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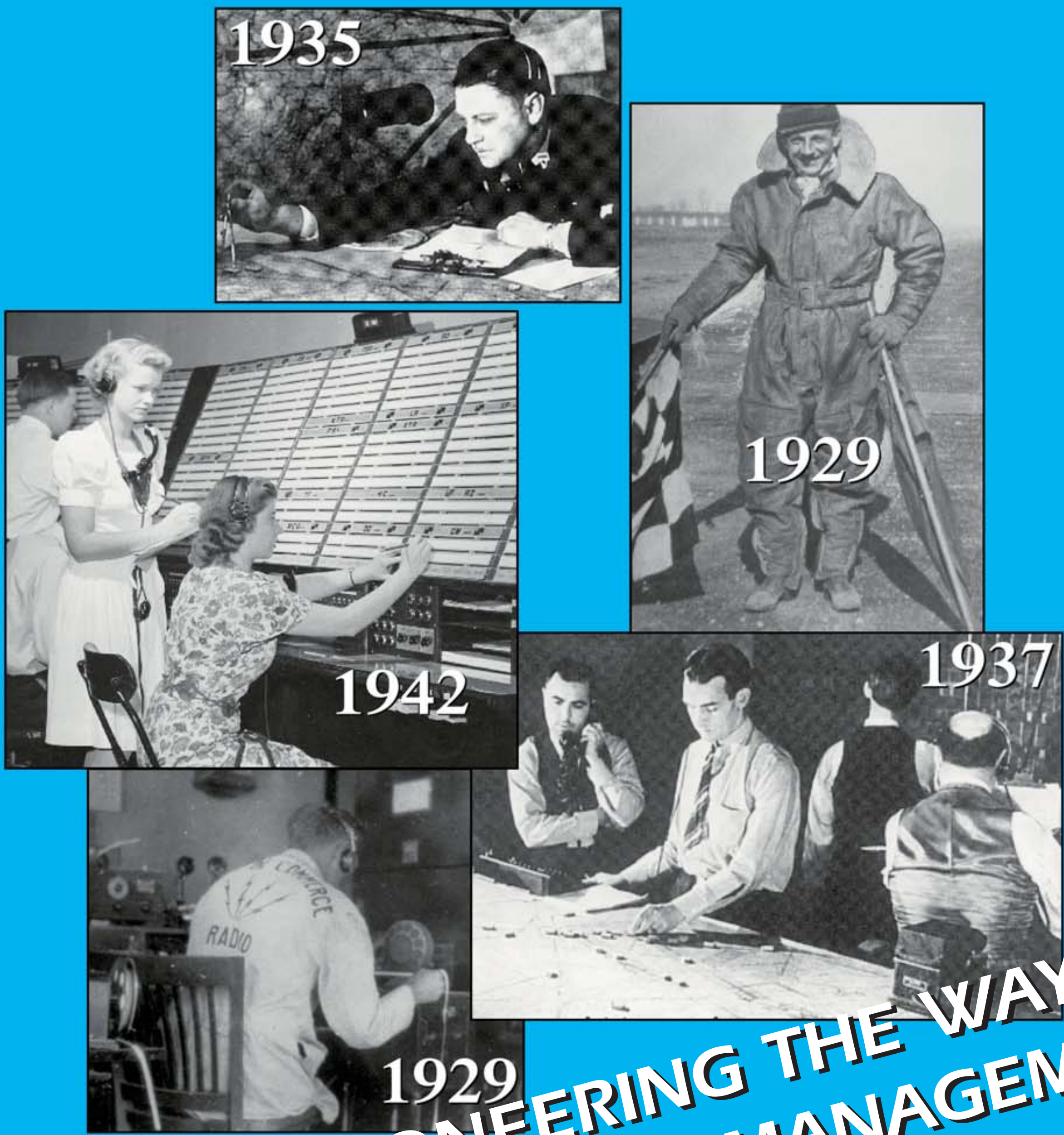

PIONEERING THE WAY TO AIR TRAFFIC MANAGEMENT

Next Generation ADS-X Surveillance Technology

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Air Traffic Control systems and operators have traditionally depended on radar for surveillance, however new technologies promise better performance than radar at much lower cost. **Extended Automatic Dependent Surveillance (ADS-X)** combines two contemporary technologies to deliver cost-effective performance and reliability.

