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Understanding Risk in Urban Air Mobility: Moving Towards Safe Operating Standards

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Table of Contents

Acronyms and Definitions

ARMD	Aviation Research Mission Directorate (NASA)
ATM-X	Air Traffic Management eXploration (a NASA project)
e-VTOL	electric-powered vertical takeoff and landing
EASA	European Aviation Safety Agency
FAA	Federal Aviation Administration
ICAO	International Civil Aviation Organization
IPP	Integrated Pilot Program
JARUS	Joint Authority for Rulemaking of Unmanned Systems
kg	kilogram
LOSA	Line Operations Safety Assesment
NASA	National Aeronautics and Space Administration
NPRM	Notice of Proposed Rulemaking
ODM	On Demand Mobility
SAE	Society of Automotive Engineers
SORA	Special Operational Risk Assessment
sUAV	small unmanned aircraft vehicle
UAM	Urban Air Mobility
UAV	unmanned aircraft vehicle
UTM	UAS Traffic Management (a NASA project)

Understanding Risk in Urban Air Mobility: Moving Towards Safe Operating Standards

Mary M. Connors[1]

1. Introduction

Urban Air Mobility (UAM), i.e. on-demand urban passenger (and cargo) transportation services, represents a new technology and potentially an emerging industry. It is not simply an extension of commercial aviation as we know it—it is a different domain. A first priority for UAM is that it be safe and secure (Booz, Allen, Hamilton, 2018; Crown, Consulting, Inc., 2018). A workshop held in Arlington, Virginia, brought together experts from the on-demand world (including UAM) to assess and prioritize the challenges and barriers to be addressed in successfully introducing On Demand Mobility (ODM) vehicles and services (ODM and Emerging Technology Workshop, 2016). Of the nine challenges assessed, the highest priority was assigned to certification, followed by affordability, and then safety. Considering the confluence of certification and safety, it is clear that risk and its assessment were judged to be of high relevance to workshop participants.

For the UAM domain there is a range of questions concerning the projected safety of vehicles and their intended operational environment. We assume here that, at least for the near future, these vehicles will be piloted, but it is likely that one day they will be unmanned. Many questions involving UAMs cannot be answered at this point (see UBER Elevate, 2016, 2017), however, developers are eager to get started and—lacking specific guidance—a number of going-in assumptions are being made. For instance, developers are working to meet the operational requirements under Title 14, Code of Federal Regulations, Part 135. These requirements cover commuter and on demand operations and rules governing persons on board such aircraft. The Society of Automotive Engineers (SAE) International also provides some aid in anticipating requirements from an international perspective (SAE International, 2010). While these documents are insufficient for the yet-to-be-developed electric-powered vertical takeoff and landing (e-VTOL) vehicles, they do provide help in thinking about the safety needs, risk levels, and eventual certification requirements needed for UAM missions. The purpose of this report is to help advance the discussion by considering how various factors could contribute to the establishment of guidelines and standards for UAM systems.

2. Emergent Vehicles and Missions

The demand for UAM travel has evolved from a confluence of factors including technological improvements, cost of human capital, urban crowding, ground transportation saturation, and a myriad of fallouts from digitization that has changed the way people live and work.

In addition to on-demand passenger transportation systems, there are similar demands coming from operators of unmanned vehicles and operators of drones. The result is a bow wave of fledgling

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industries—all impatient to grow and all requiring access to the valuable resource of airspace. This is a huge challenge at a time when the present air traffic control system is struggling to keep up with growing conventional demands. The question is how to accommodate these various demands while keeping the system safe. To date no specific procedures addressing either unmanned aircraft vehicles (UAVs) or drones have been established. However, the UAV community—facilitated by the International Civil Aviation Organization (ICAO) (Malaud, 2019)—has adopted operational procedures to allow its vehicles, at least for the present, to interact with other aircraft and with air traffic control as if they were piloted vehicles (ICAO, 2015; FAA, 2018). For drones that impact the controlled airspace, the present approach is to apply for permission to fly and to be evaluated on a case-by-case basis (Federal Drone Law, 2018). However, the Federal Aviation Administration (FAA) is in the process of exploring the potential adoption of a more general approach to drone operation based on a remote monitoring system. Such a system would require every drone to be identifiable for monitoring purposes. At this writing this proposal is in the public comment stage. On-demand (UAM) vehicles are not yet sufficiently mature to require immediate airspace entry. In none of these cases (UAVs. drones, or UAM) does the existing status appear to be a scalable solution of risk level needs, with UAM likely posing the greatest future challenge.

