Challenges with GBAS VDB Flight Inspection

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BIOGRAPHY

Mike Spanner spent many years as an Operational Flight Inspector inspecting and calibrating all type of Radio Navigational Aids, including GBAS. Latterly is the subject matter expert for GBAS within NATS; the UK based Air Navigation Service Provider. He regularly attends and presents papers at ICAO meetings whilst representing the UK CAA on GBAS issues and is also the current chairperson of Eurocae WG28 which focusses on GBAS ground MOPS within the European environment for the implementation of GBAS GAST-D. His current role also includes the management of the Flight Inspection contract on behalf of NATS, through which 18 ILSs at major and minor UK airports in the UK are inspected along with all the Enroute VORs and DMEs.

He holds various technical and management qualifications including a Bachelor of Engineering Degree in Electronics and Electrical Engineering and a Diploma in Management.

ABSTRACT

Flight Inspection of GBAS presents many challenges compared to traditional navigation facilities. The VDB SARPS include not only minimum field strengths, but also include maximum figures in order to ensure the maximum data transmission loss rates are not exceeded. This, coupled to the use of multiple VDB transmitter locations supporting the same approach, leads to a complex set of flight inspection requirements and new measurement uncertainty evaluations to be performed. Along with this, it is noted that ICAO are currently examining the potential effect of ILS and VOR overflights which may affect the ability of the GBAS VDB receiver to perform correctly. This may lead to the necessity of performing measurements to evaluate potential adjacent-channel interference issues.

This paper examines practical flight inspection results and uses the measurements to highlight where improvements in measurements techniques and resultant uncertainty specification are required. Evaluation of the latest recommendations being discussed within ICAO that may affect flight inspection measurements are also presented.

1. INTRODUCTION - GBAS FUNDEMENTALS ASSOCIATED WITH FLIGHT INSPECTION

GBAS is a ground based system intended for use at airport locations to provide a means of supporting instrumented approaches to landing. The service provided is dependent on the implementation of ground monitoring systems and the technical components that provide the GBAS VDB signal. A single ground subsystem (GBAS) comprises of:

- A set of GPS receivers and multipath limiting antennae (nominally 4)
- A VHF transmitting element (VDB) to broadcast messages to approaching aircraft
- A processing system that provides correction and integrity data based on received GPS signals, along with Final Approach Segment data that defines the available approach trajectories.

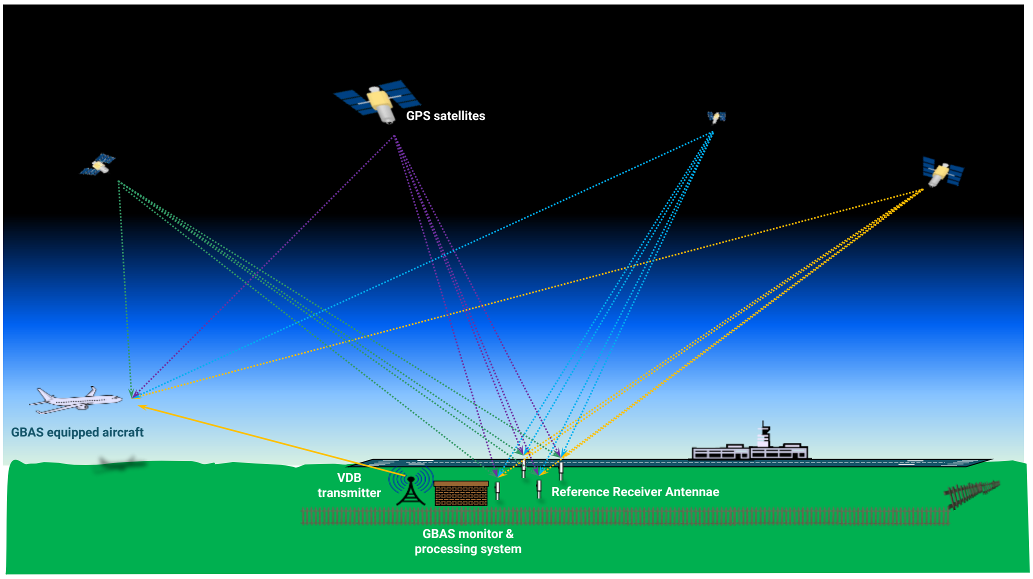


Figure 1: GBAS Ground Sub System

The GBAS Sub System elements can be located anywhere near an airport and not necessarily on it; however for security reasons current GBAS implementations are within the airfield boundary fence. The placement of the Reference Receiver Antenna is designed for the particular airport implementation considering multipath, expected Ionospheric conditions and maximum distance to threshold (circa 5km). The VDB transmitter, which could be a single or multiple site design, must ensure coverage of the VHF signal to all areas where the GBAS signal is intended to be used. Again, the VDB element may be placed anywhere on the airfield; or even up to 5 km away if required.

