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The ground controller has got to go.

The Role of Computers in Air Traffic Control

By

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A PILOT FLYING VFR in clear weather is unlikely to see more than a few other aircraft on a typical flight; to him the sky seems to be a rather empty place. Yet to the pilot stuck in an IFR hold with an estimated-further-clearance time forty-five minutes away, the sky seems to be an order of magnitude more crowded. Why? Clearly there is no shortage of airspace; every VFR pilot knows that. The aircraft flying under IFR have the best equipment and the most proficient pilots aboard. Where does the congestion come from?

The fundamental difference between VFR and IFR lies in whether pilots or air traffic controllers are separating aircraft. Therefore, it seems reasonable to attribute the comparatively low capacity of the IFR system to some failing on the part of the controller. But controllers are made out of the same sort of human protoplasm as pilots; why shouldn't they be able to separate aircraft as efficiently as pilots can? The answer: a pilot is concerned with the particular aircraft that he's flying, but a controller has to keep track of several aircraft at once. Give a person several things to do at once, even simple things like head-patting and tummy-rubbing, and his performance in each drops sharply. Keeping track of a high-speed airplane is considerably harder than either head-patting or tummy-rubbing. Keeping track of a dozen such airplanes travelling in random directions at random altitudes is simply beyond the capabilities of any man. So what can the poor controller do? He can eliminate much of the randomness by stringing all the airplanes along a few airways at a few standard altitudes, thereby making the aircraft much easier to keep track of, but thereby wasting most of the available airspace. He can slow the airplanes down to make them easier to follow. He can space them so far apart that nothing bad will happen if he "loses the picture" for a short while. If all else fails, he can make them fly little racetrack patterns in the sky. But every time the controller does one of these things, he reduces the capacity of the system.

In fact, the only congestion in the IFR system exists within the mind of the air traffic controller. The controller is being asked to do a job which is well beyond his mental capabilities. He is therefore the system's biggest bottleneck, and potentially its greatest hazard. This is true despite the fact that, in most cases, the controller is doing the very best that is humanly possible.

The ironic thing is: keeping track of a dozen or even a thousand high-speed airplanes travelling in random directions and at random altitudes is really a very simple task! For a computer.

A MODERN electronic computer is a marvelous device. For one thing, it is extremely fast. It can perform a simple operation like multiplying two ten-digit numbers in a few millionths of a second. More complex tasks, such as determining whether two aircraft are on a collision course or not, may take as much as a few ten-thousandths of a second to complete. This high speed is very important because, like a human, a computer can only do one thing at a time. But suppose a computer is watching a thousand aircraft, and suppose it takes the machine 5 ten-thousandths of a second to check on a particular aircraft and make sure that it is out of trouble. At this rate, the computer can check on each of the thousand aircraft twice a second. Since an aircraft can't get into very much trouble in half a second, it is just as if the computer were maintaining a continuous surveillance on all thousand aircraft, for all practical purposes.

An electronic computer has a very large memory, so it can remember all pertinent information about many thousands of aircraft at one time. Such data as position, altitude, speed, route, and destination of each aircraft can be remembered in high-speed memory and can be accessed in less than a millionth of a second. Less frequently referenced information, such as meteorological data, NOTAMS, aircraft characteristics, and the contents of low- and high-altitude enroute charts, can be stored in less-expensive low-speed memory, and might take as long as several thousandths of a second to retrieve.

It is important to mention that modern computers are very reliable. In fact, by making a computer system highly redundant, we can build computers that are virtually infallible. Anyone who has recently received a bill for "$0.00" may find this somewhat hard to believe, but the flawless performance of the many computers involved in NASA's Apollo missions are a good example. The fact is, of course, that extremely reliable computers cost more than fairly reliable ones. NASA's computer budget is very large. The FAA's is, too.

