

Loran-C Trials in the United Kingdom

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BIOGRAPHY

Dr. Paul Williams is a Project Engineer for Trinity House. He holds the degrees of BSc and PhD in Electronic Engineering from the University of Wales. He was involved in the development of early Loran-C coverage prediction software and is currently leading the development of second-generation Loran coverage models. He is a member of the Royal Institute of Navigation, a member of the Institute of Electrical Engineers and has recently been appointed to the Board of Directors of the International Loran Association (ILA).

Mr. Dean Furber is the Radionavigation Project Manager for the General Lighthouse Authorities of the UK and Ireland, with responsibility for the implementation and management of the research and development projects in the fields of radionavigation and lights. He holds an MA in Electrical and Information Sciences from the University of Cambridge and an MBA from the University of Oxford.

Dr. Nick Ward is Research Director of the General Lighthouse Authorities of the UK and Ireland. His area of specialisation is in radionavigation and communications, including Loran. He is current chairman of the International Association of Marine Aids to Navigation and Lighthouse Authorities (IALA) Radionavigation and AIS Committees and UK observer of the Northwest European Loran-C System Steering Committee. He is a Chartered Engineer, a Fellow of the Royal Institute of Navigation and a member of the Institute of Navigation (ION).

ABSTRACT

The three General Lighthouse Authorities (GLAs) of the United Kingdom and Ireland provide marine aids to navigation including radionavigation services for UK and Irish waters: Trinity House is responsible for England, Wales and the Channel Islands; the Northern Lighthouse Board for Scotland and the Isle of Man; and the Commissioners of Irish Lights for the whole of Ireland.

The GLAs have recently deployed a Loran transmitter at the BT Radio Station near Rugby in response to their "2020 The Vision" document that calls for the investigation and analysis of Loran as a backup to Global Navigation Satellite Systems (GNSS). An extensive trials programme is planned to take place until April 2007. The Rugby transmissions have been integrated with those of other transmitters in Europe. Potential users from all application areas are encouraged to evaluate the service and provide feedback.

1. INTRODUCTION

For a long time concern has been expressed regarding the increasing reliance upon GNSS as a single source of Position Navigation and Timing, particularly where there is an impact on safety-of-life. The general consensus is that the European maritime environment will become more crowded: an increase in trade will bring an increase in ship movements; greater affluence will increase the number of leisure craft; and developments in renewable energy will bring about more offshore wind, wave and tidal farms. Against this backdrop a backup to GNSS is a necessity.

For the GLAs these concerns were crystallised in its recently published document “2020 – The Vision” [1]. This outlines the strategy for the GLAs for the next fifteen years and calls for investigation of Loran as a backup to GNSS in terms of its performance, coverage, cost-effectiveness and user acceptance.

This policy of using Loran as a backup has also been stated by the United Kingdom’s Royal Institute of Navigation. Furthermore, the UK Department for Transport has provided funds to allow the GLAs to deploy a Loran-C transmitter at the British Telecom Radio Station near Rugby in order to follow up on the statement in “2020 – The Vision”. An extensive trials programme will now take place, concluding in April 2007.

This paper begins by giving a brief overview of the rationale for Loran before describing the Rugby station deployment. The trials plan is then outlined and the paper concludes by identifying a way forward.

2. THE RATIONALE FOR LORAN

The vulnerability of GNSS to interference and signal obstruction is well understood. Loran is an ideal complement because it is dissimilar to GNSS in many respects; relying on high-power, low-frequency transmissions from transmitters on the ground (Table 1). Because of its different characteristics it can provide an effective backup and complement to GNSS as has been demonstrated during the recent Loran evaluation efforts performed by the US Federal Aviation Administration and the United States Coast Guard [2].

The newly modernised Loran system (commonly known as enhanced-Loran or eLoran) has overcome most of the factors that formerly limited performance. Indeed, with the advent of stable time-of-emission (TOE) control systems, solid-state transmitters and modern receivers, Loran today works in a way more akin to that of GNSS. A Loran station can be used just

like a GNSS satellite allowing pseudoranges to be directly measured from each station. This has been supported by improved propagation modelling; so-called *Additional Secondary Factors* (ASFs).

Temporal variations in ASF can be taken into account by introducing dLoran (differential-Loran) services, providing propagation corrections via the Loran signal itself through Eurofix or 9th Pulse transmissions.

