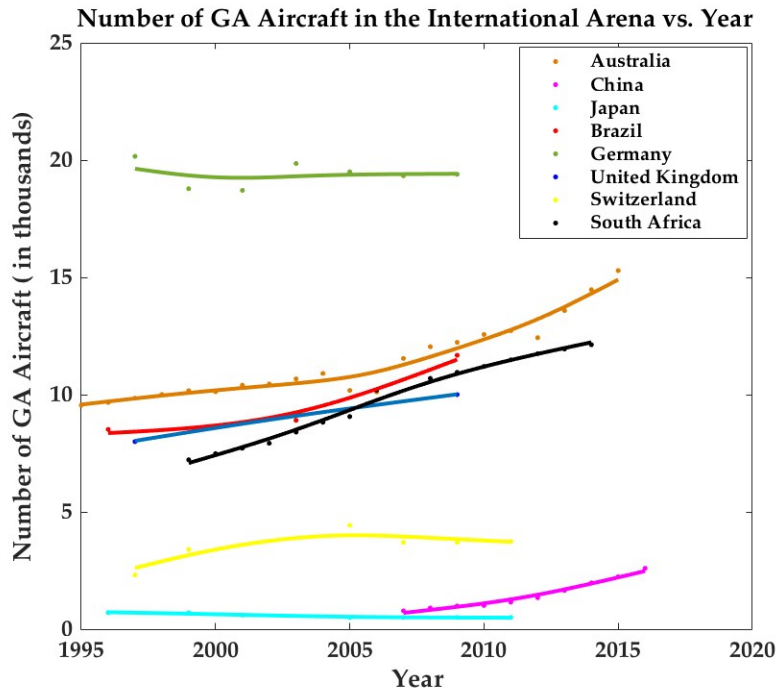
Figure 11. Number of GA aircraft in different countries versus year (sources: GAMA [3], IAOPA GA Statistics)

3. WORKSHOP 1

The 2017 industry-centric workshop was held at the Georgia Institute of Technology in Atlanta, GA on June 20–21, 2017. Thirteen high-level experts in the GA community participated in this workshop, supported by faculty and students from Georgia Tech and Purdue University. Participants of this workshop came from a variety of industries, including airframe, engine, simulator, operator, airport, and individual consultants. The intent of having this workshop with participants predominantly from the GA industry was to allow for open discussion and mitigate concerns about how comments might be perceived by the participants from government organizations. The workshop lasted for 1.5 days, during which time several planned sections were executed, including assessments of current state, brainstorming of GA in the next 15–20 years, and in-depth discussion topics. During the workshop, participants were led through a series of discussions by the project lead from Georgia Tech and the project lead from Purdue. As participants provided their thoughts and insights, a number of scribes (graduate students and research staff from Georgia Tech and Purdue) captured the discussion in real-time. This included projecting a "master set" of notes so that participants could see what was being recorded. Essential outcomes of the workshop are organized and presented in the following sections.

3.1 OBSERVATIONS, FUTURE FACTS, AND RESEARCH NEEDS IDENTIFIED

The main outcomes of the 2017 industry-centric workshop are organized below into seven themes: Pilot Training and Proficiency; Autonomy and Automation; Airport and Infrastructure; GA in the Future Airspace; Airframes, Legacy Fleet, and Maintenance; Future Propulsion Systems, and Passenger Safety. Under each theme, valuable information was extracted and sorted into two

categories: Observations and Future Facts, and Research Needs. As the workshop participants discussed future scenarios of what GA might entail around the year 2030, they began to make statements about what this future might entail in each of the identified themes. Whereas stated as facts, given their interpretation of what the future state of GA might be, this report will refer to these as "Observations and Future Facts." The following sections describe these themes in a numbered list format to keep the presentation of the ideas as close as possible to how the workshop participants presented their thoughts.

3.1.1 Theme 1: Pilot Training and Proficiency

Observations and Future Facts:

1. Pilot shortage will persist into 2030; difficult to attract new pilots to fly GA.
2. GA aircraft still require pilots unless full automation is available.
3. Pilot training currently requires too much time and money.
4. Current pilot training has not kept up with simulator technology.
5. GA is still viewed as entry point for commercial aviation.
6. Trust in autonomy or automatic technologies needs to grow.

Research Needs:

1. How to make learning to fly easier, cheaper, and more streamlined? Can introduce more high-fidelity flight simulators for training in the future, but retain basic flying skills. Need to investigate redundancies in existing private pilot training requirements. The target should be $1500 and within 20 hours for instrument-rated private pilot license.
2. Research on the current simulator technologies and what is its roadmap in the next 20 years?
3. Market analysis of the new-age pilots and their motivations, to improve the curriculum to better suit them.
4. How to encourage the use of technologies to reduce pilot's workload? Think of what can be added to the aircraft and brought on board (e.g., a tablet or smartphone).
5. Roadmap from simplified operations for current pilot to no pilot (fully autonomous) is to be identified.
6. Substantially streamlined and simplified visual flight rules (VFR) and IFR training curriculum.
7. Need to raise the accessibility to quality GA training (geographically).
8. Need more cockpit/interface designs to prevent information overload.

3.1.2 Theme 2: Autonomy and Automation

Observations and Future Facts:

1. Automation can improve current product and possibly increase market share.
2. Investment is restricted because of small market and low return on investment.
3. Accessibility of GA pilots to automated tools may be limited by cost, but technology flowing down from commercial aviation and up from UAS can help reduce the cost of automation.
4. Tasks that can be automated:

- Avoidance (traffic collision, terrain, high-density airspace)
- Air traffic control (ATC) communication
- Weather (adjust course automatically)
- Critical air vehicle

5. Autonomy can make flying and, therefore, training easier.
6. Future ImagineAir or Uber-type on-demand models will use aircraft with driver/operator instead of pilot.

Research Needs:

1. Certification of automation software for smaller GA aircraft (potentially come from Unmanned aerial vehicle (UAV) or commercial aircraft side).
2. Research on what autonomy technologies are viable for small GA.
3. Research on what sensors are required onboard the aircraft for autonomy.
4. Roadmap from simplified operations for current pilot to no pilot (fully autonomous).
5. Possibly need new certificate for autonomous operations.
6. Focus on progression of software aimed at decision-support/decision-authority.
7. Need to think of what tasks can be automated.
8. Infrastructural changes are required for more autonomous vehicles (markings, lights).

3.1.3 Theme 3: Airport and Infrastructure

Observations and Future Facts:

1. Some airports already have large traffic volumes, but others are nowhere close to the capacity they can fulfill.
2. Runway incursion issues (e.g., towered and non-towered airports).
3. Issues on oversight and ownership of runways and airports (large roads, grass fields).
4. Infrastructure issues (e.g., pavement, terminals).
5. Need more supporting infrastructure for future GA with new energy (e.g., charging stations, local electric grid).

Research Needs:

1. Suitable landing sites/emergency sites, especially for intra-urban air taxi.
2. Research on the drone ports integration into current airport infrastructure.
3. Integrating UAS near airports.
4. Better noise management around airports.
5. Infrastructural changes required for more autonomous vehicles (markings, lights) and new energy aircraft.
6. Need infrastructures required to control and manage large number of UAS and different configurations of GA aircraft.
7. Difference in infrastructure among owned airports to be investigated.
8. Determine how airports, aircraft rescue, and firefighting personnel will deal with hazardous composite airplane structures after a crash.

3.1.4 Theme 4: GA in the Future Airspace

Observations and Future Facts:

1. With growing UAS and future urban VTOL air taxi, the voice and transponder bandwidths will get overloaded. Airspace management would soon need to be automated.
2. Higher volume of vehicles in airspace.
3. Configuration of airspace today is primarily driven by commercial airlines.
4. There will be interaction with UAS and automated cargo operations or package delivery operations.
5. There is the potential for dedicated airways for UAVs or (fully) autonomous aircraft.
6. ADS-B mandate requirement exists in only certain areas and some, but not all, aircraft.
7. Current GA will be heavily influenced by Uber Elevate-type concepts in the future

Research Needs:

1. How is the airspace shared between commercial, GA, and UAS?
2. Research on the expandability of ADS-B (UAS).
3. Interaction of UAS with structures and obstacles. Intra-city operations (e.g., would 500 ft clearance be applicable in urban areas for UAS?).
4. Need more GA airplanes equipped with ADS-B.
5. Cyber security for autonomously controlled vehicles and airspace.
6. Study on artificial intelligence acting as a service provider for airspace management.
7. Evolution of airspace restrictions.
8. Simulations of high-density airspace with various aircraft types and modes of operation.