AT THIS POINT, there is an obvious question to be answered. The FAA has been installing multi-million dollar computer systems in the various air route traffic control centers (ARTCC's) at a brisk pace. How come the congestion is getting worse? The answer is sad to relate in an audience of fellow taxpayers: the FAA is using these fabulous machines to do the wrong jobs! They are being used to display little identification labels next to targets on a radar scope (the so-called "alphanumeric" radar). They are being used to calculate and display the groundspeed of these targets, and their altitude as well when the aircraft is squawking mode C. They are being used to check that the routes that we file in our IFR flight plans really make sense, and get us where we want to go. They are being used to distribute flight plan information to the various sector controllers involved in a flight. But the sole responsibility for separating IFR aircraft remains with the human controller, and so the fundamental limitation on the capacity of the IFR system remains.

IF A COMPUTER were given direct responsibility for controlling and separating aircraft, how could it communicate with the pilots of the aircraft it would be controlling? There are two possibilities here. Computer-driven speech generation equipment is available which permits a computer to "speak" in a voice which is highly intelligible, if somewhat unnatural sounding. But since a computer can "think" so very much faster than it could ever "speak," it seems a pity to constrain it to this slow communications medium. A better approach would be to let the computer actually print clearances in the cockpit, probably on the face of a small TV-like display located on the panel. This would be fast, noiseless, and would eliminate the necessity for "copying" clearances by the pilot. In practice, both methods could be used in parallel: the computer would "speak" to all aircraft not equipped for receiving printed clearances.

Would computerized ATC cause several thousand air traffic controllers to become unemployed overnight? Not at all. The human controller would have the important responsibility of monitoring the operation of the system, and for intervening when exceptional conditions arise. The relationship of the ATC computer to the human controller would be much like the

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relationship of an autopilot to a human pilot. The transition to a computer-controlled ATC system would be accomplished initially by placing the computer "on probation," and treating it in much the same way as student controllers are now treated. At first, the computer could be set up to give instructions only to a human controller, who would vocally relay them to the pilot after satisfying himself that they were correct. Later, the computer would be allowed to communicate directly with pilots, but a human controller would carefully monitor all communications and manually take over if any problems came up. Finally, the computer would be given its "journeyman controller" rating and would take on full controlling responsibility. When this stage is reached, the human controller will intercede only when either the computer or a pilot asks him for help in handling an unusual situation such as an inflight emergency, an equipment failure aloft or on the ground, etc.

The kind of computerized air traffic control that we have been discussing has been easily within the scope of computing technology for several years. In fact, the computers presently installed in ARTCC's are quite adequate for the job. It is not a lack of technology or funds that stands in the way of automated ATC, but rather the conservatism and inertia of the FAA combined with a lack of imagination on the part of government contractors.

TWO VERY RECENT technological developments promise to revolutionize air traffic control. They permit a system to be developed in which the pilot and his passengers enjoy the speed and flexibility of VFR combined with the weather independence of IFR, and considerably greater safety than either. Let's examine these two developments, and then take a look at what the ATC system of tomorrow might look like.

One of the country's leading aerospace firms has recently announced the development of a system of synchronous orbiting satellites which could have significant impact on air traffic control. The details of this system are proprietary, but generally speaking the system consists of several satellites which interact with inexpensive transponders installed in airborne aircraft; these satellites are then capable of keeping a large ground-based computer system continuously informed of the precise position of each aircraft. This system has neither the coverage limitations nor the weather susceptibility of radar, and it determines position with far greater accuracy.

A second important technological development is called "large-scale integration," or "LSI" for short. Civil rights is not involved here. LSI refers to a technique whereby hundreds of microscopic computer circuits can be created on the face of a miniscule silicon wafer. The effect is to make it possible to build "mini-computers" less than one tenth the size and cost of those presently available. The smallest mass-produced computers today weigh about 20 pounds and cost around $5,000: these do not employ LSI. It is easy to see, then, that LSI makes it possible to build high-speed electronic computers which could be installed in any aircraft as readily as a nav/comm, and at comparable cost.

