Transforming Aerospace Autonomy Education and Research

M.L Cummings
Duke University
304 Research Dr.
Durham, NC 27517
m.cummings@duke.edu

Kristi A. Morgansen
University of Washington
Guggenheim 211E, Box 352400
Seattle, WA 98195
morgansn@uw.edu

Brian Argrow
429 UCB
3775 Discovery Drive
Boulder, CO 80303
brian.argrow@colorado.edu

Sanjiv Singh
2111 Newell Simon Hall.
5000 Forbes Ave.
Pittsburgh, PA 15213
ssingh@cmu.edu

Abstract— **There is increasing commercial interest in the deployment of autonomous aircraft for both passenger and cargo transport. Indeed, with the need for more human-free deliveries, the COVID19 crisis has led to a sharp spike in drone deliveries. This increased demand is putting additional stress on supporting infrastructure like air traffic control, which is already struggling with outdated technology. The recent 737 MAX crashes also highlight the complexities surrounding the development of aircraft autonomy as well as testing and certification. In order to more precisely determine whether universities are keeping pace with both research and education needs from external stakeholders in terms of aerospace autonomy, we conducted a survey that targeted aerospace leaders in academia, industry, and government. The results show there is a significant gap between the education and research aims of academia and what is needed in industry and government. To fill this gap and maintain international superiority in aerospace autonomy, the US needs to promote the convergence in the fields of computer science and aerospace engineering, as well as safety, cybersecurity, and testing. Without such transformation, the US will not be able to maintain its technological advantage in aerospace systems.**

TABLE OF CONTENTS

1. INTRODUCTION 1
2. METHOD...2
3. RESULTS...3
4. DISCUSSION 6
5. CONCLUSION 6
ACKNOWLEDGEMENTS...6
REFERENCES...6
BIOGRAPHY 7

1. INTRODUCTION

The aerospace industry, which we define as the combined fields of aeronautics and astronautics, is experiencing change at a rate not seen since the pioneering days of the Wright brothers. Within a span of just a few years, unmanned aircraft systems (UAS, aka drones) have made the leap from a predominantly military technology to one that now can be flown by almost any person in the Unites States, as long as it is under 55 lbs, flown below 400 ft and within the line of sight of the operator. The Federal Aviation Administration (FAA) estimates that by 2024, the commercial drone market will have tripled from that in 2020, with more than 829,000 UAS estimated to be in operation and more than 1.48 million recreational UAS [1].

This early excitement in UASs has inspired new generations of engineers to revisit the idea of a flying car, which was extremely popular in the 1950s, but then lost momentum due to the costs and complexities of pilot training and certification [2]. Now, there are close to a dozen companies worldwide racing to be the first to offer autonomous on-demand air taxi services [3]. In addition to the focus on passenger transport, there is also a strong increase in demand for autonomous aircraft to transport goods from a few pounds to hundreds of tons at a time, with many companies vying to be the first to a profitable autonomous cargo market [4]. The recent COVID19 pandemic has led to a significant increase in small drone-based medical and supply deliveries, which removes delivery personnel from risk of exposure.

This increased demand in autonomous aircraft is putting additional stress on supporting infrastructure like air traffic control, which is already struggling with outdated technology. Expansion of commercial services through autonomous aircraft will require, entirely new types of air traffic control that embed significant autonomy will be needed to provide low altitude separation, a capability that does not yet exist [5-7]. There will also be significant infrastructure challenges, such as how to design new vertiports and secure communication networks [8-10].

Autonomy in this paper refers to the ability of a system to gather data and reason about that data to create and execute a plan of action, independent of direct human control. Advanced autonomous systems necessarily integrate

978-1-7281-7436-5/21/$31.00 ©2021 IEEE

elements of artificial intelligence, defined by the Department of Defense as "the ability of machines to perform tasks that normally require human intelligence – for example, recognizing patterns, learning from experience, drawing conclusions, making predictions, or taking action – whether digitally or as the smart software behind autonomous physical systems [11]." Autonomy is not a new concept in aviation, as aircraft have been flying on autopilot, which is primitive autonomy in the form of automation, and even landing themselves for many years. What has changed in recent years is the amount and degree of control given to onboard autonomy through AI.