The VDB signal, whilst providing the correction and integrity data, also contains the approach path information in the form of coordinates for each approach procedure defined. GBAS is designed to allow up to 48 different approach path definitions per given VHF frequency for the VDB transmission, which makes GBAS highly configurable compared to ILS. Each approach path is a 'straight line' in space, however each may have different Glidepath angles (GPA), threshold definitions and azimuth alignments. Approaches can be defined to Points in Space or to virtual runways; however they can also be defined to imitate conventional ILS single approaches used at an airport. Current standards allow use of GBAS within a defined Approach Service Volume of 23 NM, however changes in 2019 will allow use of GBAS outside 23 NM with a limited integrity concept. This will enable aircraft to check the station identification and potentially in future allow Localiser only type operations to a range of Dmax (maximum use distance). The Dmax parameter is defined at installation and through the certification process of the ground station and could reach to ranges of 200 NM, although more typically this may be limited to 40-50 NM to meet frequency allocation licence criteria. The Minimum Approach Service Volume is that required to support each defined approach path sent via the VDB signal.

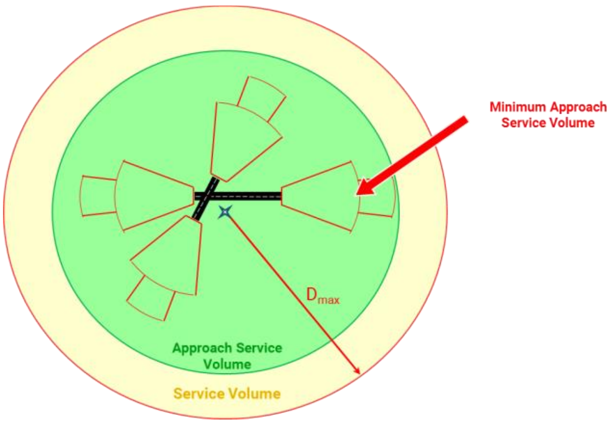


Figure 2: GBAS Service Volume

There are several different operational standards defined for GBAS, with each providing a level of service which may be utilised by the aircraft receiving the GBAS VDB data. These, coupled to the aircraft capability define the overall GBAS

Approach Service Type (GAST) and are broken down into the FAST (Facility Approach Service Type) and GAEC (GBAS Airborne Equipment Classification. Currently two main types of GAST are considered for operation:

- GAST-C- Certified for operations to 200’ in many countries, with work being undertaken to allow lower decision heights and also Auto Land in specific conditions.
- GAST-D- Industry is aiming to certify this standard to allow CAT III operations in Mid Magnetic Latitudes (which includes most of Europe), with operations starting in 2020/21 depending on market demand. Availability of this service may be limited in some counties due to the prevailing Ionospheric conditions at those locations.

The combination of the selected FAST from the ground station, along with the GAEC will define the level of service that is supported for a particular approach to an airfield. For example, Figure 3 shows a ground station with FAST-D, an aircraft with GAEC-D equipment on board thus facilitating a GAST-D approach. The GAST is defined by the lower level of service provided by either the ground or aircraft equipment.

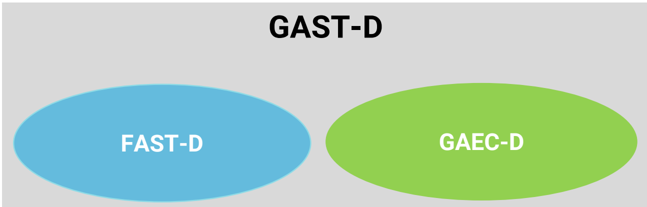


Figure 3: Approach Service Types required for CAT III operation

Other GAST have been defined and these will provide worldwide CAT III operations without limitations; however will not be available until an estimated 2025 timeframe. As Northern Europe is considered benign in terms of Ionospheric conditions, GAST-D will provide adequate performance at all airports within the UK (and most of Europe), allowing CATIII operations without the need for additional GAST to be defined and approved. Flight Inspection of the later FASTs (E and F) are not likely to require any major difference from FAST D stations, other than the requirements for Flight Validation where the aircraft must be dual frequency capable (L1, L5) and/or dual constellation capable. Along with this, the Interference Assessment must take into account of the additional Space Segment signals in use.