3.1.5 Theme 5: Airframes, Legacy Fleet, and Maintenance

Observations and Future Facts:

1. Sustainability of legacy GA will be required.
2. Renovating an old aircraft with completely new equipment is also very costly.
3. In attracting new customers and introducing new aircraft, it is also important to make sure that older aircraft can be safely operated in the same airspace.
4. The expectations would be that GA aircraft operate with the same reliability as a car.
5. Current engines are from the 1930s era without major upgrade to the basic technology. Hesitation to develop a completely new engine specifically for GA, in part because of small market.
6. New aircraft technologies out there: propulsion technologies, advanced control systems, new materials and airframes, human-machine interface, additive manufacturing.
7. Testing different fuels (e.g., unleaded) on existing platforms is underway.

Research Needs:

1. Incorporating new technologies into legacy fleet to increase capability, improve life cycle, and drive down cost.
2. Need better aerodynamic and aircraft design strategies to make aircraft safer.

3.   Research how advanced airframes will be inspected to ensure their continued airworthiness.
4.   Determine the level of approval/acceptance that the FAA will provide while conducting its oversight of the new 3D manufacturing process.
5.   Comprehensive training on the use of 3D printing machines needs to be addressed together with quality control methods when assessing components manufactured by that process.
6.   Continue to study 14 CFR 23 and 25 to determine what crossover requirements for composite structures/parts can be applied to the GA side of aviation safety.
7.   What are the implications for anti-icing or de-icing mechanisms, particularly heating elements, on composite structures?
8.   Determine if repair station ratings need to be modified to address new technologies, sensors, and/or new ways of maintaining aircraft.
9.   Will structural health monitoring and the programs that rely on this new technology be accepted in the future or approved as part of a maintenance program?

3.1.6 Theme 6: Future Propulsion Systems

Observations and Future Facts:

1.   Reluctance to develop a completely new engine specifically for GA (current engines are based on designs from 1930s era).
2.   Some statements in 14 CFR 33 (water containers) do not directly apply to GA engines.
3.   Diesel engine, electric, and gas all have their pros and cons. Each requires specific type of airframe design. Solutions can be engineered, but large investment costs are major barriers to industry R&D.
4.   Noise is a big factor for electric aircraft.

Research Needs:

1.   Research on very small turbine engine.
2.   Regulate power availability and battery state-of-charge for electric or hybrid-electric aircraft.
3.   Availability of new energy sources such as fuel cells; greener fuels.
4.   High power-to-weight electric motor.
5.   Take advantage of research performed in UAVs, automobiles, power-generation industry, and COTS technologies.
6.   Improve battery and energy storage technologies.
7.   Power plant improvements cover the whole product cycle from the manufacture of engines and batteries to all the infrastructure and materials needed for the installation and final removal of these hybrid power plants. Consider the impact of this new technology on current regulations and procedures in developing inspection and maintenance programs for engines.

3.1.7 Theme 7: Passenger Safety

Observations and Future Facts:

1.   For autonomously controlled vehicle and airspace management, cyber security and protection are important to future autonomous GA.
2.   Aerodynamic and aircraft design strategies to be used to make aircraft safer.
3.   There are still some safety improvements to be made.

Research Needs:

1.   What would define a crash in the future?
2.   Would it just be deployment of airbags and/or ballistic parachutes?
3.   What other safety measures are possible?
4.   Consider the interaction with other modes of transportation.

4. SIMILARITIES AND DIFFERENCES BETWEEN WORKSHOPS 0 AND 1

An academic-centric workshop was held in May 2016 prior to the start of Project 25, which will be called "Workshop 0." Workshop 0 helped seed the benchmarking task performed under Project 25. As part of Project 25, the industry-centric workshop (Workshop 1) took place in June 2017. Both workshops 0 and 1 had similar central themes, structure, and scenarios. The participants of both workshops answered similar questions, ranging from the current state of GA and future possibilities to in-depth analyses of factors that can influence GA in the future. Differences emerged in the responses from participants of the two workshops. These arose because of various factors, the first and most obvious being the background of the participants: Workshop 0 was comprised of participants working in academia and researching technology that could impact GA, whereas Workshop 1 was comprised of people from the industry (e.g., airframe manufacturers) who have a direct business interest in the GA market. Figure 12 shows the distribution of participants from workshops 0 and 1.
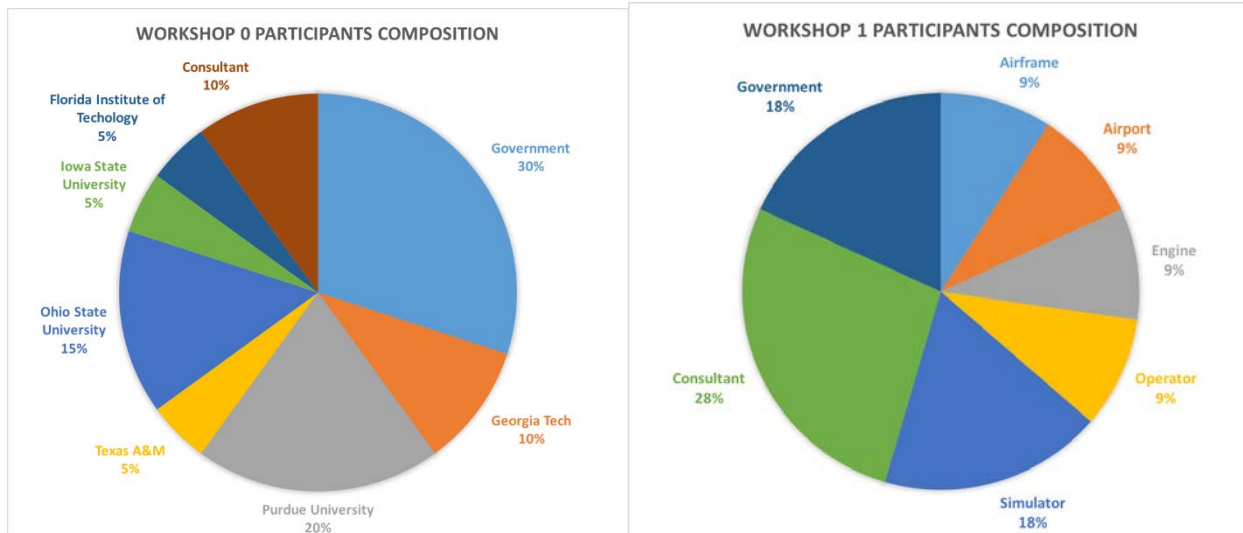
Figure 12. Participant demographics for workshops 0 and 1

Several significant events that occurred in the time interval should be noted between workshops that might have impacted the workshop discussions. Between the first two workshops, the FAA's new14 CFR 23 rule was introduced; the Uber Elevate summit was held; and ATC privatization was proposed in the U.S. Congress.

In spite of the differences, many similar themes emerged from the two workshops. The results of Workshop 0 and the benchmarking task were not presented to the participants of Workshop 1. However, some items prioritized in Workshop 0 were also prioritized during Workshop 1.

4.1 HIGH-LEVEL OVERVIEW

A major difference between the first two workshops is that Workshop 1 contained an additional question during the in-depth analysis of topics: "How should the work to satisfy these needs be conducted?" This made Workshop 1 more result-oriented than Workshop 0 and provided more insights into the research steps that would have to be taken to satisfy the needs. Workshop 0 was a preliminary workshop, which helped seed the research and the directions to follow, so that workshop was focused on raising the correct questions regarding GA. During Workshop 1, the format was slightly modified for participants to raise questions and provide their input on possible methods to find the solution to those questions.

The team performed a word search of some selected critical words, which imply a specific item or technology for GA 2030 and were decided on from both the workshops and the benchmarking tasks. Each word is of equal importance, and the number of occurrences does not signify a greater importance. Figure 13 shows the word density from both Workshop 0 and Workshop 1. This exercise was performed to throw a "safety net" on the details of the workshop information collected to look for minute details that may have been missed while looking at the bigger picture. This search also provides insight into what the attendees in both workshops considered a priority when discussing GA 2030.
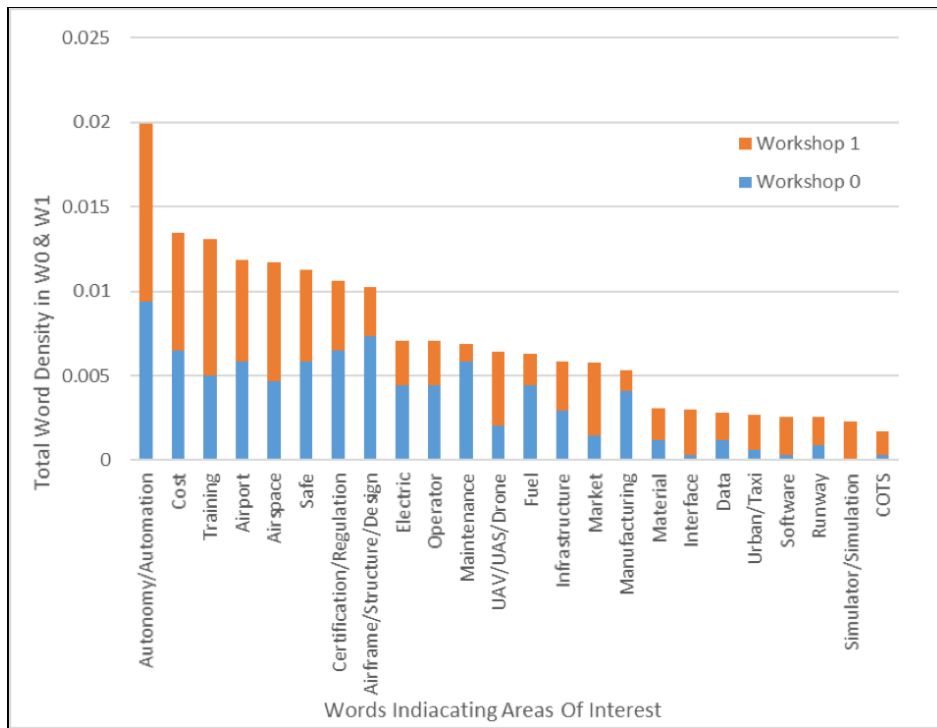
Figure 13. Word density from workshops 0 and 1

