GLOBAL POSITIONING SENSE II:

AN UPDATE

Presented to:

THE AIR TRAFFIC CONTROL ASSOCIATION

WASHINGTON, DC

OCTOBER 2, 1997

by:
Langhorne Bond
Pittsboro, NC 27312
(919) 545-0125

Because the discussion on the future air traffic control system has grown in volume and intensity lately, I will attempt a statement of first principles to clarify the debate. This is necessary because so much of the discussion is bogged down in peripheral issues—contract cost overruns, cost allocations, electronic minutiae—that the big picture is lost. It is very complicated and not many people, including experts in one part of the equation, put it all in perspective.

The ideal air traffic control system would permit every aircraft to depart immediately, fly the most direct and efficient route to its destination, and land immediately. Most aircraft in the IFR system do not achieve this ideal, but they come remarkably close today. There are good reasons for falling short of the ideal.

I. The Problems

Putting aside externalities for the moment, there are three main operational problems to users: capacity, delay, and efficiency.

A. Capacity

Capacity is the ability of the ATC system to handle numbers of aircraft.

- <u>En route capacity</u> is almost universally agreed not to be a problem in the US domestic environment. There is a lot of room in the medium and upper atmosphere, which is why we can now permit direct (i.e., great circle) routing above 29,000 feet with existing navaids and on-board avionics. All foreseeable growth can be accommodated.
- <u>Terminal area capacity</u> is more complicated. Most US air carrier airports, and nearly all general aviation airports, use only a fraction of the runway capacity and arrive and depart immediately. I would estimate some 70-80% of air carrier movements (including regional carriers) operate without significant capacity restrictions.

Hub airports are different. O'Hare, DFW, Atlanta, LaGuardia, Miami, and Minneapolis, to name a few, are capacity constrained. The air carriers at these airports schedule flights to arrive at the same time and to depart at the same time. The airport's capacity is determined, and is limited by, wind direction, number of runways and runway separation, and, of course, by FAA safety criteria for in trail vortex avoidance and runway clearance. These factors are fixed and will not be altered by changing the source of a navaid signal. Indeed, they are not ATC issues at all, and are set by FAA's flight standards office for safety reasons.

Hubbing strains airport capacity and increases gate to gate trip time in perfect weather. It is a normal condition. To air carriers, hubbing makes good economic and competitive sense, especially in a deregulated world. The increase to trip time is accepted—chosen is a better word—by the carriers.

B. Delay

Delay is an increase in normal trip time. It is an expensive problem to air carriers and general aviation alike, and deserves lots of effort in mitigation.

Here is the first rule in the delay book: 80% of delay is caused by weather. The main types of bad weather are:

- Severe weather. Aircraft cannot fly safely in thunderstorms. A thunderstorm near, or over, an airport causes routing detours, holding, and even deviation to another airport. A line of thunderstorms, a front, can cause flow control to re-route hundreds of aircraft and to delay movements into and out of an entire region. The Midwest, the northeast, and Florida are subject to this in the summer months.
- Low ceilings and visibility. When ceilings are low and lateral visibility (RVR) is limited, airports lose capacity significantly or even entirely. Some airports with closely spaced runways (such as St. Louis, LAX, and

SEATAC) lose capacity when ceilings limit ILS approaches because simultaneous, independent approaches cannot be made. And when the ceiling goes below minima, the airport is closed.

Interestingly, the technology to land with ultra-low ceilings, or even to use auto land in zero-zero weather, has been available and certified for 25 years. But it is expensive to equip ILS's, equip and maintain aircraft, and train crews for low ceiling approaches. The Europeans, with lots of foggy weather, choose to spend the money to land in low ceilings: the Americans, with much less of a problem, do not. There is a lesson here: the technology must produce a worthwhile benefit or it won't be used.

- Snow. Snowstorms are a weather problem in the mid-Atlantic from Washington north, in the mid-Atlantic, in the Midwest, in the upper Midwest, in the Plains and Rockies, and in the Pacific Northwest. When an airport is hit with a severe snowstorm, aircraft are diverted all over the map. And it can take days to reopen the airport.

None of the principal weather delays—thunderstorms, low ceilings, and snow—will be reduced by a change in ATC technology.

The remaining 20% of delay is caused by a miscellany of factors: disabled aircraft, holiday peaks, and aircraft failure. Let me single out one particular item: ATC equipment failure. It can and does happen. But consider: the current ground based ATC system is redundant, independent, and increasingly failure resistant. It has been described as expensive and obsolete. I regard it as safe, invulnerable and comforting. The notion that an ATC system-navaids, comm, and surveillance-channeled through a few unreachable satellites can be less failure-prone than the current ground based system is a fantasy. Reliance on satellites for navigation (or for comm or surveillance) has the potential for vastly increased delay, or total shutdown, of the ATC system.

