Assessing the Risks of Integrating Unmanned Aircraft Systems (UAS) into the National Airspace System (2018)

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ASSESSING THE RISKS OF INTEGRATING UNMANNED AIRCRAFT SYSTEMS INTO THE NATIONAL AIRSPACE SYSTEM

Committee on Assessing the Risks of Unmanned Aircraft Systems (UAS) Integration

Aeronautics and Space Engineering Board

Division on Engineering and Physical Sciences

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Preface

In 2017, the Federal Aviation Administration (FAA) asked the National Academies of Sciences, Engineering, and Medicine to undertake a study of the risks of unmanned aircraft systems (UAS) integration into the National Airspace System. The National Academies formed a committee that met three times between fall 2017 and early 2018. This is a dynamic subject that was changing as the committee was finalizing its report and even during the report's review. Nevertheless, the committee sought to provide findings and recommendations that will help the FAA to foster an environment in which UAS can operate safely within the National Airspace System while also contributing to public health, safety, and economic growth.

George Ligler, *Chair*
Committee on Assessing the Risks of Unmanned Aircraft Systems (UAS) Integration

Acknowledgment of Reviewers

This Consensus Study Report was reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise. The purpose of this independent review is to provide candid and critical comments that will assist the National Academies of Sciences, Engineering, and Medicine in making each published report as sound as possible and to ensure that it meets the institutional standards for quality, objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process.

We thank the following individuals for their review of this report:

Norman Abramson, Southwest Research Institute (ret.),
Ella Atkins, University of Michigan,
Gary Church, Aviation Management Associates,
John-Paul Clarke, Georgia Institute of Technology,
Christopher Hegarty, The MITRE Corporation,
Robert Kayen, University of California, Berkeley,
Vijay Kumar, University of Pennsylvania,
Ali Mosleh, UCLA Institute for Risk,
Peter Sachs, Altiscope,
John Tylko, Aurora Flight Sciences, and
Harrison Wolf, World Economic Forum.

Although the reviewers listed above provided many constructive comments and suggestions, they were not asked to endorse the conclusions or recommendations of this report nor did they see the final draft before its release. The review of this report was overseen by Robin McGuire of Lettice Consultants, International. He was responsible for making certain that an independent examination of this report was carried out in accordance with the standards of the National Academies and that all review comments were carefully considered. Responsibility for the final content rests entirely with the authoring committee and the National Academies.

Contents

Summary

On January 18, 2018, in New South Wales, Australia, a drone—otherwise referred to as an unmanned aircraft system (UAS)[1]—was used to save two swimmers who had been caught in rough ocean surf. Australian lifeguards operating the drone were not even using it in an operational capacity that day. A lifeguard supervisor was practicing with the drone, which was designed for spotting sharks, when he spotted the swimmers in trouble and used it to drop an inflatable device to them. Normally, lifeguards have to swim out to people to make a rescue, endangering their own life and increasing the time to bring aid to people in a dangerous situation.

This recent incident, which occurred while this report was being written and which received extensive coverage in the news media, highlights the potential value of this still-emerging technology to reduce risk and save lives. There are numerous other examples of UAS that can be used in various applications to reduce risk to civilian populations. From long-range inspection of rail lines to prevent derailments, to inspection of power lines and cell phone towers, to delivery of medicine and automated external defibrillators to people in cardiac distress, to assessment of wildfires to assist firefighters, the full value of UAS has yet to be realized. What these various examples illustrate is that when discussing the risk of introducing drones into the National Airspace System, it is necessary to consider the increase in risk to people in manned aircraft and on the ground, as well as the various ways in which this new technology may reduce risk and save lives, sometimes in ways that cannot readily be accounted for with current safety assessment processes.

The Committee on Assessing the Risks of Unmanned Aircraft Systems (UAS) Integration examined the various ways that risk can be defined and applied to integrating UAS into the National Airspace System managed by the Federal Aviation Administration (FAA). The committee looked at recent developments in this field and consulted numerous experts in academia, industry, and government.

The committee has drawn the following key conclusions, listed alphabetically:

- *Consider the* de minimis *risk.* With regard to the risk that an aircraft accident poses to people on the ground, the public already accepts a background level of risk that is extraordinarily low. The public also accepts the higher level of risk that the crew and passengers of general aviation aircraft currently face, likely because the vast majority of the public does not fly in general aviation aircraft and has no intention of doing so. The

[1] "Unmanned aircraft system" (UAS) is a more encompassing term that refers to the aircraft, the control system, and the system for communicating between them. Technically speaking, a drone or an unmanned aircraft is only one part of a UAS. Throughout this report, the committee primarily uses the term UAS.

public also accepts that medical evacuation helicopters face a risk that is higher still. The level of acceptable *de minimis* risks varies widely for other societal activities such as traveling by car or motorcycle, swimming in the ocean, or walking across the street. Understanding the level of *de minimis* risk that the public is likely to accept for small UAS operations, in the context of levels of *de minimis* risk for other levels of societal activities, would be useful in establishing safety standards for small UAS operations.

- *Consider the safety benefits.* Some UAS operations will increase safety both inside and outside the aviation system. These safety benefits could be considered as UAS operations are considered for approval.
- *Delegate responsibility.* Where it can be demonstrated that the risk is low enough and can be mitigated in this manner, the FAA could delegate to the UAS industry responsibility for quantitative risk assessment activities for UAS operations or it could require the UAS industry to obtain insurance for UAS operations in lieu of having a separate risk analysis.
- *One size does not fit all.* The level of FAA scrutiny for approval of a UAS operation needs to match the level of potential risk.
- *Philosophy is not reflected in the practice.* FAA executives speak about the importance of taking a performance- and risk-based approach for approval of UAS operations, with streamlining where appropriate. However, the committee heard both from within the FAA and from the UAS industry that such an approach is not being reflected in actual approvals of UAS operations.
- *Promote the systematic collection and analysis of empirical data.* Such collection and analysis is needed to inform the evolution of quantitative risk assessment for UAS operations.
- *The FAA Safety Management System (SMS) process as applied to approval of UAS operations is highly subjective.* Because of its qualitative nature as applied to UAS operations, the SMS process is not repeatable and not predictable. Quantitative risk assessment techniques are needed.

Consistent with these key conclusions, the committee developed 11 recommendations that are presented in this report.

The committee concluded that "fear of making a mistake" drives a risk culture at the FAA that is too often overly conservative, particularly with regard to UAS technologies, which do not pose a direct threat to human life in the same way as technologies used in manned aircraft. An overly conservative attitude can take many forms. For example, FAA risk avoidance behavior is often rewarded, even when it is excessively risk averse, and rewarded behavior is repeated behavior. Balanced risk decisions can be discounted, and FAA staff may conclude that allowing new risk could endanger their careers even when that risk is so minimal that it does not exceed established safety standards.

The committee concluded that a better measure for the FAA to apply is to ask the question, "Can we make UAS as safe as other background risks that people experience daily?" As the committee notes, we do not ground airplanes because birds fly in the airspace, although we know birds can and do bring down aircraft.

The safety of the National Airspace System has been achieved in large part as a result of the FAA's risk decision process, which has been characterized by a culture with a near-zero tolerance for risk. Applying this same culture to safety risk management (SRM) processes for UAS, however, has too often resulted in overly conservative risk assessments that have prevented safety-beneficial operations from entering the airspace. In many cases, the focus has been on "What might go wrong?" instead of a holistic risk picture: "What is the net risk/benefit?" Closely related to this is what the committee considers to be paralysis wherein ever more data are often requested to address every element of uncertainty in a new technology. Flight experience cannot be gained to generate these data due to overconservatism that limits approval of these flights. Ultimately, the status quo is seen as safe. There is too little recognition that new technologies brought into the airspace by UAS could improve the safety of manned aircraft operations or may mitigate, if not eliminate, some nonaviation risks.

Recommendation: The FAA should meet requests for certifications or operations approvals with an initial response of "How can we approve this?" Where the FAA employs internal boards of executives throughout the agency to provide input on decisions, final responsibility and authority and accountability for the decision should rest with the executive overseeing such boards. A time limit should be placed on responses from

each member of the board, and any "No" vote should be accompanied with a clearly articulated rationale and suggestion for how that "No" vote could be made a "Yes." (Chapter 3)

Due to the lack of empirical data in this nascent industry, the current FAA approaches to risk management are based on fundamentally qualitative and subjective risk analysis. These subjective approaches require a depth and breadth of subject matter expertise for the approval process that the FAA generally does not possess for UAS operations. The qualitative nature of the current approach leads to results that fail to be repeatable, predictable, and transparent. Evolution to an approach more reliant on applicant expertise and investment in risk analysis, modeling, and engineering assessment, as is practiced in many other areas of federal regulation, might better achieve a quantitative probabilistic risk analysis basis for decisions.

Traditionally in manned aviation, assessments of risk have focused on probability of passenger fatality. This measure clearly does not correspond well to UAS operations. Further, given the substantial variety of types of UAS operations, no single measure of risk can likely be found that can adequately characterize the benefit and risk of all UAS operations. Concerns by the drone industry of overly stringent certification requirements for relatively low-risk operations place unnecessary burden on the business case and can stifle innovation.

Recommendation: The FAA should expand its perspective on a *quantitative* risk assessment to look more holistically at the total safety risk. Safety benefits, including those outside of aviation (e.g., the benefit of cell tower inspections without a human climbing a cell tower), should be part of the equation. UAS operations should be allowed if they decrease safety risks in society—even if they introduce new aviation safety risks—as long as they result in a net reduction in total safety risk. (Chapter 4)

Recommendation: Within the next 12 months, the FAA should establish and publish specific guidelines for implementing a predictable, repeatable, quantitative, risk-based process for certifying UAS systems and aircraft and granting operations approval. These guidelines should interpret the Safety Risk Management Policy process described in Order 8040.4B (and in accordance with International Civil Aviation Organization Doc. 9859) in the unique context of UAS. This should include the following: (1) Provide, within 18-24 months, risk-based quantitative performance standards that can serve to establish compliance with FAA rules and regulations. (2) In the interim, encourage applicants to provide quantitative probabilistic risk analyses (PRAs) to demonstrate that their operation achieves the requisite level of safety. (3) Within 18-36 months, update FAA rules to reference new performance standards with the goal of minimizing the need to grant waivers or Certificates of Authorization (COAs). (Chapter 4)

Recommendation: Where operational data are insufficient to credibly estimate likelihood and severity components of risk, the FAA should use a comparative risk analysis approach to compare proposed UAS operations to comparable existing or *de minimis* levels of risk. The FAA should research and publish applicable quantitative levels of acceptable risk in comparison to other societal activities that pose *de minimis* risk to people. Risk level and risk mitigation strategies should consider not only aircraft collisions but also third-party risks (e.g., to people on the ground). (Chapter 4)

Recommendation: Over the next 5 years, the FAA should evolve away from subjectivities present in portions of the Order 8040.4B process for UAS to a probabilistic risk analysis (PRA) process based on acceptable safety risk. In the interim, the FAA should improve the 8040.4B process to conform better with quantitative PRA practice. For the new acceptable risk process, the FAA should consider relying on the applicant to provide a PRA demonstrating the achieved level of safety, as is common in other regulatory sectors such as nuclear, dam, or drug safety.

- **The FAA should screen applicant PRAs by comparison to existing or *de minimis* levels of risk. The FAA needs to research applicable quantitative levels of acceptable risk in comparison to other societal activities in establishing a level of *de minimis* risk for aviation.**

- **These acceptable levels of risk need to include risk to people on the ground and risk of collisions with a manned aircraft, particularly with regard to collision with a large commercial transport.**
- **In evaluating applicant-generated PRA, the FAA should value the importance of risk mitigation opportunities and their potential for simplifying the analysis of risk.**
- **In situations where the risk is low enough, the FAA should encourage applicants to obtain insurance for UAS operations in lieu of having a separate risk analysis.** (Chapter 4)

Recommendation: The FAA should create the following two mechanisms that empower and reward safety risk management decisions that consider the broad charter of the Department of Transportation to "serve the United States by ensuring a fast, safe, efficient, accessible and convenient transportation system that meets our vital national interests and enhances the quality of life of the American people, today and into the future" (DOT, 2018):

- **The FAA administrator should establish an incentive system that measures, promotes, and rewards individuals who support balanced comparative risk assessments.**
- **Within the next 6 months, the FAA administrator should publicly commit to ensuring time-bound reviews of risk assessments so that proponents receive timely feedback.** (Chapter 4)

Recommendation: Within 6 months, the FAA should undertake a top-to-bottom change management process aimed at moving smartly to a risk-based decision-making organization with clearly defined lines of authority, responsibility, and accountability. To that end, the FAA should establish and maintain technical training programs to ensure that agency risk decision professionals can fully comprehend the assumptions and limitations of the probabilistic risk analysis techniques appropriate to current and future UAS operations. (Chapter 4)

Recommendation: The FAA should identify classes of operations where the level of additional risk is expected to be so low that it is appropriate to base approval of those operations on requiring insurance in lieu of having a separate risk analysis. (Chapter 4)

More empirical data are needed to support probabilistic risk analyses for UAS collision modeling. Rapid advances in autonomous vehicle technology are providing effective integration of sensors and analytics. These developments present an opportunity for the FAA to learn and test new models for better data collection and analysis with the aim of improving overall safety. Even so, it may be difficult to collect enough data to assess some risks that have a very low probability of occurrence. In those cases, it could be useful to draw upon research being conducted for other applications that is exploring how to use limited data in combination with simulations to draw conclusions about safety.

Accepting risk is far easier when the risk is well quantified by relevant data. Uncertain risk does not equate to high risk, however. By accepting the uncertain risk associated with a new technology, with reasonable mitigations, one can obtain the data needed to better quantify that risk. As the uncertainty diminishes, one can remove or augment the mitigations as appropriate. In the current environment, uncertain risk has made operational approvals for routine civil UAS operations difficult to obtain and, when issued, unnecessarily restrictive. As a result, the ability to collect data that might reduce uncertainty in the risk has been severely limited.

Recommendation: The FAA should, within 6 months, collaborate with industry to define a minimum operational safety data set and develop a plan for the voluntary collection and retention of data by the operators in a central repository, following the model of the Commercial Aviation Safety Team (CAST) and the General Aviation Joint Steering Committee (GAJSC), with a goal of full implementation within 1 year. The FAA should also consult with the Drone Advisory Committee to help define the minimum operational safety data set and plan for collecting, archiving, and disseminating the data. (Chapter 4)

Recommendation: For operations approvals for which there are no standards, as operational data are collected and analyzed, the FAA should, as part of Improved Safety Risk Management,

- **Publish requirements for operational approvals with associated restrictions that can be adjusted and scaled based on industry past experience and the accumulation of related data;**
- **Expand single operation approvals as experiential data accumulate and risks are assessed;**
- **Permit repeated or routine operations based on the accumulation and analysis of additional data; and**
- **Continuously update operational approval practices to incorporate emerging safety enhancements based on industry lessons learned until standards have been established.** (Chapter 4)

Increased levels of autonomy have the potential to improve the operational safety of UAS. However, it cannot currently be guaranteed that such a nondeterministic learning system would respond safely in every conceivable situation. For this reason, true autonomy, as opposed to well-defined automatic operation in well-defined circumstances, is not currently allowed for commercial UAS flying within the National Airspace System. Opportunities to increase the safety of UAS operations, and of aviation in general, through increased autonomy are being missed, however, due to a lack of accepted risk assessment methods.

Recommendation: In coordination with other domestic and international agencies, the FAA should pursue a planned research program in probabilistic risk analysis (PRA), including the aspect of comparative risk, so that FAA personnel can interpret or apply PRA for proposed technology innovations. (Chapter 5)

During the course of its deliberations, the committee heard from a variety of experts from academia, other government agencies (e.g., the U.S. Navy), and even other international civil aviation authorities such as the German Aerospace Center (DLR). The committee consulted with industry groups such as Google, Boeing, Airbus, PrecisionHawk, and others, as well as a representative of the aviation insurance industry. Their input helped to inform the committee's report and shape its findings and recommendations.

Overall, this report endorses a more holistic approach to assessing UAS integration into the airspace based directly on risk (using other factors such as size, weight, and location only as inputs to the assessment of risk, rather than as broad-brush constraints). Such a holistic approach should also account for mitigations to potential risks within the entire UAS system (including its interactions with a human operator and ground control stations) and operational factors constructed to mitigate potential risks.

The committee has concluded that the introduction of a robust set of UAS operations into the National Airspace System both is achievable and has the potential to provide significant net safety benefits to society in addition to whatever economic benefits those operations might provide. Following the recommendations in this report would accelerate and facilitate the safe integration of UAS operations into the nation's airspace.

REFERENCE

DOT (Department of Transportation). 2018. "Mission." https://www.transportation.gov/tags/about-us. Accessed August 31, 2018.

1

Introduction

The FAA Extension, Safety, and Security Act of 2016 called for the Federal Aviation Administration (FAA) to "enter into an arrangement with the National Academies to study the potential use of probabilistic assessments of risks by the Administration to streamline the integration of unmanned aircraft systems into the national airspace system, including any research and development necessary." The FAA and the National Academies of Sciences, Engineering, and Medicine agreed that because various types of risk assessments were being used, depending on types of vehicles and methods of operation, the National Academies could best assist the FAA by looking at a broader set of risk issues. The Committee on Assessing the Risks of Unmanned Aircraft Systems (UAS) Integration was formed to evaluate the potential of probabilistic assessments of risks and other risk assessment methods for streamlining the process of safely integrating unmanned aircraft systems into the National Airspace System and identifying supporting research and development opportunities in this field.

In undertaking this study, the committee considered recent, current, and planned FAA efforts to evaluate the risks associated with the integration of UAS into the National Airspace System and risk assessment methods. It also considered mechanisms for assessing severity and likelihood metrics required for probabilistic and other appropriate risk assessment methods based on UAS design characteristics (e.g., weight, speed, materials, and technologies) and operational characteristics (e.g., airspace characteristics, population density, and whether UAS are piloted remotely or autonomously). The committee also sought to determine how the scope and detail required of risk assessment methods may vary for different sizes and operations of UAS (e.g., Part 107 versus Part 91 operations) or whether a certain class of UAS (micro, etc.) could be approved to operate with the assumption they are inherently low risk. In addition, the committee sought to evaluate other methods that could reasonably be used to evaluate the risks of UAS integration in the National Airspace System.

The committee was guided by a number of questions, such as the following:

- What are the benefits and limitations of these alternative risk assessment methods? How do these alternative methods compare to probabilistic risk analysis methods as well as severity and probability metrics traditionally used by the FAA for manned aircraft?
- What state-of-the-art assessment methods are currently in use by industry, academia, other agencies of the U.S. government, or other international civil aviation authorities that could benefit the FAA?
- What are the key advancements or goals for performance-based expanded UAS operations in the National Airspace System that can reasonably be achieved through the application of the recommended risk assessment methods in the short term (1-5 years), mid-term (5-10 years), and longer term (10-20 years)?

- What are the key challenges or barriers that must be overcome to implement the recommended risk assessment methods in order to attain these key goals?

In light of ongoing research and likely advances in risk assessment methods by other organizations, the committee also considered what research and development projects related to risk assessment methods should be the highest priority for the FAA. Last, the committee investigated whether there are other related recommendations to streamline FAA processes (not governed by regulation) that would either improve the effectiveness of risk assessment methods for integration of UAS into the National Airspace System or expedite the development of such methods. (The committee's full statement of task is included as Appendix A.)

The committee was able to consider and comment on the effectiveness of risk assessment methods as they pertain to decision making and different modes of UAS operations. However, the committee does not recommend changes to regulations governing UAS operations, nor does the committee recommend changes to the organization of the FAA. The scope of this study includes UAS certification as well as operational approval.

The committee has concluded that an evolution of current FAA risk assessment methodologies is needed to integrate UAS into the National Airspace System in a timely yet safe manner. A principal driver of this conclusion is the wide variety and number of UAS operations in tandem with societal safety-related benefits that those operations can provide the public.

UAS operations vary from (1) those under Part 107 (i.e., the UAS weighs less than 55 pounds, it is within visual line of sight of an operator who is operating only that UAS, it is operating at a maximum altitude above ground of 400 feet, and it is not over people not participating in the operation); to (2) low-altitude micro UAS and small UAS operating beyond visual line of sight in rural areas; to (3) UAS operating beyond visual line of sight at low altitude over people at varying population densities, including in cities; to (4) large UAS whose missions take the platforms into controlled airspace at en route altitudes.

Applying probabilistic risk analysis methods developed over several decades for operations of manned aircraft, from which huge amounts of operational data are available, to the full range of UAS operations does not take into account either fundamental differences from manned aviation present in most UAS operations, particularly low-altitude operations, or the relative youth (compared to manned aviation) of the UAS industry and lack of operational data.

Figure 1.1 is illustrative of the aforementioned societal safety-related benefits, when an emergency flotation device was dropped to swimmers in danger. There are numerous additional examples: support for emergency responders, such as safer disaster assessment; improved safety and effectiveness in infrastructure assessment, such as for cellular telephone towers and railroad rights-of-way; emergency delivery of medicine; and reduction in highway accidents and environmental pollution resulting from safe UAS delivery of packages. Such safety-related societal benefits are additional to, and in many cases independent of, any economic benefits that UAS operations might have.

The U.S. military has extensive experience with UAS, both large and small, but to date that experience has not translated well into the integration of civilian UAS into the National Airspace System. Military UAS usually operate in airspace segregated from manned airspace. Many UAS operations take place in airspace over ground troops, and those operations certainly pose some risk to those soldiers. The military conducts such operations, however, in part because the magnitude of that risk is balanced against the much more substantial risk that soldiers face in combat and the ability of UAS to mitigate that risk and support mission success.

