PITFALLS ON THE ROAD TO THE GOLDEN AGE OF NAVIGATION

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Presented To:
The Royal Institute of Navigation
Church House, Westminster
London
1 November 1999

I. THE GOLDEN AGE OF NAVIGATION ?

In June I said to the ATCA meeting in Vienna that we're in the Golden Age of Navigation. Perhaps my brief graduate student stay at The London School of Economics gave me a utopian outlook.

My optimism was caused by the wonderful array of tools we now have to support navigation—GPS, LORAN C, DME, ILS, MLS, and modern inertial systems. These high accuracy positioning systems are capable of sub-meter accuracy, are available at altitude, in valleys, and buildings (almost, but not quite, ad coelum et ad infernos), and are backed by atomic timing. These systems, in combination, are also virtually invulnerable and assure national security and economic growth.

Unfortunately, people, politics, and institutional interest have intervened. We haven't got to the golden age yet.

The first glimmer of the golden age came when the GPS military system arrived in the early 1970's. The splendid civil potential of satellite positioning and timing was immediately apparent. Twenty-five years later we have GPS in service for aviation, marine, and vehicle navigation; surveying; all sorts of tracking systems; recreational services; and telecommunication timing, to name a few civil applications.

Here's the problem: we went overboard.

The US Government and many others said satellite service is perfect. Put all the existing systems in the rubbish heap. This was a

big—a colossal—mistake. If we rely on satellite alone, there is the risk, indeed the likelihood, of multiple aviation and marine catastrophes, telecommunication, banking, and power distribution collapse; military and terrorism vulnerability; and loss of national sovereign independence. This risk extends not only to user nations but also to provider nations such as the US and, in the future, the EU with Galileo.

II. GNSS VULNERABILITY

Satellite positioning and timing signals are sent from a medium earth orbit of 11,000 miles height. The birds are energized by solar collectors and transmit with just one watt of power, about the same as your home cordless, not cell, phone. The power received on earth is 1^{-16} watt—one ten quadrillionth of a watt. GPS receivers work fine with this signal.

But... at this ultra low power level the signal is extremely vulnerable and can be interrupted. Unintentional interference from atmospheric effects and stray radio emissions are interferences which we regularly see now. I think these can be managed.

Intentional interference is more serious. For example, a simple 5-watt noise jammer for sale in a booth at the Moscow Air Show in 1997 killed the GPS signal for 200 kilometers. Retail price: $3,500. If you want to make one at home, the parts are available from a radio store for $50. Consider now spoofing jammers which mimic the GPS signal and fool the receivers. Spoofing jammers are complicated and expensive to make but their effect is amazing. A 1-watt spoofer can

disrupt GPS for 350 miles. Every defense ministry in the developed world is working in secret to find ways to jam GPS so GPS can't be used to bombard its troops, installations, and cities. The civil GPS signal is agnostic: it's as good a guidance system for a terrorist missile as it is for US ordinance.

III. SOVREIGNTY ISSUES WITH GNSS

GPS was developed, paid for, put in orbit, and is controlled by the US Defense Department. The DOD can degrade the accuracy of GPS and turn it off over all or part of the orbit. The famous Presidential Decision Directive (PDD) on GPS specifically states that GPS will be "responsive to the national command authority," i.e., the President. Despite repeated requests, at ICAO, the US has refused to enter any agreement to limit its freedom to turn off GPS.

There are no villains of this piece. The technology is simply that way: the one who puts up the system controls it. Every satellite in the sky is like that. Nor can the US be faulted for retaining control of the Put-Outer.* US and NATO troops would be at risk otherwise.

The EU is going forward with GALILEO, an EU controlled system which will be interoperable with GPS. The rationale for this is obvious: the EU wishes to control its own system and to protect against possible acts by the US. I understand and fully support this decision.

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* AKA "off button" or "switch." See "Harry Potter and the Sorcerer's Stone," J.K. Rowling, 1997, p. 16.

For the 150 nations of the world outside the US and the EU, the dilemma remains. They are at risk from intentional interference from any source and from a decision to withdraw the signal by the provider.

IV. THE SOLUTION: REDUNDANCY

The solution to this problem: retain a reduced array of ground based positioning and timing systems. Then if GNSS disappears the navigation and timing services continue.

The US, my country, is reassessing its initial position now. And the decision has been made: FAA Administrator Jane Garvey announced at the ATCA conference in San Diego two weeks ago that an array of ground based navaids would be retained for the foreseeable future, not just to some near term date. Here is the death in the US of GPS sole service.