The search was performed on the entire document for words expressing a closely related subject. For example, the words "autonomous" and "automation" counted as a single category. Workshop 1, because of the additional question during the in-depth analysis, resulted in a set of recorded notes that is also larger in content. The number of instances of the words were, therefore, divided by the words in the given workshop report to normalize the value and provide a word density.

The word counts from the two workshops were also compared. The difference in word density between Workshop 0 and Workshop 1 is shown in figure 14. Words discussed more often in Workshop 1 can be found in the left (yellow) part of the graph; words that were discussed to approximately the same extent in both workshops can be found in the center (green) part; and words discussed more often in Workshop 0 are in the right (blue) part. This graph gives the team insight into topics prioritized by the workshop participants. Studying figure 14 and figure 12 together allowed the team to determine if all items were sufficiently discussed and if additional stakeholder input is required for in-depth analysis into some known topics or to find additional items that are critical to GA in 2030.
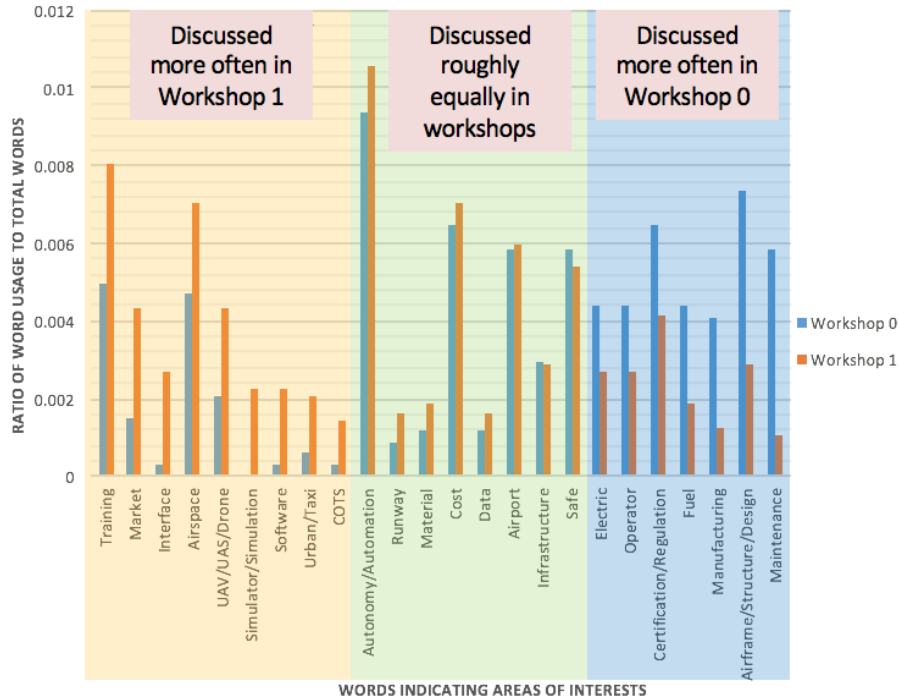
Figure 14. Word density comparison

The graph above is a clear indication that the participants of Workshop 1 prioritized the following items:

- Training
- Market
- Interface
- Airspace
- UAS/UAV/Drone
- Simulator/Simulation
- Software
- Urban/Taxi
- COTS

Participants of Workshop 0 appear to have given a higher preference to the following items (words) more than that of Workshop 1 participants:

- Maintenance
- Airframe/Structure/Design
- Manufacturing
- Fuel
- Certification/Regulation
- Operator
- Electric

Topics that appear to be of roughly equal importance to participants of both workshops are:

- Infrastructure
- Airport
- Data
- Cost
- Material
- Runway
- Autonomous vehicle and Automation
- Cost
- Safety

However, GA is a broad and complex industry. A basic word search is insufficient in understanding the nuances of the ideas expressed by the participants in the two workshops. Words may have been used in different contexts to express different points concerning similar topics. Therefore, an in-depth analysis was performed and discussed, as seen in section 4.2.

4.2 IN-DEPTH COMPARISON

4.2.1 Similarities

The biggest discussion in both workshops in terms of prioritization by participants and also from the word search was "autonomy." The word search shows that Workshop 1 had a slightly higher mention on autonomy, but both workshops focused on the role of autonomous vehicles, the process of automation, various levels of capability, and market impact.

Cost was another important item on which participants from both workshops were in agreement. Participants from both workshops emphasized the need to reduce cost because of the complex certification process, maintenance, and investments to bring in new technologies. Cost was also discussed in terms of retrofitting older aircraft with newer technologies compared to building a completely new aircraft. Workshop 1 participants also identified the high cost of training as a deterrent to newer pilots. Future infrastructure and airports were discussed almost at a similar level of importance in both workshops. Workshop 1 included a specific discussion of infrastructure and airports, but the word search indicates that infrastructure and airports were of high interest to the participants from both workshops.

Analysis of workshop notes shows that even though infrastructure did not necessarily have an in-depth analysis of its own, it was a key occurrence in all the prioritized items.

Safety of operations was deemed important by participants of both workshops. No in-depth analysis was performed in either workshop on this topic. Participants from both workshops assumed that safety is a given and must be met and, therefore, other aspects can be looked into that may enhance safety. The requirement for safe operations was identified, but the process of achieving that goal in the future was not explicitly discussed. It is also important to note that even though certification was discussed more often in one workshop than the other, no prioritization was made in either workshop. Safety and certification were deemed closely related and considered

extremely important, but no actionable or future state discussion emerged from these two workshops.

Other items discussed with equivalent intensity in both workshops were that of data, materials, and runways. Data can help in quicker certification and also improve pilot situational awareness. Participants from both workshops pointed to runway incursions being a pressing problem and, with growing traffic, a potentially larger problem in the future. Workshop 1 had a slightly higher mention of runways, as the existence of road infrastructure was discussed as potential alternate runways in the future.

The possibility of communication bandwidth saturation was discussed in both workshops. The need to transfer communication from voice-based to a faster text-based or automated form of communications was also proposed in both workshops.

4.2.2 Differences

In addition to the added questions in Workshop 1, major differences exist in the results from the two workshops. The primary difference was with regard to the items prioritized by the participants to perform an in-depth analysis.

Workshop 1 participants spent significant time discussing the theme of training more than the other themes. Pilot shortage is a current problem, and this shortage was perceived to increase in the near future. The participants aimed at addressing this problem by targeting the training requirements for the future. With new technologies, the training required to reach adequate proficiency for flying future aircraft will increase. A larger pilot base will lead to a larger customer base and thereby increase the reach of GA communities. The word search also shows that participants in Workshop 1 mentioned training more often than participants in Workshop 0. The word "training" was primarily used by participants of Workshop 0 to indicate maintenance training for new types of aircraft, and less about piloting or operating the aircraft.

Workshop 1 participants, because of their affiliations, demonstrated a keen interest in the growth of technologies in the simulator segment. Their opinion was that a high-fidelity simulator would help in aiding pilot training in the future, reducing the flight time needed to become proficient and maintain proficiency in flying (piloting or operating) an aircraft. Workshop 0 participants did not investigate this aspect of GA.

Airspace was prioritized by participants from both workshops. However, the references to airspace and its management occurred to a larger extent in Workshop 0. In the backdrop of the Uber Elevate summit, the Workshop 1 participants foresaw a larger possibility of urban air mobility and the need to be prepared for such changes.