Current FAA probabilistic risk analysis methodologies do not take these societal safety-related benefits into account. Any UAS operation is therefore viewed as increasing the risk only to the National Airspace System, and improved safety for swimmers, firefighters, railroad operators, drivers, or others is irrelevant. Such a viewpoint can make the process of UAS integration into the National Airspace System start off with a negative bias.

One of the major issues facing the FAA is cybersecurity. Cybersecurity is one of many factors to be considered in any probabilistic risk analysis, and although the committee was aware of issues related to cybersecurity, it was not tasked to focus on them. The committee believes that the FAA, industry, and operators are aware of the importance of cybersecurity and are seeking to address this subject in many different ways.

In developing its recommendations, the committee met three times, receiving presentations from the FAA,

FIGURE 1.1 Westpac Little Ripper Saver drone with inflatable lifesaving device known as a “rescue pod” that was dropped to swimmers in high surf in New South Wales, Australia, January 2018. SOURCE: Leanne St. George & Associates Pty Ltd.

academia, and industry related to probabilistic risk analysis for UAS operations. The list of speakers for these meetings can be found in Appendix C.

Chapter 2 provides background information to the committee’s recommendations, including assumptions and guiding principles that the committee formulated, and a set of key definitions that the committee adopted for this report.

Chapter 3 summarizes the committee’s assessment of current FAA practices with regard to probabilistic risk analysis for UAS operations, to include the FAA safety culture and risk assessment processes.

Chapter 4 presents the bulk of the committee’s recommendations for evolving the FAA decision-making paradigm for assessing risk of UAS operations. The chapter addresses developing a more appropriate risk analysis process, how decisions are best driven with data for a young UAS industry, and the delegation of certain levels of risk analysis by the FAA to the private sector.

Chapter 5 discusses the committee’s recommendations with regard to recommended research areas related to probabilistic risk analysis for UAS operations.

The committee made a number of assumptions in developing its findings and recommendations and discussed common definitions and points of reference. They form the basis of Chapter 2.

2

Background

Safety has been ingrained in the aviation culture from its earliest days. Aviation is often held up as the model for how to improve safety in other domains, from health care to the automotive industry.[1]

In the context of aviation, safety is defined as a state where the possibility of harm to people or property is reduced to and maintained at or below an acceptable level of risk. Because of actions by regulators, manufacturers, and operators, the aviation system provides a transportation capability that has the lowest safety risk of any mode of motorized transportation. While accidents involving large commercial aircraft do occasionally happen, the rate of occurrence is so low that safety experts no longer focus on corrective actions associated with accidents or incidents but are now focused on proactive safety initiatives based on analysis of precursors of potential accidents.

Since its inception, the Federal Aviation Administration (FAA) has been charged as the federal agency responsible for regulating civil aviation to ensure safety. The FAA promotes safety by issuing and enforcing regulations and minimum standards covering manufacturing, operating, and maintaining aircraft.[2] For the most part, the FAA focuses on ensuring the safety of the occupants of aircraft (i.e., crew and passengers) in the belief that if first-party participants are safe, third-party participants (e.g., the public on the ground) will also be safe. As a means of ensuring that aviation operations are within acceptable levels of risk, the FAA, as the regulator, generally requires the following three elements:

1. A certified aircraft,
2. A licensed pilot, and
3. Operational approval to access specific airspace.

For remotely piloted aircraft that would operate in the National Airspace System, the requirements are the same. It is important to note that unmanned aircraft including model aircraft flown for recreational purposes are considered "aircraft" under federal regulation.

[1] L.S.G.L. Wauben, J.F. Lange, and R.H.M. Goossens, 2012, Learning from aviation to improve safety in the operating room: A systematic literature review, *Journal of Healthcare Engineering* 3(3):373-380; M. Young, N. Stanton, and D. Harris, 2007, Driving automation: Learning from aviation about design philosophies, *International Journal of Vehicle Design*, https://doi.org/10.1504/IJVD.2007.014908; NHTSA Press Release, 2016, "U.S. Department of Transportation Convenes Aviation and Automobile Industry Forum on Safety," https://www.nhtsa.gov/press-releases/us-department-transportation-convenes-aviation-and-automobile-industry-forum-safety.

[2] See FAA website, https://www.faa.gov/about/mission/activities/.

Today, there are effectively five ways in which an unmanned aircraft system (UAS) can legally operate in the National Airspace System:

1. *Model aircraft.* Under 14 Code of Federal Regulations (CFR) Part 101.41, an aircraft that is "flown strictly for hobby or recreational use" can operate in the National Airspace System if it follows "safety guidelines" and other processes under the auspices of a "community-based organization" (e.g., the Academy of Model Aeronautics). The operations should not interfere with and should give way to manned aircraft, in addition to some other operational limits. Certified aircraft and licensed pilots are not required. No operational approval is needed to operate a model aircraft, but notification of air traffic control (ATC) may be required.
2. *Small UAS rule compliant.* In 2016, the FAA made 14 CFR Part 107 final, which enabled UAS to be operated without the need for an airworthiness certificate for hobby, recreational, commercial, public safety, or any other purpose in the National Airspace System. Part 107 lays out requirements for the licensing of UAS pilots as well as operational limitations (e.g., operating below 400 feet above ground level) and airspace (e.g., class G [uncontrolled] airspace) where operations are permitted (see Figure 2.1). Aircraft operating under Part 107 do not require an airworthiness certificate or operational approval if they follow all of the operating provisions outlined in the rule.
3. *Small UAS rule waivers.* 14 CFR §107.205 lists a number of provisions (i.e., operational limitations that the FAA can waive), including the following: prohibition of operation from a moving vehicle, daytime-only operations, requirement to remain in visual line of sight, and prohibition of operation over people and operation of multiple aircraft by one person. Aircraft operating under Part 107 Waiver do not require an airworthiness certificate but may need to follow additional operational provisions as defined in the waiver application.
4. *Small UAS rule airspace authorization.* 14 CFR §107.41 makes it clear that small UAS cannot be operated "in Class B, Class C, or Class D airspace [i.e., in the vicinity of airports] or within the lateral boundaries of the surface area of Class E [en route] airspace that has been designated for an airport unless that person has prior authorization from ATC." For some operations, both a Part 107 Waiver and a Part 107 Airspace Authorization will be required. In some cases, the FAA could waive the need for airspace authorization by issuing an "Airspace Waiver" that is usually for longer duration (i.e., 6 months to 2 years). Applicants are encouraged to apply 90 days prior to flight. The FAA is working to streamline this approval process through the creation of facility maps[3] and the Low Altitude Authorization and Notification Capability (LAANC) prototype.[4] The airspace authorization is operational approval to operate in the specified airspace.
5. *Certificate of Authorization (COA) or waiver.* Operational approval is available for aircraft operating under 14 CFR Part 91[5] that have an airworthiness certificate[6] and are operated by a licensed pilot. Since there are very few commercial unmanned aircraft with an airworthiness certificate (e.g., special airworthiness certificate—experimental category), the COA process is mainly used by public entities (e.g., the military services, NASA, public universities) that have the authority to designate their own aircraft as airworthy.

For proponents planning to operate in compliance with either the model aircraft rule or the small UAS rule, no additional scrutiny or review by the FAA is required, and they have operational approval as long as they remain within the operational limits expressed in 14 CFR Part 101 and 14 CFR Part 107. All other proponents must submit a request to the FAA for a waiver or authorization. The FAA has attempted to assist proponents by publishing

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[3] UAS facility maps show the maximum altitudes around airports where the FAA may authorize Part 107 UAS operations without additional safety analysis. The maps should be used to inform requests for Part 107 airspace authorizations and waivers in controlled airspace (see https://www.faa.gov/uas/request_waiver/uas_facility_maps/).

[4] LAANC is an industry-developed application with the goal of providing drone operators near-real-time processing of airspace notifications and automatic approval of requests that are below approved altitudes in controlled airspace. LAANC meets the regulatory requirements of the small UAS rule (14 CFR Part 107) and the model aircraft notification requirement (14 CFR 101.41). See https://www.faa.gov/uas/programs_partnerships/uas_data_exchange/.

[5] Efforts are under way to also exempt aircraft operated under 14 CFR Part 135.

[6] Public Law 112-095 Section 333 and Public Law 114-190 Section 2210 exempt certain aircraft from requiring an airworthiness certificate.

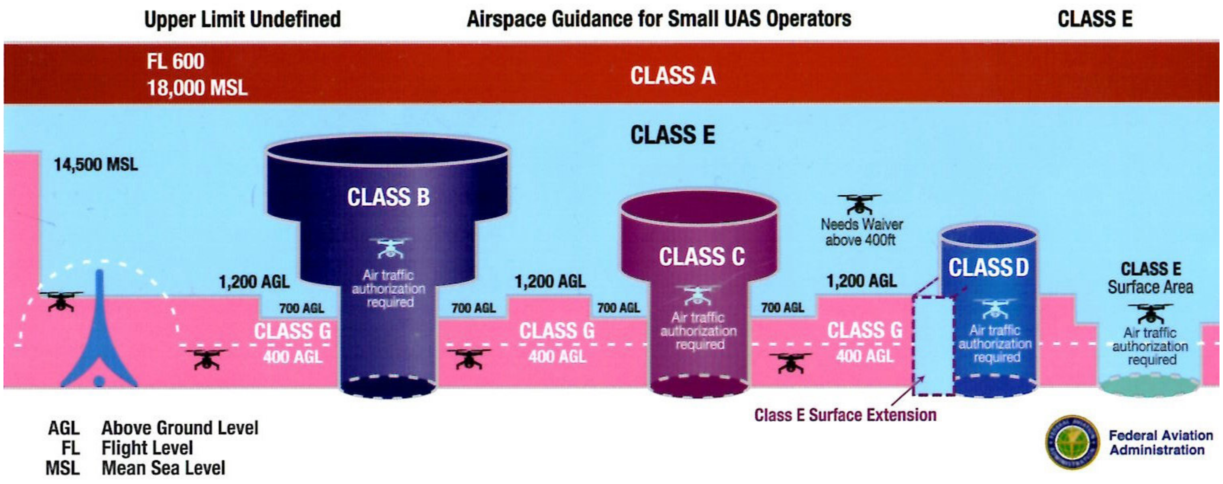

FIGURE 2.1 Airspace classification in the National Airspace System. SOURCE: FAA (2018).

guidelines[7] on what information is required and by providing electronic means to facilitate interactions, including the "DroneZone"[8] and the LAANC. These electronic tools are intended to streamline requests for waivers that can be considered routine (e.g., authorization to operate in Class C airspace below the altitude defined in the published facility maps while remaining otherwise in compliance with the operational limitations in 14 CFR Part 107).

The DroneZone website also provides a means for reporting UAS accidents and incidents. These reports should be filed within 10 days of an event if a UAS causes a serious injury or damage in excess of $500. The number of incident reports has increased from about 25 monthly in 2014 to about 125 monthly in 2016. As of September 2017, however, there has only been one confirmed collision between a UAS and a manned aircraft in the United States.[9] Research using data from incident reports is ongoing. Key goals include quantifying how unique hazards affect risk and methods for evaluating specific risks and how to mitigate them (FAA, 2017).

For new, novel, and more complex waiver requests, the evaluation process by the FAA can be significantly less predictable and not sufficiently responsive (i.e., it takes too long). FAA Order 8040.4 specifies a safety risk management (SRM) policy for the agency. As guidance to all FAA lines of business, it establishes common terms and processes used to analyze, assess, mitigate, and accept safety risk in the aerospace system. It is the intent of the order to allow flexibility in how safety risk management is conducted and the tools and techniques that are employed and at the same time help to establish some consistency in the application of key principles.

Although there is consistency, the processes implemented by the lines of business are qualitative and highly dependent on the subjective perspective of subject matter experts who may be involved. While the policy establishes a clear analytic approach, it is fundamentally operating on qualitative/subjective data. The approach requires substantial details from proponents and significant effort by FAA personnel. Consequently, the process is not timely, it is not necessarily repeatable, and proponents cannot readily predict the outcome.

This committee was charged with considering safety risk management approaches that would include quantitative methods that may be performed by proponents and then reviewed by those responsible for regulatory oversight (i.e., the FAA). Quantitative approaches would use objective data to predict potential risk as measured in adverse outcome (e.g., fatalities) per some operational unit (e.g., flight hours, flights). This predicted quantitative risk can be calculated using a combination of empirical data, simulation studies, and systems analysis. The calculated safety risk can then be compared with a target level of safety, the safety risk of the operations it replaces, or other benefits.

[7] See https://www.faa.gov/uas/request_waiver/waiver_safety_explanation_guidelines/.
[8] See https://faadronezone.faa.gov/.
[9] On September 21, 2017, a small civilian UAS entered the rotor system of a U.S. Army UH-60 Blackhawk helicopter. The helicopter continued to its intended destination, and the collision caused no injuries.

ASSUMPTIONS AND GUIDING PRINCIPLES

The following list of assumptions and guiding principles was used by the committee to steer its efforts and helped shape the findings and recommendations that are discussed later in this report. Although these are not findings and recommendations, they guided the committee in developing its findings and recommendations.

- The introduction of UAS into the airspace will not degrade safety or security.
- Rules, regulations, and restrictions for UAS operations should be commensurate with the risk posed by the specific operation.
- Regulations and standards should avoid being proscriptive, allowing for innovation.
- Potential safety risks of UAS operations primarily include collisions with other aircraft and injury to people on the ground.
- It is beyond the scope of this study to consider the risks created by UAS operated by intentional bad actors.
- UAS are here to stay and will grow in numbers, missions, diversity, and complexity. The effectiveness of rules, regulations, standards, procedures, data collection systems, risk assessment methods, simulations, and so on, will be very limited unless they are able to scale up to accommodate UAS vehicles and missions that are more numerous, more diverse, and more complex.
- UAS operations have the potential to provide societal benefits such as job creation, economic growth, reductions in environmental impacts, increased productivity, and improved safety and security.
- UAS operations can reduce safety risks by replacing operations that occur today[10] that put people in danger with a flight by an unmanned aircraft.
- Data can be collected from simulation, safety assessments, and existing operations to help quantify benefits against risks.
- The regulatory framework and practices established by other countries can inform the process of integration of UAS into the National Airspace System.[11]
- Safety is a high priority for the FAA as well as the UAS industry (i.e., manufacturers, suppliers, and operators).

DEFINITIONS

In this report the following terms are used:

- *Aircraft manufacturer*—An organization that has been recognized by its certifying authority as having manufactured the aircraft, at the time of completion.
- *Beyond visual line-of-sight operation*—An operation in which the remote crew is not able to remain in visual contact with the aircraft to manage its flight and meet separation and collision avoidance responsibilities.
- *Comparative risk analysis*—Involves contrasting risks produced by two activities using a common scale.
- *Hazard*—A condition that could foreseeably cause or contribute to an aircraft accident (FAA Order 8040.4B).
- *Likelihood*—The estimated probability or frequency, in quantitative or qualitative terms, of a hazard's effect or outcome (FAA Order 8040.4B).
- *Operator*—The individual or organization that operates aircraft.
- *Qualitative analysis*—Analysis through relative or subjective measures without specific quantities.
- *Quantitative analysis*—Numerical analysis based on empirical or modeled data.
- *Remote crew member*—A licensed crew member charged with duties essential to the operation of a remotely piloted aircraft, during flight time (International Civil Aviation Organization [ICAO] Circular 328-AN/190).

[10] As an example, UAS "technology has the potential to reduce unnecessary climbing and can avoid putting employees at risk." OSHA/FCC Communications Tower Best Practices, https://www.osha.gov/Publications/OSHA3877.pdf.

[11] For example, *Regulation of Drones*, published by the Law Library of Congress in 2016, describes UAS regulations in 12 countries: Australia, Canada, China, France, Germany, Israel, Japan, New Zealand, Poland, South Africa, Sweden, Ukraine, United Kingdom, and the European Union. https://www.loc.gov/law/help/regulation-of-drones/regulation-of-drones.pdf.

- *Remote pilot*—The person who manipulates the flight controls of a remotely piloted aircraft during flight time (ICAO Circular 328-AN/190).
- *Remotely piloted*—Control of an aircraft from a pilot station that is not on board the aircraft (ICAO Circular 328-AN/190).
- *Remotely piloted aircraft*—An aircraft where the flying pilot is not on board the aircraft (ICAO Circular 328-AN/190).
- *Safety*—The state in which the risk of harm to persons or property damage is acceptable (FAA Order 8040.4B).
- *Safety risk*—The composite of predicted severity and likelihood of the potential effect of a hazard (FAA Order 8040.4B).
- *Safety risk acceptance*—The decision by the appropriate management official to authorize the operation without additional safety risk mitigation (FAA Order 8040.4B).
- *Safety risk analysis*—The first three steps of the SRM process (analyze the system, identify hazards, and analyze safety risk) (FAA Order 8040.4B).
- *Safety risk assessment*—The first four steps of the SRM process (analyze the system, identify hazards, analyze safety risk, and assess safety risk) (FAA Order 8040.4B).
- *Severity*—The consequence or impact of a hazard's effect or outcome in terms of degree of loss or harm (FAA Order 8040.4B).
- *Unmanned aircraft*—An aircraft that is operated without the possibility of direct human intervention from within or on the aircraft (Public Law 112-95). For the purpose of this report, it is assumed that unmanned aircraft have no humans on board—neither crew nor passengers.
- *Unmanned aircraft system*—An unmanned aircraft and associated elements (including communication links and the components that control the unmanned aircraft) that are required for the pilot in command to operate safely and efficiently in the National Airspace System (Public Law 112-95).
- *Visual line-of-sight operation*—An operation in which the remote crew maintains direct visual contact with the aircraft to manage its flight and meet separation and collision avoidance responsibilities.

This report also refers to automation or automatic systems and autonomy or autonomous systems. It is difficult to provide concise definitions for these terms because there is not a definitive boundary between the two. Indeed, "the attempt to define autonomy has resulted in a waste of both time and money spent debating and reconciling different terms and may be contributing to fears of unbounded autonomy" (Defense Science Board, 2012). Furthermore, "automation changes the type of human involvement required and transforms but does not eliminate it. For any apparently autonomous system, we can always find the wrapper of human control that makes it useful and returns meaningful data" (Mindell, 2015).

One approach to understanding the difference between automation and autonomy is to consider the differences (and similarities) in their characteristics, as shown in Table 2.1. Automation and autonomy exist along a spectrum of capabilities and parameters, such as those listed in the table. As a result, referring to a system as either automated or autonomous is typically an oversimplification, although it is often convenient to do so. Generally speaking, both automated and autonomous systems have the ability to execute assigned tasks over some period of time without direct human direction. Consider, for example, the use of a UAS to survey a farmer's field overnight. With an automated system, the farmer might need to program the flight path and the parameters to be monitored (e.g., soil moisture, insect infestation, or crop yield). With an autonomous system, the farmer might simply give a verbal command to survey the crops, and the UAS would identify the crops planted in the various fields, an optimum flight path, the parameters to monitor, and the range of acceptable values based on the crop, recent and forecast weather, where the crops are in their life cycle, past experience, and so on. In this example, the basic task is within the capability of both automated and autonomous systems. Many other missions, of course, include tasks that are beyond the capabilities of an automated system.

With the definitions and assumptions listed above in mind, the committee turned its attention to the subject of current practices, looking at the relatively recent (i.e., less than 20 years) efforts to introduce UAS into the National Airspace System. That is the subject of Chapter 3.

TABLE 2.1 Characteristics of Advanced Automation and Autonomy

Characteristic	Advanced Automation	Advanced Autonomy
Reacts at cyber speed	Usually	Usually
Reduces tedious tasks	Usually	Usually
Augments human decision makers	Usually	Usually
Proxy for human actions or decisions	Usually	Usually
Robust to incomplete missing data	Usually	Usually
Reacts to the environment	Usually	Usually
Exhibits emergent behavior	Sometimes	Usually
Adapts behavior to feedback—learns	Sometimes	Usually
Responds differently to identical inputs	Sometimes	Usually
Addresses situations beyond the routine	Rarely	Usually
Reduces cognitive workload for humans	Sometimes	Usually
Replaces human decision makers	Rarely	Potentially
Robust to unanticipated situations	Limited	Usually
Behavior is determined by the experience, rather than by design	Rarely	Usually
Adapts behavior to unforeseen environmental changes	Rarely	Potentially
Makes value judgments—weighted decisions	Never	Usually
Makes mistakes in perception and judgment	N/a	Potentially

SOURCE: NRC (2014).

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3

Current Practices

The Federal Aviation Administration's (FAA's) current approach to safety risk management for unmanned aircraft systems (UAS) is to build on existing concepts of safety analysis and certification for conventional aircraft. This involves "an integrated collection of processes, policies, procedures, and programs used to assess, define, and manage safety risk in the provision of [air traffic control] ATC and navigational services" (FAA, 2017a). This approach has served the FAA and air traffic safety well in the past, but it is possibly outdated with respect to the new challenges and large volumes of operations that commercial UAS present.

FAA uses scalable, multitiered safety targets for different categories of aircraft. The expectation is that airworthiness safety targets may not be the same for all categories of UAS. For commercial transport aircraft, the default "system design" safety target is currently estimated to be one catastrophic event in 1 billion flight hours, but this safety target is less rigorous (e.g, one catastrophic event in 1 million flight hours) for some general aviation aircraft. Within the UAS industry, for example, system design safety targets are different for small recreational UAS and highly customized platforms for in-theater military missions.

