A First Look at the Evolution of Flight Crew Requirements for Emerging Market Aircraft

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This is an exciting time for aviation. New vehicle and airspace technologies promise large increases in the number of aircraft in operation. One critical technology for these emerging markets is the increased use of automated systems to reduce pilot skill, training, and proficiency requirements. While the use of these systems promises to reduce or eliminate pilot functions in the long-term, the technology development for the required functions will necessitate a phased transition. The transition to, and adoption of automated systems will generate new safety challenges. This paper is a first look at a model to help frame flight crew functions for evaluation of future operational requirements. The model is intended to provide required flight crew functions regardless of whether the functions are performed by human or artificial agent. It is hoped that the model will be useful in identifying safety challenges and enabling a safe transition for the new aviation markets. The paper presents some background for a model for framing the flight crew function model and some thoughts about next steps.

I. Nomenclature

CTOL	=	Conventional Takeoff and Land
eVTOL	=	electric Vertical Takeoff and Land
FAA	=	Federal Aviation Administration
ICAO	=	International Civil Aviation Organization
ODM	=	On Demand Mobility
UAM	=	Urban Air Mobility
uSTOL	=	ultra-Short Takeoff and Land
VMC	=	Visual Meteorological Conditions
VTOL	=	Vertical Takeoff and Land
§	=	Title 14 of the United States Code of Federal Regulations

II. Introduction

This is an exciting time for aviation. There are many new concepts of operations that are becoming closer to reality. Many of these concepts include the increased use of automated systems, as well as other new technologies (e.g. distributed electric aircraft propulsion, a service-based airspace architecture).

While the specific safety challenges of the adoption of these new technologies is not known, history shows that there will be safety challenges. Figure 1 illustrates the accident rate trends associated with the introduction of new technologies, categorized into generations of aircraft. The generations of aircraft represented in the figure correspond to the introduction of different technologies, but the trends are consistent, particularly across the latest generations of technology adoption. The figure shows that from the second generation of aircraft onwards (as aircraft component reliability improved), there are conditions that are unanticipated in the design process that appear in operations initially and take time to identify and resolve, but once solved, there is a marked drop in the accident rate.

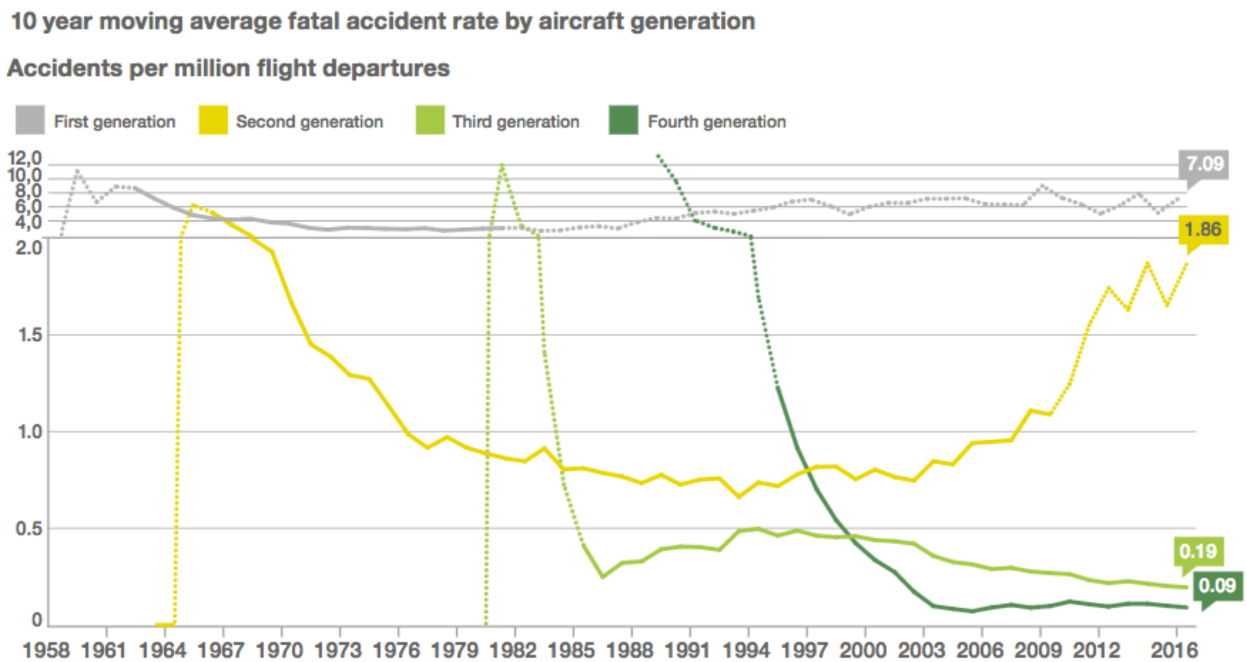

Fig. 1 Increase in accident rates associated with introduction of new technologies [1]

Safety methods are improving rapidly and effort needs to be devoted to identifying, understanding and mitigating any negative consequences from the technological advances. Continuing improvements in these methods will be needed to identify safety vulnerabilities and inform the design of the vehicle, automated systems, data collection, procedure and training development and operational evaluation.

