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**GPS NAVIGATION
AND
THE BACKUP ISSUE**

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Delivered to:

“THE FUTURE OF GPS: COMMERCIAL OPPORTUNITIES”

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GPS WORLD

I. (VERY) MODERN HISTORY

From the earliest days of GPS, technical experts have commented on, and warned about, the vulnerability of the GPS signal. And for good reason: the signal comes from low powered satellites 11,000 miles above the earth. The signal received on or above the earth is below the level of background electronic noise. One commentator, trying to describe the signal in layman's terms, compared it to the light received from a 25-watt bulb 11,000 miles away.

Modern receivers work nicely with such a tiny signal. Most of the claims made for this marvelous navigation and location system are proving out.

Marvelous as it is, however, the GPS system has one serious weakness: it is so low powered it can easily be blotted out or disrupted.

Within the past year there has been a cascade of well publicized incidents.

Here are some highlights:

- At the Moscow Air Show a primitive, first generation jammer operating on 4 GPS frequencies at only 5 watts of power was able to destroy the GPS signal for a distance of 200 kilometers. Retail price: \$3,500. Unspecified “middle eastern” customers had acquired the jammer.
- Numerous US Department of Defense exercises blotted out GPS at various regions all over the United States, leaving civil pilots scrambling to their traditional ground based receivers.
- The President's Commission on Critical Infrastructure Protection (PCCIP), a top level White House technical advisory group, described GPS navigation as the greatest single risk to America in the modern electronic era. This report spawned the establishment of a government-wide program to

study and, hopefully, mitigate a range of electronic vulnerabilities, specifically to include GPS aviation and marine navigation.

- Very recently a shadowy group of international computer hackers, known as Masters of Downloading, announced they had cracked the US DOD code that controls the GPS satellites. Now these folks, wherever they are, may be able to send up a signal that turns off the GPS birds. Or sets them spinning uselessly, like Galaxy 4.

- Two high level US government officials with impeccable credentials have publicly stated that the vulnerability of GPS requires a backup system to ensure that loss of the GPS signal will not have catastrophic navigation consequences in aviation. The first was Ken Meade, Inspector General of the Department of Transportation. The other was George Donahue, Chairman of the US Delegation to the ICAO CNS/ATM Conference in Rio, Brazil. This latter statement was made before more than 100 nations.

II. GPS AND NAVWAR

GPS was, and is, first of all a military system. The US DOD has publicly directed that all military weapons systems – aircraft, cruise missiles, and precision guided munitions such as standoff missiles – be equipped with GPS guidance. DOD, of course, has always been aware of the vulnerability of the GPS signal, and has been conducting an extensive counter-jamming program to minimize GPS signal loss, and to restore the signal. These efforts have been black; and properly so. I expect the work to go on forever: it's the fog of war.

One outcome of this work is that the DOD has decided to include inertial systems in its planes and rockets. AKA, a backup system.

Mike Shaw of the DOD's satellite office was recently quoted as saying, "There is very little we can do to prevent intentional jamming."

Is there a lesson here for civil users?

III. GPS – A LIMITED EDITION MIRACLE

Those of us who have harped on the vulnerabilities of GPS have been subject to a lot of griping from the GPS advocates, and the criticism is really not fair. Everyone realizes that GPS is a breakthrough, and it will be universally used for radiolocation and radionavigation all over the globe. It will be especially useful where there is no location signal at all – at little or no cost.

Useful though GPS is, however, it is not perfect. Vulnerability is its greatest limitation. This limitation affects different users differently.

IV. WHO IS AT RISK?

It is now estimated that only 10% of the \$10 + billion annual market for GPS products are for aviation and marine navigation. The bulk of this market – agriculture, railroad train tracking, truck and container management, surveying, backpacking, etc. – are in applications where the loss of the GPS signal is an annoyance, and is expensive. But life is not at stake.

Aviation and marine navigation are different. Plane loads of people and vessels full of thousands of passengers and explosive and toxic cargo depend for safety on radionavigation signals.

Consider a typical night when the entire East Coast of the US is under a front and ceilings are down to minima from Boston to Washington. A cluster of jammers, some floated in weather balloons, would destroy all GPS navigation and approach guidance for hundreds of airliners and GA aircraft. Many of them, perhaps most of them, would crash without back-up. The crews could never find a runway and would eventually run out of fuel.

The risk to vessels is similar. The latest mega cruise ships will have four thousands souls on board. Loss of the GPS signal will put them into danger and onto submerged rocks with great loss of life.