3. Demand Characteristics of UAM

In addition to operating personnel, today's safety standards for commercial flight are addressed under two major domains: vehicle and air traffic management. UAM introduces a number of new areas of concern that go well beyond the integrity of the vehicle and the separation of traffic. However, at this point in UAM development, vehicles still occupy a major focus of interest.

3.1. Vehicles

There are dozens of companies, both established and start-ups, competing for vehicle entry into the UAM market. Some companies are planning for piloted vehicles, others for unmanned autonomous or remotely operated vehicles. Propulsion systems may be all-electric, hybrid, or other. In some cases, standards established for passenger-carrying vehicles have direct relevance to the design of their UAM vehicles. Electric and hybrid propulsion systems are relatively new to aviation, requiring new emphasis on vertical lift and forward motion. However, in terms of safety, all need to be measured against the same safety standards. For component parts, at least, functions can be assessed and the probability of failure evaluated. But for UAM vehicle developers, an essential safety-related task will be the possible failures of the vehicle under conditions of flight (e.g., at low altitudes and close to permanent structures.) While developers intend to operate in accordance with Part 135, it needs to be understood what "meeting Part 135 standards" means in this context and how measurements are being made. There is a long history of evaluating and certifying flight vehicles and their components and it is likely that e-VTOL vehicles, considering only the vehicles themselves, will eventually be able to demonstrate levels of safety risk comparable to today's safety expectations. The challenges of where and how they operate describe a much steeper climb to attain acceptable safety risks.

3.2. Air Traffic Management

UAMs are expected to be able to fly virtually anywhere and will demand a more capable air traffic management system than exists today (Holmes et al, 2017) as well as new ways to certify operations. The FAA has initiated efforts to address these issues through collaboration with NASA's Air Traffic Management eXploration (ATM-X) project (NASA, 2018). NASA has taken an active role in researching potential air traffic control management as described in Thipphawong et al

(2018). At the same time that air traffic management becomes increasingly difficult, many UAM stakeholders are taking the position that the pilot's job (and pilot training) should be significantly reduced. This begs the question of how safe flight is to be attained and maintained, though much can undoubtedly be achieved through on-board technical improvements. There is an evolving consensus that for on-demand mobility to grow there must be a shift from prescriptive to performance-based guidelines. This shared belief provides a starting point, but only a starting point, for how the air traffic of UAMs may eventually be managed.

3.3. UAM Infrastructure

In addition to differing in size, number of passengers, distance, type of service, etc., UAMs will be supported by ground environments new to aviation. The infrastructure supporting UAM flights will include heliports, rooftops, fields, parking lots, and whatever else may be adaptable to vertical take off and landing. Cybersecure communication networks will need to be established. Flying at low altitude and (for aviation) tightly packed, it can be expected that difficulties associated with air, ground, or ground structure intrusions will arise.

