Rules for Preventing Conflicts between Drones and Other Aircraft

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Drones, broadly defined, are unmanned aircraft that can be guided remotely or that can fly autonomously without direct human guidance. This definition encompasses a wide range of aircraft—and potential future aircraft—ranging from small remotely controlled aircraft flown by hobbyists to jumbo jets carrying cargo and perhaps passengers. Many readers are familiar with small drones flown by hobbyists. There are already more of them than there are registered aircraft in the United States. At the other end of the spectrum, although jumbo jets do not yet fly without pilots, their autopilots can be programmed to fly an entire flight without human intervention, from take-off to touchdown, so it is not difficult to imagine that in the future these aircraft will fly as drones, without pilots onboard. In the United States, the Federal Aviation Administration (FAA) certifies both aircraft and pilots and sets the rules under which aircraft operate. This paper discusses how those rules can be modified to incorporate drones into the air traffic system in a way that prevents conflicts between drones and manned aircraft as well as between drones.

The technology that enables unmanned aircraft is advancing rapidly, so any rules should be designed to accommodate not only present aircraft but also future uses. Many technology companies have already begun work to develop unmanned air taxis, for example, that will fly to a customer's location, pick him up, and fly him to a

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preprogrammed destination. Amazon has experimented with package-delivery drones that will fly purchases from a warehouse to a customer. Rules should be flexible enough that they can incorporate all types of unmanned aircraft. To understand how rules can be established to integrate drones into the air traffic system requires an understanding of both the technology and the rules under which aircraft fly and how the technology and rules can prevent conflict.

The technology is available today, although one can imagine future technologies that might be better suited for drone flight. The rules require some type of modification to accommodate drones and perhaps should be completely overhauled not only to accommodate drones but also to make the air traffic control (ATC) system more efficient for all aircraft. After a brief discussion of the technology, this paper focuses mainly on the rules. The simplest possible rule change, one that would work with today's technology, would be to mandate that drones have the responsibility for avoiding all other aircraft, including other drones. Consistent with present rules, the adopted rules might require the FAA to certify the collision-avoidance technology of drones before allowing them to fly, if only to standardize how aircraft can communicate their positions and collision-avoidance strategies to each other.

This paper concludes that a redesign of the rules to accommodate drones can lead to a redesign of the rules for all aircraft, thus increasing the efficiency and utility of the ATC system for both manned and unmanned aircraft.

The Technology of Aviation-Collision Avoidance

The most basic system of collision avoidance, established early on and still in use today, is to have pilots look outside their aircraft to see and avoid other aircraft. Aircraft using that method today are required to stay clear of clouds and fly in visibility good enough to be able to see other aircraft. When weather conditions preclude this, or if aircraft operators choose to fly on a flight plan even in good weather, aircraft fly under flight plans and follow the directions of air traffic controllers, who are responsible for preventing collisions.

The present rules for ATC were developed in the 1940s and have changed little since then. Although the rules were designed for the technology available in the 1940s, the technology for collision avoidance has advanced considerably. The present rules were designed in an era when few locations had radar services, so pilots would track their own locations, aided by ground-based radio navigation facilities, and report their positions via radio to controllers. Controllers would keep track of those locations and would issue instructions to keep aircraft separated from each other. As the use of radar became more widespread, air traffic controllers could see aircraft as blips on their radar screens so that, combined with pilots reporting of their locations, controllers could identify specific blips with specific aircraft. Separation of aircraft was and still is undertaken by air traffic controllers, who keep track of the locations of aircraft. Three significant advances have enhanced the technology of collision avoidance.

First, each aircraft is required to be equipped with a transponder that transmits its location, including altitude, to air traffic controllers.[1] Transponders aid air traffic controllers in identifying aircraft and directing them to avoid conflicts. The transponder allows air traffic controllers to better manage traffic conflicts but does not provide any information or direct assistance to pilots. Transponders are one-way communication devices that send information from aircraft to air traffic controllers.

