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General Aviation 2030: GA Exploratory Analysis

February 5th, 2018

Final Report

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List of Acronyms

ABAG	Brazilian Association for General Aviation
ADS-B	Automatic Dependent Surveillance-Broadcast
AI	Artifcial Intelligence
AM	Additive Manufacturing
AoA	Angle of Attack
AOPA-J	Aircraft Owners and Pilots Association Japan
API	Application Programming Interface
ASRM	Aviation System Risk Model
ATC	Air Traÿc Control
ATM	Air Traÿc Management
AWOS	Automated Weather Observing System
CFIT	Control Flight Into Terrain
COE	Center of Excellence
COTS	Commercial O˙-The-Shelf
CPDLC	Controller-Pilot Data Link Communications
DEP	Distributed Electric Propulsion
DLR	The German Aerospace Center (Deutsches Zentrum fur Luft- und Raumfahrt)
DoD	Department of Defense
EAA	Experimental Aircraft Association
EASA	European Aviation Safety Agency
ETA	Estimated Technology Adoption
EVS	Enhanced Vision System
FAA	Federal Aviation Administration
FMS	Flight Management System
GA	General Aviation
GAMA	General Aviation Manufacturers Association
GPWS	Ground Proximity Warning System
HEPS	Hybrid-Electric Propulsion System
IAOPA	International Council of Aircraft Owner and Pilot Associations
IAP	Internet Access Provider
ICAO	International Civil Aviation Organization
IFR	Instrument Flight Rules
IoT	Internet of Things
LoC	Loss-of-Control
NASA	National Aeronautics and Space Administration
NASCAR	National Association for Stock Car Auto Racing
NCSU	North Carolina State University
NPIAS	National Plan of Integrated Airport Systems

ODM	On-Demand Mobility
OEMS	Original Equipment Manufacturer and Service
PCAS	Portable Collision Avoidance System
PEGASAS	Partnership to Enhance General Aviation Safety, Accessibility and Sustainability
PMA	Parts Manufacturer Approval
PPL	Private Pilot Licence
PRSEUS	Pultruded Rod Stitched Eÿcient Unitized Structure
SOUP	Software of Unknown Pedigree
SVS	Synthetic Vision System
SWIM	System Wide Information Management
TCAS	Traÿc Collision Avoidance System
TRL	Technology Readiness Level
UAS	Unmanned Aerial System
UAV	Unmanned Aerial Vehicle
VASI	Visual Approach Slope Indicator
VFR	Visual Flight Rules
VHF	Very High Frequency
VTOL	Vertical Takeo˙ and Landing
4G LTE	Fourth-Generation Long Term Evolution

Executive Summary

"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 identifed six major topical areas for GA in 2030: new energy, infrastructure, advanced design & manufacturing, automation, airspace management, and certifcation. The workshops developed several themes. Workshop 1 participants identifed and described themes of pilot training and profciency, autonomy and automation, airport and infrastructure, GA in the future airspace, airframes, legacy feet & maintenance, future propulsion systems, and passenger safety. Workshop 2 participants identifed one new theme - aircraft/aviation connectivity - and then provided their own discussion of the themes: autonomy and automation, pilot training and profciency, 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 e˙orts 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. While the workshop participants represented a broad spectrum of the general aviation community, input from additional sectors of GA would also ensure both that as many of the GA stakeholders as possible feel engaged in the research plan.

1 Introduction

This report documents the e˙orts of a team from PEGASAS (Partnership to Enhance General Aviation Safety, Accessibility and Sustainability), 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 General Aviation (GA) in the United States transportation system complements the many functions provided by scheduled commercial airlines, and GA has its own mature community. Recent progress in several technological areas and the potential of new GA market opportunities, perhaps enabled by the technological progress, has generated interest in the future of general aviation. There is a consensus among stakeholders in the GA community that in order 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 better 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 general aviation topics that might warrant further research in an e˙ort 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 the GA challenges, technologies, and trends impacting general aviation in 2030. Although this study was commissioned by the FAA, the resulting research needs and challenges a˙ect the broad aviation community and all of its stakeholders.

2 Benchmarking Task

Project 25 included a benchmarking task that asked the team to conduct a survey of literature and discussions (including on-line web pages, popular aviation magazines, professional society conference papers, and peer-reviewed articles). This broad nature of the 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 duration, more focused workshops. The major fndings of the benchmarking tasks appear in this chapter.

2.1 Future Trends for General Aviation

2.1.1 Overview of the Current Status

General aviation plays an important role in the national air transportation system. According to the Federal Aviation Administration (FAA), three out of four takeo˙s and landings at airports in the United States are conducted by GA aircraft. Nationwide, there are 3,300 airports and other landing facilities in the FAA's National Plan of Integrated Airport Systems (NPIAS), supporting main aeronautical functions, such as, emergency, critical community access, commercial activities and destination services. [8]. In FAA's *Plane Sense - General Aviation Information* (FAA-H-8083-19A) [9], GA fights are described as fights conducted by operators other than Title 14 of the Code of Federal Regulations (14 CFR) Part 121 or Part 135 certifcate holders. The General Aviation Manufacturers Association (GAMA) data-book shows that currently there are over 210,000 GA aircraft based in the United States, with over 24 million fight hours every year. As for the contribution to economics and creating jobs, GA activities support $219 billion in total economic output and 1.1 million total jobs in the United States. Another aspect worth mentioning is that GA fights utilize more than 5,000 U.S. public airports, compared to less than 400 airports served by scheduled airlines [6].

2.1.2 GA Forecasts for 2017-2037

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

According to these forecasts, no large changes in feet, pilot population or total fight hours are expected. The active GA feet is projected to increase at an annual rate of 0.1%, because of the general increases in fxed wing turbine, rotorcraft and light sports feet. This increase is expected to o˙set a decline in the fxed wing piston feet. 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 due to the new certifcate rules. The total number of GA fight hours is projected to increase at an annual rate of 0.9%, as the utilization rates for new business jets are expected to increase [10]. Details of the breakdown per category are shown in Figure 1.

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

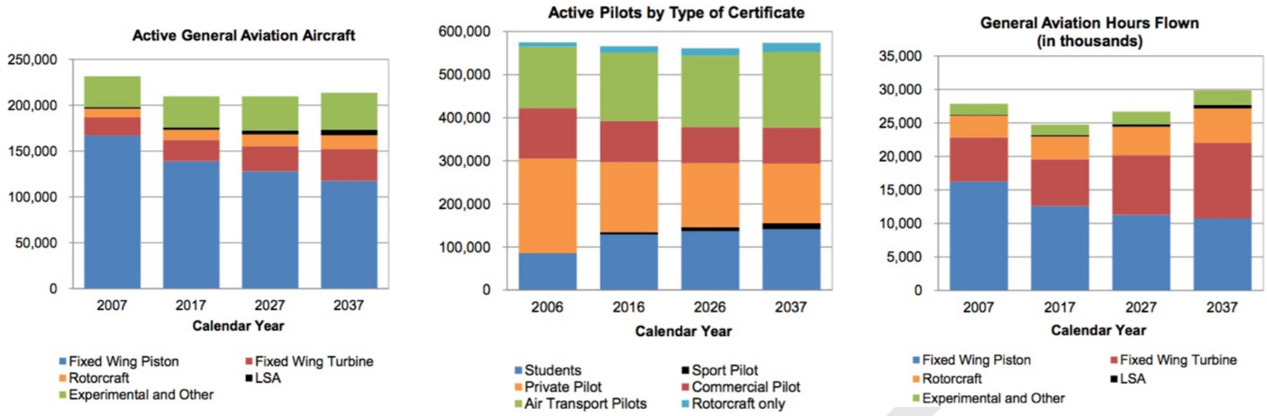

Figure 1: GA forecasts in feet (left), pilots (middle) and fight hours (right), source: FAA [1]

propulsion technologies and technologies aimed at improving safety, urban mobility using general aviation aircraft may emerge as a major transformational concept [11]. 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 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 total predicted volume of GA may stay at the same level up to the year 2030, the composition of GA in many aspects 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, eÿcient, proftable and environmentally friendly GA ecosystem are enormous.

The recent Uber Elevate summit report [12] described key challenges: the certifcation process, battery technology, vehicle eÿciency, vehicle performance and reliability, air traÿc control, cost and affordability, safety, aircraft noise, emissions, infrastructure and pilot training. The Uber report primarily refers to On-Demand VTOL concept aircraft, but it does highlight four key challenging areas identifed for GA as well: *Certifcation*, *Airspace Management*, *Infrastructure* and *Cost*.

- *Certifcation* : The new Part 23 has been e˙ective since August 2017 [1]. Certifcation is evolving more towards a performance and risk-based approach along with complex processes being modelled and results being obtained through analysis (computationally) rather than the conventional, prescribed tests. Even though these approaches help in the introduction of newer technologies and accelerate the certifcation process for existing technologies, large challenges lie ahead. With vast technological changes anticipated, processes and methods would need to be developed and identifed to quickly and eÿciently certify these new technologies while maintaining the same level of safety as before. Many technologies are not aviation specifc 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 [13]. Proper control and management of this increasingly more congested airspace is of primary concern for the safe operation of all the aircraft [14]. 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 as well as 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 important as well. The aviation infrastructure of the future will also be as varied as the technology it would need to support; for instance, if the GA feet uses a mix of future unleaded fuel(s) as well as electric power, the airports and ground facilities must address this. Fixed Based Operators will have to account for di˙erent types of technologies present on similar types of aircraft, di˙erent aircraft confgurations and di˙erent 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 infuencing public perception and, thereby, limiting or increasing the number of customers of GA.. Keeping costs to reasonable levels for researching, developing, and fnally 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, fve key transformational changes have also been identifed and listed below:

- **Urban mobility**: This may emerge as a major transformational concept. Urban air taxi service is most likely to happen frst 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 frst 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, surveillance, etc. The substantial increase of UAS will impact the shared airspace.