Furthermore, tight integration with GNSS can produce accuracy levels approaching those of satellite-only systems in conditions where satellites are occulted, signals lost or integrity diminished.

This is the system in which the GLAs are interested; a system where Loran is integrated with GNSS to produce a single position output. If one system fails, the mariner can still proceed, almost without reference to the fact that one of the systems is no longer functional. The provision of Loran can be made transparent to the user – built into future marine navigation sensors as an added-value system.

3. THE RUGBY STATION

The Radio Station at Rugby, Figure 1, was constructed in the 1920s, originally for transatlantic radio communication. Indeed the first transatlantic telephone conversation was made via Rugby in 1926. Since then the station has been pressed into service to fulfil a variety of roles, including two masts supporting the UK’s MSF 60kHz time and frequency signal.

GNSS	Loran-C
Low powered: vulnerable	High-powered: robust
Line-of-site: easily blocked	Groundwave: penetrates cities
High-frequency	Low-frequency
Single-nation control	Multi-nation control

Table 1 – Loran-C as a complement to GNSS. After [3].



Fig. 1 – Position of Rugby in relation to the NELS stations.



Fig. 2 – The two masts used to support the Loran antenna.

In 2004 ten of the twelve masts became redundant and were scheduled for demolition. The GLAs secured two of these masts for their Loran trials (Figure 2).

There are two unique characteristics associated with the Rugby station. Firstly, its location is not typical of a NELS station, being landlocked in central England. This means that there are no locations at sea where there is a near- or all-seawater path to the station. A seawater path is useful for trials, since it is the only path along which Additional Secondary Factors (ASFs) are known – being zero¹;

Secondly, the geographical location of Rugby is very close to the station at Lessay (France), and also very close to the longitudinal meridians of Lessay, Soustons (France) and Ejde (Faroe Islands) – so station geometry is not ideal.

However, when used with the Lessay and Sylt (Germany) stations, Rugby provides a much improved position-fix-geometry over the landmasses of the BENELUX countries and surrounding areas (Figure 1). Particularly important to the GLAs is the improved accuracy in the region of high vessel-traffic areas in and around the Dover Strait.

The transmitter used at Rugby was originally intended for installation at Loop Head in Ireland. The transmitter is owned by the French Government and has been loaned to the UK for the duration of the trials.

After undergoing a series of factory acceptance tests at Megapulse in the US (following 10 years of storage), the transmitter was installed at the Rugby site in May and June of this year. Since then it has undergone a further series of tests performed by both Megapulse and Control Centre Brest (CCB) in France ready for integration into the NELS time-of-emission control system.

The antenna is also unique for a Loran system. The transmitter was originally intended to be used with a 219m top-loaded monopole (TLM). The Rugby station uses a T-antenna suspended between two 250m masts. This was designed by Telefunken in Germany and constructed by a team made up of engineers from BT and Eve Group. This has necessitated specific modifications to the antenna/transmitter output network. The antenna was erected in March 2005 and the location accurately surveyed. Table 2 illustrates the location, chain and other information about the Rugby station.

¹ An Additional Secondary Factor is the additional delay due to the Loran-C signal

propagating over land. Receivers' propagation-models assume a seawater-only path.

Location	52° 22' 0.562''N 01° 11' 17.636''W
GRI	6731
Designator	Y
Emission Delay	27,300
Power	320kW
Number of HCGs	12

Table 2 – Rugby Loran-C station information.

Since the start of July this year the station has been broadcasting a stable signal 24 hours a day under the monitoring and control of CCB. Originally the station was controlled by a time-difference (TD) method with LPA (Local Phase Adjustments) made by CCB. From the start, the station has been shown very high stability, with LPAs not made significantly more often than for other stations in the NELS chains. In late September DCN Brest performed the final static calibration of the transmitter ready for integration of the station into the Time of Emission (TOE) control system.

4. TRIAL PLANS

4.1 Evaluation Criteria and Methodology

The assessment of the performance of a navigation system involves the individual assessment of the four main Required Navigation Performance (RNP) parameters:

- Accuracy
- Integrity
- Availability
- Continuity

Formal definitions of these parameters can be found in the literature, for example [4]. The main factors associated with Loran that affect each of these parameters will be examined. Although for the purposes of these trials, we will be mainly concerned with accuracy and continuity, these being the main performance drivers for a maritime application such as port approach [2].

