THE FEDERAL RADIONAVIGATION PLAN
and
THE FAA AIR TRAFFIC CONTROL SYSTEM OF THE FUTURE

Submitted To

THE DOT/DOD USERS REVIEW
OF THE FEDERAL RADIONAVIGATION PLAN

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I. GPS VULNERABILITY: THE ASSUMPTIONS CHANGE

During the past year it has become clear that the GPS signal is subject to a variety of interferences which can make the signal useless for navigation purposes.

For most civil users of the GPS signal, the signal's vulnerability is an annoyance, albeit an expensive one. But for aircraft and marine navigation, loss of the GPS signal for even short periods of time can affect schedules and revenues, and can even be catastrophic.

II. SOLE MEANS: THE NAVIGATION OF THE FUTURE BY GPS

The federal government, under the leadership of the White House science and technology advisors has urged the USDOT to adopt the satellite GPS signal as the primary guidance for navigation. Initially it was thought that the GPS signal was perfectly reliable and invulnerable, and therefore that no other radionavigation signals would be needed. GPS would be acceptable as the "sole means" of navigation.

The consequences of this (erroneous) assumption were that all of the expensive ground based radio navaids for planes and vessels, such as LORAN, VOR/DME, ILS, NDB, etc., could be decommissioned and scrapped. The savings to the federal budget would be impressive.

The use of GPS as a "sole means" of navigation is embedded in the Presidential GPS directive, the 1996 Federal Radionavigation Plan, the FAA's Air Traffic Control System of the future, and in the Coast Guard's maritime navigation plan. The International Civil Aviation Organization (ICAO) has accepted the GPS sole means logic.

The recognition of GPS's vulnerability, and therefore that GPS cannot be relied on as the sole means of navigation, has destroyed the foundation of every one of the plans. They will be revised.

III. FOR EVERY PHASE OF FLIGHT

The potential for loss of the GPS signal means that alternate/back-up systems must be in place to provide radionavigation service to permit aircraft to fly to their destination and to land safely under all conditions of weather and traffic. An alternate/back-up system <u>for every phase of flight</u> is needed.

To date the focus has been on retaining the Loran signal, which according to the 1996 Federal Radionavigation Plan (and also the 1994 Plan, after a sudden change from the 1992 FRP) is scheduled for termination in the year 2000.

But LORAN, as well as VOR/DME, is an en route system capable only of non-precision approaches with higher minimum descent altitudes. Neither LORAN nor VOR/DME *used alone* can be used for low ceiling precision approaches.

The ubiquitous ILS systems provide this service. They must be retained.

IV. RETAINING THE GROUND BASED NAVAIDS

The FAA and DOT planners are now beginning the healthy process of discussing which of the ground based navaids should be retained as a “back-up” or “complement” to GPS. There is an unspoken assumption that the original decommissioning plan was about right, and that only a skeleton system of navaids need be retained.

Not. The pilot unions and general aviation groups will be heard on this issue. The airport lobbies and members of Congress will speak up when ILS’s are to be removed. There is a genuine aviation safety issue here: can aviation safety be assured with a severely reduced navaid system when GPS is gone? Probably not.

Here is a good starting point for the discussion: Since the GPS signal can be lost, the navaids that could be removed pre-GPS are the same as those that could be removed post-GPS.

Each of the present navaid systems presents a different service, user, and cost picture. Here is a brief summary for each of the three principal navaid systems.

A. <u>VOR/DME</u>

There are more than 1,000 VOR/DME transmitters in the US. They are the basic en route navaid and the airways system is laid out from one VOR/DME to the next. Virtually all instrument equipped aircraft are equipped with this technology.

VOR/DME technology is inherently inefficient, and relatively costly. The main drawback is that the signal is very high frequency and therefore line of sight. It disappears over the horizon, and there are large chunks of mountainous, low altitude or rural US airspace with no VOR/DME signal, even with 1,000 sites in operation.

On the other hand, the VOR/DME system serves nearly all the significant airports in the US. The air carriers are basically 100% served by VOR/DME plus ILS.