Second, the Traffic Collision Avoidance System (TCAS) became required equipment on all airliners and was made available for other aircraft. TCAS provides an in-cockpit display of the transponder returns of other nearby aircraft. Coupled with transponder technology, TCAS allows aircraft to electronically see and avoid other aircraft. TCAS-equipped aircraft do not need to visually see other aircraft to detect potential conflicts and steer away from them because TCAS electronically displays them.

Third, Automatic Dependent Surveillance–Broadcast (ADS-B) is available now and will be required equipment on most aircraft beginning in 2020. Similar in principle to TCAS but using different technology, ADS-B uses a global positioning system (GPS) so aircraft can determine and broadcast their own positions. Other ADS-B-equipped aircraft then receive the locations of nearby aircraft, which are displayed in the cockpit. Like TCAS, ADS-B allows aircraft to electronically see nearby aircraft regardless of whether those aircraft can be seen visually, allowing aircraft to steer away from potential traffic conflicts. ADS-B does not require any action on the part of air traffic controllers. Aircraft broadcast their ADS-B data, and other aircraft receive those data directly. Air traffic controllers also receive the data, which help them separate aircraft, but one big difference between ADS-B and the earlier transponder technology is that ADS-B shares data among aircraft directly so they can electronically see each other without involvement by air traffic controllers, whereas transponder data are sent only to controllers, not to other aircraft.[2]

This is a brief summary of the currently available technology for air traffic conflict avoidance. The key point is that the technology already exists for aircraft to electronically locate nearby aircraft so that they can avoid collisions, without the guidance or intervention of air traffic controllers.[3] The following analysis takes this technology for granted to focus on the rules for avoiding conflicts between drones and other aircraft.

1. Transponders report information to air traffic controllers to add a data block to the aircraft's radar-identified location. Transponders send a unique identifier (transponder code) and the aircraft's airspeed and altitude. The aircraft's location over the ground is determined via radar, but its altitude is determined by its transponder and is broadcast to the radar controller.

2. The exception is that TCAS-equipped aircraft can also pick up the data sent by transponders.

3. A more detailed discussion of the technology and the rules is given in Holcombe 2016.

Two Types of Flight Rules

The current ATC system allows aircraft to fly under two sets of flight rules. Some flights operate under one set of rules, whereas others operate under the other set. Under visual flight rules (VFR), aircraft fly where they want, when they want, and are responsible for seeing and avoiding other aircraft. No flight plan is required under VFR, and although pilots can file a flight plan, they are not required to follow it. Exceptions are that at altitudes higher than 18,000 feet or when in the vicinity of an airport with a control tower, pilots must follow the instructions of air traffic controllers.[4] Under instrument flight rules (IFR), aircraft are required to file a flight plan, which then must be approved by and may be modified by ATC. Aircraft flying under IFR are required to fly their approved flight plan, and deviations must be approved by ATC except in the rare case when an aircraft declares an emergency. Airlines are required to fly under IFR, so their flights are always under the control of ATC. ATC is responsible for avoiding conflicts between IFR flights, but VFR flights may present conflicts, and IFR flights are responsible for seeing and avoiding any VFR traffic.

The IFR system is a top-down system for the central planning of air traffic. While trying to accommodate the requested flight plans, ATC assigns routes and altitudes to avoid traffic conflicts and may modify routes and altitudes in midflight if conflicts arise. Flights are directed centrally by ATC, and aircraft must fly on the flight plans assigned them. Collision avoidance is the responsibility of ATC. The IFR system runs as if controllers but not aircraft operators know the locations of aircraft. Although this was true prior to TCAS (unless aircraft could visually be detected), the previous section made clear that today's technology does allow aircraft to electronically see each other and provides the same information about the location of other aircraft to pilots as it does to air traffic controllers. Nevertheless, under IFR, aircraft follow controller instructions, and controllers are responsible for traffic separation, just as in the 1940s, when pilots had no way to electronically locate other aircraft.[5]

The VFR system is a bottom-up system in which pilots fly when and where they want, and they have the responsibility for seeing and avoiding other aircraft. Because in this system pilots are responsible for seeing and avoiding other aircraft, they are required to stay out of clouds and fly in weather conditions good enough that they are able to identify conflicting traffic visually. Under VFR, collision avoidance is

4. The United States has more than 15,000 airports and more than 5,000 airports with paved runways. Control towers operate at only 512 of these airports, so most airports do not have control towers. Aircraft flying above 18,000 feet are required to be on an IFR flight plan. VFR flight is allowed in the vicinity of airports, but pilots must follow controller instructions, just as IFR pilots do.

