Keynote address:
Loran: Coming home?

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Abstract
The world of Loran is changing. In many European countries it is no longer regarded as a stand-alone navigation and timing system, but rather as an augmentation for satellite navigation. In that role Loran has many advantages: it is in place, it does the job well, and its weaknesses so complement those of GPS as to make of the two a powerful combination. Exceptionally among GPS augmentations, Loran is a navigation and timing system in its own right, able to take over when the satellite signals are lost; hybrid receivers go even further, combining the two systems into a navigation aid of high availability and excellent performance. These benefits are being increasingly accepted, as the shortcomings of satellite-only systems, notably WAAS and EGNOS, are beginning to be recognised. The future role of Loran, therefore, may well be in combined satellite/terrestrial augmentations to GPS. One such system is now operating in Europe, and the concept may well prove equally valuable in the US and other parts of the world.

Introduction
I was delighted to be asked to give this keynote address, but also quite alarmed. Loran! In Washington! What is it about Loran that leads to controversy, especially in this country and this city? Such confrontations with GPS! Friends won and lost, so many bold claims, threats and boasts. It's like an argument in an Irish pub! So, you understand my misgivings.

I have always felt uncomfortable in Loran versus GPS fights. In a balloon debate, with one thrown out to ensure survival, I would jettison Loran. I would stick with GPS. And, as a European, I dislike some things I hear in GPS-Galileo debates. Frankly, I start from this viewpoint: that satellite navigation is one of the outstanding technological achievements of the 20th Century. To have created a system, precise, reliable, yet so simple to use, then to have devised manufacturing technologies to produce it at consumer prices, is an immense achievement of which this country should be intensely proud. If they were British, chaps like Tom Stansell and Brad Parkinson would be in the House of Lords - arise Sir Brad! And to have shared that technology openly with other nations (of course that is good for US commerce, and of course the system can be denied in a war, but these are details) is an act of exceptional generosity in a wicked world. So, as we look during this conference at the limitations of that technology, let us recognise that the world owes the US a very big thank-you for GPS and that satellite systems are undoubtedly the basis of navigation technology for the foreseeable future.

Just six years ago, in a keynote address to the IALA[1] Conference in Hawaii, I took my life in my hands and dared suggest that sole-means GPS was unsafe [1]! I was talking about raw, unaugmented, GPS. Most folk then thought such GPS was enough for safety-critical services. Who of us now believes that? Augmentations to GPS have been the focus of satellite navigation development ever since. Now we argue for WAAS[2] against LAAS[3], for satellite against terrestrial; we discuss which augmentation, not the need for augmentation. Yet the current debate is still about whether satellites alone can give us all the navigation and timing we need.

This debate sometimes takes on the most arcane forms, almost theological, like the medieval question of how many angels could dance on the head of a pin. With us it is: sole-means, sole-system, primary-means, only-means - until your head spins! But on both sides of the Atlantic, and elsewhere, I sense a backing off from the extreme "satellite-only" position. And the reasons: well, just read the list of improvements to GPS now being called for at the highest levels in the US (Fig. 1).

The wish-list shown in the Figure helps us identify the current shortcomings of the GPS system. We see that GPS needs more power to improve the signal's ability to penetrate jungle canopies in military use and urban canyons in civilian use. It

[1] Name then: International Association of Lighthouse Authorities
[2] Wide Area Augmentation System
[3] Local Area Augmentation System

needs, and is to get, additional frequencies, certain of them better protected for the safety of aviation. It needs higher accuracy, even without SA[4]; and SA's demise has focussed attention on new ways of denying the service to the guys in the black hats. The list calls for more satellites, to improve coverage when the going gets tough. And the integrity of GPS - knowing for sure you are where it says you are and being told immediately it goes wrong - needs substantial enhancement.

Fig. 1 – Improvements required in GPS

Finally, interference and jamming. The John Hopkins study said these could be beaten, but it would take more power and much better technology than GPS has currently [2,3]. The Chief Engineer of the Joint Program Office has called for six orders of magnitude better jamming resistance for military use [4]. Such improvements are also vital for civil users in safety-critical and mission-critical applications.

