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Global Positioning Sense

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1. INTRODUCTION

The U.S. Defense Department's Global Positioning System (GPS) is now so ubiquitous, and has so many obviously useful civilian applications, that it has taken on a reality of its own.

There are military applications galore. A U.S. Air Force spokesman on TV recently spoke about cruise missile guidance. There is military aircraft navigation over hostile territory. Squad leaders carried receivers in the Gulf War.

On the civilian side, rental cars are now available with GPS-directed road maps. Shippers track trailers and containers. Railroads follow trains. Backpackers use GPS navigators in the wilderness. My own Garmin hand-held unit tells me where my desk is. All these new, useful applications have this in common: loss of the signal, or imprecise accuracy, is not catastrophic.

This paper is not about these uses of GPS.

II. AVIATION NAVIGATION

This paper is about GPS as a navigation aid for civil aircraft. In this field the standards are precise and the integrity must be absolute. If the signal is lost, or strays, the consequences can be catastrophic. Anything less than precision, redundancy, and perfect reliability is unacceptable. In modern aviation, you cannot pull out a road map and keep going.

GPS aviation navigation has been the subject of so much understandable enthusiasm that its limitations have been ignored.

III. VULNERABILITY

Civil aviation directors lose sleep worrying about calamitous failures. One area they do not worry about much these days is a massive failure of the navigation/communications/surveillance system. The reason is that there are literally tens of thousands of transmitters, receivers, remote-control communications sites, primary and secondary radars, Flight Service Stations and so on. Today, most of these units and facilities are redundant, have back up power, and don't drift or go off line much.

To a remarkable degree, this array of equipment and people operates separately and independently. If one element goes out, the thousands of others continue to play and provide alternative guidance. For all practical purposes, the system is invulnerable. This is a great comfort to those who are entrusted with the military and economic security of their countries.

GPS is different, to wit:

- Signal Strength of GPS is tiny, a small fraction of the powerful, reliable emissions in the current navigation system. It is easy to disrupt. The British recently demonstrated that a one watt, — repeat — one watt weather balloon transmitter could disrupt the GPS signal for 30 miles around. And then there are electromagnetic and particle emissions from the sun. These eruptions can damage satellites and interfere with signals transmitted from them. Solar flares could disrupt GPS signals for hours - worldwide.

- Star Wars. It's almost impossible to imagine a more vulnerable place to put a navaid than in a precisely located, constantly squawking earth-orbit satellite. Using another satellite or a high altitude aircraft, to disable a GPS bird you could:

- melt it with a laser
- pulverize it with a cloud of brilliant pebbles
- bombard it with EMP

- The Switch. GPS was designed as a military system. Given that the GPS signal can be used by unfriendly interests, the Defense Department, I am relieved to know, can degrade and deny the signal of one or all of the satellites. Specifically, it can turn them off—completely—and has done so. The President recently erased doubt on this matter when he signed an executive order empowering himself to turn them off. The order restricted the exercise of the power to militarily grave circumstance, and I'm sure the assurance can be taken on faith. On the other hand, I'm equally sure the President will throw the GPS switch when U.S. interests gravely dictate.

This puts other nations in a bind. Assuming GPS is a complete aviation navigation system, are countries with secure, successful ground-based systems going to scrap their VORs, ILSs, NDBs, and DMEs and rely solely on America's satellites? Among the countries that have a good ground based system, the answer is: No. Not one country will do so. Right now the world is divided into two groups: those countries which have stated they will retain a ground-based system, and those who will so state when they figure it out.

- Stealing the Switch. The switch is actually a complex, coded radio signal sent from U.S. DOD to the GPS birds. I presume that only the U.S. has the codes.

I do not, however, assume that only the U.S. has the signals which are sent up to the GPS birds. These signals have been picked off by curious intelligence agencies of many nations. Can the codes be obtained?

