

The Navigation of Navigation

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Ladies and Gentlemen, Good evening!

It's a delight to be back in Stanford, 50 years to the day almost since I first set foot on this campus.

You've asked me to speak while you finish your meal; this is bad for both of us. I miss my coffee and I may well upset your digestion. Now, I'm actually British. And it's not how the Queen or I do things. Heavens, to show you how to live graciously and manage your servants we do now send you Downton Abbey! My butler simply wouldn't stand for this. But I'm honoured to be invited to speak at the second-best university in the world – the first is the University of Wales - so I will sing for my supper. Let me talk about navigation!

****** Title slide ******

We professionals in the navigation business are the stewards of an exceptionally successful technology. Satellite navigation has been one of the outstanding technical achievements of the late twentieth and early twenty-first centuries. Among science-based industries, it has been a star. It doesn't pollute the atmosphere, cause global warming, or involve fracking, natural selection or creationism, or the politicians of the Great State of Alaska: everybody loves GPS!

But satellite navigation has raised challenges that navigation professionals - and especially their governments - now appear unable to meet.

****** A Proper Navigator ******

Life used to be simple: proper navigators were professionals. They wore uniforms and they had beards. This one was a sailor. Others flew aircraft or drove military vehicles. Matching government departments administered these separate activities and helped achieve international cooperation and standardisation. But those modes of transport remained apart: aviation technology was completely separate from this chap's world, or from what happened on land.

God was in his Heaven and all was well!

****** Mining, farming, trucking ******

- until along came this wretched satellite navigation and spoiled it! Soon, this single technology served navigators across all modes of transport. And then it escaped from us

navigators and became a tool for many professions, and then, Heaven forbid, a consumer product.

***** RAE Report headlines *****

This report by the UK's Royal Academy of Engineering struggled to find in Britain a single area of transportation, of commerce, of industry or telecommunications that doesn't now employ satellite navigation.

My government, your government, national governments around the world were completely unprepared to respond to this single technology on which depended, and from which profited, activities as diverse as missiles, farming and the stock market. Governments had separate ministries for the traditional modes of transport – land, air and sea – but also for industry, trade or communications. Absolutely no-one was responsible for setting national policy in navigation: there simply was no clear plan for the navigation of navigation!

Yet such leadership was essential, especially outside the US where governments realised that this GPS, this technology on which so much in their economies depended, was controlled not only by a foreign power – the US, but by its military!

****** The whole lot of GNSS ******

In response, those countries - or regions like Europe - that could afford to, set up their own satellite navigation systems. Thus, GPS, which much earlier had inspired GLONASS now begat Galileo and Beidou, and QZSS and IRNSS. Plus a host of augmentation systems: WAAS, EGNOS and other funny names.

Soon, these new GNSS became invested with immense national, or regional, pride. Their vast cost had to be justified by claims of technical superiority. In reality, we engineers know that their designers had no choice but to make them compatible with GPS, since GPS was decades ahead and the world standard. And these new systems had to squeeze into the narrow radio frequency bands allocated to navigation. Not surprisingly, indeed happily, all our GNSS turned out to look very like GPS, versions of the same technology - with just a hint of garlic here, a whiff of curry there. This similarity is obvious to engineers and navigators, though rarely to politicians.

And now each of these new systems is following a similar trajectory to GPS. For its first decade, GPS was seen as the way to meet every significant navigation need; to replace all older aids across land, sea and air. That was the clear view of the US Government Accountability Office, strongly supported in Europe. And why not? The growth of GPS did indeed result in the demise of Omega, Decca Navigator, Datatrak and a host of national systems you've never heard of, that simply couldn't compete technically or commercially. But this triumph of satellite navigation bred a certain hubris.

Unexpected events began to shake confidence, and concern increased as vulnerabilities appeared. You know the kind of thing. Occasionally, an individual satellite would fail – not an entire GNSS, as now seems popular with GLONASS - and Galileo!

****** Jan 04 SVN23 clock failure ******

In this event, the final atomic clock in satellite **SVN23** gave up the ghost, with exciting consequences for Europe.

