Partnership to Enhance General Aviation Safety, Accessibility and Sustainability (PEGASAS) PROJECT 25 "GENERAL AVIATION 2030: GA EXPLORATORY ANALYSIS" Interim Report

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1 Project Overview

The General Aviation 2030 - GA Exploratory Analyses is Project No. 25 within the Partnership to Enhance General Aviation Safety, Accessibility and Sustainability (PEGASAS) under the Federal Aviation Administration (FAA) Center of Excellence (COE) for General Aviation. The objective of this project is to analyze and explore future general aviation topics that warrant research efforts so that various stakeholders in the GA community are better prepared to address needs in the next fifteen or so years. The project has two main components: a thorough benchmarking task and two GA workshops.

The benchmarking task is a review of the future of General Aviation to help uncover topics and issues that may reside outside of the workshop participants' expertise. The first workshop was a industry-centric one held by the Georgia Institute of Technology in Atlanta, Georgia back in late June, 2017. And the decision was made to host a second government-centric workshop held by Purdue University in West Lafayette, Indiana to get broader input about future topics. Format of the workshops repeats the basic format used in the May 2016 workshop to elicit input from industry and government colleagues.

The final product of this project will be a final report documenting the information gathered from the benchmarking and the output of the workshops (including the May 2016 workshop). A presentation will also be created to highlight the key findings and facilitate the dissemination of the research efforts. The project will generate three deliverables:

1. An interim report that identifies similarities and gaps between the FAA/PEGASAS Workshop from May 2016 and the industry workshop generated information. Due date of the interim report will be August 31, 2017.

2. A final technical report addressing findings and recommendations, incorporating feedback gathered in response to the interim report as well as additional information from the government-oriented workshop. The draft version will be due on November 30, 2017.

3. A briefing by the team at the 2018 PEGASAS Annual Meeting (late May or early June 2018).

2 Report Overview

This interim report marks the end of Task 1 - Benchmarking of Future GA Trends and Workshop Preparation, and Task 2 - Workshop I Execution. The main outcomes of the benchmarking task, Workshop I, and the post-processing works of the collected workshop inputs, are documented in this report. Overall the report contains three main sections:

- Summary of the findings from the benchmarking task.
- Main outcomes from 2017 Workshop I.
- Identification of similarities and gaps between the FAA/PEGASAS Workshop from May 2016 and the industry workshop from June 2017.

3 Benchmarking Task

3.1 Future Trends for General Aviation

3.1.1 Overview of the Current Status

General aviation plays an important role in the national air transportation system. According to FAA's report, three out of four takeoffs and landings at United States airports are conducted by general aviation aircraft [1]. 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 [3]. General Aviation Manufacturers Association (GAMA)'s data-book shows that currently there are over 210,000 general aviation aircraft based in the United States, with over 24 million flight hours every year [2]. As for the contribution to the economy and creating jobs, latest data in 2016 show that general aviation activities are supporting $219 billion in total economic output and 1.1 million total jobs in the United States [2]. Additionally, general aviation activities are estimated to reach to more than 5,000 U.S. public airports, compared to less than 400 airports served by scheduled airlines [2].

Changes in advanced technologies, regulations and economic activities observed over the past few years will profoundly alter the future of general aviation. With the advancement of distributed electric propulsion (DEP) technology and technologies aimed to improve safety, urban mobility may emerge as major transformational concepts. Autonomy level is most likely to be raised, in areas such as trajectory planning, to further simplify the role of human pilots. Furthermore, issues in predicted congested airspace resulted from the increasing UAS activities are yet to be solved. Rewrite of FAR 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. With all these foreseeable changes, the FAA have projected forecasts for general aviation between 2017 and 2037.

3.1.2 GA Forecasts for 2017-2037

Among the numbers projected by the FAA, changes in three characteristics are worth mentioning here: numbers of active general aviation aircraft, active pilots and general aviation hours flown [1].

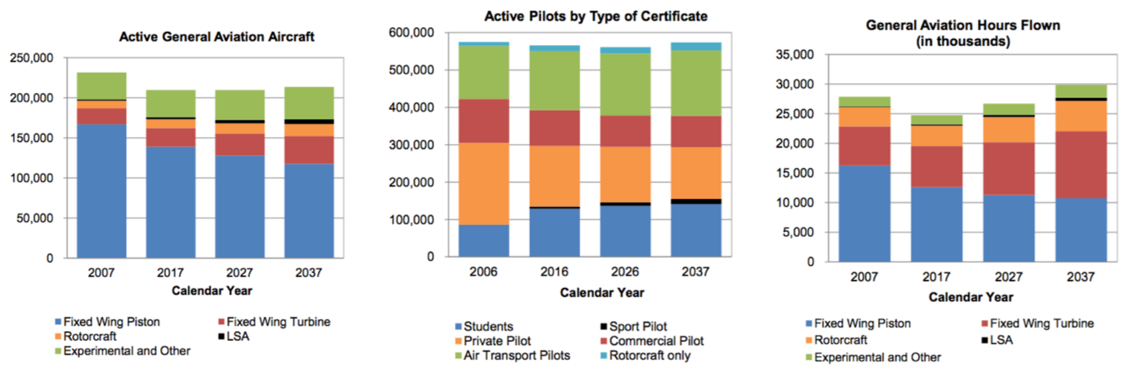

Figure 1: GA forecasts in fleet (left), pilots (middle) and flight hours (right), source: FAA [1]

According to the forecasts, no substantial changes in fleet, pilot population and total flight hours, are expected. The active general aviation fleet is projected to increase at an annual rate of 0.1%, because of the general increases in fixed wing turbine, rotorcraft and light sports fleet. This increase is expected to offset a decline in the fixed wing piston fleet [1]. 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 certificate rules [1]. The total number of general aviation flight hours is projected to increase at an annual rate of 0.9%, as the utilization rates for new business jets are expected to increase [1].

3.1.3 Top Challenges in Future GA

Although the total volume of general aviation may stay at the same level by the year 2030, the composition of general aviation in all the aspects is expected to change. In transitioning from its current state to the projected state in 2030, general aviation may face many challenges. With newer forms of technology, innovative operations, larger data and cross-domain technology, the challenges for a safe, efficient, profitable and environmentally friendly general aviation ecosystem are enormous.

The recent UBER Elevate summit report described key challenges as the certification process, battery technology, vehicle efficiency, vehicle performance and reliability, air traffic control, cost and affordability, safety, aircraft noise, emissions, infrastructure and pilot training [4]. The UBER report is primarily for the On-Demand VTOL concept aircraft, but it does highlight the four key challenging areas identified for general aviation as well: *Certification*, *Airspace Management*, *Infrastructure* and *Cost*. The top four challenges in Future GA are listed below with descriptions.

- **Certification**: The new Part 23 will be applicable in mid-2017 [5]. Certification 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 tests. Even though these approaches help introduce newer technology and accelerate process for existing technologies, large challenges lie ahead. With vast technological changes anticipated, processes and methods must be developed and identified to quickly and efficiently certify these new technologies while maintaining the same level of safety as before. Many technologies are not aviation specific but trans-domain, and their operability and airworthiness would have to be quickly determined.

- **Airspace Management**: With the advent of UAS and its growing popularity, the number of aerial vehicles to be operated in the common airspace will be unprecedented [6]. Proper control and management of this ever-crowding airspace is of primary concern to the safe operations of all the aircraft [7]. Conventional general aviation aircraft are the most likely to share the airspace with UAS and other new generation aircraft. Another concern for the airspace is the variation in levels of control of the aircraft operating. Piloted, remotely piloted and autonomous aircraft will soon have to share the same airspace. The growing numbers, types of aircraft and level of control make airspace management a key challenge for the future.

- **Infrastructure**: Newer maintenance and housing infrastructure is required for the expected newer generation of aircraft and new technologies. With growing numbers, larger and more ground service stations will be required. The safe operation of these ground facilities is important for safe vehicle operations. The aviation infrastructure of the future will also be as varied as that of the technology it would need to support. Fixed Based Operators will have to account for different types technologies present on similar types of aircraft, different aircraft configurations and different conditions of operations.