Communication of the GBAS information via the VDB signal is broken down into time divided ‘Slots’ containing set data message types within a frame. The breakdown of the message content is beyond the scope of this paper, however it is important for flight inspection purposes to know which VDB system is sending within each time slot.

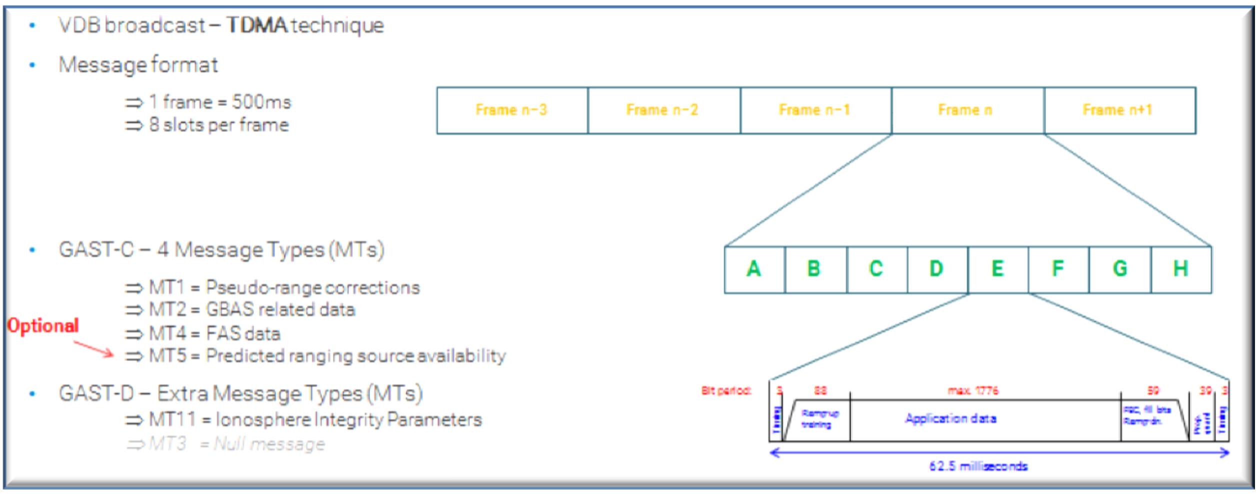


Figure 4: VDB Message Structure

In general, a GBAS Ground Sub System frequency licence will include both the VHF frequency in use and also the assigned Slots for use. The number of slots assigned will depend on the intended use of the station, with 1-2 normally assigned for

FAST-C, 2-3 for FAST-D stations. Other GBAS stations in the vicinity of the GBAS under inspection may also be assigned the same frequency, but different time slots. This precludes the use of general receivers and/or low performance spectrum analysers for signal level measurements, since it would not be possible to determine where the received signal level comes from. In addition, the signal level must be made during the start-up sequence of each time slot (as per [1]), which introduces a minor complication in the measurement timing. A further more complex issue discussed in section 3 is that two different VDB ground stations associated with a single GBAS Ground Sub System may transmit in the same time slot on an alternating basis. Unfortunately the origin of the signal is not coded within the transmission, making identification of which station is responsible for the data received relatively complex.

Recent work at ICAO has focussed on the interaction between traditional navigation aids that may already be on the airfield such as ILS and VOR which share the same frequency allocations as VDB from GBAS. The work has resulted in RTCA defining new tolerable Desired to Undesired signal levels for aviation receivers. The new specifications have been carefully designed to be backward compatible with existing GAED-C equipment fitted to the current fleet of aircraft. The work highlighted the need to consider whether there is a role in flight inspection to assist with the qualification of a GBAS installation, providing objective results of both VDB and ILS/VOR signal levels that show that the requisite D/U ratios are respected throughout the coverage volume. The complicating factors in this respect are the different frequencies in use and the assumed line aircraft antenna gain and feeder frequency loss variation as discussed in paragraph 4.