First and second generation satellite systems

What we have now is first-generation GPS: a brilliant start to general-purpose satellite navigation, with better to come. Second-generation GPS (Fig. 2) will have extra power, frequencies, jamming protection and integrity. And Europe's Galileo, if it comes, will be a second-generation satellite navigation system. But to create these systems will require international spectrum negotiations, the setting of requirements, the obtaining of funding, and the building and deployment of a complete new constellation. Only then will we get all the benefits shown in Fig 1. And the wise heads tell us that all that will take until 2015 or so.

[4] Selective Availability

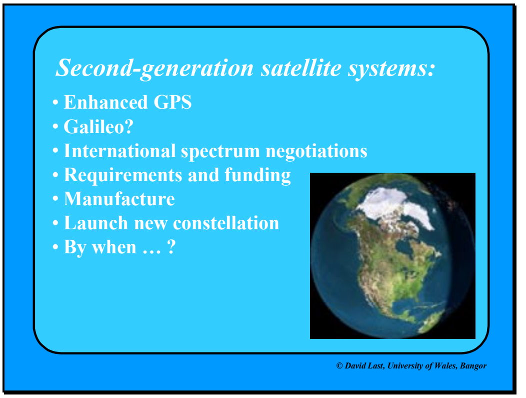

Fig. 2 – Second generation satellite systems

Satellite augmentations in the medium term

So what do we do in the meantime, the medium term, for the next 15 years? We will go on minimising the effects of the shortcomings of GPS by means of augmentations. That brings us back to the question: do we rely solely on satellite augmentations? Many people think we should, by means of WAAS in the US or EGNOS[5] in Europe.

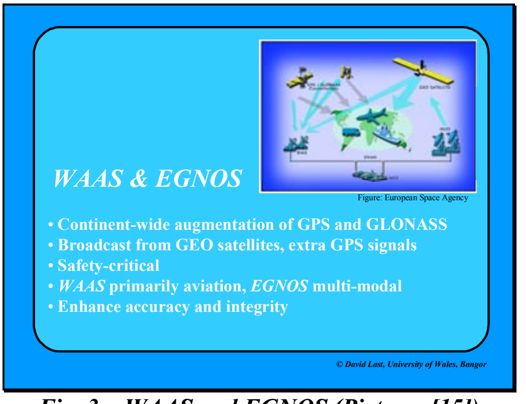

Fig. 3 – WAAS and EGNOS (Picture: [15])

These two systems employ very similar technologies (Fig. 3), with multiple reference stations providing augmentation across whole continents. Augmentation data, plus additional GPS signals, is transmitted by geo-stationary satellites. Both systems are support GPS, while EGNOS augments GLONASS[6] as well. They are safety-critical services, WAAS intended primarily for aviation, and EGNOS for all modes of transport. And like all augmentations, they improve accuracy - though no longer dramatically with the passing of

[5] European Geostationary Navigation Overlay System

[6] Global System for Satellite Navigation

SA – and increase integrity, making satellite navigation much safer.

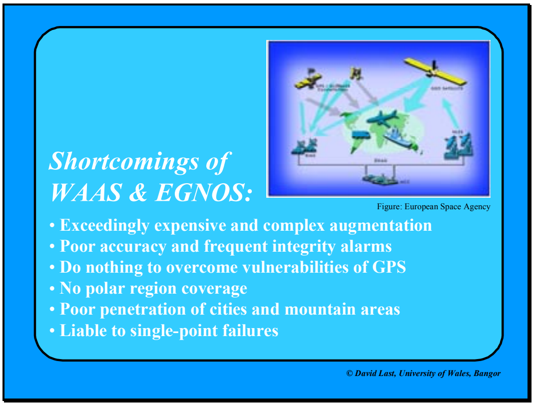

Fig. 4 – Shortcomings of WAAS and EGNOS (Picture: [15])

WAAS and EGNOS are elegant solutions: the user gets all signals from space via a single antenna and receiver. If they worked well, they could be the way ahead. But there are big problems (Fig. 4). Firstly, they are hugely more expensive than other marine and land GPS augmentations, such as coastal radiobeacons [5,6] or NDGPS[7] [7]. They are no more accurate (often less), and they offer only similar integrity. Neither WAAS nor EGNOS does anything to solve the serious problems of GPS jamming, interference or signal blockage, other than telling users more promptly that they've lost service. Indeed, the augmented system is much more vulnerable than GPS alone because the WAAS/EGNOS data signals reach the user from satellites over the Equator, as in satellite television. So there is no service in polar regions, poor performance on land at higher latitudes, and worse penetration than GPS into cities, valleys, and harbours.