Another key question raised by Workshop 1 participants was whether the urban air taxi/mobility would be a subpart of commercial aviation or GA. Yet, like Workshop 0 participants, they believed that personal air vehicles would surely become part of GA in the future. The impact of urban taxi/personal vehicles on the airspace was recognized by all. However, it was mentioned to a larger extent in Workshop 1, and the group prioritized and performed in-depth discussion on the concept of "simplified vehicles" that would be a direct enabler to the future personal or air taxi vehicles.

Workshop 1 participants expressed the opinion that to enable the simplified vehicle in the future, in-service or fairly mature technologies would have to be leveraged from the UAS/drone domains. UAS and drones were not specifically prioritized, but they were of a very high interest to the participants of Workshop 1. UAS and drones also came up in other contexts such as airspace management and infrastructure of future airports. The word search and analysis show that Workshop 1 participants felt that software, its interfaces, and the leveraging capability from the drone technologies present today are key for autonomous GA vehicles in the future. Workshop 0 participants mentioned drones in the context of their growing numbers and crowded airspace. They also brought up the safety question of a GA aircraft's capabilities of handling drone strikes, similar to that of aircraft dealing with bird strikes today.

Workshop 1, being industry-focused, raised the question of addressing market needs. It was evident from the discussions that in GA, market needs do drive the technologies being used. That is why many of the participants in this workshop repeatedly coupled the technology discussion with that of the GA market. In the opinion of the participants of Workshop 1, legacy aircraft will still play a big role in the 2030 time frame. Because of a small market segment, investment by GA companies into revolutionary airframes or engines will be low. Prototypes do exist, but creating a push for market acceptance is a large investment cost with very low surety of return on that investment.

Certification was not prioritized in either of the workshops. It was mentioned to a higher extent in Workshop 0 than in Workshop 1. Workshop 1 participants showed enthusiasm regarding the new modifications to 14 CFR 23 and wanted to work toward such methods of certification. It was discussed initially, and it appeared that the participants were focused on how to achieve these new standards for the remaining of the workshop rather than conducting research directly in support of the new 14 CFR 23. With market constraints and the new 14 CFR 23, Workshop 1 participants emphasized the need for COTS equipment. COTS was seen to be a possible solution with regard to cost, acceptance, better performance, and quick certification. COTS parts, specifically from the automobile industry, can be used for the new generation of engines, which may be partially electric powered.

From the word search, airports and infrastructure appear to be of equal importance in both workshops. In Workshop 0, infrastructure or airports were not discussed exclusively, but questions regarding infrastructure were raised in most of the prioritized topics. In Workshop 1, participants specifically discussed airports, the possibility of drone ports, remote controlled airports, and other possibilities for increasing the number of landing locations.

Workshop 0 participants identified electric (hybrid, complete) propulsion to be a key enabler in the future. Workshop 1 participants felt that electric propulsion is bound to happen and requires a dedicated workshop. In this regard, the Workshop 1 participants spent much less time discussing electric propulsion, but sent the message that it was an important topic. Workshop 1 participants pointed out that commercial aviation companies have invested in that technology, and prototypes are currently being tested and will soon be on the market.

It was also the opinion of the Workshop 1 participants that the discussion of future airframes and designs can only occur with the discussion of future propulsion systems; participants generally viewed a move toward electric propulsion as both important and inevitable. The inevitability led

the team to not spend much time developing this theme during Workshop 1. As a result, future airframes and designs were deemed important but not prioritized during this workshop. Workshop 0 participants prioritized both the future propulsion techniques and the possible future airframe structures and designs. The word search also points to Workshop 0 participants' interest in aircraft design and structure.

Workshop 0 participants also prioritized the maintenance aspect of future GA. This topic or theme received the greatest amount of attention during Workshop 0, and the participants conducted an in-depth discussion of maintenance. However, Workshop 1 participants also identified maintenance as being an important aspect.

Fuel and alternative energy sources for GA were discussed to a larger extent in Workshop 0 (e.g., possible future fuel scenarios, fuel efficiency through better-designed airspace, regulatory framework required for alternative fuels). Workshop 1 participants raised research questions about what would be the transition roadmap from current fuels to green fuels and, finally, electric propulsion. Workshop 1 participants did mention that the research for alternative diesel engine fuels is small because of the small market size for the diesel engines.

Workshop 0 participants strongly felt that new techniques and technologies in the manufacturing sector will be a strong driver for GA in 2030. Advanced manufacturing was prioritized during Workshop 0, and the word search indicated a higher level of interest from participants. Workshop 1 participants, however, felt that advanced manufacturing is important for GA to take advantage of but will not initiate market changes in the near future.

With respect to next-generation flying, the word search shows that "operator" was used more often by the Workshop 0 participants. An in-depth look into the notes shows that even though "operator" needs were not specifically prioritized, they were of high interest to the participants from this workshop. Workshop 1 participants were focused on the transition from a conventional pilot to an operator and the necessary training that would be required.

5. WORKSHOP 2

The second workshop was hosted at Purdue University on November 1–2, 2017. The majority of the participants were from government agencies, with a few participants from the GA community and industry who could not attend the first workshop. The government representation included the FAA and the United States Air Force. Although representatives from NASA were unable to attend the workshop, input from participants familiar with ongoing NASA aeronautics research were available. Participants with expertise in the areas of airports/infrastructure, data/communication networks, and avionics were also present. The GA community was represented by participants from the GAMA and Experimental Aircraft Association. The workshop took place in 1.5 days, during which the participants reviewed a set of proposed future GA scenarios, research themes developed in earlier workshops, and developed new themes. There was an effort to prioritize these themes in the context of developing a research road map to address the future challenges for GA. Because of the different set of participants and the desire of the moderators to allow the participants to freely contribute their inputs, there were some differences in emphases. To maintain some consistency between the two workshops, a set of research assistants and research staff from Purdue and Georgia Tech acted as scribes to record the discussions. The project team then used these notes

to capture the Workshop 2 perspectives on research themes, using the same ideas of "Observations and Future Facts," and "Research Needs."

5.1 OBSERVATIONS, FUTURE FACTS, AND RESEARCH NEEDS IDENTIFIED

Workshop 2 participants reviewed the themes developed in the previous workshops and performed an in-depth analysis into the themes the participants considered important. An additional theme, Aircraft/Aviation Connectivity, was introduced during Workshop 2, which joins previously developed themes: Autonomy and Automation, Pilot Training and Proficiency, Airport and Infrastructure, GA in the Future Airspace, and Increased Crashworthiness and Survivability. After the conclusion of the workshop, the Project 25 team felt that this discussion was a slightly more focused version of the Passenger Safety theme identified during Workshop 1.

5.1.1 Theme 1: Pilot Training and Proficiency

Observations and Future Facts:

1. The demographic of potential users of GA aircraft is changing. There is a need to market and package aviation to new users to maintain a user base.
2. Shared ownership and travel in GA will be a reality in the future, requiring some sort of pilot/operator.
3. Pilot training and proficiency can only improve pilot ability for see-and-avoid to a certain extent; pilots/operators will need additional assistance in highly crowded airspace.
4. Prototype for robot pilot present today. A virtual/robotic co-pilot could make training and proficiency requirements for operating a future GA aircraft easier.
5. Simulation technology:

   - Different levels of simulation technology exist.
   - Use of high-fidelity, high-cost simulation is a barrier in GA today. Process of implementation is time consuming to effectively use this currently for training credit.
   - Full potential of simulator technology not in use; future should see pilots/operators exploiting simulation to gain or maintain proficiency.

Research Needs:

1. Remote trainer and remote monitoring with full situational awareness in addition to pilot (trainee) on board is a possibility.
2. Should the revisions to the Airman Certification Standards with regard to demonstrating stall recovery procedures necessitate changes to stall characteristics of new aircraft certified under 14 CFR 23? If so, of what nature?
3. How to enable automation of "sense and avoid" with the correct "override authority" control between human and machine?
4. An autonomous (robot) pilot may be "trained" as a human pilot. What can be automated using this concept? To what extent?
5. Concept of "in-flight simulator" using augmented learning. Some form of autopilot controls flight envelope until human proficiency is achieved:

- What is the technological feasibility of this idea? Can the simulator sense pilot proficiency and reduce augmentation?
- Will this lead to different levels of pilot certification based on the proficiency level obtained/demonstrated? A possible case is to certify pilots based on the functions in which full piloting capability has been reached. This could be considered certification of specific functions. Follow a competency training model. This is similar to type rating aircraft.

6. Collect data on current simulation implementation and impact on pilot proficiency and, in the future, collect data for every level of augmentation implemented in flight training to enable future technology development.
7. How to reduce cost of retrofitting autopilot (to include various advances in automation and/or autonomy) in aging fleet?
8. Type of aircraft maintenance certification required? UAS influence on new aircraft type to provide the need for skillset to maintain new autonomous aircraft and manned skillset required for legacy aircraft. Would future passenger GA aircraft fall in between?
9. Determine what airman certification standards/limitations would apply to an airman flying or maintaining a fully electric airplane (Note: the person certified to fly/operate may not be certified to maintain).