III. Urban Air Mobility (UAM) as an Emerging Market

In 2016 Uber described a vision for the use of distributed electric VTOL aircraft flying in large numbers in urban areas [2]. This vision consolidated years of research development on distributed electric propulsion, aircraft automation and concepts for on-demand aviation using small aircraft [3-6]. This paper will use the current NASA concept of operations for Urban Air Mobility (UAM) as an example of the type of operations that will present challenges to current methods for certification and operational approval.

The UAM concept of operations starts with the use of vehicles with 4 passenger capacity, with pilots on-board operating under FAA 14 CFR 135 (hereafter referred to as § 135), under Visual Flight Rules (VFR) and transitioning to increasing use of automation to enable more capability in more varied conditions with reduced flight crew training, performance and proficiency requirements.

The Urban Air Mobility (UAM) concept of operations plans for increasingly automated or autonomous flight operations in the future but initially will require human pilots onboard the aircraft. This paper will use “flight crew” as an agnostic term to refer to piloting tasks that are performed either by humans or by artificial agents. The paper will briefly describe the functions that will need to performed either by human flight crew or automated systems, and some of the challenges and possible paths forward for the transition period.

A key to the long-term success of Urban Air Mobility is on-board autonomy to help solve the challenges introduced by the large quantity of vehicles proposed by the UAM concepts. The challenges include not only a projected shortage of qualified pilots for current aircraft noted above, but also a significant barrier of improving safety from current on-demand aviation operations (e.g. US FAA 14 CFR part 135) safety levels without increases in costs.

Given the need for some level of human pilots for the foreseeable future, as noted, one question is how to meet the growing demand for qualified pilots in a changing landscape. There is a current and projected shortage of pilots for the current operational model (i.e. not considering UAM implementation). Regional Airlines are already facing pilot shortages, some have cancelled flights, and one US regional airline has recently attributed the lack of qualified pilots as the primary reason for the cessation of their operations [7, 8].

These shortages are predicted to get worse [7, 9]. The shortfall is anticipated to be a significant challenge for the U.S. aviation industry, with regulatory measures already in discussion, even without additional demands for pilots from emerging markets.

One option to meet the demand for pilots is a significant reduction in training time, performance and proficiency standards. While increased use of simulation, and some reduction in time spent learning manual control skills is likely, there will need to be a research investment into what level of training and proficiency will be required to increase the level of safety for § 135 operations today.

IV. Increasingly Automated Aircraft Systems

Aviation has a long history of using automated functions. The first autopilot was developed in 1912, and systems to automatically land aircraft were in use in the 1960s. Since that time other functions such as navigation and some engineering functions have been reliably automated to a point where the flight crew complement has reduced to the current standard of a pilot and first officer for airline operations, and the ability to conduct on-demand operations with a single pilot with a working autopilot (§ 135.105).

The Society of Automotive Engineers (SAE) has developed an illustration [10] of the current categories for describing different levels of automation (figure 2). While the illustration refers to levels of automation for drivers of automobiles, the levels are comparable for aircraft automation and useful for describing the amount of automated assistance provided at each level.

