Satellite based Navigation in Iceland

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***Abstract*— An overview of Satellite based Navigation in Iceland is given, beginning with a short history of radio navigation. GNSS usage by the maritime sector is treated including a survey of EGNOS usage by the Icelandic fleet. Future maritime needs are reviewed. A similar treatment is given for the aviation sector in Iceland, outlining the challenges at hand in utilizing SBAS. Due to the country's northerly latitude there are challenges that require specialized solutions that are addressed in the paper.**

Keywords—GNSS, SBAS, EGNOS, WAAS, High Latitude, Approach profiles

I. INTRODUCTION

Since the discovery of Iceland, navigation has been vital for the well-being of the population. Vikings from Scandinavia discovered the country but how they navigated to the shores of Iceland is still to some extent a mystery. It is e.g. postulated that they really made use of the so-called „sunstone" (solsten) that allegedly enabled them to see or detect the sun's location despite cloudy skies. They also made observations of cloud formations and other natural phenomena to determine their whereabouts. It is beyond doubt that the Vikings possessed superb navigation skills that later led to their discovery of Greenland and the American mainland.

Iceland has always depended on communications to the European mainland and later to America. The nation's fortunes and communications to and from the country, primarily in the form of sea transport, have been highly correlated throughout the centuries. Navigation is one of the primary enablers of transport and therefore of high importance to Iceland. Fishing became the nation's main industry in the 20th century and is still one of the main pillars of the economy. Accurate positioning is essential to efficient fishing operations and safety at sea. Icelanders have operated air services on North Atlantic routes since 1945, using Iceland as a hub with destinations in Europe and North America. In recent years, Iceland has become a popular destination for tourism, which is an industry that depends heavily on satellite navigation, perhaps sometime without realizing or recognizing its importance to that growing segment of the economy.

The advent of GPS in the early nineties marked a milestone in navigation and positioning all over the world. In Iceland, the number of accidents at sea and in the air has dropped markedly due to more readily available positioning. All ships and aircraft now carry GNSS receivers and we await even more progress and cost savings from the utilization of GNSS. Autonomous ships are likely to appear on the oceans within a few years and aviation will seek new modes of operation and cost benefits from GNSS. In countries located at high latitudes like Iceland, there are specific issues that must be addressed before all those potential benefits can be fully enjoyed. Those issues will be described and addressed in this paper..

II. A BRIEF HISTORY OF RADIO NAVIGATION IN ICELAND

In the early 20th century, fishing in Icelandic waters became a large-scale industry. With the advent of radio navigation, the fishing fleet began to utilize the new technology for increased efficiency of operation and to reduce cost. With Loran-A, which became available to civil users after WWII, fishing vessels were able to locate and record good and generous fishing spots and return to them later with a relatively high degree of accuracy. Furthermore, they could avoid areas where the fishing trawls were endangered. Fishermen with gillnet or longline could now check their nets or hooks with increased certainty. Radio navigation became an essential aid for fishing and with the availability of Loran-C in the nineteen-sixties the coverage area was greatly extended and the accuracy of positioning increased. In the 1990s, Loran-C operation in the North Atlantic was reduced and the Icelandic Loran-C station at Sandur was shut down at the end of 1994. The replacement was in the form of basic civil GPS service with Selective Availability (SA) with a positioning error of approximately 100 m. This error magnitude was unacceptable for the fishing fleet which had become used to the high precision of Loran-C due to its outstanding repeatability. The Icelandic Differential GPS system was therefore initiated in 1994 [1]. Corrections were transmitted from seven radio beacons on the Icelandic coastline and the fleet enjoyed positioning with errors under 5 m. SA was turned off in 2000 and uncorrected GPS had improved to the point of being good enough for the fishing fleet. The DGPS system was turned off in 2016 nearly without protest, partly because 10 m GPS error is sufficient for the fishing fleet and partly because the fleet is now using EGNOS, a GPS overlay system designed primarily for aviation. There are two EGNOS RIMS (Ranging and Integrity Monitoring Stations) in Iceland but the availability of EGNOS signals is limited. The signals are transmitted from geostationary satellites that are viewed at a low angle in northerly latitudes yielding difficulty of reception in narrow fjords where increased accuracy is needed for manoeuvring.

