Clocking On

Ronald Bruno and Charles Schue discuss eLoran as a PNT resiliency solution for ATM applications

ATM is but one community, among a number of diverse and critical industries that have come to rely on GPS for positioning, navigation, and timing (PNT). While ATM and other communities may independently adopt application-specific solutions for PNT resilience, it is important to recognise the commonality of the challenge to provide assured PNT and explore the efficiency of implementing a common set of solutions across all industries.

Much of the world's critical infrastructure has come to rely on the PNT services that GPS provides. The future only points toward increased reliance on GPS. Its use in ATM is illustrative. In accord with FAA planning, a principal surveillance source in the US National Air Space (NAS) by 2020 will be ADS-B, where the required positional accuracy of aircraft relies on GPS position. Moreover, the independent validation and backup of GPS-derived positions relies on accurate time-of-arrival measurements at a network of over 650 radios stations in the NAS that currently use GPS disciplined clocks with accuracy down to 30 nanoseconds. These radio stations are critical infrastructure of the Surveillance and Broadcast Services (SBS) system, built and operated by Harris Corporation, providing ADS-B surveillance to FAA Air Traffic Control.

Need for PNT Resiliency

The resiliency of GPS has come under increasing scrutiny because of its widespread use in critical infrastructure and its vulnerability to outages, particularly from interference, both deliberate and unintentional. The response of the technical community to the critical reliance on GPS has been to seek to increase the resiliency of GPS PNT by initiatives that protect GPS, toughen GPS, and augment GPS with complementary technologies. GPS augmentation may be specific to applications and industries, but there is an evolving and broad consensus forming around the triad of GPS, Enhanced Loran (eLoran), and inertial systems as the firm basis for resilient PNT across multiple industries.

PNT Resiliency for ATM Surveillance and Navigation

The FAA recognises the need for a backup to surveillance and navigation in the event of local, regional, and wide-scale GPS outages, and is examining both near-term and long-term strategies for continuity of operations during outages. Because of the long lead times for

ATM technology insertion, near-term mitigation strategies out to at least 10 years are constrained by existing ATM ground infrastructure and current avionics capabilities. Long-term solutions are not so constrained, and may be based on new signals in space, new ground infrastructure, and new avionics capabilities. As FAA planning is underway, but not complete, we provide here a top-level summary of the elements under consideration. This should not be interpreted as a representation of formal FAA policy or decisions.

Surveillance. Beginning in 2020, ADS-B will be a principal surveillance technology. In recognition of the need for a backup if GPS fails, the FAA is planning to maintain a mix of beacon-interrogation radar and Wide-Area-Multilateration (WAM) in the near-term. The radar capability involves the maintenance of radars in all en route and selected terminal service volumes. The WAM capability involves use of the SBS radio stations to support time difference of arrival (TDoA) data for WAM position determination. The long-term strategy is still very much in the evolutionary stage.

Navigation. Near-term strategies involve a mix of approaches based upon existing infrastructure and the current capability of avionics. A leading approach, referred to as DME/DME/IRU, uses two-way ranging to multiple Distance Measuring Equipment (DME) facilities augmented by the avionics Inertial Reference Unit (IRU). This approach is practical and applicable more to air carrier aircraft than regional jets or general aviation. Other approaches rely to some extent on the use of VHF Omni Directional Range (VOR) facilities. As with surveillance, the long-term strategy is very much evolutionary.

It is instructive to note that near-term solutions rely on existing radar, DME and VOR infrastructure because it is in place and is compatible with existing avionics. However, in the long-term, many near-term solutions are not cost-effective because maintaining this infrastructure is expensive, involving thousands of DME and VOR facilities and investments in technology upgrades. Moreover, this infrastructure is dedicated to ATM, providing only ATM benefits, so that ATM applications must bear the total costs. Thus, in the long-term view, new technologies with less costly infrastructure are likely to be more cost-effective, especially if they provide benefits beyond ATM applications. eLoran is such a technology.

eLoran and Loran-C History

eLoran is a major technology upgrade of Loran-C, but can be provided by the same sites and antenna technology used for Loran-C. The US portion of the North American Loran-C system served the CONUS, Alaska, Hawaii, and EEZ. Eighteen stations provided CONUS coverage. At one time, there were 78 operational Loran-C stations in the Northern Hemisphere. Many countries, including the UK, Germany, Denmark, France, Norway, South Korea, the Kingdom of Saudi Arabia, Japan, China, and Russia, continue to provide Loran-C service, and there are international initiatives to upgrade those services to eLoran.

When GPS was declared fully operational in 1994, the US military eliminated its requirement for Loran-C. In recognition that Loran-C did not meet emerging PNT requirements, the US Government invested over $160 million from 1997 through 2010 to modernise and upgrade Loran-C to eLoran. The programme was executed with coordination between the USCG and the FAA, and was designed and tested to meet Non-Precision Approach (NPA) performance in support of aviation, Harbor Entrance and Approach (HEA) in support of marine, and Stratum 1 time and frequency in support of communications and network operations.

In addition, a variety of policy decisions were made at the US executive level that recognised the value and importance of eLoran. Moreover, government, academic, and industry studies, nationally and internationally, have evaluated the operational and cost-benefit of eLoran and overwhelmingly reported positive findings. A relatively recent and authoritative study was the Benefit-Cost Assessment Refresh: The Use of eLORAN to Mitigate GPS Vulnerability for PNT Services, 11/5/2009 (prepared for the USCG/DH and FAA/DOT by the John A Volpe NTSC, US DOT, Cambridge, MA.