Now, suppose there are 10,000 aircraft airborne in U.S. airspace. (It's unlikely that that many aircraft could ever be flying at one time, but let's be pessimistic.) Further suppose that each of them has a $500 satellite-transponder and a $1,500 mini-computer aboard. By means of the synchronous orbiting satellite system, a large computer complex on the ground knows the position of each aircraft at all times. The computer complex is hooked up to a nationwide network of radio transmitters, which we shall call "the ATC network." Each second, the network transmits the identification and precise position of every airborne aircraft.

Wait a minute, I hear you cry! How on earth could the precise positions of 10,000 aircraft be broadcast in the space of one second? In fact, this is quite easy to do. Con-

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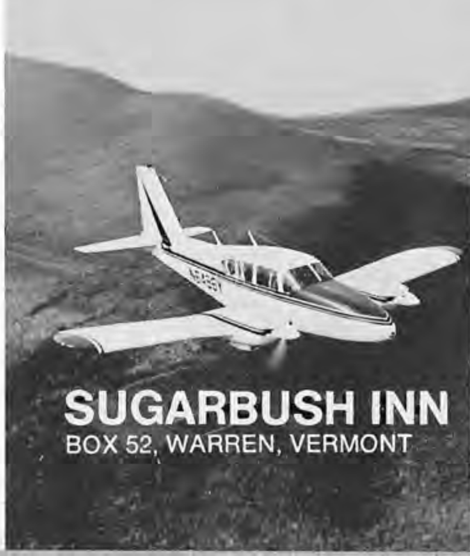

sider an ordinary color television screen: it is made up of about 1.2 million red, yellow, and blue dots. To broadcast a single picture frame, a television station must transmit enough information to tell the TV set just how bright or dim to make each of its 1.2 million color dots. Furthermore, a television station transmits 30 of these frames each second! As it turns out, the information required to transmit the i.d. and position of 10,000 aircraft, locating each one within a tenth of a mile horizontally and ten feet vertically, is less than the information in one frame of a color TV picture. So the transmitters in the ATC network are actually slowpokes in comparison to those in the television networks.

NOW LET'S GO UP in one of the airborne aircraft and see how its mini-computer works. The airborne computer is connected to a receiver tuned to the ATC network, and so it is exposed to a continuous high-speed stream of aircraft position reports. Obviously, one of the 10,000 position reports in each one-second broadcast is the position of the particular aircraft in which the computer is installed, or "host" aircraft. Since the computer knows the identification of its host aircraft, it can pick this position report out of all the rest and treat it specially. As the computer goes through the remaining 9,999 position reports, it simply ignores all aircraft which are more than 100 miles horizontally or 10,000 vertically from the host aircraft, but it keeps track of the positions of the few hundred aircraft which fall within these bounds (including the host itself). Furthermore, since the computer is very good at arithmetic, it can work simple rate-time-distance problems on each of these aircraft, and thereby determine the course, groundspeed, and vertical speed of each one.

The airborne computer is hooked up to a small cathode ray tube (CRT) display located on the pilot's instrument panel; the display resembles a tiny television screen. Upon this screen, the computer depicts the positions of those aircraft which are potential collision hazards to the host aircraft. These include all other aircraft within a 25-mile radius which are cruising at an altitude within 1,000 feet of the host's altitude, or which are climbing or descending in such a way that they might pass through the host's altitude. The display also includes any aircraft within 25 miles whose altitude is unknown to the computer (more on this later).

This computer-generated picture bears some resemblance to a radar display. Each aircraft is represented by a symbol whose position on the screen indicates the distance and relative bearing of the aircraft from the host; the symbol representing the host aircraft itself appears in the center of the screen. The shape of the symbol indicates whether the traffic is flying level, climbing from below, or descending from above. Extending from each symbol is a "tail" – a small line whose direction and length represent the course and groundspeed, respectively, of the corresponding aircraft. Recall that the airborne computer starts watching aircraft when they're 100 miles out; by the time they get close enough to be displayed, the computer knows exactly what they are doing.