- **Cost**: In overcoming all the challenges, it will also be essential to manage costs down, making cost another major challenge for the future. Cost and safety are two of the primary influencing factors to the public, and thereby the customers of general aviation. Keeping costs to a reasonable amount for researching, developing, and finally introducing new technologies, while overcoming the challenges, will be important in determining the success of new technology and the aviation companies of the future.

3.1.4 Key transformational changes

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

- **Urban Mobility**: It may emerge as a major transformational concept. Urban air taxi service is most likely to happen first in the Dallas - Ft. Worth area and the San Francisco Bay area.

- **Transformational propulsion architectures**: More aircraft will be powered by new energy, such as electric, hybrid-electric and fuel cell.
- **Enabling technologies**: Many new technologies will be used to enhance GA safety, including Ballistic Recovery Systems, NextGen, pilot aids, runway incursion prevention system, and real time weather.
- **Automation**: Level of automation in air transportation will be raised. Some examples are increased autonomous operations and trajectory planning.
- **UAS activity**: UAS will be used a lot more in the areas of package delivery, agriculture, civil engineering, surveillance, etc. The substantial increase of UAS will impact the shared airspace.

3.2 Formulation of the Six Main Areas

To formulate the main topics in general aviation for further studies, a text mining task was conducted on detailed notes from the academic-centric workshop in May 2016 - the notes that include all the previous year outputs regarding general aviation topics, issues and themes. In the data mining process, vocabularies with the highest frequencies were deemed to be points with higher significance in general aviation. Conclusions from the data mining process, combined with the brainstorming, finally generated six main topics for further in-depth studies in general aviation, as shown in Figure 2. Under each main area, some secondary and tertiary topics were developed, many of which are at the juncture of more than one main areas. The whole picture of the topics, as well as their connections, can be found below in Figure 3.

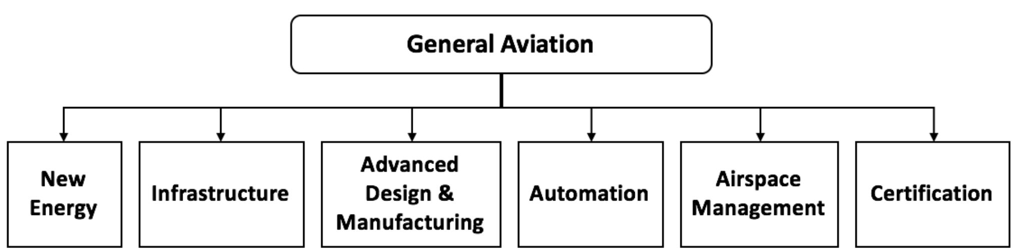

Figure 2: Formulation of the six main areas in general aviation

In-depth studies of the six main areas: *New Energy*, *Infrastructure*, *Advanced Design & Manufacturing*, *Automation*, *Airspace Management* and *Certification*, were assigned to researchers at Georgia Tech and Purdue University.

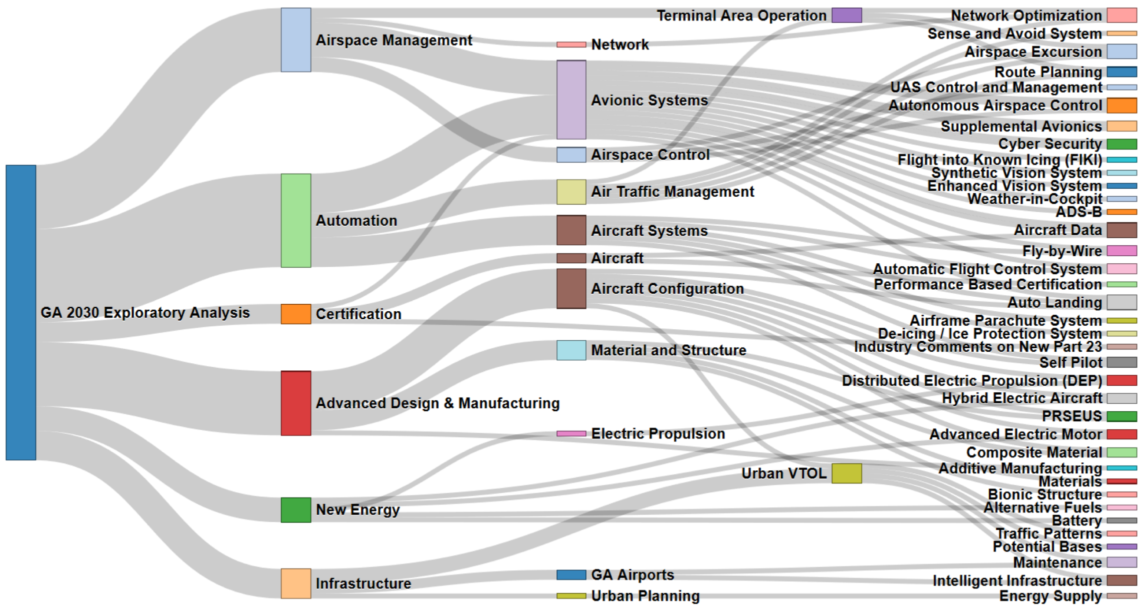

Figure 3: Topic Taxonomy with Secondary and Tertiary Topics

3.3 New Technologies and Technology Metrics

3.3.1 The Full List of New Technologies

After the six main areas were identified, tasks were given to the teams members to first investigate new technologies that have the potential to transform the future of GA in the six areas. Representative new technologies in each of the six areas had been studied individually. A full list of new technologies studied can be seen in the Table 1 below.

3.3.2 Technology Metrics and TRL

A combination of two metrics (TRL and ETA) was used to assess the feasibility and potential influence of each new technology in the 2030 time frame.

The technology readiness level (TRL) is used to assess the maturity level of a specific new technology. A widely used version defined 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 flight proven). Detailed definitions of the nine nine technology readiness levels are shown in Table 2 [8]. During the investigation process, current development of each new technology is evaluated against definitions and descriptions for each technology readiness level, and is assigned with a TRL level. Technologies with current TRL level of at least 5-6 have the potential to be developed to TRL 9 in 10 years.

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	ADS-B Related
Solar-powered Aircraft	Efficient Electric Aircraft Charging Station	Fly-by-Wire Tech
Autopilot System	Auto landing (hands-off)	Flight Data Monitor
Synthetic Vision System (SVS)	Enhanced Vision System (EVS)	Weather-in-Cockpit
ADS-B (out)	ADS-B (in)	ABS-B Self-Separation Application (Sense-and-Avoid)
CPDLC	PBN: RNP & RNAV	TCAS/PCAS/GPWS
SWIM (ATM Perspective)	Air Traffic Management Tech: ATD-1 (TSAS & FIM) & ATD-2	UAS Traffic Management
AM Process and Methods	AM Materials	AM Applications
Electric Aircraft Design	Hybrid Aircraft Design	VTOL Aircraft in GA
PRSEUS	Bionic Structure (AM + Design Optimization)	Airframe Parachute System
Ice Protection System on GA	Seatbelt Airbag System	AoA System

Table 2: Technology readiness level definitions, source: NASA[8]

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

3.3.3 Estimated Technology Adoption (ETA)

The estimated technology adoption (ETA) metric was developed in this project to provide another dimension in the technology evaluation process. The motivation for ETA is that technology 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 technology, which depends ultimately on the mastery of the science and engineering embedded in technology. The adoption of the innovation and technology embedded however, depends on non-technological factors [9]. Some high TRL technologies are not adopted in GA today. Technologies being developed today show great promise, but in reality may not be adopted into the GA community and industry. As part of the exploratory analysis of GA 2030, this matrix helps drive discussion toward why a technology expected to have a high TRL by 2030, may not be widely adopted. The estimated technology adoption scale has three levels as shown in Table 3.

Table 3: Estimated technology adoption level definitions

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

The stakeholders in GA are numerous. Factors affecting technology adoption vary with each type of stakeholder involved. One of the key stakeholder is the aircraft customer/pilot. From our benchmarking and literature survey we understand the factors that influence the adoption of technology to this stakeholder are:

1. **Cost:** Amount of money required to install new technology into an existing aircraft or the additional increase in price of new aircraft due to 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 flight safety? Does the new technology make the flight safer? Is the new technology in itself safe to use?
5. **Reliability:** How often the new technology operates at the required and accepted level of performance.