2.2 Identifcation 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-centric workshop conducted in May 2016, prior to the start of Project 25. The notes from that workshop included all the previous year outputs regarding GA topics, issues and themes. In particular, topics or themes that occurred frequently in these proceedings were identifed. Conclusions from the data mining process, combined with a brainstorming process, fnally 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 captured in Figure 3 using a 'Sankey Diagram', a fow diagram that can visualize the proportion of the major components within the system, and locate the dominant contributions.

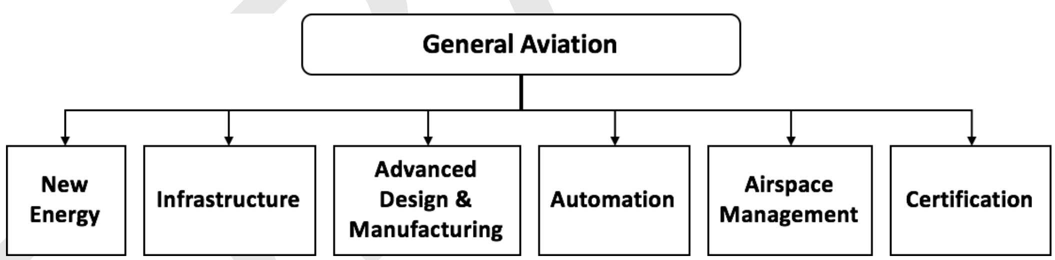

Figure 2: Down-selection of six major topic areas for future GA

The researchers at Georgia Tech and Purdue undertook a more in-depth literature review of the six main identifed areas: *New Energy*, *Infrastructure*, *Advanced Design & Manufacturing*, *Automation*, *Airspace Management* and *Certifcation*.

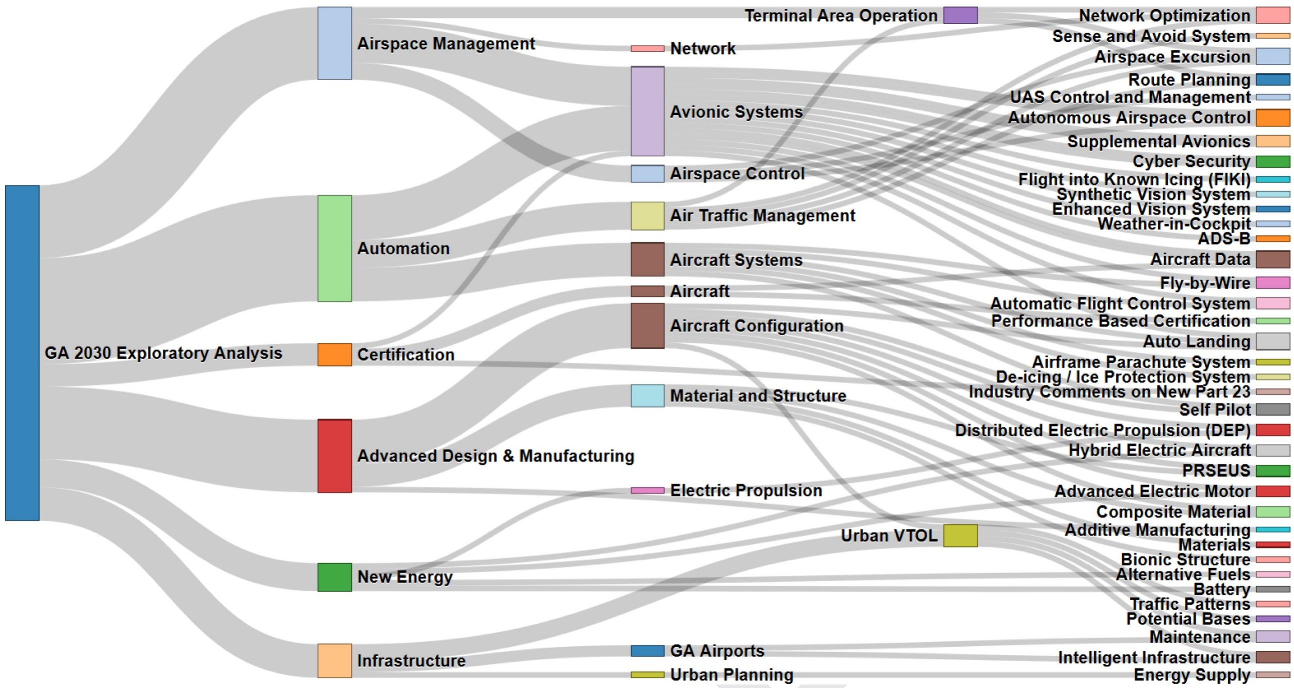

Figure 3: Topic taxonomy with secondary and tertiary topics

2.3 New Technologies and Technology Metrics

2.3.1 The Full List of New Technologies

The team identifed representative new technologies in each of the six areas to investigate further. A full list of new technologies studied is presented in the Table 1 below. A combination of two metrics (Technology Readiness Level (TRL) and Estimated Technology Adoption (ETA)) was used to assess the feasibility and the potential infuence of each new technology on GA in the 2030 time frame.

2.3.2 Technology Metrics and TRL

The TRL characterizes the maturity level of a new technology. A widely used version defned by the National Aeronautics and Space Administration (NASA) has nine technology readiness levels, ranging from TRL 1 (basic principles observed) to TRL 9 (actual system fight proven). Detailed defnitions of the nine technology readiness levels are shown in Table 2 [7]. During the investigation process, the TRL for each GA-relevant technology is assigned by evaluating its current development against defnitions 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.

2.3.3 Estimated Technology Adoption (ETA)

The PEGASAS Project 25 team developed the Estimated Technology Adoption (ETA) metric to provide another dimension in the technology evaluation process. The motivation for an ETA is that technol-

Table 1: List of new technologies investigated for GA

Distributed Electric Propulsion (DEP)	Hybrid-Electric Propulsion System (HEPS)	Hydrogen-Powered Aircraft
Diesel Aircraft Engine	Advanced Battery	Automatic Dependent Surveillance-Broadcast (ADS-B) Related
Solar-powered Aircraft	Eÿcient Electric Aircraft Charging Station	Fly-by-Wire Tech
Autopilot System	Auto landing (hands-oˆ)	Flight Data Monitor
Synthetic Vision System (SVS)	Enhanced Vision System (EVS)	Weather-in-Cockpit
Automatic Dependent Surveillance-Broadcast (ADS-B) out	Automatic Dependent Surveillance-Broadcast (ADS-B) in	ABS-B Self-Separation Application (Sense-and-Avoid)
Controller-pilot data link communications (CPDLC)	Required Navigation Performance (PBN): RNP & RNAV	Traÿc Collision Avoidance System (TCAS) and Ground Proximity Warning System (GPWS)
System Wide Information Management (SWIM) (ATM Perspective)	Air Traÿc Management Tech: ATD-1 (TSAS & FIM) & ATD-2	UAS Traÿc Management
Additive Manufacturing (AM) Process and Methods	Additive Manufacturing (AM) Materials	Additive Manufacturing (AM) Applications
Electric Aircraft Design	Hybrid Aircraft Design	VTOL Aircraft in GA
Pultruded Rod Stitched Eÿcient Unitized Structure (PRSEUS)	Bionic Structure (AM + Design Optimization)	Airframe Parachute System
Ice Protection System on GA	Seatbelt Airbag System	AoA System

Table 2: Technology readiness level defnitions, source: NASA [7]

TRL	Defnition
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/sub-system model or prototype demonstration in an operational environment
7	System prototype demonstration in an operational environment
8	Actual system completed and 'fight qualifed' through test and demonstration
9	Actual system fight proven through successful mission operations

ogy readiness and its adoption into the market do not necessarily go hand in hand. The successful development of a technological innovation depends on the availability as well as the 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 [15]. 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 these 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: Estimated Technology Adoption (ETA) level defnitions

ETA	Defnition
Low	A less than 30% technology adoption by applicable GA feet of aircraft in 2030
Medium	A technology adoption of 30% to 60% for the applicable GA feet of aircraft in 2030
High	A more than 60% technology adoption by applicable GA feet in 2030

There are numerous stakeholders in GA, for whom the factors a˙ecting 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 infuence 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 in 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 fight safety? Does the new technology make the fying safer? Is the new technology in itself 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 and/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 in turn 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]** appears in Figure 4.