The one-in-a-billion (also written 1E-09) safety target for commercial aircraft is based on historical data for which the empirical (or assumed) rate of catastrophic accident per flight is approximately one in a million (1E-06), of which 10 percent of the failures are due to system deficiencies and assuming 100 failure conditions on the aircraft. The product of these yields a safety target of 1E-09. This calculation presumes failures due to "systems deficiencies" and not to other causes (e.g., operations, human errors, weather). U.S. commercial airlines have demonstrated the ability to meet this stringent standard; they have experienced only one fatality since 2009. The presumption of 100 failure conditions, however, is not easily validated with respect to new systems such as UAS. Each of these numbers is a supposition. (The safety target is not the same as the International Civil Aviation Organization [ICAO] target level of safety for vertical separation minima of 5 fatal accidents per billion flight hours (5E-09).[1])

The contributing factors to the concept of the present risk assessment include the following: vehicle design or systems, operational risk, area of operational airspace, the separation strategy, and human versus automation. These, in turn, depend on the established factors of airworthiness, pilot, maintenance, operation, and airspace. Few if any of these risk factors appear to be based on empirical data.

The present approach is to develop a qualitative (ordinal) ranking of probability and consequence for particular categories of UAS operation, and to interpret these rankings of probability and consequence in a so-called risk

[1] See ICAO Document 9574, para. 1.1.10, http://code7700.com/pdfs/icao_doc_9574.pdf.

Likelihood \ Severity	Minimal 5	Minor 4	Major 3	Hazardous 2	Catastrophic 1
Frequent A	Low	Medium	High	High	High
Probable B	Low	Medium	High	High	High
Remote C	Low	Medium	Medium	High	High
Extremely Remote D	Low	Low	Medium	Medium	High
Extremely Improbable E	Low	Low	Low	Medium	Medium / High*

***Risk is high when there is a single point or common cause failure.**

FIGURE 3.1 Sample "heat diagram" showing a risk matrix. SOURCE: FAA (2017a).

matrix or "heat diagram" (see Figure 3.1). Such ordinal rankings are subject to a variety of logical inconsistencies, and good risk practice seeks to avoid them.[2]

Since small-scale UAS differ considerably from larger-scaled manned aircraft in terms of consequences, the empirical history of their performance should inform a risk analysis.

CLASH OF CULTURES

Safety has been ingrained in the aviation culture from its earliest days. At its birth, aviation was an innovative industry that continually improved the performance of aircraft; to be successful, the industry also needed to enhance the safety of aircraft, crews, processes, and procedures. In its early years, manned aviation had a much higher tolerance for risk than now. Even so, aviation innovators were careful to avoid unnecessary risks. For example, the Wright brothers never flew together. As aircraft grew larger and carried more passengers and as the skies grew more crowded, the tolerance for risk diminished. Government regulations emerged to reduce safety risks, often in response to accidents and incidents. Today's aviation culture is inseparable from a culture of safety. This relationship is codified in FAA policy; one of the principles of a safety management system is the notion of promoting a culture of safety.[3]

[2] L.A. Cox, 2008, What's wrong with risk matrices? *Risk Analysis* 28(2):497-512.
[3] For additional information, see the section on FAA Safety Management Policy in Chapter 4.

FIGURE 3.2 The contrast between the EIT and aviation cultures.

In the context of aviation, safety is defined as a state where the possibility of harm to people or property is reduced to and maintained at or below an acceptable level of risk.[4] This safety culture has resulted in a system that provides a commercial transportation capability that has the lowest safety risk of any mode of motorized transportation. While accidents involving large commercial aircraft do occasionally happen, the rate of occurrence is so low that safety experts no longer focus on corrective actions associated with accidents and incidents. They focus instead on proactive safety initiatives based on analysis of precursors of potential accidents. The goal over the next decade is to transition to prognostic safety analysis.[5]

As a result of this safety culture, the aviation community tends to take a conservative stance to new technology and employs an evolutionary approach to change. New technologies are carefully examined to assure that they can meet aviation's stringent safety requirements. The emergence of unmanned aircraft, especially small unmanned aircraft less than 55 pounds, has tested this culture.

For the most part, the development of small unmanned aircraft is not being driven by the traditional aviation community, but by new participants that have evolved from the electronics and information technology (EIT) culture. Large EIT companies, including Google, Amazon, Intel, AT&T, Facebook, and Verizon, have major initiatives in the unmanned aircraft arena. They are joined by hundreds of new entrants with a Silicon Valley start-up culture. This EIT culture is driven by innovation and is contrasted with the aviation's safety culture (see Figure 3.2).

While no company would advocate creating an unsafe product, the EIT corporate approach to safety is different. The need to develop innovative products and bring them to market quickly tends to drive strategic decision making and corporate priorities. There is a different threshold and willingness to assume some levels of risk associated with experimenting with new technology, because problems can typically be corrected with software updates after systems are introduced into the market. In other words, innovative EIT companies try new concepts, fail fast, learn, and move on. In contrast, the traditional aviation industry has evolved into one that strives to ensure that safety-critical systems never fail. EIT companies are motivated by competitive market pressures—to take risk in pursuit of potential rewards—and, in some cases, corporate survival. This approach to safety is acceptable for the vast majority of EIT systems, which do not present a direct risk of injury or loss of life if the product does not work as intended. Clearly this is not the case with manned aviation.

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[4] ICAO, 2013, Safety Management Manual (SMM), Document 9859.
[5] FAA, 2016, Fact Sheet—Commercial Aviation Safety Team, April 12.

TABLE 3.1 The Contrast Between Small Unmanned Aircraft and Large Manned Aircraft

Small UAS	**Large Commercial Transports**
Low cost of entry	High cost of entry
Fail fast	Try never to fail
Limited track record/data	Long enviable safety record
Risk assessment focused on third parties	Risk assessment focused on first parties

It is the opinion of this committee that the aviation industry and the public would benefit from an appropriate merging of the diverse safety cultures of the manned aviation industry and the EIT and drone industries. Policy makers have acknowledged that there is a need to be responsive to technology innovation while ensuring continued safety. As FAA Administrator Michael Huerta stated, "No doubt, industry is moving at the speed of imagination. At the FAA, we can't afford to move at the old speed of government. We have to be willing to innovate the way we do our work, and we are."[6]

FAA safety inspectors and others involved with certifying aviation technologies and approving operations tend to make decisions based on analysis of years or decades of data and often are focused only on granting permission for a variant on current technologies or practices. However, unmanned aviation safety regulators are often faced with making decisions about technologies where there is little precedent or direct experience (e.g., electric propulsion, fully automated flight control, multirotors, sense and avoid, and network-based communications) and a dearth of data.

Table 3.1 illustrates the wide disparity between small UAS and large manned aircraft. The disparity between other classes of manned and unmanned aircraft, such as large UAS and small general aviation aircraft, are not as stark as those shown in the table. In fact, the cost of entry of a large UAS could exceed the cost of entry for a small general aviation aircraft. Nonetheless, some differences persist regardless of size: the risk assessments for all unmanned aircraft are focused on third parties (since no people are on the aircraft), and the risk assessments of manned aircraft are focused on first parties (i.e., crew and passengers) because the risk they face is very much greater than the risk faced by people on the ground.

Proper identification and classification of the very different safety cases involved in UAS operations and developing, as an industry, the ability to focus on specific use cases and to get their safety analyses is a prerequisite for embarking on further specific use cases. Later in this chapter, an example of the use of small UAS to monitor sea-ice conditions for climatological studies in remote regions of the Arctic is described, where a detailed safety assessment was effectively disregarded. This small UAS use case illustrates how development of priorities for use cases has been, and is likely to remain, difficult. Proper identification and prioritization of use cases should lead to fewer simultaneous UAS standards efforts and standard developing bodies; such focusing of industry resources will inevitably be resisted by portions of the UAS industry.

While the elimination of aircraft accidents and serious incidents remains the goal, it is recognized that the aviation system cannot be completely free of hazards and associated risks. The only absolutely safe aircraft is one that is out of service. Aviation cannot be guaranteed to be free of errors and their consequences. Indeed, the FAA itself has cautioned against driving safety targets to be overly rigorous, as this in fact can reduce the overall level of safety. As Figure 3.3 points out, too much rigor in the targeted level of safety prevents safety improvements from making their way into aviation.

As the FAA is assessing risk for UAS, it is important that an appropriate risk culture be established for this form of aviation. As with small manned aircraft, the collision of a UAS with a manned aircraft poses a threat to human life, with the gravest consequences potentially arising from the collision of a UAS with a large commercial transport. Many UAS safety processes and technology development programs are dedicated to preventing such accidents. Nevertheless, because unmanned aircraft have no humans on board, there is an enormous risk reduction embedded in this form of aviation. A UAS accident does not necessarily mean that a human will be hurt or

[6] Michael Huerta, FAA, 2016, "New Horizons," speech to the Aircraft Electronics Association, Orlando, Fla., April 27.

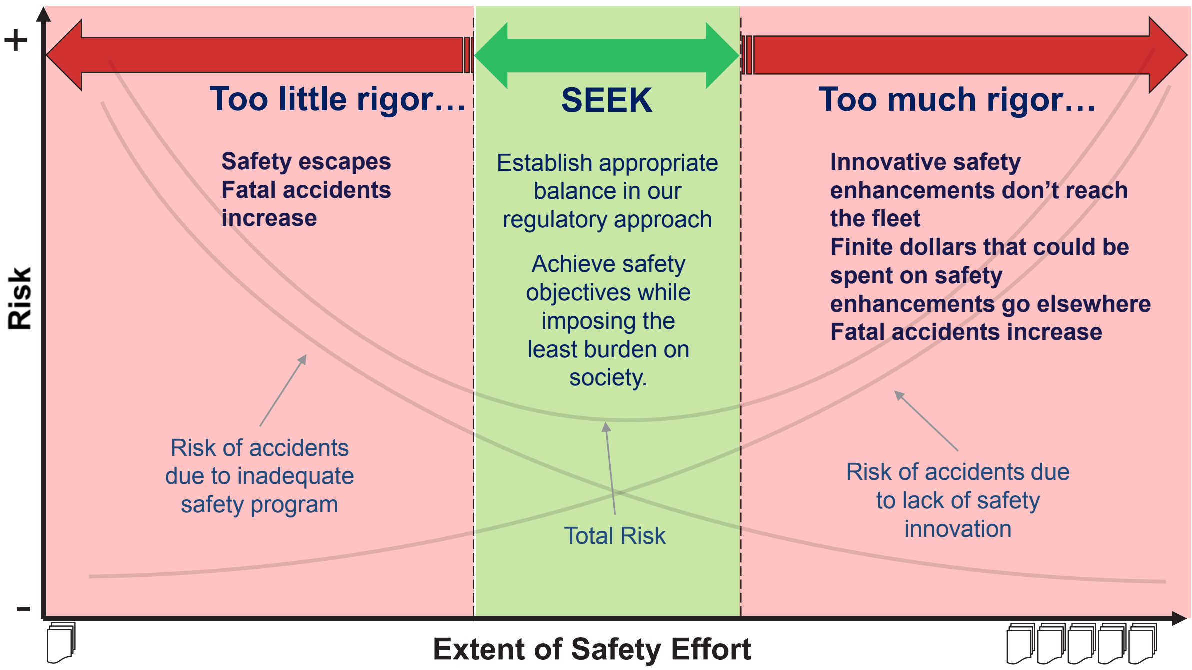

FIGURE 3.3 System safety—the safety continuum. SOURCE: FAA (2017b).

killed. Furthermore, the public already accepts a background level of risk that is extraordinarily low. The public also accepts the higher level of risk that the crew and passengers of general aviation aircraft currently face, likely because the vast majority of the public does not fly in general aviation aircraft and has no intention of doing so. The public also accepts that medical evacuation helicopters face a risk that is higher still. The level of acceptable *de minimis* risks varies widely for other societal activities such as traveling by car or motorcycle, swimming in the ocean, or walking across the street. Understanding the level of *de minimis* risk that the public is likely to accept for small UAS operations, in the context of levels of *de minimis* risk for other societal activities, would be useful in establishing safety standards for small UAS operations.

UAS provide an excellent opportunity for the development of technologies that can be tested and flown in service that can improve safety for manned aviation at a reduced cost. However, an overly conservative risk culture that overestimates the severity and likelihood of UAS risk can be a significant barrier to introduction and development of these technologies. Specifically, the following behaviors would impede the process of establishing safety regulations for UAS:

- *Transposition and assumption of the burden of safety*. The burden for safe operations rests on the operator. When the FAA takes on the primary burden for safety, the fear of making a mistake can drive an overly conservative risk culture. Additionally, there is the potential that overregulation actually reduces the competence of regulated organizations.
- *Risk avoidance*. As stated elsewhere in this report, operation of UAS has many advantages and may improve the quality of life for people around the world. Avoiding risk entirely by setting the safety target too high creates imbalanced risk decisions and can degrade overall safety and quality of life.
- *Overanalysis and overreliance on data*. When considering the adoption of new technologies, a chicken-and-egg situation can occur where the regulator demands data but simultaneously closes opportunities to collect these data in flight. In addition, in some cases, the expertise and size of the workforce is insufficient to regulate new technologies using traditional approaches.

- *Status quo thinking*. Sometimes, the regulator will seek to maintain the status quo without acknowledging the technology shifts that are occurring. This is particularly appealing as a safe career choice, given the outstanding safety record for manned aviation. Maintaining the status quo is also attractive if implementing proposed changes would incur substantial costs. However, failure to adapt and make risk decisions based on new technology can have the deleterious effect of keeping helpful technologies out of aviation, missing opportunities to further improve safety and (in some cases) the potential to reduce recurring costs.

Finding: "Fear of making a mistake" drives a risk culture at the FAA that is too often overly conservative, particularly with regard to UAS technologies, which do not pose a direct threat to human life in the same way as technologies used in manned aircraft. This overly conservative attitude can take many forms:

- FAA risk avoidance behavior is often rewarded even when it is excessively risk averse, and rewarded behavior is repeated behavior. Balanced risk decisions are too often discounted: Why risk my career?
- Multiple FAA presenters to the committee stated something to the effect of "we have to protect society" or "society expects the FAA to protect them." Such a "protect" mentality can result in overconservatism if, for example, it holds UAS technologies and operations to the same standards historically applied to technologies for and operations by manned aircraft.
- Better measures for assessing UAS risk could be considered: Can we make UAS "as safe as other background risks that people experience daily"? And how can the concept of *de minimis* risk inform the process of assessing acceptable levels of risk posed by UAS? For example, the FAA does not ground airplanes because birds fly in the airspace, although birds can and do bring down aircraft.

The objective is to keep risks under an appropriate level of control, so that they are managed in a manner that maintains the appropriate balance between value and safety. It is important to note that the acceptability of safety performance is often influenced by society norms and culture.[7] Accordingly, it is appropriate to objectively evaluate the level of risk the public is willing to accept with respect to UAS (e.g., flying over people, critical infrastructure, etc.) and to consider the results of this evaluation when establishing risk-based standards and regulations. As part of this evaluation, assisting the public with understanding risks that are avoided by UAS operations is important. As stated earlier, this approach has worked well for the FAA in achieving a very high level of safety for air transportation.

Reviewing approaches used by other nations is also informative. For example, Sweden requires equipping all UAS with an emergency shutdown capability. In France, under certain circumstances, some UAS are required to have an automatic system to prevent them from going beyond a specified distance from the operator (Law Library of Congress, 2016).

As highlighted above, the FAA administrator recognized several years ago the need for government to move faster in addressing the burgeoning drone industry. But how should that recognition be put into action? The first step is to listen to and collaborate with industry. The FAA is doing that through many venues, including the National Academies of Sciences, Engineering, and Medicine and this committee. The FAA has established the Drone Advisory Committee and numerous aviation rulemaking committees through which they work closely with their stakeholders. The FAA also works with organizations such as RTCA to develop minimum performance standards that serve as a means of compliance with FAA regulations. The use of performance standards rather than prescriptive design standards encourages industry to develop innovative designs and solutions that comply with the standards. This approach has never been so important and pertinent as it is now when applied to new entrants into the airspace such as small drones.

There are opportunities to further incorporate these innovative and collaborative approaches into the FAA's internal culture. Doing so could lead to an environment in which FAA personnel charged with any part of the regulatory process are encouraged to accept reasonable risks rather than avoid action as a way to avoid accountability and negative impacts on their careers. This could also lead to the creation of a proactive safety culture that

[7] ICAO, 2013, Safety Management Manual (SMM), Document 9859.

looks for how to get to "yes" without compromising safety, rather than one that dwells on what might go wrong. A system that rewards finding ways to enable new operations and penalizes inaction is the best way to jump-start the cultural change needed to "move at the speed of imagination." Further, in a proactive safety culture, responsibility, authority, and accountability are clearly articulated for each member of the safety organization, and no one person can derail an initiative simply by not saying yes; this is in contrast to a culture of management by committee or internal boards or panels.

PROCESSES

The current FAA process for considering and approving routine UAS operations (see Chapter 2) continues to stifle needed industry investment in developing technical and operational risk mitigations. The lack of empirical data continues to be the driver for the agency's subjective approach to approvals. Each request requires, even for "one-off" operations, an extremely labor-intensive, detailed description of an operational plan and system description. Commercial operations and public UAS operational approvals differ somewhat, but both are subject to significant scrutiny prior to approval with scant guidelines for how to show compliance with rules and regulations. The current Certificate of Authorization (COA) application, required for public aircraft operations, requires detailed descriptions of more than 15 separate items (see Table 3.2). Although the FAA's "Accountability Framework" clearly states that the responsibility for having safe airborne systems is with operators and manufacturers, with the FAA providing oversight, there is a strong culture within many parts of the FAA that it is the FAA that is responsible for airborne platform safety. This culture has led to highly prescriptive FAA guidance for many

TABLE 3.2 Details of Certificate of Authorization Information Requirements

Proponent Information Name of sponsor, address, and contact information	**Vehicle Performance** Description of aircraft type, number of certified components, ground station description, climb, cruise, descent performance	**Operational Description** Request effective period, approval effective period, executive summary, operational summary
Airworthiness Statement FAA-type certificate data for civil aircraft, airworthiness declaration for public aircraft	**Procedures** Lost link, lost communications, emergency procedure description	**Avionics/Equipment Description** Equipment suffix type, GPS capability and description, description of Traffic Collision Avoidance System/Midair Collision Avoidance System, transponder capability
Lighting Landing, anticollision, infrared	**Spectrum Analysis** Data and control link description with spectrum approval documentation included	**ATC Communications Plan** Two-way voice communication capability description (instantaneous), guard frequencies
Electronic Surveillance/Detection Capability Onboard aircraft electro-optical/infrared, radar, terrain detection, ground station-ATC radar access	**Aircraft Performance Recording** Flight data recording capability, ground control station recording, voice recording	**Operational Plan Area Description** Latitude/longitude description of operational area, flight plan waypoints
Flight Crew Qualification Certification level, medical certification, DOD or FAA currency	**Special Issues** Self-explanatory, requires supporting documentation	**Other**

NOTE: ATC, air traffic control; DOD, Department of Defense; FAA, Federal Aviation Administration; GPS, Global Positioning System.
SOURCE: Adapted from FAA (2008).

aspects of airworthiness certifications. While the FAA is attempting to "streamline" certification in a number of certification domains, the streamlining initiatives face ongoing internal debate and resistance within the agency as well as expectations for harmonization with international airworthiness authorities (e.g., ICAO Cir. 328, ICAO A39-WP/116).[8]

If approvals are granted, they are valid only for specific operations over a finite period, are subject to continued FAA scrutiny, require data sharing with the agency, and do not apply to commercial operations. Approvals are granted only after internal FAA discussion and risk assessment, because there are few if any specific performance standards available to serve as a means of compliance with rules and regulations. The only exception to the above process is for emergency approval issuance in the case of significant threat to life or property (natural disasters or other emergency applications).

Civil or commercial operational approval requests can be even more daunting and uncertain as to the probability for success. In addition to the above, civil airworthiness requirements are added to the process. Experimental, Restricted Category, or Special Airworthiness certification is normally required. The approval process involves the action of a formal safety risk panel if the national airspace is impacted and pertains only to specific operations. Routine "file and fly" operations of commercial UAS are still essentially prohibited.

The decision-making process within the FAA for a Safety Risk Management Document (SRMD) requires sign-off by Senior Executive Service (SES) personnel in multiple FAA organizations. In a recent case, the SRMD for UAS Detect and Avoid (DAA) Safety Assessment acceptance, submitted to the FAA in May 2017, required SES personnel from 12 organizations to sign off on the document before it could be accepted. In this case, not a single FAA person has signed off on the document as of February 2018. This is true, despite the fact that (1) the FAA initiated the creation of the DAA Minimum Operational Performance Standards (MOPS); (2) the FAA was integrally involved in the creation of the MOPS; and (3) the estimated cost of the development of the MOPS is approximately $250 million (including NASA verification and validation work, safety and safety assessment, and all the resources brought to the RTCA Special Committee-228 to complete the MOPS).

Recommendation: The FAA should meet requests for certifications or operations approvals with an initial response of "How can we approve this?" Where the FAA employs internal boards of executives throughout the agency to provide input on decisions, final responsibility and authority and accountability for the decision should rest with the executive overseeing such boards. A time limit should be placed on responses from each member of the board, and any "No" vote should be accompanied with a clearly articulated rationale and suggestion for how that "No" vote could be made a "Yes."