6. **Privacy:** User perception of the new technology, if it provides information of its users to other stakeholder that the primary user may object to.

Such factors and many more can be used as lenses during this project while exploring possible new types of technology entering GA and in turn deciphering why a technology appears to have a particular adoption state. The schematic diagram for the usage of estimated technology adoption in 'exploratory' analysis of GA in 2030 for a [New Technology A] is shown below in Figure 4:

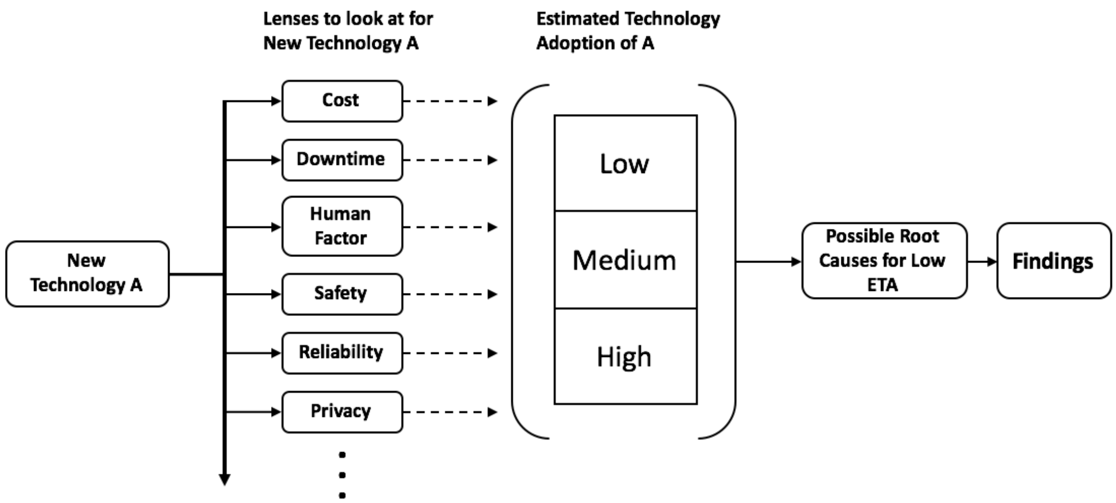

Figure 4: Schematic diagram for the usage of estimated technology adoption

3.3.4 Technology Evaluation Table

For each new technology, a TRL value between 1 to 9 and a ETA value between Low to High were assigned in the table shown in Figure 5. In this table, TRL values were assigned based on the information in 2017, and ETA values were assigned for both 2017 and 2030, based on currently available information and expectations. One thing to mention is that during the workshops, ETA level of each technology may be collected as the result of a survey to general aviation experts, to represent the attitude of GA community. This table is used to assess if a technology has the potential to be part of the general aviation operations in 2030. A good candidate should be one that has high TRL value and 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

3.3.5 Conclusion of the Technology Metrics Analysis

With the criteria described above (with TRL of at least 5-6 and ETA of Medium to High), a set of new technologies had been identified 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, takeoff and landing-hands off)
- **Air Traffic Control**: PBN: RNP & RNAV, TCAS/PCAS/GPWS, and SWIM (ATM Perspective)
- **Airframe Safety Measurements**: Airframe Parachute System, Ice Protection System, Seatbelt Airbag System, and AoA System

3.4 Technology Portfolio Study

3.4.1 Overview

The formulation of six major topics helped us identify the most popular research areas. Subsequently, the state-of-the-art techniques are studied in each area for challenges and the general spectrum of their future influence through TRL and ETA. However, the linkages that connect advanced technologies to general aviation aircraft is still missing. The aircraft technology portfolio in this section provides another approach that can help us to explore the pattern between technologies and aircraft systems.

GA Aircraft TechnologyC	Manufacturer	Manufacturer #1		
	Aircraft	Model #1	Model #2	Model #3
Airframe Safety Measurement	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

The current aircraft technology portfolio includes 128 GA aircraft models in 2017 and 18 expected models in 2030. The expected models are future aircraft that has been recently proposed or tested. All the investigated technologies were categorized into five technology areas: propulsion system, airframe material, advanced avionics/control systems, aircraft configuration, and airframe safety measurements. Within each area, more detailed methods, systems, or equipment were grouped into more specific subareas accordingly based on the aircraft's technical information sheets and the news reported from multimedia for the aircraft model under study.

3.4.2 Technology Portfolio Analysis Formulation

A table of aircraft technology portfolio can be created, and the structure of the table is shown in Figure 6. Figure 7 is an example of the portfolio tables for fixed-wing single engine. In both tables, if a technology or an equipment is expected to appear in the investigated aircraft model, it will be marked as Y in the portfolio table; if it is an optional component, it will be marked as O, and N otherwise (not an option).

GA Aircraft Technology	Manufacturer	Cirrus			Cessna							
	Aircraft	SR20	SR22	SR22T	Skyhawk	Skyhawk JT-A	Skylane	Turbo Stationair HD	TT*	Caravan	Caravan EX	Denali
Safety Measurements	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	Traditional (turbo-/piston)	piston	piston	piston	piston	piston	piston	piston	piston	turboprop	turboprop	turboprop
Avionics	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
Structure 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 Snap Shot of Portfolio Table

Many more tables of aircraft technology portfolio were created to enclose all the aircraft models that have been surveyed, including business jet, fixed-wing twin engine, rotor-wing, multicopter, VTOL, electric aircraft, and so on. After all these portfolio tables were established, a vector is assigned to each aircraft model, recording the number of technologies that are available (marked as Y or O in the table) on this particular aircraft model (mark **1** if available, mark **0** if not, and adds up all the availability if there are multiple choices), as shown as an example in equations 1-3 for Figure 6. In each vector, S stand for airframe safety measurement, P for propulsion system, A for avionics/control systems, M for airframe material, and for C airframe configuration.

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

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

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

Then, by using these portfolio vectors, the total cumulated technology counts can be calculated using equation 4, where, N is the total number of new aircraft models in 2017 or the models expected in 2030.

$$T = \sum_{i=1}^{N} S_i + \sum_{i=1}^{N} P_i + \sum_{i=1}^{N} A_i + \sum_{i=1}^{N} M_i + \sum_{i=1}^{N} C_i \tag{4}$$

Ratios of summation of S, P, A, M and C to T can be carried out, and these are the ratios for the five areas of aircraft technology portfolio. In the case of the table in Figure 6, the ratios (in percentages) for airframe safety measurement, propulsion system, avionics/control systems, airframe material, and airframe configuration are: 32%, 12%, 32%, 12%, 12% respectively.

Similarly, each of the 5 areas of aircraft technology portfolio can be further broken down into many sub categories. For example, avionics/controls system is comprised of synthetic vision system (SVS), enhanced vision system (EVS), weather-in-cockpit technology, and autopilot / automatic flight control system. Therefore, A_1, A_2 and A_3 in equations 1-3 can be decomposed into the following factors:

$$A_1 = (1, 0, 0, 0) \tag{5}$$

$$A_2 = (1, 1, 1, 1) \tag{6}$$

$$A_3 = (1, 1, 0, 1) \tag{7}$$

The components in each vector representing the availability of each avionics and control systems technology (from left to right are: SVS, EVS, weather-in-cockpit, autopilot and automatic flight control system) in the investigated aircraft model. Similarly, an overall ratio relative to T for each specific technologies or equipment can be calculated. In the case of Figure 6, the overall ratio for SVS is 12% (3/25), 8% (2/25) for EVS, 4% (1/25) for weather-in-cockpit, and 8% (2/25) for autopilot and automatic flight control system.

3.4.3 The Sankey Diagram

Once area vectors and sub category vectors were established for the actual portfolio tables for new aircraft models in 2017 and expected models in 2030, a method of data visualization called "Sankey diagram" is used to exhibit the shifting trends of implementing aircraft technologies in the next 10 to 20 years. Figure 8 and 9 shows the Sankey diagrams of aircraft technology portfolio for new aircraft model in 2017 and expected model in 2030 respectively.