Whilst GBAS is considered an Approach and Landing Aid, it provides this service essentially though the provision of Satellite Segment correction and integrity data, along with the approach path definition. All of this information can be corrupted in terms of 'continuity' however the transmission path cannot corrupt the accuracy or integrity of the data. In this respect, the VDB signal is more akin to a communication system in that it either works (meets the specifications) or it does not. Unlike ILS and VOR, the VDB signal is more tolerant to multipath scenarios in that 'beam bending' or 'scalloping' of the approach path cannot occur. In this respect, DOC 8071 [2] considers that periodic inspection of GBAS is not required and hence only commission and special inspections are referred to. This is unlikely to change with the introduction of FAST-D (or E/F).

The following paragraphs cover the flight inspection considerations for current FAST-C and future FAST-D Ground Sub Systems and also provide more detail of the more complex issues related to flight inspection considering D/U ratio checks, frame to frame variations and measurement uncertainty.

2. TRADITIONAL FAST-C INSPECTIONS

The commissioning of a GBAS is potentially the only time that traditional flight inspection will take place. To determine that the predicted coverage is adequate, manoeuvres are flown to assess the Approach Service Coverage Volume, which with today's standards is limited to 23 NM range and is similar in size and shape to an ILS coverage requirement as per Figure 5.

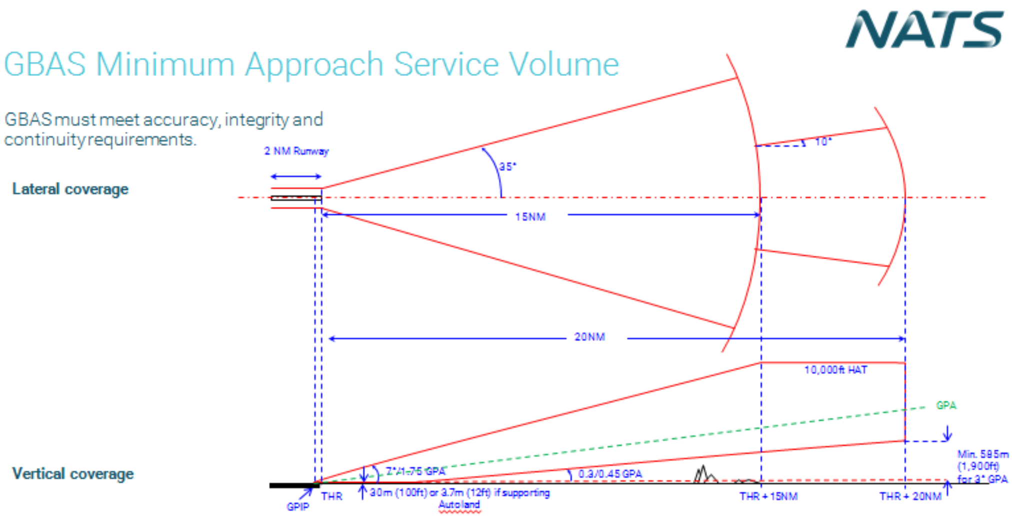


Figure 5: GBAS Minimum Approach Service Coverage Volume

Flight Manoeuvres can be designed to test this volume to ensure that at all places an aircraft may use the GBAS no drops in signal level below -99 dBW/m^2 are found, and that that levels remain below -35 dBW/m^2. The reason for both minimum and maximum limits being defined is to ensure that the line aircraft receiver designed to RTCA MOPS will not have more than 1 in 1000 missed messages. Note the maximum level will increase by 8dB in the next version of [1] as discussed in section 3. For FAST-C, the coverage volume would be expected to support operations to 200' decision height, therefore in keeping with ILS inspections, it is recommended to fly to a minimum of 100' (half the decision height) when near the threshold. There is no reason or requirement to check coverage along the runway or in the immediate vicinity of the threshold, or outside the range of Dmax.