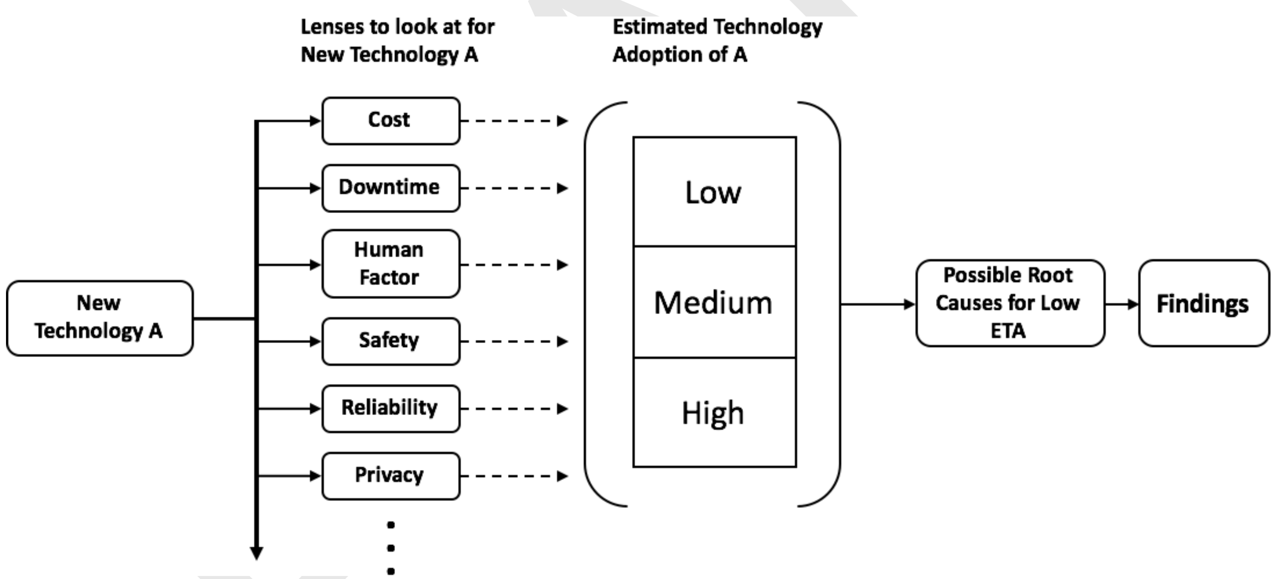

Figure 4: Schematic diagram for the usage of Estimated Technology Adoption

2.3.4 Technology Evaluation Table

For each new technology, the team assigned a TRL value between 1 to 9 and an ETA value of Low, Medium, or High as displayed by the table in Figure 5. In this table, 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 e˙orts seek to develop specifc 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 the GA operations in 2030. A good candidate should be one that has 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 the Appendix.

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 [2, 3, 4, 5]

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 were identifed to have the potential of shaping the future of GA in the 2030 time frame. A list of such technologies is provided below:

- **Propulsion System**: Distributed Electric Propulsion (DEP), 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 Controller-Pilot Data Link Communication (CPDLC)
- **Flight Control & Automation**: Fly-by-Wire and Autopilot System (Navigation, takeo˙ and landing-hands o˙)
- **Air Traÿc Control/Management**: Performance Based Navigation (PBN): RNP & RNAV, TCAS/PCAS/GPWS, and SWIM for Air Traÿc Management

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

- **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 infuence on GA 2030. Subsequently, the technology state-of-the-art 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 specifc 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 frst 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 around 2030. The next step was to categorize the technologies into fve areas: propulsion system, airframe material, advanced avionics/control systems, aircraft confguration, and airframe safety measures. Within each area, detailed methods, subsystems, or equipments were further divided into more specifc sub-areas accordingly. Information on aircraft models and aviation technologies were sourced from aircraft

GA Aircraft Technology	Manufacturer	Cirrus			Cessna							
	Aircraft	SR20	SR22	SR22T	Skyhawk	Skyhawk JT-A	Skylane	Turbo Stationair HD	TT^x	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

technical information sheets, news reported in multiple media, and journal papers. The aircraft technology portfolio table structure appears in Figure 6. Figure 7 shows an example portfolio table for a single engine fxed-wing aircraft.

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 include ones for business jet propeller driven fxed-wing twin engine aircraft, rotorcraft, multi-copters, VTOL concepts, electric aircraft, etc.

After the portfolio tables were created, mathematical interpretations were generated using portfolio vectors that were assigned to each aircraft model to record the number of available technologies. There are fve 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 confguration. Some examples for 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 that are available to the aircraft model being studied. The way to interpret these numbers is as follow: in Figure 7, take Cirrus SR20 as an example, it has 2 Y in safety measures, 1 propulsion architecture, 2 Y and 2 O in avionics/control system which (4 in total), 1 Y in structure material, and 1 airframe confguration. 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 total cumulative technology count can be calculated by using Equation 5, in which N is the total number of aircraft models reported in 2017 or the total 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 fve aircraft technology portfolio areas. For example, with the table in Figure 8, the ratios (in percentages) of airframe safety measurement, propulsion system, avionics/control systems, airframe material, and airframe confguration 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 sub areas. For example, avionics/controls system is comprised of synthetic vision system (SVS), enhanced vision system (EVS), weather-in-cockpit technology, and autopilot/automatic fight control system. Therefore, A_1, A_2 and A_3 in Equations 1-3 can be further decomposed into the following vectors:

$$A_1 = (1, 0, 0, 0) \tag{6}$$

$$A_2 = (1, 1, 1, 1) \tag{7}$$

$$A_3 = (1, 1, 0, 1) \tag{8}$$

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 fight control system) for the aircraft models under study. Similarly, the ratio between T and each specifc 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 fight control system.

2.4.3 The Sankey Diagram

Once the area vectors and sub-area 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 over the next 10 to 20 years. Figures 8 and 9 illustrate 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

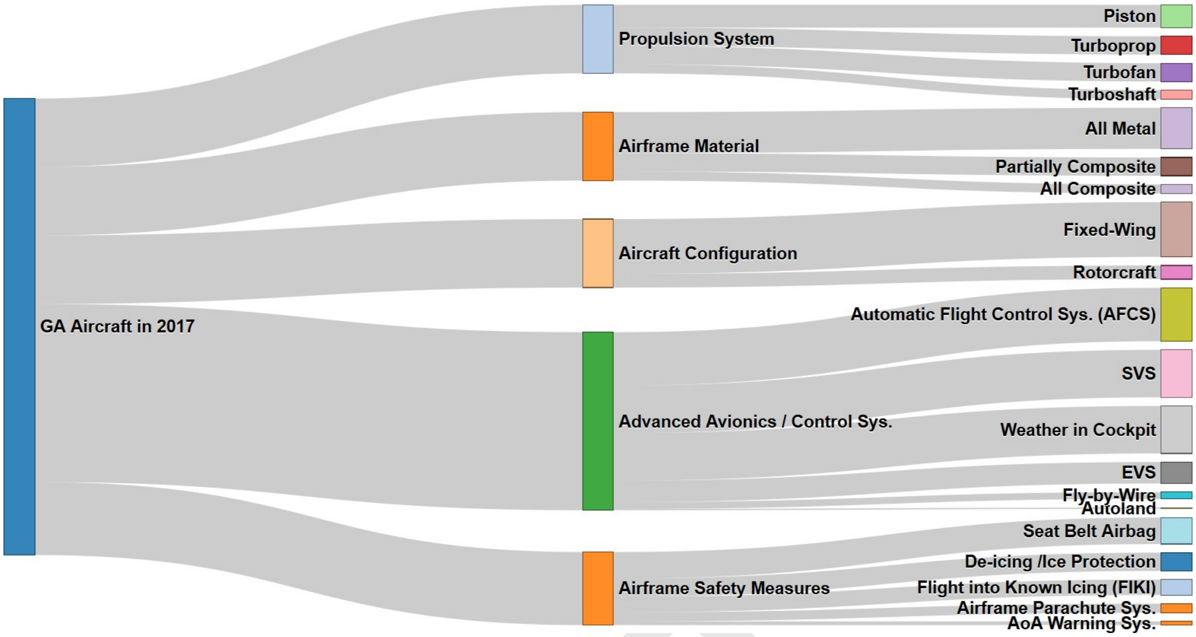

Figure 8: Sankey diagram of aircraft technology portfolio for new aircraft models in 2017

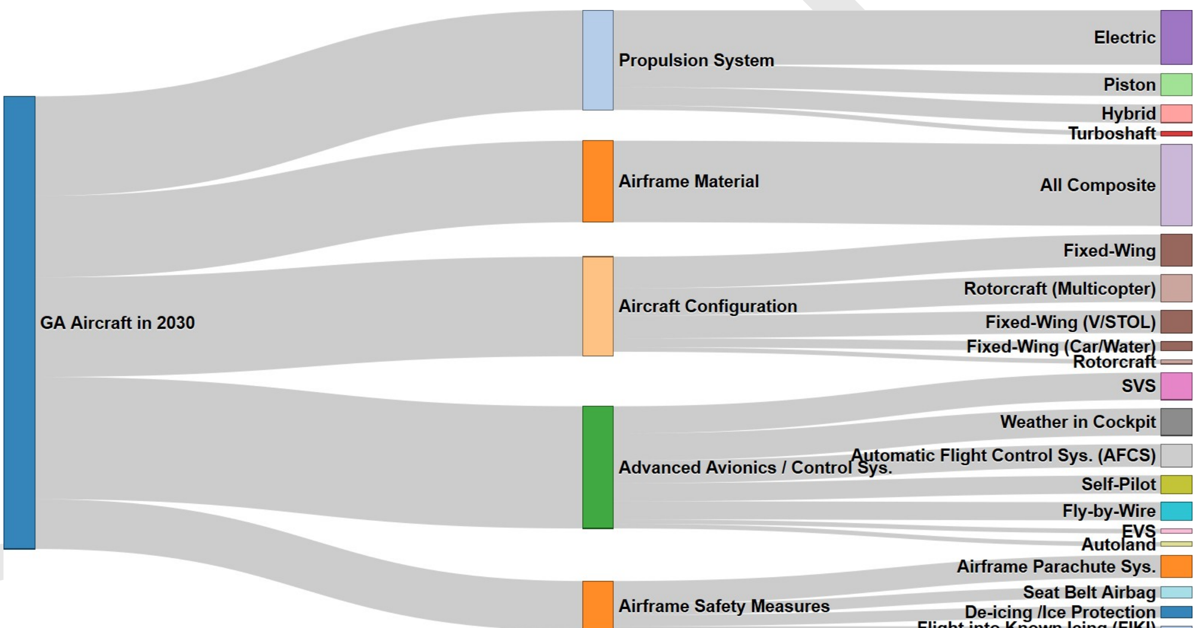

Figure 9: Sankey diagram of aircraft technology portfolio for expected aircraft models in 2030

engines, and their confgurations are either fxed-wing or rotary-wing. In the list of projected 2030 models, however, there are more diverse developments in aircraft confgurations. There are many new proposed confgurations in addition to fxed and rotary-wing confgurations such as multi-copters and V/STOL aircraft; this refects much of the current discussion about new vehicles being proposed or under development.

