Good afternoon, ladies and gentlemen!

It’s 4 years now since the first of these sessions - sponsored by EUGIN, IAIN & IALA - in Rotterdam. In that period, the question of the resilience of satellite navigation has moved from being seen as the obsession of a group of difficult eccentrics, to a topic that now dominates many navigation conferences. “The problem” is now clearly understood. “The solutions” have proved more elusive. I want to talk today about a route to solutions that appears to be developing here in the UK.

Our focus then is “PNT” - the Position, Navigation and Timing provided by GPS and similar satellite systems.
This has become so essential to both critical and non-critical infrastructure that this Royal Academy of Engineering report struggled to find a single sector of transportation, or commerce, industry or telecomms in Britain that does not now depend on satellite navigation.

**** NAV2664 – The whole lot of GNSS ****

When governments realised how dependent on this technology their economies had become, some set up their own satellite systems. So, GPS - which in the Cold War had inspired the Soviet GLONASS - now begat China’s Beidou and Japan’s QZSS, Europe’s Galileo and India’s IRNSS. Plus a host of augmentation systems: WAAS, EGNOS and other funny names.

These newer “Global Navigation Satellite Systems” – we now say “GNSS” - had to be compatible with GPS: they’re versions of the same technology, and they’re squeezed into the same radio frequency bands – so they are rich in common modes of failure. What kinds of failure?

**** NAV2804 – GPS & GLONASS failures ****
Here, the final *atomic clock* in GPS satellite *SVN23* failed, causing position errors that built up slowly to *kilometres*. Then we saw a *double failure* of *GLONASS* – suddenly, errors of 55 kilometres.

**** NAV1933 – Solar flare ****

On this day the *Sun* emitted *radio noise* so *intense* that GPS receivers *stopped working* across the entire sunlit side of the Earth.

**** NAV1979 – San Diego event ****

*GPS navigation* was *lost* for *two hours*, across the *San Diego area*, due to *accidental radio interference*. In the *city* there, many *mobile phone* sites that use *GPS synchronisation* were impacted.

**** NAV2681 – 26 January 2016 event ****

Recently a failure of the precise *timing that GPS delivers* took broadcasting systems off the air and impacted telecoms worldwide.

And *intentional jamming* appeared:
**** NAV2509 - Bob Cockshott’s blue jammer ****

This little hand-held device, sold world-wide, has been carefully designed to block all the frequencies of Galileo, plus Beidou and QZSS and all the GPS frequencies. Oh, and of course, all the augmentations like EGNOS, as well.

**** NAV2806 – Hong Kong drones ****

A couple of weeks ago we saw a much more powerful jammer in the hands of a person of malicious intent cause substantial economic damage. We have yet to see high-powered jammers being operated by technically-capable terrorists.

**** NAV2347 – Korean jamming ****

But several times now we have seen a sovereign state – which shall be nameless - launch prolonged high-powered GPS jamming attacks on its neighbour, impacting maritime navigation, aviation, cell-phones and (no doubt the principal target) critical military capabilities.

**** NAV2652 – Spoofing threat ****
And now simple, low-cost, hacker-style *spoofers* have appeared. Spoofers transmit *false GPS signals* that *take over* a receiver. They can be used to drive a *ship off course*, to cover up a *vehicle hi-jacking* or shift the *GPS timing* used by *Stock Exchanges* or national *power grids*.

How should we *protect ourselves*? Well, *South Korea* has just announced it has adopted the eLoran *terrestrial* technology that has no common mode of failure with satellites:

**** NAV2540 – The eLoran technology ****

The *UK* took this *US eLoran* concept to a *successful prototype* system in the North Sea, with *10 metre accuracy* for shipping in key harbours. It delivered *timing* as *precise as that of GPS* across much of Western Europe. But many European *nations* were simply *not interested*. Why, *they* had invested in *Galileo*, which they believed *protected them* from the vulnerabilities of *GPS*.

Now, this presentation will focus on the *UK’s* way of addressing the *protection & resilience* of its *Critical Infrastructure*. Of course, the *UK*, as ever, needs to be *different*, think *Brexit*!

