

EUROPEAN CERTIFICATION OF THE FIRST GPS-BASED PRECISION APPROACH SYSTEM IN COMMERCIAL USE

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BIOGRAPHIES

Börje Forssell is Professor of Navigation at the Norwegian University of Science and Technology, Trondheim, since 1983. He participated in the development of the first Norwegian-built GPS receiver already in 1977 and is active in most fields of navigation, including precise positioning and aircraft navigation and landing. He is the author of numerous papers in these fields and of the book "Radionavigation Systems".

David Last is a Professor Emeritus in the University of Wales and President of the Royal Institute of Navigation. He holds the degrees of BSc(Eng) and PhD, and a DSc higher doctorate. His 40-year research and consultancy career in radionavigation systems has encompassed GPS, differential GPS (including precision landing systems), land vehicle tracking and recently Loran-C and Enhanced Loran for aviation and maritime navigation. He is an instrument-rated General Aviation pilot, with 30 years flight experience.

Günter W. Hein is Professor and Director of the Institute of Geodesy and Navigation at the University FAF Munich. He is responsible for research and teaching in the areas of high-precision GNSS positioning and navigation as well as physical geodesy. He has been active in the GPS field since 1984 and is the author of numerous papers concerning kinematic positioning, navigation and sensor integration. In 2002, he received the ION Johannes Kepler award for "sustained and significant contribution to satellite navigation".

Gunn Marit Hernes graduated from the Norwegian University of Science and Technology (NTNU), Trondheim, in 1993 with an M.Sc. in Electronics Engineering. After positions at the Norwegian Mapping Agency and the North-West European Loran-C System, she has been working as an ATM Inspector in the Norwegian CAA since 2004. There she has been involved with the operational approval process of the SCAT-I ground station.

ABSTRACT

The first European-certified precision approach system in commercial use guides passenger-carrying aircraft to touchdown in Brønnøysund, central Norway, since October last year. Brønnøysund is the first Norwegian

regional airport at which this SCAT-I (Special Category I) system has been certified. Another 20 such airports are planned to have SCAT-I within the next three years. SCAT-I is a local-area precision approach system based on differential GPS. It will replace the non-precision, step-down approaches in use today at most of those regional airports in Norway at which difficult terrain makes establishing ILS glidepaths either very complicated or impossible. The ground-based parts of the system were developed in Norway and the airborne parts on the other side of the Atlantic.

An important role in the certification process has been carried out by the SCAT-I Integrity Panel (SIP). Originally, the FAA set up its own panel, the mandate of which was to evaluate the integrity of the SCAT-I system and ensure that this had been established properly. Following the withdrawal of the FAA from the project, the Norwegian Civil Aviation Authority established the SIP in the autumn of 2002. Its mandate was to take to completion the work begun by the FAA of certifying both the ground station and the avionics.

The European Aviation Safety Agency (EASA) became operational in 2003. As an independent EU body under European law, it is accountable to the Member States and EU institutions. Norway has been a member of EASA since 2005. EASA became a certification authority in 2006 and has been responsible for the validation of the SCAT-I avionics in this case.

The certification process has involved several players, and a number of parts of the system required separate certification. This has been challenging, in particular since no similar certification process had been carried out elsewhere, and so incomplete guidance material was available for certification. The certification process ended with a SCAT-I guided passenger-carrying aircraft successfully reaching touchdown in Brønnøysund on 29 October 2007.

INTRODUCTION

Norway has 29 regional airports with regular services. Most are in remote areas surrounded by mountainous terrain (e.g. Fig. 1). Generally they are served by turboprop aircraft carrying 20-70 passengers. Runway lengths are 800-1200 metres. The biggest operator is SAS group company Widerøes flyveselskap, the largest

regional airline in the Nordic countries, with smaller companies also contributing.

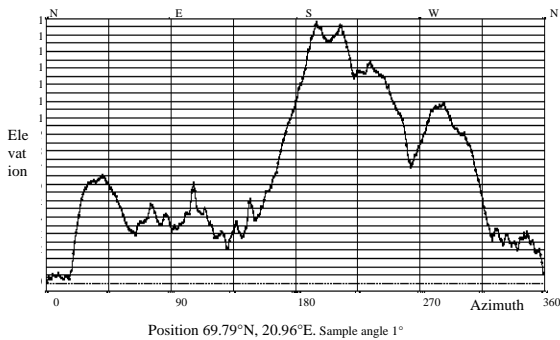


Fig. 1. Horizon diagram of Sørkjosen community airport in northern Norway (ENSR). The approach to runway 15 lies along a fjord from the north between mountains.

