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on

U.S. Unmanned Aircraft Systems: Integration, Oversight, and Competitiveness

before the
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Committee on Transportation and Infrastructure
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Chairman LoBiondo, Ranking Member Larsen, and Members of the Subcommittee:

Thank you for the opportunity to appear before you to discuss the unmanned aviation industry in the United States.

I am a professor in the Department of Aeronautics and Astronautics and the Computer Science and Artificial Intelligence Laboratory at MIT. I have conducted research on unmanned aerial vehicles for 11 years, primarily focused on developing UAVs for operation in urban, civilian and populated environments. I have collaborated closely with a number of US companies to develop and deploy technologies to enable unmanned aerial vehicles to fly autonomously. Most recently I worked with Google to found Project Wing, a UAV-based package delivery system. I returned to MIT full-time in September of this year.

In this testimony, I am speaking solely for myself and cannot speak for either MIT or Google.

My main message is that the US leads the world in UAV development. However, the commercial UAV market, while predicted to grow in coming years, is currently very small due to substantial technical limitations. The US is very well-positioned to develop the next wave of UAV technologies that are needed for safe, reliable and cost-effective commercial UAV operation. Unfortunately, the process of testing new UAV technologies and training new engineers is more difficult in the US than in other countries. The hurdles to testing and to training may very well affect the US position of leadership in the future.

There is currently a great deal of excitement around the world at the idea of using UAVs in a variety of ways and in a variety of industries. Agriculture, civil infrastructure inspection, emergency medical response, film-making and local transportation or delivery are examples of real applications where UAVs could provide substantial cost savings or provide considerable increase in productivity. There are three primary reasons for the recent excitement and popularity of UAVs. Firstly, the requisite component technologies for UAVs have shrunk considerably in size. Secondly, the cost of manufacturing small UAVs has fallen enormously. Thirdly, substantial advances in computation and information processing have allowed much of the aircraft control to be carried out by the vehicle itself, reducing the level of expertise needed of the pilot. Technologies such as on-board computers, GPS receivers and battery power are now powerful enough yet small enough and cheap enough to allow us to create little "drones" that are easy, safe and cheap for everyone to fly under the proper conditions, such as the guidelines of the Academy of Model Aeronautics. This is without a doubt a new phenomenon.

Let me contrast these small UAVs with the larger UAVs which are primarily, if not exclusively, military assets. The large UAVs are complex to operate, require large support organizations, and as a consequence have limited interaction with the general public. The large UAVs have compelling safety records, and unparalleled reliability as demonstrated by the remarkable performance of the X-47B. The US is and has been an unquestioned leader in the technical development of these vehicles for many years. Because of the current excitement around small UAVs, the potential for these vehicles to integrate into our daily life, and the commercial markets that might result from doing so, I will focus the rest of my remarks on small UAV technology in civil and commercial domains.

What is the current state of small unmanned aircraft?

The vast majority of small UAVs that are sold today are essentially toy vehicles, whether they are traditional RC aircraft like model airplanes, or quadrotor helicopters that have become popular very recently. The technology in these toy aircraft has evolved rapidly in recent years, and many have an impressive level of autonomy. They can fly reliably from place to place using GPS and databases of maps, execute entertaining flight manoeuvers, and some are starting to perform rudimentary collision avoidance. Nevertheless, small UAVs available commercially are all more or less at the same level of performance: they can carry very limited useful payload, and the market for these vehicles is recreation. There are a small number of companies that sell products that promise to support useful commercial applications such as agricultural imaging or inspection, but these UAVs are not yet significantly more capable than the recreational vehicles. As a result, the current markets for commercial UAVs are not particularly large. The exact numbers are difficult to determine, but in Europe the current market for inspection UAVs appears to be less than 1000 vehicles per year, and in Japan, the entire agricultural UAV system appears to be supported by about 3000 vehicles.

Why is the commercial market for small unmanned aircraft not larger?

Put simply, the commercial market for small unmanned aircraft is not larger because the state of current UAV technology does not yet support a robust functional market. The numerous recent example demonstrations of commercial applications overseas, especially the various delivery examples, have demonstrated prototypes at best, and "vaporware" at worst. The UAV technology certainly exists today to support a video showing one-off prototype missions, and these demonstration videos and prototypes sketch a compelling vision of a future for UAVs. Nevertheless, before the vision can become reality, there are currently significant technology gaps. Another wave of UAV technology is still required to scale up current UAV systems into widely available products that the general public can use for applications such as imaging or package delivery.

The recent FAA call for proposals to establish a Center of Excellence for Unmanned Aircraft Systems is a good roadmap for what the open problems are, but some of the key areas include:

- Technologies for reliable vehicles. The majority of small UAVs are built using consumer-grade components that have highly variable reliability, affecting how reliable the UAVs themselves are. By virtue of size, energy and operational conditions, the consequences of a small UAV failing are often much less than a manned aircraft, and it is important not to over-react to the recent spike in small UAV failures reported in the news, but as the population of vehicles increases, the failures may eventually become significant. For safe and reliable operation, commercial vehicles must have the ability to monitor their own health and be able to react to component failures appropriately by themselves.
- Technologies for reliable navigation: Many people have experienced the sometimes-comic effects of large position errors in our GPS-enabled cellphones while walking down the street. For reliable operation, UAVs need to know where they are, even when GPS is unreliable, the so-called "GPS-denied" problem. Similarly, UAVs must know about objects

around them and be able to avoid collisions, the so-called "detect-and-avoid" problem. Algorithms and sensors must be developed to solve both these problems that match the size, weight, power and computation that can be supported on small UAVs.