Breaking the code, generated as it is by modern computers, is very difficult. Speaking historically, however, it is foolish to say that a code cannot be deciphered. So the GPS code—the switch—can be broken.

Stealing the code is the other method of getting control of the GPS satellites. Good Old Humint could do the job. The point is: if the U.S. can control the GPS system from the ground, so can someone else. And this opens a wide field of uncertainties.

For example: could a mid-Eastern country manipulate the GPS to the detriment of another mid-Eastern country? Could Russia affect China by GPS manipulation or denial? The combinations are endless.

And here's the biggest issue of all: could another country get control of GPS and ... turn it off over the United States?

The answer, of course, is yes. That's why I said that no country will give up its ground-based system, including the U.S.

IV. THE BLESSINGS OF GPS

To understand the benefits of GPS to the civil aviation community, we need to restate what GPS actually does. The GPS signal comes down from above and the receiver, using at least 4 satellite signals, can locate a point in space with remarkable accuracy. The airborne receiver, connected to the computers and instruments and flight control systems, does the rest.

Like many ground-based navaids, the GPS signal is limited by the line of sight and is blocked by obstacles. However, because the signals come down from the sky, signal availability is almost universal because there is little curvature of the earth effect and obstacle blockage is reduced. For aviation purposes, basic GPS guidance is available almost everywhere.

While the GPS signal is very accurate for lateral location, it isn't by itself sufficiently accurate vertically for purposes of approaching the runway. This is critical for aircraft: errors in measuring the distance to the ground can ruin an entire day.

To improve the vertical accuracy, FAA is developing a series of ground reference receivers (either the Wide Area Augmentation System, WAAS, or the Local Area Augmentation System, LAAS; depending on your application), the signal from which, when received by an airborne user, improves vertical accuracy and makes possible some categories of approach to landing.

To understand the real-world benefits of GPS to civil aviation, it is necessary to understand at least three things: one, what GPS does; two, what it cannot do; and three, what it does that is already done by ground-based transmitters. Each particular application should be considered.

A. En route Domestic Navigation

Overland en route guidance over the industrialized countries is by the ubiquitous VOR/DME ground transmitters. That stands for VHF Omnirange, the azimuthal guidance and Distance Measuring Equipment, for range from the station. The system is highly reliable, highly redundant (there are 1025 VORs in the U.S.) and highly safe.

VOR-based navigation, however, is laterally inaccurate and this has caused the airways to be nine miles wide. A high accuracy navigation system, such as GPS (or FMS/DME, with which most air carrier aircraft are now equipped, or LORAN) can dramatically reduce the width of the airways. This in turn will free up lots of airspace for additional tracks.

High accuracy navigation systems such as GPS, FMS/DME, and LORAN hold promise for increasing en-route tracks and for driving conflict resolution systems used in free flight regimes.

B. Terminal Maneuvering

Terminal maneuvering occurs when the aircraft is handed off from the en-route controller to the approach controller. The approach controller slows the aircraft and puts it in line with other arrivals to get to final approach with proper spacing in trail. Air traffic control in terminal areas is as much art as it is science. Not every controller has the intuitive skills to work the busier airports.

Ground transmitters such as VOR/DMEs, NBDs, and ILSs support the charted approaches. But the busiest U.S. airports are radar controlled and much of the maneuvering is by controller-issued vectors, frequently without much use of navaids at all. GPS will do well in terminal maneuvering—just as well as the existing system.

With regard to terminal maneuvering, or approach control as it is called in the U.S., remember that airport capacity is determined (and limited by) the runway acceptance rate, a fixed figure. GPS will not increase the acceptance rate. However, at some foggy airports with closely spaced runways, loss of capacity may be avoided.

C. Final Approach

Final approach is the most critical and potentially dangerous phase of flight. The safety standards covering descent to touchdown through clouds are, for good reason, unbelievably exacting.

Using electronic guidance, a pilot descends toward the runway without seeing it. The safety standards for accuracy, dependability, redundancy, fail safe, and so on become ever more exacting as the aircraft gets nearer the ground.