**** NAV2769 – GO-Science montage ****
*UK Critical National Infrastructure* is handled at *Cabinet* level. And because it is a highly *technical* matter, decisions such as the role of eLoran, fell into the lap of the Government’s *Chief Scientific Adviser*, at that time the fine moustachioed figure of Professor Sir Mark Walport. A man who gives “scientific advice to the Prime Minister”. So now the issue had gone to the *highest level of our administration*, well above the individual *departments* that in various countries have scrapped and bickered over these vulnerabilities – and *done very little* about them.

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**NAV2737 – London Economics – Title***

Government first *followed the money*: they commissioned an *economic* assessment of the *impact* on the UK of a disruption to satellite navigation. Given the … widespread use, plus the vulnerability, of GNSS just what would happen if it were disrupted, temporarily? They estimated the loss of *Gross-Value Added* and *utility benefits*, including *damages*. They considered a *standalone* event of *whatever cause*.

The results were clear and dramatic!

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**NAV2773 – LE – Summary***
The economic impact on the UK of a 5-day disruption of GNSS was estimated at £5.2 billion pounds, 5.8 billion Euros. A lot of money in any currency. “5 days” is one of our standard periods for assessing Critical National Infrastructure. Notice: this is not a loss of GPS but of GNSS, so switching to Galileo is not a solution.

****NAV2738 – LE – Loss table and summary message ****

They examined the impact in each of these many domains: but 88% of it fell into just three: road transport, emergency and justice services and maritime.

****NAV2739 – LE – Road ****

In road transport, there is an immense loss of utility. When navigation devices fail, those many industries that now depend on them are directly impacted. But the economists predicted that the resulting increase in congestion and journey times would delay all drivers. They estimated the total loss in the Road sector at £1.9 billion.

**** NAV2740 – LE – Emergency and Justice ****
GNSS is built into our first responder services at multiple levels of despatching and navigation that would be affected directly. Plus they too will be slowed down by congested roads. So, £1.5 billion.

**** NAV2741 – LE – Maritime ****

Maritime: this one came as a surprise to those of us who are navigators. In our blinkered way, we had thought only about the loss of safety, the cost of collisions. But the financial loss turns out to be dominated by slowing down the supply chains that carry goods internationally for our industry and commerce. You don’t need a port to be closed, just disrupted - £1.1 billion.

**** NAV2742 – LE – Migration technologies & Strategies ****

As for mitigations, the report concluded that there is no silver bullet. For timing: the better your clocks, the longer you can survive interruption. But “the most applicable mitigation strategies for the largest number of applications” – the best bang for your buck - are eLoran and the new system Satelles. And wherever you need very high location accuracy over a local area, maybe Omnisense or Locata.

**** NAV2743 – LE – Contribution of Public Funding ****
Finally, should the government put its hand in its pocket or just leave the solution to others? These economists say a resounding: “yes”; “there’s a strong economic case for government intervention, with benefits of 4 to 5 times the public investment”.

Now look, like all products of the “dismal science” that is economics, you and I may disagree with the details. But the message is loud and clear: a loss of GNSS can cost you billions per day. Our industry here is now that important!

This London Economics report

**** NAV2770 – Blackett – Foreword and Aims ****

was followed recently by this study of Critical Dependencies on Satellite PNT. Its aims: to lay out the breadth, scale and implications of our reliance on this “invisible utility”, in our critical national infrastructure. To understand them and to improve our resilience so as to realise the full benefits of GNSS. Now, this report was produced by the Government Chief Scientific Adviser himself and approved at ministerial level.

**** NAV2771 – Blackett – What is it? ****
It’s what we call a Blackett Review – *something so British that I’d never heard of it either* - a government *expert panel* for consulting departments and agencies, academia and industry on a challenging *technical* problem in the *security* domain. Sir Mark Walport *chaired* the review. I was one of the *experts*.

The report makes *10 specific recommendations* to the Cabinet Office which I do suggest you study offline, because they’re pretty *indigestible*; here’s *my* quick-fire *summaries* of them.

