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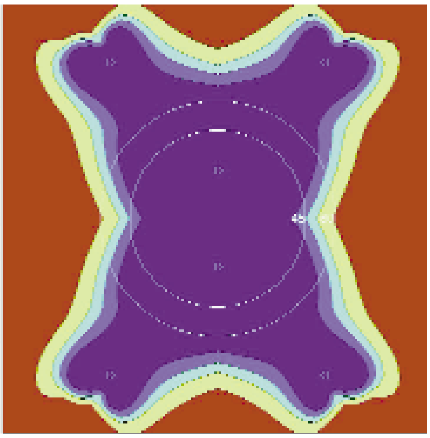
Perfect timing



Height monitoring technology is playing a vital role in the introduction of reduced vertical separation minimum regions worldwide

Reduced vertical separation minimum (RVSM) regions are gradually being introduced around the world. Until recently the minimum vertical separation for aircraft flying above 29,000ft has been 2,000ft. In RVSM regions this is being reduced to 1,000ft giving major benefits such as increased capacity, saving operators millions of dollars in fuel bills (by increasing the availability of fuel-efficient altitudes) and giving controllers more flexibility in managing the traffic.

RVSM has become possible due to progressive improvements in aircraft altimetry systems. In the 1940s the vertical separation of aircraft was set at 1,000ft at all flight levels, but with the advent of commercial turbojet aircraft it was necessary to take account of the reduction in accuracy of altimetry equipment that occurred at higher flight levels. In 1954 the Vertical Separation Panel was formed by ICAO and, following review of technical performance, in 1958 it was agreed that vertical separation above 29,000ft (FL290) would be increased to 2,000ft. As early as 1963 ICAO produced a resolution stating:

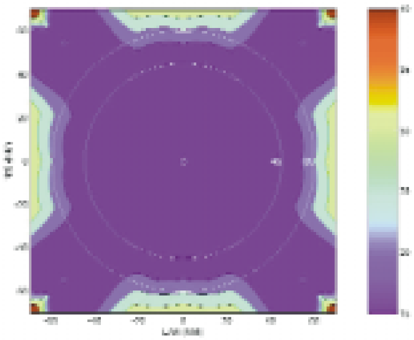
"In view of the importance of vertical separation in the planning of air traffic services, particularly in regions of higher traffic density, and the desirability of reducing vertical separation intervals above Flight Level 290, work in the field of vertical separation be vigorously pursued by all concerned to an early conclusion and presented to ICAO in a form suitable for early application in ATS planning on a worldwide basis or, if this is not attainable, at least on a regional basis."

Since then there has been a large growth in air traffic and consequently increased demand on the available airspace. The lack of progress was, in part, caused by the inability to obtain accurate data on aircraft performance and therefore the inability to determine whether it was possible to reduce vertical separation safely.

An international campaign to assess height-keeping performance started in the early 1980s. This programme led to confirmation that vertical separations could be reduced subject to aircraft altimetry performance meeting certain minimum standards known as Minimum Aircraft System Performance Specifications (MASPS).

To ensure that safety levels are maintained with the reduction in separation, ICAO has defined a tolerable risk level or Target Level of Safety (TLS) for RVSM implementation. The TLS ($5x10^{-9}$ fatal accidents per aircraft flight hour with half ($2.5x10^{-9}$) being attributable to altimetry system errors) is used with a collision risk model to assess the effect of RVSM introduction. Height monitoring is an essential part of any RVSM programme and is used to gather data to ensure that the TLS is met. Height monitoring is also used to examine the ongoing safety of RVSM and to identify any problems at an early stage.

There are two types of height monitoring systems in use – the GMU and



Above: Predicted accuracy of 120x120 nautical mile five-site system
Right: Inspecting the combined GPS and SSR antenna assembly

the HMU. The GMU, or Global Positioning System (GPS) measurement unit, is carried on board an aircraft for a specific flight and measures the height keeping performance of that aircraft. In contrast the HMU, or height monitoring unit, is a ground-based system that monitors all aircraft over-flying the monitor region (90x90 nautical miles for the European systems). To provide effective coverage of the aircraft population, a mixture of HMUs and GMUs is usually required, with strategically placed HMU systems monitoring the bulk of air traffic and GMU systems to monitor the remaining aircraft that do not normally fly over the HMU systems.

North Atlantic (NAT) RVSM

The NAT region was an ideal first candidate for RVSM as the traffic density was relatively low and the unidirectional flow of traffic made the task of meeting the TLS easier than in a high-density structure such as Europe with bi-directional and crossing routes. In addition the 1980s monitoring trial demonstrated that the aircraft types approved for operation on the NAT Organised Track Structure were capable of meeting the altimetry MASPS.