With the aid of data visualization, through Sankey diagrams, some interesting trends were revealed. In 2017, most of the new aircraft models were made from all metal, with traditional piston or turbine based engines, and the configurations are either fixed-wing or rotor-wing. In the expected case of 2030, however, there is more diverse development in aircraft configuration, as there are many new concepts other than fixed-wing or rotor-wing, such as multi-copters and V/STOL aircraft. In propulsion, electric or hybrid electric driven general aviation aircraft becomes a future trend for those models expected in 2030. Almost every newly proposed aircraft or those under development are made from composite materials, such as fiber glass, carbon fiber, etc. As for airframe safety measurements, parachute systems and seatbelt airbags are currently used and

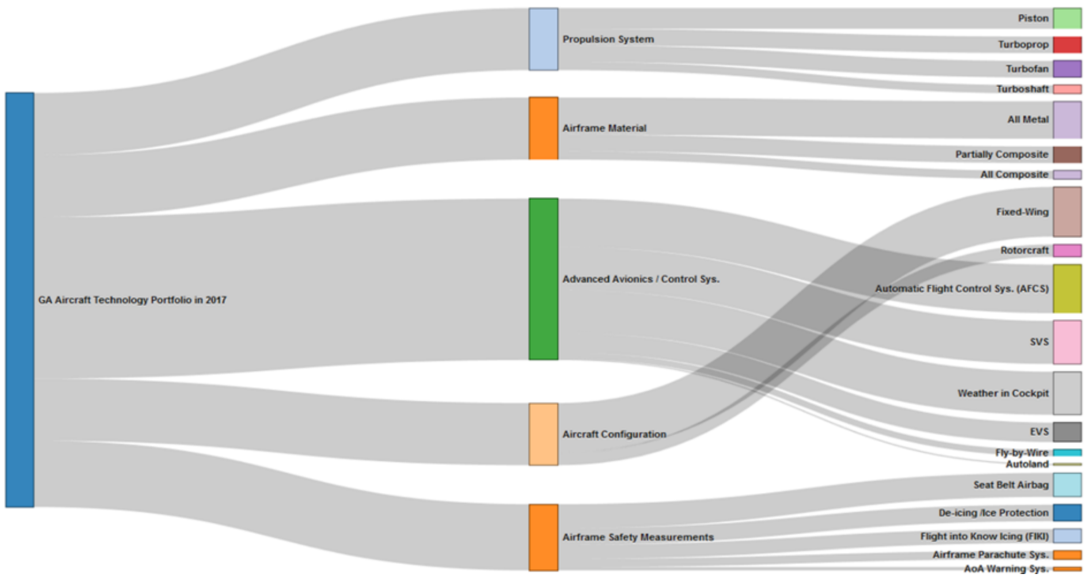

Figure 8: Sankey Diagram of Aircraft Technology Portfolio for New Aircraft Models in 2017

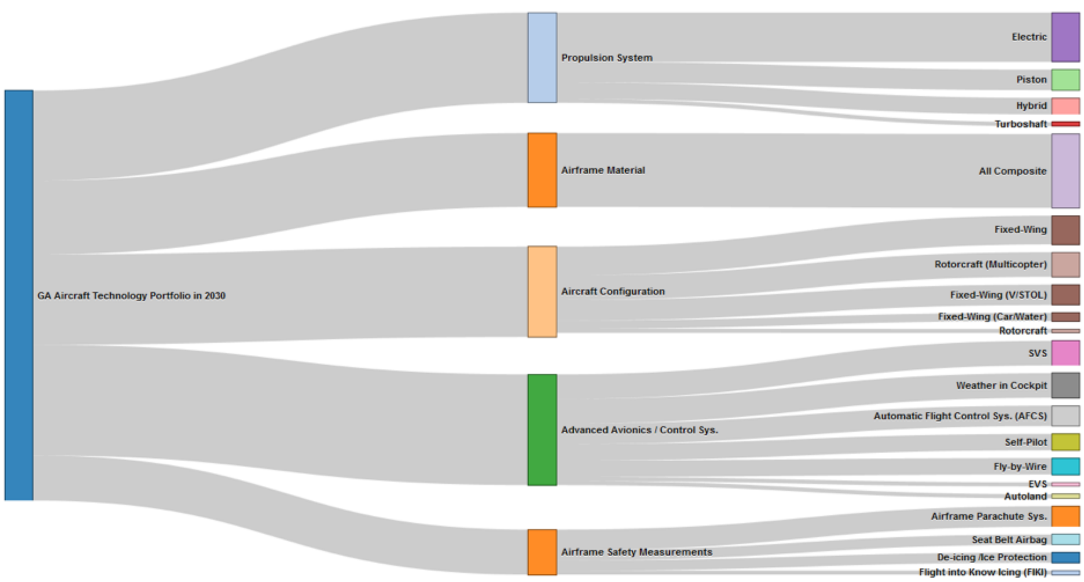

Figure 9: Sankey Diagram of Aircraft Technology Portfolio for Expected Aircraft Models in 2030

proposed on several of the future general aviation aircraft. Lastly, technologies such as self-pilot, fly-by-wire, and auto landing/takeoff also have high likelihood of implementation in future general aviation.

The aircraft technology portfolio analysis helps in creating a series of technology portfolio tables for current and future aircraft models. These portfolio tables contain aircraft specific technology breakdown with technology composition ratio and distribution which are then synthesized and represented by Sankey diagrams. Therefore, providing another approach, in addition to the conventional literature survey discussed before, in identifying advancing aviation technology by studying industry aircraft development and thereby, the trends.

3.4.4 Technology Portfolio Analysis Conclusion

With the aids of Sankey diagram, the percentages for each technology sub-area in 2017 and 2030 are listed in Figure 10, and some comparisons as well as takeaways are discussed in the following bullet points:

- **Advanced Avionics/Control Systems**: Reduced from 39% to 27%. The reduction is projected to happen not because it is not important in the future, but the ratios in other subarea are predicted to increase (airframe configuration, airframe material, and propulsion system). Technologies such as self-pilot, fly-by-wire, and auto landing/takeoff have likelihood of implementation in future GA.

- **Airframe Configuration**: It is projected to increase from 15% to 22%. New drivers in aircraft design such as VTOL and multi-copter could be the potential options for future GA airframe configuration.

- **Airframe Material**: Projected to increases 3%, from 15% to 18%. Almost every newly proposed aircraft or those under development will mostly be made from composite materials, fiber glass, carbon fiber, etc.

- **Airframe Safety Measurements**: Airframe parachute systems and seatbelt airbags are currently used and proposed on several for future GA aircraft.

- **Propulsion System**: Expected to changed from 15% to 22%. Beside traditional turbo or piston based engine, electric and hybrid propulsion architectures are the major changes for future GA aircraft.

As can be concluded from the trends mentioned above, propulsion system, airframe material, and airframe configuration are the subareas that have higher ratio (significance) in future aircraft technologies; therefore, they might contain the key technologies that have the potential to reshape the development works of GA aircraft for 2030.

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

Figure 10: Percentages of the Sub-areas in Both Sankey Diagrams

3.5 Certification

The new Part 23, which is soon to be in use, is already a step forward towards better certification by risk based and performance based certification. This is expected to enable the industry to introduce new technology at a much faster rate into the GA market. There is growing consensus in the general aviation community and the industry in utilizing this new Part 23. With growing number of use cases of GA aircrafts in the future, such as, urban taxi, VTOL and personal vehicles, a risk based analysis and system level tools are being proposed.