While autonomy advancements have been critical for the rise of UASs/drones that cannot depend on a backup human pilot, there are similar advances in traditional aerospace, but integration has been difficult. The recent 737 MAX crashes highlight the complexities surrounding the insertion of advanced autonomy in aerospace systems [12], especially those that require human supervision, and there is still much to be learned about the development, testing and certification of such technologies.

In addition to the need to address the complexities of advanced autonomy onboard current manned aircraft, there are many autonomy issues that need to be addressed with the rise of commercial and recreational unmanned aircraft and supporting infrastructure such as air traffic control [6] [13, 14]. The United States has struggled to meet National AirSpace (NAS) capacity demands [15], so the dramatic increase in commercial drones will drastically compound this issue. The intersection of autonomy and commercial space exploration applications is also a rich area of future research [16-18]. With the added layers of autonomy needed to both improve efficiency and guarantee safe operations, ensuring the integrity and cyberphysical security of such systems is of utmost importance [19, 20].

The effects of increasing autonomy in aerospace applications are impacting aerospace research and development communities and are leading to demands for enhanced and different skill sets for jobs in these sectors. Jobs in the artificial intelligence (AI) sector have grown more than 167% since 2012 and in a 2019 survey, 58% of large companies reported adopting AI across at least one major enterprise [21]. While autonomous systems are growing in every facet of commercial aviation and space applications, indeed in all transportation sectors, aerospace education has not kept pace with this demand. Since 2015, aerospace undergraduate enrollments have grown 10%, while computer science undergraduates have grown 56% [22].

Aerospace systems that incorporate autonomy are hybrid systems with both software and hardware elements, so the aerospace community needs people with both traditional engineering and computer science backgrounds. Unfortunately, traditional aerospace education programs are often unable to incorporate the computer and data science classes needed to fill this gap, due to a lack of faculty, the lack of available space in computer science classes and lack of curriculum flexibility in accredited undergraduate aerospace programs.

In order to more precisely determine whether universities are keeping pace with both research and education needs from external stakeholders in terms of aerospace autonomy, we conducted a survey that targeted aerospace leaders in academia, industry, and government. The goal was to determine what gaps in research may exist from industry and government perspectives, as well as how aerospace education may need to change to reflect the need for stronger interactions between traditional aerospace and computer science education communities. As will be discussed in detail, results show that there is a distinct gap in what universities are teaching and what industry and government agencies require, and that there is a significant need for a convergent approach for transformation of the aerospace engineering enterprise.

2. METHOD

An IRB-approved online survey was developed and distributed to senior leaders and managers in aerospace companies and government agencies and to senior academics in the United States. Links to the survey were sent to senior leaders in 57 small and large aerospace companies (both aviation and space companies, as well as companies with aerospace divisions), to 12 US government agencies including the FAA, NASA, Federally-Funded Research and Development Centers (FFRDCs), and University Affiliated Research Centers (UARCs), to senior leaders in professional societies including the American Institute for Aeronautics and Astronautics and the American Helicopter Society, and to all 64 US aerospace department heads.

In total, 135 agencies and companies were contacted leading to 132 responses, with industry at a 75% (N= 44) response rate, government at 100%+ (N= 43), and academics at 70% (N = 45). These numbers are approximate response rates because the online survey was anonymous, and identities could not be verified. The government response rate number is higher than 100% because many government agencies have multiple relevant divisions, and participants could send the link to other relevant senior leaders. For example, NASA has both space and aviation programs, and even across the various space and aviation centers, different centers focus on different aspects of operations, such as aircraft design versus air traffic control support. So, while NASA counts as one agency, a strong possibility exists that multiple people responded from various divisions. Overall, it is impossible to know the exact response rate for specific government agencies, but these numbers demonstrate that there was strong participation, which is an indicator of just how important this topic is to stakeholders.

The specific surveys sent to academics (the service providers) and to those who identified in the industry and government groups (the customers) were similar but not identical. Academics were asked 15 questions that focused on education and research topics, student quality and demand, and university support, while those in government and industry were asked 11 questions about topical areas of importance, the number and quality of desired hires, and the need for retraining of the existing workforce. These questions and results are detailed in the next section.