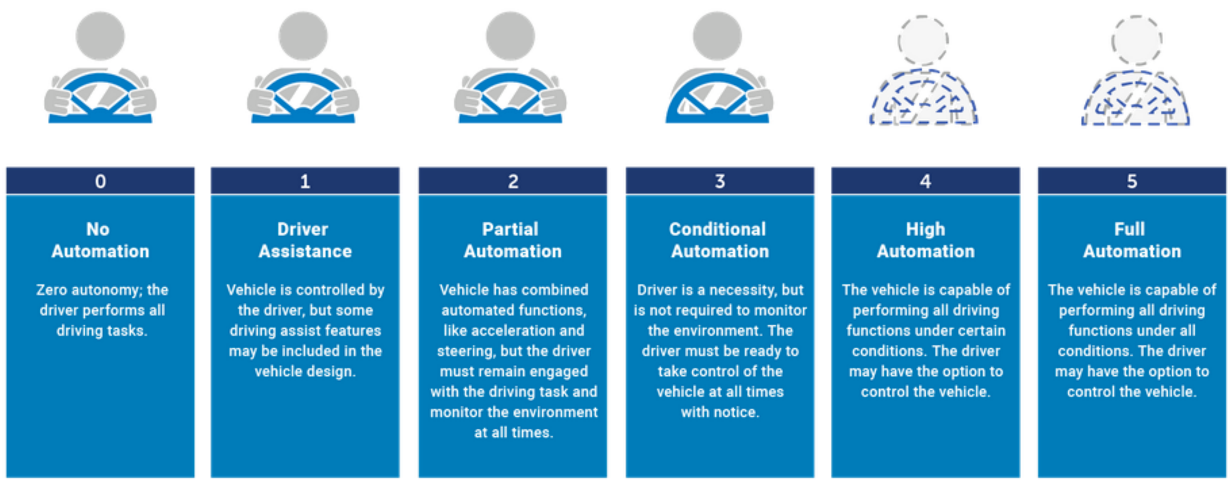

Figure 2. SAE levels of automation

The approval and adoption of increasingly automated systems onboard aircraft has continued at a steady pace, and many aircraft systems are at level 2 or 3 using the SAE scale. Despite this progress, fully automated or autonomous flight will require unprecedented changes, particularly in information automation and possibly a paradigm change in the way aircraft airworthiness certification and operational approval processes are carried out.

This will not happen overnight, as new transport category aircraft that are still in the design phase are designed for a traditional two-person flight crew. Some of these aircraft may be years from entering service, and are designed to have an operational lifespan of 20-30 years and therefore are likely to remain in service for many years.

Based on this foundation, it is clear that if the UAM concept is to be successful, many pilots may be needed for the UAM concept in the near-term and the current training, performance, and proficiency requirements may be a barrier to producing enough pilots to keep pace with demand using traditional training methods and aircraft capabilities.

As aviation is a safety-critical mode of transportation, the expectation is that there will be a transition from current commercial aviation flight crew skill and expertise requirements towards reducing the skills and expertise needed for human flight crew, as aircraft automation matures from current levels to level 4 and 5 (figure 2).

While the expectation for UAM is to move to level 5, or full automation eventually, the adoption of full automation will come in phases as different automation functions reach maturity. Even after reaching the threshold of level 5 operations, there will be an additional time period, during which time a human in the loop will be needed to handle unforeseen contingencies until enough data has been collected to assure safe operations under all conditions. This paper will review current flight crew functions for on-demand aviation, and then examine changes in flight crew functions for the UAM concept, and an initial look at some research topics for changes needed to enable the concept without compromising safety.

V. An Abstract Analysis of Flight Crew Functions

The current concept of operations calls for pilots who can meet the § 135 regulation minimums for operating under Visual Flight Rules (VFR). In the United States, this translates to pilots with an FAA Commercial pilots certificate and at least 500 hours of fight experience, among other requirements for operations.

Pilot training experiences can vary widely. As a starting point for training, an FAA private pilot certificate can be obtained with as little as 35 hours of flight experience and from 3 weeks of training time, and a commercial certificate could be obtained with a minimum of 150 hours of flight experience. However, most pilots require more time for training. The Aircraft Owners and Pilots Association, (AOPA) [11] states an average 50-70 hours of flight experience for private pilot, with an average of four months of training time for a private pilot and eight months for a commercial pilot. Since the minimum flight experience requirement for § 135 VFR operations is 500 hours, there is an implicit acknowledgement that operational experience is necessary beyond what can be provided in formal training.

In other countries and the US military, pilots can be legally qualified to act as professional pilots for on-demand or scheduled operations with less flight experience. These, competency-based training programs target specific flight operations and result in qualifications that may be limited to those operations. Examples include training in the US military and the ICAO Multi-Crew Pilots License (MPL), which evaluates readiness based on performance rather than total flight experience. It should be noted that the graduates of training programs like MPL are only qualified to serve as Second in Command, with a fully qualified Pilot in Command until meeting the regulatory experience minimums for full qualifications (e.g. Airline Transport Pilots License). These training and certification models have not been adopted in the U.S. civil aviation, but are among the training models being examined by the US aviation community for future professional pilot training.