In the inspection of FAST-C (and D, F,G etc) it is not necessary to check the accuracy of the correction signals provided by the GBAS Ground Sub System. The accuracy of the GBAS approach is determined by the ability of the ground station to measure the Space Segment element and associated multipath, along with the same for the aircraft receiver. This is tested and validated during ground commissioning of the GBAS and therefore flight inspection of the approach accuracy, whilst it may be of interest as a final assessment, is not required [2]. Procedure Validation of the approach is of course required and this would be carried out as part of the approval of the Instrument Approach Procedure validation process, either by simulator trials and/or practical flight validation activities depending on the requirements of the ANSP/regulator.

The interference environment for GPS L1 should also be assessed as part of the flight inspection. It has been shown in many studies that GPS receivers are more likely to lose lock on a satellite (or all satellites in view) when in the presence of interference. Unless deliberate spoofing is being carried out, the reduction in Signal to Noise ratio for satellites is a good indicator for the presence of interference. Due to the low noise thresholds required of spectrum analysers to measure down to the levels associated with the GPS interference masks in [1], it is not necessarily practical to run spectrum analysis during flight manoeuvres. However, this may provide some indication of the source of interference if the interfering signal is broadband and constant, covering a large enough area to be detected.

3. GAST-D SARPS DEVELOPMENT DERIVED ADDITIONAL REQUIREMENTS

During the work related to the introduction of GAST-D SARPS a number of issues were identified relating to the way in which it was possible to interpret the GAST-C SARPS. To ensure the SARPS were used as intended ICAO developed more detailed requirements that in turn should be taken into account when planning the flight inspection of VDB signals. Indeed whilst these were developed during the GAST-D standards development, some are equally applicable to FAST-C Ground Sub System inspections.

In particular, an increase in the allowed maximum received signal level will change from -35 dBW/m^2 to -28 dBW/m^2, which requires the measurement receiver/analyser to have an increased (linear) dynamic range. This increase will allow the GBAS to provide a greater 'desired' signal level at all points within the coverage volume served. The higher signal level has advantages for a proposed increase in the allowable Dmax to ranges greater than 23NM. The change to >23NM is still under discussion at ICAO and this will most probably only support Localiser only type guidance. It would be used operationally to allow Pilots to verify they are tuned to the correct GBAS, rather than being used for approach guidance at that point in space.

GAST-D allows full approach guidance to the equivalent of ILS Point 'E', thus inspection of the coverage from a decision height of 100' (as required for FAST-C stations) along the runway at 12' is required. In terms of GBAS installations, it is highly likely that more than one VDB ground station will be required to ensure full coverage of the landing runway. Since the advantage of GBAS is that one station can provide approaches to multiple runways, these additional runways may also need a VDB antenna to serve them, or filling for where poor VDB reception is found. One aspect of the VDB antenna not being aligned with the runway is the angle of reception of the signal cannot be assumed to be in front of the aircraft as per ILS. This is discussed further in section 5 as it relates directly to the flight inspection system measurement uncertainty. A further aspect of note for inspections is that there is a discontinuity in the SARPS at point of the Threshold Landing Point (LTP). Eurocae Working Group 28 have developed a 3D model of the approach service volume specifications, seen in Figure 6, which will be presented to ICAO [3] for inclusion within the SARPS. This shows that at 35° either side of centreline coverage is required before threshold, however at threshold the requirement immediately reduces to a linear specification relating to runway width. This discrepancy will be highlighted to ICAO for consideration at a later stage for resolution.