However, in spite of the successful development, favourable technical assessments, and a longstanding presidential mandate for GPS backup, in 2010, eLoran funding, and Loran-C transmissions in the US and Canada were terminated. But recently, with the increasing awareness of the security threat posed by GPS denial, there has been a renewed interest in eLoran. The Howard Coble Coast Guard and Maritime Transportation Act of 2014 (H.R. 5769) directed the USCG to cease activities related to the dismantling or disposal of infrastructure that supported the former Loran-C sites, and further encourages 'cooperative agreements, contracts, and other agreements with federal entities and other public or private entities, including academic entities, to develop a positioning, timing, and navigation system, including an Enhanced Loran system, to provide redundant capability in the event GPS signals are disrupted'.

GPS	eLoran
Satellite based transmission (24+ SV constellation)	Land based transmission (18 stations for CONUS); 1,000 mile range via ground wave propagation
Easily jammed /spoofed	Extremely difficult to jam or spoof
Various L-Band frequencies	Low Frequency (100 kHz); protected spectrum
Low transmission power	Very high transmission power
Subject to blockage	Low Frequency signal invulnerable to blockage
Needs outdoor antenna	Signal penetrates indoors and underground

Figure 1

eLoran Technical Description

eLoran is an overlay on the internationally standardised Loran-C PNT service, and is 'defined' as a PNT solution that includes transmissions synchronised to UTC, at least one Loran Data Channel (LDC), Additional Secondary Factor (ASF) mapping, and differential corrections. It is ideally suited to serve as a complement to GPS as its signal generation and transmission is quite different and completely independent of GPS as **Figure 1** indicates.

Basic eLoran PNT performance starts off good, and improves with static and dynamic configuration data. During the implementation of a fully realised eLoran service, users can take advantage of interim capabilities. The cited eLoran accuracies below are in terms of 2DRMS, 95 per cent.

- **'Basic Initial Operational Capability (IOC)'. Includes UTC synchronisation, LDC, and rudimentary propagation delay corrections (ASF) based upon ITU conductivity maps**
- Timing typically better than +/- 500 nanoseconds
- Timing often better than +/- 100 nanoseconds after one-time calibration
- Positioning typically less than 100 metres

- **'Advanced Operational Capability (AOC)'. Basic IOC eLoran plus modeled or surveyed delay corrections**
- Timing typically better than +/- 100 nanoseconds
- Positioning typically 50-100 metres, or less

- **'Full Operational Capability (FOC)'. AOC with differential delay corrections**
- Timing typically better than +/- 50 nanoseconds
- Positioning typically better than ten metres (~ 33 feet)

eLoran is a mature technology developed and refined in the US. Its development goals included low cost of ownership, very high reliability, and improved accuracy, availability, reliability, and continuity, as compared to Loran-C. We estimate that, if the US set a priority for implementation of an eLoran system to provide PNT over CONUS using the existing legacy Loran-C sites, a system could be built and operated very quickly, and sustained for decades with an annual budget between $20 million - $30 million, depending upon the number of stations, station configuration, and user requirements.

Cooperative Research and Development Agreement (CRADA) Overview

On May 21, 2015, Harris and UrsaNav entered into a CRADA with DHS S&T and USCG. Under the CRADA, existing resources (i.e., facilities and equipment) at legacy Loran-C transmitting stations are being made available which, when combined with our own technology and expertise, provide advanced research capabilities. Specific areas of research include a combination of analysing, simulating, evaluating, testing, and/or demonstrating eLoran's ability to meet benchmark PNT requirements.

The FAA, in concert with the USCG, had previously fully tested eLoran for multi-modal use. The FAA's final report on Loran's Capability to Mitigate the Impact of a GPS outage on GPS Position, Navigation, and Time Application (March 2004) concluded that '… the modernised Loran system can satisfy the current NPA, HEA, and time/frequency requirements in the coterminous United States and could be used to mitigate the operational effects of a disruption in GPS services, thereby allowing the users to retain the benefits they derive from their use of GPS'. Aviation position accuracy requirements cited in the CRADA are from the same FAA final report, and are summarised in **Figure 2.**

Over a wider set of target environments, navigation accuracies as low as RNP 0.1 (185 metres) are required. At a minimum, an alternative PNT system would need to support at least RNP 0.3 (556 metres) to sustain departure and arrival paths at high-density airports. In fulfillment of the objectives of the CRADA, Harris and UrsaNav, in coordination with DHS S&T and USCG, are initiating a comprehensive test programme that will be conducted over a minimum of a year. This CRADA also provides for 'industry days', which will enable the government and industry to evaluate the utility and suitability of eLoran as a complement to GPS for providing assured PNT.

Aviation Requirements (Non-Precision Approach – NPA)

Performance Requirement	Value
Accuracy at airports	307 metres
Monitor Limit (HPL) at airports	556 metres
Accuracy Enroute/Terminal	0.25 nm
Monitor Limit (HPL) Enroute	2 nm
Monitor limit (HPL) terminal	1 nm

Figure 2

Summary

The performance of today's eLoran technology can meet aviation PNT requirements for terminal and enroute navigation and surveillance and does so with a small number of facilities relative to ATM-specific DMEs and VORs. It also can meet the timing requirements of the ATM ground infrastructure. And like GPS, it is a general purpose, multi-modal, utility that can serve a number of other government and industry applications. Accordingly, the benefits of an eLoran system would be integrated over a number of government and industry sectors, and thus supports a very favourable overall cost-benefit ratio.

Because of the long lead times associated with the introduction of a new onboard avionics, the use of eLoran on board aircraft is applicable only for the long term. However, ATM ground infrastructure has a need for accurate time that is currently provided by GPS, and eLoran can readily complement GPS to provide the timing resiliency appropriate for this critical infrastructure. eLoran may also be useful to the general aviation community in the near term.

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