Roke Manor began work on height monitoring for the North Atlantic region in 1989. This ground-based height monitoring technology grew out of previous work on radar systems, primarily bi-static and multistatic. A typical radar has the transmitter and receiver as part of the same equipment, sharing the same antenna, but a bi-static system has a physically separate receiver and transmitter, with an arbitrary geometry between them. The multistatic scenario extends this to have several receivers and/or transmitters, often with some form of synchronisation between them.

The HMU works on the principle of multilateration, which can be considered as a passive multistatic radar. It requires no transmitter or interrogator of its own; instead it receives and time-stamps replies from the SSR transponders already installed on board aircraft. These replies are solicited by the existing secondary surveillance radar (SSR) installations as part of their normal operation. To determine an aircraft's XYZ position, a minimum of four receiving stations must be used, although more may be added to improve accuracy, coverage or availability. The time of arrival (TOA) of the SSR pulses at each site is sent to a central processing unit where the difference in time of arrival (DTOA) is calculated, leading to a 3D aircraft position.

Roke Manor began trials at its Hampshire site in the UK during the early 1990s, leading to a concept demonstrator HMU in 1993 deployed close to Strumble Head in the UK. This system was used by the UK's National Air Traffic Services (NATS) to prepare for the introduction of RVSM in the North Atlantic region.

In 1997 Roke Manor installed the first production HMU near Strumble Head followed by a second system centred on Gander Airport in Newfoundland. These systems allowed NATS and Nav Canada to monitor aircraft height keeping performance during the introduction of RVSM in the North Atlantic and more recently as a supplemental sensor for the European RVSM programme. These first production HMU systems cover an area of 20x20 nautical miles and measure aircraft height to an accuracy of 25ft. This stringent accuracy requirement implies that the receiver sites need to be synchronised very closely. This is done by sending out a synchronisation signal from the central site every second. The signal is received by the outlying sites and used to discipline the receivers' local oscillator to the central site.

This system works very well but requires line of sight visibility between the receiving stations and the central site, limiting the choice of site and usable terrain. The two systems have been operational since 1997, with the busier Strumble sensor measuring the height keeping performance of approximately 150 aircraft a day.

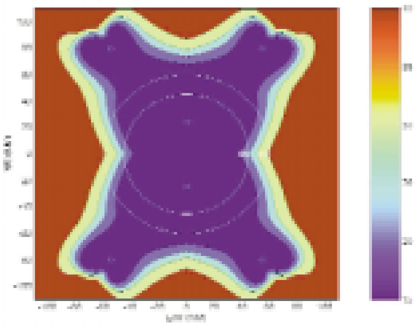
ECAC RVSM

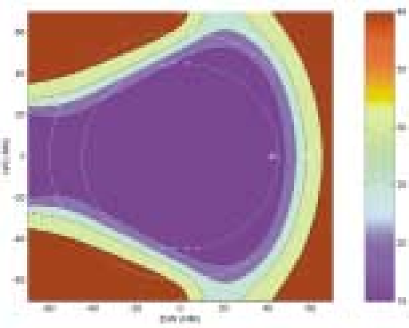
Since the successful introduction of RVSM in the North Atlantic a number of other regions have started RVSM programmes, including the European Civil Aviation Conference (ECAC), Asia Pacific and the West Atlantic Route System (WATRS). Roke Manor has been working with Eurocontrol since 1996 to provide a height monitoring solution for the ECAC region.

European route structures are much more complex than those over the North Atlantic region due to the variety of destinations. This requires a ground-based height monitoring system to cover a much larger area to monitor the different routes and the aircraft population.

To provide coverage, Eurocontrol chose three 90x90 nautical mile regions in Europe for ground-based monitoring – Nattenheim, Linz and Geneva. The coverage area was determined by the need to maximise the potential tracking of aircraft within these complex air-route intersections.

A number of sites were considered with regard to maximising the total number of different aircraft tracked. Any set of fixed monitoring structures suffers from the law of diminishing returns and a compromise has to be





Left: Magnification of RCMS receiver window showing synchronisation stability in nanoseconds
Above: HME receiver site in France
Above right: Predicted accuracy of 120x180 nautical mile six-site system
Right: Predicted accuracy of an offshore monitoring system

made between maximising capture and achieving a cost-effective system. It was finally decided, following detailed evaluation of flight plan data, that three areas together captured around 65 percent of the traffic and adding further units could not be regarded as cost-effective. The three sites identified were Nattenheim, based on the Nattenheim VOR on the German/Luxembourg border; Geneva, covering the Swiss/French border; and Linz in Austria. The remaining traffic would be monitored with GMUs.