- Technologies for reliable communications: It is essential that a pilot-in-command be able to give commands to an autonomous UAV at all times. Cellphone infrastructure was not designed for communication with fast-moving, high-altitude entities, nor is it designed to support reliable command-and-control. This is partly an issue of spectrum regulation, but as the number of UAVs grows, the air traffic management infrastructure must grow alongside to support large numbers of UAVs in the national airspace system.
- Technologies to reduce operational costs: Commercial UAV markets will only be viable if the operational cost of a UAV is less than the cost of a manned aircraft. Despite being unmanned, current UAVs rely heavily on the pilot-in-command to monitor the flight and react to unexpected conditions. Algorithms must be developed to support a much higher degree of autonomy with minimal operator intervention in order to become economically justifiable.

US researchers and companies lead in these and other technology areas. As but one example, GPS-denied navigation and collision avoidance are maturing to support autonomous ground vehicles such as the self-driving cars, even if the technologies are not yet commodities that can be adopted immediately for use on UAVs. US companies have publicly demonstrated technologies that do not exist elsewhere. No other country currently has the same advantage in the technologies required to grow the UAV market from recreational or one-off demonstrations to fully viable commercial applications.

Will the US leadership continue?

The essential issues that will affect the future US position of leadership are the ability for engineers and researchers to carry out technology development at will and in unexpected ways, and the ability to train the engineers who will do this technology development.

The creation myth of some of the most successful technology companies in the world is the small team of inventors tinkering in a garage. Hewlett-Packard, Apple and others have turned garages in Santa Clara valley into historic landmarks. Perhaps the most relevant example is the brick house in Ohio that housed the Wright Cycle Exchange in 1892. The garage narrative makes a great story about the humble beginnings of these companies, but there is a real purpose to letting people develop technology literally out of their garage. A key requirement for creating any new technology is the ability to rapidly test and iterate during development. Giving engineers latitude to develop and test anywhere that is safe can massively accelerate the development cycle.

Unfortunately, this latitude for development and testing in the UAV domain is much harder to obtain in the US than it is in other countries. The FAA has established a number of mechanisms for companies and research agencies to obtain legal authorization to fly UAVs, from special airworthiness certificates, to petitions for exemption under Section 333, to the six UAS test sites. Given these mechanisms, it would be incorrect to state that the US has blanket prohibitions against testing for technology development. However, the current authorization mechanisms still represent a considerable bar to entry for businesses and individuals who are interested in addressing the technical challenges that will lead to a robust UAV system and the real problem is that the barrier to entry for testing and technology development in the US is as high as the barrier to entry for commercial deployment. These processes are reasonable for authorizing a UAV-based pipeline inspection service to run 24/7 across the length of North Dakota, but are onerous for authorizing testing operations for small UAVs in unpopulated areas. The current US processes are only realistic for large organizations, inhibiting the organic growth of startups building new technologies.

Garage development has indeed been the hallmark of the recreational RC community in the US, but the lower bar to entry elsewhere means we are starting to see in other countries much more of a UAV startup culture. For example, jurisdictions such as Australia or the UK draw an explicit distinction between flight areas that are lightly regulated, and flight areas that are strongly regulated, such as unpopulated areas and populated areas respectively. The definition of unpopulated areas varies around the world, but authorization requirements for flight in unpopulated areas are typically easy to meet. The clear definition of a legal flight area gives engineers the confidence to establish test operations in these countries; to know where they can literally set up their garage and start developing. In contrast, in the US, operational areas are evaluated on a case-by-case basis without clear parameters, with considerable delays in the evaluation.

Unfortunately, there is not a single set of rules or procedures that can be adopted wholesale from another country that would immediately enable US companies to begin testing and development. The US is a unique country, with a unique airspace and cultural acceptance of technology. The ubiquity of general aviation, and the specific air traffic management system require rules specific to this country. Nevertheless, there may be ideas to be learned from other jurisdictions. For example, a set of clear rules to identify safe test environments throughout the country, rather than a process for approval or a small set of pre-approved sites, would help US companies and researchers to develop the necessary technologies at the same rate as other countries.

Finally, and perhaps most importantly, the US position of leadership is fundamentally affected by the numbers of engineers and scientists that are being trained in this country with the skills necessary to develop the requisite technologies.

There are a growing number of universities and educational institutions offering courses of instruction in UAV technology at the undergraduate level. Learning the foundations of flight for UAVs necessarily requires the students to actually fly vehicles. While some of these institutions have access to COAs and are near one of the approved test sites, there are far too few and the cost is substantial. For the same reasons that inhibit access to test areas, our processes in the US are not suited to allowing enough educational institutions in the nation to provide training areas for undergraduates.

Furthermore, the support for graduate students to conduct basic research in UAV technologies has diminished recently. Much of the progress in unmanned vehicles in the US has been funded by forward-thinking program managers in ONR, ARO, AFOSR, DARPA and NASA. These program managers have not only funded the development of autonomy, control and sensing technologies to enable autonomous UAVs, but have funded the students who in the course of their education wrote software that is running on UAVs today. Whether it is properly the role of government or private industry to fund doctoral students, it is these students that will ultimately solve the technology challenges I have outlined, and there are now more opportunities for these students outside the US. Educational institutions outside the US are acting both as training grounds for a generation of UAV researchers and as incubators for UAV companies.

In conclusion, the US is not currently lagging other countries, regardless of the publicity around prototype demonstrations. There are significant technical hurdles that must be overcome in any country, before safe, scalable operations of UAVs becomes a reality. Nevertheless, there are issues and constraints that may allow other countries to overtake the US both in developing the next generation of UAV technology and in training the next generation of UAV engineers.