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 fber glass or carbon fber composites, etc. As for airframe safety measures, parachute systems and seatbelt airbags are currently implemented and proposed in several future GA aircraft. Last but not least, technologies such as self-pilot (i.e., autonomous fight with passengers aboard), fy-by-wire, and auto landing/takeo˙ are also expected to be used extensively on future general aviation 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 specifc 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 general aviation aircraft models.

Table 4: Percentages of the sub-areas in both Sankey diagrams

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

2.4.4 Technology Portfolio Analysis Conclusion

Finally, with the aids of the Sankey diagrams, the percentages for technology sub-areas in 2017 and 2030 are listed in Table 4. 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 confguration, airframe material, and propulsion system). Technologies such as self-pilot, fy-by-wire, and auto landing/takeo˙ are expected to be widely used for future GA aircraft;
- **New Airframe Confguration**: 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 confguration, 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, fber glass, carbon fber, etc.;

- **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 engine, 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 confguration are the subareas that emerge with a higher implementation ratio for future aircraft. This may be an indication that these key technology areas could infuence and drive the research and development work of GA aircraft over the next 10 to 20 years.

2.5 Certifcation

The new Part 23 has been in use since August 2017. It removes prescriptive design requirements and replaces them with performance based airworthiness standards [16]. As for the industry and GA community, the rewrite is a big step forward towards better certifcation 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 Part 23. The FAA has introduced a risk-based parts manufacturer approval (PMA) program which will enable newer and more cost e˙ective 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 di˙erent operational characteristics, all operating in a complex airspace. Techniques have been developed for UAS certifcation 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 certifcation of UAS based on they are operated [18, 19]. NASA has developed the Aviation System Risk Model (ASRM) 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 having di˙erent 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, 23, 24]. The increasing use of Commercial O˙-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].

Additive manufacturing is currently used in creating small, non-critical components of aircraft today. The use of additive manufacturing in GA aircraft is expected to grow rapidly in the future. The FAA

Technique		Applicability/ State of Usage	Since
Certification by Analysis	Conventional FEM method	AC No: 20-146. Followed largely in cabin crashworthiness certification	2003
Certification by Analysis	Argument-Goal Based	NASA has been developing argument based airworthiness strategy for UAS	2015
Certification by Analysis	Reduced order Modelling (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 or not, in modelling.	2012
Certification by Analysis	Model Checking and Simulation	Autonomous UAS operation certification.	2012
Certification by Analysis	Zone based Damage Tolerance framework	This methodology is proposed by FAA. FAA also working with industry in developing other strategies with respect to AM.	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.	2016
System Level Airworthiness Tool		Tool developed by NCSU to provide a comprehensive approach to sUAS airworthiness.	2010
Run-Time Assurance		The air-force research laboratory proposed this methodology for safety critical flight control systems. Air Force research Lab, Univ. Tulsa, NASA and FAA collaborated in developing certification strategies for Part 23 autopilot using RTA.	2016
Run-Time Assurance		NASA also worked on using run-time assurance of advanced propulsion algorithm.	2014
Advanced In-Flight Measurement Techniques (AIM^2)		Developed in collaboration of DLR, Gottingen 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 as they are able to capture a large number of parameters within a short time.	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.	2015

Figure 10: Certifcation technologies

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

Key to the eÿciencies promised in the Part 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 certifcation process quickly and are able to capture the levels of safety intended in these standards. Overall, certifcation plays a key role in the success of GA in the future. The above are examples of ongoing e˙orts to help demonstrate the level of required aircraft performance, system level airworthiness and risk based assessment, as well as show the path towards the future certifcation of new technologies.

2.6 Overseas Development

The benchmarking e˙orts 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: number of GA aircraft, number of GA airports, number of GA operating hours, number of GA related companies, etc. Nevertheless, due to the diÿculty of collecting data for all the indicators mentioned above, only the number of GA aircraft in di˙erent countries over the past 20 years are used to quantitatively compare status in di˙erent countries. Using data from GAMA [6] and the International Council of Aircraft Owner and Pilot Associations (IAOPA), Figure 11 shows the changes in the number of GA aircraft in di˙erent countries over the past 20 years 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.

In Figure 11, it can be observed that some countries, including China, Australia, Brazil and South Africa, have an increasing number of GA aircraft over 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 about the same level, or the authors do not have adequate information to comment on the trend. Below are the analyses of individual countries regarding their current GA status and future trends.

- **China**: As of June 2017, China has 2,776 GA Aircraft (1,808 fxed wing aircraft, 903 rotorcraft, and 65 airships and balloons), 22 fight academies, 311 GA airports, 2,524 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 around 15%. In recent years, the role of the GA industry has gradually been recognized by the Chinese government. As a result, relevant policies had been introduced to simplify the approval procedures, deregulate, and improve GA infrastructure [31]. In addition, a guideline published by China's General Oÿce of the State Council stated the

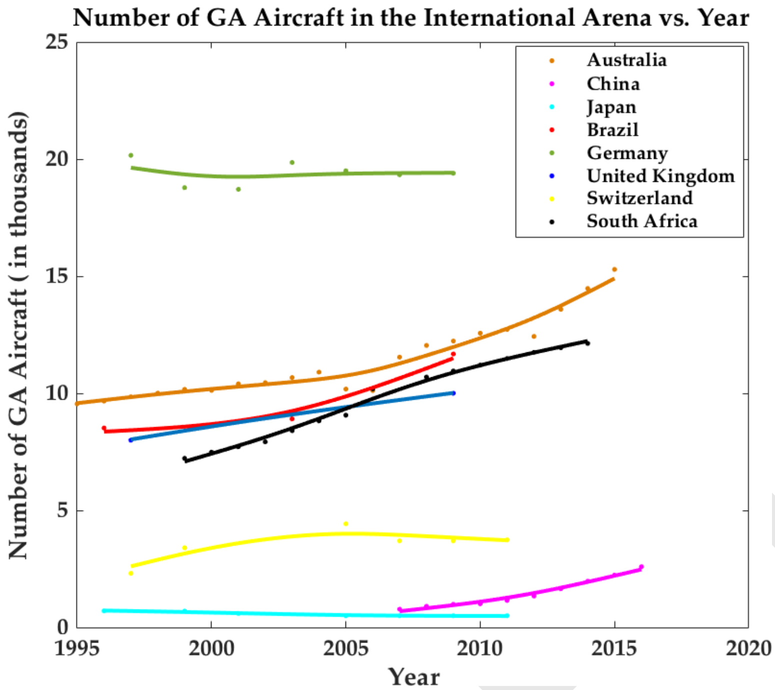

Figure 11: Number of GA aircraft in di˙erent countries vs. year (Sources: GAMA [6], IAOPA GA Statistics)

development objectives for 2020: over 500 GA airports, over 5,000 GA Aircraft and over 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 feet has over 140,000 aircraft and can access over 4,200 airports [6]. Currently available data are inadequate for a thorough economic analysis for GA in Europe, yet many indicators suggest that GA activities play a signifcant 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 towards simpler, lighter and better regulations for GA in Europe. Their latest actions including the new Part-DTO that alleviates the GA training domain, easier access to IFR fight, reorganization of CS-23, simpler rules for aircraft maintenance, etc. [33] Additionally, new technologies for future GA aircraft are extensively studied in Europe to keep pace with the evolving GA industry in EU. There are three main bottlenecks in developing GA in Europe: regulation, taxation, and access to services [32].

- **Australia**: The latest statistical report from Australian Government's Department of Infrastructure and Regional Development shows that as of 2015, Australia has 8,976 GA Aircraft and 1,544,400 GA and sports aviation operating hours/year [34]. GA in Australia consists of 5 sectors: aerial work (40.1%), instructional fying (27.8%), sport and pleasure fying (18.2%), own use business (12.7%), and others (1.2%). While commercial air transport hours in Australia increased by 4.8% in 2015, GA hours fown by VH (ICAO Aircraft Registration Prefx for Australia)-registered aircraft decreased by 2.6%. It is worth mentioning that out of the total hours fown in Australian aircraft activity in 2015 (3,432,100), 45.0% were GA and sports aviation hours, indicating that GA takes up a signifcant portion of Australia's aviation activities.

