# STATE OF THE ART IN THE US

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I am here to talk about the report (Slide 1) for which I was the Co-Chairman, along with John Paul Clarke. This study was commissioned a little over a year ago by the Associate Administrator for Aeronautics Research at NASA, Jaiwon Shin, who asked the National Academies of Science and Engineering, through the National Research Council, to assemble a study committee to address the question of what is needed in terms of a national research programme to address the issues of autonomy in the civil aviation system. That was the charge that we were given (Slide 2). It was not to develop a NASA research programme, but to take into account all the research issues to be addressed in order to accomplish this integration of unmanned aerial vehicles and other forms of autonomy in the aviation system. That's what my report is going to cover this morning.

My talk will be a very quick, high level run through the report. As Bertrand said, the report is available in hard copy and I think most of the slides have an URL from which you can download the report directly if you want, and I would encourage you to do that.

Basically, our charge was that we were to develop a national research agenda to address these issues. We had to decide initially what we were going to focus on. There are many ways to approach these issues of UAS, RPAS and autonomous systems in civil aviation. What we chose to do for the purposes of this study was to focus on what we called "Increasingly autonomous systems" (Slide 3). We envisioned a system that starts with today, with the here and now levels of automation and technology, both in manned and unmanned systems and building on those in order to achieve increasingly autonomous capability. By that, we mean systems capable of operating for extended periods of time without direct human intervention. That's the key characteristic that we chose to address in our study.

We did not limit our study to vehicles or particular systems, but rather looked at both aircraft and ground systems and looked for opportunities where autonomy and autonomous technology could provide new or improved capabilities (Slide 4). Throughout, as you have already heard from a couple of speakers, safety is an underlying issue that must be addressed. Basically, we didn't consider ourselves constrained by anything other than the limits of technology and what becomes practical in the real world. We envisioned an operation which involves a mixture of unmanned and manned vehicles in the civil aviation system. We also looked at the potential application of autonomous capabilities in air traffic management systems as an example. We addressed other things as well, such as ground systems. You can envision autonomous technology being applied for snow plough operations on runways for example, or for aircraft towing, or for many other functions. So we kept in mind that scope of activities as we went through our study. All of this envisioned system designs that minimized the various kinds of failure modes.

We looked at all the major sectors of aviation – air traffic management and all of the various vehicle-specific and mission-specific applications (Slide 5). Cutting across all of these are the functional capabilities that autonomous technology will address in the systems of the future. The autonomous technology that's needed to make all of this work together will be based on the acquisition and monitoring of data from all sources and on the use of that information to identify problems and situations that need to be addressed, such as equipment anomalies, traffic conflicts, all the things that people currently do in the system. We envision many of those functions being transferred to the technology. Then to take that information, turn it into recommended solutions and implement those when such actions are within the scope of authority of the autonomous systems involved.

The question of the scope of authority is one of the fundamental issues to be addressed. How far do we let autonomous vehicles and autonomous systems go before human intervention is required in order to change or affect outcomes in some way? And then, of course, all of this needs to be communicated to all other elements of the system. Those are the functions.

We've heard from previous speakers about potential benefits (Slide 6). Safety and reliability are of course at the very top. Civil transport operations have achieved a level of operational safety that is unparalleled. For many practical purposes we can state that we are in a near zero accident environment with regard to civil transport operations. Other sectors not so much. General aviation in the United States has an accident record rate that is unacceptable. We envision autonomous technology being applied in single pilot operations as a sort of technology co-pilot, a pilot assistant that could address many of the fundamental causes of accidents that occur in single pilot general aviation operations.

UAS opens up a whole new world. This we all know and are going to hear about repeatedly throughout the next two days. Then there are the other issues.

You may remember there was an accident in Scotland involving the police helicopter that was on a surveillance mission, and through a power issue of some sort, they crashed onto the top of an occupied building. There were many fatalities, fire and a very serious accident. We used that accident as a prime example of what UAS or RPAS vehicles can do. All they were doing was putting a pair of eyes in the sky. It was a surveillance mission. They needed an individual to go up and assess a certain situation. That could have been done with a light, small, multirotor vehicle which didn't involve hundreds of kilos of jet fuel and vehicle and pilots and putting others at risk. The introduction of these UASs into mission profiles can have a profound effect on system safety.

Cost and efficiency – some of these systems offer the promise of offloading and minimizing risk, reducing the need for highly trained, highly skilled operators. I say "some of them" and I say "offer the possibility" because there are always trade-offs. Wherever you replace one highly trained, highly skilled individual with someone else, there may be another set of skills and training required to support that. The efficiency issues I've already addressed. The introduction of UAS or RPAS into the civil aviation systems opens up the possibility for missions that simply are not feasible under existing capabilities.

Our approach to this study was to start by identifying what we call barriers to the implementation of autonomy or autonomous technology in civil aviation (Slide 7). We wanted to start with the identification of the issues and areas that needed to be addressed in this national research programme.