In addition, coverage prediction modelling software is being refined by the GLAs to take into account the new generation of transmitter control equipment and receivers. Measurement results from these trials will be used to validate the software development.

In the trials it will be assumed that the receiver is **fault-free**, that is we are looking at the parameters of the service rather than the user equipment. However, multiple receivers will be carried on the various trial runs to separate receiver and service dependent issues.

4.2 Performance Challenges

Accuracy

Absolute accuracy is the accuracy with respect to the geographic or geodetic coordinates of the earth, while **repeatable** accuracy is a measure of the precision with which a user can return to a previously occupied location using the same navigation system.

Absolute accuracy of Loran is dominated by ASFs – the effect of the surface of the earth on the propagation time of the Loran signal. A limited set of ASF measurements will be made to assess the amount of effort required to establish high accuracy Loran in UK port approaches and high traffic areas.

Repeatable accuracy is affected by temporal variations in ASF and atmospheric effects. Further, low signal-to-noise ratio (SNR) signals result in pseudoranges with higher variances.

Both types of accuracy are affected by station geometry and this can be predicted using the concept of Horizontal Dilution of Precision (HDOP).

Integrity

Integrity is defined as the ability of the system to warn users, within a specified time, whenever the system should not be used for navigation. Integrity is affected by

temporal variations of ECD (Envelope to Cycle Difference). The ECD is a measure of how well the signal will be tracked by a receiver, and known values of the ECD at any location can be used to assist the receiver to lock on and track the signal. Related to ECD are phase variations of the component frequencies making up the Loran signal. Another phenomenon that affects integrity is the presence of early skywave. This latter effect is somewhat mitigated by the phase encoding of the Loran pulses themselves and the design of the rising edge of the pulses. However, under exceptional ionospheric conditions, such as those seen approximately every eleven years, early skywave can be problematic, severely interfering with the rising edge of the pulse. Integrity performance analysis can be a complicated parameter to assess, particularly since there is no definition of the ECD of a propagated signal!

Availability

This is the percentage of time that an aid or system of aids is performing a required function under stated conditions. The availability of the signal-in-space is affected by transmitter outages. System availability includes such outages in addition to signal-to-noise ratio (SNR), man-made radio interference (RFI) – both continuous wave and cross-rate – and terrain effects. System availability typically includes the availability of the user's receiver, however for the performance of these trials we will assume a fault-free receiver. Availability will be determined via a long-term static measurement campaign.

Continuity

Continuity gives a measure of the probability that the service is available for a fixed duration period. Typically for the maritime mode, this period is chosen to be three hours, being the typical time it takes for a vessel to enter, approach a harbour and dock. Continuity depends on the same phenomena as availability, with the addition of spatial variations of the Loran groundwave signal along the particular

approach to the harbour, and the dynamics of the vessel.

4.3 Static Trials Plan

A series of static measurements will be conducted over the duration of the trials. In assessing the four RNP parameters outlined above, these measurements will characterise the stability of the signal over a period long enough to quantify several characteristics; specifically the following.

Seasonal variations. Loran propagation is via groundwave – the signal propagates along the surface of the earth. The electrical ground conductivity is subject to variations due to weather and seasons. In parts of the northeast United States these seasonal conductivity variations are quite pronounced as the ground passes through regular freeze-thaw cycles. Whilst the UK, having a more temperate climate, is not as susceptible to this phenomenon we intend to measure what, if any, seasonal variations take place.

Weather fronts. In the US variations of some 500ns (150m) in propagation time have been witnessed due to passing weather fronts. These effects are caused by variations in the refractive index of the atmosphere, which alters the primary factor velocity – the component of velocity of the signal due to propagation in the earth's atmosphere. The extensive static measurements made during these trials will provide the opportunity to measure such effects.

Transmitter Outages. Static availability tests will concentrate on the effects of transmitter outages, with varying SNR and phase monitored throughout a year-long period.

Skywave. Certain receiver locations may allow the detection of early skywave, which is an important consideration for maintaining integrity.

ECD. In addition, although not defined for propagating signals, the receivers' measure of ECD will be collected.

Figure 3 shows the desired locations of static receiver sites (yellow triangles). For the most part the receivers used will be those produced by Reelektronika under contract to NELS.