The difference between the flight hours required for the commercial pilots license and the flight hours and other requirements for operating as Pilot in Command for § 135 or § 121 operations reflects a reality that it is difficult or impossible to train a pilot for every situation that may be encountered. Assuming that the adoption of some competency based training principles allows for a reduction in the flight experience requirement, there will still be a need to understand what additional experience provides for the current pilots, and how to translate that into improved training, or commensurate improvements in flight crew automated systems. This paper will look at the topics that will likely be needed for the human or artificial agent flight crew to operate in the UAM environment.

A. Current Flight Crew Function and Task Models

One high level task model that becomes familiar to pilots in primary training is known as the Aviate – Navigate – Communicate – Manage Systems model, shown in Table 1. The A-N-C-M model is useful as a simple method for framing and prioritizing pilot tasks.

Table 1. Basic piloting A- N- C-M task model

Aviate	Navigate	Communicate	Manage Systems
Example: Maintain continuous control of Aircraft	Example: Identify and track progress toward mission objective	Example: Communicate intentions and state to Air Traffic Control Coordinate with other crew members (on the ground or onboard)	Example: Monitor alerts Identify and diagnose abnormalities

After completion of primary pilot training, pilots have a model of aircraft systems and performance, characteristics of operating in different environments and knowledge of dealing with emergency situations. Once a pilot has the appropriate pilot certificates and is hired as a professional pilot, additional training is required. The current training requirements for US on-demand pilots, found in § 135.329 state:

- Basic indoctrination including training in at least the:

- operating certificate
- operations specifications
- operating manual
- standard operating procedures

- Initial, transition, upgrade and recurrent training as specified in § 135.345 and §135.349, including
  - aircraft systems
  - emergency training (§ 135.331)
  - crew resource management training (§ 135.330)
- Ground and flight training, instruction, and practice necessary to ensure that each crewmember
  - remains adequately trained and currently proficient for each aircraft, crewmember position, and type of operation in which the crewmember serves; and
  - qualifies in new equipment, facilities, procedures, and techniques, including modifications to aircraft.

Typically, pilots will receive written and electronic training materials covering the specific aircraft systems and company policies before the formal training begins. It is also typically expected that the student will learn this material on their own time, and most training organizations expect to spend little formal time training aircraft systems knowledge, but will check to verify that the pilot understands the material.

FAA training programs do allow competency based training programs. One such method currently used by both § 135 and § 121 operators is the Advanced Qualification Program (AQP). AQP is a voluntary program that allows the FAA to reduce training requirements if the operator can meet the requirements of the program and show a safety benefit. One requirement for the AQP program is that the operational certificate holder (e.g. airline) perform a thorough task analysis for each type of aircraft and operation it presents for AQP approval. An example task analysis from the FAA AQP program for a transport category airliner was used as a baseline for the tasks that are required to be trained to a FAA § 135 or § 121 flight crew.

The example task analysis used phases of flight as a primary means of organization, augmented by operations and procedures that cut across the phases of flight, including:

1) Pre-departure tasks
2) Takeoff
3) Climb
4) Cruise
5) Descent/Holding
6) Approach
7) Landing
8) Post-arrival ground operations
9) Non-normal/emergency procedures
10) System operation procedures
11) Environmental-Induced procedures
12) Special Operations

The example task analysis consisted of 2463 tasks, decomposed into six levels and categorized by the skill type required to perform the lowest level task. The skill categories include required “Knowledge”, “Cognitive skills”, “Motor skills” and Attitudes”. Knowledge requirements include aviation specific knowledge, such as knowledge of aircraft system operation, or weather phenomena. Cognitive skills are skills that require application of knowledge, such as using rules or problem solving, including hazard detection and mitigation. Motor skills are those skills required to perform and action, such as moving a control command on a control yoke or stick or pushing an autopilot control button. Attitudes include communication, coordination and information integration, including integration of information from flight briefings.

The skill category breakout is shown in table 2.

Table 2. Example AQP Task Analysis skill categories

Skill Category	# of skills
Cognitive	787
Motor	892
Knowledge	610
Attitude	174
Total	2463

B. Reducing Flight Crew Training and Expertise Requirements for Emerging Markets

Many emerging market concepts, such as UAM are dependent upon significant reductions in pilot training time and costs. The path forward is to try to automate systems that can be automated, specifically for functions that require skill and expertise. While some aircraft systems can be automated, removed or simplified for electric vehicles, some functions will be more difficult to automate. Examples of these flight crew functions are illustrated in figure 3, and include company procedure/SOPs, Crew Resource Management (with ground based crew), security, inspection and test, etc.