Furthermore, the US air carrier fleet is rapidly equipping with expensive, sophisticated Flight Management Systems (FMS). FMS are often based on powerful computers fed by receivers which receive multiple DME’s (up to 12 at once) and which can fly direct, great circle routes (RNAV) with accuracy almost equal to GPS. However, the US air carrier fleet is rapidly achieving navigation performance nearly equal to GPS without receiving GPS. This is why the ATA is not enthusiastic about WAAS or GPS for domestic service.

It has long been recognized among ATC professionals that the US is probably over-equipped with VOR/DME transmitters. But this view is not necessarily shared by general aviation pilots who are the principal users of the VOR/DME's which fill the rural gaps.

Turning off, or pruning, the VOR/DME system will prove to be a slow grudging process. But a good case can be made for some reduction.

B. LORAN

The LORAN navaid signal is at a low frequency and therefore follows the curve of the earth. It is available to the surface of the earth over all the US and far out to sea (and, significantly, in a lot of other countries). The signal is much more accurate than VOR/DME. The entire US, and much of the ocean, is served by just 29 LORAN transmitters. LORAN is suitable for en route and terminal navigation and for non-precision (laterally-guided) approaches. The problems which plagued early LORAN receivers (such as p-static) have been solved.

By every standard—coverage, accuracy and operational cost—LORAN is significantly superior to VOR/DME. There is only one obstacle—aircraft equipage. Even though more than 100,000 general aviation aircraft are LORAN equipped, two thirds of the aircraft are not. And none of the air carrier fleet is LORAN equipped.

There is a special, more acute, problem with LORAN in marine navigation. The LORAN signal, which follows the surface of the earth, is the only alternate back-up signal to GPS for marine navigation. Since the cut off date of Y2K for LORAN was published in the 1994 Radionavigation Plan, sale of marine LORAN receivers was chilled. Unless the Y2K LORAN termination date is abandoned, there will be tankers full of crude oil and toxic chemicals, and bulk carriers full of explosive fertilizers, navigating in Valdez, New York, and San Francisco with only GPS for radionavigation. In the marine world, the proposal to cut off LORAN was a blunder and presents an acute, here-and-now problem.

LORAN is the alternate navigation system of the future. It should be retained and modernized by DOT. The decision to do this will immediately invigorate world-wide LORAN development, modernization and expanded presence.

C. ILS

The Instrument Landing System (ILS) navaid provides precision guidance through bad weather right down to the runway. Next to the jet engine, ILS was probably the most important safety advance in aviation history. There are nearly 1,200 ILS's in the US, at the 630 busiest airports. The US has 50% of the ILS's in the world.

The ILS is the last critical navaid in aircraft flight, permitting the plane to return safely to the ground, even in otherwise lethal weather. Because the alternate/back-up system must cover every phase of flight, full ILS service must be maintained.

Will it be possible to scrap some of the ILS transmitters? That question will be answered by pilots and by airport managers. There will be great resistance.

V. SHARPENING THE GPS SIGNAL

In the early, bright days of GPS planning there was the mind-set that the dependability and coverage of the GPS signal could provide a radionavigation signal for every phase of flight, and that all the ground based navaids could be scrapped. Expensive, technically challenging programs would be launched by FAA to increase the accuracy of the GPS signal to permit low DH precision approaches to replace even the ILS.

Two types of systems were proposed: wide area and local area systems.

A. WIDE AREA AUGMENTATION SYSTEM (WAAS)

The WAAS was originally designed as a means for transmitting integrity messages as an augmentation to basic GPS. That purpose has been expanded to include differential refinement of the basic GPS signal in space to the Category I (CAT I) precision approach standard, close to a garden-variety ILS with a 200' DH. WAAS/GPS will be available everywhere in the US and would provide a precision approach (horizontal and vertical guidance) capability to all qualifying runways.

A CAT I approach requires a signal accuracy of 4 meters or less. The initial tests of WAAS did not meet a CAT I standard, and the Hughes contract requires delivery of only a 7.6 meter vertical accuracy, which would not support a CAT I approach to a 200-foot DH. However, more recent tests are said to indicate WAAS/GPS can be brought within 4 meters. This indicates good technical work by Hughes and FAA.