3.4. Flight Requirements

Because e-VTOLs will operate in urban areas, UAM must address conditions that make the assurance of safety new and very demanding. In turn, these conditions are likely to impact the requirements demanded of the vehicles themselves. UAM flights and e-VTOL vehicles will need to be able to:

- Fly at low altitudes (maximum of 1,500 ft).
- Ascend, hover, transition, climb, cruise, and reverse the process rapidly and smoothly.
- Maintain sufficient electrical (or hybrid) energy for the mission plus reserves for emergencies.
- Land safely in a potentially busy area in the event of a critical failure or a collision.
- Deal with rapidly changing upward/downward drafts and weather conditions related to buildings and "urban canyons."
- Maneuver to and from vertiports and avoid buildings, power lines, and other obstructions, as well as each other.
- Operate on a very tight schedule: Some assume a turn-around time for most flights to be 10 minutes (UBER, 2016).
- Avoid disturbance to other users of the airspace. Malaud (2019) points out that UAM operations will likely conflict with fundamental principles of aviation, the rules of air, i.e., general flight rules, visual flight rules, and instrument flight rules (height, proximity, established right of way).

A possible way to move forward into an urban area and maintain a level of safety (and acceptability) is to establish pre-determined routes. These routes are likely to be along railroad tracks or over freeways. These routes could provide some protection for ground personnel, especially from noise, but they will not satisfy the variety of trajectories required of UAM flights. As an initial, top-down look into the issues associated with UAM flight paths, a full analysis is needed of scenarios that can describe representative UAM flights. These scenarios should include not only the mission and flight paths anticipated but also how they are to be scheduled, what networks are required for secure communication with the ground and other vehicles, how arrival availability is to be assured, what air traffic or other support is needed, how contingencies are to be managed, et cetera.

3.5. Urban Residents and Workers

Often overlooked in considering the shift from conventional missions to UAM missions is the importance that must be given to those under the flight paths of the UAMs. In the past, safety considerations were focused primarily on the on-board personnel—pilots and passengers. For UAM flights, more consideration must be given to those on the ground who are engaged in their normal activities but whose safety could be compromised by UAM flights.

Though not directly related to flight safety, there are also other considerations that could impact the health and well-being of ground personnel and will impact their willingness to approve UAM missions. These conditions include emissions, noise, anxiety or fear, and the presence of visual clutter. Emission problems should be reduced for all-electric vehicles but may still be an issue for hybrid vehicles due to their low altitude during flight. As has been mentioned, noise is a widely recognized issue for UAM and research to reduce its negative impact is currently on-going (NASA Advisory Council, 2018). The experience of fear could hamper acceptance of UAMs, especially at their introduction when they are unfamiliar but also later in the process as penetration reaches a critical level. In terms of visual clutter, at some point there could be a reaction against the loss of visual access to sky, clouds, sunsets, mountain tops, or other visual scenes associated with a serene environment. UAM issues as they impact the welfare of communities and the relationship to community acceptance are discussed in Connors (2019). Anticipated experiences of e-VTOL passengers and their projected responses are discussed in CCI (2019).

4. Data-gathering

In addition to the specific testing being conducted by the various vehicle, air service and other developers, some broader testing is planned for acquiring data based on real-world, field operations. In 2020, UBER, with its partners, will begin demonstration flights in Melbourne, Australia; in Dallas/Fort Worth, Texas; and in Los Angeles, California, in preparation for the planned 2023 introduction of service (Aviation Week and Space Technology, 2019a). These demonstrations should offer opportunities to gain insight into vehicles, their components, their operations, how to manage vehicles in close quarters, and possibly on responses to noise and general feedback from on-ground persons.

A potentially more-open opportunity is found in NASA's UAM "Grand Challenge." The plan is for a series of demonstrations beginning in 2020 and lasting through 2022. These demonstrations are designed to gain understanding of the complexities of operating in a field setting and to assess safety and scalability issues. NASA has been working closely with the FAA to conduct research that will aid the FAA in developing an approval process for UAM vehicle certification; in providing flight procedure guidelines; in evaluating communication, navigation, and surveillance requirements; in defining airspace operations management activities; and in characterizing vehicle noise levels. The first series of Grand Chalenge demonstrations are limited to U.S. companies are planned to be conducted out of NASA's Armstrong Flight Research Center in southern California. Subsequent demonstrations are open to both U.S. and foreign companies and will be originating from other U.S. locations. Various scenarios are planned to examine different aspects of UAM flight; subsets of these scenarios will be included over the course of the Grand Challenge demonstrations. Each succeeding demonstration in the series is intended to increase the understanding needed for real-world operations. Organizations selected to participate will need to meet minimum requirements in order to support the safety and success of the demonstrations, which in turn may contribute to an understanding of UAM flight needs generally.