To cope with the relentless growth in air travel, Air Navigation Services Providers (ANSPs) look to reduce aircraft separation to maximize the use of scarce resources such as runway capacity and air routes. At the same time, safety can never be compromised and technology is required to deliver new and better solutions to meet these apparently competing needs.

In dense airspace, improved surveillance performance is driven by the introduction of Reduced Vertical Separation Minima (RVSM), increasing numbers of closely-spaced parallel runways and the need for higher throughput. At the other end of the scale, the low cost airline phenomenon has led to an increase in the number of regional airports requiring surveillance and separation services.

As part of a complete CNS/ATM response, surveillance systems, traditionally dominated by radar technology, must deliver better accuracy, faster update rates, and higher levels of reliability with the economics required in today's competitive aviation environment.

LIMITATIONS OF RADAR TECHNOLOGY

Primary radar, which bounces high energy radiation from the reflecting surface of the aircraft, requires no co-operation from the target aircraft, and will always have a valuable role to play in perimeter security, but the high costs of acquisition, operation and maintenance of primary radar systems has led to standardization on *secondary surveillance radar* (SSR) for most terminal area and approach surveillance needs.

The costs of SSR systems are lower than primary radar because they rely on transponders installed in each aircraft to reply to interrogations from the radar, which greatly reduces the transmission power required in the SSR itself.

The transponders, now almost universally installed in commercial, civil and military aircraft, also contribute to the richness of the surveillance data by including data such as beacon codes, and barometric altitude in the reply. Indeed, modern Mode S transponders, which are mandatory in larger aircraft because of their contribution to Airborne Collision Avoidance Systems (ACAS) provide rich target information.

A modern SSR can cost around U.S. $3 Million (M) and will provide well proven levels of performance and reliability, but there are a number of limitations to radar technology:

- The high cost of each radar installation and the requirement for line of sight between radar and aircraft often prohibits radar coverage from being deployed in a all desirable areas, especially where hills and valleys demand a large number of separate radars.
- Radar position is derived from a combination of range (derived from the time taken from transmission of interrogation to reception of response) and azimuth (derived from the direction that the radar faces when the signal is received). Accuracy decreases with distance from the radar head as a fixed angular azimuth error becomes multiplied by the effect of distance.
- The speed of radar rotation is limited by the need to turn the heavy radar antenna and by the need to send and receive transmissions from remote aircraft. As a result the update rate for data received from radar is typically around 5 seconds which, while adequate for many traditional applications, is less than optimal for advanced applications such as Precision Runway Monitoring (PRM), which can be required for closely-spaced parallel runways.
- Traditional radar systems provide only two-dimensional surveillance and are unable to report aircraft altitude independently from the aircraft barometer reports received from Mode C and Mode S transponders; however an independent assessment of altitude is desirable when introducing RVSM procedures.

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Special purpose radar-based equipment has been developed for both PRM and height monitoring applications, however these come with high price tags and alternate technologies are needed to fully address radar's limitations.

AUTOMATIC DEPENDENT SURVEILLANCE BROADCAST (ADS-B)

The apparent heir to the surveillance throne is Automatic Dependent Surveillance Broadcast (ADS-B), which relies on GPS (or other GNSS satellite constellations as they emerge) positioning systems installed in the aircraft combined with a new ADS-B transponder which regularly broadcasts position information to listening ADS-B Ground Stations

These ground stations are relatively simple receivers, which can detect and decode ADS-B signals from aircraft up to 250 nautical miles (nm) distant, providing that line of sight is maintained. Furthermore, the ADS-B message is longer and more complex than traditional radar transponder signals and can contain information such as velocity, heading and intent, providing even more information to complete the surveillance picture.