However, there are a number of caveats to the WAAS/GPS project, to wit:

- Cost Saving. The vulnerability of the GPS signal has eliminated the possibility of scrapping many, and probably any, of the existing ILS's. Neither WAAS/GPS (nor LAAS/GPS) can now claim the original estimates of cost avoidance.

- Service. There are more than 1,000 ILS's in the US serving 630 airports. These ILS's handle the majority of instrument approaches, and probably 95% of the air carrier instrument approaches. For these approaches, WAAS/GPS is now merely duplicative.

- Qualifying Airports. A signal in space is only one of numerous requirements for a certified CAT I approach. Other requirements include runway length and width, runway marking and lighting, and obstacle clearance. Obstacle clearance is especially expensive, and perhaps impossible to establish. As an example, Washington National Airport has six runway ends, five of which cannot qualify for a CAT I approach because of obstacles. Unless all of these requirements are met, an airport cannot have an approved CAT I approach.

- Since the ILS service will be retained at the top 630 airports, the WAAS approach signal will benefit only the smaller airports. WAAS precision approaches are therefore a benefit primarily to general aviation.

- The cost of WAAS has escalated from an estimated $500 million to a life cycle cost of $3 billion. The benefits have contracted. The economic rationale must be recalculated.

B. LOCAL AREA APPROACHES. A second GPS sharpening project is underway at FAA to improve GPS signal accuracy to a higher standard than WAAS. The Local Area Augmentation System (LAAS) would have a limited range of 25-30 miles and would provide a signal accuracy to permit CAT II and CAT III approaches. Cat II would provide a 100' DH and CAT III would even permit autoland.

CAT II and CAT III are required and usable only by commercial air carriers since almost no other civil user has this requirement or capability. The latest plan is to provide 143 LAAS systems in the largest metropolitan hubs, where they would replace ILS systems providing the same service.

However, because GPS vulnerability requires an alternative/back-up service for every phase of flight, ILS systems will remain in service. The planned LAAS systems are largely duplicative of ILS.

There are other local area approach systems to improve GPS. The SCAT/MIG systems are based on differentially corrected GPS signals and are designed to provide a CAT I signal at an airport for a very reasonable price—about $300,000 to $400,000 compared to a CAT I ILS for about $500-700 thousand. If the purchaser is willing to live with GPS vulnerability, which may be acceptable at a small airport, there could be a useful role for some local GPS precision approach systems in the rural US or in the developing world.

VI. DIFFERENTIAL GPS USING LORAN COMMUNICATIONS

The Europeans are well aware of the vulnerabilities of GPS and of the necessity of a secure back-up/alternate ground-based system. They have formed and are implementing an elegant, low cost solution—EUROFIX.

Under the leadership of Prof. Durk van Willigen, GPS differential messages have been combined with the standard LORAN signal. The differential data is simply <u>added</u> to the signal at the existing LORAN stations. The combined signal provides the DGPS communication to improve GPS accuracy when it's available, and an independent navigation signal for vessels and aircraft when it's not.

The results are encouraging. The Eurofix/LORAN differential signal has been demonstrated to provide accuracy within 5 meters, and it could be improved to as sharp as 1 meter. This is better than WAAS (<7 meters) and perhaps as accurate as LAAS (about 1 meter).

The cost of the EUROFIX solution applied to the US would be low. Adding the DGPS communication to the existing 24 US LORAN stations would cost a total of $10 million.

The US LORAN station chain is aging and it does need to be upgraded. Upgrading the LORAN stations would require a one-time expenditure of $75-100 million, and would not be repeated for at least 20 years. The annual operating cost would fall from $18 million to $6 million.

VII. SURVEILLANCE GOES DARK: SINGLE THREAD INTERDEPENDENCE WITH GPS

Dependence on the GPS signal is not limited to the navigation system. Satellite dependence has crept into the controller's world as well.

In the ATC system of the future, the aircraft broadcasts directly its position (ADS-B, based on GPS).