Low visibility instrument approaches are divided into two categories—non-precision approaches and precision approaches. Non-precision approaches, as the name suggests, have a lower level of accuracy and no continuous vertical guidance. Pilots are therefore restricted to relatively high minimum altitudes above the runway. A non-precision approach often has minima as low as 400 feet above the runway but, if there are obstacles nearby, the minima can be 1000 feet or more above the runway. Non-precision approaches are frequently flown using a nearby VOR/DME or a non-directional beacon (NDB). A non-precision instrument approach is certainly better than no instrument approach at all, but the relatively high minima cam cause the airport to be unusable during just that bad weather which requires such operations.

Precision approaches, by contrast, are extremely accurate, safe, and they vastly increase the all-weather use of an airport. The standard navaid for precision approaches at civil airports is the Instrument Landing System (ILS), a system with two transmitters next to the runway with phenomenal accuracy and dependability. The standard, garden- variety Category I ILS has a decision height minimum of 200 feet, and this is good enough for most air carrier airports in the U.S., a country with comparatively little ground fog. The

Europeans, on the other hand, with more foggy days, routinely use advanced Category III ILS which permits safe landings in zero visibility, zero ceiling weather.

Now consider GPS as an approach aid. Because the GPS signal can be received right down to ground level, it was initially thought that GPS could easily become a precision approach aid. As time went by, however, closer analysis of the GPS signal has revealed that it cannot by itself meet the rigorous safety standards required for low decision heights. The initial estimate was that GPS with WAAS could be used for Category I 200-foot minima approaches, equal to a standard ILS. Recent analysis, however, suggests that GPS with WAAS cannot be certified below 350-400 feet. This is extremely useful given that the signal is available to almost every runway and almost every airport. But it is still limited.

- Because of its high minima, GPS with WAAS will not displace all the ILSs in the world. There are 1155 ILSs in the U.S. alone, and most will continue in use for the foreseeable future.
- Airports needing new precision approaches may well, in the future, acquire ILSs. GPS/WAAS won't necessarily do the job.
- I would estimate that at least 95% of the scheduled air carrier flights in the U.S. are into airports with ILSs. Most of the rest have non-precision approaches now. GPS with WAAS doesn’t add much here, except that vertical guidance to the same decision height would be provided.

On the other hand, in the U.S. there are many small, general aviation airports without a non-precision approach. Assuming the obstacle clearance, runway length, and lighting criteria (and expense) will be met, GPS with WAAS could provide a useful approach. FAA recently estimated that there are 1200 NDBs installed at small airports for the benefit of, and at the expensive of, local charter operators. A GPS approach could permit the decommissioning of these NDBs, saving the local operators a good deal of money.

Let me add for the sake of completeness that it may be possible to refine further the GPS signal to permit precision low minima approaches. This would be done by placing a Local Area Augmentation System (LAAS) transmitter on each airport. A large airport such as O’Hare, with many precision approaches and therefore the need for extreme reliability, might need more than one LAAS transmitter just for backup. Then, as long as the GPS signals will support the precision approaches, we’re in business. It’s still fewer LAASs than present-day ILSs. But this raises the question: what airport operation would choose to remove an existing invulnerable, redundant, robust ILS and install another ground transmitter with possible similar performance and lesser dependability?

D. Oceanic Flight

Oceanic flight is where GPS really shines. Oceanic flight (or polar flight or flight over an uninhabited or unequipped land mass) is by definition en-route flight, and over these vast stretches there are no signals from ground based transmitters. Aircraft flying the oceans use inertial navigation systems (INS) which have gyros for guidance. The best of them are none too accurate, and the occasional bad INS is way off track. As a result, the oceanic tracks are very widely separated.

GPS's excellent en route accuracy will permit many more tracks, and its ability to secure a confirmed location will permit an oceanic aircraft to chase favorable winds, thereby saving fuel.