- **Japan**: Information on GA in Japan is limited in general. According to data provided by Aircraft Owners and Pilots Association Japan (AOPA-J) oÿcial website, back in 1968, there were over 1,000 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 less than 600 GA aircraft and around 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 has 15,342 general aviation/business aircraft and 5,867 experimental aircraft in 2017. The 2014 Brazilian Yearbook of General Aviation by Brazilian Association for General Aviation (ABAG) shows that since 2007, the GA feet 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 GA feet from around 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].

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 sta˙ 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 Identifed

The main outcomes of the 2017 Industry-centric workshop are organized below into seven themes: *Pilot Training and Profciency*, *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 & Future Facts* and *Research Needs*. As the workshop participants discussed future scenarios of what general aviation might entail around the year 2030, they began to make statements about what this future might entail in each of the identifed themes. While 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 these ideas as close as possible to how the workshop participants presented their thoughts.

3.1.1 Theme 1: Pilot Training and Profciency

Observations & Future Facts:

1. Pilot shortage will persist into 2030 - diÿcult to attract new pilots to fy GA
2. GA aircraft still requires 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 fy easier, cheaper and more streamlined? Can introduce more high-fdelity fight simulators for training in the future, but retain basic fying skills. Need to investigate redundancies in existing private pilot training requirements. The target should be $1,500 and within 20 hours for instrument rated PPL.
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 simplifed operations for current pilot to no pilot (fully autonomous) is to be identifed
6. Substantially streamlined and simplifed 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 & Future Facts:

1. Automation can improve current product and possibly increase market share
2. Investment is restricted due to small market and low return on investment
3. Accessibility of GA pilots to automated tools may be limited by cost, but technology fowing down from commercial aviation and up from UAS can help reduce the cost of automation
4. Tasks that can be automated:
   - Avoidance (traÿc collision, terrain, high density airspace)
   - ATC Communication
   - Weather (adjust course automatically)
   - Critical air vehicle
5. Autonomy can make fying easier and thereby training easier
6. Future ImagineAir or Uber-type on-demand models will use aircraft with 'driver/operator' instead of pilot

Research Needs:

1. Certifcation of automation software for smaller GA aircraft (potentially come from UAV or commercial aircraft side)
2. Research on what autonomy technologies are viable for small GA
3. Research on what sensors are required on board the aircraft for autonomy
4. Roadmap from simplifed operations for current pilot to no pilot (fully autonomous)
5. Possibly need new certifcate 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 & Future Facts:

1. Some airports already have large traÿc volumes, but others are nowhere close to the capacity they can fulfll
2. Runway incursion issues (e.g., towered and non-towered airports)
3. Issues on oversight and ownership of runways and airports (large roads, grass felds, etc.)
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, etc.)

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 di˙erent confgurations of GA aircraft
7. Di˙erence in infrastructure among owned airports to be investigated
8. Determine how will airports, aircraft rescue and fre fghting personnel deal with hazardous composite airplane structures after a crash

3.1.4 Theme 4: GA in the Future Airspace

Observations & Future Facts:

1. With growing UAS and future urban VTOL air taxi, the voice and transponder bandwidths will get overloaded. Airspace management would soon be needed to be automated.
2. Higher volume of vehicles in airspace
3. Confguration of airspace today is primarily commercial airline driven
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 aircraft but not all
7. Current GA will be heavily infuenced 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 (for example 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 artifcial intelligence acting as a service provider for airspace management
7. Evolution of airspace restrictions
8. Simulations of high density airspace with various aircraft type and modes of operation

3.1.5 Theme 5: Airframes, Legacy Fleet, and Maintenance

Observations & 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 a GA aircraft operate with the same reliability as a car
5. Current engines are from the 1930s eras without major upgrade to the basic technology. Hesitation to develop a completely new engine specifcally 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 di˙erent fuels (e.g., unleaded) on existing platforms is underway now

Research Needs:

1. Incorporating new technologies into legacy feet 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 Part 23 and Part 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 stations ratings need to be modifed 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 & Future Facts:

1. Reluctance to develop a completely new engine specifcally for GA (Current engines are based on designs from 1930s era)
2. Some statements in Part 33 (water containers) do not directly apply to GA engines
3. Diesel engine, electric and gas all have their pros and cons. Each requires specifc type of airframe design. Solutions are engineer-able, 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 done in UAVs, automobiles, power-generation industry, and COTS technologies
6. Improve battery and energy storage technologies
7. Powerplant improvements cover the whole product cycle from the manufacture of engines and batteries to all the infrastructure and materials needed for the installation and fnal removal of these hybrid powerplants. 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 & 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 defne 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 Di˙erences Between Workshops 0 and 1

An academic-centric workshop was held in May 2016, prior to the start of Project 25; hence, the title "Workshop 0". Workshop 0 helped seed the benchmarking task being 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 the workshops answered similar questions, ranging from the current state of GA, future possibilities, to in-depth analyses of factors that can infuence GA in the future. Di˙erences emerged in the responses from the participants from the two workshops; these arise from to various factors, the frst and most obvious one being the background of the participants: Workshop 0 comprised participants working in academia and researching technology that could impact GA, whereas Workshop 1 comprised people from the industry (e.g., airframe manufacturers) who have a direct business interest in the GA market. Figure 12 illustrates the distribution of participants from Workshops 0 and 1.

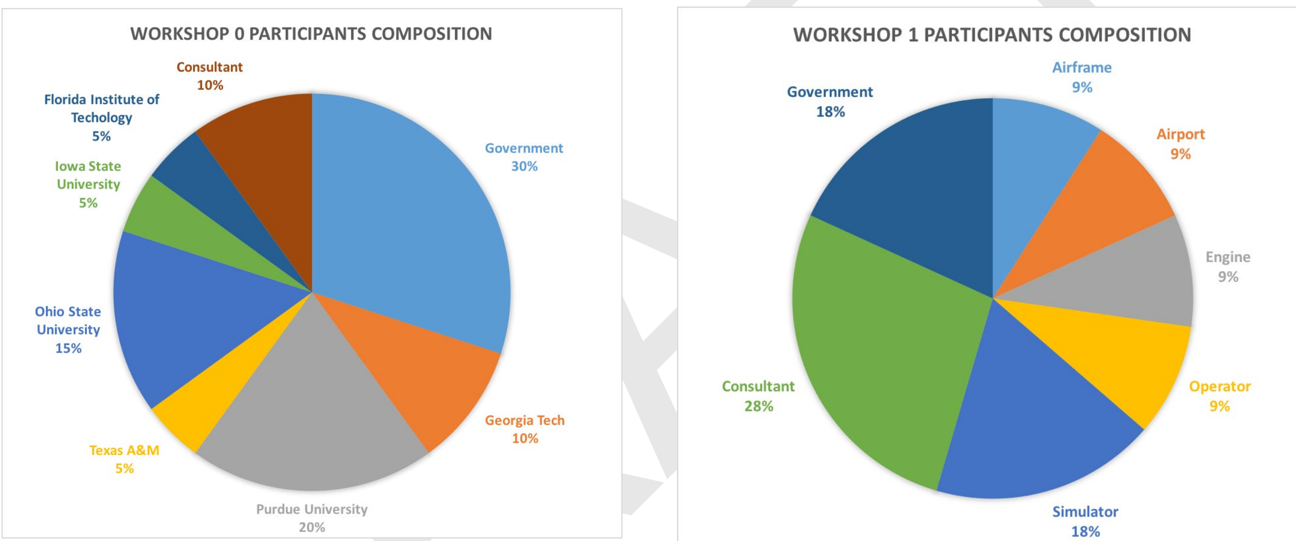

Figure 12: Participant demographics for Workshops 0 and 1

Several signifcant events that occurred in the time interval should be noted between workshops that might have impacted the workshop discussions. Between the frst two workshops, the FAA's new Part 23 rule was introduced, the Uber Elevate summit was held, ATC privatization was proposed in the US Congress, etc.

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

4.1 High Level Overview

A major di˙erence between the frst two workshops is that Workshop 1 contained an additional question during the in-depth analysis of topics: *"How should the work to satisfy/address the identifed needs to be* *conducted?"*, making Workshop 1 more result-oriented than Workshop 0. This provided more insights into the research steps that would need 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 the workshop was more focused towards raising the correct questions regarding GA. During Workshop 1, the format was slightly modifed for participants to raise questions and also to provide their inputs on possible methods to fnding the solution to those questions.

The team performed a word search of some selected 'critical words', which imply a specifc item or technology for GA 2030 and were decided upon 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 total word density from both Workshop 0 and Workshop 1. This exercise was done to throw a 'safety net' on the details of the workshop information collected to look for minute details that may have been missed out, while looking at the bigger picture. This search also provides insights to what the attendees in both workshops considered a priority when discussing GA 2030.