5. When flying in good visibility, IFR aircraft could come in conflict with VFR traffic, and it is the pilots' responsibility to avoid these conflicts. ATC often provides traffic alerts for potential VFR conflicts but is not required to. It is required to maintain separation between all IFR aircraft but is not required to maintain separation between VFR aircraft or between IFR and VFR aircraft.

decentralized, and it is the responsibility of all air traffic to see and avoid other air traffic. Because general aviation aircraft can choose to fly under either set of rules, aircraft flying under IFR also have the responsibility to see and avoid aircraft flying under VFR.

Although there are many more details in these two types of rules,[6] one big difference is that the IFR system is a top-down system for avoiding conflict among aircraft, in which the responsibility for avoiding conflicts lies with ATC, the central planner, which controls the routing of all such flights. Aircraft are required to follow the plan, including any deviations assigned en route. The VFR system is a bottom-up system in which pilots make their own decisions about how to avoid conflicts, flying when and where they want in a spontaneous order. Each pilot has the responsibility for seeing and avoiding other aircraft.

There are "rules of the road" for VFR flight, but, in contrast to the rules for driving on roadways, most of these rules are advisory and following them is not mandatory.[7] The spontaneous order of VFR flight is similar to the order of automobile traffic. Drivers drive when they want and where they want but follow rules of the road to avoid conflicts. They do not need government's permission before they embark on a trip, and they can change their routes or destinations if they so choose without needing permission. Traffic signals determine who has the right of way, and drivers drive on the right side of the road (in most countries), so that collisions are avoided (for the most part), and drivers can get to their destinations without a central plan, just following their own individual plans.[8]

These two types of flight rules have coexisted essentially in their current state since the 1940s and seem to work remarkably well in the sense that there are very few aircraft collisions. Some aircraft fly government-approved routes and are directed by ATC to maintain separation and avoid collisions. Other aircraft fly under a different set of rules wherein they are responsible for seeing and avoiding collisions. Thus, with these sets of rules in mind, the questions to be explored here are: How can drones be added to the mix, and how can conflicts between drones and manned aircraft as well as between drones themselves be avoided?

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6. These regulations are in Title 14, chapter 1, "Aeronautics and Space," of the Code of Federal Regulations. Flight rules are in part 91, subpart B. VFR are found in part 91.151–61, and IFR are found in part 91.167–93.

7. For example, when flying eastbound, pilots should fly at odd thousands of feet plus 500, and when flying westbound, they should fly at even thousands plus 500, which means they will not be flying directly head on toward each other. For example, eastbound traffic would fly at 5,500 feet or 7,500 feet, and westbound traffic would fly at 6,500 feet or 8,500 feet. This rule also separates IFR traffic from VFR traffic because IFR traffic flies at round thousands of feet—for example, 8,000, 9,000, or 10,000 feet—so there should always be at least 500 feet of vertical separation between IFR and VFR aircraft.

8. Richard Wagner (2007) uses the examples of a parade as a planned, top-down order and of people in a shopping mall as a bottom-up spontaneous order. In both cases, there is an orderly flow of people, one centrally planned and the other individually planned.

Types of Drones

Drones can be divided into two distinct categories: *remotely controlled drones,* which are controlled by someone on the ground, and *autonomous drones,* which are programmed to complete flights by themselves without any human intervention during their flights. Remotely controlled drones can easily be integrated into the ATC system. These drones are controlled by a pilot, but the pilot is on the ground in a remote location rather than in the aircraft. Examples of this type of drone range from military predator drones to small drones used by hobbyists.