5. Existing Passenger-carrying Requirements

The rapid emergence of demand for new travel venues and new vehicles to support these venues will trigger a need for reassessment and potential realignment of safety standards, both for the operation of the vehicles themselves and for their introduction into the intended environment. To examine whether existing standards make sense for UAM operations—or if they can be adapted for UAM—it is useful to consider the passenger vehicle requirements that are in place today that are likely to form the bases for the safety requirements of future vehicles.

In terms of developing safety broadly applied to UAMs, two questions need to be addressed: (1) how to apply what we have learned from existing risk-level analysis; and (2) what more is needed that is particular to the assessment of UAM flights. It can be assumed that UAMs will need to meet the same safety standards as other passenger-carrying vehicles so existing requirements could provide a useful foundation for consideration of UAM.

5.1. Risk Levels for Passenger-carrying Commercial Operations

Under the present system some aspects of safety requirements can be directly evaluated and numerically specified, as described in FAA Advisory Circulars. Others, though requiring the same level of safety, cannot be so easily evaluated and must take into account a wide variety of conditions and situations. To support these different demands, the FAA has adopted both a quantitative and a qualitative approach to assessing safety risk. The fundamental principle underlying both approaches is to demonstrate that whatever requirements are established define a safe situation.

Flight safety is evaluated by the interaction of three characteristics or conditions: (1) *criticality* of the function; (2) *severity* of a failure; and (3) *probability* of an event, with criticality of the function and severity of a failure overlapping concepts.

Criticality. Criticality of a function is established by the importance of the function to safe operations and is described as:

1. Non-essential. Non-essential functions are those functions that do not contribute to or cause a failure condition which would significantly impact the safety of the airplane or the ability of the flight crew to cope with adverse operating conditions.
2. Essential. Essential functions are those that could contribute to or cause a failure condition which would significantly impact the safety of the airplane or the ability of the flight crew to cope with adverse conditions.
3. Critical. Critical functions are those whose failure would cause a condition which would prevent the continued safe flight and landing of the airplane.

Severity. Severity conditions are categorized in terms of their likely impact, i.e. as determined to result in:

1. Failure with no safety effects.
2. Minor failure conditions.
3. Major failure conditions.

4. Hazardous failure conditions.
5. Catastrophic failure conditions.

Probability. The importance of a failure event is evaluated in terms not only of its severity but also of its likelihood of occurrence. Probability refers to the expectation that a failure will occur at a given rate. Probability is assessed in situ (e.g., equipment is assessed as installed on the aircraft) and calculated in terms of aircraft hours of flight. Probability can be evaluated quantitatively and/or qualitatively. Quantitatively, the occurrence of a failure condition can be described as:

1. Extremely improbable (1 X 10-9 or less). Failure would be expected to occur no more than once in a billion hours of flight.
2. Improbable or remote (1 X 10-5 or less). Failure would be expected to occur no more than once in 100,000 hours of flight.
3. Probable (1 X 10-5 or more). Failure would be expected to occur more than once in 100,000 hours of flight.

Assessing the severity and probability of an individual element failure is relatively straight forward. However, the emergence of highly integrated and autonomous systems has resulted in the need for more complex assessment techniques. This complexity has led to a greater emphasis on qualitative measures to complement quantitative measures. For qualitative measures, the probability of a failure condition is described as:

1. Extremely improbable. A failure condition is not expected to occur during the entire operational life of all airplanes of this type.
2. Improbable or remote. A failure condition is not anticipated to occur during the entire life of a single random airplane. However, a failure may occur occasionally during the entire operational life of all airplanes of one type.
3. Probable. A failure condition is anticipated to occur one or more times during the operational lifetime of each aircraft.