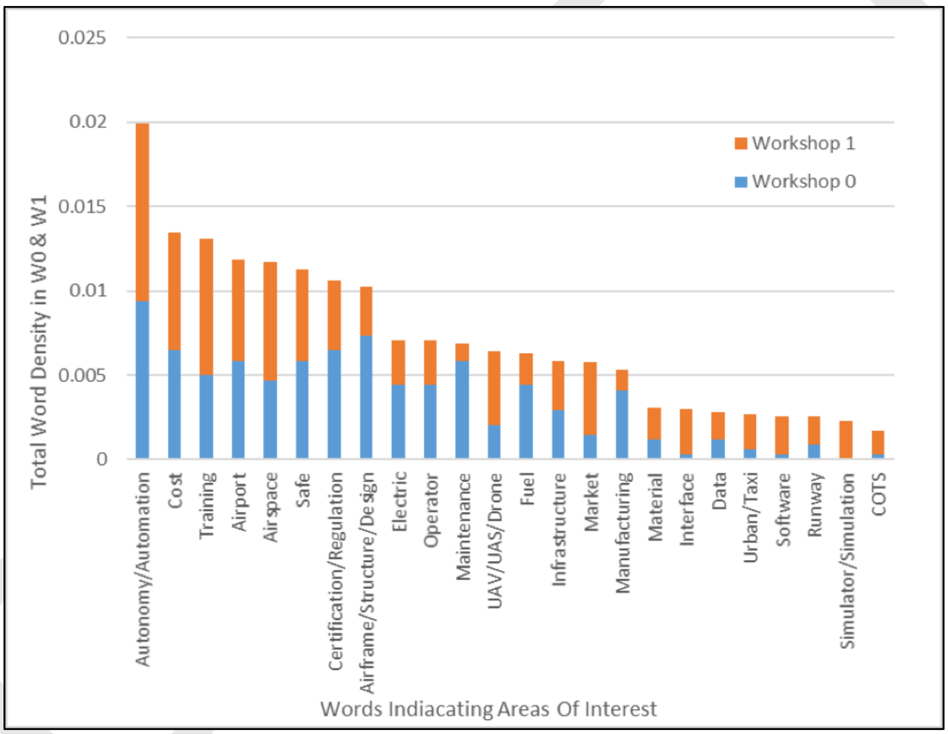

Figure 13: Total word density from Workshop 0 and 1

The search was done 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, due to 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 total 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 di˙erence 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 about the same extent in both workshops can be found in the center (green) part and words discussed more often in Workshop 0 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 suÿciently discussed and if additional stakeholder input is required for in-depth analysis into some known topics or to fnd additional items that are critical to GA in 2030.

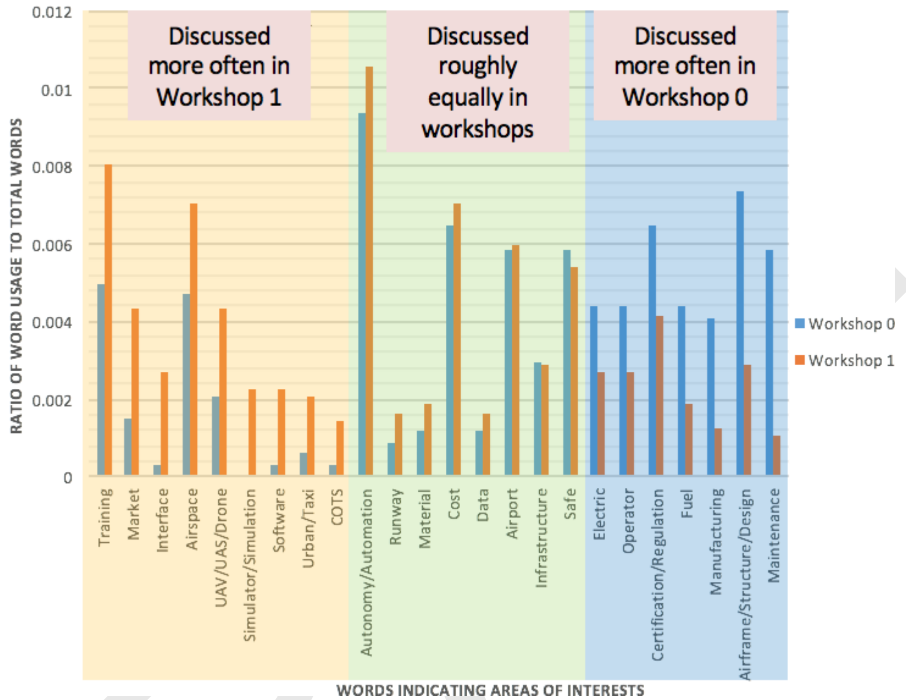

Figure 14: Word density comparison

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 for 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
- Certifcation/Regulation
- Operator
- Electric

Topics that appear to be of roughly equal importance to participants from 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 insuÿcient in understanding the nuances of the ideas expressed by the participants in the two workshops. Words may have been used in di˙erent contexts to express di˙erent points concerning similar topics. Thus, an in-depth analysis was performed and discussed in the next section.

4.2 In-Depth Comparison

4.2.1 Similarities

The largest discussion in both workshops in terms of prioritization by participants and also from the word search is 'autonomy'. The word search shows that Workshop 1 had slightly higher mention on autonomy, but both the 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 due to complex certifcation process and maintenance and investments to bring in new technologies. Cost was also discussed in terms of retroftting older aircraft with newer technologies compared to building a completely new aircraft. Workshop 1 participants also identifed 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 specifc discussion of infrastructure and airport, 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 which may enhance safety. The requirement for safe operations was identifed, but the process of achieving that goal in the future was not explicitly discussed. It is also important to note that even though certifcation was discussed more often in one workshop than the other, no prioritization was done in either workshop. Safety and certifcation 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 certifcation and also improve pilot situational awareness. Participants from both workshops pointed to runway incursions being a pressing problem and with growing traÿc, a potentially larger problem in the future. Workshop 1 had a slightly higher mention of runway, 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 Di˙erences

In addition to the added questions in Workshop 1, major di˙erences exist in the results from the two workshops. The primary di˙erence was with regard to the items prioritized by the participants to perform an in depth analysis on.

Workshop 1 participants spent signifcant 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 growing new technologies, the training required to reach adequate profciency for fying future aircraft needs. 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 aÿliations, demonstrated a keen interest in the growth of technologies in the simulator segment. Their opinion was that a high fdelity simulator would help in aiding pilot training in the future, thereby reducing the fight time needed to become profcient and maintain profciency in fying (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 general aviation. 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 'simplifed 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 'simplifed 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 specifcally 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 is 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. Due to 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.

Certifcation 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 modifcations to Part 23 and wanted to work towards such methods of certifcation. 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 Part 23.

With market constraints and the new Part 23, Workshop 1 participants emphasized the need for commercial o˙ the shelf (COTS) equipment. COTS is seen to be a possible solution with regard to cost, acceptance, better performance and quick certifcation. COTS specifcally 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 the workshops. In Workshop 0, infrastructure or airports were not discussed exclusively, but questions regarding the infrastructure were raised in most of the prioritized topics. In Workshop 1, participants specifcally discussed airports, the possibility of drone ports, remote controlled airports and other possibilities for increasing the number of landing locations.

Workshop 0 participants identifed electric (hybrid, complete, etc.) 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 by itself. 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 airframe and design can only occur along with the discussion of future propulsion systems; participants generally viewed a move towards 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 airframe and design was deemed important but not prioritized during this workshop. Workshop 0 participants prioritized both the future propulsion techniques and the possible future airframe structure and design. The word search also points to the 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 in depth discussion of maintenance. However, Workshop 1 participants also identifed maintenance as being an important aspect.

Fuel and alternative energy sources for general aviation were discussed to a larger extent in Workshop 0: possible future 'fuel' scenarios, fuel eÿciency through better-designed airspace, regulatory framework required for alternative fuels, etc. Workshop 1 participants raised research questions about what would be the transition roadmap from current fuels to green fuels and fnally electric propulsion. Workshop 1 participants did mention that the research for alternative diesel engine fuels is low due to the small market size for the diesel engines themselves.

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 indicate a higher level of interest from participants. Workshop 1 participants on the other hand 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 fying, 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 specifcally 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 frst 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 was available. Participant expertise in the area of airports/infrastructure, data/communication networks and avionics was also present. The GA community was represented by participants from the General Aviation Manufacturers Association (GAMA) and Experimental Aircraft Association (EAA). The workshop took place over one and half 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 e˙ort to prioritize these themes in the context of developing a research road map to address the future challenges for GA. Because of the di˙erent set of participants and the desire of the moderators to allow the participants to freely contribute their inputs, there were some di˙erences in emphases. To maintain some consistency between the two workshops, a set of research assistants and research sta˙ 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 Identifed

Workshop 2 participants reviewed the themes developed in the previous workshops and performed an in-depth analysis into the themes the participants considered important. One additional theme, *Aircraft/Aviation Connectivity*, was introduced during Workshop 2 which joins previously developed themes: *Autonomy and Automation*, *Pilot Training and Profciency*, *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 identifed during Workshop 1.

5.1.1 Theme 1: Pilot Training and Profciency

Observations & 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 profciency 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 profciency requirements for operating a future GA aircraft easier

5. Simulation Technology:

    - Di˙erent levels of simulation technology exist
    - Use of high fdelity, high cost simulation is a barrier in GA today. Process of implementation is time consuming to e˙ectively 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 profciency

Research Needs:

1. Remote trainer and remote monitoring with full situational awareness in addition to pilot (trainee) on board a possibility

2. Should the revisions to the Airman Certifcation Standards (ACS) with regard to demonstrating stall recovery procedures necessitate changes to stall characteristics of new aircraft certifed under Part 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-fight simulator” using augmented learning. Some form of autopilot controls fight envelope until human profciency is achieved:

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

6. Collection of data on current simulation implementation and impact on pilot profciency and in the future collect data for every level of augmentation implemented in fight training to enable future technology development

7. How to reduce cost of retroftting auto-pilot (to include various advances in automation and/or autonomy) in aging feet?