Most seriously: because GPS and the augmentation use the same frequency, antenna and receiver, a failure of either is a single-point failure of the whole system. That is unacceptable in safety-critical navigation systems. It can also lead to the loss of national timing services, with disastrous consequences for the telecommunications industry, if no backup is provided.

You hear these criticisms more loudly in Europe than in the US. One reason is because WAAS is seen in the US as a system primarily for aviation use, whereas EGNOS is promoted as the answer to the prayers of many maidens, including mermaids and milkmaids! On land all these shortcomings apply, but in the air only some.

[7] National Differential GPS

Terrestrial augmentation of satellite systems

It is from Europe, too, that you hear a growing swell of argument in favour of a terrestrial backup to WAAS and EGNOS that might overcome these problems. We will learn a good deal about that idea in this conference, since it involves Loran.

Fig. 5 - Loran-C in Europe (Picture: [16])

It is not surprising that new thinking on Loran often comes from Europe. European administrations see Loran very differently from the US (Fig.5). The Federal Radionavigation Plan claims that there are 500,000 US Loran users at sea, 100,000 in the air, and 30,000 on land. In Europe there are almost none, and very little Loran tradition. The Europeans took over US Coast Guard Loran stations and re-equipped them with highly efficient, economical, systems that largely run unattended. There is a freshness about Loran in Europe, driven by research. And there is also a widely-held view, promoted by the European Commission, that a navigation system should if possible serve all modes of transport: land, sea and air. So Loran in Europe has been thought out anew, and the result is rather different from US Loran.

Fig. 6 shows the policy adopted by the European administrations that run the NELS system [8]. Satellite navigation is seen as the primary component in the future mix of systems; that is, principally GPS now and maybe Galileo in the future. Existing satellite systems do not meet all user requirements; augmentation systems and integration with terrestrial systems are required. The original NELS service (ie Loran) no longer meets the requirements for a separate stand-alone system and its future role is as part of an integrated system.

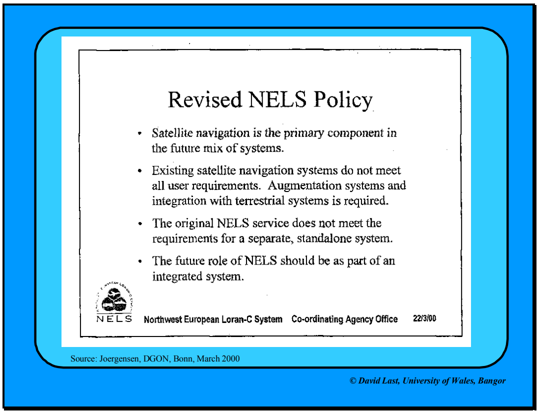

Fig. 6 – Policy of Northwest Europe Loran-C System (NELS) [8]

Loran augmentation of satellites in Europe

An integrated system with terrestrial and satellite components makes sense. But why use Loran? Well, as Fig. 7 shows, Loran is there, it does the job well, and its weaknesses are so different from those of satellite systems that while separately they are have shortcomings, together they make a class act! The reason satellite systems are so vulnerable to jamming and interference is because they deliver so little power to receivers; in contrast, Loran with its high power is very hard to jam. Then, the signals from satellites are easily blocked by buildings, mountains, or forests, while the groundwave signals of Loran penetrate deep into cities and even into buildings. Single-point failures are eliminated by the use of high-frequency technology in satellites and (completely different) low-frequency technology in Loran. Finally, all satellite systems so far have been controlled by single nations; Loran lets other nations take responsibility within their own regions.