3. RESULTS

The first set of results examines how important autonomous systems research and development is to academic, industry and government institutions. Whether these agencies can recruit and retain the people they need for autonomous aerospace applications will be addressed, as well as the perceived gaps in knowledge of recent hires from academia. Lastly, future of work-related issues such as retraining of the workforce, including senior leadership, will be addressed.

Importance of Aerospace Autonomy

To get a sense of the perceived degree of importance of aerospace autonomy, the companies, organizations, and academic units were asked "How important is aerospace autonomy to your organization?" Figure 1 illustrates the responses. The overwhelming majority of industry people think autonomy is very or extremely important to their aerospace efforts (85%), with 100% of government personnel in agreement. One academic reports aerospace autonomy is not at all important, and four feel it is only moderately important. Zero people in industry think aerospace autonomy is not important, and 6 state it is moderately important, with only 1 person agreeing with the slightly important category.

When industry and government personnel were asked whether their organizations' senior management layer understands the importance of aerospace autonomy, industry people reported that 22% likely do not, but government respondents indicated that this number was 34%. When academics were asked if their Deans of Engineering support

Figure 2: Responses to "How would you rank your need for people with an aerospace autonomy background?"

their efforts in aerospace autonomy, 19% report that their Deans do not appear to be supportive.

Supply and Demand

One set of questions targeted the supply and demand of graduates, since as noted above, the demand for people with backgrounds in autonomous systems and artificial intelligence has been growing across all sectors. When industry and government people were asked how they rank their need for people with an aerospace autonomy background, 84% of industry and 89% of government respondents state their need is urgent or critical (Fig. 2).

When academics were asked about the perceived demand from industry, 79% of respondents agree that industry demand is high to very high for their students with aerospace autonomy backgrounds, so most professors are aligned with demand. When asked what demand exists at their schools from students for programs related to aerospace autonomy, 77% of professors agree that aerospace autonomy classes are in the top three choices for programs in their aerospace departments for both graduate and undergraduate students. Clearly, students and faculty see opportunities coming from industry and government in aerospace autonomy applications.

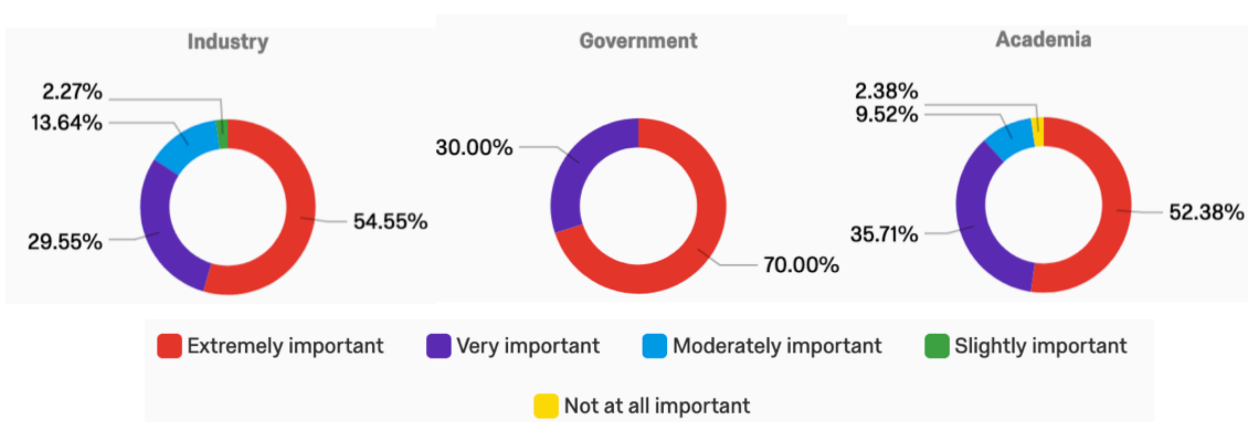

Figure 1: Responses to "How important is aerospace autonomy to your organization?"

