Analysis

An air traffic control system for the twentieth(!) century

By Richard L. Garwin | 4 November 2007

In recent weeks, news reports have brought attention to a vision of air traffic control that would increase safety, reduce costs, and increase the capacity of the national and international air space to facilitate air travel. This same vision was specifically proposed in 1971 by the Air Traffic Control Panel (ATCP) of the President's Science Advisory Committee (PSAC), which I led. (See our final report, "Improving the Nation's Air Traffic Control System" PDF [PDF].)

Neither President George W. Bush's demand for the Federal Aviation Administration (FAA) to increase capacity of the commercial aviation sector, nor the disappearance of the private craft piloted by Steve Fossett will suffice to change a system for the better. But it may help to know what can be done.

In brief, after a substantial analysis of the problems and opportunities, including a comparison with the actual FAA plan, the 1971 ATCP proposed an all-satellite system that would replace voice communication with the cockpit with text communication that would be displayed and stored onboard, a position-monitoring system that would use time difference of arrival (TDOA) of radio signals to or from the aircraft to determine their precise positions, and autonomous navigation provided by TDOA in precisely the fashion that the Global Positioning System (GPS) now operates. This is also a TDOA system, with the radio receiver and computer in the cockpit, or available by radio relay in the case of small aircraft that in the 1970s might not have been able to carry computing capability.

Thus, the three essential functions of air traffic control (communication, monitoring, and navigation) would all be performed via satellite systems, which might or might not be integrated on the same satellites.

For the United States, it was clear that a single ground station would suffice to do all of the computations and control, although the report recommended at least two such facilities to reduce the vulnerability to natural disaster or attack on the facility.

Both the substance and context of the report are of possible interest. In fact, it is bizarre that the control of air traffic, which touches the lives of almost all of my readers, has not attracted more attention from the general public. 1969 was the peak of frustration for flight delays and disruptions. I flew every few days from LaGuardia Airport in New York City to Washington National Airport in D.C.; in that era, air traffic controllers would get the aircraft off the ground on time as much as possible and accommodate landing delays by holding the aircraft in "stacks" near the terminal area. I recall once taking 11 hours and two stops in flying on the Washington-New York air shuttle, and 6-hour trips were not that unusual.

ATCP members visited both en-route and terminal air traffic control centers; we had passes that allowed us to fly in the cockpit of commercial aircraft to gain firsthand experience. As usual, we met two days a month for deliberations and to gather information from government organizations, contractors, airlines, airline pilots, and operators of private aviation.

Our report not only analyzed the situation as it existed in 1970, but also the FAA plan for the future. The FAA plan included greater use of data link to reduce the reliance on radio voice communication. Our report also investigated altitude-reporting radio transponders that en-route FAA radar would (and now does) use to display the altitude of the aircraft being viewed by means of the aircraft-carried beacon responding to the radar pulses. Our approach looked at system performance and investment and operating costs and took advantage of new computer and communication technology.

We proposed that satellites should carry out communication, minimizing the communication burden and the deployment and operating cost by emphasizing data communication instead of voice. We worked out the number of bits required for standard air traffic control messages and found them well within the capacity of the era's economically deployable systems to handle the entire communication load for 50,000 aircraft simultaneously airborne within the United States. Each of the messages would be recorded in computer storage at each end and displayed routinely and on demand.

Today, it is easy to describe our proposed "one-way" navigation system, which was indeed GPS. But in those days, the self-contained GPS computer would have cost several thousand dollars; we therefore also provided the option of a two-way navigation system that would work with the aircraft's position-monitoring system. For such a system, receivers on separate satellites (or co-located on navigation satellites) retransmit to ground stations a special pulse that each aircraft would radiate. In principle each aircraft would possess a distinguishable pulse of 511 "chips" that would be broadcast in a sequence of 0.1-microsecond chips, for a total pulse length of 51.1 microseconds, once a second, for each aircraft. But in order not to require 50,000 different pulses, we categorized them by the pulse repetition rate (PRR), over a range from 1 to 1.1 seconds. Each aircraft would be assigned a specific PRR, which would serve to distinguish one pulse sequence from another. The fact that the navigation pulse from aircraft A, for instance, would come at this precisely fixed interval would allow the ground computers to search for the next pulse from an aircraft, from a location that for a subsonic aircraft would always be within 1,000 feet of the previous location. Each pulse would be received on at least four satellites and retransmitted to the operating ground station and to any number of backup stations.