Traffic at these airports is generally light, but regularity requirements are demanding since the airports are the best means of rapid transport for small communities with advanced commercial and industrial activities.

The approach and landing aids at these airports are usually NDB, DME or VOR/DME, and ILS localiser, with non-precision step-down procedures using baro altimeters. The difficult terrain surrounding many of the airports makes installing Cat. I glidepaths either impossible or technically very demanding, and extremely costly.

BACKGROUND FOR THE INTRODUCTION OF SATELLITE AIDS

There have been two serious CFIT (Controlled Flight into Terrain) accidents at these airports. In May 1988, a Dash-7 flew into a mountain due to a missed step-down fix. There were no survivors. In October 1993, a DHC-6 crashed short of the runway because of the so-called ‘black hole effect’: pilots approaching visually at night, over featureless terrain, tend to keep the visual angle of the runway constant and so sometimes fly an arc of a circle, which can result in an impact short of the runway. There were a few survivors of this crash.

In 1996, in the aftermath of these accidents the Norwegian parliament resolved to improve considerably the approach and landing aids at these airports in order to minimise the risk of such accidents in the future. Since the accidents had been due to poor vertical guidance, the need was for electronic glidepaths. Developments in satellite navigation offered long-term alternatives to ILS technology with the potential to meet ICAO Cat. I standards. But at that time, the only system sufficiently developed was the interim solution known as “Special Category I” (SCAT-I).

SCAT-I

SCAT-I (Fig. 2) is a GPS Ground-Based Augmentation System (GBAS). It uses a local-area differential reference station at the airport to support specially-authorised approaches to MLS/ILS Cat. I minima. SCAT-I specifications were produced by the RTCA Special Committee 159 [1]. The standards follow the Required Navigation Performance (RNP) concept in which the primary parameters are accuracy, availability, integrity and continuity.

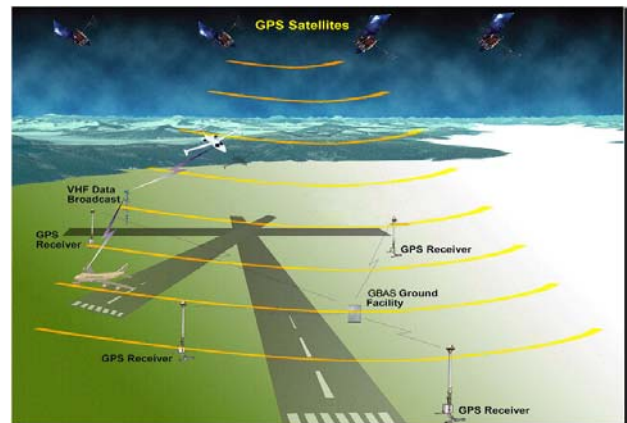


Fig. 2. Special Category-I approach system.

The system consists of four functional segments: satellites, airborne subsystem, ground subsystem, and data link. The ground subsystem produces ground-monitored differential corrections, plus integrity and precision-approach waypoint data. This information is transmitted via the data link to the airborne subsystem in which it is validated and processed. The airborne subsystem corrects its pseudorange measurement from the satellites by using the differential correction data from the ground subsystem. In this way it generates position, velocity and heading values of enhanced accuracy. These parameters, in conjunction with approach waypoint data from the airborne navigation database and/or the data link, supply navigation guidance signals to drive the pilot displays, and any autopilot or flight director. A Total System Error (TSE) containment-warning algorithm is executed in the airborne subsystem to provide additional system integrity. The airborne receiver function complies with Technical Standard Order (TSO) C-129a [2].

The most significant parameters transferred via the VHF data link are:

- Integrity information;
- Satellite identity;
- Pseudorange corrections (PRC);
- Range-rate corrections (RRC);
- Issue of data (IOD), Z-count, etc;
- PRC standard deviation;

- Difference between corrections derived from two independent GPS receivers and antennas;
- Approach path (final approach segment);

Key performance parameters are:

- Accuracy: 1.1 m;
- Integrity risk: 10^{-7} ;
- Continuity: $3.8 \cdot 10^{-4}$;
- Availability: 95 %.