Communication and data acquisition: on the one hand, unmanned aerial vehicles may cut down on the amount of bandwidth required for voice communications for air traffic control or air traffic management purposes. On the other hand, real-time control links can add significantly to bandwidth requirements. So there are going to be some interesting trade-offs and some interesting issues with regard to the allocation of spectrum, and how all this plays out to support aeronautical operations, not only for systems today, but in the future. Communications and data acquisition involve interconnected networks. We hear every day in the news about new attempts to hack into important civil government and industrial systems. With the proliferation of UAS and other kinds of autonomous technology, we open up all kinds of possibilities and opportunities for others to hack into the system and to exploit the vulnerabilities embedded in the system. Issues having to do with cyber-physical security merited significant mention, in our view.

Diversity of aircraft: we envision a civil aviation system in which there will be fifty, sixty, seventy-year old aircraft operating along with the latest state of the art autonomous remotely-piloted or unpiloted vehicles. How we accommodate this mix in a functioning civil aviation system is a major challenge. In our discussions, this emerged as a major barrier that needs to be addressed. Many people think that when we start to talk about autonomous systems, we are somehow thereby minimizing the need to address human-machine interface issues. Our committee feels exactly the opposite. On the contrary, we are asking people and new technology, people and machines to interact in ways that we have never dealt with before. We have a whole new realm of human-machine interaction. Humans will always be involved in the operation of these systems, even if for no other purpose than to initiate the mission. And we may have human involvement in other ways. Typically, what we do is to allow an autonomous or semi-autonomous system to perform whatever function until something happens, until something unforeseen happens, and then we ask the human to step in and take over and rescue the situation. This imposes serious requirements with regard to human-machine integration issues.

One of the characteristics of autonomous technology is that it often, or almost always, involves some form of adaptive and non-deterministic system. Here we are talking about technology that learns from experience, and that adapts and changes over time. This has some very profound implications for the certification of these systems. You can’t just take a set of test conditions, input them to the system, look at the output conditions that obtain and say “Yes, this is what it is supposed to do, or not supposed to do.” That sort of input condition can result in a completely different set of output conditions, depending upon the experience of the autonomous system. So these issues of decision-making are a major problem.

We are very good at building sensing systems. You can buy a small printed circuit board for about €18 on a site called sparkfun.com which is billed as a nine-degrees of freedom initial management unit. It has one active chip on it, a triple axis accelerometer, a triple axis gyroscope and a triple axis magnetometer, all in one small unit. Hobbyists and other open source people are buying these things by the thousands and integrating them. So the sensor side of things is fairly far advanced and well developed.

Perception and cognition, that is, applying that information in order to solve practical problems in civil aviation operations is entirely different.

We do not know how machines can perform the perceptual and cognitive tasks that we require of humans. And finally, there is the issue of system complexity and resilience. The civil aviation system is very complex and interconnected. There are many interdependencies. One of the things that we have to ensure is that we design the civil aviation system that will prevent a failure in one part of the system propagating downstream and disrupting the operations of the entire system.

There is a whole area having to do with system complexity and resilience. And finally, there are verification and validation steps. It’s our view that we really don’t have a handle on how to verify and validate, in the formal sense, as we do with present systems. These are non-deterministic and adaptive systems, and verification and validation of them are big issues.

We’ve already heard a little bit about airspace access (Slide 8). Part of the solution to how we keep these vehicles from running into each other is to restrict access to certain kinds of air space. We envision, for example, that many of agricultural operations could be performed in the airspace, say, below 500 feet or 1,000 feet above the ground. There are many ways to go about approaching the issue of keeping these vehicles from colliding with each other or people or structures.

Certification processes will be very challenging. Many of the safety criteria that were used for certification and regulation are based on manned systems or systems that carry either live crew or payload in the form of passengers. The acceptable levels of risk are very, very low indeed. We need to readdress these issues and make sure that the levels of safety we use for regulation are appropriate.

We also identified an issue of trust. Certification of a system is not sufficient. If people don’t trust the technology, they are not going to use it in the way that it was intended or designed to be used. There is a whole area of research into the characteristics of these systems and how they affect the trust of individuals who use them or operate them in the real world. We’ve identified this as one of the major barriers. Finally, we’ve already heard reference to legal and social issues (Slide 8). There is public concern about privacy. These issues are real and very legitimate.

On legal issues, some jurisdictions in the United States and others have recently passed legislation that would allow citizens to shoot down drone aircraft--we think that is probably not a very good thing to do!

In regard to the research issues or barriers, I can be brief, as the research questions that need to be addressed are implicit in all I that I have just covered. Our high level assessment is that in the civil aviation system, a profound change is being brought about by this technology, which also affects many people. Tens of thousands of hobbyists in the US are engaged flying these devices. Every day we see more problems arising. We do not have a regulatory framework in place that adequately addresses these issues and we need to make that happen as soon as possible. The benefits are tremendous, the potential is there – tremendous economic potential for all of these, but moving forward is no simple task. We feel that it is essential that research should be focused on overcoming these problems in practical ways with assistance from the regulation and certification of these systems.