5.1.2 Theme 2: GA in the Future Airspace

Observations and Future Facts:

1. Current long-term view for UAV/UAS is that they are going to be handled like any other aircraft in the airspace. The FAA does not want to dedicate airspace, specifically to UAS.
2. Current airspace map was drawn based on the 1980s hub airports. Some Class B airports are currently less busy than some Class C airports.
3. On-Demand Mobility (ODM) will change traffic counts in certain areas (e.g., downtown). Everyone will have to be accommodated equally in restructuring.
4. Increased infrastructure will largely enhance accessibility of today's low-traffic airports.
5. The number of air vehicles will increase. Currently, two-way avoidance of aircraft. Visual avoidance will not work with large number of UAS—potential of too many small aircraft to identify.
6. Current ADS-B protocol does not include information about aircraft intent. Vehicle position can be deconflicted, but cannot currently deconflict intent.
7. There is currently low computing power onboard GA aircraft. Low-level flight management system-type equipment and current human-machine interface require lots of human involvement. Future GA will change this.
8. Any potential in uncontrolled airspace will have pushback from flying/pilot community.

Research Needs:

1. Determine whether there is a need to redefine the airspace in the future. Map large underused portions of the airspace.
2. Need for ubiquity in airspace services. Newer operations will open accessibility to areas that currently have low traffic. Need to identify such locations and upgrade infrastructure.

3.   Need to incorporate 4G LTE and Internet Access Provider at airports to provide better infrastructure for connected aircraft and Internet of Things (IoT). May need a dedicated "aviation Internet" (see Connectivity theme).

4.   Need to investigate collision avoidance techniques in high-traffic environment with manned UAS (e.g., passenger carrying vehicles) in airspace. Agent-based collision avoidance is a possible solution. Can collision avoidance occur in layers? That is, first the pilots avoid, but if that fails, the second layer of automation still achieves separation.

5.   Can ADS-B protocol be expanded to included "intent" of the aircraft? This will enable better agent-based decision making in completely connected airspace.

- What defines the intent of an aircraft?
- How to identify intent when the flight plan is prone to dynamic changes with human intervention?
- How much intent information from a flight is required at a given time to enable sufficient agent-based decision making?
- What would be the interfaces in such a system between machine-to-machine and human-to-machine?
- How to perform large computations onboard for agent-based decision-making (or other techniques) based on amount of data collected from various neighboring aircraft?
- How to incorporate machine-to-machine communication and interface in GA?

6.   Create experimental National Airspace System (NAS). Have NASA, FAA, and DoD collaborate to check operability of simulated future airspace in which the number of aircraft exceed even the projected increase in aircraft in the future.

7.   It would be valuable to understand whether any of these proposed ODM strategies could feed back into the situation GA is in today by showing how the future needs for ODM in the airspace will make it easier and safer to fly more traditional GA aircraft with much less expense. Research required to show dynamic feedback.

8.   How can users be aware of compliance of the rules (VFR/IFR)? And can that be present in the machine enabling the pilot to fly? Ties in with airspace management (controller providing guidance).

9.   In a world in which major aircraft original equipment manufacturers are going for electric alternatives, what are the capacity issues at major airport hubs?

10.   Is it feasible to have specific routes for different aircraft with different purposes? Different types of routes for different types of operations?

11.   Conduct a review of the impact of drones on GA aircraft. Aside from the existing certification standards for GA aircraft, consideration should be given to the damage from exploding lithium batteries and other power sources for drones.

5.1.3 Theme 3: Aspect of Connectivity

Observations and Future Facts:

1.   Currently, pilots obtain flight information from several sources. With application programming interface (API), essential flight information (e.g. weather, obstacles, clearance) or the best solutions for flight condition (e.g., to minimize fuel/time, the system

gives the optimal solution) can possibly be integrated into a single display to pilots without changing the hardware on board. However, there is currently no such app to put all this information on displays together.

2. Very positive feedback from the pilot community with respect to mobile device applications. Certified API will provide many ways to integrate with the FAA's information. Pilots will be in a better position to make more informed decisions.
3. Faster and more efficient recovery from adverse conditions compared to traditional method set and user-defined object.
4. The implementation of API to an "aviation Internet" opens scenarios for ODM, and there is a financial benefit if companies build apps to tap into this source of aviation-related data and information.
5. Barrier that can be overcome by API technology:

   - Constant and expensive updates of software charged by avionics company.
   - The API can replace the need to add antennas and hardware. It opens avenues for these by simply using the current network.

6. This has potential to accelerate innovation (e.g., there is protocol for creating apps in App Store). FAA can set the standards and certify apps.
7. IoT is a revolutionary concept for future aviation network, and GA could be a good test for the implementation of related technologies.

Research Needs:

1. Comparison of hosting apps in the cloud versus specific aircraft.
2. Standards for API algorithm development and what they should look like are required to reduce regulatory burden and allow manufacturers to follow.
3. Investigate what is needed to establish an aviation Internet as a dedicated Internet-like, high-bandwidth connectivity service. Is there any other bandwidth that could establish an aviation Internet? What are they?
4. Deploying network now available in 2018. What can people do now with Iridium Next, SatCom, and air-to-air?
5. Setting standards to narrow down the gap between business and GA on the implementation of technology in cockpit.
6. Setting standard for the framework that the tech can be built on apps are cost efficient and more flexible than changing hardware.
7. For weather-related accidents, the operators have weather in their cockpit, but something still missing or issues when forecasts change. The difficulties and potential issues to put all the information together need further study.
8. Aircraft network is not secured; data can be accessed/hacked if not controlled. Security aspect of the API to prevent hackers intruding the system.

   - Key to FAA store as an analog to the "Play Store."
   - There is a track of which aircraft/who is in the network.
   - Cybersecurity is a field that is growing, and things like blockchain technology are allowing for secure information exchange in other domains.

5.1.4 Theme 4: Airport Infrastructure

Observations and Future Facts:

1.   Benefits of hybrid-electrification of aircraft, electric aircraft, is more than environmental. It can carry people hile they could not go before, more types of missions are possible and are extremely efficient. Even the regional airports that were dying off might come back to life.
2.   Establishing a future biofuel for GA might be problematic; a particular biofuel might not work for all aviation applications. In the future of fossil fuels, it may not be practical to have a wide range of fuel options available at the airport. Perhaps this will only be Jet-A or diesel (or high octane unleaded replacement avgas) for fossil fuels.
3.   As GA evolves, there is still a strong desire for a healthy recreational GA community that uses the GA airport as a social place. This keeps aviation attractive and accessible to pilots and aircraft owners.
4.   Currently, airports must accept equipment from lowest bidder for infrastructure requirements. Because of this, airports must maintain spare parts from different manufacturers.
5.   Requirements for airport projects can be tailored when it comes to choosing manufacturers.
6.   Federal funding is geared toward commercial airports and commercial air transportation is projected to increase. Different revenue streams for commercial airports, but smaller airports servicing GA have lower revenue streams. This may continue to inhibit infrastructure changes/growth at GA airports.
7.   To expand GA operations, increased use of non-towered airports is likely.
8.   With increased use of UAS by hobbyists and commercial operators, managing use near airports is crucial for future. Currently, hobbyists just notify airport manager (at best).

Research Needs:

1.   How are dual-use spaceports/airports going to work in the future?
2.   Infrastructure: Background checks for persons entering the airport? At what stage and where does security happen if GA airports are more widely used for regular transportation?
3.   Electrification of airports will happen soon, but they might require an incredible amount of electric power for charging electric aircraft and operating the airport. How can these airports achieve this? Can the energy resources in parking garages for electric cars at airports be shared with the aircraft?
4.   Compatibility issues in fuel replacement—unique blend for small user (aviation) will drive costs up. Current estimates that 80% of international fleet and 54% of U.S. fleet can burn unleaded fuel, but GA is a small user group and needs to consolidate to one fuel to reduce costs. A lot of alternatives are emerging, but eventually it will consolidate toward one option for the entire market. The decision about emerging GA fuel will impact the airport infrastructure.
5.   How to help GA airports keep up so that they have the infrastructure to support future technologies? How people pay to use the airport?
6.   Investigate ways to improve use of non-towered airports. This could including cameras capable of monitoring traffic that can be provided to pilots. A Super Automated Weather Observing System is another option; knowing precise weather conditions without

personnel at airport. Leesburg, VA remote tower airport provides another example. What is the right way for remote tower operators to properly feel like they are at a remote airport to facilitate safe operations?

7. With increased UAS operation and growing airport traffic, under what conditions should information be relayed to airport authorities so as not to load the ATC with unnecessary information?