With this kind of display on the panel, the instrument pilot can "see" and avoid other aircraft even more easily than a VFR pilot on a CAVU day. The responsibility for separation is in the cockpit, where it belongs. Instrument flight is conducted without the necessity for clearances from the ground, and the pilot is free to select his own routes and altitudes (subject to hemispherical-rule and terrain-clearance considerations). Of course, if the flight proceeds from or to a controlled airport, the normal tower communications are necessary, but outside of the control zone the pilot is on his own. IFR and VFR are indistinguishable except for weather minima.

SINCE the airborne computer is continuously aware of the host aircraft's position, it can be used for navigation as well as collision-avoidance. The computer can easily supply the pilot with his course and groundspeed, since it calculates this information anyway. Furthermore, if the pilot supplies the computer with the geographical coordinates of any point (such as the destination airport), the computer can provide a continuous readout of the distance and direction of that point from the aircraft, plus a continuously updated ETA. Thus, it is easy to see that the airborne computer can provide a comprehensive area-navigation capability. This capability is superior to that provided by VOR/DME/CLC equipment, because its accuracy is better and because it does not depend upon reception of ground-based navigation facilities. (Of course, it does depend on reception of the ATC network.) When the host aircraft is within 25 miles of the destination, the computer can even display a special airport symbol on the CRT, permitting the pilot to fly as if he had the airport in sight!

UP UNTIL NOW, we have assumed that all aircraft are equipped with the transponder, computer, and display equipment. Clearly such avionics are mandatory for any instrument operations, but there is likely to be a class of VFR-only aircraft which aren't equipped this way. The present IFR system does not attempt to provide separation from non-IFR aircraft, but we can do much better than that. Suppose the large ground-based computer complex which feeds the ATC network is connected to the existing system of primary radar. The ground-based computer can then attempt to correlate each radar target with a corresponding satellite-provided aircraft position. Any targets which cannot be so correlated are assumed to be unequipped aircraft. Position reports for these aircraft are included in the ATC network broadcast, and these reports are tagged to indicate that the altitude is unknown. A special symbol is provided on the airborne CRT displays for such targets.

FINALLY, let us consider what happens if an aircraft experiences an inflight failure of any of the special avionics that we have been discussing. If the computer/display system fails, the pilot becomes immediately aware of the situation because he loses "the picture" from his CRT. Since he has a conventional nav/comm aboard, he can use ordinary VOR navigation to reach his destination or a nearby alternate. Since his transponder is still operating, other aircraft can still "see" and avoid him. When the pilot gets a chance, he dials a special "failure code" into his transponder (not unlike the present 7600 squawk). When the ground based computer sees this code, it tags the position report of the distressed aircraft so that it appears as a special symbol on airborne CRT's to indicate that this airplane is flying "blind."

Suppose, on the other hand, that the satellite-transponder fails. The ground-based computer immediately becomes aware of the situation because the satellite system ceases to provide the distressed aircraft's position. If the aircraft happens to be in primary radar coverage, the computer will follow him by radar. If there is no radar contact, the computer continues to broadcast estimated position reports, based on the aircraft's last known position, altitude, course, and groundspeed. This position report is specially tagged as "estimated," and appears as a special symbol on airborne CRT's. Other pilots will note the special "estimated position" symbol and give the aircraft an extra wide berth. Meanwhile, the pilot of the no-transponder aircraft will observe the special symbol in the center of his CRT, and can determine that his transponder must be out. He will then transition to VOR navigation, and use his comm transceiver to make frequent position reports. These reports will be manually fed to the ground-based computer, and used to revise the computer generated position estimates.

How soon could such a utopian system of air traffic control be developed? An educated guess is that, if a full-scale effort were begun now, such a system could be both technically and economically feasible with five years.

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