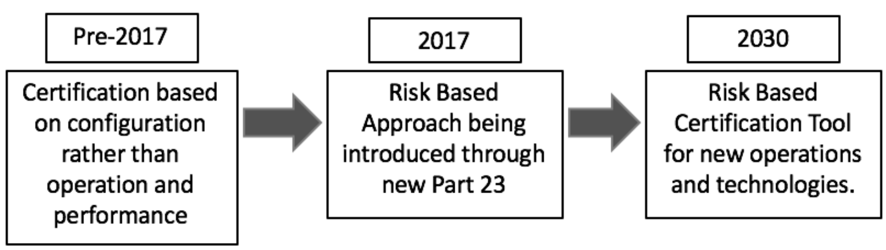

Figure 11: Certification Analysis Scheme

Certification by analysis is another field which is currently being used by industry in providing certification evidence. Techniques are currently researched to provide better proof, reduce the number of test flights and introduce new technologies such as 3D printing of aircraft parts.

Automation will play a key role in general aviation of the future. Software to enable this autonomy or simplified vehicle has to be quickly certified. Leveraging open source or commercial

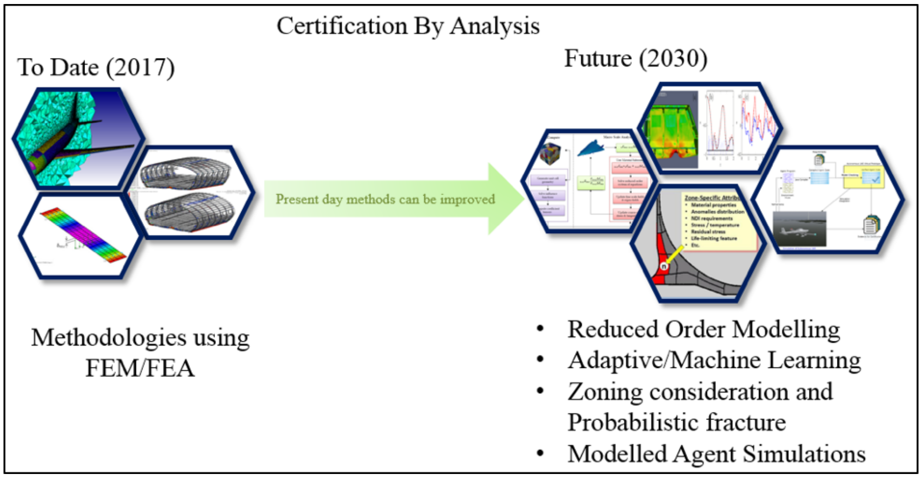

Figure 12: Certification by Analysis

off the shelf software is one possibility. Run time assurance of software on board is another, since UAS currently use such software and tools are being developed to certify these based on risk and operational scenario.

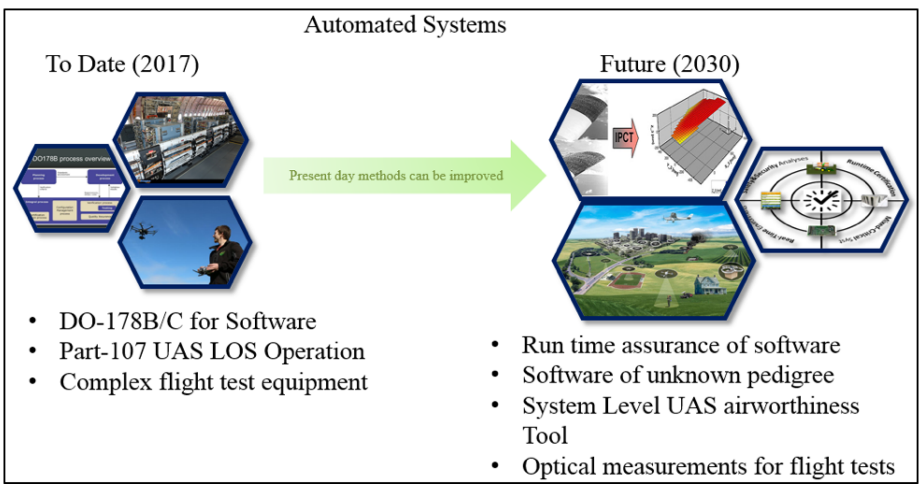

Figure 13: Automated Systems

Applicability, state of usage and time period of methods mentioned in the figures above is provided in the table in Figure 14 in the next page.

Technique		Applicability/ State of Usage	Since
Certification by Analysis	Conventional FEM method	AC No: 20-146. Followed largely in cabin crashworthiness certification	2003
	Argument-Goal Based	NASA has been developing argument based airworthiness strategy for UAS	2015
	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
	Model Checking and Simulation	Autonomous UAS operation certification.	2012
	Zone based Damage Tolerance framework	This methodology is proposed by FAA. FAA also working with industry in developing other strategies with respect to AM.	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
		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 14: Certification Technologies

4 Workshop I

4.1 Workshop Overview

The 2017 industry-centric workshop was held by 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 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. Essential outcomes of the workshop are organized and presented in the following sections.

4.2 Facts and Research Needs Identified

Main outcomes of the 2017 Industry-centric Workshop are organized below into seven themes: *Pilot Training and Proficiency*, *Autonomy and Automation*, *Airport and Infrastructure*, *GA in the Future Airspace*, *Airframes, Legacy Fleet, and Maintenance*, *Future Propulsion Systems*, *Passenger Safety*. Under each theme, valuable information are extracted and sorted into two categories: *Facts* and *Research Needs*.

4.2.1 Theme 1: Pilot Training and Proficiency

Facts:

1. Pilot shortage - difficult to attract new pilots to fly 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 still viewed as entry point for commercial aviation
6. Trust in autonomy or automatic technologies needs to grow

Research Needs:

1. How to make learning to fly easier, cheaper and more streamlined? Can introduce more high-fidelity flight simulators training in the future, but retain basic flying 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 technology and what is its roadmap in the next 20 years
3. Market analysis of the new age pilots and their motivations, to improve the curriculum to better suit them
4. How to encourage the use of technologies to reduce pilot's workload? Think of what can be added to the aircraft and brought on board (e.g., a tablet or smartphone)?
5. Roadmap from simplified operations for current pilot to no pilot (fully autonomous) is to be identified
6. Substantially streamlined and simplified 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

4.2.2 Theme 2: Autonomy and Automation

Facts:

1. Automation can improve current product and possibly increase market share
2. Investment is restricted due to small market and low ROI
3. Accessibility of GA pilots to automated tools maybe limited by cost, but technology flowing down from commercial aviation and UAS can help reducing the cost for automation
4. Tasks that can be automated:
    - Avoidance (traffic collision, terrain, airspace)
    - ATC Communication
    - Weather (adjust course automatically)
    - Critical air vehicle
5. Autonomy can make flying easier and thereby training easier
6. Future ImagineAir or Uber-type models will be with 'driver/operator' instead of pilot

Research Needs:

1. Certification 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 simplified operations for current pilot to no pilot (fully autonomous)
5. Possibly need new certificate for autonomous operations
6. Focus on progression of software aimed at decision-support /decision-authority
7. Need to think of what tasks can be automated
8. Infrastructural changes required for more autonomous vehicles (markings, lights)

4.2.3 Theme 3: Airport and Infrastructure

Facts:

1. Some airports already have large traffic volumes, but others are nowhere close to the capacity they can fulfill
2. Runway incursion issues (e.g. towered and non-towered airports)
3. Issues on oversight and ownership of runways and airports (large roads, grass fields, etc.)
4. Infrastructure issues (e.g. pavement, terminals)
5. Need more supporting infrastructure (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 different configurations of general aviation aircraft
7. Difference in infrastructure between among owned airports to be investigated

4.2.4 Theme 4: GA in the Future Airspace

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. Configuration of airspace today its 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 and not all
7. Current GA will be heavily influenced with Uber Elevate type concepts in the future

Research Needs:

1. How is the airspace shared between commercial, GA, and UAS
2. Research on 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 vehicle and airspace
6. Study on artificial intelligence acting as a service provider for airspace management
7. Evolution of airspace restrictions
8. Simulations of high density airspace with various aircraft type and modes of operation

4.2.5 Theme 5: Airframes, Legacy Fleet, and Maintenance

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 operate safely in the same airspace

4. The expectations would be that a general aviation aircraft operate at the same reliability of a car
5. Current engines are from the 1930s eras without major upgrade to the basic technology. Hesitation to develop a completely new engine specifically for GA, in part because of small market
6. New Aircraft Technologies out there: Propulsion Technologies, Advanced Control Systems, New Materials and Airframes, Human-machine Interface
7. Testing different fuels (e.g., unleaded) on existing platforms is underway now

Research Needs:

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

4.2.6 Theme 6: Future Propulsion Systems

Facts:

1. Reticence to develop a completely new engine specifically for GA (Current engines are the 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 require specific type of airframe design. Solutions are engineer-able, but large investment costs are major barriers to industry R&D.