****** 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.

****** San Diego event ******

In this event – now officially denied - GPS navigation was lost, accidentally, and without warning for two hours, across the San Diego area. In the city there many mobile cell-phone sites using GPS timing were affected.

And intentional jamming appeared on the scene.

****** Cliff-top jammers ******

A low-power device tested at this lighthouse disrupted GPS throughout this red zone, out across the North Sea to the horizon at 30km. This ship – the blue track - lost GPS entirely here. But out here, and here, the jammer caused these false positions; some ships appeared to track over land.

****** Single Galatea slide ******

The effect of jamming on a ship is dramatic. Less than one milliwatt aboard this vessel caused false positions on the chart displays; the autopilot would steer the ship off course; the ship reported false positions to other ships nearby and to the shore; it lost satcomms; the distress system that raises alarms and guides in rescuers failed; even the ship's clocks – 4 bells in the dog-watch and so on – went wrong. And when the officers sensibly reverted to good old radar and gyrocompass, to their shock: those were affected too. Ships nowadays – like so many critical systems ashore - have multiple GPS receivers embedded in multiple systems in ways no-one understands. When one fails, they all fail.

******* North Korea Kim Un *******

In a recent dramatic demonstration of this, South Korea experienced attacks using real, prolonged, high-powered GPS jamming. It blocked maritime navigation in just the way I've shown – plus aviation systems and cell-phone services and critical military capabilities.

****** Blue jammer ******

This jammer on the European market is hundreds of times more powerful than early ones. It's really not difficult to create a jammer powerful enough to affect large areas of a city. But what's interesting about this device is how carefully it has been designed to block all GPS frequencies, plus all the frequencies of Galileo, plus Beidou, plus QZSS. Oh, and of course, all our augmentations, like WAAS, as well. In Europe, there is a Great Myth: that Galileo is immune to GPS jamming.

****** Volpe and recommendation ******

In the US, growing concern among navigation professionals culminated in the 2001 Volpe Report of the Department of Transportation that clearly and officially recognised the multiple threats to the nation posed by the vulnerability of GPS - and recommended independent backup systems. That was a pretty grown-up response!

****** Highway gantry near airport *****

Since then, interference and jamming events have multiplied in all our countries. A detector on this UK highway close to the threshold of a regional airport, gets up to 200 jamming hits a month. Similar data from France and the US. Oh, there's no question: there are plenty of jammers out there right now.

Criminal use them to block GPS and cell-phones. But most events are caused truckers, not criminals, not terrorists, not rogue states. It still matters: any jamming, irrespective of its purpose hits all users of GNSS in range. It doesn't matter whether you are the intended target or a collateral victim; you get clobbered.

****** Spoofing threat – super-yacht ******

Now there's this new threat of "spoofing": transmitting false GNSS signals that commandeer a receiver. Researchers from the University of Texas at Austin used a laptop and spoofer to lead this yacht silently and gently off course. There was no alarm on the bridge navigation display to tell the crew anything was wrong. I have the greatest admiration for a university research team who get a sponsor to pay for 10 summer days on a super-yacht in the Mediterranean - no doubt drinking pink gins and surrounded by topless models.

****** Spoofing threat - montage ******

Spoofers commandeered this drone, diverted it, landed it. When criminals hijack a truck in future, they will make its on-board tracker show it on course, when really they have diverted and robbed it. And the Texans have also demonstrated how to shift precise timing using a spoofer. This opens the door to a range of interesting retirement plans for ageing techies like me, spoofing the automated systems of banks and stock exchanges with their million trades a second.

So, what do we do about this vulnerability of satellite navigation, to jamming, interference, spoofing, solar weather or equipment failure? Well, first, we must recognise the problem and face up to the need for Resilient PNT. Almost without exception, engineers - our profession - now do so. Almost without exception, politicians do not.

Of course, we must harden our technology.

****** Adaptive antenna technology ******

We'll use intelligent adaptive receiving antennas that favour satellite signals over interferers. The military do that, and the top end of the civil market will in future. But they're a long way ahead of the mass of vulnerable users already out there.