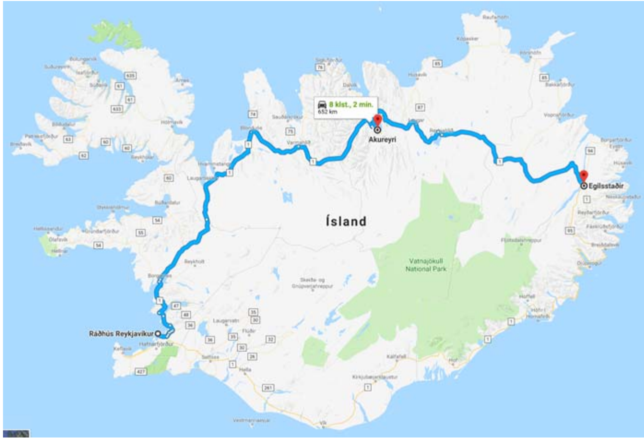

Figure 1. Road distance from Reykjavik to Akureyri is 387 km and 652 km to Egilsstadir

Icelandic society depends heavily on air transport as air services are the only practical means of travelling to the rest of the world. Notably the connections across the North Atlantic to Europe and North America as well as domestic services which connect distant regions with the capital area constitute this network. In 2017 more than 80 international destinations could be reached directly from Keflavik Airport with high frequency. Domestic aviation is also vital for the population outside the capital area. Driving from Reykjavik to Akureyri, the largest city outside the capital area, takes nearly 5 hours in optimal conditions, Figure 1. Approach and landing is complicated due to terrain close to important airports such as Akureyri and Isafjördur where GPS based approach profiles have been designed. Future landing systems will be increasingly GNSS based requiring high integrity GNSS overlay/augmentation systems especially in order to provide accurate vertical guidance. The fact that Iceland is on the boundary of EGNOS and WAAS services presents a particular problem that is being addressed by Isavia, the Air Navigation Service Provider in Iceland.".

III. SATELLITE BASED MARITIME NAVIGATION

Satellite navigation systems are available in virtually all Icelandic ships and boats. The Icelandic fishing fleet is generally well equipped with navigation, communication and fish finding gear. A typical new trawler is shown in Figure 2..

A. Current situation

Current performance of GPS is satisfactory for most maritime operations like fishing and general navigation between ports. Furthermore, it is also used for fisheries control and automatic safety monitoring of all Icelandic vessels that are required by law to report position, heading and speed with regular intervals to the Maritime Watch Centre. This reporting is based on the Automatic Identification System (AIS) for sea area A1 according to IMO classification, but fishing vessels out of AIS range report over a satellite link. This safety monitoring has been operated since 1967, and was set up due to high accident rates and many lives lost at sea. The service was manual until the early nineties when it became automatic using position reporting over VHF that was later replaced by AIS.

Recent measurements of L1, C/A code GPS performance in Reykjavik indicate a very small horizontal error. The measurements were done with a stationary U-blox NEO-8T receiver located on a building with free sight to all directions. The scatter diagram is shown in Figure 3. All measurement points are within a radius of 4 m and only a few outside 3.5 m.

Despite this accuracy, EGNOS is deployed in many Icelandic vessels. The main reason is not that the navigators demand EGNOS but rather that it is already a feature of the GPS receivers purchased. More advanced systems for SOLAS vessels emit a warning sound when EGNOS is not functioning. This is a nuisance to the vessel crew and therefore EGNOS is manually disabled in many vessels. The alarms are frequent due to the low availability of EGNOS west of Iceland and in fjords where visibility to the EGNOS satellites is hindered. It is likely that a majority of the larger Icelandic vessels do have EGNOS enabled GPS receivers. Many of them however do not deploy the EGNOS service or they are not aware that it is available in their receivers. This confirms the hypothesis that the accuracy offered by uncorrected GPS suffices for their operations. Of course there are applications at sea where more accuracy is needed, e.g. by many projects taken on by the Icelandic Coast Guard and Coastal Administration, e.g. in placing buoys. In such cases, the expert users are well aware of EGNOS and its advantages and limitations.

B. Future needs

The introduction of unmanned navigation of vessels is probably going to cause a paradigm shift in the field of maritime navigation in a near future [2]. Being very dependent upon shipping for freight and fishing, Iceland needs to follow the development closely and be prepared to install the necessary infrastructure. Furthermore, Iceland needs to have a voice in international bodies that both decide upon and build infrastructure to support autonomous navigation. Among the key areas to be developed to enable the introduction of autonomous vessels are accurate navigation systems that are resilient against jamming and spoofing, accurate maps of harbors, tidal areas, rivers and monitoring of sandbars and other underwater obstructions [3]. Furthermore, shore support facilities need to be installed, equipped with high data rate communication systems between vessel and shores.