Despite the alignment in demand, when industry and government respondents were asked whether recent hires have the needed background in aerospace autonomy, results were mixed (Fig. 3). Only 30% of government and industry respondents have confidence that hires are prepared for careers in aerospace autonomy. This result suggests that there is a gap between what students, both graduate and undergraduate, are taught and what industry desires.

When asked to comment on what is missing from new hires, the most numerous comments from industry and government indicate a lack of systems engineering understanding, safety-critical software development, especially for complex systems with computer vision, and methodologies for reliable evaluation of systems with embedded machine learning. Several industry and government people commented that they want recent graduates to have more interdisciplinary skills and knowledge that cover aeronautics and AI, as well as more experience in taking lab demonstrations from proofs of concept to certified, trusted autonomous systems.

One industry respondent said "To be honest we have way too many controls/dynamics/structures folks. We should be hiring from CS and robotics programs, but management won't change the culture to attract them." Another said, "It's commonplace to find people with either knowledge in computer science/software/algorithm development or people with autonomous systems or aerospace and safety critical systems. However, hiring both is hard." Addressing how industry is currently meeting its need, one person said "Scarcity means we have to do in-house ad hoc training."

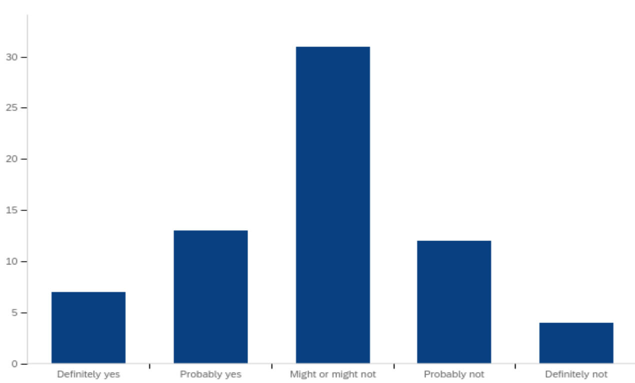

Figure 3: Responses from Industry and government to "Do you think people you are hiring have the needed background in aerospace autonomy?"

Gaps in Skills and Knowledge

To further explore a potential gap between acquired versus desired skill and knowledge sets for university graduates, industry and government personnel were asked to rank the importance of various topics related to aerospace autonomy. The related academic question asked which of these same topics should be taught as part of an aerospace autonomy program. Table 1 captures the industry, government, and academic rankings with a value of 1 indicating the topic of highest importance and 18 as the lowest. Highlighted entries indicate a disparity in rankings across all three groups with the difference in values having magnitude three or more. The starred entries indicate an academic ranking that is different from industry and government rankings by three or more.

Safety, cybersecurity, systems integration and certification are the top-rated categories for industry, with similar rankings from government people. One industry person had this to say about the current state of academia, "I wish people would focus less on making something cool happen and more on making predictable, safe systems and limiting risk." The lower rankings of the safety, testing, and certification topics and the higher rankings of machine/deep learning for academia and other starred topics likely reflect academia's comfort with topics that *seem* to be more knowledge-based and rely less on a specific application and real-world experience.

One academic offered this following observation, "Testing and evaluation are a critical aspect of certification. It is not clear how to teach these at an R1 university, if at all." So, while safety, testing and certification are seen as critical topics by industry and government personnel, they may not seem by some academics as appropriate for formalized education.

Table 1: Importance of Topics in Aerospace Autonomy

	Industry	**Government**	**Academia**
Safety	1	4	9
Cybersecurity	2	5	6
System integration	3	8	3
Certification	3	1	15*
Software engineering	5	7	6
Testing	6	1	11
Legal & regulatory frameworks	6	15	16
Human-autonomous system interaction	6	1	2
Machine/deep learning	7	11	1
Motion planning	8	9	3*
Computer Vision	8	8	3*
Perception	12	6	6
Ethical impact	16	18	10*
Planning	13	12	11
Mapping	14	13	11
Operator training	17	14	17
Maintenance	18	15	17
Networks	14	17	11*

All three groups were asked to offer new possible topic areas that they would like to see addressed. Academics only offered up three (dynamics, control & simulation), which are already established courses in most engineering programs. Industry and government people suggested these as well as almost two dozen topics that were derivatives of the original list including system health management (both diagnostic and prognostic), formal methods, and public education, perception and communications.