The accuracy of ADS-B position reports is derived from the satellite system and, with today's augmentation systems such as the U.S.'s WAAS, extremely high performance can be achieved. ADS-B data is usually broadcast at least once per second, which is also a significant improvement on radar capabilities.

While ADS-B promises significant improvement in surveillance price-performance, its long-term value may lie in the two-way nature of the technology. Early ADS-B systems are already available which can provide "ATC-like" traffic displays of all nearby ADS-B equipped aircraft to the cockpit, contributing to safety in uncontrolled airspace and reducing controller workload in controlled space.

TWO OBSTACLES TO ADS-B DEPLOYMENT

With such attractive capabilities, there is considerable interest in ADS-B deployment and adoption, with notable projects in U.S., such as the Capstone project in Alaska, and in Australia, where a continent-wide upper airspace ADS-B surveillance system is being deployed.

On the whole, however, while ADS-B standards and technologies have been around for many years, there are few examples of ADS-B in operation; a situation strongly influenced by two factors:

- ADS-B requires new avionics in each aircraft and can only be a radar alternative once all aircraft are equipped.
- ADS-B transfers the responsibility for surveillance data from the ANSP or airport, who owns the radar, to the aircraft operator, who owns the ADS-B avionics. This transfer raises some interesting safety and operational issues.

ADS-B EQUIPAGE WILL TAKE TIME

There have been a number of ADS-B studies, surveys and trials conducted by the world's ANSP's and by aviation consulting organizations, and all tend to reach the same conclusions:

- ADS-B equipage is currently limited, especially in older commercial fleets and in the general aviation sector.
- New aircraft from Airbus and Boeing are often being delivered with ADS-B avionics and this is contributing to increasing ADS-B equipage rates over time.
- It is hard to predict how long it will take for all aircraft to be equipped and this is likely to involve new mandates and regulations.

For example, a 2005 study of US ADS-B adoption by Mitre Corporation [(1)] found that only around 5% of aircraft were equipped, and predicted that it will take well over a decade until almost all of the fleet was ADS-B capable.

ADS-B SURVEILLANCE SAFETY CONSIDERATIONS

The same studies and trials have found many examples of inconsistent or inappropriate use of ADS-B technologies and avionics which can result in incomplete or inaccurate position information.

As ADS-B standards and operating procedures develop, the incidence of these anomalies will probably reduce, however there will always remain the issue that ADS-B position information is derived exclusively from aircraft avionics. For the ANSP providing separation services, this raises questions about the integrity of the data and the responsibility for any errors, and ultimately about the ability to establish a complete safety case for the use of ADS-B as a sole surveillance source in place of radar, especially if it is intended to replace existing radar with ADS-B.

Some form of backup or validation technology is likely to be required in at least some part of the surveillance domain in order to validate accurate operation of ADS-B avionics and, while radar could meet this requirement, the need for such an expensive backup system would significantly detract from the financial business case for ADS-B.

MULTILATERATION CAN HELP TO ADDRESS THESE ISSUES

Multilateration systems locate aircraft by receiving aircraft transponder signals at a distributed network of receivers and using at least three such receivers to triangulate on the aircraft, based on the different time taken for the same signal to reach each receiver.

This approach is well proven in airport surface movement surveillance where it has become a standard com-

Figure 1. Multilateration principle.

ponent of modern Advanced Surface Movement Guidance and Control Systems (A-SMGCS). Wide Area Multilateration (WAMLAT) systems have also been deployed in terminal area and wide area applications around the world.