Therefore, if the GPS signal is lost, the controller's picture is lost! This is the ultimate in ATC vulnerability: a single hand held jammer can destroy not only all GPS navigation for a radius of 200 kilometers, but also the controller's ability to see the aircraft as well.

The current ATC surveillance system relies on a network of radar installations which are independent of each other and which incorporate two different types of sensors—primary radar (a "skin paint") and secondary radar, which is transponder beacon based. This system may look inelegant to the satellite technician, and expensive to the budgeter. But it is very reliable and therefore, very safe.

At least <u>two</u> steps should be taken to minimize the spread of the GPS virus into the controller's suite:

- any downlink of aircraft position should be based on a multi-sensor navigation receiver, i.e., GPS plus LORAN, or GPS plus VOR/DME, or GPS plus INS/FMS. When GPS is lost there will be a back-up fix for the controller as well as the pilot.

- retain the secondary (beacon) radar systems.

VIII. THE NEXT STEPS FOR DOT

A. NO SOLE MEANS FOR AIRCRAFT

The DOT should state publicly that the GPS signal is vulnerable and cannot be a sole means of navigation for aircraft.

B. CHANGE FRP NOW

The DOT should immediately amend the 1996 Federal Radionavigation Plan by deleting all termination dates for navaids, including LORAN, VOR/DME, and ILS.

C. UPGRADE LORAN

The DOT should declare the LORAN system a permanent navaid and should upgrade all 29 stations with modern, low maintenance, solid state components. Blink and GPS differential correction should be added.

D. FIX MARINE RADIONAVIGATION

The DOT should reject GPS sole means marine navigation and should require GPS and LORAN receivers on all large vessels, on all HAZMAT cargo vessels, and on all passenger-carrying vessels of US registry and in US waters.

E. LORAN AS A DISTRIBUTION CHANNEL FOR GPS CORRECTIONS AND INTEGRITY

The DOT should add the differential GPS signal to all US LORAN stations.

F. MAKE ILS PERMANENT

FAA should declare ILS a permanent precision approach and should initiate an open dialogue with users about eliminating some ILS's.

G. CONTINUE VOR/DME

FAA should affirm the continuation of VOR/DME and should initiate an open dialogue with users about reducing the number of VOR/DME sites. The air carriers will shortly need only the DME signal to drive their FMS systems. Therefore, the carriers should state how many DME's they will need in the future. The general aviation community is now using VOR/DME, as well as LORAN, but LORAN is a complete substitute for VOR/DME. FAA should open a dialogue with the general aviation community about transitioning all GA aircraft to LORAN and, at some future point, decommissioning VOR.

This would lead to an ultimate terrestrial system with DME, LORAN, and ILS.

H. REASSESS WAAS

All of the permutations of GPS are radio signals which make it possible to determine an accurate point in space. The unique requirements of aviation are now known to limit the benefits and cost savings of WAAS. But radio location, of which radionavigation is only a part, has other useful roles for WAAS.

The benefits to <u>all</u> users of WAAS should be evaluated before a final disposition of WAAS is made.

I. LORAN APPROACHES

FAA should direct its ATC procedures office to establish LORAN non-precision approaches.

J. LORAN/GPS RECEIVERS

FAA should develop the technology for low cost LORAN/GPS integrated receivers for general aviation aircraft.

K. MULTI-SENSOR FREE FLIGHT

The Flight 2000/Free Flight Program should be modified slightly to accept GPS, INS, VOR/DME & LORAN. This includes the Conflict Probe Project.

L. NO CONTROLLER GPS VIRUS

FAA should modify any use of satellites for surveillance to eliminate sole reliance on GPS and to maintain independence between navigation and surveillance.

M. EVALUATE ADS-B

FAA should initiate an independent assessment ADS-B to be certain the independence between navigation and surveillance can be assured and that GPS vulnerabilities are not a safety problem in the surveillance area.

N. ICAO.

FAA should notify ICAO that GPS as a sole means of navigation involves very significant risk and that alternate/back-up systems should be provided. FAA should initiate action in ICAO to recognize LORAN and variants such as the Russian/CIS “Chayka” system as internationally-standardized navaids.