At present, unmanned aircraft designed to fly beyond visual line of sight for commercial purposes require a formal airworthiness certification. To date, only two viable paths exist to accomplish this: either Restricted Category or Special Class Type Certification. Both are difficult to obtain and have restrictions and limitations associated with them, and neither guarantees access to airspace. Special Class Type Certification under CFR 14 Part 21.17(b) has yet to be granted to any UAS, even after more than 2 years of effort by the proponents. The man-hour expenditure associated with obtaining the currently required certification and operational approvals generally well exceeds the value of the majority of commercial business opportunities. The expense and uncertainty associated with meeting the vague "risk-based" requirements imposed by the FAA make it difficult if not impossible to compete with certified manned aircraft serving the same mission.

A key product sold by commercial UAS service providers and manufacturers is data. UAS are operated under the assumption that they would offer an efficient and safer method to collect information for a customer. The systems are designed and operated to carry sophisticated payloads capable of capturing a wide variety of data and imagery in missions considered too "dull, dirty, or dangerous" for manned aircraft. Unfortunately, the onerous requirements to obtain approval to conduct such missions have resulted in many UAS service providers transfer-

[8] ICAO, 2011, Cir. 328, "Unmanned Aircraft Systems (UAS)"; ICAO, 2016, A39-WP/116, Working Paper, "The Need for Standards in Support of Harmonized UAS Operations." Presentation, https://www.faa.gov/uas/resources/event_archive/2017_uas_symposium/media/Breakout_3A_Global_Leadership.pdf, is a good example of the efforts for international harmonization.

FIGURE 3.4 Boeing ScanEagle. SOURCE: DOE (2013).

ring their payloads to manned aircraft to meet customer requirements. The ScanEagle UAS (a Group 2 UAS with over 1 million logged flight hours) (see Figure 3.4) is one example of a commercial business that is structured around data collection utilizing a combination of manned and unmanned aircraft when it would be safer and more cost-effective to conduct operations solely with unmanned aircraft.

In all likelihood, requirements for additional equipage—to be compliant with detect-and-avoid and command-and-control standards to operate routinely in the national airspace—will add to this burden. The addition of air-to-air radar, additional command-and-control capability, and increased aircraft performance to meet collision-avoidance requirements will likely force redesign of existing UAS in order to accommodate the additional size, weight, and power necessary to comply. All of these issues add to the challenge of closing a business case for UAS in the near term.

Commercial/civil operations can be categorized in two market segments. The most widely enabled are those conducted by small UAS (vehicles weighing less than 55 pounds) operating at altitudes below 400 feet above the ground and within visual line of sight of the pilot. These operations serve rather modest markets, such as real estate surveying, news media, some first responder activity, and localized precision agriculture. With FAA's current "risk-based" approach to operational approval, these types of operations are accommodated by compliance with the fairly easy requirements of 14 CFR Part 107.

The larger, more robust market opportunities exist in operations characterized by higher altitude, beyond visual line of sight, long-duration, and linear surveillance applications. The FAA considers these operations much riskier because of the size and performance of the vehicles needed to carry them out and because aircraft conducting these operations typically will share airspace with passenger aircraft. To the FAA's credit, emergency operation of these larger vehicles has been approved in response to some recent natural disasters. However, routine use for such applications as long-distance power line and infrastructure inspection, large-tract agriculture, wildfire monitoring, oil and gas pipeline inspection, severe weather monitoring, search and rescue, and law enforcement has been highly restricted.

Although there may be additional risk associated with operations of larger, higher-performance vehicles, the operations most attractive to industry are normally conducted over very remote locations where the risk of encounters with other aircraft or people not associated with operation is sufficiently low. Unfortunately, the current anecdotal approach to assessing the risk and the associated uncertainties of gaining operational approval make it difficult to establish a sustainable business model. Accordingly, industry continues to be wary of making additional aggressive investments in the technology.

The FAA has underutilized the test sites, pathfinder programs, and the upcoming UAS Integration Pilot Program by not defining and collecting data that could inform risk assessments. There are numerous examples of how UAS could be used to deliver emergency services to people in need:

- Delivering life preservers to swimmers in lakes or the ocean (extended visual range),
- Delivering automated external defibrillators to distressed persons in state parks,
- Searching for lost hikers in national forests, and
- Monitoring ice and tracking whales in remote marine environments off the coast of Alaska (beyond line of sight).

Finding: The safety of the National Airspace System has been achieved in large part as a result of the FAA's risk decision process, which has been characterized by a culture with a near-zero tolerance for risk. This culture, however, has too often resulted in overconservatism in the SRM process as it has been applied to UAS technologies and systems. The SRM process is particularly vulnerable to overconservatism due to its subjective nature. In particular,

- An overly conservative culture prevents safety-beneficial operations from entering the airspace. The focus is on what might go wrong. More dialogue on potential benefits is needed to develop a holistic risk picture that addresses the question, What is the net risk/benefit?
- Paralysis by analysis, where more data are requested in light of uncertainty about new technology, but flight experience cannot be gained to generate these data due to overconservatism.
- The status quo is seen as safe. There is too little recognition that new technologies brought into the airspace by UAS could improve the safety of manned aircraft operations, or may mitigate if not eliminate some nonaviation risks.

PROCESSES THAT DO NOT WORK

During its deliberations, the committee heard of numerous examples where proposals to use UAS in ways that were only slightly changed from previous practices met lengthy delays and were ultimately rejected for reasons that the proposers could not understand. Consider, for example, the Marginal Ice Zone Ocean and Ice Observations and Processes Experiment (MIZOPEX). This experiment was a $3.5 million project funded by NASA with the goal of helping to address information gaps in measurements of basic parameters, such as sea surface temperature, and a range of sea-ice characteristics, through a targeted, intensive observation field campaign that tested and exploited unique capabilities of multiple classes of UAS. To help achieve this goal, the experiment as designed included the use of a UAS weighing just 1.5 pounds and flying at a maximum height of only 50 feet over water in a very low traffic area north of Alaska. After a yearlong review, the COA to include this UAS in the experiment was denied.

FIGURE 3.5 DataHawk UAS. SOURCE: DOE (2013).

Appendix C provides a detailed description of the experiment and the long sequence of events that prevented the MIZOPEX field campaign from including what seems to have been very low risk flights by a small DataHawk UAS (see Figure 3.5). One of the participants in the project, J.A. Maslanik, summarized lessons learned during the MIZOPEX project as follows (Maslanik, 2016):

> The iterative nature of the COA application process, in which the COA requester prepares and submits the application, then waits for FAA reactions regarding problems or issues, creates problems for challenging field campaigns such as MIZOPEX. Researchers hoping to propose non-standard UAS field campaigns have no way of gauging ahead of time whether FAA will accept certain approaches, and the tell-us-what-you-want-to-do-and-we-will-respond process leads to delays and some confusion.
>
> Provision of exemptions for very low risk UAS such as DataHawk under Part 101 (i.e., treating the aircraft as posing risk comparable to a weather balloon) would open up considerable capabilities for sensing using UAS. An alternative would be to allow such aircraft to operate under a COA in fully autonomous mode outside communications range (i.e., in a planned lost-link mode).

This example, unfortunately, is not unique and is one reason why news of many of the most innovative uses of UAS often comes from non-U.S. locations. In Chapter 4, the committee offers recommendations on how to improve this situation.

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4

Evolving the Decision-Making Paradigm

When unmanned aircraft system (UAS) integration into the National Airspace System was first being seriously discussed about 15 years ago, the focus was on UAS with similar size and flight characteristics to manned aircraft. The Federal Aviation Administration's (FAA's) first set of expectations for UAS airspace integration was (1) an insistence that there would be no new segregated airspace class for UAS operations, (2) the integration of UAS could not cause any changes to air traffic management and operations for manned aircraft, and (3) UAS operations must demonstrate an "equivalent level of safety" to manned aircraft. The FAA approach was to require UAS to be "remotely piloted," meaning that the unmanned aircraft was expected to behave in the airspace system exactly like a manned aircraft, including communications between air traffic control (ATC) and the (remote) pilot, and the expectation that UAS would respond to ATC voice commands exactly as if the remote pilot was on board the aircraft. The emergence of small UAS over the past 15 years, accompanied by a multitude of unanticipated applications beyond those performed by manned aircraft, has been the primary driver behind the need to develop standards and regulations to address a class of aircraft with which FAA has no regulatory experience.

UAS OFFER MANY BENEFITS

In 2007 and 2008, the NASA Ikhana UAS completed remote-sensing missions that helped firefighters as part of the Wildfire Research and Applications Partnership, a joint effort between NASA and the U.S. Department of Agriculture Forest Service. These highly publicized missions represented the potential benefits of a carefully operated public safety mission, even with the restrictions of a public UAS operating under Certificates of Authorization (COAs).[1] A more common story of an opportunity lost, where the public safety benefits clearly outweighed the potential risk to the National Airspace System, was the denial by the FAA of Global Hawk flights over the post-Hurricane Katrina disaster area in 2005. In that case, the Global Hawk was described as "fully fueled and ready to fly"; however, the FAA's perceived risk to the airspace prevented its flights.[2]

The ability to use UAS in emergency response has improved in recent years. For example, during the aftermath of Hurricane Harvey in 2017, the FAA issued COAs to oil and gas companies, the Union Pacific Railroad, local governments, the Red Cross, and insurance companies to assess damage to facilities and the extent of flooding in

[1] See https://www.nasa.gov/offices/ipp/centers/dfrc/news_events/SS-Ikhana.html.

[2] L.M. Totten, 2012, "Remotely Piloted Aircraft: An Integrated Domestic Disaster Relief Plan," Air Command and Staff College, Air University, Maxwell AFB, Ala.

and around Houston, Texas. Even so, the many examples of opportunities for UAS missions to contribute to the public good that were prevented by the risk-averse regulatory environment far outnumber the stories of opportunities realized. The FAA recognizes this concern and has embarked on a deliberate path to modernize its approach to regulating UAS operations in the nation's airspace. New entrants bring with them unique opportunities that have the potential to benefit many, pose a different risk profile from traditional transport manned aviation, and also pose a new set of risks to those with whom they propose to share the airspace as well as those on the ground.

Both the FAA and the aviation industry have recognized the need to progress from current-day proscriptive or performance-based safety assessments to risk-based assessment when determining whether to allow an operation in the airspace. The diverse nature of the UAS industry, along with the lack of empirical data in this relatively young field, hampers the ability to develop quantitative bases for performance requirements.

Numerous approaches have been proposed, each with distinct benefits as well as challenges and disadvantages. The FAA has established an approach to safety assessment that is risk-based. While it is a substantial step in the right direction, it suffers from relying too heavily on subjective evaluations that are inherently limited by the expertise of the specific reviewer and subject to different evaluations by different reviewers. It is not yet the robust, repeatable process that is needed to enable the nascent UAS industry to prosper while keeping the skies safe and secure for all.

Based on the competing yet insistent needs to enable efficient operations as quickly as possible while ensuring their safety and security, the committee believes that the FAA must address key issues as presented in this chapter. In the pages that follow, this report describes the FAA philosophy and policy and the resulting regulatory environment and processes honed over decades by the FAA to ensure safety while enabling aviation to flourish. The report then explains the inappropriateness of simply applying processes developed for manned transport aviation to the smaller UAS industry and encourages the FAA to move as quickly as possible beyond issuing quick rules with little quantitative analysis behind them, as this leads to the need for many waivers and an indefensible, unrepeatable, and confusing process. The report then recommends quickly transitioning to a process that is based on quantitative risk assessment. This report endorses a more holistic approach to assessing UAS integration into the airspace based directly on risk (using other factors such as size, weight, and location only as inputs to the assessment of risk, rather than as broad-brush constraints). This holistic approach should also account for mitigations to potential risks within the entire UAS system (including its interactions with a human operator and ground control stations) and operational factors constructed to mitigate potential risks. The committee recommends starting with a comparative risk analysis until enough operational data are collected to provide a basis for safety assessments. Last, this chapter addresses the FAA's culture and the need to engage in top-to-bottom change management to usher in and inculcate the FAA's workforce with the risk-based approach recommended by the committee, and to appropriately delegate assessments of comparatively standard and low-risk operations.

FAA SAFETY MANAGEMENT POLICY

FAA Order 8000.369 (FAA, 2016), Safety Management System (SMS), establishes safety management policy and requirements that FAA organizations must follow. This order mandates that safety risk management (SRM) must include the following steps:

- Conduct systems analysis to establish an understanding of systems design performance;
- Identify and document hazards that have the potential to affect safety risk;
- Analyze safety risk to determine the severity and likelihood of potential effects;
- Assess safety risk to establish safety performance targets or rank hazards on risk; and
- Control safety risk by implementing controls for hazards with unacceptable risk.

FAA Order 8040.4B (FAA, 2017), Safety Risk Management Policy, supports Order 8000.369 by establishing requirements on conducting SRM, which is a part of the larger SMS.

This process is abbreviated as DIAAT: describe, identify, analyze, assess, and treat. The DIAAT approach, which is described in more detail in Chapter 5, is implemented using a panel of experts and affected stakeholders.

Using this approach of data-informed, expertise-driven management to integrate safety into operations and decision making, the FAA has achieved an impressive level of aviation safety for the National Airspace System.

DIAAT is a systematic approach to safety risk management, but it is fundamentally qualitative and subjective. The FAA Extension, Safety, and Security Act of 2016, Section 2213, calls for a study of probabilistic assessments of risks to streamline the integration of unmanned aircraft systems into the National Airspace System. The current DIAAT approach is not (quantitative) probabilistic risk analysis (PRA) in the sense of the FAA Act.

Subject matter expert opinions are relied upon to characterize the probabilities and consequences of potential risks. An insufficient empirical history of adverse incidents precludes the use of purely actuarial data in establishing risks, while the use of quantitative engineering-risk modeling along the lines of the bowtie method or stochastic simulation has been hindered by the breadth of the issue. FAA personnel are aware of this issue, pointing out to the committee the need for objective data, analytical approaches based on geometry and density, and the prospect for increased use of modeling.

The nature of risk matrices is also problematic. Risk matrices or heat charts are used to categorize and to communicate probabilities and consequences associated with risks. While these diagrams are widely used in federal practice, *their principal benefit is communication and not risk assessment*. A fundamental issue is that the classification schemes for probability and consequence are commonly based on ordinal scales, such as low-medium-high. Common mathematical operations like differences and ratios are inadmissible on these scales. Further, such scales are normally subjective interpretations. Different subject matter experts may come to different ratings for the same quantitative risk. The results often fail to be repeatable, predictable, and transparent. Risk matrices should be used only with caution and only with careful explanations of embedded judgments (Cox, 2008).

The Joint Authorities for Rulemaking of Unmanned Systems (JARUS)[3] Specific Operations Risk Assessment (SORA) approach is in large measure similar to the present DIAAT approach and thus fails to offer an alternative. This methodology divides UAS classes into weights and kinetic energy bins, and similarly harm barrier classes related to robustness. Ground risk is categorized by safety assurance and integration levels. While the JARUS approach is more detailed than that used by the FAA, the categorizations of probabilities and consequences are still inherently subjective.

Finding: The current FAA Order 8040 approach to risk management is based on fundamentally qualitative and subjective risk analysis. The Specific Operations Risk Assessment approach of the Joint Authorities for Rulemaking of Unmanned Systems is conceptually the same. These subjective approaches require a depth and breadth of subject matter expertise for the approval process that FAA does not possess. The qualitative nature of the current approach might lead to results that fail to be repeatable, predictable, and transparent. Evolution to an approach more reliant on applicant expertise and investment in risk analysis, modeling, and engineering assessment, as is practiced in many other areas of federal regulation, might better achieve a quantitative probabilistic risk analysis basis for decisions.

THE CURRENT UAS ENVIRONMENT: REGULATORY CONSTRAINTS AND MISSED OPPORTUNITIES

As explained in Chapter 2, there are five ways in which drones may be operated in the National Airspace System. Drones flown purely for recreational purposes ("model aircraft") may be operated under Part 101.41 and require no further operational approval. Part 107 and its two associated waiver processes provide three ways for small drones under 55 pounds to obtain operational approval under specific, limited conditions. All other drone operations must use the manned aircraft COA process.

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[3] JARUS provides a forum for experts from dozens of national aviation authorities (such as the FAA) and regional safety organizations to facilitate development of technical, safety, and operational requirements for the certification and safe integration of UAS into regulated airspace. JARUS has published a document, JARUS Guidelines on Specific Operations Risk Assessment (SORA), that recommends a risk assessment methodology to ensure that a specific operation can be conducted safely. See JARUS, 2017, http://jarus-rpas.org/sites/jarus-rpas.org/files/jar_doc_06_jarus_sora_v1.0.pdf.

Part 101.41, by its nature and intent, permits only a very limited, noncommercial, set of operations. Part 107 is the first Federal Aviation Regulation to address directly the certification of *small* UAS and UAS pilots and their operations.[4] The Part 107 rule enables daytime operations by visual line of sight of small (less than 55 pounds) UAS in Class G airspace for altitudes less than 400 feet above the ground or obstacles, with additional restrictions that include the prohibition of flying over people. The FAA estimated that the benefit of this regulation would be between $733 million and $9.0 billion in 5 years by allowing some operations such as real estate surveying, news media, some first responder activity, localized precision agriculture, and research and development of further small UAS technologies and applications. However, all other small UAS operations require a waiver. Few data exist to support requests for such waivers, making the outcome of such requests highly uncertain.

As noted in Chapter 3, larger drones (greater than 55 pounds) provide significant market opportunities, but obtaining operational approval is particularly difficult because of the elevated risk posed by the size and performance of the vehicles and because relevant missions will require these aircraft to share airspace with passenger aircraft.

Applicants must use the same COA application that is required for public aircraft operations. This application is onerous, requiring, among other things, detailed descriptions of items of varying relevance to UAS operations, including proponent information, program objectives, operational summary, aircraft description, performance characteristics, airworthiness statement, procedures for lost link, lost communications, emergencies, avionics, lights, spectrum analysis, ATC communications, electronic surveillance/detection capability, visual surveillance capability, aircraft performance recording capability, flight plans, flight crew qualifications, and special circumstances.

Further, the largest challenge in obtaining a COA is the requirement for an airworthiness certification. Public entities such as NASA or public universities may issue their own airworthiness certificates, but commercial entities must first apply for and obtain an FAA airworthiness certificate. There are very few commercial unmanned aircraft with airworthiness certificates. Experimental, Restricted Category, or Special Airworthiness certification is normally required, with the last two being the only options for beyond visual line of sight. All are difficult to obtain and have restrictions and limitations associated with them, and none guarantee access to airspace. Special Class certification under CFR 14 Part 21.17(b) has yet to be granted to any UAS after more than 2 years of effort by the applicants. In practice, the COA process is mainly used by public entities that can grant their own airworthiness certificates.

Overall, the COA process is still opaque and the outcome uncertain. COAs are granted only after nontransparent internal FAA discussion and risk assessment. Because there are few specific standards or rules available on which to base the approval decisions, the outcome can never be assured and certainly is not repeatable. If COAs are granted, they are valid only for specific operations over a finite period, subject to continued FAA subjective scrutiny, and require data sharing with the agency. The only exception is for emergency approval issuance in the case of significant threat to life or property (natural disasters or other emergency applications). The result of this opaque and uncertain COA process is that routine "file and fly" operations of commercial UAS are still essentially prohibited or rendered financially impossible.

The committee concurs with the views of many in industry that applying regulations intended for manned aviation to unmanned aviation is inappropriate and will not meet the needs of the burgeoning industry. The FAA appears to agree, at least when it comes to small UAS. The FAA's Final Rule for Operation and Certification of Small Unmanned Aircraft Systems, published in 2016,[5] acknowledges that applying regulations developed for manned aircraft to unmanned aircraft systems is inappropriate:

> [The] FAA's current processes for issuing airworthiness and airman certificates were designed to be used for manned aircraft and do not take into account the considerations associated with civil small UAS. Because the pertinent existing regulations do not differentiate between manned and unmanned aircraft, a small UAS is currently subject to the same airworthiness certification process as a manned aircraft. These existing regulations do not contemplate small

[4] The FAA has issued Technical Standard Orders for detect and avoid (DAA) and C2, referencing RTCA DO-362, DO-365, and DO-366 for large UAS.

[5] Department of Transportation, FAA, 2016, Operation and Certification of Small Unmanned Aircraft Systems; Final Rule, Federal Register, Vol. 81, No. 124, Tuesday, June 28, 2016 (p. 42069).

UAS operations that could, as a result of their operational parameters, safely be conducted without any airworthiness certification. This framework imposes an undue burden on such operations.

Finding: The FAA's current and evolving process for conducting risk assessments for UAS operations in the National Airspace System includes numerous cross-agency panels and a complex decision-making process. Thus, this process takes an excessive amount of time to complete, particularly given the number of requests that the FAA is asked to consider. Attempts are being made to streamline the process outlined in the regulations, but the process is not repeatable and does not provide applicants with clearly articulated criteria. Lack of transparency and data render the process and its outcomes difficult to defend.

The FAA briefed the committee on its current plans as well as its risk assessment processes. The committee was struck by the absence of specific dates in the FAA's plans. For example, the FAA is working on an Advisory Circular to provide guidance on preparing for the risk assessment, yet could not offer a date for its publication. All charts presented with timelines were notional and either contained no dates or commitments or had notional dates. The FAA seems more focused on processes and activities than on outcomes.

The FAA did provide briefing charts to the committee describing a waiver processing tool for drones, called Waiver Wizard. It is described as applying to low-risk operations, although "low risk" is not defined. It aims to automate and thus streamline the process of granting waivers for low-risk operations. The committee identified several concerns about using SORA as the basis for this process. Automation to support the process is not yet developed, and it proposes to base the risk assessment on the JARUS SORA method. It does allow for incorporation of FAA and industry standards as a means of compliance. The outcomes of this process will be only as good as the data used to assess risk, and to the extent that such assessments are qualitative and subjective, the outcomes will be questionable at best.