Remotely controlled drones can easily be integrated into the ATC system by applying to them the same requirements for manned aircraft. IFR require aircraft to be equipped with technology that allows ATC to identify the aircraft's location, altitude, and airspeed, and ATC is responsible for separating aircraft. The remote pilot can follow ATC instructions just as if the pilot were in the aircraft and can detect nearby aircraft with its onboard technology. One can easily imagine FedEx jets and eventually passenger airliners being remotely piloted.

IFR flight for the remotely controlled drones of hobbyists seems infeasible for several reasons. First, the expense of the equipment to broadcast the drone's location and electronically see other aircraft would far exceed (at current prices) the cost of the drone. Second, the weight of that equipment (at current weights) would prevent most hobbyist drones from being able to fly. Third, the practicality of having hobbyists file flight plans is questionable. And fourth, if they did file flight plans, the ATC system would be overwhelmed with drone flight plans.

Under current rules, hobbyists must fly their drones within line of sight, so they can see and avoid conflicting traffic, just as under VFR. Also, current rules require drones to fly at altitudes lower than 400 feet above the ground, whereas manned aircraft are required to maintain altitudes of at least 500 feet under most conditions, except when taking off or landing. Essentially, current rules segregate drones and manned aircraft by defining separate blocks of airspace for each and by requiring hobbyists flying drones to maintain visual contact with their drones.

Amazon's proposal of package-delivery drones is not feasible under current rules, first, because these drones would fly out of operators' line of sight and, second, because they will be designed to fly autonomously, without any direct oversight by a remote pilot: program in the delivery location, and the drone will fly there without human intervention to deliver the package. At the beginning of the twenty-first century, package delivery by drone would have sounded like science fiction, but with the development of self-driving car technology, it is easy to envision how this would be done, even if there are remaining difficulties in the way.

As with self-driving cars, it is easy to imagine drones equipped with maps, with GPS to identify their current locations, and with sensors to detect obstacles in their paths, autonomously finding their way to their destinations. The engineering challenges involved in designing drones are obvious. Less obvious are the challenges involved in designing the rules that will avoid conflicts between drones and other aircraft. Challenges in the design of the rules fall into two distinct categories. The first is how aircraft can locate conflicting aircraft so they can avoid them. Aircraft have to be able to detect each other's location to avoid each other. The second is, given the information regarding the locations of other aircraft, what rules should govern how aircraft avoid the other aircraft they can see nearby.

Locating Other Aircraft

Under VFR, pilots visually see and avoid each other. For this to work, aircraft flying under VFR must abide by the rule that they do not fly in clouds because pilots cannot see other aircraft when they are flying in clouds. There are two separate questions here. The first is, How do aircraft reveal their locations? The second is, To whom do they reveal their locations? In the case of VFR, aircraft reveal their locations by remaining clear of clouds so that other aircraft in their vicinity can spot them. And they reveal their locations to other aircraft that are also clear of clouds and close enough to see them.

Now consider those same two questions with regard to IFR aircraft. With transponder technology, these aircraft reveal their locations electronically by broadcasting them using their transponders. And they reveal their locations only to air traffic controllers, who are responsible for separating the aircraft. They do not reveal their locations to other aircraft. With TCAS and ADS-B technology, however, aircraft reveal their locations to both air traffic controllers and other aircraft, so all aircraft can locate each other electronically. With respect to just the rules, however, the IFR system works as if aircraft cannot see each other, so separation of aircraft is maintained by air traffic controllers on the ground.

Under VFR, there is a rule that separates aircraft: aircraft must fly clear of clouds so they can be seen. Under IFR, under which locations are revealed electronically, a rule must specify a standard mechanism for electronically revealing location. To do so requires a standard protocol for reporting, including the frequency with which the report will be made and the format of the data so that they can be decoded by the recipient.

Is there a role for government in establishing rules for aircraft to electronically reveal their locations? One can see that standardization is necessary. For electronic "see and avoid" technology to work, it not only has to be standardized but also has to be required to prevent risk-loving aircraft operators from flying aircraft that are electronically invisible. One can see why this would be important with drone flight: drone operators with relatively inexpensive drones might be willing to avoid the cost of employing the technology and in the process endanger passenger-carrying aircraft.