Academic Needs

Academic respondents were asked whether their departments and schools had enough qualified faculty to teach the elements of aerospace autonomy education they checked as important (Table 1). The ability to teach various aerospace autonomy concepts is directly linked to qualified faculty in aerospace departments or having students take needed classes in computer science (CS) programs. At many universities, the rise in the popularity of AI and machine learning has dramatically increased enrollment in CS departments, leading to limited seats available to engineering students. This shortage has been exacerbated by the increasing number of faculty leaving academia to take autonomy-related jobs in industry [21].

Fifty-eight percent of academic respondents were either not sure or did not think their departments or schools have the right faculty to teach these programs. Furthermore, when asked if CS departments were supportive of aerospace students taking their classes, only 37% of academic respondents agree. Most of the faculty (65%) who do not think the CS departments are supportive agree that they would likely be more supportive but high CS enrollments prevent them from having more availability.

The popularity of CS-related programs and the lure of highly-paid industry jobs also has the unintended effect of reducing the graduate student pool available as research assistants. This is particularly problematic in departments trying to build expertise and research capacity in aerospace autonomy. It also has the downstream impact of reducing the rate of innovative research coming out of these departments, as well as future faculty. To understand the scale of this possible problem, academics were asked whether they needed higher quality graduate students (Fig. 4). Only 20% of respondents feel their graduate students are of a high enough quality, suggesting that a larger national recruitment effort may be needed to communicate the growing interdisciplinary opportunities between aerospace and computer science.

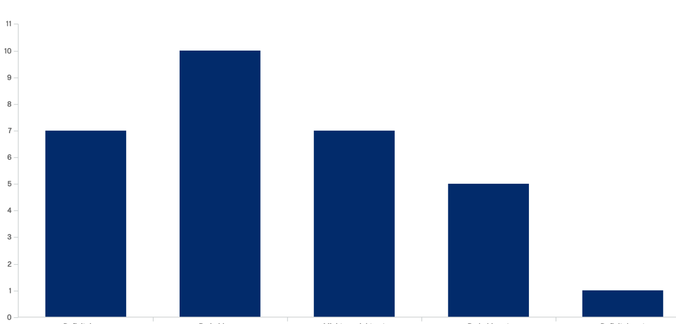

Figure 4: Responses by academics to "To effectively conduct more research in aerospace autonomy, my department needs higher quality graduate students."

When asked to comment on any other needs related to aerospace autonomy, one faculty member said that one issue was the "lack of willingness of aerospace engineering faculty and Department Heads to consider autonomy an important area in their departments. The basis is too often a financial one: hypersonics can bring in an order of magnitude more external research funding than autonomy, so autonomy often loses out or at best is a second-tier research thrust." The need for more funding was also mentioned by several faculty.

The Future of Work

One core issue that cuts across all industries with the rise of AI and, more generally, software and digitization requirements is the need for reskilling of current employees who have no formal background in these areas. One forecast has predicted that possibly 375 million workers, approximately 14% of the global workforce, will need either reskilling or upskilling due to digitization, automation, and advances in artificial intelligence [23]. This problem has been made much worse recently with the economic fallout of the COVID-19 pandemic.

Understanding that education needs go well beyond that of undergraduate and graduate education, the industry and government respondents, who were all senior people in their organizations, were asked "Do you think you need continuing education classes about elements of aerospace autonomy?" Their responses are illustrated in Fig. 5. Half of these senior individuals feel they need more education, and these people already lead various aerospace autonomy initiatives. Curiously, 11% of government personnel do not think they need any further education, which is surprising given the rapidly evolving nature of autonomy in safety-critical aerospace programs.