A recent EUROCONTROL report(2) has compared multilateration to SSR and concluded, inter alia, that:

- "Where coverage exists a WAM system will generally outperform MSSR for accuracy"
- "The hardware costs of a WAM system are (very roughly) around 50 % of those of an SSR system"
- "The maintenance cost of WAM systems will be much lower than MSSR as there are no rotating mechanical parts. A 6 monthly maintenance check at each site to maintain ancillary equipment such as UPS systems may be required; otherwise there is very little to do."

Other analysis has suggested that the economic advantages of multilateration may be even greater than those quoted by EUROCONTROL, especially for larger surveillance domains.

ADS-B VERSUS MULTILATERATION

So which technology represents the best option for ANSPs and airports looking to invest in surveillance?

Multilateration is an ANSP-controlled solution which provides better price-performance than radar and requires no new avionics, however triangulation requires more sensors than simple ADS-B reception, and multilateration does not provide the two-way, in-cockpit capabilities of ADS-B.

ADS-B provides the most attractive performance economics and functionality, but it will take some years for aircraft to be equipped and, even then, some form of backup or validation system may be required.

ADS-X - EXTENDED AUTOMATIC DEPENDENT SURVEILLANCE

There is no need to select one solution or the other as it is possible to achieve a pragmatic synthesis of the two technologies which leverages the strengths and addresses the challenges of both platforms. This approach is called "E**X**tended Automatic Dependent Surveillance" or ADS-X.

ADS-X incorporates both ADS-B decoding and time difference of arrival triangulation in the same network of distributed sensors and provides:

- ADS-B reception and decoding of all ADS-B equipped aircraft.
- Simultaneous multilateration derived position information for the same ADS-B equipped aircraft.
- Multilateration derived position information only for aircraft equipped with older Mode 3/A, Mode C or Mode S transponders.

The advantage of the ADS-X approach is shown in the graph above.

For ADS-B equipped aircraft, two position reports are derived simultaneously and independently for each aircraft transmission, providing the independent source of backup and validation required to complete ADS-B safety case analysis.

For all other aircraft, multilateration-derived position information is provided, which delivers complete fleet coverage whilst ADS-B equipage continues over the next few years.

By combining the two technologies ANSPs and airports now have a deployable, high-performance, and cost-effective option to expensive SSR systems and the ability to invest in tomorrows technology today.

ADS-X INTEGRATION WITH EXISTING SYSTEMS

In most cases, ANSPs seek to integrate updated surveillance solutions into existing ATC automation or tower systems and ADS-X provides a number of standards based options to achieve this objective.

- ADS-X Mode 1 provides separate ASTERIX Category 20 (multilateration) and Category 21 (ADS-B) feeds

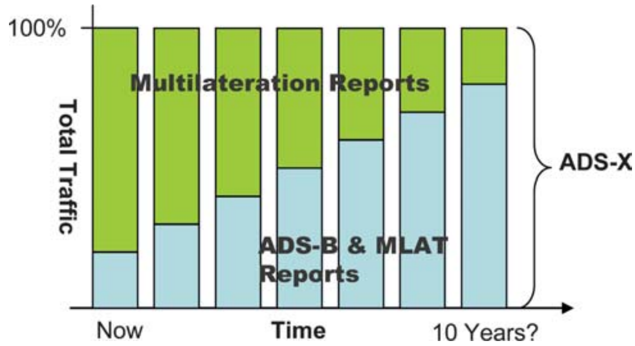

Figure 2. ADS-X coverage over time.

which allows fusing and decision making to be undertaken in the ATC system.

- ADS-X Mode 2 provides a single fused Category 21 feed using multilateration data to create artificial ADS-B records which are presented to the ATC system as if all aircraft were ADS-B equipped.
- ADS-X Mode 3 provides a single fused Category 20 feed using ADS-B data to improve the data & tracking performance of the multilateration data.
- ADS-X Mode 4 provides a single fused feed in ASTERIX Category 1 or 48 formats, with the data being presented in a pseudo-radar sweep format to be easily absorbed into older ATC systems which require data in that format.