Administrator Garvey's statement was addressed to aviation users and was solidly grounded on established safety principles of fail safe redundancy. But the lesson applies to all users, very much including users of timing.

V. THE MIXED ARRAY: WHAT TO RETAIN

The world's navigation systems are mostly based on old, line of sight technology. The old VOR/DME system is ultra reliable and ultra safe. But its coverage is poor because the signal is lost if the aircraft is over the horizon out of sight of the transmitter. To compensate for this, the VOR/DME sites are closely spaced. The US has nearly 1100

VOR/DME sites. The system is very expensive to operate and provides no service to users on the ground or on the water.

Most of the modern air carrier aircraft are equipped with navigation receivers that rely exclusively on DME (not VOR). EUROCONTROL has intelligently decided to retain and expand the DME network and to phase out VOR. The US should follow suit.

Precision approach—landing in bad weather—is a separate matter. ILS and MLS are the only terrestrial precision landing aids in service and these must be retained.

Inertial systems are now installed on most modern air carrier aircraft. Inertials are self-contained and are the ultimate in security since they do not rely on an external signal. The military loves inertials for this reason. Inertials are now used by air carriers as a back up for DME and for oceanic flight, where they team perfectly with GPS. Inertials are not now accepted as a stand-alone system in busy airspace. But inertial accuracy is going up and the price is going down, as Vic Strachan will tell you later today.

VI. LORAN C

Which brings us to LORAN. I will not go into technical detail about LORAN because it is the subject of many papers at this ILA/RIN three-day conference. But I am familiar with the application and safety aspects of navigation systems, and I have concluded that LORAN is the perfect system to team with GNSS. LORAN will flourish and will be

adopted worldwide as a partner with GNSS—GPS and GALILEO. Here's why.

- LORAN is a high accuracy navigation system like GPS. LORAN's present accuracy is .25 mile, GPS (with SA) is .15. For all present and future aviation navigation purposes, they are equivalent and sufficient.
- LORAN, like GPS, is a grid type positioning system and is capable of direct routing—RNAV.
- The LORAN signal is available on the earth's surface, like GPS, as well as in the atmosphere. So LORAN is useful for marine users as well as railways, motor vehicles, and recreational users. The old line of sight systems such as VOR/DME and DME/DME leave huge coverage gaps in airspace where the terrestrial transmitters are not in view.
- LORAN, like GPS, carries a timing signal from an atomic clock. Timing users such as telecommunications nets, financial systems, and power grids that rely solely on GPS will collapse if GPS is jammed or turned off. LORAN's timing signal provides a back-up to GPS.
- LORAN (and DME/DME) can be used to guide ADS-B for situational awareness and collision avoidance. These programs can continue with LORAN if GPS is lost. FAA has notified ICAO and the US Congress that ADS-B works well with systems other than GPS.

- LORAN is controlled by the host nation and therefore eliminates concerns about dependence on the US and about sovereignty. Unfortunately, both Britain and Ireland have no LORAN transmitters and are at risk of loss of GPS. They are also dependent on their European neighbors in the NELS chain for LORAN. This is a significant vulnerability in UK national security.
- LORAN has been proven to carry GPS augmentation signals. Because the GPS signal is bent hither and yon by atmospheric forces, a separate signal to the receiver is needed to correct these relatively small inaccuracies in order to provide high accuracy applications such as precision approach for aircraft. This LORAN modification, called EUROFIX, was developed at the University of Delft, Holland, under the leadership of Prof. Durk van Willigen, and is evidence of the continued leadership of the EU in radionavigation.
- Finally, LORAN is extremely cheap to establish and maintain. One LORAN transmitter can be installed for only $10 million. Because of the extremely long range of LORAN, the entire US/Canada North American land mass, from Alaska to the Maritime Provinces, can be covered with only 29 transmitters. Similar aviation (but not marine) coverage is provided by 1200 VOR/DME sites, with big voids at ground level. The annual cost to operate privately the entire US LORAN system of 25 sites is only $10 million.

VII. IN CONCLUSION

The world radionavigation situation is now in a state of uncertainty and flux. The technology is splendid: we just haven't figured out how to use it. Our fascination with the splendid satellite technology has caused us to ignore its limitations.

Now we are reassessing our plans, and the outcome will be a mixed system of celestial and terrestrial systems that will assure safety, frustrate terrorists, strengthen national security and sovereignty, and promote the creation of wealth in the developed and developing world.

Looking ahead to the third millennium I still predict... a golden age of navigation.

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