INTEGRITY

The most important performance parameter of an approach and landing system is integrity. This is a measure of the trust that can be placed in the correctness of the information supplied by the navigation system. It includes a measure of the ability of the system to provide timely warnings to users when the whole system, or parts thereof, should not be used for navigation. Integrity requirements are generally expressed quantitatively using three parameters:

- *Integrity risk* is the probability that an error caused by the system leads to a computed position error that exceeds the *alert limit* without warning users within the specified *time to alert*.
- The *alert limit* is the maximum allowable error in the user's position solution before an alarm must be given within the specified *time to alert*.
- *Time to alert* is the time from the occurrence of the system error that causes the computed position error to exceed the specified alarm limit, to the display of the alarm at the user's interface.

The system integrity risk for SCAT-I is specified as 10^{-7} per approach [1]. Allocation of risk to the various functions is shown in Fig. 3. (The values are inherited from terrestrial systems.)

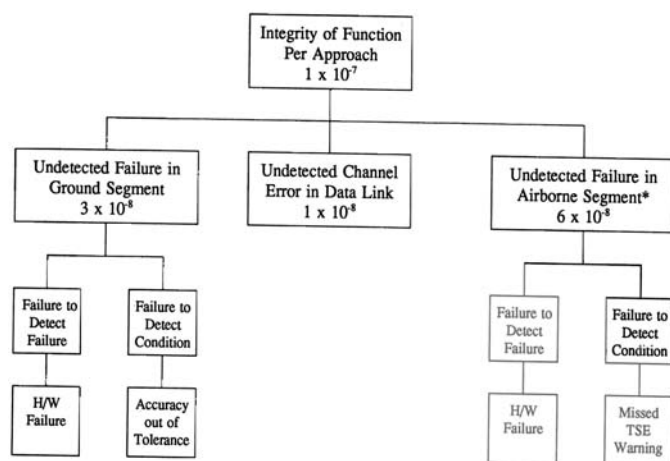


Fig. 3. Allocation of the total SCAT-I system integrity (10^{-7} per approach) among the various functions [1].

INTEGRITY PANEL

Because of the extremely small probability values, of 10^{-7} per approach or less, involved in integrity specifications, it is impossible to verify compliance with these requirements by measurements alone. Instead, theoretical calculations must be used to extrapolate from careful measurements. To ensure that such calculations made in the equipment will be reliable and trustworthy, "integrity panels" are employed. Their members are highly-qualified people, independent of the system designers, manufacturers, etc. They scrutinise the assumptions and calculations embodied in the system in order to verify that the results can be trusted. The panels examine in detail the system and subsystem descriptions, assumptions, algorithms, formulas and calculations, to ascertain that they meet the integrity requirements. Approval by such an independent integrity panel is required before the system may be certified and used.

THE NORWEGIAN SCAT-I PROJECT

Following the parliamentary decision in 1996, a project group was established under the leadership of *Avinor*, the state-owned airport owner and operator. The task of developing the ground system was given to the Oslo-based company then known as *NAVIA* and now as *Park Air Systems (PAS)*. PAS is a leading manufacturer of ground-based navigation and landing aids for air traffic, well known worldwide for its ILS. Funding came jointly from Avinor and NAVIA/PAS. The development of the airborne avionics was entrusted to *Universal Avionics Systems Corporation (UASC)* of Tucson, Arizona, USA.

The other organisations involved were:

- Widerøe (Headquarters in Bodø), the airline intending to use the new system in its Bombardier DASH-8 (DHC) aircraft;
- The US Federal Aviation Administration, specifically the Los Angeles Air Certification Office (FAA LA ACO), responsible for the approval of the airborne avionics;
- The Norwegian Civil Aviation Authority (NCAA), (located in Bodø), the highest authority for civil aviation in Norway under the Ministry of Transport and Communications, responsible for approval of the ground equipment, each individual SCAT-I ground installation and its approach procedures, and validation of aircraft installation approval;
- Transport Canada (Ottawa), the department within the Government of Canada responsible for developing the regulations, policies and services for transportation in Canada.
- Field Aviation (Toronto, Canada), responsible for the installation of avionics in the DASH-8.