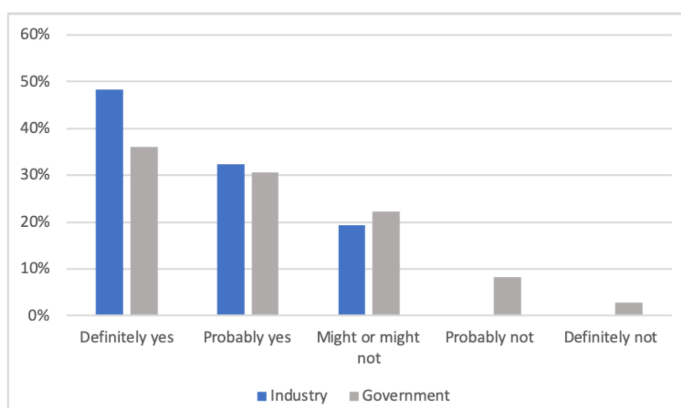

Figure 5: Responses to "Do you think you need continuing education classes about elements of aerospace autonomy?"

4. DISCUSSION

This survey of managers and leaders in aerospace autonomy across industry, government, and academic organizations was designed to determine what gaps exist in research and education, with the ultimate goal of developing a roadmap for both closing this gap and for helping to build capacity. The results from this survey demonstrate that while generally industry, government and academia are aligned in terms of understanding the importance of the rapidly growing field, there is a significant gap between the education and research aims of academia and what is needed in industry and government.

Overall, industry and government want to see more formalized instruction in safety, testing, and certification, as well as in systems engineering and in cyber security. They also desire a stronger focus on interdisciplinary skills and knowledge that address both aeronautics and AI. Traditional approaches to certification are not adequate for autonomous systems that incorporate probabilistic reasoning [13, 24, 25], so new methods for adequately testing and certifying these safety-critical systems are unquestionably needed.

A few academics in the survey question whether it is appropriate for universities to teach these topics. Some universities offer degrees in occupational safety, and testing and certification concepts are occasionally taught in systems engineering programs but little progress has been made in adapting such programs to autonomous systems. These results suggest that academia needs to work with industry and government across the areas of safety, testing, certification, cybersecurity and systems engineering to determine how such courses could be taught, and more broadly how a field of certification science could or should evolve. In addition, accreditation processes need to be reviewed for core engineering requirements.

This issue raises a problem that is well known in academia, which is the struggle to build a successful interdisciplinary program. Aerospace autonomy is essentially the blending of aerospace engineering and computer science, which makes it interdisciplinary by definition. If such a program were to consider the breadth of needs outlined by industry and government personnel in Table 1, it would also include not just safety, testing and certification but also legal and regulatory aspects which are tightly coupled in safety-critical systems. Unfortunately, these kinds of interdisciplinary programs have struggled to be successful due to cognitive, philosophical, and institutional problems [26, 27]. Competition for resources in restricted budget climates only makes building successful interdisciplinary programs even more difficult. However, the transformational need for aerospace autonomy can only be met by coordinated, convergent research and innovation across multiple fields.

While these survey results illustrate some academic resistance and programmatic challenges to interdisciplinarity, they also illustrate a dramatic need for interdisciplinary research and education in aerospace autonomy. Moreover, the topics of safety, testing and certification raised by industry and government have broad application, and not just for aerospace systems. Autonomy and AI are becoming core technologies in other safety-critical settings like surface transportation (i.e., self-driving cars) and medical systems with automated image processing and monitoring systems. The education and research concerns raised in this report, while acute for aerospace systems with embedded autonomy, also apply to many other applications.

Lastly, this survey highlights a distinct need for programs that help employees, even senior leaders, to upgrade or learn new skills related to safety-critical autonomous systems. Software engineering is the one area in this survey that all three groups agreed upon as important, which is relatively new as is the focus in artificial intelligence. Given the increasing prevalence of both software engineering and AI in future aerospace programs and the difficulty companies have in attracting the right talent from universities, this survey demonstrates that more work is needed in developing more targeted workforce retraining plans.

5. CONCLUSION

This survey highlights that aerospace autonomy is an inherently interdisciplinary field that requires collaboration and convergence across aerospace engineering and computer science, along with new efforts in safety, testing, certification, systems engineering and cybersecurity. Currently no dedicated undergraduate or graduate education programs exists in the United States that focus on the many interrelated aspects of aerospace autonomy. Developing such a program at both these levels that combines computer science and aerospace curricula is a critical step towards developing true convergence.