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 Commercial off the shelf technologies

4.2.7 Theme 7: Passenger Safety

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 exists a perception of GA being unsafe exists

Research Needs:

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

5 Similarities and Gaps Between 2016 and 2017 Workshops

The academic workshop ('Workshop 0') was held in May, 2016. This workshop was used to seed the benchmarking task being performed under Project 25. As part of Project 25, the industry centric workshop ('Workshop 1') was held in June, 2017. Both the workshops had similar central theme, structure and scenarios. The attendees of both these workshop answered similar questions. Ranging from current state of GA, future possibilities and in-depth analysis of factors influencing GA in the future. Differences emerged in the responses from the attendees from the two workshops. The variations could be due to a lot of factors. The first and the most obvious being the background of the attendees. The Workshop 0 contained people with academic backgrounds researching on technology that could possibly impact GA, whereas Workshop 1 contained people working in the industry or consulting the industry, who have a direct focus on creating revenue from the GA market. Figure 15, gives the pie chart distribution of the attendees from the two workshops.

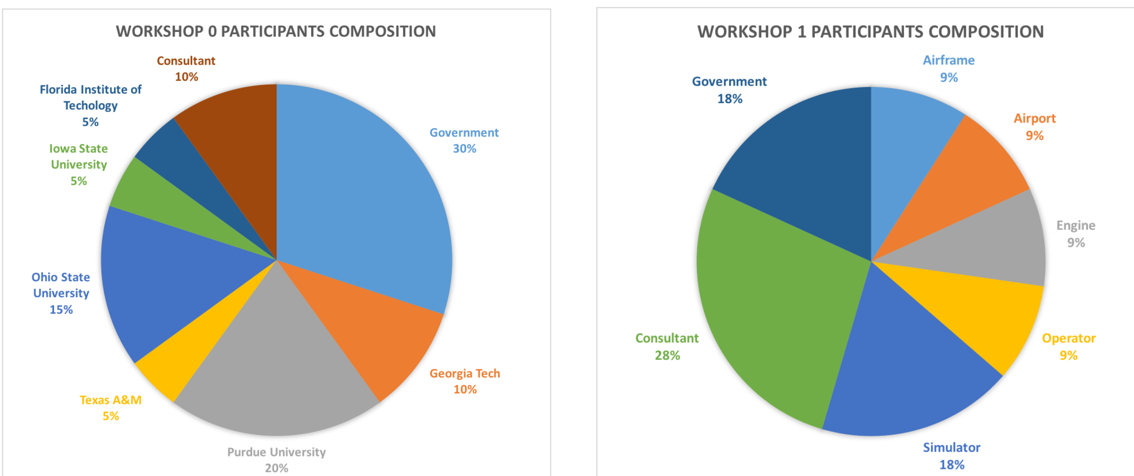

Figure 15: Workshop Compositions

The timeline too is an important factor. In the year between the two workshops, FAA's new Part 23 was announced, Uber elevate summit was conducted, ATC privatization was proposed in Congress, etc. In spite of the differences, many similar themes emerged from the two workshops as well. The results of Workshop 0 or the benchmarking task results were not presented to the attendees of Workshop 1. Yet, some items prioritized in Workshop 0 were also prioritized during Workshop 1.

5.1 High Level Overview

A major difference between the two workshops is that Workshop 1 contained an additional question during the in-depth analysis of topics. This was: "*How the work to satisfy, recognized needs,* *be conducted?*"; making workshop 1 more result oriented than workshop 0. Workshop 0 was a preliminary workshop which helped 'seed' the research and the direction to follow. It however was more focused towards raising the correct questions only. During Workshop 1, the format was slightly modified for attendees to raise questions and also provide their inputs on possible methods to finding the solution to those questions.

We performed a word search of some selected 'critical words'. These words imply a specific 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 16 shows the total word density from both workshop 0 and workshop 1. Words appear more often in one workshop than the other. In a complex system as that of General Aviation, no topic is truly independent of each other. 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 visibility on what the attendees in both the workshop consider priority for GA 2030.

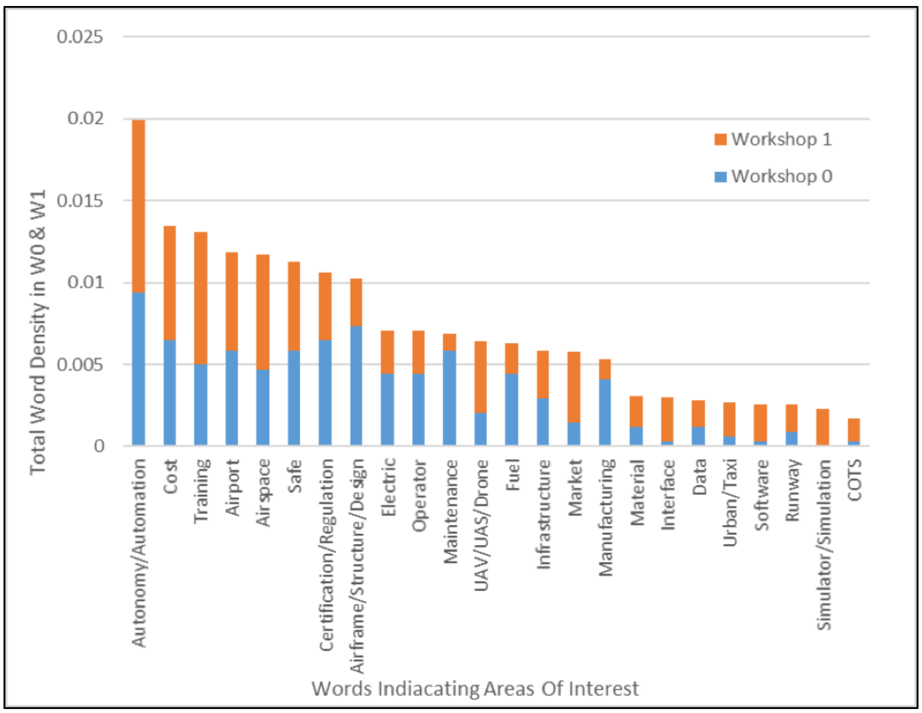

Figure 16: Total Word Density from Workshop 0 and 1

The search was done on the entire document for words expressing an item. For example, the words autonomous and automation were both counted as a single category. Workshop 1 due to its additional question during the in-depth analysis 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.

The word count from the two workshops were also compared. The difference in word density between workshop 0 and workshop 1 is shown in Figure 17. Words discussed more often in workshop 1 is to the left of the graph, about the same in both workshop is in the center and more often in workshop 0 is to the right. This graph gives us an indication of which workshop's attendees priorities what topics or items. Studying Figure 17 and Figure 15 together helps the team determine if all items were sufficiently discussed and if additional stakeholder inputs is required for in-depth analysis into some known topics or find additional items critical to GA in 2030.