Some aircraft manufacturers are intending to reduce training through the addition of automation for guidance and control. While this is likely to make aircraft easier to fly, until automated systems meet SAE level 5 requirements human flight crew will need the ability and expertise to handle abnormal or emergency situations. In fact, the trend amongst traditional airline operations is to reintroduce upset recovery training for envelope protected aircraft after a trend of accidents involving loss of attitude or energy state, including some aircraft with envelope protection.

Reductions in aircraft complexity will enable some training reductions and possibly simplify the adoption of automated systems. Based on some assumptions about the eVTOL aircraft proposed for UAM, and the systems that may be eliminated, an assessment of the AQP task was conducted. In the analysis flight crew functions or procedures related to systems that would likely be eliminated in UAM aircraft were collapsed or removed.

The starting assumptions for the aircraft did include some systems that might be optional, including an auxiliary power unit, some fire protection, and speed control devices. Additionally, it was assumed that the aircraft designed for UAM would have limited endurance and short range, and therefore no skills or flight crew functions for international operations were included.

The assessment did remove a number of systems and procedures from the example AQP task analysis, including:

- hydraulic systems
- pneumatics/bleed air systems
- pressurization systems
- fuel system knowledge or actions that aren't equivalent to electric propulsion
- non- precision approaches
- extra intra-cockpit procedures
- crew cockpit communication
- some weather detection, but no onboard radar control
- no leading edge lift devices
- Inertial Reference System (IRS)
- wheel well fire system independent cargo fire system
- retractable landing gear system, and alternate landing gear extension systems

Examination of the example task analysis and removal of functions based on the above criteria, resulted in a significant reduction in the number of tasks listed in the AQP example tasks analysis, as shown in table 3.

Table 3. Comparing Tasks numbers for example UAM aircraft operations

	Original AQP example	Revised UAM aircraft	Difference	Reduction
Knowledge	610	337	273	45%
Cognitive	787	542	245	31%
Motor	892	486	406	45%
Attitude	174	91	83	48%
Total	2463	1456	924	41%

While the results of the analysis in table 3 show a significant reduction in the number of tasks, it is less clear what the impact is for pilot training and the development of automated systems. Evaluation of the modified AQP task analysis for likely operations and vehicle configurations results in a new task breakdown, illustrated in figure 3.

VI. A Flight Crew Function Model

While the AQP example task analysis is comprehensive for the flight tasks, it is apparent that the analysis is missing some required flight crew functions. Some of the missing functions are illustrated in in § 135.329, and the A-N-C-M model. Combining these models with the high-level AQP example task analysis described earlier results in a new combined Flight Crew Function Model as shown in figure 3.

Examination of figure 3 reveals a few themes emerge across the functions. The first theme consists of cross cutting functions that are relevant regardless of the type of vehicle. The second column consists of functions that contain actions or knowledge that are specific to the type of aircraft and objectives of the mission that is flown. The third column consists of the phases of flight as used to organize the example AQP task model.