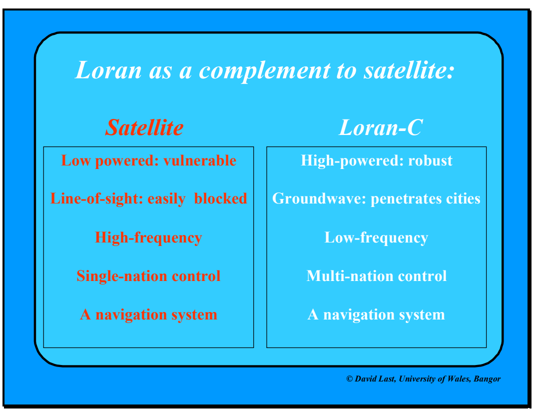

Fig. 7 – Loran-C as a complement to satellite in augmenting GPS and GLONASS

Perhaps the most important advantage of Loran, though, is that it is itself a navigation and timing system, like GPS. In contrast, WAAS, EGNOS, IALA beacons, NDGPS, and the dozen other GPS enhancements are simply communications systems. If you lose the satellite signal, you lose your ability to navigate. With Loran, though, if you lose the GPS, you keep right on navigating.

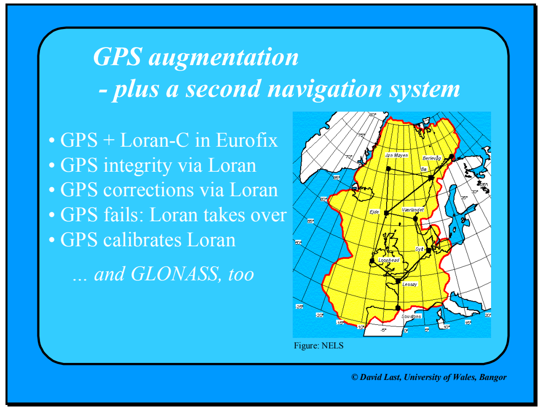

Fig. 8 – Loran-C augments GPS, with a second navigation and timing system for Europe [8]

Those are the arguments that appealed to European nations. Fig. 8 shows the system they have implemented. Navigation and timing are normally provided by GPS; that is, fully augmented, high-accuracy, high-integrity differential GPS, as with WAAS or EGNOS. But here Loran is the communications system that carries the augmentation messages, by means of the Eurofix technique [9]. As with other augmentations, those messages confirm the health of GPS, giving high integrity and rapid warning of failures. The corrections provide metre-level accuracy, performance at least as precise as with WAAS or EGNOS. Then, when you lose GPS signals in cities, forests or mountains, Loran takes over temporarily. But, this is not ordinary Loran, rather a much more accurate version in which the so-called "fixed errors" (Additional Secondary Factors) have been removed by constant calibration against GPS. It is even possible to have hybrid receivers that treat Loran stations as additional satellites. With these, you can fix your position in difficult locations using, say, two satellites and a couple of Loran stations.

Combined this way, the "whole" of GPS plus Loran is better than "the sum of the parts"! And the arrangement has also been shown to work well with GLONASS.

This system is now operating 24 hours a day, on a "test and validation" basis. Its augmentation serves most or all of the territory of the 15 countries shown in Fig. 9, a population greater than that of the United States. We will hear a good deal about this system in the conference. We will learn, too, of discussions about making it a terrestrial component of EGNOS and possibly of Galileo, too. There are papers on the integrated GPS/Loran receivers I mentioned and also about the GAUSS initiative. GAUSS[8] is aimed at amending the international regulations of the RTCM[9], ITU[10] and IMO[11], so as to facilitate the adoption of integrated satellite/terrestrial navigation [10]. And, finally, we will hear about the many nations - including my own - now lining up to join the party.