**** NAV2745 – Blackett – Recommendations 1-7 ****

- First, Cabinet Office – not some department – *Cabinet Office* requires all *Critical National Infrastructure operators* in the UK to audit and report their dependence on GNSS.

- Then, we add this vulnerability to our National Risk Register, *in its own right*; at present it’s just a dimension of *space weather*.

- 3: We take this PNT resilience into account in allocating *radio spectrum*, something that is a very hot political topic in Washington – *Ligado* - and could become so in Europe.

- Number 4 calls for *legal* sanctions against folk who jam or spoof GNSS – lock ‘her up!
• 5: is about monitoring interference at our key sites, like ports.

• 6 - one of great interest to me: we must employ GNSS-independent backup systems!

• 7: Then report back to Cabinet Office, via a cross-government group.

**** NAV2746 – Blackett – Recommendations 8-10 ****

• Nearly done with this “death by Powerpoint” list: we must specify performance standards for our CNI, map our national testing facilities and make them available to users and coordinate our academic and industrial expertise in PNT.

In summary: Cabinet Office – at the top of government - has taken ownership of the problem. On a personal note: throughout the Blackett consultations with multiple departments and agencies of government, my own observation was of acceptance of the vulnerabilities of GNSS and agreement on the need to tackle them.

**** NAV2747 – Blackett – Mitigations 1-4 ****

But what actual mitigations were recommended? Well, as you would expect: very different for each sector, as prescribed by the specialists in that sector. Telecoms, Finance and Energy all depend on GNSS
timing, so better hold-over clocks and more robust time distribution. Emergency services look for multi-constellation receivers with inertial backup. But notice: every sector here includes “a terrestrial radio system”.

**** NAV2748 – Blackett – Mitigations 5-8 ****

And that’s the case, too, for the traditional navigation sectors: road, rail, maritime and aviation. Terrestrial radio systems have been “successfully demonstrated”, “eLoran meets international standards”, “would maximise safety”. Plus, of course, the specialist requirements that will always be so different as between, say, rail and aviation.

**** NAV2772 – Noakes letter re eLoran ****

So, those are the recommendations. And, by the way, the day following publication of the Blackett Report the government released a response to a study into the viability of eLoran as a mitigation. They said: “The Government is supportive of any progress towards initiating and maintaining an operational eLoran network that can provide PNT services, and they’ll lend support where appropriate to aid its establishment and continued use.”

**** NAV2774 – So, what happens now? ****
Where does government go from here? Specifically, what action – “if anything” the cynics will say – will the Cabinet Office take, since they now own the problem?

**** NAV2775 – BRIG and PNTTG ****

Well, Cabinet Office almost immediately set up a Blackett Revue Implementation Group. It reports to the National Security Council. It brings together senior policy advisers from across government; it has been meeting at roughly 6-week intervals; it’s their job to deal with the How and the Who to fix the problems.

But they’re not specialists – they’re all Latin scholars, civil servants. So, they have set up a Technical Group – rather as in the US (though rarely in Europe) – of government, industry and academia to provide technical input and policy advice.

**** NAV2803 – RNTF Prioritizing document ****

There is a parallel very active debate on this matter in the US currently. The Senate is expected to vote tomorrow on the authorisation of eLoran. You may want to download this document, issued by the non-profit Resilient Navigation and Timing Foundation.

**** NAV2802 – Title again ****
Those of us who’ve been concerned about the resilience of GPS and later GNSS – and I first spoke on this matter 24 years ago – have come to realise that satellite navigation and timing are now so deeply embedded in all our national systems that solutions cannot be found at the level of individual government departments or agencies, where the “Tragedy of the Commons” applies: that is, no-one wants to take on the problems that belong to everyone. The solutions can only be found at the highest level of government. Now, I don’t know whether that will happen here in the United Kingdom, but I am optimistic that at last we do have the attention and commitment at the only level of government that can protect and provide resilience to all our Critical National Infrastructure.

Thank you.

17.5 minutes at a good clip

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