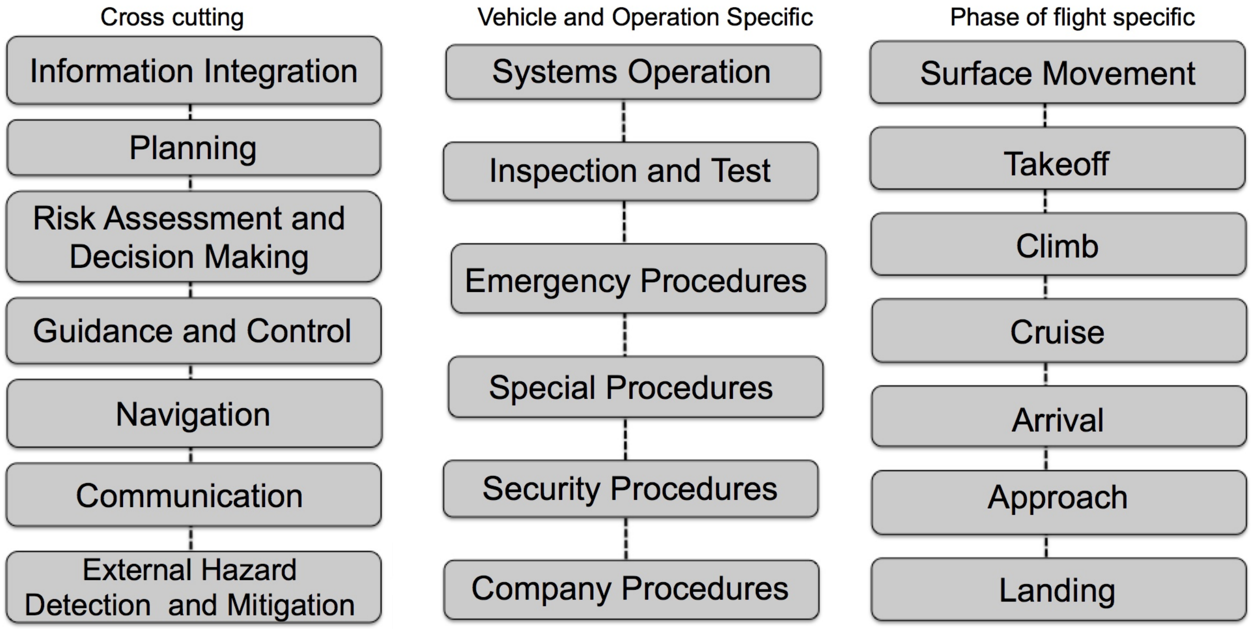

Figure 3. Categorized Flight Crew Function Model (FCFM)

Further inspection reveals that the cross cutting and vehicle/operation specific functional categories correspond to each phase of flight. Decomposing the functions to reflect this relationship allows examination of the flight crew functions independently, and application to the different challenges presented by each phase of flight. Figure 4 shows the reformatted model.

The combination of models and reorganization results in a model that can examined for pilot and automation requirements.

The first column consists of functions that are applicable as flight functions regardless of the vehicle or type of operation. Included in this category are:

Information Integration. Much of what pilots do in modern aircraft can be considered “Information Integration”, as it is combining many pieces of knowledge and actions. Examples of information Integration include the collection, and analysis of information as part of the pre-flight briefing, and continued integration of information while underway that may impact the successful completion of the mission. Many details of information integration are poorly understood, including:

- monitoring of aircraft health and systems state,
- assessments of information properties (urgency, duration, frequency, recovery, etc.)
- assessments of data integrity and confidence

Current safety focuses on understanding the contributors to accidents, but good data sources on “almost accidents” are not easily accessible. Data from a 2009 Line Oriented Safety Audit (LOSA) report suggest that pilots take intervention actions in approximately 30% of flights. What is not well understood is how many of those actions have safety implications [12], and how many precursors to accidents are detected and trapped before an incident or accident sequence can begin to develop.

Planning is very broad category of activities and is relevant to many domains. In aviation planning includes schedule concerns, in-flight re-planning, performance prediction and mitigation of hazards. Many airlines have personnel that have operational authority to perform the flight planning and plan cooperatively with the pilots.

Risk Assessment and Decision Making uses the results of the Information Integration function to assess risks, make decisions, use controls, and monitor results. There are many examples of risk assessment and decision making. Some including the PAVE, CARE and TEAM checklist and the 5P model help the flight crew detect any risks or hazards to perform the flight, by examining the status of the pilot, aircraft, environmental hazards and any external pressures (schedule delays, impending weather concerns, etc.). Others decision making tools such as the TEAM checklist help the flight crew to implement risk control. Additional tools such as the DECIDE model help the flight crew mitigate risks and hazards [13].

Navigation, Guidance and Control refer to the determination of aircraft position, a path for travel to a destination and control to that path.

Communication includes communications with other crew members, in the air or on the ground, for dispatch, re-planning, medical emergencies and other situations requiring extra handling, in addition to communications with Air Traffic Control.

External Hazard Detection and Mitigation: This is a big category, including detecting, mitigating and avoiding environmental hazards (e.g. poor weather and high winds), conflicts with traffic, or obstacles.

The second column includes functions that may change depending on the aircraft, the objectives of the operation and the rules and procedures of the operational certificate holder.

Systems operation refers to any systems required to enable the flight as well as onboard aircraft systems. Examples include ground infrastructure systems such as ground power equipment, fueling/charging, etc.

Inspection and Test includes activities such as exterior inspection, and initial test to ensure all systems are working before departure, but also includes testing of in-flight systems

Emergency Procedures: This function has some overlap with hazard detection and mitigation, however emergency procedures typically have to do with onboard hazards such as fires or propulsion failures. Emergency procedures also involve information integration, risk assessment and decision making currently since the state of art for most aircraft automation is to alert the pilot to a failure, and direct the pilot to a procedure to safe or remedy the problem. Most aircraft do not include implications of an emergency, or include any contextual information integrated with a component failure.

Special Procedures involve operating into airports with unusual operational conditions (e.g. military airfields, high altitude or surrounded by terrain). It also includes ferry procedures for returning aircraft that are not fit for carrying passengers, but can be returned to a maintenance base.

Security Procedures include flight crew detection and identification of potential security threats at any point of the flight, pre-flight or post-flight.