In principle, a single short pulse of duration 0.1 microseconds at a suitable frequency would serve. But it would require a peak power of about a megawatt (an average power on the order of 0.1 watts), and in order to use the era's tiny vacuum tubes or transistors, we selected a so-called "compressible pulse."

To minimize the burden on the air traffic control system, each aircraft was proposed to file a digital flight plan and to follow that plan unless an updated plan was filed. Because all aircraft could use "area navigation," they would not bunch (or potentially collide) along the routes defined by ground navigation aids; we recommended a concept termed "intermittent positive control" that would require the air traffic controller to intervene only when a potential collision might occur in the next minute or so, on the assumption that each aircraft followed its flight plan as updated by the pilot or by the surveillance system if the flight plan was being followed, but perhaps with some delay.

We gave considerable attention to the ground stations' physical vulnerability, and some to intentional interference (jamming) of the links to or from the satellites. In military systems, operations in the face of hostile acts such as jamming is a primary concern; it would be here as well, if the world's air traffic control system depended on unimpaired operation of the system. The report does consider the benefits of the all-satellite system with a navigation or surveillance accuracy on the order of 100 feet in providing the basis for blind landings at airfields without expensive equipment. Airports could, however, have inexpensive pseudolites that would receive GPS signals and broadcast their own, to provide both a stronger signal locally and one that is geographically more advantageous than any of those received from satellites. This would substantially ease the local jamming problem and provide about 1-foot accuracy, entirely adequate for blind landing and taxi.

Naturally, we planned to distribute the unclassified report widely within the government and to publish it. Instead, in PSAC's waning days (President Richard Nixon eventually eliminated it in February 1973, purportedly "to save money"), the Department of Transportation suppressed the report--an unprecedented act by a government department. In 2007, I placed a copy in the "Garwin Archive."

The TDOA system had historic roots. President Dwight D. Eisenhower proposed the "Open Skies" regime on July 21, 1955, with the purpose of preventing an accidental war because of a possible Soviet response to what Moscow might regard as U.S. bombers penetrating its airspace. In response, I proposed implementing a system in which U.S. bomber aircraft would carry free-running transmitters (each broadcasting about once every second, the signals from which would be picked up by special satellites and returned to ground stations on Earth) to provide TDOA locations of the bombers; the time differences in arrival of radio signals at the ground stations via the various satellites would be converted to path differences by multiplying by the known speed of radio waves--the speed of light in vacuum: 300,000 kilometers per second. This would have been used in exercise mode and presumably turned off in wartime. The purpose was to reassure Moscow that the bombers remained well outside Soviet territory. (See "Proposal for an International Air, Sea, and Space Traffic Control Using Radio Beacons on the Vehicles" PDF [PDF].)

But it was not easy for a new navigation system to gain acceptance. The airlines were fearful that they would be required to pay for the infrastructure in addition to (rather than as a replacement for) the existing navigation aids. My military aircraft panel in the 1960s had the same problem in gaining acceptance for GPS, and I personally visited the Joint Chiefs of Staff in the Pentagon's "tank" to brief our proposal in the late 1960s. After the briefing, one of the chiefs told me, "I don't have $50 million in my budget this year, and if I did, I would spend it on a ship."

In 1980, my respected colleague, Gen. Lew Allen, who had been director of the National Security Agency before becoming Air Force Chief of Staff, reprogrammed $2 million out of his budget rather than spending it on GPS. Fortunately, Defense Secretary Harold Brown and Bill Perry, director of Defense Research and Engineering, put the money back. But it took a long time to deploy GPS, primarily because of bureaucratic problems and fears from the airlines that they would be forced to pay an insupportable amount for the system. There were also technical disputes and delays in perfecting unnecessary technology such as atomic clocks for the satellites. A civilian or military system could rely on multiple transponders on the ground in geologically stable (and politically stable) locations for its calibration and for the knowledge of the crystal clock frequency on each satellite.