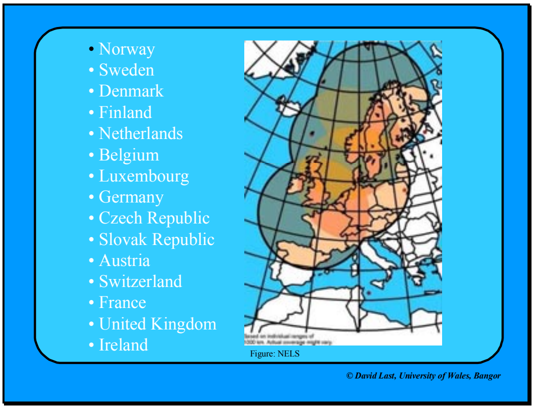

Fig. 9 – Area of Europe currently covered by present NELS augmentation [8]

So, in Europe, this concept of Loran used solely in conjunction with satellite navigation has taken hold. It looks capable of spreading across the continent. In Asia (Fig. 10) the FERNS[12] network, with its stations in Japan, China, Korea and Russia, is a traditional Loran/Chayka system - hyperbolic, stand-alone. So what about the US?

US policy

The US is unlikely ever to see matters precisely as Europe does. Why? Because, in radio navigation the US is unique: it is the nation that developed GPS, paid for GPS, that owns GPS and controls GPS. Those facts led initially to pressures within the US to maximise the return on the GPS investment and thus to claims that GPS could replace absolutely every other navigation and timing system. Perhaps such arguments were necessary in order to get GPS funded. But not many experts believe them now. As an outside observer, I see a new sense of realism in the US, not least in the changes in the latest Federal Radionavigation Plan [11]. Now one hears analyses of the shortcomings of GPS coming from the very heart of the US military and civil navigation establishments - not just from "pinko liberal foreigners" like me! The times, they are a-changing!

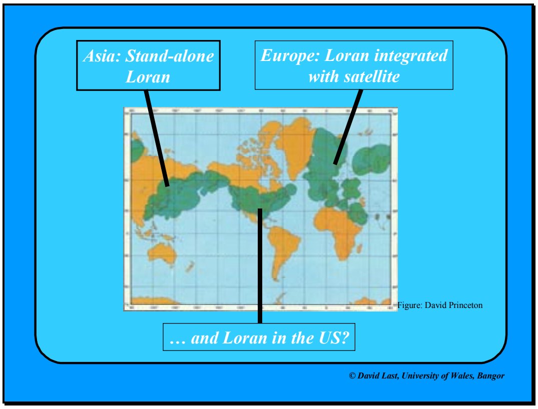

Fig. 10 – Loran-C policy in Europe, Asia and the US

The tension between the military and civil establishments here also seems to be easing. Remember that GPS was created for the military using military budgets. It is not many years ago that a friend of mine visiting the Master Control at Colorado Springs asked how some change would affect civil users. He was met with incredulity: "You mean civilians use GPS?!" The military understandably guard their asset. But Selective Availability is now gone, and a way of living together seems to have been established.

But with the new era comes a new conflict, one that certainly affects GPS internationally. Fig. 11, by way of example, shows statements made when the policy to terminate SA was announced [12]. Among the principal reasons for the change of policy were to help make GPS a global standard and so boost the US GPS industry. That argument makes sense in the US. But the message read loud and clear in Europe was: GPS is US-owned. US policy will be designed to maximise US commercial advantage. The great irony here is that the further GPS spreads and the more essential it becomes to our societies, the greater becomes the problem of sole-nation control. That fact is obvious

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[8] Global Augmentation for Satellite Systems
[9] Radio Technical Commission on Maritime Services
[10] International Telecommunication Union
[11] International Maritime Organisation
[12] Far East Radio Navigation System

when seen from Europe, but very hard for some folk in the US to perceive. Hence Galileo!

Fig. 11 – Presidential Decision Directive [12]

But in contrast to the politics of GPS, when people on either side of the Atlantic look for augmentations, the reasons are primarily safety-related - a wish to create a precise, robust, system. So how will that work out here? Eurofix, maybe? Well, in the eyes of some in the US, Eurofix is a dreadful threat, a scourge from the East, the Mongol hordes, with Durk van Willigen as Vlad the Impaler!