For older ATC systems, custom interfaces can also be developed which can incorporate any of the above design concepts and in each case, integration of the new technology will be readily achieved.

ADS-X IS INCREMENTAL INVESTMENT

At first glance, it may appear that the ability to deliver multilateration information would require at least three times as many sensors as would be required for ADS-B processing alone and therefore that an ADS-X system would require significantly higher investment. In many cases, however, the cost to provide ADS-X will be only incrementally higher than an ADS-B solution and the increment will be readily justified by the additional functionality.

- ADS-B ground stations are generally deployed in a redundant configuration, either with redundant units in a single location, or with overlapping coverage areas from adjacent ground stations. To extend coverage from two sensors to three or even four is not the same as a simple three-to-one comparison.
- ADS-X ground stations are generally simpler (and less expensive) than standalone ADS-B ground stations as they offload some of the processing to a central server, especially for the multilateration processing.
- In some configurations, it may not be necessary to provide both ADS-B and multilateration coverage to the edges of the surveillance area, relying on ADS-B only in some areas and validating the ADS-B data for each aircraft only within the multilateration zone. For non-ADS-B aircraft, especially in areas with no surveillance today, it may be sufficient to project aircraft position in zones not covered by multilateration.

In the following example, we have considered possible surveillance system designs for an area in central USA around the major cities/airports in Louisville, Cincinnati, Columbus, and Indianapolis.

In Figure 3, we show the ADS-B coverage that could be expected at 18,000ft from a single ADS-B receiver located at each of the four airports. Extensive surveillance can be achieved with good levels of coverage and redundancy around the main centers.

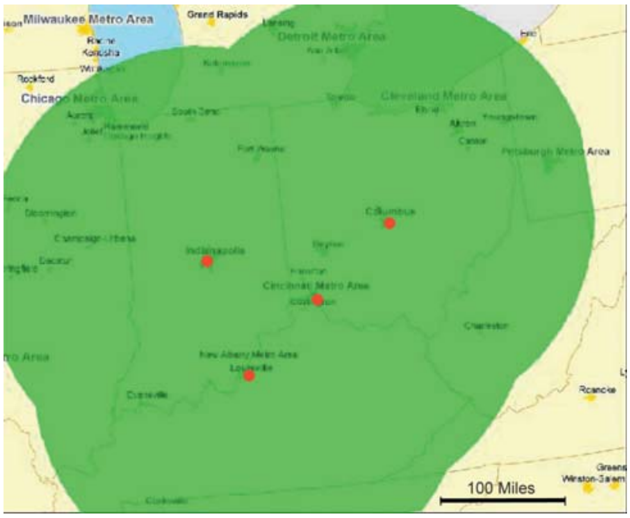

Figure 3. Single ADS-B receiver per site.

In Figure 4, we have overlaid the multilateration coverage and accuracy that would be delivered from the same four ground stations if they were ADS-X equipped.

Unlike the ADS-B solution, the accuracy of the multilateration component of the solution varies across the surveillance domain as a result of the range and geometry of the four sensors at each point in the domain, however at least "radar-like" coverage is obtained for the entire zone defined within the colored contour lines.

In this theoretical example, it is clear that the ADS-B solution can be significantly enhanced by the use of the ADS-X concept, and that the incremental costs can be quite low.

OPERATIONAL ADS-X SOLUTIONS

ADS-X is available, installed and operational today. Rannoch Corporation and other suppliers have installed