An acceptable safety level for equipment and systems is based on an inverse relationship between average probability of failure per flight hour and the severity of the failure condition being considered. Critical aircraft functions are required to be Extremely Improbable. Essential functions are required to be Improbable; while Non-essential functions have no specific probability requirements.

While these relationships are clear as stated, they may be difficult to apply in practice and also may change with changing circumstances. For instance, an auto throttle in an unmanned vehicle is deemed Critical (must meet 1 X 10-9 probability of failure) while in a piloted vehicle it would be considered Essential (probability of failure no more than 1 X 10-5) since it is assumed that the on-board crew could act to reduce the impact of a failure. More generally, any function that “involve(s) crew actions that are well within their capabilities” (FAA, 1988) allows for a higher level of potential failure since it is assumed that the crew could fill the gap and meet the 1 X 10-9 required for an otherwise critical function.[2]

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[2] It has been found (basedon LOSA data) that malfunctions occur in about 20% of normal commercial operations. It is assumed that pilots will manage these malfunctions as an important part of their piloting tasks (PARC/CAST, 2013).

5.2. Trends in Meeting Safety Requirements

Airworthiness requirements have changed over the years influenced by a number of factors: The emergence of complex and highly integrated vehicle systems; the general introduction of automation and software; and the shift in emphasis from sub-system vehicle design functions to system or whole aircraft operations. For instance, in the assessment of risk, pilot involvement was once considered primarily as a redundant system supporting the technology being evaluated and offsetting a potentially serious failure. Today's analysis views the human participants more broadly. In this view, crewmembers themselves are considered a potential source of error in assessing risk, as well as an important capability for reducing the impact of technical system failure. This whole-system approach to possible failure provides the foundation needed in evaluating new types of vehicles and new mission applications.

6. Need for New Policies and Regulations

New policies must not only incorporate what is applicable from existing safety regulations but create and incorporate policies and regulations to meet specific new needs. This is particularly salient in meeting requirements for certification (Coudert, 2019.) The resulting protocols must assure safety in a way that is reliable and robust and offer ways to mitigate failures to the extent possible.

The basic concepts of severity and probability associated with risk level assessment used to certify passenger-carrying aircraft (described in Section 5) can be transferred to UAM flights. These standards are assumed to constitute the basis for determining air worthiness, avoiding failure, and planning for safety.

6.1. Methods of Assessing Safety of New Vehicles

A valuable and highly utilized method for qualifying the safety of new aircraft components and systems is to demonstrate the essential similarity of the new system to existing systems that have been judged to meet safety standards. An overriding problem for UAM is that little—either in projected vehicle designs or in their concept of operations—is reflective of existing systems, especially when one considers the nature of the flights and the low-altitude environments in which they will operate. We need to decide where to start and how to at least advance the understanding of vehicle safety as applied to UAM flights. Like all such endeavors, as a practical matter it will be initiated under the safest conditions possible and advance in small steps. The "safest conditions possible" will mean flights in less inhabited areas and where the mission is simple—perhaps a package delivery. Successes in this semi-fenced environment, initially without passengers onboard, will provide the security to move forward.

6.2. Implementation Approaches

It is clear that new ways are needed to assess airworthiness and flight risk for a broad range of urban flights that differ among themselves in size, missions, environments, et cetera. Regulators are examining a number of approaches to address these needs.

The FAA has initiated an Integrated Pilot Program (IPP) for some delivery activities presently operating under Part 135 (FAA, 2019). The FAA has also revamped Part 23 rules for small aircraft to aid in the introduction of UAM vehicles. But for the more general UAM activities, the FAA has adopted a "crawl-walk-run" or evolutionary approach to UAM standards (Elwell, 2019). This approach stresses both the FAA's commitment to careful safety planning and their policy position to work with others to accelerate the introduction of new and innovative aviation technologies. This FAA approach is complemented by NASA's commitment to "build, explore, learn"—emphasizing their bottom-up, experience-based approach to addressing the research needs of UAM flight. Elwell also stresses the need to transition from prescriptive rules to performance-based rules with data-driven, performance-based rules forming the backbone for UAM vehicle evaluation. These changes are already reflected in the FAA's Notice of Proposed Rulemaking (NPRM) which addresses small UAVs (sUAV) flying at low altitudes over populations—a change in fundamental approach that is embraced by many for the new urban vehicles. Also, in its certification process the FAA acknowledges the necessity for further qualitative as well as quantitative analysis, with qualitative analysis likely to become increasingly important when applied to UAM systems.