The concept of the proposed SCAT-I system was approved in 1997. As early as 2001, a prototype of the

PAS NM8001 SCAT-I ground station was installed at Torp airport, southwest of Oslo. It was used for initial test flights with very satisfactory results. Subsequently it provided a great deal of test data.

THE INTEGRITY VALIDATION PROCESS

Regulatory aspects of the project, including integrity validation and certification, were to be administered by the NCAA. They agreed with the US FAA that integrity matters would be the responsibility of an existing FAA integrity panel, the LAAS Integrity Panel (LIP), who were preparing for certification of the broadly similar Local-Area Augmentation System (LAAS).

This LIP was composed of highly qualified people from the FAA itself, and universities and other research institutions. In 1999, the LIP issued its first report on the formal documentation concerning the ground and airborne avionics prepared by NAVIA/PAS and UASC. As is customary with initial integrity panel reports, the LIP raised numerous comments, questions and recommendations and required changes and improved documentation covering multiple issues. NAVIA/PAS and UASC responded to this report with revisions and additional documentation. The LIP produced its second report in May 2002.

Unfortunately, although the integrity process was proceeding well, at that point the FAA withdrew its support of the LIP, which terminated its work. Avinor resolved to proceed with the integrity process and in mid-2002 the NCAA appointed a new panel: the SCAT-I Integrity Panel (SIP). This Panel consisted of Professor Börje Forssell (chairman) from Trondheim, Professor David Last from Bangor (UK), and Professor Günter Hein from Munich. The mandate of the new SIP was to continue the work started by the LIP. This included some 80 outstanding issues. No new issues were to be raised.

The SIP initially concentrated on the ground equipment. The process of integrity panel reports and manufacturer's responses was carried through three further complete cycles until all ground equipment issues had been satisfactorily resolved by January 2004. The PAS ground station was certified in February 2005.

There were delays in the development of the airborne equipment. Its integrity process restarted in 2004 and was concluded satisfactorily in January 2006. The work of the LIP and the SIP had taken 8 years and 6 cycles.

THE TUNNEL ISSUE

One of the many intriguing questions with which the SIP had to deal was the tunnel issue, which will serve as an example of the SIP's tasks. In the tunnel concept (Fig. 4), a key component of the RNP method, the aircraft is virtually confined within an inner and an outer tunnel; the inner tunnel is defined by the accuracy requirement and the outer by the integrity requirement.

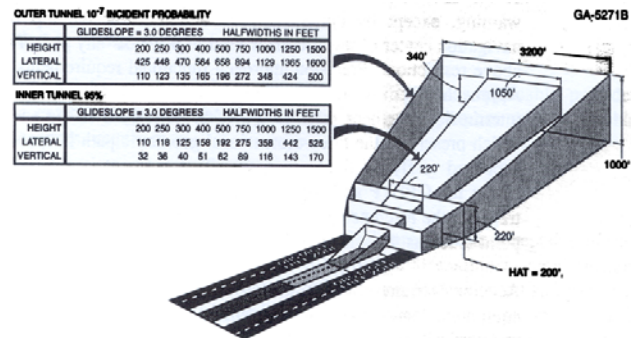


Fig. 4. Inner (accuracy) and outer (confinement) tunnels. Required Navigational Performance for Precision Approach. Accuracy figures are Total System Accuracy.

The specifications in [1] require that the probability of an outer tunnel violation be less than 10^{-7} . This leads to a Vertical Protection Limit (VPL), set at 5.33 times the Standard Deviation of the Total System Error (TSE) in the vertical direction, the assumption being that the error distribution is Gaussian. This VPL has to be computed continuously by the equipment since the accuracy, continuity and availability of GPS-based SCAT-I are not static parameters (as with ILS) but depend on the satellite geometry at any time. The specification allows this VPL to increase to about 33.5 m before an alarm must be raised.

The TSE is the sum of the Navigation System Error (NSE) plus the Flight Technical Error (FTE), the difference between the desired SCAT-I aircraft position and its actual position as estimated by the Flight Management System (FMS).