One can conjecture that private agreements and contracts could ensure standardized electronic reporting of aircraft location and require that aircraft report their locations electronically. However, the current government rules already do this via the

ADS-B requirement that takes effect in 2020, and they did so before the private sector developed its own standards. This seems like a case where Mancur Olson's (2000) market-augmenting government can aid in both standardizing the electronic reporting requirements and mandating them. Libertarian anarchists might argue that the market could do these things without government mandates. A key point, however, is that the rules have to cover two things: how aircraft report their locations and what rules govern conflict avoidance. This section has discussed only the first issue.

Rules for Conflict Avoidance

From the discussion so far, one can see that the technology for conflict avoidance has far surpassed the rules, which are based on technology developed in the 1940s. Given today's technology, a simple rule for autonomous drones could be that they can fly where they want but are required to electronically see and avoid all other aircraft. If drones were equipped with ADS-B, they could electronically spot the locations of potential conflicting aircraft, the same way that aircraft under VFR do visually. They could then autonomously follow "rules of the road" to steer away from conflicts. For example, when a conflict appears, both aircraft could turn to the right.[9] Drones could seamlessly be integrated into the ATC system this way: allow remotely piloted drones to fly IFR under the same rules as manned aircraft and allow autonomous drones to fly where they want and when they want as long as they electronically see and avoid other aircraft.

For small drones such as Amazon package-delivery drones, ADS-B may be relatively costly and heavy, but other technology could be developed to tie into the system. For example, drones could report their locations to an Amazon central reporting location via the cell phone network, and the data could then be transmitted to other aircraft by Amazon from the central location via ADS-B. Any drone operator could be allowed to do this, thus tying a privately operated network with its own standards and technology to the ADS-B network.[10] The point is that given the rules for aircraft location reporting discussed in the previous section would also apply to drones, and drones could then be integrated into the ATC system by the simple requirement that they electronically see and avoid other aircraft. The technology exists now even though the rules do not allow it.

If drones are allowed to determine their own flight paths, limited only by the restriction that they must electronically see and avoid other aircraft, it would be a small step to allow all aircraft, manned and unmanned, to do the same thing. This step would

9. There are currently other "rules of the road" that help prevent conflicts, including standard flight paths when approaching airports and different altitudes depending on direction of flight (as described in note 7). As pointed out earlier, the relatively few collisions between in-flight aircraft suggest that the current rules are fairly effective.

10. Note that ADS-B is not a government-owned or operated network. Government has established the standards and requirements, but aircraft in the network communicate with each other without any government involvement.

essentially extend the current "see and avoid" VFR to all aircraft as long as they have the capability of electronically seeing and avoiding other aircraft. With current technology, aircraft no longer need to remain clear of clouds to see and avoid each other.

The idea of aircraft being able to determine their own flight paths independent of ATC is not a new idea. It was touted in the 1990s under the name "free flight," and Jacques Leslie (1996) explained the concept and predicted that it would be in place by 2011. The Radio Technical Commission for Aeronautics (1995) initiated the technical details for how the system would work, but, despite the promotion of the idea, the rules and procedures for aircraft separation remain the same as they were in the 1940s. The issue is not that progress toward free flight has been slow. Rather, it is that there has been no progress.

Thinking about how drones can be integrated with the ATC system to avoid collisions between drones and manned aircraft suggests improvements to the system of rules applied to all aircraft. A new set of free-flight rules (FFR) could be established either to replace the current rules or to allow a third option for aircraft.[11]

Free-Flight Rules

A set of rules for how aircraft reveal their locations already exists in the ADS-B standard. It enables aircraft to electronically see other nearby aircraft, which then can be avoided the same way that aircraft flying under VFR avoid other aircraft under the current set of rules. FFR would allow aircraft to determine their own flight paths to fly where they want, when they want, and make them responsible for electronically seeing and avoiding other aircraft. Because the technology now allows aircraft to see each other electronically, FFR would essentially extend the VFR to aircraft in all weather conditions. The current VFR show that they have been effective in avoiding conflicts between aircraft.