8. Drone usage at airports: Quantifiable data on winter ops (runway temperature, type of snow, runway contaminant coverage percentage). LIDAR mounted on a truck can be driven down the runway to quantify those observations; drones can also be used. Drones can also be used to inspect things like Visual Approach Slope Indicator/PAPI lights. What do all these mean for airspace management at airports? What are the different issues for smaller GA-serving airports?

9. Connectivity solutions at airports could be improved. What would it look like to have a Wi-Fi system at airport that is collecting all information from aircraft (and ground vehicles and tower) and making it available to aircraft (and other receivers), not through VHF but through aviation intranet?

5.1.5 Theme 5: Increased Crashworthiness and Survivability

Observations and Future Facts:

1. Pilots should be able to walk away unscathed from low-speed crashes in GA (similar forces as in survivable automobile accidents).

2. GA should use different tests for crashworthiness and survivability; leverage inspiration and lessons learned from other applications (e.g., NASCAR).

3. With more composite aircraft structures in the future, these structures will consider the dynamics of the crash and address energy absorption.

4. More technologies on board can help prevent loss-of-control (LOC); therefore, there will be fewer crashes/impacts.

Research Needs:

1. Research on designs that can survive high-energy crashes such as LOC and Control Flight Into Terrain and allow occupants to walk away.

2. Can pilots be trained to brace themselves in a safe position before a pending crash? Provide composite bars and neck braces to avoid pilot movement and prevent other surrounding equipment and structures that could harm the pilot during a crash.

3. Study to mitigate crash energy: absorbents, inflatables (e.g. NASA's honeycomb design), or ballistic recovery parachutes as high-altitude safety devices.

4. Will helmets be a suggestion? This is becoming acceptable. Study to make headset a helmet or an air bag, or curtain inflation. Automatic seat belts, ejection seats, and post-crash fire prevention (e.g., improve fuel tanks) need further study and definition of standards.

5. e-VTOL safety problems:

   - More consolidated system preventing the electrocution accident
   - 2G-roll requirement for ducted fans
   - Difficult/impossible to autorotate

6. More data about incidents and accidents is better, but how to overcome the data recording issues? It may take 30 years to get enough/meaningful data about incidents and accidents to make decisions.
7. Lightning protection needs investigation for future GA, with desire for near all-weather operations, more composite materials in the airframe, more electric systems, including propulsion on the aircraft. What are the implications here? What kind of protection/discharge capability is possible?
8. If the aircraft crash is known to be survivable, the pilot may be more comfortable conducting a controlled descent into trees, which can absorb a lot of energy if the occupants are well protected. Would this change pilot behavior and lead to impacts with less energy? Could it lead to more options for an emergency landing/controlled crash?
9. Because most off-airport crashes will have law enforcement officers being the first responders to the scene, research needs to be conducted to determine if, at a minimum, the state police have the appropriate guidance on how to approach an airplane if it is suspected that there is composite debris at the site.

5.1.6 Theme 6: Autonomy and Automation

Observations and Future Facts:

1. Automation can provide and process more information than humans.
2. Human factor in automated systems is crucial. Learning new systems while learning a new aircraft is a big barrier among pilots ("automation trust human" vs. "human trust automation").
3. Complete autonomy is the end state that people want to reach, but there are currently a lot of issues to work through for automation.
4. There are a lot of tasks that can currently be automated and a combination of these small automations will define the path toward complete autonomy.

Research Needs:

1. Communication, "see and avoid" needs further work to be completely automated. Having no humans at ATC is difficult now because of human interaction (e.g., voice). Automated ATC is very difficult and still an open question. How will it turn out?
2. Road map to autonomy: have a flight training program in which there is always a flight instructor with full situational awareness? Perhaps this flight instructor is a remote instructor on the ground.
3. Looking for short- and long-term benefits of automation (e.g., if the aircraft is capable of landing, even in emergencies, then the pilots do not need a medical certificate).
4. Guidance to compliance and the ability to be within compliance; compliance inside the cockpit and outside (e.g., aircraft state, flight rule state).
5. Managing the extent of human factors within automation and operations:

    • Level of automation -> extent of control -> failure enunciations.
    • Affects level of training necessary for operation.
    • Extent of degraded mode. Define failure modes of automation in operation.
    • Level of automation and reliability dependent on proficiency of pilot.

6.   Provision for cloud-based AI (specific AIs) to get in aviation (might be easier to implement through apps, if certified API is connected to aircraft via aviation Internet concept).

    •   Specific AI has already started. You can have Watson-like cloud-based applications feeding information to pilots. There is a bit of a near-term need for FAA to get involved in specific AI that will affect GA operations.

5.2 PRIORITIZATION OF RESEARCH

Workshop 2 included an opportunity for participants to prioritize research in these themes, trying to address what areas have the most impact and what areas need to receive attention first because they are prerequisites for subsequent research. The participants provided some input; however, the time dedicated to this exercise, after the preceding sessions, was insufficient to provide a full prioritization. Based on the discussion of the participants, the team infers the following ideas about prioritization:

1.   Improvement in connectivity of aircraft and airspace is a priority. Having information available to pilots and airports would enhance safety and efficiency. Airspace redesign can follow closely.
2.   Infrastructure growth in low traffic airports to increase accessibility. Ties in with growth in connectivity and airspace redesign.
3.   In a current uncontrolled airspace, create a test for future airspace to explore implications of improved connectivity and automated functions. Build a private system of a coordinating aviation system to test ideas discussed. Alternate flight rules can be used.

During the time allocated to prioritization, the workshop participants offered two other thoughts that had not been directly addressed in the workshop. The Project 25 team believes that the participants may have offered these in the mindset that this was the last chance to add input.

1.   There should be an improved awareness of GA growth outside of the United States. What does this mean for mutually beneficial research activities?
2.   More case studies may be needed to understand the impacts of the current forecast that shows a small growth in all aspects of GA. What are the socio-economic factors that will influence future GA? Those studies could more fully describe the possible state of GA in 2030.

6. SIMILARITIES AND DIFFERENCES BETWEEN WORKSHOP 2 AND PREVIOUS WORKSHOPS (0 AND 1)

Workshop 2 was different from the previous workshops in terms of composition, format, and expected outcomes. The Workshop 2 participants were provided with information collected from previous workshops. As a result, a quantitative analysis of critical words was not conducted for Workshop 2 responses. The expected outcomes of Workshop 2 were to identify themes and research questions and add relevant context, which may have been missed in the previous workshops and benchmarking tasks. Only a qualitative analysis of this difference is presented here.

As mentioned previously, the composition of this workshop was unique. Workshop 2 was comprised of high numbers of government representatives with members of industry, the GA community, and academia. The composition of the workshop is shown in figure 15.
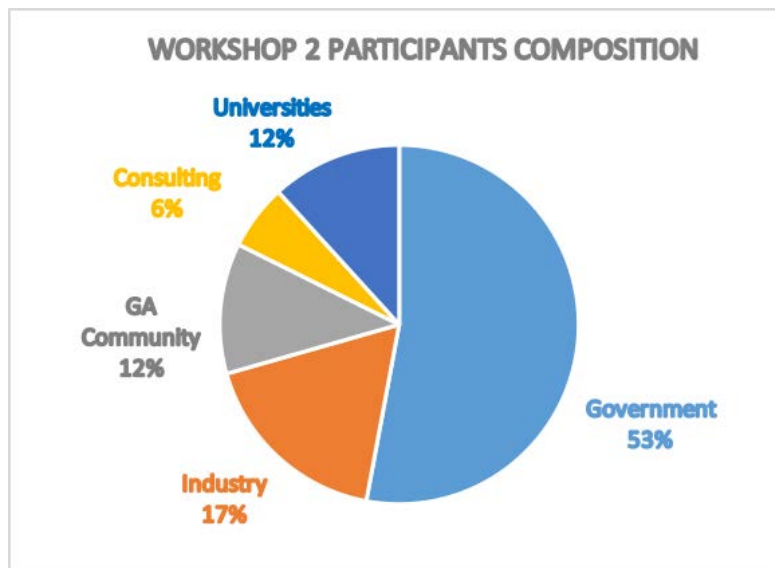

Figure 15. Workshop 2 participant demographics

As per design of the workshops under this project, government representatives were mainly presented as observers or facilitators in the previous workshops, but took a more active role in Workshop 2. It is noteworthy that several participants felt that the format and approach used during this workshop were unique. According to an industry representative, rarely do they attend a workshop such as this in which the government, industry, community, and academia convene and have an open, honest discussion regarding the possible future scenarios of GA. Some industry participants also had extensive previous work experience with government agencies, which allowed these participants to freely engage in workshop discussions. The industry representation was limited to avionics, networks, and GA airports; however, their perspectives were missed in Workshop 1, so they were included in Workshop 2. These industries play a key role in future GA. GA community representatives, who could not attend the previous workshops, were also invited to Workshop 2. Therefore, Workshop 2 consisted of participants encompassing the majority of the GA stakeholders.