C. Efficiency

The ideal ATC system as noted earlier, would permit aircraft to depart immediately fly the most direct and efficient route to the destination, and land immediately. On the airport there would be no taxi delays.

This ideal is rarely achieved at busy airports and on busy airways. The reason for “dog leg” routes, altitude restrictions, and speed restrictions is controller directed positive control. Almost every step of an air carrier’s journey is under FAA radar surveillance and subject to an elaborate set of separation protocols which have proven, through analysis and experience, to avoid mid-air collisions.

The federal airway routes have hardly changed since the VOR/DME network was set up in 1950. Using the VOR’s and intersecting radials as aerial highways allows controllers to align aircraft in trail and to establish lateral separation. Assigned attitudes do the same job vertically. The current practice is not optimally efficient but it does create order, and remarkable safety, out of what could otherwise be chaos.

You need only work at FAA a short time to understand why the procedures err on the side of conservatism. But are the procedures too safe, or are the margins unnecessarily large?

Yes. The application of technology, and a hard-eyed review of FAA procedure will permit more direct, i.e., efficient, ATC routines. This has already been achieved in two significant areas.

First, en route domestic navigation above 29,000 feet now permits a great deal of great circle, direct routing—without GPS. This is free flight at its best. Sooner or later, however, free flight has to be abandoned and aircraft have to go back in line to approach and land safely. This transition scares controllers and FAA requires that controlled, in trail separation be re-established within 200 miles of the destination airport. This gives controllers lots of room to reorder the queue.

The second current gain in efficiency is in transoceanic flight where reduced separation, and therefore more direct routings, have been achieved. This gain in efficiency is entirely attributable to GPS: no ground based navigation signal is available in transoceanic flight. The inertial systems in use for 15 years are quite accurate but can be programmed wrong with sadly calamitous results. The newest avionics combine the GPS signal with inertial systems. This permits an accurate, <u>confirmed</u> fix by GPS with an inertial backup in case the GPS signal is lost, which happens from time to time. This is a superb arrangement and its hard to imagine improving on it. Note, however, that GPS/IRS may not increase transoceanic capacity because on many of the busy routes departures are held until an arrival slot is available at the destination.

II. FORWARD WITH TECHNOLOGY

There has been so much discussion of technology lately, much of it by experts with an investment in the outcome, that perspective is sometimes lost. The most important technology of the day is…

A. The Flying Computer

The computer on a chip has revolutionized avionics. Not only has the analogue computer improved and miniaturized such routine technology as weather radar, radios, and displays, it has also allowed us to navigate differently en route.

- RNAV. Since the middle 1970's low cost computer based avionics have permitted pilots to fly direct, great circle routes from one point to another using the VOR/DME signals, plus barometric altimetry. In the US, which is well supplied—some would say over-supplied—with VOR/DME's, you can fly nearly everywhere. This lovely technology was rarely used however, because FAA required pilots to use the charted airways. Lately FAA is permitting direct routings—"free flight"—above 29,000 feet, so pilots can use RNAV derived from the VOR/DME system. Of course, the RNAV avionics computers can derive a direct route from a GPS signal, or a LORAN signal, but the point is that domestic direct routings are made possible by onboard computer based flight management systems and can use any available, certified NAV signal. GPS did not create great circle radio navigation, and the increasing use of high altitude free flight springs from reform of FAA's rigid flight procedures, not from the arrival of GPS.

- ACCURACY. The various signals for en route navigation have different levels of accuracy. The VOR/DME signal, which is ubiquitous and in near-universal use, is not precise. Eurocontrol plans to phase out VOR because of its poor accuracy, and FAA should do so as soon as possible.

For most en route navigation the greater accuracy of GPS adds nothing to system capacity because the en route system is not capacity constrained. But it may be that high accuracy nav systems such as GPS, FMS with DME/DME, and LORAN can help the efficiency of the ATC system by allowing more free flight, i.e., direct routings, below 29,000 feet. The lower the altitude, the denser the air traffic: collision avoidance becomes exponentially more difficult at lower altitudes. Greater accuracy may permit electronic collision avoidance warning systems to supplant the guaranteed safety of controller imposed separation. This definitely remains to be demonstrated and accepted by pilots, controllers, and the public.

FAA is also seeking to develop new terminal maneuvering tracks which will permit aircraft to squeeze through and around dense air space like the NY metroplex, Chicago, and the southern California basin. Again, the ability to fly RNAV precision tracks will permit this flexibility. But is GPS the key? FAA has recently found that glass cockpit aircraft with modern flight management systems, in a “DME-rich environment,” can generate tracks with GPS levels of accuracy from the VOR/DME system, or from LORAN C.