Company Procedures may include information about how companies interact with customers, reporting of expenses, preferences for decisions about resolving problems that are not safety related, or competitive information that a company may not want codified into rules.

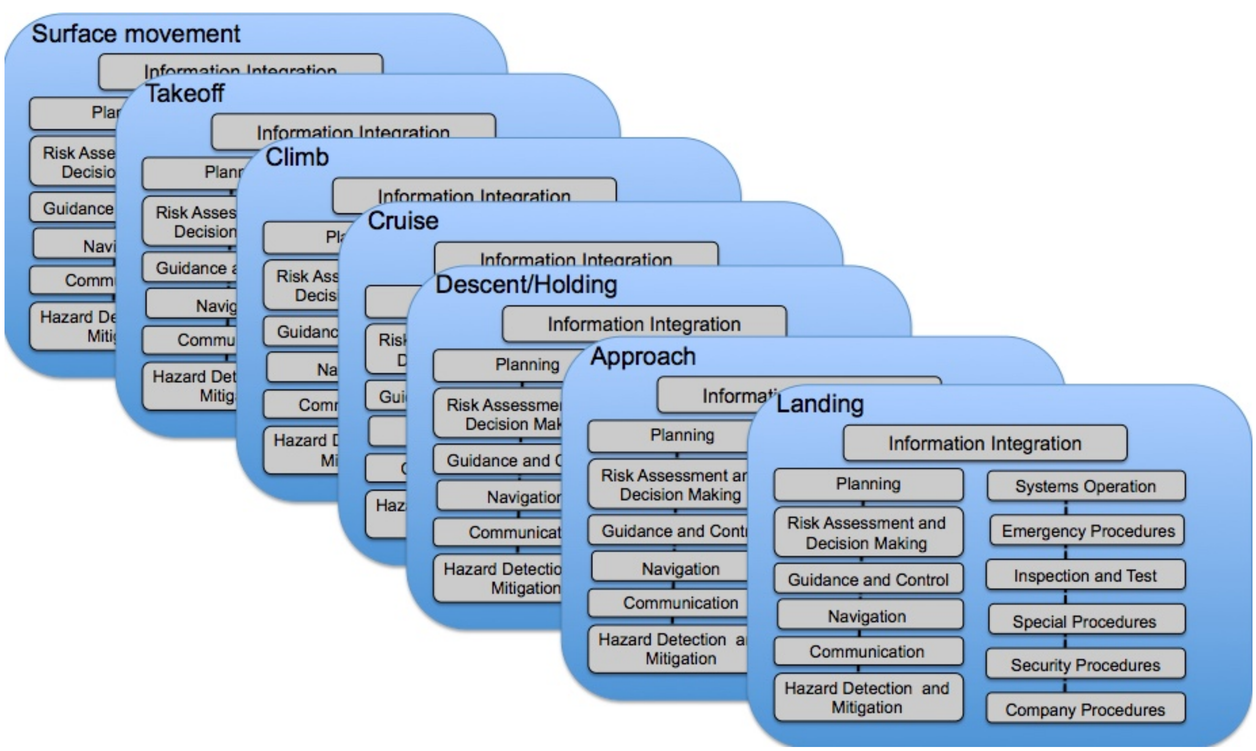

Figure 4. Flight Crew Function Model (FCFM) grouped by Phase of Flight

VII. Next Steps

The resulting FCFM is a functional framework based on what is known about flight crew operational requirements that could be useful for discussions about which flight crew functions could be simplified, how to improve training and assess the needs for development of automated systems.

A comparable framework was developed by Bowles (2017)[14]. The Bowles task framework has been used as a basis for an assessment of readiness for automation (shown as green bars) for replacing the human pilot for each functional category for General Aviation aircraft. The Automation Readiness Level illustration is shown in figure 5.