Yet, we Europeans find both GPS and Loran as American as Norman Rockwell, motherhood and apple pie. The two great navigation systems of the second half of the 20th century, one terrestrial, one satellite, but both American! Eurofix is data sent over Loran; why, the US Navy did that in the Pacific back in the seventies when Loran and GPS were both in their infancy!

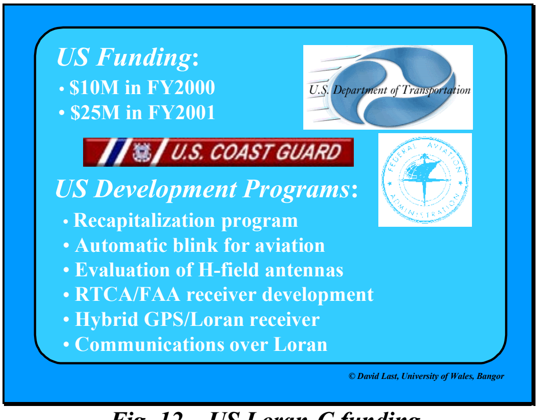

Fig. 12 – US Loran-C funding and development programmes

US actions

No, what has come from Europe is not so much Eurofix as a concept: an acceptance of the limitations of first-generation GPS and recognition that Loran-C can support GPS alongside satellite augmentation, but with added benefits. And that message is now being heard here. The evidence is to be seen in hard funding and real development programmes.

Substantial funds are now flowing into Loran in the US (Fig. 12), much greater funds than in Europe. The money is being used by the Department of Transportation, the US Coast Guard and the Federal Aviation Administration [13,14]. The aims include recapitalising the system, so modernising it and cutting its running costs. There are also a number of aviation-related programmes, specifically:

- The deployment of automatic blink to speed up failure warning,
- The investigation of aircraft H-field antennas to reduce P-static, and
- The development of Loran receivers that meet RTCA[13] DO-194 and FAA[14] TSO-C60b standards.

Other programs include:

- The development of hybrid receivers that combine GPS and Loran, and
- Investigations into the feasibility of operating a system of data communications over Loran fast enough to carry WAAS data.

There will be papers on all this US Loran activity in our conference.

Maybe, just maybe, Loran is coming home at last, back to where it belongs. It’s been staying with friends in Europe! Suddenly, walls are breaking down: we see Europe using US systems in novel ways, while the US is developing similar schemes. Both continents are integrating GPS with Loran to provide cost-effective, terrestrial support for WAAS and EGNOS.

The need for international convergence

If you stand outside these issues that so exercise us in conferences like this one and take a longer perspective, and you see that Europe, the US, the Far East have very similar requirements. And at the interface between satellite and terrestrial systems they are slowly and painfully converging in their

[13] Radio Technical Commission for Aeronautics
[14] Federal Aviation Administration

views. Such convergence is essential, and it has been too long delayed. Radionavigation policy is simply not yet coordinated between continents, nor within continents; for instance, there is no European Radionavigation plan. Policy is not even coordinated within nations, witness the inter-agency differences that so delayed the latest FRP here. Yet we all recognise that our technology is no longer national, but regional or global, and that our navigation systems now serve many modes of transport. The days when agencies - the USCG or the British CAA - ran systems for one mode of transport in one country are gone forever. Yet our agencies still behave as if nothing had changed!

Ladies and gentlemen, it is in exceptional conferences like this one, where folk from different agencies, different countries, different modes of transport meet to do battle between systems, that the future consensus is being formed, not in national meetings, not in aviation or marine-only ones. And if we can achieve that consensus, the right balance between satellite and terrestrial, between modal and national interests, we do great work for the future safety of navigation and transportation in all our countries.