Whatever the regulatory status that emerges, it is clear that it will rely less on prescriptive rules and more on the ability of UAM developers to document the safety of their systems. Initially short-term testing of UAM vehicles may be approved on a case-by-case basis. But at some point it will be necessary to develop a more comprehensive capability for evaluating the safety of e-VTOLs and UAM missions generally.

7. Research Needs

NASA has taken a primary research role in working with the FAA to help implement Urban Air Mobility, with all programs under NASA's Aviation Research Mission Directorate (ARMD) contributing to this effort, including those with particular reference to safety and risk assessment.

One of the most pressing research needs for advanced technology systems such as UAM is in the area of human-computer interaction. For several decades and continuing today, researchers at NASA and elsewhere have worked to understand the relationship of autonomous/semi-autonomous systems and humans in optimizing safe and effective systems, including both direct and remote human-automation partnerships. In terms of air traffic management, NASA's UAS Traffic Management (UTM) project has established a model for drone management that, with further development, could be applicable to UAM vehicles. Both of these on-going research areas have much to contribute to UAM implementation. In additin, if UAM vehicles are to be flown as currently envisioned, i.e., by pilots with limited skills, an important research challenge is to identify how that will be done, which skills must be retained by the pilot, and to develop a training protocol that will meet piloting requirements. Other needs are to identify and test relevant scenarios and procedures. Also, as the industry begins to take shape, a reporting system that captures experiences and provides lessons learned will need to be developed. Methodologically, it needs to be determined how safety can be built into and measured reliably in UAM vehicles and systems. Billman et al (2020) have provided detailed methods for assessing how display devises, assessed at various phases of development, can be evaluated for their impact on users' attention, awareness, and understanding. While established for transport aircraft, similar methods will be needed—and could be adapted—for UAM vehicles. At the system level, fast-time simulation, human-in-the-loop simulation, and field trials are approaches that can address questions of density and scalability for a UAM system.

While NASA's contributions to UAM, including those to safety and risk assessment, are presently included in their several established aviation programs, ARMD is standing up a Virtual Development and Integration Office for future direction and coordination of UAM activities.

8. National Policy and Global Reach

Holmes et al (2017) and others have emphasized that if progress on the implementation of UAM is to be realized, there is a need to develop and adopt a national policy. This national policy must involve all stakeholders: research organizations, developers, operators, entrepreneurs and investors, regulators, as well as legislators, passengers, media spokespersons, and community representatives.

The United States is not alone in its attempts to develop and implement urban air mobility. And while establishing a national policy for UAM flights is a necessary step, it is also necessary to be cognizant of what other nations are doing and to join them when possible to ensure that flights, wherever conducted, meet prevailing safety standards. Also, the many companies developing UAM vehicles are looking to both domestic and foreign markets. Safety is a universal concern and is a natural focus for international as well as domestic cooperation.

The European Aviation Safety Agency (EASA)—like the U.S.—is looking to a 1 X 10-9 probability level of catastrophic failure. EASA has taken a first step in establishing a framework for eventual certification of small vertical take off and landing vehicles (EASA, 2018). This proposed framework is applicable to vehicles carrying five or fewer persons and having a takeoff mass of 2000 kg or less. Entitled "Special Condition-VTOL-01" and issued on October 18, 2018, the proposal relies heavily on standards used for CS-23 (their certification standards for small commuter aircraft.) Although primarily only a framework or structure from which guidelines can be developed, the proposal does include new emphasis on changes that will be needed to accommodate lift control systems and controlled emergency landing while revisions to other areas that are relevant to UAMs (e.g. protecting passengers against bird strikes) are also mentioned. A theme throughout the document is the application of standards for the specific flight envelopes to be flown and their intended operations. This emphasis acknowledges the range of vehicles and missions anticipated from the various UAM developers.