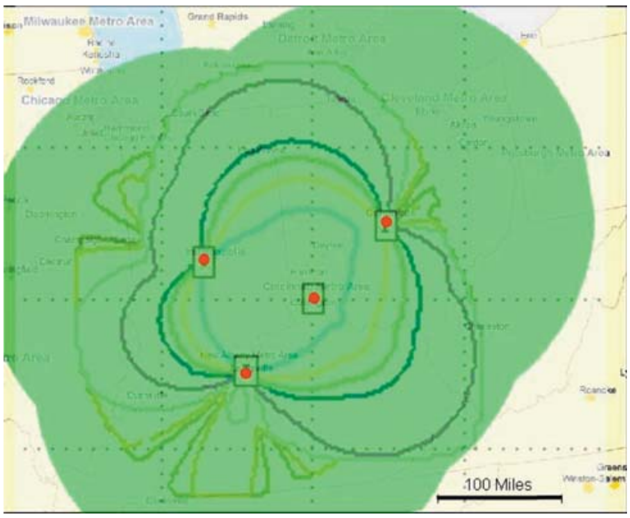

Figure 4. Single ADS-X receiver per site.

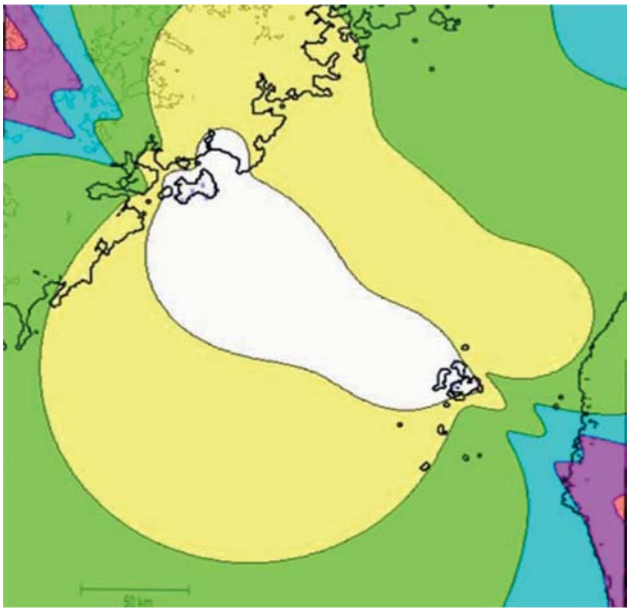

Figure 5. ADS-X operational in Taiwan.

a number of systems in the U.S. and elsewhere that incorporate some or all of the elements of the ADS-X approach.

In Taiwan, Rannoch has worked with the Taiwanese CAA to deploy an operational ADS-X surveillance solution that covers the airspace over the Taiwan Strait, with coverage from the surface at Kinmen Airport and extending across some of the world's busiest international airspace.

Figure 5 shows the coverage achieved by the ADS-X solution in Taiwan. The Chinese mainland can be seen at the top left of the diagram while Taiwan is visible at bottom right. The islands of Kinmen and Peng Hu are at each end of the central zone of very high dual (ADS-B and multilateration) surveillance accuracy. Radar-quality multilateration coverage extends to all but the dark pink areas; and ADS-B data is received consistently across the whole surveillance domain.

Using 6 ADS-X ground stations on Kinmen Island (near the Chinese mainland) and another two on Peng Hu Island across the Taiwan Strait, the Taiwan CAA now has access to "better than radar" surveillance in this critically busy airspace and have also established extremely accurate surface surveillance which can track aircraft on the runways and taxiways of Kinmen Airport to within a few meters.

The solution cost a fraction of the equivalent cost for SSR, has low ongoing maintenance costs, and has established next-generation ADS-B capability in Taiwan earlier than almost anywhere else in the world.

CONCLUSION

The challenges facing today's air traffic control providers require better surveillance performance and lower costs than can be delivered by traditional radar solutions.

ADS-B offers highly attractive performance, functionality and economics, whilst multilateration can be applied without avionics changes and under the control of the ANSP.

ADS-X, which blends aspects of both technologies in a single dynamic system, presents a pragmatic solution to these issues.

REFERENCES

1. Mitre presentation to RTCA Spring Forum, May 2005
2. EUROCONTROL "Comparative Assessment of SSR vs Wide Area Multilateration", September 2005.