We can integrate satellite navigation with other technologies: dead-reckoning in land vehicles, clocks for precise telecomms timing. The powerful solutions are navigation technologies independent of GNSS yet complementary to it.

****** London Heathrow instrument approaches ******

Aviation is rich in these. It's maintained multiple independent technologies. So, London Heathrow runway 27 Left now has a GNSS Instrument Approach, but supported by an ILS, an MLS, plus DME, VOR, ADF, inertial navigation, radar and baro altimeters and magnetic compasses. Aviation GNSS has mandatory high standards, with RAIM and WAAS and reversion to a legacy system as soon as GNSS is less than perfect. What a contrast with maritime and land!

****** FAA study ******

And, prompted by the Volpe Report, the FAA developed Enhanced Loran (eLoran). Applying GPS digital techniques to the widely-deployed, but obsolete, Loran-C low-frequency technology they created a system that met the accuracy, integrity, availability and continuity standards of certain aircraft instrument approaches plus the demanding harbour entrance requirements of ships. It could also deliver timing of GPS quality to support telecomms. Brad Parkinson's high-level study group of industry leaders concluded that this was the only cost-effective substitute for US needs.

****** DHS announcement ******

The DHS announced its adoption as the US national backup to GPS; and then completely failed to implement it! Delivering a navigation system that benefits multiple areas of national life has turned out to be beyond the capabilities of governments. In Washington, no single department owns either civil GPS, or this powerful backup. So when it came to cost-benefit analyses there was no-one to aggregate the benefits across the whole of government, industry and commerce. Each department feared being landed with the check for the costs. Some call this dilemma the 'Tragedy of the Commons'. And before it could be resolved, a budget cut closed down the obsolete precursor system recently modernised for the move to eLoran!

****** eLoran IOC roll-out ******

The UK and Ireland took this US concept and have created a system, re-using obsolete Loran-C infrastructure from the North of Norway to South of France, and adding a new station. This Friday – in under 48 hours - the announcement will be made that this system has achieved Initial Operational Capability with 10-metre accuracy at 7 of our major ports. Ship-borne equipment switches automatically and seamlessly to eLoran when GPS is lost.

****** Europort eDLoran ******

Separately, a high-precision version of the technology has been developed for the maritime pilots at Rotterdam, Europe's largest port.

What excellent news! Apparently Europe has recognised GNSS vulnerability and adopted an insurance policy. Well, actually, no! These systems may never reach Full Operational

Capability. Europe lacks any such plan to respond to the vulnerability of GNSS – why, who needs that when we have EGNOS and Galileo?! You know, there's never been a Volpe Report on GPS vulnerability in Europe or anywhere outside the US.

My guess is that both here and in Europe the Loran infrastructure will be operated by industry. Its benefits will be sold to the individual groups of users, inside government and outside. The market – and good old greed – will provide the mechanism for realising the benefits.

What this example has shown is the lack of any informed debate on this matter – let alone policy - in most countries. A third of a century after the launch of the first GPS satellite, there is little recognition by governments anywhere in the world, of how essential resilient PNT has become to the critical infrastructure of their nations? I cannot identify a single country that has a clear plan encompassing applications from maritime navigation through telephone systems to banking transactions?

This is not a speech to sell eLoran – that's hardly necessary to an audience containing many who have contributed immensely to its technical success. But arguing for eLoran has demonstrated a much wider truth; that our immensely successful navigation industry has simply out-stripped our systems of government.

****** GPS funding – USAF ******

Even now, even here in the country with the most sophisticated understanding of the civil benefits of satellite navigation, funding decisions are still largely determined by the budget of a single part of the military. Your government and mine cannot cope with a ubiquitous industry that encompasses so many national functions.

Tell me this: would the US government, or any government, have funded satellite navigation had there not been a cold-war imperative? Would you be sitting here – and me standing, talking?

****** Title slide ******

Ladies and gentlemen, this Symposium is about delivering to all users the resilient PNT they need and deserve. Technically we can do that. But to implement it requires political will and wisdom. So, we need something else, we need it urgently and nationally and internationally and it's this: a way ahead, a clear path, a course, a direction and a flight-plan for: the navigation of navigation.

Thank you.

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