GPS will also permit more aircraft to transit oceanic airspace, but this alone will not increase system capacity. On the busy routes most departures are now held until an arrival slot is available at the destination. Runway acceptance rates, not navaid performance, dictate productivity.

E. Environmental Benefits

In the terminal maneuvering area, GPS's accurate signal has been said to provide environmental benefits by enabling aircraft to fly precise, curved tracks to minimize noise impacts. The famous river approach to Washington National Airport would be a candidate. GPS performance for curved approaches is similar to that of microwave landing systems (MLS). Environmental applications were found, in the U.S., to be limited.

V. COST SAVINGS

The campaign for GPS as a civil aviation navigation system was at first based on the notion that GPS could handle virtually every phase of flight and, therefore, all those ground based transmitters could be unplugged and scrapped. The cost savings, it was said, would be huge and would fully justify the considerable cost of putting up all 24 birds and keeping them in service.

Reality has intruded. As one top FAA GPS expert said, "I think we've oversold GPS." He's right about that. To begin with, GPS with WAAS cannot be certified for the really low-minima precision approaches. So those ILSs, and ILSs to come, have a long life ahead.

More fundamentally, GPS is vulnerable to all sorts of interference ranging from tiny ground based transmitters to code breaking to destruction in orbit. If GPS goes dark, and there is no alternate aviation navigation system, the United States is in an unimaginable fix. Vulnerability is the great, and undiscussed, problem of GPS aviation navigation.

Recently FAA leadership has begun to acknowledge the need for a "back up system" to GPS. What would a back up system consist of? The answer to that question requires a frank discussion of the possibility, and scope, of the loss of GPS signal.

FAA recently published a "Decommissioning Plan" for all its ground based navaids. Treat it with skepticism.

VI. WINNERS AND USERS

GPS aviation navigation is arriving rapidly. ICAO has recognized it, and FAA and other civil aviation authorities are busily certifying receivers and approving GPS uses. For en route and terminal area service GPS is every bit as good as what we have now, and the signal coverage is better.

If you are flying off the main line, the biggest benefit of GPS is that it provides a good signal where none now exist. If you are flying over the ocean, or if you are flying in a developing country without much infrastructure, or if you are flying to a small, rural airport in the U.S. - GPS is a breakthrough.

Within the continental U.S. the big winner with GPS is general aviation, and specifically those corporate and commercial users sophisticated enough to use those high decision height instrument approaches. GPS … corporate America salutes you!

VII. THE FUTURE: GPS PLUS … WHAT?

In the near term GPS with WAAS will become an important and useful addition to the existing aviation navigation system worldwide, but it will not immediately permit phasing out the entire VOR/ILS network.

In the longer run, however, there is growing belief that Loran-C may be the ultimate ground based, secure complement to GPS. The Loran-C signal, where it reaches, is a ground level signal, unlike VOR which disappears at the horizon. The entire continental US is now served by 29 Loran-C transmitters, which provide an accurate and complementary signal that can be received in locations invisible to VOR and DME. The cost savings could be significant compared to VOR/DME.

The combination of GPS plus Loran-C is now being actively investigated by the Europeans and the Japanese, neither of whom are interested in relying solely on GPS.

In the U.S. the DOT has announced plans to unplug the Loran-C stations at the end of the century; however, Congress has other ideas. It has passed a law requiring DOT to provide a plan for the continued operation of Loran-C beyond the year 2000. The maritime world is put particularly at risk by an early turn-off of Loran-C: the GPS signal is as vulnerable to outages during marine navigation as it is for aviation navigation. If the Coast Guard really goes through with this plan, my advice is: preserve the Loran-C transmitters in storage.

The U.S. navigation plan for aviation and marine, civilian and military users is fundamentally flawed in its reliance solely on satellite guidance. Common sense dictates that a multi-faceted and secure combination of systems is necessary. A complete re-think is needed.