The LIP had identified a problem with the tunnel concept. If the FTE is small, the NSE is allowed to become quite large before an alarm is raised. Consider the case where the aircraft touches the "ceiling" of the tunnel at + 33.5 m (approximately 100 ft), as the aircraft approaches the 200 ft Cat. I decision height. The aircraft will then actually be at 300 ft. Tests have shown that pilots, expecting to be at 200 ft but unexpectedly 300 ft as they transition to visual flight, tend to over-control the aircraft, resulting in a dangerous situation.

In response to the LIP and to solve this problem, the manufacturer proposed implementing a 'pre-approach test' to ensure that the VPL did not exceed a very conservative 14 m before the SCAT-I approach was allowed to commence. The SIP now questioned whether this lower VPL could be maintained throughout the approach. It was concerned about possible changes in satellite geometry, and especially the loss of one or more satellites, during the approach. On the basis of further study, the manufacturer showed that significant growth of the VPL would be extremely unlikely: the satellites most vulnerable to loss would be low-elevation satellites and their loss has little effect on VDOP. The probability of losing even a single low-elevation satellite due to shadowing, multipath, RFI, ionospheric scintillation, etc. during the 150 s of an approach was demonstrated to be

of the order of 1%. The probability of losing a high-elevation satellite due to satellite failure was very much lower, of the order of 10^{-5} .

It should be stressed that the aircraft's being close to the tunnel ceiling at the time of this pre-approach test is not a problem as long as the pilot is aware of it and simply chooses a steeper descent early in the approach. The pre-approach error can also be checked using the baro altimeter, part of the required onboard equipment. In addition, because the VPL is a 5.33σ value, the probability of the vertical error's exceeding the VPL is only 10^{-7} , given the Gaussian distribution. The SIP accepted the manufacturer's proposed solution.

The tunnel issue was important since the Norwegian airfields at which SCAT-I will be deployed are surrounded by terrain in which low-elevation satellites are more likely to be lost because of shadowing than in flat terrain. Such losses can to a large degree be predicted. However, the solution agreed upon avoided any requirement for a mechanism to predict satellite loss. It is not required for GBAS Cat. I either.

ACTIVITIES IN PARALLEL WITH THE SIP WORK

The process of approving a new approach and landing system such as this is exceptionally long and complex, and involves many aviation authorities. Although the SIP had taken over the integrity studies from the FAA LIP, the FAA continued its support for the remaining certification activities related to the airborne avionics of the Norwegian system under its bilateral agreement with the NCAA. Once the development of the ground station had almost been finished in early 2004, PAS applied to the NCAA for technical approval of the station. This required flight trials, so PAS sent a ground station to UASC in Tucson for trials in conjunction with UASC's certified (TSO approved) aircraft avionics.

Completion of the project was delayed by administrative problems, and economic limitations had slowed down the development of the airborne equipment. However, by 2004 the two other main participants, Avinor and Widerøe, were sufficiently satisfied with progress to authorise Field Aviation to install the avionics in 18 Widerøe aircraft. At the same time, the FAA's LA ACO worked on completing certification of the airborne avionics. In 2004, the participants accelerated their activities, so that by the end of 2005 the following had been completed:

- RTCA 178B approval of the ground station software (follow-up after SW audit);
- The SIP's review of the integrity of the airborne processing;
- Verification by system-level testing that the ground station met the accuracy requirements; and

- Completion by PAS of the system's Technical Handbook covering the installation, maintenance and operational safety procedures.

THE FINAL PROCESSES OF SCAT-I APPROVAL

After the successful resolution of the remaining airborne equipment integrity issues, the SIP formally declared to the NCAA in January 2006 that its tasks had been completed with a positive outcome.

OPERATIONAL APPROVAL OF THE PAS NM8005 SCAT-I GROUND STATION

In March 2006, Avinor applied to the NCAA for operational approval of the first SCAT-I ground station, installed at Brønnøysund airport. The NCAA inspected the installation there in October 2006 and, after minor modifications and flight inspection in December 2006, approved it in January 2007. The approval included the approach procedures developed by Avinor which were based on ICAO requirements. An Aeronautical Information Circular (AIC) and a supplementary Aeronautical Information Publication (AIP) were then issued. As is customary, the AIP contained airport charts, charts of airspace and military low-flying areas, radio frequencies, opening times, deviations from international regulations, etc. This kind of information changes relatively infrequently. The AIC contained the short-term technical, administrative and regulatory aspects of air safety and air navigation matters.