The Nattenheim and Geneva regions presented the most technically challenging problem due to the difficulty in finding suitable sensor locations with line of sight to a common point. This meant that the remote sites could not be synchronised by a signal from the central site, as had been done in the North Atlantic system. Roke Manor was awarded the contract to provide the sensors for these two systems, which would use a GPS-based non-line of sight synchronisation system.

Research into GPS based synchronisation had been ongoing at Roke Manor prior to the European programme, but a fully developed solution had to be implemented rapidly in order to meet Eurocontrol's monitoring schedule. The accuracy of height measurement is dependent upon a number of factors, with one of the most important being synchronisation accuracy. Roke Manor attempted to procure a near commercial-off-the-shelf (COTS) solution but a satisfactory solution with the required accuracy could not be found.

To ensure that Eurocontrol's monitoring deadlines were met with the minimum risk, Roke Manor concentrated on developing its own advanced timing solution with the aim of achieving 1ns accuracy. Previous work at Roke Manor suggested that the long-term stability of GPS timing information may be combined with the short-term stability of high-precision oscillators. Various algorithms and receiver system architectures were developed. Initial trials suggested that values close to the target 1ns synchronisation accuracy between sites was achievable.

During the summer of 2000 Roke Manor installed two Height Monitoring Equipment (HME) systems, which form the height monitoring part of the HMU systems in the Nattenheim and Geneva regions using GPS synchronisation. By November 2000 the Nattenheim system was commissioned and declared operational by Eurocontrol. Since then further optimisation work has been done and the Geneva System was commissioned before the systems were handed over in April 2001.

The accuracy of each system was assessed by flight trials with DGPS-equipped aircraft and by monitoring aircraft of opportunity. Following optimisation both systems are achieving the required 25ft accuracy. The Nattenheim system, with more optimal geometry, was able to demonstrate a mean offset from the DGPS data of less than 10ft. Since the sensors were declared operational, Eurocontrol has reported that Nattenheim is monitoring approximately 650 aircraft a day. Geneva will be adding a further 450 a day.

Future technology

In operation the time synchronisation system used in the two sensors has far exceeded expectation, providing a relative time difference stable to within a fraction of a nanosecond. This has opened up new possibilities for future height monitoring systems and other areas of multilateration technology. As it is no longer necessary for receiver sites to be located within sight of a central synchronisation point, systems can be built to cover much larger areas than previously conceived, several hundred miles across, and can be deployed in difficult terrain. By way of example, trials have been conducted showing that the synchronisation technique also works over much longer baselines than are currently used. Extensive data has been gathered for synchronisation between the Nattenheim and Geneva systems, showing sub-nanosecond relative timing over baselines of at least 400km.

The location of receiver sites for the Nattenheim and Geneva systems was a conservative choice to reduce risk with the new synchronisation system. The results now show that future systems could use sites much further apart to cover a much larger region with the same accuracy. Studies have shown that with optimal site location, a region of 120x120 nautical miles could be covered with the same accuracy. This is almost twice the area of the current systems. Even larger areas could be covered with the addition of more receiver sites.

Now that line of sight visibility between receivers is no longer required there is no theoretical limit to the number of possible receivers. An array of receivers could be used to provide coverage of a complete country or region if required. Until now ground-based systems have not been able to monitor offshore coastal areas. However by combining directional antennas with the

Above: RCMS window for one receiver
Right: RCMS display for the HME

use of the new GPS timing solution it is now possible to monitor regions up to at least 40 nautical miles offshore, and possibly beyond. This will allow routes that follow a coastline to be monitored effectively.

The GPS timing synchronisation technique has been a major breakthrough for multilateration. It has helped Eurocontrol prepare for the introduction of RVSM in the ECAC region and offers a potential solution for other monitoring requirements. The data required for the safety case has been gathered and the introduction of RVSM remains on schedule for January 2002. The European HMU systems are expected to continue monitoring for at least seven years to ensure that safety standards are maintained.

The application of this new technology is not limited to height monitoring for RVSM. Multilateration technology has many uses and Roke Manor is actively involved in many areas of multilateration from passive surveillance to mobile phone positioning systems. The advanced GPS timing solution guarantees that multilateration will continue to be a growth area in civil aviation and beyond. ❖