A new paradigm is needed for combining experimental design, formal methods, risk assessments and other evaluation techniques in a formal educational setting to develop a core curriculum in safety and testing. In addition, a clear need also exists for educational initiatives that provide new and upgraded abilities for employees of companies increasingly incorporating software engineering and AI. Thus, the educational needed reforms also should address continuing education for industry and government stakeholders. Without this transformational convergence of computer science and aerospace engineering in both education and research, in coordination with the aerospace industry, the US will not be able to maintain its technological advantage in aerospace systems.

ACKNOWLEDGEMENTS

This effort was sponsored by the National Science Foundation as an Engineering Research Center planning grant.

REFERENCES

[1] FAA, "FAA Aerospace Forecast: Fiscal Years 2020-2040,"

Federal Aviation Administration, 2020.
[2] M. L. Cummings, “A drone in every driveway,” *Scientific American,* vol. 308, no. 1, pp. 28-29, 2013.
[3] D. Wakabayashi, "Flying Taxis May Be Years Away, but the Groundwork Is Accelerating," *New York Times*, 2018.
[4] F. Shivakumar. "Giant cargo drones will deliver packages farther and faster," June 1, 2020.
[5] B. Elias, *Flying Cars and Drones Pose Policy Challenges for Managing and Regulating Low-Altitude Airspace,* IN10934, Congressional Research Service, 2018.
[6] NASA Facts, "UTM: Air Traffic Management for Low-Altitude Drones," NASA, 2015.
[7] The National Academies of Sciences, Engineering, and Medicine, *In-Time Aviation Safety Management: Challenges and Research for an Evolving Aviation System*, The National Academies Press, Washington, DC, 2018.
[8] T. E. Humphreys, B. M. Ledvina, M. L. Psiaki, B. W. O. Hanlon, and P. M. Kintner, “Assessing the Spoofing Threat: Development of a Portable GPS Civilian Spoofer,” in ION GNSS, Savannah, GA, 2008.
[9] G. Berz. "GNSS Spoofing and Aviation: An Evolving Relationship," 21 May, 2019; https://insidegnss.com/gnss-spoofing-and-aviation-an-evolving-relationship/.
[10] K. Sampigethaya, and R. Poovendran, “Security and privacy of future aircraft wireless communications with offboard systems,” in Third International Conference on Communication Systems and Networks (COMSNETS), 2011.
[11] Defense Innovation Board, *AI Principles: Recommendations on the Ethical Use of Artificial Intelligence*, Department of Defense, Washington DC, 2019.
[12 D. Campbell. "Redline: The many human errors that brought down the Boeing 737 MAX," May 17, 2019; https://www.theverge.com/2019/5/2/18518176/boeing-737-max-crash-problems-human-error-mcas-faa.
[13] Committee on Autonomy Research for Civil Aviation, *Autonomy Research for Civil Aviation: Toward a New Era of Flight*, National Research Council, Washington DC, 2014.
[14] The National Academies of Sciences, Engineering, and Medicine, *Assessing the Risks of Integrating Unmanned Aircraft Systems (UAS) into the National Airspace System*, The National Academies Press, Washington DC, 2018.
[15] FAA, "FACT3: Airport Capacity Needs in the National Airspace System," Federal Aviation Administration, 2015.
[16] D. P. Watson, and D. H. Scheidt, “Autonomous systems,” *Johns Hopkins APL Technical Digest* vol. 26, no. 4, pp. 368-376, 2005.
[17] C. R. Frost, "Challenges and Opportunities for Autonomous Systems in Space," *Frontiers of Engineering: Reports on Leading-Edge Engineering from the 2010 Symposium* A. R. Butt and D. D. Silva, eds., Washington DC: National Academies Press, 2011.
[18] M. D. Watson, S. B. Johnson, and L. Trevino, "Systems Engineering of Autonomous Space Vehicles," *Proceedings of the IEEE Prognostics and Health Management Conference (PHM) 2014*, Spokane, Washington, 2014.
[19] G. Lykou, A. Anagnostopoulou, and D. Gritzalis, “Smart Airport Cybersecurity: Threat Mitigation and Cyber Resilience Controls” *Sensors,* vol. 19, no. 1, 2019.
[20] GAO, "Homeland Defense: Urgent Need for DOD and FAA to Address Risks and Improve Planning for Technology That Tracks Military Aircraft," Government Accounting Office, 2018.
[21] R. Perrault, Y. Shoham, E. Brynjolfsson, J. Clark, J. Etchemendy, B. Grosz, T. Lyons, J. Manyika, S. Mishra, and J. C. Niebles, *The AI Index 2019 Annual Report*, Stanford University, Stanford, CA, 2019.
[22] J. Roy, *Engineering by the Numbers (2016-2018)*, American Society for Engineering Education, Washington DC, 2019.
[23] P. Illanes, S. Lund, M. Mourshed, S. Rutherford, and M. Tyrema, *Jobs lost, jobs gained: What the future of work will mean for jobs, skills, and wages*, McKinsey & Company, New York City, 2018.
[24] M. L. Cummings, and D. Britton, "Regulating Safety-Critical Autonomous Systems: Past, Present, and Future Perspectives," in *Living with Robots: Emerging Issues on the Psychological and Societal Implications of Robotics* R. Pak, E. d. Visser, and E. Rovira, Eds, pp.119-140.
[25] P. H. Kopardekar, “National Unmanned Aerial System Standardized Performance Testing and Rating (NUSTAR),” in Technology and Standards Forum, San Diego, 2016.
[26] M. MacLeod, “What makes interdisciplinarity difficult? Some consequences of domain specificity in interdisciplinary practice,” *Synthese* vol. 195, pp. 697–720, 2018.
[27] National Academy of Sciences, National Academy of Engineering, and Institute of Medicine, *Facilitating Interdisciplinary Research*, The National Academies Press, Washington DC, 2005.