Figure 2. A typical new Icelandic trawler, Björgúlfur EA312. (Photo by Haukur Sigtryggur Valdimarsson)

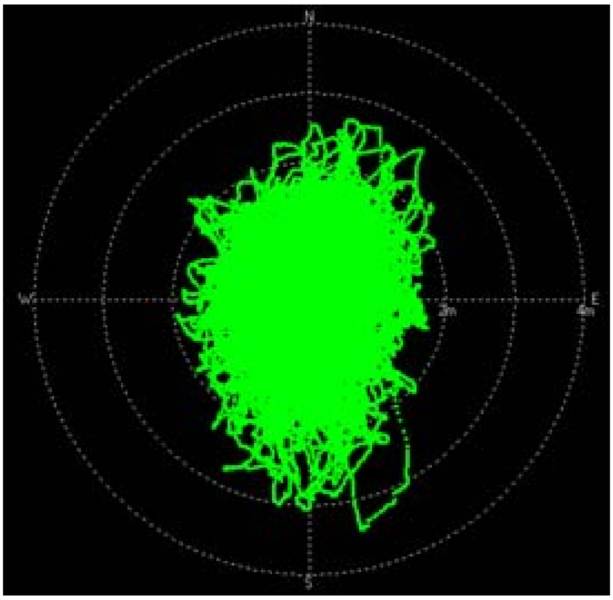

Figure 3. Scatter diagram from GPS measurements in Reykjavik during 24 hours in early May 2018

IV. SATELLITE BASED NAVIGATION FOR AVIATION

Like the rest of the world, Iceland enjoys a good situation in terms of GNSS availability and accuracy for en-route flying based primarily on the use of the basic civil services provided by GPS. Virtually all Icelandic aircraft are equipped with GNSS navigation equipment and this is in practice their main navigational aid although the traditional systems of VOR/DME and even Non-Directional Beacons (NDB) are still the back-bone of the route network where ILS is only available on a limited basis except for Keflavik Airport. Using GNSS for precision approaches of aircraft is a challenging task that would be highly rewarding in Iceland. This is a mountainous country, especially along the Western, Northern and Eastern coastlines where small towns and villages are located in fjords and inlets. These communities depend on good and reliable air travel, notably Isafjördur in the Westfjords and Akureyri in the North in addition to ambulance services that provide priority air transport of patients to the National University Hospital in Reykjavik. Rescue services by helicopter, provided by the Icelandic Coast Guard also require precision navigation into locations everywhere in the country and also at sea.

A. Current situation

A Google Earth view of Isafjördur is shown in Figure 4, where the approach by air has been drawn in red color. The town is surrounded by high mountains and the airport is located on a spit of land beneath one of the mountains in the small fjord of Skutulsfjördur where the town of Isafjördur is situated. Landing is only possible by descending into the larger Isafjördur bay towards the North-West until flight under Visual Flight Rules (VFR) is reached and the approach can be continued visually to the single runway shown in the picture which depicts the more difficult landing path in northerly winds. Reception of Geostationary Satellite signals, such as those transmitting EGNOS signals is not possible at Isafjördur due to mountain blocking. The EGNOS transmitting satellites Inmarsat 3-F2 at 15.5°W is at 15,3° look angle from Isafjördur and the SES-f at 5.0°E is at 12.4° look angle. Hence, EGNOS reception is not possible flying low during approach into the airport.

The situation at Akureyri is not as dramatic as in Isafjördur. The runway lies North-South and landings are possible from both directions. However, mountainous terrain affecting the approach profile is located in all directions except due North. The approach to Akureyri is considered complicated with the main approach requiring a knee-bend change of course to align with the final approach at a critical point. An Instrument Landing System (ILS) is in place for a straight-in approach towards North, however requiring a steep approach path of 5.5 degrees instead of the standard 3.0 degrees. No ILS is yet available for approach from the other direction although this is now being planned. This has had the consequence that foreign pilots, not familiar with the surrounding area, have decided to abandon landing at Akureyri Airport and have turned instead to the international airport in Keflavik.

Iceland is close to the boundary between the EGNOS and the WAAS service areas. The WAAS service area extends to the region south-west of Greenland. Iceland on the other hand is at the western edge of the EGNOS area. The two EGNOS RIMS ground stations in Iceland are located one in the Eastern part at Egilsstadir Airport and the other at Reykjavik Airport in the South-West. Accuracy and Integrity of EGNOS data in Iceland is therefore up to standards. However, as can be seen in Figure 5 [4], availability is limited. The availability referred to in this case is in accordance to APV-1 performance criteria. This means that the signal may be used for approach operations with vertical guidance where the required horizontal accuracy is 16 m and the vertical accuracy is 20 m. ICAO requires at least 99% availability for APV-1, which generally means EGNOS may not be unavailable for more than 14 minutes per 24 hour window. The colored areas vary with time and depend upon ionospheric conditions. From the map it is obvious that APV-1 availability requirements are met only in the easternmost part of Iceland. This is however not guaranteed at all times because the red area “breaths” a few degrees East and West, depending on the ionospheric conditions.