ONE SIZE DOES NOT FIT ALL: MISSING DIMENSIONS IN CONSIDERATIONS OF UAS RISKS AND BENEFITS

The FAA's comprehensive set of analysis methods and processes for safety risk management and system safety assessment has long served to ensure safety within the manned aircraft sector. However, unmanned systems present many new and unique challenges and opportunities, and thus it is important to recognize that a broader view on risk analysis is needed, in at least four ways:

1. Consider broader societal benefits in addition to risk when conducting safety assessment.
2. Do not simply treat UAS risk in the same manner as the single probability assessed when evaluating risk of manned aircraft operations: consider risk as a multivariate measure.
3. Performance requirements for UAS should be commensurate with risk and backed by performance-based standards.
4. Consider new institutional mechanisms for conducting, or delegating, risk analysis.

UAS BROADER COST BENEFIT

UAS have the potential to take on new roles in society that bring tremendous societal benefit. Yet these roles will not be realized unless the system safety assessment process admits a broader view of risk and, in particular, considers the notion of safety-benefit-risk trade-offs.

The current risk assessment process employed by the FAA when determining whether to allow an operation addresses only the risk added to the National Airspace System by that proposed operation, without considering the safety benefit provided beyond the National Airspace System. In some cases, this one-sided approach has led to disallowing operations that would actually enhance safety and save lives. For example, reductions in the number of film and TV workers killed by helicopter accidents can reasonably be predicted to outweigh the risks to the aviation system in using UAS as airborne camera platforms.[6]

Finding: Drones have and will continue to be used to carry out missions of measurable economic and safety benefit to society. Examples include such activities as inspection of critical infrastructure that pose tangible danger to human inspectors, humanitarian delivery of medicines and other lifesaving cargo to rural areas or areas hard to reach by other transportation means, emergency response, search and rescue, and agricultural sensing, leading to reduction in use of pesticides, water, and other chemicals. These benefits to society may outweigh the (typically small) risks added to the National Airspace System by their operations.

UAS VERSUS MANNED AIRCRAFT

There are no general metrics or commonly agreed upon definitions of what outcome should be used to define risk. Some studies/analyses define risk as the probability of a fatal injury, while others define risk through the probability of failure, and again others as a probability of an accident, and so on. The definition of risk cannot simply be transferred from the manned aircraft case to UAS. There is substantial variability in the hazards and potential consequences across different kinds of UAS operations as well as potential mitigations. It is advisable to consider risk as a multivariate measure in order to allow comparison across various aircraft types without having to hold all UAS to the same standard (or to the same standard as larger aircraft).

In some cases, the FAA actually imposes even higher standards on UAS than on manned aircraft. In particular, the FAA has chosen to only lightly scrutinize manned aircraft in many circumstances, such as experimental aircraft, but they have chosen to regulate 4-pound flying objects to a much more stringent requirement. Their actions with respect to small drones would indicate that they have decided that 4-pound flying robots are more dangerous and require more stringent standards than a light sport airplane.

Finding: Traditionally in manned aviation, assessments of risk focused on probability of crew and passenger fatalities. This measure clearly does not correspond well to UAS operations. Further, given the substantial variety of types of UAS and UAS operations, in order to properly characterize the benefit and risk of all UAS operations, we will need multivariate measures that include as co-variates the mission type, characteristics of the vehicle (e.g., weight) and other environment variables.

UAS VERSUS OTHER UAS

The FAA is responsible for ensuring the safe integration of all sizes of UAS in all airspace classes conducting many diverse missions. No matter the size, the performance required should be commensurate with the risk posed. As shown in Figure 4.1, UAS operations span a broad range, from low-risk, low-consequence to high-consequence operations, thereby requiring different approaches depending upon the size and mission of the UAS.

Over the past 12-24 months, the FAA has shifted its focus on UAS integration from full integration of larger, predominately military UAS into the National Airspace System to the integration of small commercial and consumer drones operating at lower altitude and lower risk. With this shift to smaller aircraft, the FAA has paid less attention to the needs of the larger UAS that do or will operate in Class A, B, and C airspace (i.e., in controlled airspace, including in the vicinity of airports). RTCA Special Committee-228 (Standards for UAS) continues to develop minimum performance-based standards for end-to-end systems and equipment for detect and avoid and command and control for UAS operating in all airspace, with a solid foundation in quantitative safety and hazard assessments. RTCA is integrating these assessments into the FAA's risk matrix to ensure that standards are commensurate with not only the intended operational environment but also the level of risk. It is the understanding

[6] From 1980 through 2014, helicopter accidents in the United States killed 14 film and TV workers. *Deadline Hollywood*, April 8, 2014, "Safety on Set: Helicopter Crashes Have Taken Most Lives on TV and Film Sets," http://deadline.com/2014/04/helicopter-crash-deaths-hollywood-safety-history-709487/.

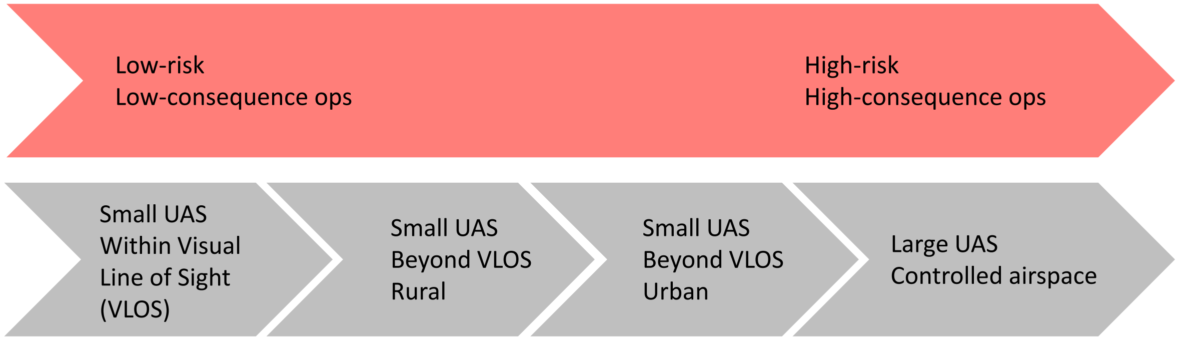

FIGURE 4.1 Regulations commensurate with risk and backed by standards.

of the committee that this work will continue and that SC-228 will complete the standards for UAS DAA and C2 for Classes A, B, C, and G airspace and all sizes and missions.

UAS RISK ANALYSTS VERSUS MANNED ANALYSTS

The unique nature of UAS operations opens the door to reconsider who is best suited to conduct the risk analysis for different classes of UAS, as well as what regulatory institutional mechanism is best suited to ensure and incentivize safety. This is in stark contrast to the air transport category, where the FAA is the final authority on performance requirements and safety and risk assessment. But even in this higher-risk transport category, where RTCA conducts and incorporates detailed safety assessments into the performance standards that the FAA subsequently references in its Technical Standard Orders and Advisory Circulars, in many cases the FAA conducts its own safety assessments even after RTCA has completed them.

THE HUMAN-MACHINE TEAM

The current risk assessment procedures typically focus on the technology and on the operation, without properly capturing the human-machine teaming aspects of UAS operations in which the entire system includes a human operator not located near the vehicle. Thus, there seems to be attention on “system failures” associated with small UAS, but each of these UAS comprises a team of humans and machine technologies. U.S. airlines have used teaming and humans and machines to achieve and maintain their current high levels of safety: technology failures can be detected and resolved by human pilots, and the technology is structured to prevent many forms of slips and mistakes by humans and to detect and help resolve those human slips and mistakes that do occur.

The UAS community has not consistently demonstrated proper use of this teaming concept, and current risk assessment methods do not adequately identify problems in teaming beyond labeling breakdowns as either machine failures or human error. Many UAS accidents are caused by technology failures that the human operator could not detect or resolve. Likewise, the technology does not gracefully accommodate foreseeable human slips and mistakes, allowing them to evolve into single-source system failures without mitigation. (For example, anecdotes by speakers to the committee described numerous accidents with small UAS resulting from confusion by the operator about the state of the machine and from lack of error-reduction design methods such as guards on key switches.)

Finding: Concerns related to the teaming of humans and machines can be reflected in the risk analysis methods applied to UAS. They reflect the unfortunate reality that there are no broad-brush statements that can be reliably made about the role of the human and machine technologies within UAS. Instead, those design variables that determine system sensitivity to likely machine failures, and to foreseeable inadvertent slips and mistakes by humans, can be accounted for within each system. Further, this risk analysis, by examining how the human-machine team interacts, can better capture how the UAS will detect and resolve hazards that arise within the team. This risk analysis would also determine the extent to which humans and machine technologies are able to coordinate to resolve hazards arising in the broader operational environment outside the UAS.

Recommendation: The FAA should expand its perspective on a *quantitative* risk assessment to look more holistically at the total safety risk. Safety benefits, including those outside of aviation (e.g., the benefit of cell tower inspections without a human climbing a cell tower), should be part of the equation. UAS operations should be allowed if they decrease safety risks in society—even if they introduce new aviation safety risks—as long as they result in a net reduction in total safety risk.

Figure 4.2 illustrates one way that a holistic consideration of safety benefits could be introduced to the risk assessment process, together with a more streamlined approval process.

A NEW TOOLBOX FOR UAS RISK ASSESSMENT

Given the nascent nature of the UAS industry, it is not surprising that there is a lack of data on the safety of operations. Still, to continue the enviable safety record of the National Airspace System, some method(s) must be established to determine whether to allow a new operation that could change the National Airspace System.

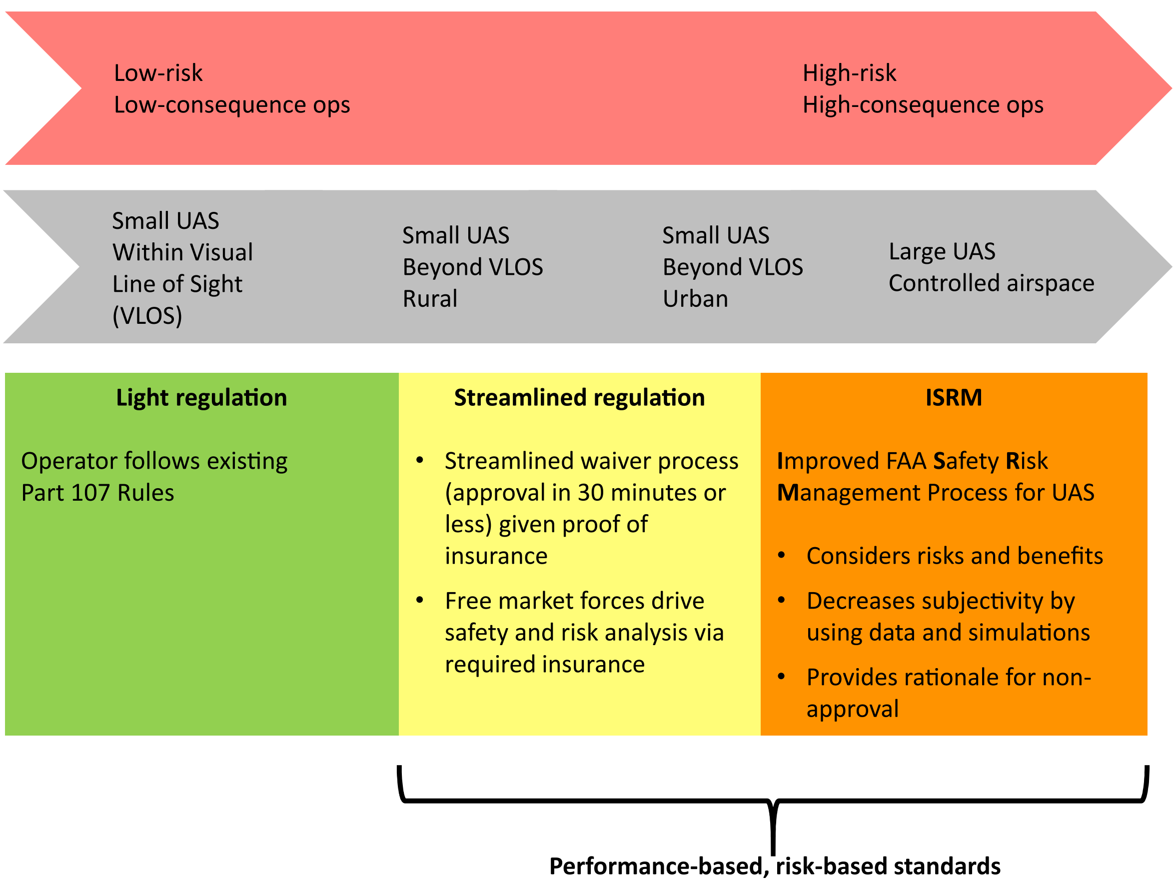

FIGURE 4.2 An improved risk assessment process would include holistic consideration of safety benefits, as well as recognize a need for different safety assessment and regulation requirements for different classes of operations.

Such determinations cannot be based solely on opinion or subject matter expertise. When data are lacking or non-conclusive, other approaches such as simulation, test site experimentation, and pathfinders can help fill in the gaps. RTCA's SC-228 UAS committee has relied heavily on NASA's simulation and testing to develop and validate the safety assessments that serve as the foundation of their standards for detect and avoid and command and control.

For the fast-paced small UAS industry, comparative risk analysis (CRA) offers a way forward. CRA is a tool for comparing and ranking risks and for identifying strategies for managing risk. It has been applied widely in U.S. government practice (Environmental Protection Agency, Occupational Safety and Health Administration, U.S. Nuclear Regulatory Commission, U.S. Army Corps of Engineers, Consumer Product Safety Commission, and other agencies), especially with regard to environmental and technogenic risk. The World Bank notes that CRA can assist in setting priorities, promoting coordination, and promoting consensus (Ijjasz and Tlaiye, 1999). CRA is especially useful when, as is the case with UAS, simple common metrics are not appropriate. For example, the National Research Council, in its *Review of the Department of Homeland Security's Approach to Risk Analysis* (NRC, 2010), recommended a comparative risk analysis approach, arguing that for the Department of Homeland Security, "a fully integrated analysis that aggregates widely disparate risks by use of a common metric [was not at the time] a practical goal." Risk ranking can be made within a portfolio of regulated risks (Florig et al., 2001), or in comparison to generic risks that society routinely faces (Fischhoff and Morgan, 2008). In the case of UAS, which in contrast to manned aviation pose primarily third-party risk, potential appropriate comparative risks include the risk of automobile-to-pedestrian accidents, death or injury from other common activities such as falling tree branches, or the impact of birds with flying aircraft. The FAA could undertake research studies to better understand these common daily risks, and other *de minimis* risks, as a point of comparison (Melnick and Everitt, 2008), without necessitating a precisely specified target level of risk.

Another, complementary approach to CRA is to use applicant-driven risk assessments. Here, the applicant or licensee takes on the financial burden and provides a probabilistic risk analysis (PRA), which is then evaluated and approved or rejected by the regulatory authority (e.g., the U.S. Nuclear Regulatory Commission, the Federal Energy Regulatory Commission, and the U.S. Food and Drug Administration).

The FAA can have the applicant perform a detailed engineering and operational risk assessment using modern quantitative tools and possibly simulation models by which to demonstrate the safety of its proposed use cases. The applicant or vendor may have risk analysis expertise superior to that available to the FAA in the normal course of its operations. There are many different methods—using countless different algorithms—for conducting PRA. Each of these methods and algorithms has advantages and disadvantages for a particular analytical problem. The applicant's PRA can be evaluated by FAA experts for its conformance with modern engineering and safety standards. Comparative risks, as discussed earlier in this section, can be used to determine whether a proposed operation poses acceptable risk. This would be in keeping with the FAA's approach of enabling industry either to show compliance with existing standards or to provide an alternative means of compliance.

For the applicant-driven PRA to lead to predictable outcomes that encourage innovation and do not compromise safety, applications need to be grounded in a common framework. For the myriad manufacturers and operators to coexist and bring innovation to the skies, it would behoove them to establish a common language and a common risk-based framework for developing minimum performance requirements. Such a framework and associated risk-based minimum performance standards could serve as a means of compliance and make it easier for the applicant to know what the FAA requires.

The goal of an applicant-driven PRA approach, based on industry standards, cannot be achieved immediately. Thus, an interim solution is desirable. This solution could build on the current DIAAT (describe, identify, analyze, assess, and treat) concept while making the individual steps in the process more quantitative, subject less to the qualitative opinions of subject matter experts. The following recommendations suggest one such evolutionary path:

Recommendation: Within the next 12 months, the FAA should establish and publish specific guidelines for implementing a predictable, repeatable, quantitative, risk-based process for certifying UAS systems and aircraft and granting operations approval. These guidelines should interpret the Safety Risk Management Policy process described in Order 8040.4B (and in accordance with International Civil Aviation Organization Doc. 9859) in the unique context of UAS. This should include the following: (1) Provide within 18-24 months

risk-based quantitative performance standards that can serve to establish compliance with FAA rules and regulations. (2) In the interim, encourage applicants to provide quantitative probabilistic risk analyses (PRAs) to demonstrate that their operation achieves the requisite level of safety. (3) Within 18-36 months, update FAA rules to reference new performance standards with the goal of minimizing the need to grant waivers or Certificates of Authorization (COAs).

Recommendation: Where operational data are insufficient to credibly estimate likelihood and severity components of risk, the FAA should use a comparative risk analysis approach to compare proposed UAS operations to comparable existing or *de minimis* levels of risk. The FAA should research and publish applicable quantitative levels of acceptable risk in comparison to other societal activities that pose *de minimis* risk to people. Risk level and risk mitigation strategies should consider not only aircraft collisions but also third-party risks (e.g., to people on the ground).

It appears to the committee that developments by current FAA contractors and research centers (e.g., Virginia Tech, MIT Lincoln Labs, the Volpe Center) may provide directions for making such adjustments.

Recommendation: Over the next 5 years, the FAA should evolve away from subjectivities present in portions of the Order 8040.4B process for UAS to a probabilistic risk analysis (PRA) process based on acceptable safety risk. In the interim, the FAA should improve the 8040.4B process to conform better with quantitative PRA practice. For the new acceptable risk process, the FAA should consider relying on the applicant to provide a PRA demonstrating the achieved level of safety, as is common in other regulatory sectors such as nuclear, dam, or drug safety.

- **The FAA should screen applicant PRAs by comparison to existing or *de minimis* levels of risk. The FAA needs to research applicable quantitative levels of acceptable risk in comparison to other societal activities in establishing a level of *de minimis* risk for aviation.**
- **These acceptable levels of risk need to include risk to people on the ground and risk of collision with a manned aircraft, particularly with regard to collision with a large commercial transport.**
- **In evaluating applicant-generated PRA, the FAA should value the importance of risk mitigation opportunities and their potential for simplifying the analysis of risk.**
- **In situations where the risk is low enough, the FAA should encourage applicants to obtain insurance for UAS operations in lieu of having a separate risk analysis.**

QUANTIFYING HUMAN FACTORS AND SOFTWARE CONTRIBUTIONS TO RISK FOR UAS

In recommending the PRA approach, the committee was cognizant that some contributors to risk are difficult to quantify, yet contribute substantially to the overall operational risk. Human factors, for example, were prominent in the Nogales Predator B crash.[7] Because pilot awareness and response is affected by several factors (e.g., visual displays, aural warnings, rest, training), it is difficult to quantify with confidence the contribution of pilot awareness to probabilistic risk analysis. Nevertheless, the implementation of a training program and pilot experience gives some level of confidence in estimating the contribution of the human pilot (and air traffic controllers, maintenance staff, etc.) to the overall probabilistic risk.

Another such contributor is software. Because many of the onboard pilot functions on UAS are instead implemented by software, UAS are by nature software-intensive systems. Therefore, the contribution of the software to the overall PRA needs to be well understood. While there have been some attempts to quantify the reliability of software and its contribution to the PRA,[8] an overarching standard methodology has not been established. Addition-

[7] See https://www.ntsb.gov/safety/safety-recs/recletters/A07_70_86.pdf.

[8] See https://www.ncbi.nlm.nih.gov/pubmed/16268949 and https://www.researchgate.net/publication/254407479_Software_Failure_Probability_Quantification_for_System_Risk_Assessment.

ally, many of the models used in research to date are based on safety-critical software that has been cordoned off from networks and in a stable, locked-down configuration. Many UAS manufacturers have a vision for managing software in a similar manner to that of consumer electronics software, where updates are frequently available and "pushed" to the end user platform. While these updates may improve safety by fixing known bugs and vulnerabilities, they also make UAS more vulnerable to cybersecurity risks, as there are increased attack surfaces and additional vulnerabilities that pose new safety risks.

For traditional manned aviation, software behavior is ensured through the use of prescriptive standards with regard to requirements decomposition, development process, testing, configuration management, and other practices (e.g., see RTCA DO-178C). The degree of rigor of these processes for a specific module of code is based on a system-level functional risk assessment, directly tied to the consequence of failure of function on the aircraft that the software is implementing. In implementing the recommended PRA approach, a similar—but scalable—construct could be useful for UAS software. One such approach has been proposed by ASTM Standard F3201 "Standard Practice for Ensuring Dependability of Software Used in Unmanned Aircraft Systems,"[9] which bases the required software assurance activities on an operational risk assessment—and which takes into account the concept of operation of the UAS—rather than the traditional functional risk assessment. In assessing the risk of software to the overall operational risk, areas to consider include the development methodology, evaluation of cyber vulnerabilities to include deliberate attacks, missing/spoofed data, incompatible software, frequency of software updates, and so on.