The composition of Workshop 2 affected the format and expectations of the workshop. The following key format changes were made to Workshop 2 (compared to the previous workshops):

- Ongoing and near-term FAA research themes were shared with participants.
- The themes developed by previous workshops were shared with participants.
- Scenario brainstorming was limited. Scenarios not captured by themes were mainly addressed.
- Analysis and discussion of already developed themes

The format was similar to the previous workshops that took place with regard to new theme development. The main expectation of this workshop was to find gaps in scenarios and themes that

have not already been captured and to address them. The goal was to find and develop new themes that were not discussed in previous workshops and enhance critical themes previously identified. Another key expectation was to define a possible direction for research based on the themes discussed.

Connectivity of aircraft and airspace emerged as an important theme, which had not been captured in previous workshops and benchmarking. Concepts of software, cybersecurity, and data were mentioned in the previous workshops but the identification of the role of connectivity in GA in the future had not previously been taken into consideration. Workshop 2 participants discussed the impact of connectivity on airspace and airport infrastructure.

Differences between automation and autonomy were more fully established in Workshop 2. Autonomy was considered to be the final expected state of complete automation. It was the viewpoint of the participants that several small levels of automation can be performed currently, but a big leap, specifically in public trust, would be required to achieve states of complete autonomy. Previous workshops concluded that the road map to complete autonomy is important. Workshop 2 discussed what could be a possible road map for automation of GA aircraft.

Workshop 1 emphasized the need to change and explore pilot training for future GA. Workshop 2 participants discussed current simulator concerns and limitations, possible technologies that enable competency-based training, and "specific-function" pilot certification.

UAS was discussed in Workshop 2 from various perspectives: crowded airspace, technology enabler, future operations, noise and environmental concerns, certification dissimilarities with conventional GA, and even airport management. It was pointed out that for similar roles (e.g., photography), conventional GA is required to get tower permission, whereas for the same task, UAS operators flying under a community-based set of standards (14 CFR Part 101) are required only to notify the tower (14 CFR 101.41(e)). Those UAS operating under 14 CFR Part 107 need prior authorization when operating in Class B, Class C, or Class D airspace or within the lateral boundaries of the surface area of Class E airspace (14 CFR 107.41).

Workshop 0 and 1 participants emphasized the importance of safety, but given the safety of the pilot/operator/passenger, participants looked further into enabling operations and technologies in the future. Workshop 2 participants re-emphasized the need for safety, but in particular the need to increase the survivability of an aircraft crash. In their opinion, public trust will increase if crashes occur less frequently or do not necessarily result in loss of life. Most GA aircraft do not operate at jet aircraft speeds but in the range of a speeding car, for which technology exists to protect the occupants from fatal injury. Therefore, improvements can be made to procedures and on-board equipment to prevent loss of life to a large extent.

7. CONCLUSIONS

This report summarizes the activities conducted under the Partnership to Enhance General Aviation Safety, Accessibility and Sustainability (PEGASAS) Project 25 with the addition of information collected from a prior FAA/PEGASAS workshop in 2016. The objective of these efforts was to explore and analyze future general aviation (GA) topics that might warrant further research by the FAA and/or the industry. The subject matter expert workshops were successful in

identifying important research themes. Initial research questions emerged from these research themes that warrant further investigation. These questions provide the basis for more specific workshops or other focused efforts to convert these research themes and questions into a specific strategic research plan. This plan may then provide guidance for future research requirements.

The benchmarking task identified the top four challenges in future GA: Certification, Airspace Management, Infrastructure, and Cost. The investigators also identified five key transformational changes that will impact the future of GA: Urban Mobility, Transformational Propulsion Architectures, Enabling Technologies, Automation, and Unmanned Aerial System Activities. Through the technology metrics study, the team investigated 36 new technologies using a combination of two metrics—technology readiness level (TRL) and estimated technology adoption (ETA)—to assess if those new technologies have the potential to be part of GA operations in 2030. A list of promising technologies is provided in this report. In the aircraft technology portfolio study, the team identified that new technologies in the areas of Airframe Materials, Propulsion Systems, and Aircraft Configuration are expected to have higher implementation ratios for future GA aircraft in the 2030 timeframe. Observations on certification and overseas status of GA are also included in the benchmarking section.

Table 5 summarizes the themes identified through the efforts of this project. Recurring themes of similar intent are adjacently placed. From all the tasks performed during this project, 10 unique themes emerged for future GA research activities.

Table 5. Identified research themes

Benchmarking	Workshop 1	Workshop 2
		Aspect of Connectivity
	Pilot Training and Proficiency	Pilot Training and Proficiency
Infrastructure	Airport and Infrastructure	Airport Infrastructure
	Airframes, Legacy Fleet, and Maintenance	
Automation	Autonomy and Automation	Autonomy and Automation
	Passenger Safety	Increased Crashworthiness and Survivability
New Propulsion Systems	Future Propulsion Systems	
Airspace Management	GA in Future Airspace	GA in the Future Airspace
Advanced Design and Manufacturing		
Certification		

7.1 RESEARCH RECOMMENDATIONS

In the view of the project investigators, common topics from the benchmarking activity and the workshops that address the system-level questions are of the highest priority. The platforms on which the next generation of GA can function require attention. A list of such high-priority topics are:

- Airspace Management: New air traffic control methodology development by simulating future airspace scenarios.
- Airport Infrastructure: Future aircraft and traffic would need to be accommodated by the network of airports.
- Automation: Systems onboard or external to the aircraft would reduce pilot workload to a minimum while increasing safety and building trust in automated systems.
- Connectivity: Connectivity of airspace and airports, and the establishment of standardized Application Programming Interface.

Through the tasks performed, the project investigators understand that it requires greater public trust achieved through higher safety assurance for passengers and pilots for GA to be accessible to the masses in the future. Therefore, crashworthiness and survivability research are also crucial to the growth of GA.

The development of the previously mentioned topics will fuel innovation in specific GA areas. In the view of Workshop 1 and 2 participants, new propulsion concepts are already under development and require immediate attention. With large original equipment manufacturers investing in newer concepts, GA propulsion systems will change significantly. In the opinion of Workshop 1 participants, developments in new airframe configuration and new propulsion systems will have to occur simultaneously as they are coupled to each other. With the advent of unmanned

aerial systems, future GA will include a form of hybrid rotorcraft. The noise emanating from the rotors of future aircraft will be a social hindrance that requires attention. Even though this topic did not surface from direct study in any tasks, noise management will be of high importance in future GA operations.

7.2 OPPORTUNITIES FOR NEXT STEPS

In the future, more activities can be undertaken to assist the FAA in the development of a strategic GA research and development (R&D) plan for the 2030 timeframe. The next steps of this project may involve the following processes:

1.   Further streamlining research topics: Some themes and research topics identified during the workshops in 2017 are interdependent, which means that a streamlined process can further combine and consolidate themes based on similarities. In addition, some research would need to be performed as soon as possible to meet near-term needs. A prioritization process can be used to eliminate themes that are not conducive to the development of a strategic GA roadmap for the 2030 timeframe. The streamlined list of themes would be used to define focus areas for further in-depth workshops and as the basis of a roadmap for the strategic GA R&D plan for the 2030 timeframe.

2.   Topic-specific workshops: Potential topic-specific workshops can be held to help develop the roadmap for a GA R&D plan for 2030. Using the streamlined process for the most relevant research topics, the team will identify subject matter experts or domain experts for relevant areas. If the number of subject matter experts identified is small enough, the workshops may be replaced by interviews or teleconferences. Workshops will be organized if the number of participants is high or the topic area is broad.

3.   Surveys: More surveys can be conducted to further consolidate conclusions from the benchmarking tasks (e.g., timeframe from the perspective of the subject matter experts, the expected TRL and ETA levels of the new technologies investigated for GA in the 2030 timeframe). The surveys can also be used to further prioritize research topics and create business cases for several GA scenarios and new technologies.