Fig. 3 – Location of receivers for static measurement campaign.

4.4 Kinematic Trials Plan

Whilst the static phase of the trials is taking place, the GLAs intend to conduct a series of kinematic measurements.

Loran will be assessed in areas sensitive to the maritime industry. The specific application of Port Approach has been chosen upon which to concentrate. LORAPP (Loran Accuracy Performance Panel) studies in the USA show that a modernised Loran is capable of meeting the accuracy requirement of 8-20m for Harbour Entrance and Approach (HEA) using a combination of modern transmitters, modern timing and control equipment, and modern receivers. This new and updated Loran system, which has now passed the evaluation stage, is commonly known as enhanced-Loran (eLoran). The European Loran infrastructure has not undergone the same modernisation programme as that in the US so we would not expect to attain the same level of performance. However, Europe already has a time of emission control system and solid-state transmitters, and so can be considered a good way through the “modernisation process”. An overarching aim of the trials should be to enable future international interoperability

through technical recommendations for the completion of the process.

It is also noted that European GNSS performance requirements for Port Approach are at a more stringent level of 10m. However, it is important to quantify the actual performance under European conditions as this will allow educated decisions to be made as to what degree of further system modernisation, if any, is required to ensure Loran has a future as a GNSS backup.

Kinematic measurements will be made in two phases.

Phase 1

The GLAs have vessels at their disposal, which can make measurements as they go about their routine duties. A measurement system is being constructed by the GLAs, Figure 4, consisting of a Locus Satmate 1030 receiver, a Reelektronika LORADD receiver and a DGPS receiver used as ground truth, with the option of swapping out the DGPS receiver for a dual frequency survey receiver for more precise future harbour surveys.

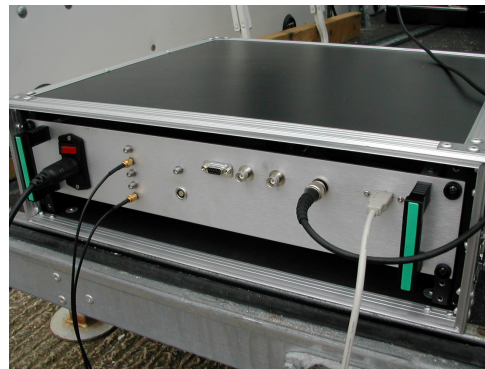


Fig. 4 – GLAs measurement system.

The measurements performed in Phase 1 will be used to obtain quick and convenient results.

Phase 2

Phase 2 will consist of more specific routes not covered by those measurements performed in Phase 1. Figure 5 shows the

approximate locations of the various specific routes.

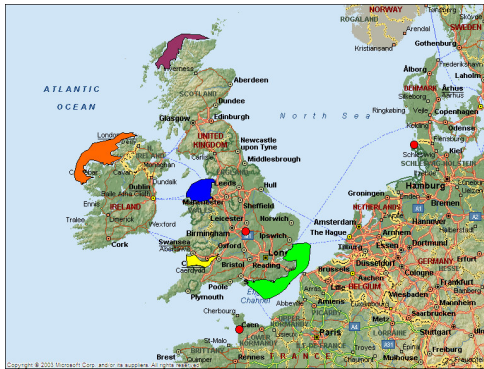


Fig. 5 – Approximate locations for specific kinematic surveys

Listed in order of priority these are:

1. Dover Strait and English Channel
2. Liverpool Bay
3. North of Scotland
4. Severn Estuary
5. West of Ireland

In a climate of budgetary constraints and system change it is vital that the highest levels of Loran performance are matched to the areas where it will achieve the greatest benefits. The Dover Strait between France and the UK is one of the world's busiest shipping lanes (Figure 6), with vessel traffic upwards of 500 vessels per day. The stations at Rugby, Lessay and Sylt appear to be beneficially located to provide high levels of accuracy in this region.

In view of the future increases in traffic density and a greater reliance on traffic separation schemes, a major focus of the trial will be the assessment of the performance of Loran in this area, together with a survey of the ASFs, which if neglected can result in positional errors on the order of several kilometres.

Furthermore, by observing actual traffic patterns around the UK and comparing these with predicted Loran performance we can determine, not only the marginal benefit of a new station at Rugby, but also the potential of permanently locating the UK station at an alternative site.