In summary, it is important that the recommended PRA approach address the contribution of human factors and software to overall operational risk. As the FAA moves toward implementation of the recommended PRA approach, it may consider the following:

- Establishing and publishing a standard, repeatable methodology for calculating the quantitative risk contribution of software and human factors so that they can be included in the PRA;
- Establishing and publishing processes and procedures for managing the risks due to software and human factors so that they do not have to be included in the PRA; or
- Some combination of these two approaches that would yield a rough estimate into the PRA calculation without necessitating a detailed assessment and calculation of the exact risk contribution.

EMPOWERING THE WORKFORCE

The FAA has inculcated its workforce with processes steeped in its safety-critical, risk-averse culture. These processes have evolved over decades along with the growth of manned aviation into the safest air transportation system in the world. In many ways, the FAA is defined more by its processes than its outcomes. Now, new unmanned aircraft of all shapes, sizes, and missions are rapidly emerging, demanding to share the airspace. In response, the FAA must also rapidly evolve its processes to accommodate manned aircraft to new approaches that will enable timely introduction of drones without compromising safety, security, or efficiency of the nation's airspace system.

The move to risk-based decision making will require a top-to-bottom change management initiative, championed and driven by the top-level executive in the FAA and that individual's management team. This will not be easy, nor will it happen overnight. A clear delineation of authority, accountability, and responsibility is essential to successful decision making in any organization, but especially so for the regulator and provider of the nation's air traffic management system. Appropriate empowerment to make decisions at all levels of the FAA is also a critical element of success. Such empowerment can happen only when all decision makers are fully versed in the new risk paradigm.

Recommendation: The FAA should create the following two mechanisms that empower and reward safety risk management decisions that consider the broad charter of the Department of Transportation to "serve

[9] See https://www.astm.org/Standards/F3201.htm.

the United States by ensuring a fast, safe, efficient, accessible and convenient transportation system that meets our vital national interests and enhances the quality of life of the American people, today and into the future" (DOT, 2018):

- **The FAA administrator should establish an incentive system that measures, promotes, and rewards individuals who support balanced comparative risk assessments.**
- **Within the next 6 months, the FAA administrator should publicly commit to ensuring time-bound reviews of risk assessments so that proponents receive timely feedback.**

Recommendation: Within 6 months, the FAA should undertake a top-to-bottom change management process aimed at moving smartly to a risk-based decision-making organization with clearly defined lines of authority, responsibility, and accountability. To that end, the FAA should establish and maintain technical training programs to ensure that agency risk decision professionals can fully comprehend the assumptions and limitations of the probabilistic risk analysis techniques appropriate to current and future UAS operations.

As highlighted above, the FAA administrator recognized several years ago the need for government to move faster in addressing the burgeoning UAS industry. But how should that recognition be put into action? The first step is to listen to industry and to collaborate with industry. The FAA is doing that through many venues, including the National Academies and this committee. It has established the Drone Advisory Committee and numerous aviation rulemaking committees through which it works closely with its stakeholders.

The FAA works with organizations such as RTCA to develop minimum performance standards that serve as a means of compliance with FAA regulations. By insisting on performance standards rather than proscriptive design standards, the FAA encourages industry to develop innovative designs and solutions, all of which comply with the standards. This approach has never been as important and pertinent as it is now when applied to new entrants into the airspace such as small drones.

The FAA should carry these innovative and collaborative approaches further into its internal culture. FAA personnel charged with any part of the regulatory process should be encouraged to take reasonable risk rather than avoiding action as a way to avoid accountability and negative impacts on their careers. The FAA should take measures to create a proactive safety culture that looks for how to get to "yes" without compromising safety, rather than one that dwells solely on what might go wrong. A system that rewards finding ways to enable new operations and penalizes inaction is the best way to jump-start the needed culture change. Responsibility, authority, and accountability should be clearly articulated for each member of the safety organization.

INSURANCE FOR LOW-RISK OPERATIONS

At this time, some types of UAS operations have sufficiently low risk that they may neither warrant individualized assessment nor require detailed regulatory oversight on those aspects of the operation that use well-established technologies and operating concepts. In such cases, rather than require detailed evaluation by the regulator, the regulator can instead choose to require insurance at a sufficient level of coverage for liability and indemnity. Precedents exist in many other countries (including Canada, China, Germany, Poland, Sweden, South Africa, and the United Kingdom) for requiring UAS operators to acquire liability insurance (Law Library of Congress, 2016). The specifics vary from country to country. Canadian Aviation Regulations, for example, establish requirements for insurance that vary based on the type of operation and vehicle size, where the parameters behind the insurance are also regulated (Transport Canada, 2018; Canadian Aviation Regulations, 2018).

Insurance agencies with detailed expertise and experience in a particular field are inherently situated to examine the holistic risk and other relevant factors. For example, an insurance agent for a commercial entity responsible for inspecting large infrastructure (e.g., communications towers) can compare the risks (and commensurate cost of insurance) of manned inspections incurring risks to the human inspectors versus the aviation system risks of using UAS without placing human inspectors at risk.

As demonstrated in many other domains, the market forces of the underwriting community can ensure sound oversight and routine data collection, and can provide detailed instructions by insurers to UAS operators as to what risk (as reflected in the cost of insurance) is predicted to correspond to different technologies and types of operations. For example, it is common practice in manned aviation for underwriters to adjust insurance rates based on a number of factors ranging from the technology, to the type of operation, and to other operational factors including maintenance and inspection protocols, operator training, and the implementation of safety management systems and processes in the operation. In addition, in the automotive industry insurance rates are influenced by many factors, including risk associated with the vehicle type, vehicle location, the nature of vehicle operations (commercial or private), operating hours (as indicated by expected miles driven per annum), safety features incorporated into the vehicle, and the safety record of the driver. This variability in rates is an inducement for drivers to reduce risk. In the extreme, insurance rates can become so high for some drivers that they are unable to afford insurance—or insurance companies will refuse to issue insurance to them—which generally makes it illegal for a driver to operate a vehicle.

Initially, given the lack of historical data, insurance rates would likely be set somewhat subjectively. For example, conservative insurance companies would likely set rates based on a conservative estimate of accident rates and liability costs. Over time, as data accumulate, insurance companies will be able to adjust insurance costs based on demonstrated accident rates and liability. Rates could also change as new types of technologies, vehicles, and operations are introduced. The underwriting community is inherently more capable of agile responses to such changes than regulatory bodies such as the FAA. Further, the underwriting community is well situated to establish insurance rates for different types of operations (with and without a UAS) that account for broader societal risks. For example, insurance rates could serve as a comparison between using UAS versus manned helicopters for filming, as noted earlier.

Recommendation: The FAA should identify classes of operations where the level of additional risk is expected to be so low that it is appropriate to base approval of those operations on requiring insurance in lieu of having a separate risk analysis.

DRIVING DECISIONS WITH DATA

There is no doubt that UAS integration into the National Airspace System could greatly benefit from rigorous PRA. Currently, very little consideration, if any, is being given to uncertainties in the reported risk and estimated loss. While point estimates are useful, without a quantification of the corresponding uncertainties, they can be very misleading. It is important to understand both the uncertainties involved in the risk estimation procedure and the variability of such estimates. The latter in principle can be reduced by taking more data, whereas the former requires better models and deeper understanding. In any case, understanding the degree of certainty of the risk estimates and how they vary across populations is essential for decision making and risk management.

The problem is that a fundamental component of probabilistic risk analysis is the existence and ready availability of the relevant data. Because UAS operations are very diverse, still relatively new, and limited, data are expensive to collect, scarce or nonexistent, and in some instances still not very reliable (e.g., number of UAS sightings near manned aircraft).

Nevertheless, the number of UAS users is rapidly growing and expected to reach over 3 million UAS hobbyists and about half a million commercial drones by 2020, making it imperative on one hand to speed up and streamline the current operations approval procedures, while maintaining reasonable safety standards, and on the other, to improve and speed up as well the data collection processes and the related risk analysis assessments.

On top of this, UAS is a fast-evolving technology with a growing set of applications and operational use. Today's security envelope will change, as will the commercial and societal benefits of UAS use. In this dynamic environment of evolving use patterns and application areas, continuous data acquisition and evaluation and adaptation of decision rules are required to balance risk and benefits.

Robust and consistent data collection with concurrent updated risk assessment processes will in time move us from a pattern that currently calls for more mitigation with less data. Over time as data volume and quality increase, mitigation decreases. In areas where there are insufficient data, preliminary and temporary approvals can be made with the requirement to provide specific data. As more data become available, the estimates can be refined. Agency decision risk is reduced by refining the time period of operations. This of course is not a solution that supports routine operations.

While any new technology that puts participants, third parties, or property at risk requires engineering safety analysis, the extent of that analysis should be in parity with potential outcomes. In one limiting case, analysis might end with a convincing argument that the worst-case scenario poses *de minimis* risk. At the other extreme, the safety analysis might mirror that required for a passenger transport aircraft. On the spectrum between these limiting cases, data are needed to support the safety case. For risks that have a very low probability of occurrence, it may be difficult to collect enough data to make risk assessments in a timely fashion. In those cases, it could be useful to draw upon research being conducted for other applications that is exploring how to use limited data in combination with simulations to draw conclusions about safety.

The need for data should not automatically preclude an operational approval, however, if the uncertain risk can be mitigated. Moreover, if the mitigations are not overly restrictive, the operational approval may accelerate the collection of relevant data to support a stronger safety case and a corresponding reduction in mitigations and limitations. Operations beyond visual line of sight for which an aircraft maintains proximity to a structure, such as a powerline or pipeline, for example, provide the opportunity to document hazards and hazard statistics while providing a valuable commercial service. In some cases, safety data may then support other, less-restricted operations. For example, the analysis of data on detect-and-avoid system performance during linear infrastructure inspection operations may support package delivery operations.

The UAS Traffic Management (UTM) program is a potential source of critical data on small UAS operations. This program is led by NASA in collaboration with the FAA and other partners. The goal of the UTM program is to identify services, roles, responsibilities, information architecture, data exchange protocols, software functions, infrastructure, and performance requirements for enabling large-scale operations of UAS in low-altitude uncontrolled airspace. UTM is intended to support operations of UAS operating within visual line of sight as well as UAS operating beyond visual line of sight. Development of the UTM system will use a risk-based approach to achieve four key milestones (Kopardekar, 2017):

1. Demonstrate how to enable multiple operations under constraints (e.g., operations over unpopulated land or water).
2. Demonstrate how to enable expanded multiple operations (e.g., operations beyond visual line of sight and sparsely populated areas).
3. Focus on how to enable multiple heterogeneous operations (e.g., operations over moderately populated land and operations involving some interaction with manned aircraft).
4. Enable multiple heterogeneous high-density urban operations.

The data, analytical models, and assessments that are needed to achieve these milestones, as well as the data that will be acquired as UAS operate within the UTM system, could greatly facilitate efforts to assess the risks of UAS operating in the National Airspace System.

The FAA-established UAS test sites can be another useful source of data, and one purpose of establishing the test sites was to implement the UAS Test Site Data Collection and Analysis Program (FAA, 2018). Yet, to date, the committee is unaware of a concerted or comprehensive effort by the FAA to collect or disseminate such data, despite known requests from research organizations as well as standards development organizations such as RTCA and the Drone Advisory Committee. The FAA established six of these sites in response to the FAA Modernization and Reform Act of 2012 (a seventh site at New Mexico State University existed prior to the establishment of these six). These test sites support the integration of UAS into the National Airspace System by making it easier for the UAS industry and other interested parties to field-test UAS systems and operational concepts. The FAA also implemented the Unmanned Aircraft Systems Test Site Data Collection and Analysis program to collect operational and test data from all of the test sites (FAA, 2018).

Finding: Additional empirical data are needed to support probabilistic risk analyses for UAS collision modeling. Some examples where relevant data are lacking or are being reported only on a voluntary basis include the following:

- UAS-encounter statistics to inform the assessment of midair collision risk,
- Low-altitude environmental data to inform the assessment of flight performance in cluttered environments, and
- Performance data for UAS detect-and-avoid technologies in conditions relevant to proposed operations beyond visual line of sight (e.g., the Center for UAS has established a public repository for voluntary reporting of detect and avoid data: https://sites.google.com/vt.edu/safe-repository).

Finding: Accepting risk is far easier when the risk is well quantified by relevant empirical data. Uncertain risk does not equate to high risk, however. By accepting the uncertain risk associated with a new technology, with reasonable mitigations, one can obtain the data needed to better quantify that risk. As the uncertainty diminishes, one can remove or augment the mitigations as appropriate. In the current environment, uncertain risk has made operational approvals for routine civil UAS operations difficult to obtain and, when issued, unnecessarily restrictive. As a result, the ability to collect data that might reduce uncertainty in the risk has been severely limited.

The previously acknowledged lack of empirical data and a methodology to obtain, protect, and analyze the data has been recognized by the FAA and industry. To the credit of both, the Unmanned Aircraft Safety Team (UAST) has been formed as a joint effort to begin addressing these issues and tasked to develop safety recommendations and enhancements relative to UAS operations based on the data.

The UAST and its charter are modeled after the very successful Commercial Aviation Safety Team and from the General Aviation Joint Steering Committee efforts to collect voluntarily submitted safety-related data from the manned aircraft community. Both groups have processes to obtain, analyze, and protect information gathered. Key to the success is transparency and the availability of findings and recommendations to the aviation community.

The UAST is developing a governance plan modeled after processes in place by these groups and includes the following core goals:

- Establish a systemic assessment process.
- Define stakeholder organization commitment.
- Define roles and responsibilities.
- Operate the UAST as a consensus-based collaborative effort.
- Foster voluntary participation.
- Ensure nonpunitive use of UAST information.
- Deidentify data (i.e., remove information on data origin).
- Ensure data quality.
- Ensure transparency of UAST process.

There is no publicly published timeline for the UAST to complete its work.

Finding: Processes and plans for the collection, retention, analysis, and protection of UAS operational and risk-related data are currently under development by the UAST.

Acquisition of better and timelier data is possible through the integration of smart sensor deployments and data analytics to provide improved situational awareness. This, when combined with uncertainty quantification, will improve our predictive ability for probabilistic risk analyses for UAS collision modeling.

Finding: Rapid advances in autonomous vehicles are providing effective integration of sensors and analytics. This presents an opportunity for the FAA to learn and test new models for better data collection and analysis with the aim of improving overall safety.

The persistent development of modeling and simulation tools in every engineering domain, and integration tools for multiphysics modeling, makes it possible to synthesize data sets where empirical data are impossible or infeasible to obtain. Physics-based air traffic simulations that incorporate unmanned aircraft, for example, can inform encounter models and perhaps reveal rare hazards that require scrutiny. The generation and analysis of simulation data can be as costly as flight-testing, however, and the results may provide false security, given inevitable deficiencies in simulation fidelity. Despite these caveats, computational analysis can provide evidence to support initial operational approval when empirical data are unavailable.

Simulation studies can further improve system safety by helping to identify unanticipated, emergent hazards. Exhaustive human- and hardware-in-the-loop simulations of operational scenarios, for example, can reveal problematic interactions that require remediation. For example, simulation studies/desktop games can be used to bring together the various stakeholders and serve as communication tools.

Finding: Computational models are being used scarcely and are not being fully taken advantage of to address with increasing accuracy and cost-effectiveness some of the current data deficiencies that might otherwise impede probabilistic risk analysis. In addition, even when computational models are being used, model prediction uncertainties are not always being calculated and no distinction is being made to distinguish between uncertainties due to lack of knowledge and those due to natural variability of the data.

A web-based repository for data is needed that includes empirical data as well as data resulting from simulation studies, risk analysis methodologies relevant to UAS integration, and other case and testing studies. Such a repository would benefit the whole community working on UAS integration by allowing collaborations, testing different methodologies on existing data sets, and allowing future users to better understand existing operations. The repository could also hold the data that will be collected as recommended by the UAST.

Other benefits of the repository include easily being able to update existing risk assessment analysis as new data become available and as data change, possibly due to newer risk mitigation implementations and changes in technology, speeding up the needed risk reassessment.

Such a repository would also present an opportunity for meta-analysis that combines the results from multiple studies to improve our understanding. By analogy to other data repositories (e.g., HIV database[10]), it would be useful to make analysis methods available within the repository). By controlling the analysis methodology, one can help to ensure the validity of the analysis methods and provide reproducibility of the results. In principle, there is a wealth of opportunistic data available by which to quantify/estimate risk and loss. Having a good central repository can help with the development and application of modern data science tools and machine learning algorithms to improve our understanding of risk factors and provide better predictions.

Finding: Currently, the FAA assumes responsibility for safety evaluation and delegates to the applicant assessing the risk of the proposed operation, without ensuring that the analysis tools are available to all proponents to guarantee a transparent process.

Finding: Guidance on how FAA's UAS risk assessment process is used in decision making is undocumented, and the process is not broadly communicated. Documentation, including Order 8040.4B and Part 107.200, is inconsistent, lacks specific numeric guidance, and does not provide sufficient guidance for proponents.

Finding: Organizations like VaTech's Mid-Atlantic Aviation Partnership have leveraged existing FAA guidance together with information from other sources like the U.S. Coast Guard's Spread out, Transfer, Avoid, Accept, and

[10] See https://www.hiv.lanl.gov/content/index.

Reduce (STAAR) model to elaborate on how the guidance might be used successfully and in a repeatable fashion. In addition, the pathfinder and partnership for public safety efforts have determined successful approaches.

Recommendation: The FAA should, within 6 months, collaborate with industry to define a minimum operational safety data set and develop a plan for the voluntary collection and retention by the operators in a central repository, following the model of the Commercial Aviation Safety Team (CAST) and the General Aviation Joint Steering Committee (GAJSC), with a goal of full implementation within 1 year. The FAA should also consult with the Drone Advisory Committee to help define the minimum operational safety data set and plan for collecting, archiving, and disseminating the data.

Recommendation: For operations approvals for which there are no standards, as operational data are collected and analyzed, the FAA should, as part of Improved Safety Risk Management,

- **Publish requirements for operational approvals with associated restrictions that can be adjusted and scaled based on industry past experience and the accumulation of related data;**
- **Expand single operation approvals as experiential data accumulate and risks are assessed;**
- **Permit repeated or routine operations based on the accumulation and analysis of additional data; and**
- **Continuously update operational approval practices to incorporate emerging safety enhancements based on industry lessons learned until standards have been established.**

The committee's objective of recommending collecting data is to (1) develop data-driven models and not models based on subject matter experts and (2) to move to quantitative PRA methods instead of qualitative ones.

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5

Building the Future

Through its engagement in a range of unmanned aircraft research programs, the Federal Aviation Administration (FAA) can help move unmanned aircraft system (UAS) technology forward in keeping with the Department of Transportation mission to ensure "a fast, safe, efficient, accessible and convenient transportation system that meets our vital national interests." One of the most pressing topics for the FAA's consideration is the future role of increasingly autonomous systems, which have the potential to dramatically improve both the efficiency and the safety of the U.S. air transportation system. To realize these benefits, though, will require that risk assessment methods keep pace with advances in automation. By becoming engaged in research on autonomous systems and on complementary risk assessment methods, the FAA can help ensure that potential benefits of autonomy in aviation are realized without costly and unnecessary delay.

A major motive for increasing automation is to reduce the possibility for human errors that result in accidents. But while human factors play an important role in the majority of commercial aviation accidents (Shappell et al., 2007), human operators can also help prevent accidents by reacting appropriately to unexpected or unprecedented situations.

Automated systems, which respond in a deterministic way to predetermined conditions, can help to address previously identified hazards and their causes. Considerable advances are being made in developing perception and reasoning capabilities to address unusual yet previously identified situations, such as loss of communication with a ground control station or airspeed sensor corruption. However, automated systems may respond inappropriately in complex situations that were not anticipated in their design, such as situations where multiple hazards arise simultaneously in unanticipated combinations. Such situations can result in an accident when a human operator is suddenly required to take control (Strauch, 2017). Thus, while increased automation promises measurable benefits for system safety, it requires parallel advancements in effective human interfaces.

Autonomous systems that are adaptive and nondeterministic[1] will have the ability to learn and continually

[1] "Adaptive systems have the ability to modify their behavior in response to their external environment. For aircraft systems, this could include commands from the pilot and inputs from aircraft systems, including sensors that report conditions outside the aircraft. Some of these inputs, such as airspeed, will be stochastic because of sensor noise as well as the complex relationship between atmospheric conditions and sensor readings that are not fully captured in calibration equations. Adaptive systems learn from their experience, either operational or simulated, so that the response of the system to a given set of inputs varies over time. Systems that are nondeterministic may or may not be adaptive. They may be subject to the stochastic influences imposed by their complex internal operational architectures or their external environment, meaning that they will not always respond in precisely the same way even when presented with identical inputs or stimuli. Many advanced AI systems are expected to be adaptive and/or nondeterministic." National Research Council, 2014, *Autonomy Research for Civil Aviation: Toward a New Era of Flight*, The National Academies Press, Washington, D.C.

improve their performance as humans do. This may help to maintain safety in complex environments by combining the computer's advantage of processing speed and capacity with the ability to respond to novel situations. Similarly to automated systems, though, autonomous systems may not respond appropriately to situations that lie outside their design parameters and experience base, and it may be difficult for a human operator to step in and take appropriate action if the autonomous system fails to respond appropriately. And because human operators may rely even more on autonomous systems than on automated ones, operators' ability to intervene suddenly may be further compromised. Conversely, a human operator may not trust an autonomous system enough to allow the system to maintain control if the operator perceives, rightly or wrongly, that the system's actions are unsafe. Operators of self-driving cars, for example, have posted videos of themselves sleeping or sitting in the back seats of their vehicles (Davies, 2016). The ability of an autonomous system to respond more like a human comes with an additional downside: one cannot predict with certainty what a learning system will do in a given situation. In particular, it is impossible to guarantee the system will always respond in a safe manner.