8. Type of aircraft maintenance certifcation required? UAS infuence 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-carrying GA aircraft fall in between?

9. Determine what airman certifcation standards/limitations would apply to an airman fying or maintaining a fully electric airplane [Note: the person certifed to fy/operate may not be certifed to maintain]

5.1.2 Theme 2: GA in the Future Airspace

Observations & 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 specifcally 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 today

3. On-Demand Mobility (ODM) will change traÿc 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 traÿc 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 de-conficted, but cannot currently de-confict intent

7. There is currently low computing power on-board GA aircraft. Low-level FMS-type equipment and current human-machine interface requires lots of human involvement. Future GA will change this.

8. Any potential in uncontrolled airspace will have push-back from fying/pilot community

Research Needs:

1. Determine whether there is a need to redefne the airspace in the future. Map large underutilized portions of the airspace

2. Need for ubiquity in airspace services. Newer operations will open accessibility to areas which currently have low traÿc. Need to identify such locations and upgrade infrastructure.

3. Need to incorporate 4G LTE and IAP 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 traÿc environment with manned UAS (e.g., passenger carrying vehicles) in airspace. Agent-based collision avoidance is one possible solution. Can collision avoidance occur in layers? That is, frst 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 defnes the 'intent' of an aircraft?
   - How to identify intent when the fight plan is prone to dynamic changes with human intervention?
   - How much 'intent' information from a fight required at a given time to enable suÿcient 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 NAS. Have NASA, FAA and DOD collaborate to check operability of simulated future airspace where 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 the proposed on-demand mobility 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, safer to fy more traditional GA aircraft with much less expense that is today. 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 fy? Ties in with airspace management (controller providing guidance)

9. In a world where major aircraft OEMs are going for electric alternatives, what are the capacity issues at major airport hubs?

10. Is it feasible to have specifc routes for di˙erent aircraft with di˙erent purposes? Di˙erent types of routes for di˙erent types of operations?

11. Conduct a review of the impact of drones on GA aircraft. Aside from the existing certifcation 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 & Future Facts:

1. Currently, pilots obtain fight information from several sources. With Application Programming Interface (API), essential fight information (e.g. weather, obstacles, clearance, etc.) or the best solutions for fight condition (e.g. for 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, currently, there is no such app to put all this information on displays together.

2. Very positive feedback from pilot community with respect to mobile device applications. Certifed API will provide many ways to integrate with FAA's information. Pilots will be in a better position to make more informed decisions.

3. Faster and more eÿcient recovery from adverse conditions compared to traditional method-set and user-defned object.

4. The implementation of API to an "aviation internet" opens scenarios for ODM, and there is a fnancial beneft to it 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, hardware, etc. 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. Internet of Things (IoT) is a revolutionary concept for future aviation network, and GA could be a good test bed for the implementation of related technologies

Research Needs:

1. Comparison of hosting apps in the cloud vs. aircraft specifc

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 maybe 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 eÿcient and more fexible than changing hardware

7. For weather related accidents, the operators had weather in their cockpit, but something still missing or there are issues when forecast changes. The diÿculties 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 hacker 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
    - Cyber-security is a feld 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 & Future Facts:

1. Benefits of hybrid-electrifcation of aircraft, electric aircraft, is more than environmental. It can carry people where you could not before, more types of missions are possible, and extremely eÿcient. Even the regional airports that were dying o˙ 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 equipments from lowest bidder for infrastructure requirements. Due to this, airports must maintain spare parts from di˙erent manufacturers

5. Requirements for airport projects can be tailored when it comes to choosing manufacturers

6. Federal funding is geared towards commercial airports and commercial air transportation projected to increase. Di˙erent 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. Electrifcation 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? Also, 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 feet and 54% of U.S. feet can burn unleaded fuel, but GA is a small user group and need to consolidate to one fuel to reduce costs. A lot of alternatives are emerging, but eventually it will consolidate towards 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 traÿc that can be provided to pilots. Super AWOS is another way to capability; 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 remote airport to facilitate safe operations.
7. With increased UAS operation and growing airport traÿc, 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: Quantifable data on winter ops (runway temperature, type of snow, runway contaminant coverage percentage, etc.) - LIDAR mounted on a truck can be driven down the runway and quantify those observations, drones can also be used. Drones can also be used to inspect things like VASI/PAPI lights. What all these mean for airspace management at airports? What are the di˙erent issues for smaller GA-serving airports?
9. Connectivity solutions at airports could be improved. What would it look like to have 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 Crash-worthiness and Survivability

Observations & 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 di˙erent tests for crashworthiness and survivability; leverage inspiration and lessons learned from other applications (like NASCAR)
3. With more composite aircraft structure in the future, these structures will consider the dynamics of the crash and address energy absorption
4. More technologies on board can help prevent LOC, hence there will be fewer crashes / impacts

Research Needs:

1. Research on designs that can survive high energy crashes such as LOC and CFIT 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 structure that could harm the pilot during a crash.
3. Study to mitigate crash energy: absorbents, infatables (e.g. NASA's honeycomb design), or ballistic recovery parachutes as high-altitude savers
4. Will helmets be a suggestion? This is becoming acceptable. Study to make headset to be a helmet or an air bag, or curtain infation. Also, automatic seat belts, ejection seats, and post-crash fre prevention (e.g. improve fuel tanks) need further study and defnition of standards.
5. e-VTOL safety problems:
   - More consolidated system preventing the electrocution accident
   - 2G-roll requirement for ducted fans
   - Diÿcult/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 to conduct a controlled descent into trees, which can absorb 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. Since most o˙-airport crashes will have law enforcement oÿcers being the frst 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 & 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 amongst pilots ("automation trust human" vs. "human trust automation").

3. Complete autonomy is the end state where people want to reach, but there are lot of issues to work through for automation currently

4. There are a lot of tasks that can currently be automated and combination of these small automations will defne the path towards complete autonomy

Research Needs:

1. Communication, "see and avoid" need further work to be completely automated. Having no humans at ATC is currently diÿcult now because of human interaction (voice, etc.). Automated ATC is very diÿcult and still an open question: how it will turn out?

2. Road map to autonomy: have a fight training program where there is always a fight instructor having full situational awareness? Perhaps this fight instructor is a remote instructor on the ground.

3. Looking for short and long-term benefts of automation (e.g. If the aircraft is capable of landing by itself, even in emergencies, then the pilots don't need a medical certifcate)

4. Guidance to compliance and the ability to be within compliance. Compliance inside the cockpit and outside (aircraft state, fight rule state).

5. Managing the extent of human factors within automation and operations:

   - Level of automation -> extent of control -> failure enunciations
   - A˙ects level of training necessary for operation

- Extent of degraded mode. Defne failure modes of automation in operation
- Level of automation and reliability dependent on profciency of pilot

6. Provision for cloud-based AI (specifc AIs) to get in aviation (Might easy to implement through apps, if certifed API is connected to aircraft via aviation Internet concept)

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

5.2 Prioritization of Research

Workshop 2 included an opportunity for participants to try to prioritize research in these themes, trying to address what areas have the most impact and what areas need to receive attention frst because they are prerequisites for subsequent research. The participants provided some inputs; however, the time dedicated to this exercise, after the preceding sessions, was insuÿcient 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 eÿciency. Airspace redesign can follow closely.

2. Infrastructure growth in low traÿc airports to increase accessibility. Ties in with growth in connectivity and airspace redesign.

3. In a current uncontrolled airspace, create a test bed for future airspace to explore implications of improved connectivity, automated functions. Build a private system of a coordinating aviation system to test ideas discussed. Alternate fight rules be used.

During the time allocated to prioritization, the workshop participants o˙ered two other thoughts that had not been directly addressed in the workshop. The Project 25 team believes that the participants may have o˙ered these in the mind-set that this was the “last chance” to add input.

1. There should be an improved awareness of general aviation growth outside of the United States. What does this mean for mutually-benefcial research activities?

2. With concern that the current model of general aviation remaining at a relatively small and steady level, as refected in some of the forecasts, with an aging pilot base, there appears to be some room or scope for business case studies. What are the socio-economic factors that will infuence future GA? Those studies could more fully describe the possible state of GA in 2030.

6 Similarities and Di˙erences between Workshop 2 and Previous Workshops (0 & 1)

Workshop 2 was di˙erent from the previous workshops in terms of composition, format and expected outcomes. The Workshop 2 participants were provided with the information collected from previous workshops. Due to this fact, 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 di˙erence is presented here.

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

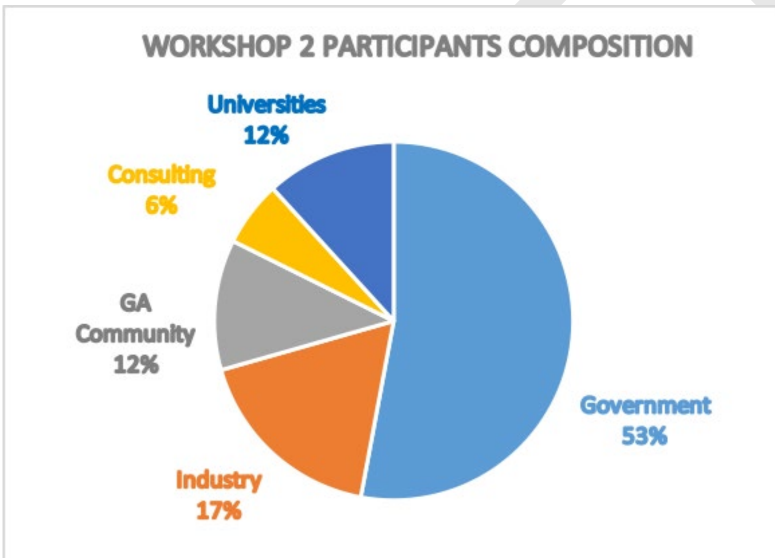

Figure 15: Workshop 2 participants demographics

As per design of the workshops under this project, government representatives were present mainly presented as observers or faciliators 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 where the government, industry, community and academia convene and have an open honest discussion regarding the possible future scenarios of GA. Some industry participants had extensive previous work experience with government agencies as well, 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 invited to Workshop 2. Thus, from being a purely government-centric workshop, Workshop 2 consisted of participants encompassing the majority of the GA stakeholders.