Some of the leaders in the foreign market are Lilliam (Germany) and Vahana (a project of Airbus). Of the Asian companies, of special interest is the Chinese company EHANG. The vehicles EHANG is now testing serve 1–2 passengers. Their approach is notable for several reasons. First, they have opted for a "self-piloted" vehicle (no trained pilot required). Also, EHANG envisions its role as a "full service" operation, including all aspects of implementation from vehicle development and air traffic management to scheduling, maintenance, and even the design and development of infrastructure. EHANG reports that they have moved well beyond prototyping and early testing and have delivered vehicles to Canada and Norway as well as within China (Aviation Week and Space Technology, 2019b). In terms of meeting safety requirements, EHANG is presently developing an approach to risk-based air worthiness management using the Special Operational Risk Assessment (SORA) tool. SORA is the standard adopted by the Joint Authority for Rulemaking of Unmanned Systems (JARUS), reflecting EHANG's UAM approach of a self-piloted vehicle.

A broad-service approach has also recently been announced by Bell in describing their all-electric eVTOL UAM passenger vehicle (Warwick, 2020.). Bell anticipates that their vehicle will carry four-to-five passengers and a pilot, and they envision that it will eventually be fully autonomous with human-based ground oversight.

9. UAM Industry

While safety predominates, if Urban Air Mobility is to succeed as an industry there are a number of other barriers that must be overcome. These challenges are both technical (e.g. the need to accommodate dynamically changing trajectories) and non-technical (costs must come down). But if this new industry is to succeed, there must be to some extent a coming-together of UAM players to address their shared needs, particularly those related to safety and risk. As long as the various players are moving ahead to achieve their individually determined solutions, it will be difficult-to-impossible to accomplish the unity of purpose that a viable industry requires. The competitive environment must yield, at some point and at some level, to the needs for coalescence. It will require some sharing of approaches, intentions, and experiences if UAM is to move forward and grow. By imposing mission requirements, the NASA Grand Challenge provides a specific opportunity to begin to understand shared needs while safety concerns, considered broadly, provide an ideal domain for focusing the coming-together process.

10. Conclusions

UAM systems differ from previous air transportation systems along many dimensions: Propulsion; flight routes; altitude flown; capacity; infrastructure; relationship to people on the ground; et cetera. It follows that issues of safety and risk assessment for UAM vehicles, missions, and operation, while aligning on some existing standards will diverge on others. There is a need to fully understand the requirements of all UAM vehicles since different vehicle types will represent a variety of missions and operate in diverse, dynamically changing environments. From this understanding a determination can be made of what current standards apply or can be adapted and what new approaches to risk assessment need to be developed, as well as the research needed to support this development. Some re-assessments have already started. For example, in anticipation of emergent vehicles the FAA is overseeing a transition from prescriptive (rule-based) standards to demonstrative (performance-based) standards of air worthiness. The density, low altitudes, and flight envelope demands of UAMs will also require a greater flexibility in relevant air traffic management systems.

Whatever the new approach, approval cannot long be applied on a case-by-case basis. If the industry is to take root, grow, and mature, it must do so around some agreed-upon and accepted principles and practices. For best outcomes this harmonizing of understanding and acceptance should begin while the industry is in its formative stage and involve all interested parties, both national and international. Meaningful risk assessment and safety standards will require shared principles and practices. In addition, this activity will need to be guided by an organization familiar with negotiating for best overall outcomes. ICAO is a leading candidate to fulfill this role having extensive experience and demonstrated success in working with member states and industry groups. If Urban Air Mobility is to become a new mode of transportation, it is time to build the foundations for its success.

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