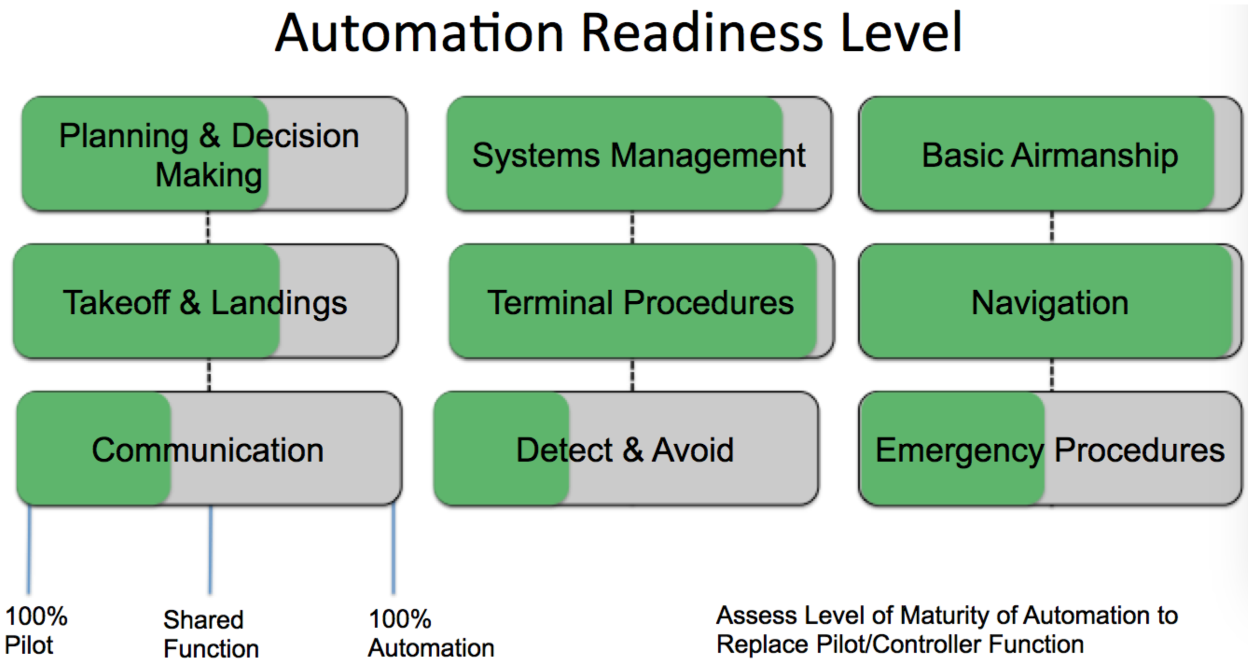

Figure 5. Automation Readiness Levels (Bowles, 2017)

The next step for this research project is to perform an analysis of automation readiness for each functional category, similar to the Bowles analysis. As the underlying functions are different it should be useful to compare and contrast the differences in the functional descriptions and the basis for determining automation readiness. There has been great progress automating some flight crew functions, but there are many functions that are not as well understood. The FCF model attempts to provide to a decomposition that can take advantage of automation development from other domains (e.g. planning and scheduling systems, hazard detection sensor development).

It is hoped that the model will be particularly helpful for assessing the differences between traditional commercial aviation domains to emerging markets, such as UAM. The assumptions being described about UAM predict many differences in vehicle characteristics and operating environments. Examples include UAM approach operations. The approach trajectories for UAM are likely to be specified by obstacle and noise requirements, and may be made more difficult when operating in close proximity to other aircraft. In addition wind modeling for urban environments is immature for these purposes, although wind modeling could be significantly improved by sharing information between vehicles about weather conditions. [1].

VIII. Discussion

This is an exciting time in aviation. The mix of new technologies, new business models and development of technologies in other domains (e.g. cars) that could aid development could spur unprecedented density of flights in the future. The transition to these new operations requires deliberate consideration of the safety challenges or risk impeding the concept.

There are many challenges to overcome for the emerging aviation markets concepts to be successful. A primary challenge is to develop a plan that allows a phased implementation of automated systems and the early identification and mitigation of safety hazards. History has shown that there are typically unforeseen safety hazards with the adoption of new technologies, and the combination of new aircraft technologies combined with new operational paradigms will present new and, for now, unforeseeable safety vulnerabilities.

The transition to greater use of automated systems will generate additional challenges. A phased transition should help to mitigate some safety issues, but in the short term the industry will still have a requirement to provide large numbers of safe and capable pilots. The industry is projecting a shortage of pilots for traditional airline operations, and new flight crew training and performance requirements will likely be necessary.

It also appears that if the UAM concept is successful, there may be operators of fleets of eVTOLs that are much larger than the fleet sizes of current on-demand aviation operators today, which will likely require more formal implementation of management processes and operational models that may be more similar to § 121 airlines than most §135 operations today.

The mid- to long-term vision for UAM is more interesting from a perspective of research into Human-Automation Teaming, as more authority is given to autonomous functions. This will change the nature of piloting, as more aircraft control is likely to be given to the aircraft while decision making authority and response to unusual situations will be some of the last functions to be automated.

It is hoped that some of the early thoughts about research topics illustrated by the flight crew function model will help frame the relevant research questions.

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