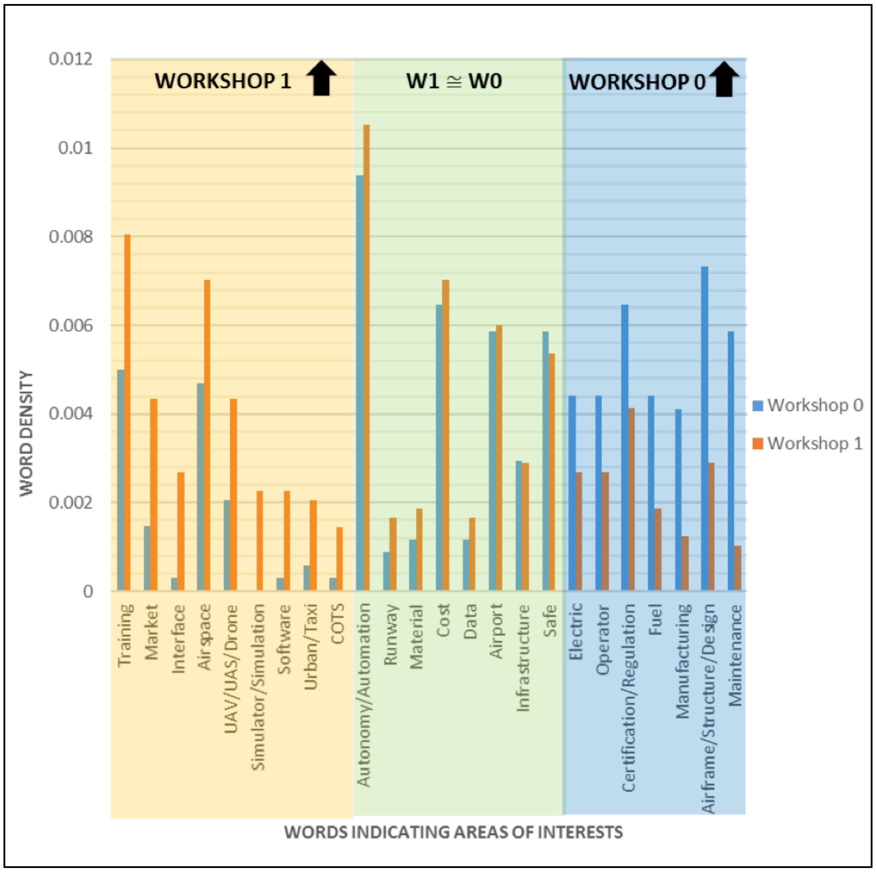

Figure 17: Word Density Comparison

From the graph it is a clear an indication that that the attendees for Workshop 1 prioritized the following items:

- Training

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

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

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

Topics that appear to be of equal importance to attendees from both the Workshops are:

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

- Cost
- Safety

General Aviation is broad and complex environment. A basic word search is insufficient in understanding the nuances of the ideas expressed by the attendees in the two workshop. Words may have been used in different context to express different points concerning similar topics. Thus, an in-depth analysis was performed.

5.2 In-Depth Comparison

5.2.1 Similarities

The largest discussion in both the workshops in term of prioritization by the attendees and also from the word search is 'autonomy'. The word search shows, workshop 1 having slightly higher mentions, but both the workshops were very 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 attendees from both the workshops were in agreement. Attendees from both the workshops emphasized on the need to reduce cost due to large certification process, maintenance and investments done to bring in new technologies. Cost was also discussed in terms of retrofitting older aircraft with newer technology compared to building a new aircraft completely. Workshop 1 attendees also identified the high cost for training as a deterrent to newer pilots.

Infrastructure and airports of the future were discussed almost at similar level of importance in both workshops. It was prioritized specifically in one, but the word search indicates that infrastructure and airports were both of high interest to the attendees from both workshops. Analysis of workshop notes show that even though infrastructure did not necessarily have an in depth analysis on its own, it was a key sub-point in all the prioritized items.

Safety and safe operations were deemed important by attendees from both workshop. No in-depth analysis was performed in either workshops. The requirement for safe operations was identified but the process of achieving that goal in the future was not explicitly discussed. It also important to note that even though certification was discussed more often in one workshop than the other, no prioritization was done in either. Safety and certification are closely related and considered extremely important, but no actionable or future state discussions emerged from these two workshops. Attendees from both the workshop made the assumption that safety is a given and has to be met and therefore other aspects can be looked into which may enhance safety.

Other items discussed with equivalent intensity in both the workshops were that of data, materials and runways. Data can help in quicker certification and also improve pilot's situational awareness. Attendees from both the workshop pointed out to runway incursion being a current problem and with growing traffic may be a larger problem in the future. Workshop 1 has slightly higher mention of runways, as existing road infrastructure, was discussed as optional runways of the future.

The possibility of communication bandwidth saturation was discussed in both workshops. The need for transfer from only voice to faster text or automated forms of communications were also proposed in both workshops.

5.2.2 Differences

In addition to the added question in Workshop 1, major differences exist in the results from the two workshops. The primary difference exist in the items prioritized by the attendees to performed an in depth analysis on.

Workshop 1 attendees prioritized the item of Training the most. The problem of pilot shortage is a current problem and appears to deteriorate in the near future. The attendees aimed at addressing this problem by targeting the training requirements for the future. With growing technology, the training required to reach adequate proficiency for flying a future aircraft needs to be investigated. Larger pilot base will lead to a larger customer base and thereby increase GA communities reach. The word search too shows that training was mentioned more frequently by attendees in Workshop 1 than in workshop 0. The word 'training' was primarily used by attendees at workshop 0 to indicate maintenance training of new types of aircrafts.

A keen interest was shown by workshop 1 attendees in the growth of technology in the simulator segment. Their opinion was that, a high fidelity simulator would help in aiding pilot training in the future. Workshop 0 attendees did not investigate this segment of the GA community.

Airspace was prioritized by attendees from both the workshops. However, the reference to airspace and its management happened to a larger a degree in that of Workshop 1. In the backdrop of the Uber elevate summit, the attendees foresaw a larger possibility of urban air mobility and the need to be prepared for such changes.

Another key question brought about by Workshop 1 attendees was that would the urban air taxi/mobility be a subpart of commercial aviation or of general aviation; but like Workshop 0 attendees, believed that personal air vehicles would surely be part of GA. The impact of Urban Taxi/Personal Vehicles on the airspace was recognized by all. However, it was mentioned to larger degree in workshop 1 and the group prioritized and performed in-depth discussion on the concept of 'simplified vehicles' which would be a direct enabler to the future personal or air taxi vehicles.

It was of the opinion of workshop 1 attendees that to enable the 'simplified vehicle' of the future; technologies would have to be leveraged from UAS/Drone existing today. UAS and Drones were not specifically prioritized, but they were of a very high interest to the attendees 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 attendees felt that software, its interfaces and the leveraging capability from the drone technology present today is key for autonomous GA vehicle of the future. Workshop 0 attendees mentioned Drones in the capacity of 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 aircrafts dealing with bird strikes today.

Workshop 1, being industry focused brought about the question to address market needs. It was evident from the discussions, that in GA, market needs do drive the technology being used. That is why many of the attendees in this workshop repeatedly coupled the technology discussion with the GA market. In the opinion of the attendees at Workshop 1, legacy aircrafts will still play a big role in the 2030. Due to a small market segment, investment by GA companies into revolutionary airframe or engine is low. Prototypes do exists, but creating push for market acceptance is a large investment cost with very low surety of return on that investment.

Certification was not prioritized in either of the workshops. It was mentioned to a higher ratio in Workshop 0 than in workshop 1. Workshop 1 attendees showed enthusiasm in the new modifications of Part 23 and wanted to work towards such methods of certification. It was discussed initially and it appeared the attendees were focused on how to achieve these new standards for the remaining of the workshop.

With market constraint and the new part 23, the workshop 1 attendees emphasized the need for commercial off the shelf (COTS) equipment. COTS is seen to be a possible solution to the cost, acceptance, better performance and quick certification. COTS specifically from the automobile industry can be used for the new generation engines, which may be partially electric powered.

From the word search, Airport and Infrastructure appear to be of equal importance in both the workshop. In workshop 0, infrastructure or airports was not discussed exclusively, but questions regarding the infrastructure was raised in most of the prioritized topics. In workshop 1, attendees specifically discussed Airports; the possibility of drone ports, remote controlled airports and other possibilities of how number of landing locations can be increased.

Workshop 0 attendees identified electric (hybrid, complete, etc.) propulsion to be a key player in the future. Workshop 1 attendees felt that electric propulsion is bound to happen and requires a dedicated workshop by itself. Large commercial aviation companies have invested in that technology and prototypes are currently being tested and it will soon be in the market.

It was also the opinion of the workshop 1 attendees that the discussion of future air-frame and design can only occur along with the discussion of future propulsion systems. It was deemed important but not prioritized during this workshop. Workshop 0 attendees prioritized both future propulsion techniques and possible future airframe structure and design. The word search also points to the workshop 0 attendees' interest in aircraft design and structure.