V. SOLE MEANS NAVIGATION

Originally it was thought that GPS, because of its universal coverage and great accuracy, would be all that was needed for every phase of flight. Now we know better. The notion of GPS as the “sole means” of navigation for aircraft and vessels is dead. The passing was officially announced to the world by the United States at the ICAO Conference in Rio.

VI. GPS NAVIGATION LIVES!

GPS navigation is alive and well. It just needs a little help.

The serious debate amongst navigation and safety experts now is about the most effective, lowest cost mix of systems that will meet the public’s need for assured safety.

The outcome of this debate is very important to the manufacturers and users of navigation systems. The first company to figure it out and put the right equipment on the market, the first company fully to embrace the new reality, will get out ahead of the pack.

The question of the hour is – GPS plus what?

VII. THE GREAT BACK-UP DEBATE

FAA system architects and planners are trying to define the appropriate navigation service needed for the various areas of the world, classes of users, and kinds of air traffic. Here is an outline of the issues.

A. Enroute Flight Over the Oceans, the Poles, and Unequipped Land Masses

Today these parts of the globe are overflowed by heavy, well-equipped aircraft—airliners and biz jets—going from one well equipped airport to another. There are no ground based radio signals available here and virtually all aircraft use modern inertial systems with a very high level of accuracy. These triple redundant systems are self-contained and therefore immune to jamming or outside interference. GPS may have benefits here. The ideal is an integrated GPS/inertial nav system which protects against loss of GPS.

B. The Outback/Forward Areas/the Interior

Undeveloped areas of the world such as the Canadian north, Alaska, central Australia, much of Africa, central Asia, the interior of Brazil, to name a few, have little density of air traffic and no ground based radio navigation at all. GPS in these undeveloped areas is a real breakthrough, providing accurate navigation, and a vertically guided precision approach to a high decision height, to the small aircraft typical in these regions. In these areas where no terrestrial radionavigation signal at all is available, GPS is an obvious safety improvement. Here, a back-up system is not yet in place, so loss of GPS is just a return to the status quo ante.

C. The Developed World

The developed world—Europe, North America, Japan, and the populated conurbations of the rest of the world, are now equipped with totally reliable ground based nav aids whose accuracy and continuity meet world standards of safety.

In these areas traffic is heavy, the routes are tightly spaced, and the loss of all navigation and approach signals would be catastrophic.

The standard nav aids in developed areas are VOR/DME, NDB, LORAN C, and ILS. In these areas a back-up system for all phases of flight—en route, terminal maneuvering, and precision approach—is mandatory.

VIII. PROTECTION AGAINST LOSS

A. RAIM

RAIM—receiver autonomous integrity monitoring—is a mnemonic for a GPS receiver feature which tells the pilot or ship captain immediately when the GPS signal is lost or unusable. This feature is the first line of defense against

GPS unreliability and should be mandatory for all GPS navigation receivers, both airborne and maritime.

FAA and the Coast Guard should require RAIM for all GPS receivers, even when teamed with dissimilar systems such as VOR/DME, ILS, and LORAN C.

B. VOR/DME

The VOR/DME system includes 1027 transmitters in the US and is the basic enroute and terminal maneuvering system for aircraft. The technology is antique, provides poor coverage for general aviation, and is costly to operate. Aircraft flying the VOR feature cannot fly accurate tracks, which accounts for the nine mile width of current airways. However, the system is totally reliable and has been laid out to serve the major airports—i.e., air carriers—well. Furthermore, modern receiver technology using only the DME transponders has permitted air carrier aircraft equipped with flight management systems (FMS) to fly tracks as accurate as GPS. For aircraft equipped with FMS receivers (50% of the air carrier fleet rising to 100%), GPS is merely duplicative since FMS equipped aircraft are capable of RNAV and accurate tracks. DME-based FMS units are not only a sufficient back-up to GPS, they are virtually an equivalent for enroute flight and terminal maneuvering.

C. ILS

There are 1,100 ILS's in the US, about one half of the world's total. The ILS is the totally dependable, highly accurate precision approach aid that permits pilots to land safely in foul weather. ILS is unquestionably the premier navigation safety aid in aviation history.

FAA plans to scrap all 1,100 ILS in the near future. At least that's the plan.

The GPS signal would supplant ILS within a decade. The GPS signal, when augmented by WAAS and LAAS, can provide an accuracy to CAT I or better precision approach standards. The problem is that the GPS signal often disappears, sometimes because of the inherent causes, often from intentional interference.

ILS is the only back-up for GPS for precision approach, and it is now universally acknowledged that a complement of ILS's will remain in service for the foreseeable future. So the commercial opportunity for every IFR equipped aircraft lies with an integrated ILS/GPS precision approach receiver. This will permit a descent-stabilized precision approach wherever a GPS signal can be received plus an ILS approach when needed.