11. This discussion has focused on flight rules and drone regulations in the United States. Rules in other developed economies are similar and often more restrictive. Germany requires drones to remain in sight of their operators, to remain below 100 meters, and to follow other restrictions. Drones must be labeled with the name and address of the operator and are required to carry liability insurance (which typically costs around $100 per year). Drones heavier than eleven pounds require special permission from local governments. Exemptions can be requested, but the application process is costly and requires some time for approval. Drones are not allowed to be flown within 100 meters of federal highways, waterways, rail systems, and hospitals and may not be flown above nature reserves.

Great Britain also requires drones to remain in sight of their operators and has a 400-foot height restriction. Drones with cameras are subject to additional restrictions. The line-of-sight requirement applies to commercial as well as recreational drone use. In France, drones also must remain in sight of their operators and may not be operated at night, over public spaces in urban areas, or over sensitive or protected sites. Drones must be flown at heights lower than 150 meters. Rules are even more restrictive in Belgium, Netherlands, and Austria. Spain requires a license to fly a drone and has restrictions similar to those of other European nations. Canada has a 90-meter-height restriction and requires drones to remain in sight of their operators and to be marked with the operator's name, address, and telephone number.

A review of drone regulations indicates that regulations in the United States are similar to those in other countries and that where they differ, they are less restrictive. The requirement that drones remain in sight of their operators is especially limiting to commercial operations such as package delivery. Rules surely will adapt to commercial drone activities, but the point of this review is to indicate that other countries have not developed rules more friendly to commercial drone operations than the rules followed in the United States.

The FFR could either replace IFR and VFR or be added as an option so that aircraft could fly under any of these rules, as their operators choose. Some complications and how to resolve them are discussed in Holcombe 2016, but the basics of FFR are very straightforward and simply allow the adoption of current state-of-the-art technologies to extend the availability of current VFR flight to all weather conditions.

The Advantages of Decentralized Decision Making

Proponents of the current sets of rules rightly point out that they have been very effective at avoiding conflicts among aircraft. At the same time, critics complain about congested airspace, and pilots and flight operations are prone to complain about routings that add time and distance to their flights. These complaints are often the result of the centralized separation of air traffic in the IFR system. VFR flight and the proposed FFR flight would be decentralized, with aircraft operators making their own decisions about where to fly and how to avoid conflicts with other aircraft. A decentralized system would add capacity to respond to some of the complaints people make about the current system, which was designed around the technology of seventy years ago.

Automobile travel operates under a decentralized system where drivers see and avoid other traffic, following rules of the road that make it easier for them to coordinate their activities with each other. Imagine how much the traffic capacity of roads would shrink if autos operated in a system like the IFR system. Drivers would have to file their travel plans ahead of time and have them approved by the road traffic controllers, and then the controllers would be responsible for separating traffic. This would necessitate much greater vehicle separation because controllers could let traffic on the road only if they could be assured there were no collision potential. Vehicles would have to receive permission before they could deviate from their driving plans and might be rerouted if conflicts appeared in midtrip. It does not require much imagination to see that such a centralized system of traffic control for automobiles would greatly reduce the traffic-carrying capacity of roads. The same is true of the ATC/IFR system, with its centralized control: it greatly reduces air traffic capacity. Adopting FFR would increase system capacity and reduce airspace congestion.[12]

12. My own experience as a pilot reinforces this conclusion that ATC reduces capacity because of its separation rules. I often have to wait to take off at airports with control towers because of landing traffic even though that traffic is far enough away that I could make a safe take-off. On a recent flight, I was landing when an airliner was ready to take off on a crossing runway. The tower controller told the airliner to hold short until I landed. I could see that there was plenty of separation to allow the airliner to take off ahead of my landing, and without the controller I would have radioed to the airliner that there was a safe separation for it to depart. (Not surprisingly, the controller would not have taken kindly to any suggestion I might have made to that effect.) When landing at airports with control towers, I am often routed unnecessarily away from the airport to avoid other traffic that is not a factor in my landing. On occasion, the radar has been out of service at my home airport (Tallahassee International Airport), and when that happens, pilots are on their own after departure and when approaching the airport. I have consistently found that this has allowed me to follow a more direct route to and from the airport and that there have been no accidents during those (rare) times when the radar has been out of service.