Figure 4. Google Earth view on Isafjördur. An approach path is drawn in red

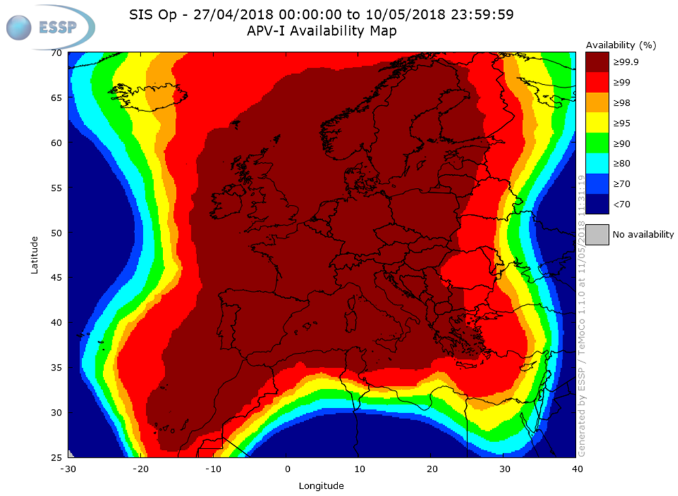

Figure 3. Availability of EGNOS averaged over 14 days

B. *Future needs*

The airports at Akureyri at 18.1°W and Husavik at 17.4°W do not reach the 99% availability area in all cases as is shown in Figure 3. However a collaboration between Isavia and the European Satellite Service Provider (ESSP) in 2016, based on Iceland-specific data collection demonstrated that Husavik Airport is on the boundary of the 99% availability area. Therefore has the Icelandic Transport Authority (Samgöngustofa) permitted Isavia, to design EGNOS supported approach paths for airports east of 19°W [5]. This is mainly for research and demonstration purposes. If it can be demonstrated that Husavik Airport can make use of EGNOS APV-1, this will apply for all airports east of Husavik. Additionally, Akureyri Airport is of interest due to the high traffic volume through Iceland´s second largest domestic airport. EGNOS based approach e.g. in Akureyri would greatly enhance air operations to and from Akureyri and make Akureyri a viable destination for international flights, in particular, as it would lower the minimum ceilings of missed approaches as well as increasing pilot confidence. For this to happen, EGNOS signals need to be available at Akureyri in a form receivable by standard airborne EGNOS-enabled navigation systems. This can be achieved in two ways:

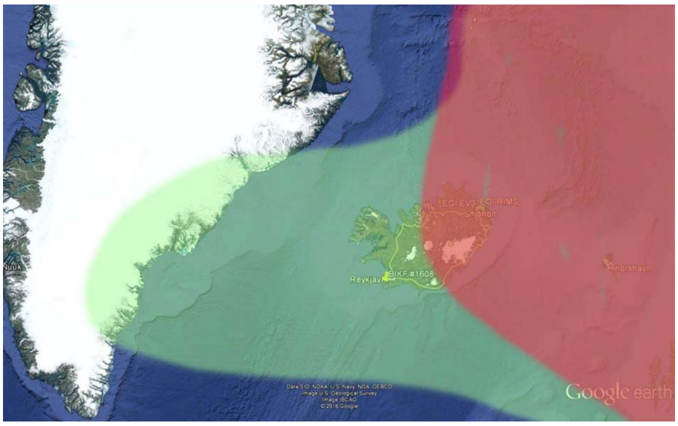

Figure 4. An EGNOS availability "dream" scenario for Iceland

i. A technical solution could be to install a pseudolite at the Akureyri Airport site, i.e. a transmitter that transmits EGNOS corrections on the L1 frequency using the same signal structure as a GPS satellite. This possibility has not been investigated but it would require permits and certifications from relative authorities, both domestic and international.

ii. Another possibility is for Icelandic authorities to seek negotiations with the European Union and ESA to enhance EGNOS coverage over Iceland. There are ideas to install high elliptical orbit (HEO) satellites that would provide good coverage over Scandinavia and the North Atlantic [5]. This would have the advantage that the look angle in high latitudes would no more be small and enable EGNOS approaches into many airports, even similar to the one at Isafjördur.

It would be very advantageous to Iceland to enlarge and extend the EGNOS service area to the West of Iceland. This would require at least one EGNOS RIMS station on the Greenland East coast that would support the Icelandic RIMS and increase their availability and integrity. A coverage map with this scenario is shown in Figure 4.

Conclusions

Satellite based navigation plays an important role for the main pillars of the Icelandic economy especially transport, tourism and the fisheries. It is also essential for the safety and well-being of the general population inasmuch as it enables ambulance and search and rescue services to be delivered with the highest level of navigation performance. This field enjoys a rapid pace of development that enables new possibilities and services previously unthinkable. If the Icelandic society wants to enjoy those benefits, Icelandic authorities must take on a more proactive role and increase their co-operation with the neighbouring states. Investments in knowledge and co-operation in this field are likely to provide very good returns, as has been experienced by many neighbouring nations.

Acknowledgment

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