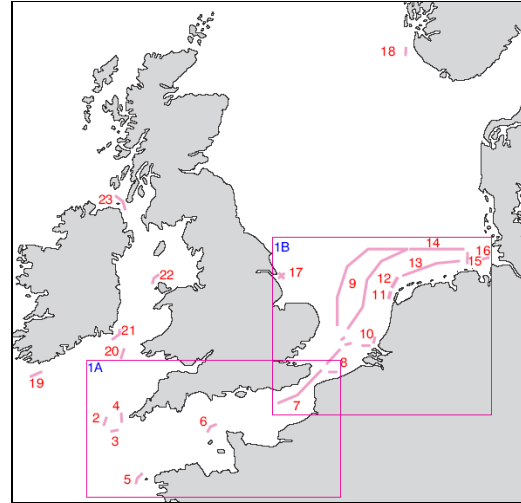


Fig. 6 – Diagram of traffic separation schemes around the British Isles.

In addition, the following will be under consideration:

Accuracy analysis. We intend to measure the accuracy of Loran in unfavourable locations. In all-in-view mode the best repeatable accuracy is obtained when stations surround the user, since HDOP is low in such situations. HDOP is defined in Equation 1.

$$HDOP = \frac{DRMS_{2D}}{\sigma_0} = \frac{\sqrt{\sigma_E^2 + \sigma_N^2}}{\sigma_0} \quad (1)$$

Where σ_E^2 is the variance of the user's position along the east co-ordinate axis in local East North Up (ENU) co-ordinates; σ_N^2 is the variance along the north axis and σ_0 is the standard deviation of the measured pseudorange, which for simplicity is assumed to be the same for all transmitters (although in reality this may not be the case). Equation 1 can be interpreted as the ratio of the change in user location to the resulting change in pseudorange to each of the associated transmitters. This can be determined without making measurements through geometrical and differential analysis. Figure 7 shows a Matlab™ plot of HDOP (Horizontal Dilution of Precision) in the

NELS coverage area, determined from such an analysis.

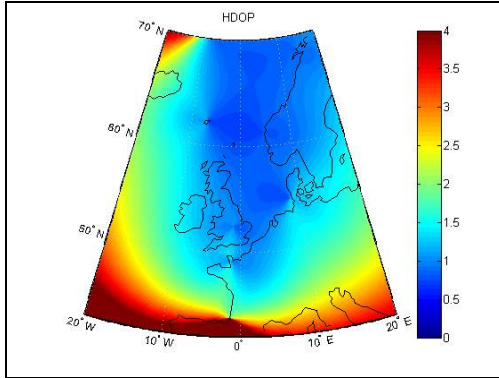


Fig. 7 – HDOP in the NELS coverage area.

The lower the value of HDOP the better the positioning accuracy. In general an HDOP of less than 4 can be regarded as indicating good positioning quality. Figure 7 shows that for all of NELS the HDOP is indeed less than 4, and in a large area is less than 2. Figure 7 shows that users to the west of the UK are further away from the optimal area as can be seen from the increase in HDOP in such regions.

The effect on accuracy of removing Rugby from the system mix can be determined by calculating the ratio of HDOP without Rugby to the HDOP with Rugby. This gives an indication of the change in accuracy with and without Rugby as Equation 2 shows, again assuming uniform pseudorange standard deviation over all transmitters.

$$HDOP_{RATIO} = \frac{DRMS_{WITHOUT_RUGBY}}{DRMS_{WITH_RUGBY}} \quad (2)$$

Figure 8 shows this ratio calculated over the NELS region. In the region of the Dover Strait the effect of removing Rugby is to decrease the accuracy by a factor of approximately 1.25, due to geometry alone.

It is important to understand the effects of geometry on repeatable accuracy. Although difficult to accomplish with a limited set of measurements, such

measurements can augment and validate coverage prediction software. The use of such software will directly inform decisions as to the location of any permanent Loran station.

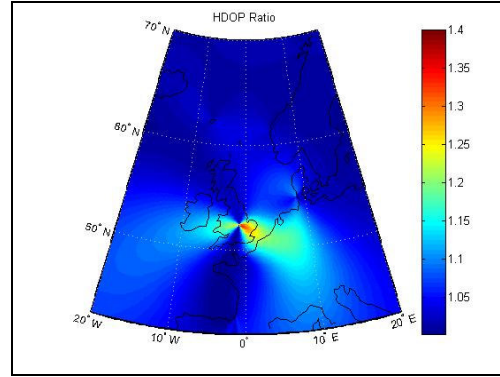


Fig. 8 – HDOP Ratio and the effect of removing Rugby from the system mix.