So the question is, how many ILS's (and VOR/DME's) should be retained as a back-up?

D. The Skeleton System

FAA's answer is the skeleton system, a name only FAA could have come up with. Within the agency there is now a draft plan to retain a skeleton system of VOR/DME's and ILS's. Approximately 80% of both networks would be scrapped. The remaining 250 or so of each would be available for those days when the sun, or terrorists, or the DOD blot out the GPS signal.

The skeleton system has been carefully coordinated with the satellite enthusiasts in the Air Transport Association's staff. You will not be surprised to learn that only the major airports keep ILS's and VOR/DME's. The little airports and the smaller hubs are stripped bare. At least 500 of the 630 airports with ILS's are to be denuded. In my opinion, this ATA-sanctioned scheme is a severe threat to air carrier safety.

The general aviation situation is even worse. FAA proposes to scrap virtually all the VOR/DME's and ILS's used mainly by the little guys. GA gets no back-up at all.

Amazingly, the AOPA has joined forces with ATA in this plan. The carriers and the GA lobby have jointly endorsed the "sole means" doctrine and have endorsed a skeleton back-up network that is inadequate for air carriers and non-existent for business and small aircraft. Are the general aviation leaders paying attention?

E. LORAN C

The LORAN C navigation system presents a special case because it serves both aviation and maritime users.

Approximately 1.3 million LORAN C navigation sets are in use in the US, 80,000 of them by AOPA—member general aviation pilots, the rest by mariners.

The use of LORAN C for marine navigation is critical. Only the LORAN C signal follows the surface of the earth and is therefore received by vessels at distances of 500 or more miles. LORAN C is the only back-up signal to GPS for vessels. That's why the NTSB has endorsed its teaming with GPS.

The LORAN C signal is very difficult to jam. The high powered long wave signal covers the entire US right to the ground, which is why the little guys flying into remote airports love it so. Its accuracy, for enroute and terminal navigation flight, is as accurate as GPS. It is approvable for non-precision approaches to 400 plus foot decision heights. Modern receiver and antenna technology has eliminated all the reliability and continuity issues of the early LORAN systems. It is in every way—accuracy, coverage, cost—vastly superior to the VOR/DME system.

LORAN C costs, by government standards, virtually nothing. A private firm has offered to operate and modernize the entire US LORAN C chain of 26 stations for \$12 million per year.

And the US DOT proposes to close down every LORAN C station and take the navigation signal off the air.

This position is incomprehensible. The FAA's historic antipathy to LORAN C is at least understandable—the Coast Guard runs it. But the Commandant's silence, and Secretary Slater's disengagement, are harder to fathom. Did the Vice-President's technology-dazzled staff send down orders to kill all but the satellite systems? That is the rumor.

IX. THE LIABILITY SYNDROME

On the afternoon of the last day of the Rio Conference something very important happened. You may have missed it, because the entire aviation trade press missed it. The delegates from 100 nations endorsed a multi-lateral treaty to establish the obligations and liability of GNSS providers, namely the US and Russia.

Here is the reason. The Presidential Decision Directive (PDD) that set out US policy on GPS specifically reserved to the President ("the National Command Authority") the right to degrade, spoof, or turn off the GPS signal at any time, anywhere, for any reason. And we have refused to enter a GPS agreement to which we would be bound. Given that our troops use the GPS signal for virtually all our delivery systems, and that our enemies can use the signal against our troops, this is absolutely the right policy.

But it makes other nations more than nervous when they tie their economies to GPS. This is why the Europeans almost certainly will put up their own GPS look-alike satellite system.

Hence the decision to move toward a multi-lateral treaty which will require the provider to enter a binding commitment to keep the signal going without interruption and which will also pin liability for failure of the system on the provider and, probably, on the manufacturers of the satellites and of the receivers.

The formal approval for a liability convention must come from the ICAO Assembly this fall and the convention itself would be a year from then. Ratification into effect would take still longer but not, I predict, too long. What nation will delay ratifying a treaty that pins liability for an aircraft crash or surveying error caused by loss of the US satellite signal... on the US or its companies?

I doubt the US would ratify, or even sign, such a treaty. But it will still establish a worldwide liability regime for the US and for the manufacturers of satellites and receivers.

This is a matter to which the companies pursuing the \$10 billion GPS market might want to pay attention.

May I suggest the most promising defense against a bankrupting liability suit in, say, India? It's a BACK-UP SYSTEM, put in place by the host country. Then it's their fault for going single thread, which aviation wisdom tells us is a very bad idea.

There is only one ultra low cost, unjammable, highly accurate back-up system with coverage right down to the ground. It's LORAN C.

Thank you.