Another potential problem with centralized ATC is that if there is a system failure, it affects all the aircraft in the area. There have been a few widespread system failures, with examples reported by Fredrick Kunkle (2015) and Bradley Sunshine (2015), in which technical problems with ATC have greatly reduced the system's capacity. These technical problems do not affect VFR traffic, which finds its own way, but they delay or cancel IFR flights, including all airline flights. With FFR, a decentralized system, any failures would be in individual aircraft and would affect those aircraft only, not the entire system.

The general principles underlying the advantages of decentralized decision making in the separation of aircraft are the same as the principles related to decentralized decision making in economies. Friedrich Hayek (1945) discussed the way market economies coordinate the activities of individuals so that they can make best use of the knowledge that other individuals have without actually having to acquire that knowledge. In ATC, the decentralized knowledge of the locations and intentions of aircraft operators is passed up and aggregated by air traffic controllers, who then take that information, create a central plan that separates traffic, and then pass instructions back down to the pilots, who are treated as if they do not have a good picture of their surrounding environment because they interact only with the controller. But current technology does enable aircraft operators to electronically see the traffic in their vicinity so they can determine how they can best coordinate with other aircraft and fly where they want to while minimizing deviations from their plans.

What Role Should Government Play?

This paper has distinguished two types of rules necessary to prevent conflicts among aircraft. The first type sets rules for how aircraft electronically disclose their locations, and the paper has noted the potential for government to play a productive role by setting standards so that all aircraft would use the same electronic reporting systems and by requiring that aircraft use them. Given these rules, the second type of rules dictates when and where aircraft can fly and how conflicts are avoided. There is less of an argument for government involvement in this type. Given that all aircraft electronically report their locations, aircraft operators have all the information they need to avoid conflicts with other aircraft. They could avoid conflicts without any government oversight.

The squeamish might argue for government oversight for the same reason that (some) people see utility in traffic police on roadways: to make sure that certain protocols are followed so that some aircraft do not recklessly endanger others. Even so, current technology would allow a system in which government ATC would play much less of a role, perhaps limited to monitoring the decentralized decisions made by the operators of individual aircraft. There is a more solid argument for government involvement in setting standards for aircraft to electronically report their locations than for government to centrally organize and direct the flights of aircraft.

Conclusion

Policy makers are currently grappling with designing rules under which unmanned aircraft are allowed to fly. The major challenge has been fashioning those rules so that unmanned aircraft do not conflict with manned aircraft. The technology already exists that would allow drones to electronically see and avoid other aircraft, so the only rule that would be necessary is to require that drones are equipped with that technology and that they have the responsibility for avoiding other aircraft. Under this type of rule, conflict avoidance would be undertaken in a decentralized manner, with drone operators making their own decisions rather than utilizing the centralized system that airlines and many other aircraft now use.

The current ATC system is mostly a design from the 1940s, intended to separate aircraft using the technology that was available then. With current technology, it would be possible to extend the decentralized system proposed for drones to all aircraft, not just to drones. Current technology allows aircraft to electronically see each other, so conflict avoidance can be undertaken by the aircraft operators themselves rather than being centrally directed by ATC. This decentralized system would have the advantages of reducing air space congestion and minimizing the cost of equipment failures, which under the current system can greatly reduce the ability of centralized ATC.

Commercial drones show incredible economic promise, with applications ranging from package delivery to pipeline patrol, crop dusting, and taxi and ambulance service. As technological developments bring these possibilities closer to fruition, government rules for air traffic control may stand in the way. Consideration of the rules to enable these potentials for drones points toward rule changes that can enhance manned aviation as well.

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