BIOGRAPHY

Professor Mary (Missy) Cummings *received her B.S. in Mathematics from the US Naval Academy in 1988, her M.S. in Space Systems Engineering from the Naval Postgraduate School in 1994, and her Ph.D. in Systems Engineering from the University of Virginia in 2004. A naval pilot from 1988-1999, she was one of the U.S. Navy's first female fighter pilots. She is currently a Professor in the Duke University Electrical and Computer Engineering Department, and the Director of the Humans and Autonomy Laboratory. She is an AIAA Fellow, and a member of the Defense Innovation Board.*

Professor Kristi A. Morgansen *received a BS and a M.S. in Mechanical Engineering from Boston University, respectively in 1993 and 1994, an S.M. in Applied Mathematics in 1996 from Harvard University and a PhD in Engineering Sciences in 1999 from Harvard University. Currently the department chair of the University of Washington's William E. Boeing Department of Aeronautics and Astronautics, her research interests focus on nonlinear systems where sensing and actuation are integrated, stability in switched systems with delay, and incorporation of operational constraints such as communication delays in control of multi-vehicle systems.*

Professor Brian Argrow *(PhD 1989 Aerospace Engineering, University of Oklahoma) is the chair of the University of Colorado Boulder Aerospace Engineering Science department. His current research includes small UAS airframe design and sensor integration, and integration into the National Airspace System, with other research including aero/gas dynamics, and engineering education. He is currently a member of the Aeronautics and Space Engineering Board of the National Academies of Sciences, Engineering, and Medicine, and he serves on the ASTM Committee F38 on UAS, F38.02 Flight Operations.*

Dr. Sanjiv Singh *received his B.S. in Computer Science, University of Denver in 1983, his M.S. in Electrical Engineering, Lehigh University in 1985, his M.S. in Robotics, Carnegie Mellon University in 1992, and his Ph.D. in Robotics, Carnegie Mellon University in 1995. He is currently a research professor at the Robotics Institute at Carnegie Mellon University and CEO of Near Earth Autonomy which he co-founded. Near Earth Autonomy develops autonomy for next-generation aircraft and will inspect infrastructure, deliver cargo, and transport people. Sanjiv led a team that demonstrated the first autonomous full-scale helicopter capable of take-off, landing zone evaluation, and safe descent.*