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APPENDIX A—COMPLETE TRL AND ETA TABLES

Table A-1. Complete TRL and ETA table

Technologies	TRL	Status in 2017	ETA	Status in 2030	ETA
Distributed Electric Propulsion	5-6	First NASA DEP manned flight demonstrator had been achieved in 2017	Low	No forecast yet.	Low - Medium
Hybrid-Electric Propulsion System	2-3	Airbus's plan initialed back in 2013.	Low	Regional hybrid electric flight demo before 2021, practical airliners in 2030–2035.	Medium
Hydrogen Powered Aircraft	6-7	First passenger aircraft prototype took off in Germany in 2016.	Low	May enter service later than 2030 because of the change to new energy infrastructure.	Medium
Diesel Aircraft Engine	9	Many diesel aircraft engines already in operations.	High	May be chosen as retrofit and in new aircraft following the high price of AV gas and possible fuel transition.	Medium - High
Advanced Battery	4	Current battery density at 250-300 Whr/kg. Latest outcomes in lab can already reach more than 400 Whr/kg.	Low	Need more than 400 Whr/kg for DEP for electric propulsion market.	Medium - High
ADS-B Related	9	Technologies for ADS-B in/out units and ground stations are mature.	Medium	Will require most GA aircraft to equip ADS-B out by 2020. Need to investigate ground stations.	High
Solar powered Aircraft	7	Already have a few successful prototypes.	Low	Not a practical solution for future GA aircraft because of the aerodynamics design, efficiency, and operational limits.	Low - Medium

Table A-1. Complete TRL and ETA table (continued)

Technologies	TRL	Status in 2017	ETA	Status in 2030	ETA
Efficient Electric Aircraft Charging Station	3	First EA charging station in 2011. Two cities in California are installing the first network of charging infrastructure.	Low	Expect to form charging station networks in some areas (like SF bay area).	Medium
Fly by Wire	8	Successful flight test by Diamond Aircraft on DA42 in 2015.	Medium	More prototype aircraft with similar system will initiate their flight test.	Medium - High
Autopilot System	9	Current autopilot systems can help pilot reducing workload and flying with higher precision and increased situation awareness.	Medium	More prototype aircraft with similar system will initiate their flight test.	Medium - High
Auto Landing	8	Successful flight test: DA42 in 2015.	Medium	More advanced autopilot prototypes will be demonstrated.	Medium - High
Flight Data Monitor	9	There are several companies providing relevant equipment and analysis service.	Low - Medium	Because of the increased operation safety by implementing the FDM, similar equipment might become a standard feature for most of the GA aircraft.	Medium - High
Synthetic Vision System	9	Many avionic companies already have synthetic vision system on their machine, but not every GA aircraft has the equipment.	Medium	More GA aircraft equipped with these aiding systems to help pilots flying in hazardous weather or environment with low visibility.	High
Enhanced Vision System	9	Some avionic companies provide instruments with infrared or night vision system, but still not a standard feature.	Medium	More GA aircraft equipped with these aiding systems to help pilots flying in hazardous weather or environment with low visibility.	High

Table A-1. Complete TRL and ETA table (continued)

Technologies	TRL	Status in 2017	ETA	Status in 2030	ETA
Weather in Cockpit	9	Most of the GA aircraft has this technology as an optional feature, not a standard feature.	Medium	More GA aircraft equipped with these aiding systems to help pilots flying in hazardous weather or environment with low visibility.	High
ADS-B (out)	9	By 2020, every GA aircraft in US will be equipped.	Medium	ADS-B in and ADS-B out will be a standard feature for every GA aircraft and UAS.	High
ADS-B (in)	9	With ADS-B in system. Some GA operators already implemented the ADS-B in/out on their aircraft. However, security breach is possible.	Medium	ADS-B in and ADS-B out will be a standard feature for every GA aircraft and UAS.	High
ABS-B Self Separation Application (Sense and Avoid)	8	An UAS with sense-and-avoid system based on ADS-B was successfully tested by NASA in a designed flight test mission in 2016.	Medium	ADS-B in and ADS-B out will be a standard feature for every GA aircraft and UAS.	High
CPDLC	9	Controller-Pilot Data Link Communication is available on the majority of airlines and few business jets for transoceanic flights.	Medium - High	FAA planned to implement CPDLC for domestic routes in 2019. By 2030, 85% of Air Traffic Service communications are to be provided via data-link.	Medium - High
PBN: RNP and RNAV	9	Major airports and Class A-C airspace have RNP regulations. Most GA aircraft with a GPS have the RNAV capability.	Medium	All instrument flight rules regions to have RNAV capability, including LNAV, VNAV and LPV. Higher RNP may be required for continental flight.	Medium - High

Technologies	TRL	Status in 2017	ETA	Status in 2030	ETA
TCAS/PCAS/ Ground Proximity Warning System	9	TCAS is available on jets, and new propeller aircraft. Pilots use PCAS (portable) /FLARM in some cases. TAWS mandated on Turbine aircraft greater than 12500 lbs.	Medium	Portability of the terrain awareness and avoidance system are projected to increase. Different levels of services could be bought by users.	High
SWIM (ATM Perspective)	8	Limited to major airline operators and major airports. Subscription can be acquired through FAA.	Low	Could provide higher accuracy data to GA pilots. May still require subscription for FAA SWIM.	Medium
ATM Technology: ATD-1 (TSAS & FIM) & ATD-2	8	These technologies help in better separation, sequencing, scheduling, and terminal area management. Currently deployed by major Metroplex airports.	N/A	Expected to be deployed across NAS and all major Metroplex airports. Class B and Class C airspaces.	N/A
UAS Traffic Management	6-7	NASA recently demonstrated the UTM technology by conducting "out-of-sight" tests.	N/A	Expected to reach high fidelity by 2020, but mainly for UAS applications in uncontrolled airspace. Next steps could expand to controlled airspace.	N/A
AM Process and Methods	7	The process needs to be further simplified and standardized. However, many AM technique providers already had their products for aerospace usage in demonstration.	Low	By 2030, some AM products can be applied on GA aircraft. The safety and airworthiness of AM parts has standardized regulations to control and regulate their quality.	Low - Medium

Technologies	TRL	Status in 2017	ETA	Status in 2030	ETA
AM Materials	7	Having different materials for different purposes, material properties hard to control (100+ parameters for the process).	Low	(see above)	Low - Medium
AM Applications in Aerospace	7-8	There are some demonstrations and tests of aircraft parts made by AM, but actual implementation in aircraft operation is rare.	Low	(see above)	Low - Medium
Electric Aircraft	2-4	Some future VTOL aircraft also purposed to use full electric propulsion system.	Low	With the advent of battery and motor technologies, more electric aircraft will complete their first flight tests and will be an option in the future GA market.	Low - Medium
Hybrid Aircraft	8	Some prototypes of this type of GA aircraft already had a few flight tests.	Low	More hybrid aircraft will complete their flight tests, and some will enter the GA market.	Medium
VTOL Aircraft in GA	2-4	Some concepts and new designs aimed to have flight test at the end of 2017.	Low	More proposed future VTOL aircraft designs will complete their flight tests for one or two passengers.	Medium
Pultruded Rod Stitched Efficient Unitized Structure	2-3	This new way of aircraft manufacturing technique was introduced by Boeing and NASA, but this concept of manufacturing was also introduced into GA by recent research.	Low	Prototype aircraft comprised by this method will initiate their flight tests.	Medium - High

Table A-1. Complete TRL and ETA table (continued)

Technologies	TRL	Status in 2017	ETA	Status in 2030	ETA
Bionic Structure (AM + Design Optimization)	4-5	Airbus already has a team developing this advanced structure technology with additive manufacturing with AP work.	Low	Breakthrough on manufacturing method expected. Reduced process complexity, increased stability of processed material, and implementation of the parts in propulsion and structural system.	Low - Medium
Airframe Parachute System	9	Currently, only Cirrus Aircraft uses this technology on their GA fixed-wing aircraft products.	Low	More GA aircraft will have this equipment on board.	Medium
Ice Protection System	9	Almost every GA aircraft can have this technology on board, but it is still an optional feature.	Medium	Every GA aircraft has this equipment on board.	High
Seatbelt Airbag System	9	Almost every GA aircraft can have this technology on board, but it is still an optional feature.	Medium	Every GA aircraft has this equipment on board.	High
Angle of Attack System	9	Some GA fixed-wing aircraft made this as a standard feature.	Medium - High	More fixed-wing aircraft will have this equipment on board.	High

ADS-B = Automatic Dependent Surveillance-Broadcast; AM = Additive manufacturing; ATM = Air traffic management; CPDLC = Controller-pilot data link communications; DEP = Distributed electric propulsion; ETA = Estimated technology adoption; FLARM = Flight Alarm Electronic System; LNAV = Lateral navigation; LPV = Localizer performance with vertical guidance; PCAS = Portable Collision Avoidance System; RNAV = Area navigation; RNP = Required navigation performance; SWIM = System Wide Information Management; TAWS = Terrain Awareness and Warning System; TCAS = Traffic Collision Avoidance System; TRL = Technology readiness level; UAS = Unmanned aerial system; UTM = Unmanned traffic management; VTOL = Vertical takeoff and landing

APPENDIX B—LIST OF THE INDUSTRY COMPANIES/ORGANIZATIONS OF THE
WORKSHOP PARTICIPANTS

GAMA

Adaptive Aerospace Group

Aspen Avionics

Experimental Aircraft Association

Frasca Flight Simulation

Imagine Air

Lycoming Engines

Nelson Consulting

Pfeiffer Consulting

Piper Aircraft

Port Columbus Airports

Purdue University Airport

SmartSky Inc.