B. DEPENDABILITY

The present ATC system, based as it is on redundant, reliable ground based transmitters, is almost immune to significant failure, even in the short term.

It’s not by accident. The two principal elements of the current system are VOR/DME for en route navigation and terminal maneuvering, and ILS for final approach. Here is how the reliability is assured. First, each unit has a backup source of power in case the commercial power fails. Then, the internal equipment is largely solid state, which runs cool and has an excellent MTBF. Then, it’s all made redundant: if something does go wrong, a second, duplicative system goes on line to continue the signal transmission. And the entire operation is remotely monitored at an FAA facility. If something goes wrong, a technician goes on site and fixes it immediately. Which doesn’t happen often: the scheduled routine maintenance for an M20 ILS today is 90 days, whether its needed or not. On top of all this, there are more than 2100 VOR’s and ILS’s in service, and if one goes out the pilot can tune in another.

This massive security and redundancy is based on the hard-won knowledge that unexpected navaid failure can have dire consequences, as was recently demonstrated when the loss of an ILS glide slope in Guam resulted in loss of a widebody and all aboard.

The GPS signal, in contrast, is a model of uncertainty.

- The satellites can be neutralized or destroyed in orbit by laser, “brilliant pebbles,” or electromagnetic pulse.
- Sunspots can degrade the signal or even wipe out the satellite.

- There are four ground stations controlling the GPS birds, only one of which is in the continental US. Put one out of commission and the GPS signal is gone.
- Some hostile country can steal or break the DOD codes for GPS and turn the signal off. If the US can turn off GPS, and it has done so, some other country can do so as well.
- Then there is jamming. Since I warned about jamming on this panel, there have been many jamming incidents. For a current list of DOD jamming exercises, see the US Coast Guard's notice to mariners web site.
- And this just in: At the 1977 Moscow Air Show a booth was selling handheld GPS jammers with an effective range of 100 miles. The havoc jamming could cause when the secure terrestrial are removed and the satnav signal is jammed on a night when the East Coast of the US is blanketed with low ceilings is unimaginable. There could be multiple crashes. Perhaps GPS jammers should be added to the list of weapons of mass destruction.

The US military has recently begun to talk publicly about the vulnerability of GPS signals. The details are understandably black, but it is now clear that America's defense will never rest solely on satellites. If the civilian navaids are cut off the DOD will put inertial systems in its planes and will never turn off its own ground based navaids. This lesson should not be lost on our civilian leaders.

III. THE FINAL APPROACH ISSUE

Initially it was thought that the basic GPS signal augmented by a series of ground stations (WAAS) could permit a precision approach to a Category I ILS decision height of 200 feet. Further testing has demonstrated this may not be feasible: GPS plus WAAS is accurate enough for a 400 foot decision height, which is about the same as a VOR/DME non-precision approach.

So all those ILS systems worldwide will continue in service for the foreseeable future.

There is talk of putting a ground based transmitter on every ILS equipped airport (LAAS) to improve the GPS signal to permit ILS quality Cat II & III approaches. But what airport operator will permit the removal of an accurate, robust, invulnerable ILS to be replaced by another ground transmitter vulnerable to signal interruption and with no better performance? The answer is: not many.

IV. WHITHER WAAS?

The ILS replacement role for WAAS having evaporated, what about WAAS?

Because most of the commentators and decision makers have no clear idea what GPS augmentation does, how and whom it benefits, etc., most of the discussion about WAAS has perforce turned on the cost overruns of WAAS, which everyone can understand. And this issue is a red herring. WAAS is a development program and it's hard to predict its cost. The fault lay in describing WAAS as a capital investment project.

The better question is, what is WAAS for? If WAAS won't replace the ILS's, and if the basic GPS signal and FMS's are currently doing well for en route and terminal maneuvering, do air carriers need WAAS?

One benefit of WAAS that is not in dispute is its potential to provide a vertically guided precision approach to about 400' where no ILS is available. This is a definite benefit to general aviation and to countries with few ILS's.

V. GPS AROUND THE WORLD

Now that ICAO has added GPS to its list of approved navigation systems, other countries are trying to figure out how to fit GPS navigation into their ATC systems.

There is a growing awareness that GPS, for the reasons previously listed, cannot be relied upon as a sole system of aviation navigation. Among those countries with an established ground based navigation system, there are two groups: those who have decided to retain their secure ground based systems, and those who will do so when they figure it out.