References

[1] Last, J.D., 'Satellite navigation systems - an overview', Proc. XIIIth Conf. International Association of Lighthouse Authorities, vol. Radio Aids to Navigation pp125-135, Honolulu, Feb 1994

[2] 'GPS risk assessment study – final report', Johns Hopkins University, Applied Physics Laboratory, Report VS-99-007 M8A01, Washington, USA, Jan 1999 (http://www.airlinepilots.com/Safety/GPSrisk.pdf)

[3] Strachan, V.F., 'A review of the implications of the Johns Hopkins University Applied Physics Laboratory GPS Risk Assessment Study', Royal Institute of Navigation NAV99/International Loran Association ILA28 Conf., paper 12, London, 1-3 Nov, 1999

[4] Interview with Col. Douglas Loverro & Col. Neil McCasland, Global Positioning and Navigation News (USA), 15 Dec 1999

[5] International Telecommunication Union, 'Technical Characteristics of Differential Transmissions for Global Navigation Satellite Systems (GNSS) from Maritime Radio Beacons in the Frequency Band 285-325 kHz (283.5-315 kHz in Region 1)', Recommendation M.823-2, Geneva, 1997

[6] Department of Transportation and United States Coast Guard, 'Broadcast Standard for the USCG DGPS Navigation Service', Technical Report, USCG, COMDTINST M16577.1, 1993

[7] Allen, L., 'Nationwide Differential Global Positioning System (NDGPS)' Civil GPS Service Interface Committee 7 Apr, 1998 (searchpdf.adobe.com/proxies/2/64/37/12.html)

[8] Jørgensen, T.H., 'Integrating Loran-C with satellite systems – bringing Eurofix on air', Deutsche Gesellschaft für Ortung und Navigation (DGON), Intl. Symp. on Integration of Loran-C/Eurofix and EGNOS/Galileo, Bonn, Germany, pp65-72, 22-23 Mar, 2000

[9] Van Willigen, D, Offermans, G.W.A. and Helwig, A.W.S., ' Can Eurofix improve the availability performance of EGNOS and WAAS?', Deutsche Gesellschaft für Ortung und Navigation (DGON), Intl. Symp. on Integration of Loran-C/Eurofix and EGNOS/Galileo, Bonn, Germany, pp167-184, 22-23 Mar, 2000

[10] 'Information paper on the NELS GAUSS initiative', Northwest European Loran-C system document, 15 Jul 2000

[11] US Department of Transportation and Department of Defense, '1999 Federal Radionavigation Plan', Report DOT-VNTSC-RSPA-98-1 DOD-4650.5, Dec 1999

[12] 'U.S. Global positioning system policy', The White House Office of Science and Technology Policy, National Security Council (USA), 29 Mar 1996

[13] Shirer, H & Dubay, C., 'Making a decision on the long-term disposition of Loran-C in the US', Deutsche Gesellschaft für Ortung und Navigation (DGON), Intl. Symp. on Integration of Loran-C/Eurofix and EGNOS/Galileo, Bonn, Germany, pp15-26, 22-23 Mar, 2000

[14] Peterson, B, Schue, C, Betz, J. and Boyer, J., 'Enhanced Loran-C data channel project', Deutsche Gesellschaft für Ortung und Navigation (DGON), Intl. Symp. on Integration of Loran-C/Eurofix and EGNOS/Galileo, Bonn, Germany, pp185-198, 22-23 Mar, 2000

[15] European Space Agency, www.esa.int/navigation/img/architect_03.jpg

[16] www.eurofix.tudelft.nl/Images/bigthumbs/21_Antenna_at_Wildwood_1.jpg

Biography

Professor David Last holds a Personal Chair in the University of Wales and is Head of the Radio-Navigation Group at Bangor. He was awarded the university degrees of BSc(Eng) at Bristol, England, in 1961, a PhD at Sheffield, England, in 1966 and a DSc by the University of Wales in 1995. Prof. Last is a Board Member and holder of the Medal of Merit of the International Loran Association. He is also Vice-President of the Royal Institute of Navigation, a Fellow of the Institution of Electrical Engineers and a Chartered Engineer. He has published many papers on navigation systems, including Loran-C, Decca Navigator, Argos, Omega, Marine Radiobeacons, GPS and DGPS. In Loran, he has specialised in understanding signal propagation and employing that knowledge to predict system coverage and ASFs. He has also developed receiver techniques for measuring skywave delays. He acts as a Consultant on radio-navigation and communications to companies and to governmental and international organisations. He is an instrument-rated pilot and user of terrestrial and satellite navigation systems.

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