Workshop 0 attendees also prioritized the maintenance aspect of future GA. This was the top priority for workshop 0 and in depth analysis was performed. Workshop 1 attendees mentioned that the maintenance aspect is important.

Fuel was discussed to larger degree in workshop 0. Possible future 'fuel' scenarios, fuel efficient through better designed airspace, regulatory frame work required for alternative fuels, etc. Workshop 1 attendees raised research questions about what would be the transition roadmap from current fuels to green fuels and finally electric. Workshop 1 attendees did mention that the research for alternative diesel engine fuels is low due to the small market size of the diesel engines themselves.

Workshop 0 attendees 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 attendees. Workshop 1 attendees on the other hand felt that advanced manufacturing is important and key for GA to take advantage of, but will not initiate market changes in the near future.

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

6 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	Low - 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	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 AV Gas and possible fuel transition	Medium - High
Advanced Battery	5-6	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	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 investigate ground stations	High
Solar-powered Aircraft	7	Already have a few successful prototypes	Low	Not a practical solution for future GA aircraft because of the aerodynamics design, efficiency and operational limits	Low - Medium
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
Fly-by-Wire	8	Successful flight test by Diamond Aircraft on DA42 in 2015	Medium	More prototypes aircraft with similar system will initiate their flight test, reduced cost due to advanced technologies were merged	Medium - High
Autopilot System	9	Current autopilot systems can help pilot reducing their work load during the flight, helping pilot to flight with higher precision and increasing situation awareness	Medium	More advanced autopilot prototypes will be demonstrated not only reducing the work load of pilot, more auto landing and self-pilot aircraft will be tested as well	Medium - High

Figure 18: Complete TRL and ETA table - Part 1

Technologies	TRL	Status in 2017	ETA	Status in 2030	ETA
VTOL Aircraft in GA	2 - 4	There are already some concepts and preliminary designs for future VTOL aircraft, such as Airbus's Pop. Up and Vahana, and XTI aircraft's trifan-600. Some of them are aim to have flight test at the end of 2017	Low	More and more proposed future VTOL aircraft design will complete their flight test for one or two passengers	Medium
	7	Ehang, Volovopter are the first few aerospace companies already had a flight test on their VTOL aircraft in GA	Low		
Pultruded Rod Stitched Efficient 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 aircrafts comprised by this method will initiate their flight 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. 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 using this technology on their GA fixed wing aircraft products	Low	More and 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 still an optional feature	Medium	Every GA aircraft has this equipment on board.	High
Seatbelt Airbag System	9	Almost every GA aircraft can have this technology on board, but still an optional feature	Medium	Every GA aircraft has this equipment on board	High
AoA System	9	Some GA fixed wing aircraft made this as a standard feature	Medium - High	More and more fixed wing aircraft will have this equipment on board.	High

Figure 19: Complete TRL and ETA table - Part 2

Technologies	TRL	Status in 2017	ETA	Status in 2030	ETA
TCAS/PCAS/GPWS	**9**	TCAS is available on jets, and new propeller aircrafts. Pilots use PCAS (portable)/FLARM in some cases. TAWS mandated on Turbine aircrafts greater than 12500lbs	**Medium**	Portability of the terrain awareness and avoidance system are projected to increase. Different levels of services (awareness, advisory recommendations, etc.) 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**	Concept of Aircraft Accesses to SWIM could provide higher accuracy data to GA pilots. May still require subscription for FAA SWIM	**Medium**
Air Traffic Management Technology: ATD-1 (TSAS & FIM) & ATD-2	**8**	NASA's contribution to Next Gen. These technologies help in better separation, sequencing, scheduling and terminal area management. Currently being deployed to major Metroplex airports	**N/A**	Expected to be deployed across NAS and all major Metroplex airports. Class B and Class C airspaces	**N/A**
UAS Traffic Management	**6-7**	NASA recently demonstrated the UTM technology by conducting 'out-of-sight' tests	**N/A**	Expected to reach high fidelity by 2020, but mainly for sUAS applications in uncontrolled airspace. Next steps would include operation in controlled airspace	**N/A**
AM Process and Methods	**7**	Still got over 100 parameters in the process, need to reduced and standardized. However, many AM technique providers already had their products for aerospace usage in demonstration	**Low**	Breakthrough on manufacturing method. Reduced process complexity, increased stability of processed material, and implementation of the parts in propulsion and structural system. Maybe by 2030, some AM products already applied on many GA aircraft. Most important, the safety and airworthiness of AM parts has standardized regulations to control and regulate their quality	**Low - Medium**
AM Materials	**7**	Having different materials for different purposes, material properties hard to control (100+ parameters for the process)	**Low**		**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 find	**Low**		**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 technology, more and more electric aircraft will complete their first flight test, and soon aircraft with electric propulsion system will be an option in the future GA market.	**Low - Medium**
	8	Ehang, Volovopter, Airbus's E-Fan are the first few prototype electric aircraft that already had a flight test in the field of GA	**Low**		
Hybrid Aircraft	**8**	Some prototypes of this type of GA aircraft already had flight test for few times	**Low**	More hybrid aircraft will complete their flight test, and some will enter the GA market	**Medium**

Figure 20: Complete TRL and ETA table - Part 3

Technologies	TRL	Status in 2017	ETA	Status in 2030	ETA
Auto landing (hands-off)	**8**	Successful flight test: DA42 in 2015	**Medium**	More advanced autopilot prototypes will be demonstrated not only reducing the work load of pilot, more auto landing and self-pilot aircraft will be tested as well	**Medium - High**
Flight Data Monitor	**9**	There are several companies provides equipment and analysis service to help operator learning information from flight data improving the safety of their operation	**Low - Medium**	Because of the increased operation safety by implementing the FDM, similar equipment might be becoming a standard feature for most of the GA aircrafts	**Medium - High**
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 to flight more softly in hazardous weather condition or environment with low visibility	**High**
Enhanced Vision System (EVS)	**9**	Some avionic companies provide instruments with infrared or night vision system to add aircraft operation in hazardous weather conditions. For now, not a standard feature	**Medium**	More GA aircraft equipped with these aiding systems to help pilots to flight more softly in hazardous weather condition or environment with low visibility	**High**
Weather-in-Cockpit	**9**	Most of the GA aircraft has this technology as an optional feature, not a standard feature	**Medium**	More GA aircraft equipped with these aiding systems to help pilots to flight more softly in hazardous weather condition or environment with low visibility	**High**
ADS-B (out)	**9**	By 2020, every aircraft fly in US will equipped	**Medium**	ADS-B in and ADS-B out will be a standard feature for every GA aircraft, including UAS. Sense-and-avoid system based on ADS-B will start implemented on GA aircraft. The safety of the ADS-B will be improved by any possible safety measurement (e.g. encrypting the signal transitions) either in hardware or software	**High**
ADS-B (in)	**9**	With ADS-B in system. Today, some GA operators already implemented the ADS-B in/out on their aircraft. However, since the aircraft information transmitted via ADS-B are unencrypted, security breach is possible	**Medium**		**High**
ABS-B Self-Separation Application (Sense-and-Avoid)	**8**	An UAS in 2016 with sense-and-avoid system based on ADS-B were successfully tested by NASA in a designed flight test mission	**Medium**		**High**
CPDLC	**9**	Controller-Pilot Data Link Communication is available on majority of the airlines and few business jets for transoceanic flights	**Medium - High**	FAA planned to implement CPDLC for domestic routes in 2019. By 2030, 85% of Air Traffic Service communications are projected to be provided via data-link	**Medium - High**
PBN: RNP & RNAV	**9**	Currently major airports and Class A, Class B and Class C airspace have RNP regulations. Mostly GA aircrafts with a GPS have the RNAV capability. RNP capability is mostly available in business jets	**Medium**	All IFR regions to have RNAV capability. Including LNAV, VNAV and LPV. With increasing UAS traffic, higher RNP may be required for continental flight	**Medium - High**

Figure 21: Complete TRL and ETA table - Part 4

7 References

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