VI. THE FUTURE AIR NAVIGATION SYSTEM (REVISED)

- GPS or other satellite signals are very accurate and will come into widespread use for en route, terminal maneuvering, and high DH approaches. The basic signal is very accurate for these roles and will not need to be augmented.
- All countries will retain a secure ground based system for the above roles. Since virtually all aircraft are equipped to use VOR/DME, this system will be retained.
- LORAN C is also a secure ground based system which can perform all the roles of VOR/DME. It is a superior system because it has a low frequency, ground hugging signal, whereas VOR/DME is line of sight and disappears over the horizon. The latest versions of LORAN C can generate a lateral signal <u>from the ground up</u> that is <u>as accurate as basic GPS</u>. Because only ¼ of US aircraft are equipped with LORAN C, VOR/DME cannot be withdrawn. LORAN C will be retained because some 90,000 US GA aircraft use it and because it is needed as an alternative maritime navigation system.
- ILS will continue and its use will expand because it is a developed, accurate, secure system and the only one capable of low minima approaches.

- Many off the elements of the Future Air Navigation System (FANS)—communication and surveillance—are now in doubt because they rely on satellites. Almost all of the vulnerabilities that impeach GPS satellite navigation are also issues for the “C” and “S” elements of FANS. The US military will not abandon its secure ground based communication and surveillance systems and neither, in the end, will other countries. Nor will the US. At the ICAO CNS/ATM conference in Rio in 1998 the US dramatically announced that GPS needed a backup.

VII. COSTS

The American aviation leadership is in the early stages of withdrawal from a position in which the capability of GPS navigation was over-predicted and over-promised. This is unfortunate because GPS has an important role in aviation, even if it can’t do everything. GPS will contribute mightily to civil aviation after the present controversy is forgotten.

How did this come about?

To start with, satellite technology has its champions with an unquenchable sense of optimism. Those in government outside the FAA know a good deal about satellite technology and much less about aviation. Hence the attempt to force a wonderful technology into a role it cannot perform.

More fundamental, however, was the notion which arose some five years ago that the air traffic control system was obsolete, inefficient, and too expensive—it was broken. This notion was false then, it is false now, and no one outside of the US believed it. Allied to this view was the thesis that the complex, safe, and deliberately redundant ATC system was too expensive to fund in the future.

This proposition drove the effort to substitute the GPS signal for ground based signals, and then to scrap the ground systems such as VOR/DME, LORAN C, and ILS. In reality, the numbers do not support this thesis. For example, the cost of continuing the VOR/DME network ($50 million) and LORAN C ($15 million) total less than the cost of the interest on the WAAS contract. A complete modernization of the LORAN C system would cost a total of $100 million (one fifth the cost of the <u>increase</u> of the WAAS contract), would not be repeated for 20 years, and would lower annual costs from $15 million to $7 million. The cost to maintain all of the current ATC system is about $500 million, which is 1/5 the income of the aviation trust fund.

Since the passage of the NAS plan in 1981 under Secretary Drew Lewis and FAA Administrator Lynn Helms, there has never been a capital or research funding shortfall. The Congress provided FAA all the money it thought FAA could usefully spend on ATC, and will continue to do so.

VIII. THE DEITY IN THE DETAILS

Almost 15 years ago I chaired a panel at the ATCA convention in Anaheim, CA, my purpose in which was to prove that the much needed capital improvements in the NAS plan would not provide much increase in ATC system capacity. History has proven this to be the case.

Instead, reform of FAA procedures was needed. This is still true today.

My reading of the Flight 2000 plan gave me some cause for optimism. The report is drenched with references to GPS technology, but it really relies, for navigation, on high accuracy RNAV, which can be achieved, and is being achieved, by FMS using DME/DME or LORAN C.

The heart of Flight 2000 lies in easing the FAA tradition bound ATC procedures, with perhaps a little boost from technology. Lydell Hart once wrote, “The only thing harder than getting a new idea in a soldier’s head is getting an old idea out.”

Will FAA adopt meaningful procedural reform? The record over the years does not give much cause for optimism. Here are a few snapshots.

- When en route radar surveillance came about in the early 1960's, FAA increased in trail separation compared to the previous non-radar control. Capacity was reduced, and safety improved, when radar came in.
- Flow control was really given teeth in the 70's during the gas crisis and in anticipation of the PATCO strike. Flow control has eliminated airborne holding and it has made things more orderly. But it reduced capacity.
- The "snitch patch" changed separation standards from a guideline to an inflexible, career threatening barrier. Controllers spread out the traffic to keep out of trouble.
- FAA suddenly increased wake vortex separation criteria for all aircraft after two accidents involving bizjets and the Boeing 757. This act alone may have decreased acceptance rates at major airports by 5%.

There are other self-induced procedures, such as curfews and environmental tracks, that impede the ATC system. There is a decent reason for every constriction. But the point is, technology did not induce these losses and technology will not solve them. We did it to ourselves.

As Pogo said, "I've seen the enemy and its us."