Nevertheless, systems with higher levels of autonomy are proliferating in a range of industries. Potential benefits include significant benefits in productivity and quality (e.g., in robotic manufacturing), as well as in safety (e.g., an autonomous vehicle does not become fatigued). Additional research is needed, however, to develop risk assessment and risk management methods that will enable verification, validation, and certification of adaptive/nondeterministic systems for safety critical applications such as aviation.

Finding: Systems with high levels of autonomy have the potential to improve the operational safety of UAS. However, existing verification, validation, and certification processes cannot ensure that highly autonomous systems that are adaptive or nondeterministic can satisfy safety standards for commercial aircraft. For this reason, highly autonomous systems are not currently allowed for commercial UAS flying within the National Airspace System. Opportunities to increase the safety of UAS operations, and of aviation in general, through increased autonomy are being missed, however, due to a lack of accepted risk assessment methods.

Beyond autonomy, several key topics require continuing research to address the risks posed by UAS integration. These research topics can be identified in the context of the FAA's own describe, identify, analyze, assess, and treat (DIAAT) process for safety risk management (SRM), as follows:

1. *Describe the system*. Medium-to-large UAS will share runway space and all classes of airspace with manned aircraft; small commercial UAS will continue to proliferate, serving a variety of users and, in some cases, sharing airspace with manned aircraft in class E and G airspace; and hobbyist UAS will continue operating in class G airspace with minimal oversight. As autonomy begins to pervade other technology domains, the desire of some stakeholders to incorporate fleet-wide, continual learning into UAS will strengthen.
2. *Identify the hazards*. UAS are subject to many of the same hazards as manned aircraft in terms of the vehicle, the airmen, the operation, and the environment, but there are also hazards unique to UAS, including "lost link" or failure to "see and avoid" conflicting traffic (Luxhøj and Öztekin, 2009).
3. *Analyze the risk*. The threat to human life posed by UAS is toward people on the ground or in manned aircraft. Many of the specific risks that could lead to injuries or fatalities are unknown and are poorly approximated using existing methods, requiring new investigative tools; see Campolettano et al. (2017), for example.
4. *Assess the risk*. The use of network data transfer to support UAS operations presents opportunities for real-time risk assessment using modern tools for data analytics. In parallel, the development of improved simulation capabilities supports quantitative risk assessment (Kochenderfer et al., 2008) for known risks (e.g., aircraft collision) and even the identification of rare hazards. Further, because of their unique risk profile (e.g., the absence of passengers and crew), UAS are often promoted as risk-reduction mechanisms (e.g., cellular data tower inspection). It is thus appropriate to consider comparative risk in an overall assessment.
5. *Treat the risk*. Mitigations such as flight termination systems, "geofences," and minimum-risk path planning methods can enhance safety, allowing operational limitations to be relaxed. Improved human interfaces that

ensure an appropriate level of cognitive engagement by an operator or supervisor can more fully exploit the complementary strengths of humans and automation.[2]

To summarize, a range of topics that are the focus of ongoing research can inform the FAA's evolving strategy for risk assessment in the era of UAS integration. A short (and clearly incomplete) list includes the following:

- Testing and evaluation, verification and validation methods for autonomous learning systems;
- Human interaction with automated systems (e.g., effective human-machine interfaces for automated, multi-UAS networks, and optimal cognitive loading in varying conditions); and
- Real-time data analytics (e.g., probabilistic inference using dynamic Bayesian belief networks, and classification using convolutional neural networks).

These topics, as well as many other topics also related to improved risk analysis for UAS, are the focus of major domestic and international research initiatives (see Figure 5.1) that cut across many technology domains. Many of these initiatives are aimed at accelerating the integration of learning and autonomy into essential technology domains, from energy to medicine to transportation. Developing risk assessments in belated response to the emergence of new concepts would stunt the pace of innovation and clog the technology transition pipeline with increasingly obsolete ideas. A better approach would be to develop risk assessment methods concurrently with developmental research so that promising technologies can be safely transitioned into use as they emerge. Consider, for example, the UAS Traffic Management (UTM) program, which is described in Chapter 4. In this effort, the FAA has presented a timeline for the operational implementation of UTM once it transitions from NASA to the FAA. NASA introduced the concept of UTM more than 3 years ago and has been working in open and transparent collaboration with industry throughout its development and validation of the concept, including multiple demonstrations building upon lessons learned from each. The FAA established the program as a research program 3 years ago, and it is not clear to the committee why the transition is taking so long.

Recommendation: In coordination with other domestic and international agencies, the FAA should pursue a planned research program in probabilistic risk analysis (PRA), including the aspect of comparative risk, so that FAA personnel can interpret or apply PRA for proposed technology innovations.

[2] A "geofence" is a modification to a UAS's navigation software that forbids the UAS from operating in or traveling into a restricted area such as the airspace around an airport. As an example, many hobbyist UAS will not activate when close to an airport.

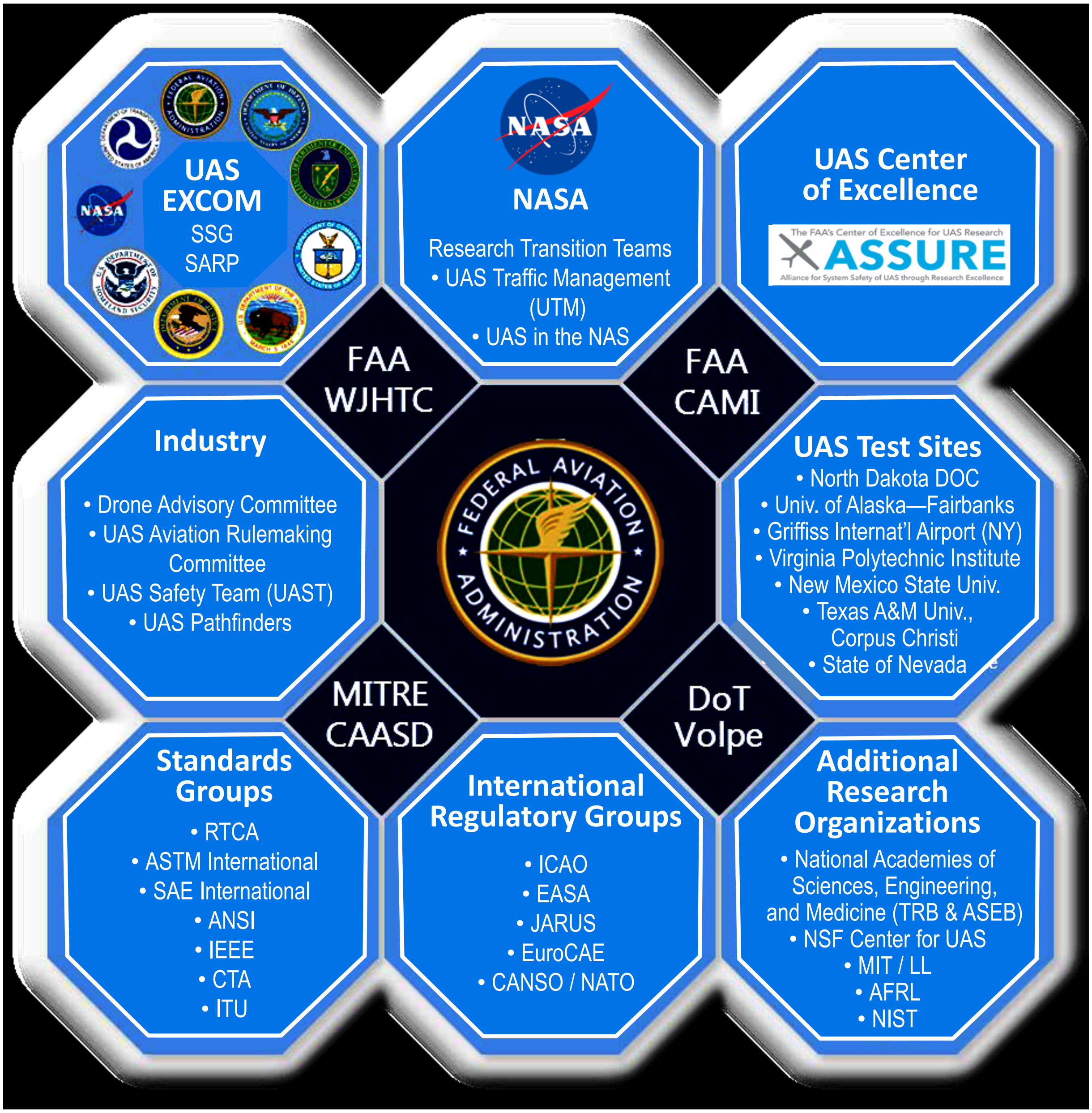

FIGURE 5.1 Through its engagement in a range of domestic and international research and standards activities, and through its direct support for internal and external research, the FAA can access and influence innovation in risk assessment for increasingly automated systems. SOURCE: FAA (2017).

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Appendixes

A

Statement of Task

The National Academies of Sciences, Engineering, and Medicine will appoint an ad hoc committee with representation from industry, academia, and government to undertake a study to evaluate the potential of probabilistic assessments of risks and other risk assessment methods for streamlining the process of integrating unmanned aircraft systems (UAS) into the National Airspace System and identify supporting research and development opportunities in this field. The committee will execute the following tasks:

- Consider recent, current, and planned FAA efforts to evaluate the risks associated with the integration of UAS into the National Airspace System and risk assessment methods.
- Consider mechanisms for assessing severity and likelihood metrics required for probabilistic and other appropriate risk assessment methods based on UAS design characteristics (e.g., weight, speed, materials, and technologies) and operational characteristics (e.g., airspace characteristics, population density, and whether they are piloted remotely or autonomously).
- Determine how the scope and detail required of risk assessment methods may vary for different sizes and operations of UAS (e.g., Part 107 versus Part 91 operations) or whether a certain class of UAS (micro, etc.) could be operated with the assumption they are inherently low risk.
- Evaluate other methods that could reasonably be used to evaluate the risks of UAS integration in the National Airspace System. What are the benefits and limitations of these alternative methods? How do these alternative methods compare to probabilistic risk assessment methods as well as severity and likelihood metrics traditionally used by the FAA for manned aircraft?
- What state of the art assessment methods are currently in use by industry, academia, other agencies of the U.S. government, or other international civil aviation authorities that could benefit the FAA?
- What are the key advancements or goals for performance-based expanded UAS operations in the National Airspace System that can reasonably be achieved through the application of the recommended risk assessment methods in the short term (1-5 years), midterm (5-10 years), and longer term (10-20 years)?
- What are the key challenges or barriers that must be overcome to implement the recommended risk assessment methods in order to attain these key goals?
- In light of ongoing research and likely advances in risk assessment methods by other organizations, what research and development projects related to risk assessment methods should be the highest priority for the FAA?

- Are there other related recommendations to streamline FAA processes (not governed by regulation) that would either improve the effectiveness of risk assessment methods for integration of UAS into the National Airspace System or expedite the development of such methods?

The committee may also comment on the effectiveness of risk assessment methods as they pertain to decision making and different modes of UAS operations. However, the committee will not recommend changes to regulations governing UAS operations, nor will the study recommend changes to the organization of the FAA. The scope of this study includes UAS certification as well as operational approval.

B

Committee and Staff Biographical Information

COMMITTEE

GEORGE T. LIGLER, *Chair*, is the proprietor of GTL Associates, which provides systems integration/engineering and product management services related to telecommunications, computer system and hardware/software engineering, and information management to domestic and foreign customers. Dr. Ligler has worked as a subject matter expert to support the Federal Aviation Administration's implementation of both satellite-based navigation and Automatic Dependent Surveillance–Broadcast (ADS-B) as components of the Next Generation Air Transportation System. Dr. Ligler is a member of the RTCA Program Management Committee, the RTCA NextGen Advisory Committee Subcommittee, and the Plenary leadership group for the Industry-FAA Equip 2020 initiative related to ADS-B out equipage. Dr. Ligler is co-chair of RTCA Special Committee-159 (Navigation Equipment Using the Global Navigation Satellite System) and a former founding co-chair of RTCA Special Committee-228 (Minimum Operational Performance Standards for Unmanned Aircraft Systems). He has also been active in RTCA Special Committee-186 (Automatic Dependent Surveillance–Broadcast) since its inception in 1995. Dr. Ligler was awarded the 2006 RTCA Achievement Award, RTCA's highest award, for his contributions to ADS-B and satellite-based navigation system initiatives. He is also a co-recipient of the 2016 RTCA Achievement Award for his contributions to the development of standards for unmanned aircraft systems (UAS). Dr. Ligler holds a D. Phil. in computer science from Oxford University, with his studies supported by a Rhodes scholarship. He is a member of the National Academies' Standing Committee on Reengineering Census Operations, and he has served on four other National Academies' panels, most recently the Committee on National Statistics Panel to Review the 2010 Census.

BRIAN M. ARGROW is chair of Ann and H.J. Smead Aerospace Engineering Sciences, director of the Integrated Remote and In Situ Sensing Program, and director emeritus of the Research and Engineering Center for Unmanned Vehicles at the University of Colorado, Boulder (CU). Dr. Argrow has served as associate dean for education and is a CU president's teaching scholar. His research topics include small UAS design and airspace integration, high-speed aerodynamics, sonic boom, and engineering education, with more than 100 research publications. He is a fellow of the Center for STEM Learning and a recipient of the W.M. Keck Foundation Award for Excellence in Engineering Education. He is a fellow of the American Institute of Aeronautics and Astronautics (AIAA) and is a past chair of the AIAA Unmanned Systems Program Committee, and he organized/chaired the first major joint events by the AIAA and the Association for Unmanned Vehicle Systems: the 2nd and 3rd Workshops on Civilian Applications of Unmanned Aircraft Systems. He served on the NASA Advisory Council UAS Subcommittee and several other NASA and NOAA advisory boards and committees. Dr. Argrow currently serves on the ASTM F38 Subcommittee for Specifications for UAS Operations over People. Dr. Argrow is an alumnus of the DARPA/IDA Defense Science Study Group, and he received the Air Force Exemplary Civilian Service Award for his service on the Air Force Scientific Advisory Board. He has a Ph.D. in aerospace engineering from the University of Oklahoma. He is a member of the National Academies' Aeronautics and Space Engineering Board and the Aviation Safety Assurance Committee.

GREGORY B. BAECHER is the Glenn L. Martin Institute Professor of Engineering at the University of Maryland, College Park. Dr. Baecher is a civil engineer with 40 years' experience specializing in risk and reliability of civil infrastructure, with emphasis on water resource development, dam and levee safety, hydropower, and coastal protection. He is the author of five books on risk, safety, and the protection of civil infrastructure. He is a recipient of the U.S. Army Corps of Engineers Commander's Award for Public Service for his contributions to the levee system risk analysis of New Orleans following Hurricane Katrina, and of the Panamanian National Award for Science and Technology Innovation for his contributions to enterprise risk management at the Panama Canal. Dr. Baecher earned his Ph.D. in civil engineering from the Massachusetts Institute of Technology (MIT). He has served on many National Academies' committees and boards, most recently as chair of the Committee on Long-Term Management of the Spirit Lake/Toutle River System in Southwest Washington; as a member of the Committee on U.S. Army Corps of Engineers Water Resources, Science, Engineering, and Planning; and as chair of the Committee on the Updated Site-Specific Risk Assessment for the National Bio and Agro-Defense Facility in Manhattan, Kansas.

STEPHEN P. COOK is a Northrop Grumman Technical Fellow in Airworthiness at Northrop Grumman Aerospace Systems. Dr. Cook is responsible for developing and implementing airworthiness policy and strategy across Northrop Grumman's portfolio of manned and unmanned aircraft programs. Additionally, Dr. Cook is leading the Remotely Piloted Aircraft Airworthiness subgroup at the International Civil Aviation Organization Remotely Piloted Aircraft Systems (RPAS) Panel. This group is charged with the development of standards and recommended practices needed for RPAS to integrate into international airspace. Previously, Dr. Cook was principal safety engineer in the Navigation and Unmanned Aircraft Systems Department at the MITRE Corporation. In this role he supported multiple efforts to integrate civil and military aircraft into the National Airspace System. He co-led the UAS Sense-and-Avoid Science and Research Panel (SARP), a multi-agency organization charged with identifying key research gaps associated with integrating UAS into the National Airspace System. A key output of the SARP was a risk-based recommended definition for UAS "well clear" to enable UAS to comply with the rules of the air. This UAS "well clear" recommendation informed the work of RTCA Special Committee-228 on Unmanned Aircraft Systems, leading to the publication of Minimum Operational Performance Standards for UAS Detect and Avoid. Before coming to MITRE Dr. Cook served as the head of the UAS Division of the U.S. Navy and Marine Corps Airworthiness Directorate. In this position he was responsible for airworthiness policy and flight clearance approvals for all Navy and Marine Corps UAS. He also represented the United States in the development of NATO STANAG 4671, the first airworthiness standard developed specifically for fixed wing unmanned aircraft. His research interests include novel risk assessment approaches for UAS and methods to safely bound the flight behavior of UAS containing complex adaptive algorithms. Dr. Cook has completed formal training in the FAA Safety Management System and the U.S. Navy Test Pilot School UAS Flight Test Procedures and Practices Short Course, where he logged UAS flight time. He has been appointed an adjunct visiting professor on the faculty of North Carolina State University. Dr. Cook is an associate fellow of the AIAA. Earlier this year he received the Engineers' Council Distinguished Engineering Project Achievement Award for leading the development of a first-in-the-nation graduate program in airworthiness, in partnership with Embry-Riddle Aeronautical University. At MITRE he was awarded the Director's Award for innovative safety risk analyses and simulations in support of the UAS Limited Deployment—Cooperative Airspace Project flight tests. Dr. Cook earned his Ph.D. in aerospace engineering from the University of Maryland.

LOUIS ANTHONY COX, JR. is president of Cox Associates, an applied research company specializing in quantitative health risk assessment, causal modeling, probabilistic and statistical risk analysis, data mining, and operations research. Since 1986, Cox Associates mathematicians and scientists have developed and applied computer simulation and biomathematical models, statistical and epidemiological risk analyses, causal data mining techniques, and operations research and artificial intelligence risk models to improve health, business, and engineering risk analysis and decision making. Dr. Cox is on the faculties of the Center for Computational Mathematics and the Center for Computational Biology at the University of Colorado, Denver, and is clinical professor of biostatistics and informatics at the University of Colorado Health Sciences Center, where he has focused on uncertainty analysis and causation in epidemiological studies. He was elected to the National Academy of Engineering based on his application of operations research and risk analysis to significant national problems. He earned a Ph.D. in risk analysis from MIT. Dr. Cox has served on many National Academies' committees, most recently as a member of the Committee for a Study of Performance-Based Safety Regulation and the Industrial, Manufacturing and Operational Systems Engineering Peer Committee. He is also a former member of the Board on Mathematical Sciences and Analytics.

LETICIA CUELLAR-HENGARTNER is a statistician in the Information Systems and Modeling group at Los Alamos National Laboratory (LANL). Dr. Cuellar has worked in various groups at LANL since 2006, including Discrete Simulations Sciences, Information Sciences, Risk Analysis and Decision Support Systems, and Intelligence and System Analysis. She has expertise in statistics, stochastic modeling, machine learning, and model validation. Her work at LANL includes modeling of critical infrastructure protection, telecommunication systems and networks, transportation networks, disaster response modeling, modeling illegal trafficking of nuclear materials, and methods development enabling soft cosmic ray tomography. These projects used stochastic modeling, agent-based simulations, modeling of human activity and behavior, graph theory and network analysis, and Bayesian networks. Dr. Cuellar is the principal investigator (PI) for an Ernst & Young-founded project that focuses on developing forecasting models for quality. She is also the PI on the Probabilistic Effectiveness Methodology project, which performs probabilistic risk assessment of nuclear smuggling. She is the recipient of the 2012 Distinguished Performance Award and the 2011 Los Alamos Award Program from LANL. Dr. Cuellar earned her master's and Ph.D. in statistics from the University of California, Berkeley.

MARGARET T. JENNY is the president of RTCA, Inc., a private, not-for-profit corporation dedicated to the forging of wide-ranging consensus-based recommendations in aviation policy, technology, and modernization. Prior to joining RTCA, Ms. Jenny served as chief executive officer of MJF Strategies, LLC, an aviation consulting firm; vice president of corporate business development at ARINC; director of airline business and operations analysis for US Airways; and technical director at the MITRE Corporation. Ms. Jenny has devoted her career to helping diverse and competing stakeholders find common ground to expedite the continual modernization of the national airspace. She has served as the 2016 president of the Aero Club of Washington. Ms. Jenny earned her M.S. in computer science from American University. She has been a member of the National Academies' Committee on the Federal Transportation R&D Strategic Planning Process; the Committee on Review of the National Transportation Science and Technology Strategy; and the Aeronautics Research and Technology Roundtable.