The System Safety Assessment Operational Performance document for the Brønnøysund SCAT-I installation was then updated, and in March 2007, the NCAA received Readiness Statements from the Air Traffic Services at Brønnøysund and the regional Air Traffic Control Centre in Bodø.

Operational approval for the Brønnøysund ground station was given by the NCAA on 20 April 2007. This, together with an approved training program for Widerøe's pilots, paved the way for the approval of Widerøe as an airline operator of SCAT-I which was given on 31 August 2007.

EUROPEAN SUPPLEMENTAL TYPE CERTIFICATE (STC)

The aircraft installations also required approval. A Supplementary Type Certificate (STC) was issued for the flight inspection aircraft, LN-ILS, and for all Widerøe aircraft of types DHC 8-101, -102, -103 and -106. The STC covered the use of dual Universal GLS-1250 DGPS SCAT-I Landing System airborne equipment. All aircraft and the flight inspection procedures were approved by the NCAA.

In the meantime, other certification actions were being taken in North America and Europe:

- In February 2006, the FAA issued an STC to UASC covering the installation of the airborne equipment, a single UNS-1D Flight Management System, including the VHF data link. In March 2006, UASC applied to the European Aviation Safety Agency (EASA) for validation of this STC. In May 2006, EASA requested the NCAA to execute this validation on its behalf. The NCAA then organised test flights at Brønnøysund between 15 and 27 June 2007. These were judged to be successful, whereupon EASA issued the required European STC in July 2007.
- Just before Christmas 2005, Transport Canada issued an STC to Canadian company Field Aviation East Ltd, covering the installation of Dual GLS-1250 (Dual -1F FMS). Field Aviation sent a request to EASA in March 2006, asking for a validation of this STC by EASA. In June, EASA asked the NCAA to carry out this validation on its behalf. Three weeks later, the NCAA confirmed a successful validation to EASA by means of a Technical Visa.
- Widerøe at once started implementation of the STC in the first of their aircraft.

inauguration of the system at Brønnøysund airport on 29 October 2007, when a Widerøe passenger-carrying Dash-8 flight made the first SCAT-I precision approach. Avinor claimed to be “the first airport operator in the world to put a satellite-based precision approach system into commercial operation”.

However, the most important beneficiaries of the new system will be the passengers and pilots of Widerøe, and the citizens of the remote communities of northern Norway to whom it will bring improved flight regularity and safety.

REFERENCES

- [1] *Minimum Aviation System Performance Standards DGNSS Instrument Approach System: Special Category I*. Document No. RTCA/DO-217, 1993, revised 1995.
- [2] *TSO-C129a, Airborne Supplemental Navigation Equipment Using GPS*. Department of Transportation, Federal Aviation Administration, Aircraft Certification Service, 1996.

CONCLUDING REMARKS

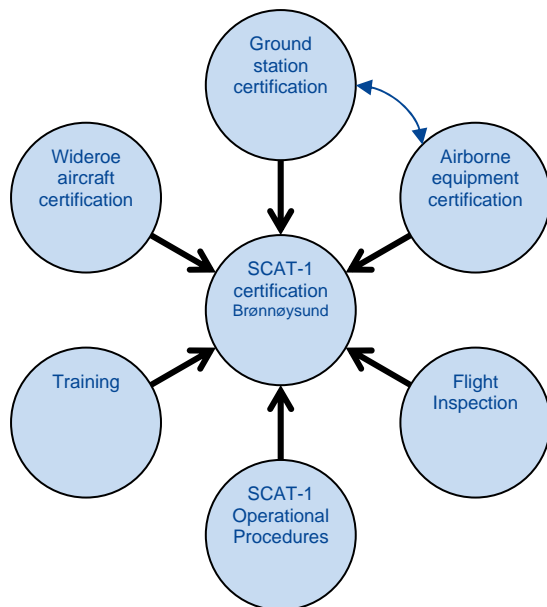


Fig. 5. The certification process for the Norwegian SCAT-I system.

A pictorial summary of this highly complex certification process is given in Fig. 5. As can be deduced from the description above, completing certification of the system was a prolonged and demanding process. But once it was complete, all parties derived great pleasure and satisfaction in participating in the official