The composition of Workshop 2 a˙ected 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 took place with regard to new theme development. The main expectation of this workshop was to fnd gaps in scenarios and themes that have not already been captured and to address them. In other words, the goal was to fnd and develop new themes that were not discussed by previous workshops and enhance critical themes previously identifed. Another key expectation was to defne a possible road map of 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, cyber security and data were mentioned in the previous workshops, but the identifcation of the role of connectivity in GA in the future had not been taken into consideration before. Workshop 2 participants discussed the impact of connectivity on airspace and airport infrastructure.

Di˙erences between automation and autonomy were more fully established in Workshop 2. Autonomy was considered to be the fnal expected state of complete automation. It was the view point of the participants that several small levels of automation can be done currently, but a big leap, specifcally 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 'specifc function' pilot certifcation.

UAS was discussed in Workshop 2 from various perspectives: crowded airspace, technology enabler, future operations, noise and environmental concerns, certifcation 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 fying under a community based set of standards (Part 101) are required only to notify the tower (14 CFR 101.41(e)). Those UAS operating under 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 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 PEGASAS Project 25 with the addition of information collected from a prior FAA/PEGASAS workshop in 2016. The objective of these e˙orts was to explore and analyze future General Aviation 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 specifc workshops, or other focused e˙orts, to convert these research themes and questions into a specifc strategic research plan. This plan may then provide guidance for future research requirements.

The benchmarking task identifed the top four challenges in future GA: *Certifcation*, *Airspace Management*, *Infrastructure*, and *Cost*. The investigators also identifed fve key transformational changes that will impact the future of GA: *Urban Mobility*, *Transformational Propulsion Architectures*, *Enabling Technologies*, *Automation*, and *UAS Activities*. Through the technology metrics study, the team investigated 36 new technologies using a combination of two metrics (TRL and 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 identifed that new technologies in the areas of *Airframe Materials*, *Propulsion Systems* and *Aircraft Confguration* are expected to have higher implementation ratio for future GA aircraft in the 2030 timeframe. Observations on certifcation and overseas status of GA are also included in the benchmarking section.

Table 5 summarizes the themes identifed through the e˙orts of this project. Recurring themes of similar intent are placed adjacent to one another. From all the tasks performed during this project, ten unique themes emerged for future GA research activities.

Table 5: Identifed Research Themes

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

7.1 Research Recommendations

In the view of the project investigators, common topics from the benchmarking activity and the workshops which 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 highest priority topics are:

- **Airspace Management**: New air traÿc control methodology development by simulating future airspace scenarios
- **Airport Infrastructure**: Future aircraft and traÿc would need to be accommodated by the network of airports
- **Automation**: Systems on-board or external to the aircraft to 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 (API)

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 topics mentioned above will fuel innovation in specifc GA areas. In the view of Workshop 1 and 2 participants, new propulsion concepts are already under development and require immediate attention. With large OEMs investing in newer concepts, GA propulsion systems will change signifcantly. In the opinion of Workshop 1 participants, developments in new airframe confguration and new propulsion systems will have to occur simultaneously as they are highly coupled to each other.

With the advent of UAS, future GA will include a form of hybrid rotorcraft. The noise emanating from the rotors of future aircraft will be a social hindrance which 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 future, more activities can be undertaken to ultimately 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 identifed 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 will be used to defne focus areas for further in-depth workshops and as the base of a roadmap for the strategic GA R&D plan for the 2030 timeframe.

2. **Topic-specifc workshops:** Potential topic-specifc workshops can be held to help develop the roadmap for GA R&D plan for 2030. Using the streamlined process for the most relevant research topics, the team will identify subject-matter experts (SMEs) or domain experts for relevant areas. If the number of SMEs identifed 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 SMEs, 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.

8 Appendix I: Complete TRL and ETA tables

Table 6: Complete TRL and ETA table - Part 1

Technologies	TRL	Status in 2017	ETA	Status in 2030	ETA
Distributed Electric Propulsion (DEP)	5-6	First NASA DEP manned fight demonstrator had been achieved in 2017	Low	No forecast yet	Low - Medium
Hybrid-Electric Propulsion System (HEPS)	2-3	Airbus's plan initialed back in 2013	Low	Regional hybrid electric fight demo before 2021, practical airliners in 2030 - 2035	Medium
Hydrogen Powered Aircraft	6-7	First passenger aircraft prototype took o˙ in Germany in 2016	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 retroft 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

Table 7: Complete TRL and ETA table - Part 2

Technologies	TRL	Status in 2017	ETA	Status in 2030	ETA
Solar powered Aircraft	7	Already have a few successful prototypes	Low	Not a practical solution for future GA aircraft because of the aerodynamics design, eÿciency and operational limits	Low - Medium
Eÿcient Electric Aircraft Charging Station	3	First EA charging station in 2011. Two cities in California are installing the frst network of charging infrastructure	Low	Expect to form charging station networks in some areas (like SF bay area)	Medium
Fly by Wire	8	Successful fight test by Diamond Aircraft on DA42 in 2015	Medium	More prototypes aircraft with similar system will initiate their fight test	Medium - High
Autopilot System	9	Current autopilot systems can help pilot reducing workload and fying with higher precision and increased situation awareness	Medium	More prototypes aircraft with similar system will initiate their fight test	Medium - High
Auto landing	8	Successful fight 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

Table 8: Complete TRL and ETA table - Part 3

Technologies	**TRL**	**Status in 2017**	**ETA**	**Status in 2030**	**ETA**
Synthetic Vision System (SVS)	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 fying in hazardous weather or environment with low visibility	High
Enhanced Vision System (EVS)	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 fying in hazardous weather or environment with low visibility	High
Weather in Cockpit	9	Most of the GA aircraft has this technology as an optionalfeature, not a standard feature	Medium	More GA aircraft equipped with these aiding systems to help pilots fying in hazardous weather or environment with low visibility	High
ADS-B (out)	9	By 2020, every GA aircraft in US will 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 fight test mission in 2016	Medium	ADS-B in and ADS-B out will be a standard feature for every GA aircraft, and UAS	High

Table 9: Complete TRL and ETA table - Part 4

Technologies	TRL	Status in 2017	ETA	Status in 2030	ETA
CPDLC	9	Controller-Pilot Data Link Communication is available on the majority of airlines and few business jets for transoceanic fights	Medium -High	FAA planned to implement CPDLC for domestic routes in 2019. By 2030, 85% of Air Traÿc Service communications are to be provided via data-link	Medium -High
PBN: RNP & RNAV	9	Major airports and Class A-C airspace have RNP regulations. Most GA aircraft with a GPS have the RNAV capability.	Medium	All IFR regions to have RNAV capability, including LNAV, VNAV and LPV. Higher RNP may be required for continental fight	Medium -High
TCAS/ PCAS/ GPWS	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. Di˙erent 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
Air Traÿc Management 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 Traÿc Management	6-7	NASA recently demonstrated the UTM technology by conducting 'out-of-sight' tests	N/A	Expected to reach high fdelity by 2020, but mainly for UAS applications in uncontrolled airspace. Next steps could expand to controlled airspace	N/A

Table 10: Complete TRL and ETA table - Part 5

Technologies	TRL	Status in 2017	ETA	Status in 2030	ETA
AM Process and Methods	7	The process need to be further simplifed 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
AM Materials	7	Having di˙erent materials for di˙erent 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 are rare to fnd	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 frst fight test, 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 fight test for a few times	Low	More hybrid aircraft will complete their fight test, and some will enter the GA market	Medium
VTOL Aircraft in GA	2-4	Some concepts and new designs aimed to have fight test at the end of 2017	Low	More proposed future VTOL aircraft design will complete their fight test for one or two passengers	Medium

Table 11: Complete TRL and ETA table - Part 6

Technologies	TRL	Status in 2017	ETA	Status in 2030	ETA
Pultruded Rod Stitched Eÿcient Unitized Structure (PRSEUS)	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 some research recently	Low	Prototype aircraft comprised by this method will initiate their fight test	Medium -High
Bionic Structure (AM + Design Optimization)	4-5	Airbus already has a team in developing this advanced structure technology along 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 use this technology on their GA fxed 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 is still an optional feature	Medium	Every GA aircraft has thisequipment on board	High
Seatbelt Airbag System	9	Almost every GA aircraft can have this technology on board, but still an optional feature	Medium	Every GA aircraft has thisequipment on board	High
AoA System	9	Some GA fxed wing aircraft made this as a standard feature	Medium -High	More fxed wing aircraft will have this equipment on board.	High

9 Appendix II: 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
Pfei˙er Consulting
Piper Aircraft
Port Columbus Airports
Purdue University Airport
SmartSky Inc

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