ANDREW R. LACHER is a senior principal at the MITRE Corporation and has over 30 years of systems engineering experience, mostly in the aviation and transportation systems domain. Mr. Lacher currently has a leadership role in defining MITRE's research strategy in unmanned and autonomous systems. Previously, he worked as a product manager for Orbcomm and was a strategic information technology consultant working with small airlines. Mr. Lacher is focused on the safe and secure integration of UAS in civil airspace as well as methods to calibrate the trustworthiness of autonomous systems. He helps manage a research portfolio that includes research into a risk-based approach to certification for UAS, UAS safety technologies, human-machine teaming, safety of autonomous systems, and counter-UAS detection and defeat technologies. Much of Mr. Lacher's research and analysis activities involve improving the safety, security, and efficiency of aviation operations through the application of new information technologies. Mr. Lacher worked on the definition of NextGen as part of the Joint Program and Development Office and was a thought leader in development of future Traffic Flow Management concepts including Collaborative Decision-Making. Mr. Lacher serves on a number of committees, standards working groups, and external research advisory panels. He currently serves on the FAA's Research, Engineering, and Development Advisory Committee for Aircraft Safety and the FAA's UAS ID and Tracking Aviation Rulemaking Committee. Mr. Lacher earned an M.S. in operations research at the George Washington University. He was a member of the National Research Council's Committee on Autonomy Research for Civil Aviation; the Aeronautics Research and Technology Roundtable; and Panel E: Intelligent and Autonomous Systems, Operations and Decision-Making, Human Integrated Systems, Networking, and Communications for the Decadal Survey of Civil Aeronautics.

KAREN MARAIS is an associate professor in the School of Aeronautics and Astronautics in the College of Engineering at Purdue University. Previously, Dr. Marais was on the faculty of Stellenbosch University (South Africa) in the Department of Industrial Engineering. She also held a postdoctoral appointment at MIT working with the FAA's PARTNER Center of Excellence. Prior to graduate school she worked as an electronic engineer in the aerospace industry in South Africa. Dr. Marais has worked on developing new ways of assessing safety and risk in complex sociotechnical systems in general, and air transportation systems in particular. Her research interests include modeling and mitigating aviation environmental impacts, improving aviation safety, and developing improved approaches to the engineering of complex systems. Recently, Dr. Marais has investigated ways of improving the success rates of systems engineering projects (through a National Science Foundation [NSF] CAREER grant) and using flight and accident/incident data to improve fixed wing and rotorcraft safety (through the FAA PEGASAS Center of Excellence). She is a recipient of an NSF CAREER Award. Dr. Marais earned her Ph.D. in aerospace engineering from MIT. She served as a member of the National Academies' Committee on Propulsion and Energy Systems to Reduce Commercial Aviation Carbon Emissions.

PAUL E. McDUFFEE is vice president of government relations at Insitu, Inc., where he is responsible for regulation shaping and development supporting Insitu's future in civilian and commercial use of unmanned aircraft. Mr. McDuffee serves as principal liaison with the FAA in matters relating to regulation of UAS operations and as an advocate for UAS national airspace integration. His involvement in UAS regulatory development is extensive. Prior to joining Insitu in 2006, he transitioned from a 30-year career in academia as a full professor and vice president of aviation training at Embry-Riddle Aeronautical University. He joined Insitu as vice president of flight operations and training before moving on to his current role. He currently serves on the Association for Unmanned Vehicle Systems International (AUVSI) board of directors and is also AUVSI's technical representative to the International Civil Aviation Organization Remotely Piloted Aircraft Systems Panel. He was a charter member of the FAA's Small Unmanned Aircraft System Aviation Rulemaking Committee and former member of the FAA UAS Aviation Rulemaking Committee. He was the working group chair on ASTM's F-38 Committee developing industry consensus standards for small UAS, and he is currently serving as co-chair of RTCA Special Committee-228 chartered by the FAA to establish performance standards for UAS command and control and detect and avoid solutions. Mr. McDuffee is a recipient of the RTCA 2017 Achievement Award and received three Outstanding Leader Awards from RTCA, is a member of the FAA/RTCA Drone Advisory Committee Subcommittee and a member of the FAA Unmanned Aircraft Safety Team Steering Committee, and has recently ended his second term as chair of the Aeronautical Industries Association UAS Committee. He is an active pilot, holding airline transport pilot and flight instructor certificates, with jet-type ratings, and he has logged more than 9,000 flight hours. He earned an M.S. in aeronautical science from Embry-Riddle Aeronautical University.

AMY R. PRITCHETT is a professor and head of the Department of Aerospace Engineering at the Pennsylvania State University. Previously, Dr. Pritchett was on the faculty of the Schools of Aerospace Engineering and Industrial and Systems Engineering at the Georgia Institute of Technology, and she served via the Intergovernmental Personnel Act (IPA) as the director of NASA's Aviation Safety Program for 2 years. Her research focuses on the intersection of technology, expert human performance, and aerospace operations, with a particular focus on designing to support safety. She is currently editor-in-chief of the *Journal of Cognitive Engineering and Decision Making*. Dr. Pritchett has received the AIAA Lawrence Sperry Award, the RTCA William Jackson Award, and, as a member of the Executive Committee of the Commercial Aviation Safety Team, the 2008 Collier Trophy. She earned her Sc.D., S.M., and S.B. in aeronautics and astronautics from MIT. She has served on many National Academies' committees, most recently as a member of the Committee of the Federal Aviation Administration Research Plan on Certification of New Technologies into the National Airspace System, chair of the Committee for a Study of FAA Air Traffic Controller Staffing, and member of the Committee on Human Spaceflight Crew Operations.

AGAM N. SINHA is the president of ANS Aviation International, LLC. Dr. Sinha retired from the MITRE Corporation in 2012 where he was a senior vice president, as well as general manager of the Center for Advanced Aviation System Development (CAASD). He also directed the FAA Federally Funded Research and Development Center (FFRDC). CAASD supports the FAA, the Transportation Security Administration, and international civil aviation authorities in addressing operational and technical challenges to meet aviation's capacity, efficiency, safety, and security needs. Dr. Sinha has over 40 years of experience in aviation and weather systems. He serves on the board of trustees of Vaughn College of Aeronautics in New York and is on the advisory board of the Ph.D. in Aviation at Embry-Riddle Aeronautical University. He also served as a member of the FAA NextGen Advisory Committee and the FAA Research, Engineering, and Development Advisory Committee. He was elected chair of the RTCA Board of Directors and the RTCA Policy Board. He was an elected member of the RTCA Policy Board, Air Traffic Management Advisory Committee, and Air Traffic Management Steering Group. In the past, he served on the advisory committee of the Lincoln Lab at MIT and of the National Center of Atmospheric Research (Research Applications Programs). He is an associate fellow of the AIAA. He has over 80 publications and has been an invited presenter to a wide range of organizations nationally and internationally. Dr. Sinha is the recipient of several awards and citations from the FAA and industry. He earned his Ph.D. from the University of Minnesota. Dr. Sinha is a member of the Aeronautics and Space Engineering Board, a former member of the Committee of the Federal Aviation Administration Research Plan on Certification of New Technologies into the National Airspace System, and a former chair of the Aviation Group of the Transportation Research Board.

KAREN E. WILLCOX is a professor of aerospace engineering in the Department of Aeronautics and Astronautics and co-director of the Center for Computational Engineering at MIT. At MIT, Dr. Willcox leads a research program that is developing the mathematical foundations and computational methods to enable design of the next generation of aerospace vehicles. Before joining the faculty at MIT, she worked at Boeing Phantom Works with the Blended-Wing-Body aircraft design group. She has also held a visiting scientist position at Sandia National Laboratories. Her current research specifically targets the design challenges and opportunities offered by new sensing technologies, increased onboard computation power, and increasing levels of autonomy. Modeling the data-to-decisions flow is key to enabling new approaches for vehicle design and operation. Dr. Willcox's data-to-decisions modeling methods have two key underpinnings: (1) exploiting the synergies between physics-based models and data and (2) explicit modeling and treatment of uncertainty. She earned her Ph.D. in aerospace engineering from MIT. She is a member of the Board on Mathematical Sciences and Analytics; she was a member of the Committee to Conduct an Independent Assessment of the Nation's Wake Turbulence Research and Development Program; and she was a member of the Decadal Survey of Civil Aeronautics, Aerodynamics, and Acoustics Panel.

CRAIG A. WOOLSEY is a professor in the Crofton Department of Aerospace and Ocean Engineering at Virginia Tech (VT). Dr. Woolsey directs the VT site within the Center for Unmanned Aircraft Systems (C-UAS), an NSF Industry/University Cooperative Research Center (I/UCRC). Dr. Woolsey's research and teaching interests include nonlinear control theory for mechanical systems, particularly energy-based control methods, and applications to ocean and atmospheric vehicles. His primary research focus is the development and validation of control methods that improve the performance and robustness of autonomous vehicles. Soon after joining VT, Dr. Woolsey received the NSF CAREER Award and the Office of Naval Research Young Investigator Program Award. He earned his Ph.D. in mechanical and aerospace engineering from Princeton University.

STAFF

DWAYNE A. DAY, *Study Director,* a senior program officer for the ASEB, has a Ph.D. in political science from the George Washington University. Dr. Day joined the National Academies as a program officer for SSB. He served as an investigator for the Columbia Accident Investigation Board in 2003, was on the staff of the Congressional Budget Office, and worked for the Space Policy Institute at the George Washington University. He has also performed consulting for the Science and Technology Policy Institute of the Institute for Defense Analyses and for the U.S. Air Force. He is the author of *Lightning Rod: A History of the Air Force Chief Scientist* and editor of several books, including a history of the CORONA reconnaissance satellite program. He has held Guggenheim and Verville fellowships at the National Air and Space Museum and was an associate editor of the German spaceflight magazine *Raumfahrt Concrete*, in addition to writing for such publications as *Novosti Kosmonavtiki* (Russia), *Spaceflight*, *Space Chronicle* (United Kingdom), and the *Washington Post*. He has served as study director for over a dozen National Academies' reports, including *Visions into Voyages for Planetary Sciences in the Decade 2013-2022: A Midterm Review* (2018), *Testing at the Speed of Light—The State of U.S. Electronic Parts Space Radiation Testing Infrastructure* (2018), *Powering Science—NASA's Large Strategic Science Missions* (2017), *Extending Science—NASA's Space Science Mission Extensions and the Senior Review Process* (2016), *3-D Printing in Space* (2013), *NASA's Strategic Direction and the Need for a National Consensus* (2012), *Vision and Voyages for Planetary Science in the Decade 2013-2022* (2011), *Preparing for the High Frontier—The Role and Training of NASA Astronauts in the Post-Space Shuttle Era* (2011), *Defending Planet Earth: Near-Earth Object Surveys and Hazard Mitigation Strategies* (2010), *Grading NASA's Solar System Exploration Program: A Midterm Review* (2008), and *Opening New Frontiers in Space: Choices for the Next New Frontiers Announcement of Opportunity* (2008).

C

The MIZOPEX Example: Flight Operations Denied

During its deliberations, the committee heard of numerous examples where proposals to use unmanned aircraft systems (UAS) in ways that were only slightly changed from previous practices met lengthy delays and were ultimately rejected for reasons that the proposers could not understand. The following example describes how a UAS weighing 1.5 pounds and flying at a maximum height of only 50 feet over water in a very low traffic area north of Alaska was denied approval after a review period of a year.

The Marginal Ice Zone Observations and Processes Experiment (MIZOPEX) field campaign was conducted in the summer and fall of 2013. MIZOPEX was a $3.5 million project funded by NASA with the intent of helping to address information gaps in measurements of basic parameters, such as sea surface temperature, and a range of sea-ice characteristics, through a targeted, intensive observation field campaign that tested and exploited unique capabilities of multiple classes of UAS. MIZOPEX was conceived and carried out in response to NASA's request for research efforts that would address a key area of science while also helping to advance the application of UAS in a manner useful to NASA for assessing the relative merits of different UAS. Figure C.1 shows the operations range for the MIZOPEX observation field campaign.

The UAS involved in MIZOPEX included the NASA SIERRA (maximum takeoff weight 400 pounds), operated by the NASA Ames Research Center; the InSitu ScanEagle (maximum takeoff weight 50 pounds), operated by the University of Alaska, Fairbanks; and the DataHawk (maximum takeoff weight 1.5 pounds), developed and operated by the University of Colorado. Federal Aviation Administration (FAA) concerns regarding the safety of the experiment focused on flight operations proposed for the DataHawk. As shown in Figure C.2, the airframe of the DataHawk consisted of a repurposed hobby aircraft made of lightweight EPP foam, a small metallic motor and battery, and miniaturized electronics for sensing and communications.

The primary mission of the DataHawk was to fly through the airspace corridor, shown in Figure C.3, from restricted airspace at Oliktok Point, Alaska, to a point in the Beaufort Sea approximately 27 nautical miles from shore, where it would land on the water and convert to a miniature surface buoy to transmit ocean surface temperature, using the foam airframe to stay afloat on the water. These surface data were to be collected over a 2-week period by overflights of the ScanEagle as the DataHawk/buoy drifted on the sea surface. Ground-based aircraft detection in the airspace along and near the transit corridor (1 nautical mile wide, 2,000 feet high) from restricted airspace R-2204 at Oliktok Point to international waters was provided by a Thales-Raytheon radar system. A test of the radar's performance in detecting air traffic was required by the FAA before it could be used as part of the sense and avoid plan.

FIGURE C.1 MIZOPEX operations area. SOURCE: ©2013 TerraMetrics, Inc., www.terrametrics.com.

- Wingspan: 1 m
- Weight: ~700 gm
- Electric propulsion
- Rear folding propeller
- Airspeed: 14 m/s
- Power: 40-minute lifetime battery
- Cost: ~$600
- Airframe: Expanded polypropylene (EPP) foam
- Autonomous flight control, with user supervision while in communications range
- Communications range: ~5 km
- Flight range: ~30 km
- Has received multiple Certificates of Authorization from the FAA

FIGURE C.2 Datasheet for the University of Colorado DataHawk UAS. SOURCE: Maslanik (2016).

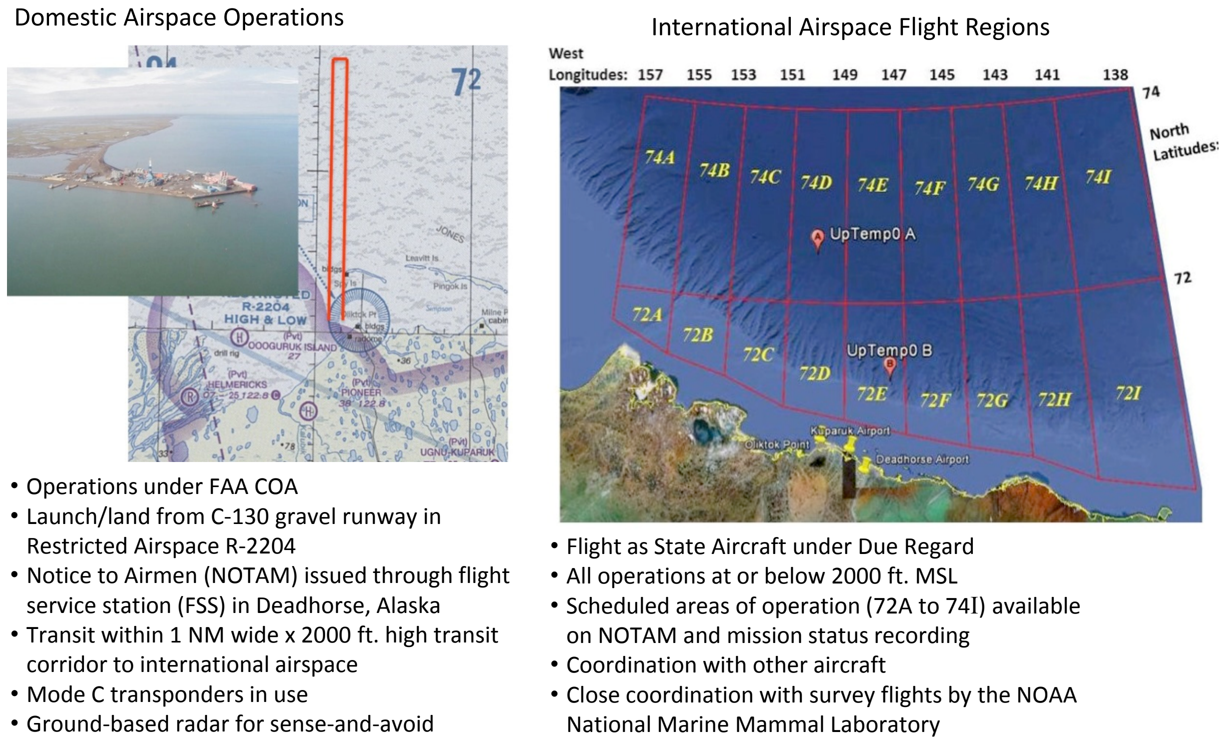

FIGURE C.3 Airspace details for UAS flights for the MIZOPEX project. SOURCE: Courtesy of J.A. Maslanik/W.J. Emery, University of Colorado Boulder.
NOTE: COA, Certificate of Authorization; FAA, Federal Aviation Administration; MSL, mean sea level; NOAA, National Oceanic and Atmospheric Administration.

The DataHawk UAS developers and operators had several years of experience in flying small UAS in several states in class G (uncontrolled) airspace and in class E (en route) airspace. There were more than 120 Certificates of Authorization (COAs) prior to the MIZOPEX campaign. For the MIZOPEX campaign, a "pen-and-ink change" was requested to modify the existing DataHawk COA at Oliktok Point to allow the DataHawk to fly through the transit corridor, where it would land on the sea surface approximately 27 nautical miles from shore to convert to a surface buoy. The safety case in the pen-and-ink request focused on the collision hazard of the DataHawk airframe with a human, a surface vessel, or an aircraft. A Safety Risk Management Document (SRMD) was prepared following the guidelines of FAA Safety Risk Management Policy, Order 8040.4A. Federal Aviation Regulations Part 101-Moored Balloons, Kites, Amateur Rockets, Unmanned Free Balloons, and Certain Model Aircraft, which allows unregulated flights of similar payload packages (up to 4 pounds, compared to the DataHawk at 1.5 pounds), was cited in the safety-case argument. Mitigations included the following: (1) the DataHawk is constructed of materials similar to many commercially available balloon-borne instrument packages, with a weight of about one-third of the maximum weight allowed for a single package under Part 101; (2) during an entire flight, the DataHawk would fly at a maximum altitude of 50 feet above the sea surface; (3) the Anchorage Air Route Traffic Control Center confirmed that if the preflight notifications were followed there would be minimal risk of the DataHawk encountering another aircraft in the transit corridor; and (4) a radar-based detection system, previously demonstrated to the FAA, would provide ground-based aircraft detection during any flights through the transit corridor.

Even though the DataHawk operators initiated discussion with FAA for the MIZOPEX mission more than a year in advance of the deployment, the COA pen-and-ink request to change the existing DataHawk COA was never approved, and a major part of the NASA-funded MIZOPEX mission was not allowed to be executed. Anecdotally, the FAA decision was based on the conclusion that once the DataHawk flew beyond the line-of-sight communication range, it would become a fully autonomous UAS, and that could not be allowed.

One of the participants in the project, J.A. Maslanik, summarized lessons learned during the MIZOPEX project as follows (Maslanik, 2016):

> The iterative nature of the COA application process, in which the COA requester prepares and submits the application, then waits for FAA reactions regarding problems or issues, creates problems for challenging field campaigns such as MIZOPEX. Researchers hoping to propose non-standard UAS field campaigns have no way of gauging ahead of time whether FAA will accept certain approaches, and the tell-us-what-you-want-to-do-and-we-will-respond process leads to delays and some confusion.
>
> Provision of exemptions for very low-risk UAS such as DataHawk under Part 101 (i.e., treating the aircraft as posing risk comparable to a weather balloon) would open up considerable capabilities for sensing using UAS. An alternative would be to allow such aircraft to operate under a COA in fully autonomous mode outside communications range (i.e., in a planned lost-link mode).

REFERENCE

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D

Speakers to the Committee

David Arterburn, University of Alabama, Huntsville
Firdu Bati, Federal Aviation Administration (FAA)
Mark Blanks, MAAP/VaTech UAS Test Site
Jeff Breunig, The MITRE Corporation
Dallas Brooks, UAS Executive Committee
James Burgess, Google Wing
Rodney Cole, UAS Executive Committee
Bill Crozier, FAA
Doug Davis, Northrop Grumman
Joerg Dittrich, DLR
Ally Ferguson, PrecisionHawk
Jonathan Hammer, Noblis
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Peter Sachs, Airbus
Sabrina Saunders-Hodge, FAA
Andrew D. Spiegel, United States Aircraft Insurance Group
Walter Stockwell, DJI
Brandon Suarez, General Atomics

E

Acronyms

ATC	air traffic control
CAST	Commercial Aviation Safety Team
CFR	Code of Federal Regulations
COA	Certificate of Authorization
CRA	comparative risk analysis
DAA	detect and avoid
DIAAT	describe, identify, analyze, assess, and treat
EIT	electronics and information technology
FAA	Federal Aviation Administration
GAJSC	General Aviation Joint Steering Committee
ICAO	International Civil Aviation Organization
JARUS	Joint Authorities for Rulemaking of Unmanned Systems
LAANC	Low Altitude Authorization and Notification Capability
MIZOPEX	Marginal Ice Zone Observations and Processes Experiment
MOPS	Minimum Operational Performance Standards
PRA	probabilistic risk analysis
SES	Senior Executive Service
SMS	Safety Management System
SORA	Specific Operations Risk Assessment

SRM	safety risk management
SRMD	Safety Risk Management Document
UAS	unmanned aircraft system(s)
UAST	Unmanned Aircraft Safety Team
UTM	UAS Traffic Management