Also, with all-in-view Loran it is possible to post-process position solutions in the same way that GPS post-processing is done. This will allow us to remove stations from solutions to assess the resulting accuracy performance due to the loss or closure of stations.

Terrain. The range of types of topography of the United Kingdom and Ireland is wide and varied, from the flatlands and fens of the east of England to the mountains of Scotland. In the northwest of Scotland a user will not only be distant from the Rugby station, but will additionally be in the radio shadow caused by the Scottish Highlands. Measurements will be made in this and other similar areas to determine the effects of mountainous terrain on accuracy and continuity. Measurements will also be compared to theoretical predictions derived from the GLA's coverage prediction software. This will assist performance assessment.

Signal strength. These values will be used to confirm Rugby performance levels and validate prediction models. Figure 9 shows an example field-strength plot produced using the GLAs' coverage prediction software. Signals whose field-strengths are too low will not be included in a position solution, and so position accuracy is then

dependent on the remaining “visible” stations. And, as already mentioned, station geometry affects accuracy.

Signal Stability. Signal phase stability is important to the RNP. Results will be used to validate the coverage prediction software’s accuracy model.

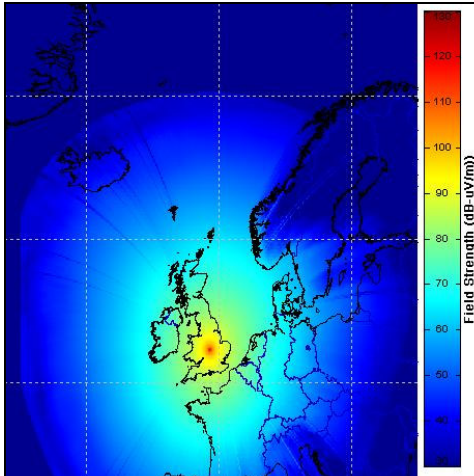


Fig. 9 – Field strength plot from coverage software.

Re-radiation. It is known that large metal structures affect the performance of Loran by introducing localised phase and field strength changes. Trials will be conducted to investigate how the signal is affected by the proximity to such structures. The Severn Bridges at the head of the Bristol Channel lend themselves well to this test, being large compared to the fundamental wavelength of the Loran signal.

Other Transport Modes. The General Lighthouse Authorities are a maritime organisation. Our responsibility and remit is to provide aids-to-navigation to the mariner. But Loran is a multi-modal system. As part of the (so far) \$140M recapitalisation effort in the US, Loran has been evaluated by the FAA for use in the US aviation sector. As such, eLoran has been shown to be capable of meeting RNP 0.3 for non-precision approach.

In addition, it is being investigated for use in land mobile applications – particularly for goods tracking and road charging. If Loran is to be financed it is vital that the costs are distributed in line with the

benefits. To this end we will invite other user groups to undertake their own set of trials in their area of interest.

Receivers. While the trials will not assess individual receiver performance, we have established dialogues with the current generation of receiver manufacturers. Through this we can ensure that we use the receivers in the most optimal way.

5. THE WAY AHEAD

eLoran, the modernised system, has overcome most of the factors that formerly limited performance, and tight integration with GNSS can produce accuracy levels close to those of satellite-only systems when loss of satellite signal occurs.

These trials will demonstrate the performance that can be delivered by Loran. The results will influence the decisions made by the UK regarding any future provision of Loran.

The trials will, however, be of little value unless Loran can attract significant numbers of maritime and other multi-modal users (e.g. time and frequency, and land mobile).

A long-term transmitter solution also needs to be resolved. There are alternative UK facilities that will be assessed as part of a long-term solution. The suitability of these locations is largely dependent on the geography of the stations in the system. Therefore, a permanent station location needs to take into account any political decisions made regarding the future of Loran in Europe.

Finally, an operational service in the UK would require a statutory instrument to be passed by Parliament. This is dependent on an international agreement and would ratify Loran as a navigational beacon. Without this no permanent funding can be made available for Loran.

6. FURTHER INFORMATION

Questions and comments on the Loran-C trial can be directed to the following:

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