As we were refining our proposal during our ATCP deliberations, we attempted to learn the judgment of some of those experienced in military navigation systems and contacted a group at the Institute for Defense Analyses (IDA). As technical people, they were quite interested, but they differed with our analysis. We had worked with David D. Otten at TRW Corporation to make a bottom-up assessment of the cost of the installed equipment and ended up with replication costs of $1,800 for a private aircraft and $4,100 for a commercial aircraft for a system that would provide a "fix" every second with an accuracy of 100 feet. Rather than validating or contesting these conclusions, the IDA group took a different approach--a regression analysis (for existing systems) of navigation costs versus accuracy and fix time. Their conclusion was that our system would cost about $200,000 per copy.

Naturally, we met with the analysts following receipt of their report, and I complained that they had done nothing to verify or challenge our analysis. They said that this was intentional: If our point-design system approach failed in development, then we would be forced into a conventional mode of operation, and we would have the same costs as everybody else. I protested that the program should be canceled if it did not achieve these goals. Apparently, that's the problem: Military systems in general are committed to achieve a goal, and if it cannot be achieved with the planned schedule and budget, the goal is pursued anyhow at whatever costs or delays. In the commercial world, developments are allowed to fail; it is inconceivable that the world would rely at any time on a single design of a digital camera. A similar approach is highly desirable for the design and elements of a worldwide air traffic control system.

Technically, the ATCP was an enjoyable activity, both from the point of view of learning and inventing the technology and for the interpersonal relations among panel members. Bureaucratically, it was disappointing to have our recommendations ignored and suppressed. Economically, it is tragic to have denied the public for two decades or more the benefits of a modern air traffic control system. The report considered potential system designs, but recognized that no such design could be selected with such a small amount of preliminary work. It therefore advocated a specific approach to doing the further analyses and developments required to field such a system.

When George A. Keyworth first took office as President Ronald Reagan's science adviser, I made a special trip to Washington to give him my views of existing problems and opportunities in the fields of national security and technology. I specifically presented the all-satellite air traffic control system as something that would have an enormous impact on both U.S. commercial and military capabilities and provide systems, products, and services for the United States to sell to the rest of the world. This was particularly true also for the introduction of a new system of vertical-landing passenger aircraft that the new ATC system would facilitate, providing a major market for the U.S. aerospace industry and an option for greatly increasing the capacity of the air transport system by physically increasing the takeoff and landing capacity of busy airports by reducing the dependence on long runways.

As is well-known, GPS was deployed by the military and has been a wild success since it proved its utility during the first Gulf War. In the work of the ATCP, we suggested that some major airline such as United might want to adopt and deploy such a system for corporate use, which would reduce the difficulties involved in the decision to go ahead.

It would be good to have a high-level technical committee similar to the ATCP convened today--with a substantial budget for technical support work--to bring the proposal up-to-date and to provide a conservative implementation plan. The scope for updating is clear from the definition of "high-performance computer" in the 1971 report as about 65 million operations per second, compared with a desktop computer costing $500 in 2007 and routinely capable of 1,000 million operations per second.

But the important goal is to deploy a reliable system rapidly, of a type that could be upgraded continuously and that would realize benefits in savings and safety even during early deployment.

It is clear that the United States now has the capability to design such a system, but it is unclear that it would be able to decide on such a system. The air force secretary recently informed the acting undersecretary of defense for acquisition that the first three space-based infrared satellites (SBIRS-high) won't be launched until 2009--seven years after their original launch date--and that the cost is projected to exceed $11 billion, considerably more than the 1996 projection of $2.5 billion. The SBIRS-high system would replace the constellation of "Defense Support Program" satellites that have operated since the 1970s to provide warning within less than a minute of any significant ballistic missile launch anywhere on the Earth's surface.

Perhaps a country with a less evolved bureaucracy might successfully design and deploy such a system to provide worldwide air traffic control services. With a 10-year time to full operation, if we start now, it might be operational in 2017--at least a third of a century after it was technically feasible.

Profile

Richard L. Garwin

A physicist, Garwin is IBM Fellow Emeritus at the Thomas J. Watson Research Center in Yorktown Heights, New York. He has contributed to the design of nuclear weapons, instruments and electronics for research in nuclear and low-temperature physics, and superconducting devices. His work for the U.S. government includes studies on antisubmarine warfare, military and civil aircraft, and satellite systems. In 1998, he served as a member of the nine-person Rumsfeld Commission to assess the ballistic missile threat to the United States. He received the Presidential National Medal of Science in 2003.

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