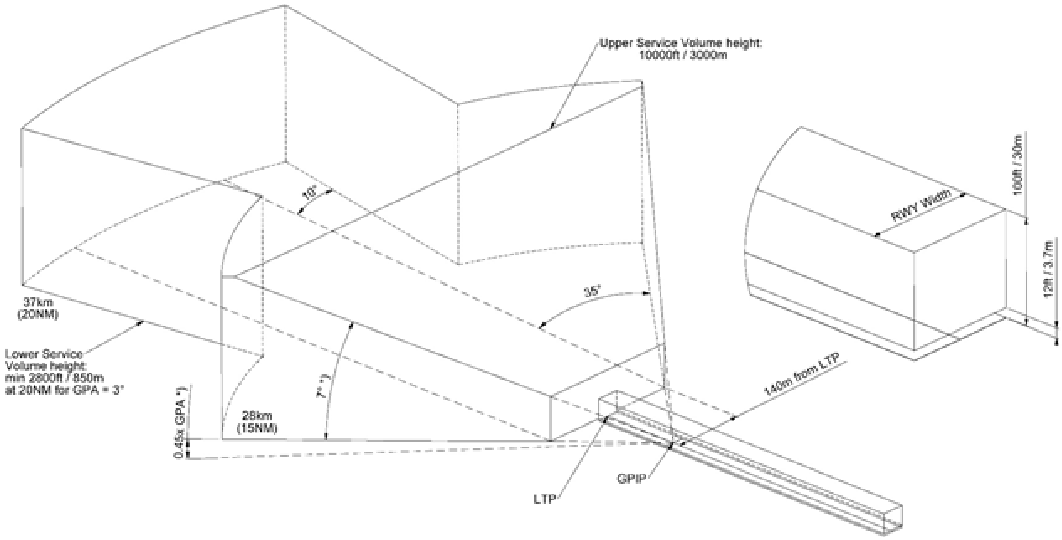


Figure 6: 3D Approach Service Volume

The main consideration for the use of more than one VDB transmitter is an issue with the current SARPS and in particular the current GAST-D requirement. Since a security measure named ‘Authentication’ must be used in GAST-D operation, certain message types must be transmitted in the first of any assigned slots within a frame for the ground station. To ensure this message type is received, it must be transmitted from all VDB stations in use within the coverage volume. This leads to the conclusion that the message must be ‘interleaved’ and time sequenced with each ground station. The practical result, as seen within research in SESAR 1 (Single European Sky ATM Research (European air traffic management system) phase 1) and presented at LATO [4] with a dual VDB antenna system implemented, showed variations in signal level in excess of 35dB at the same point in space for the same slot allocation but when looking from frame-to-frame as shown in Figure 7. This was due to normal VHF vertically polarised signal formation where nulls can be expected in the vertical plane. Since both antennas are not collocated, the nulls will be at different points in space, and are defined not only by antenna height but also by the terrain and buildings in the vicinity.

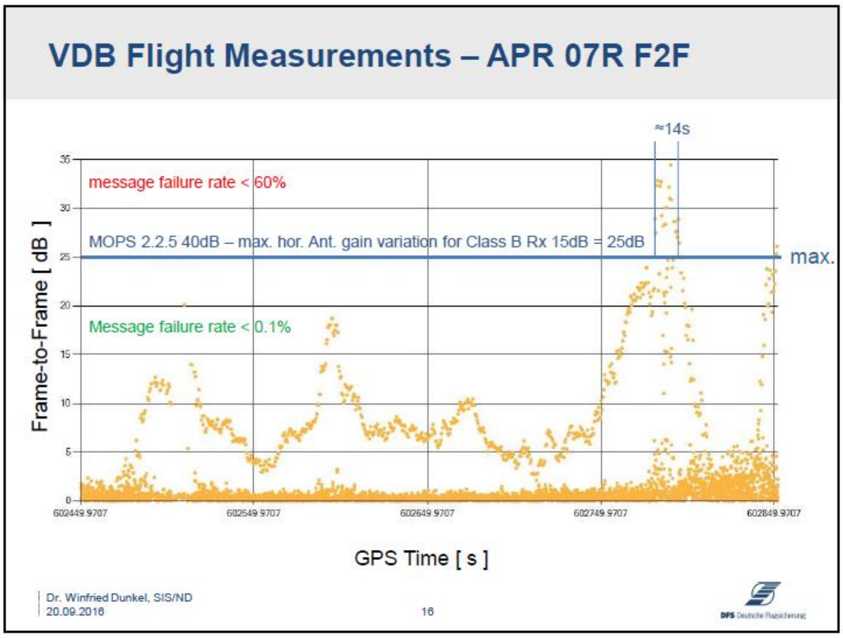


Figure 7: Slot to Slot variation measurements

Whilst an aircraft receiver is capable of coping with a frame-to-frame variation (same time slot) of 40dB, this in effect only allows 25 dB Signal in Space variation due to the assumption that must be made for line aircraft implementation losses. The 'fix' to this for the next version of the SARPS is to allow the specific message to be transmitted in any of the allowed slots assigned to the station. Whilst this works for most installations, there may be however systems set up to use interleaved messages and this will be the case if three or more VDB stations are used, or if frequency congestion restricts the number of slots assigned to a station. Therefore in planning inspections, as it is not readily possible to determine which VDB station is radiating in a particular sequence, it may be necessary to inspect one VDB at a time with the other VDB stations switched off.

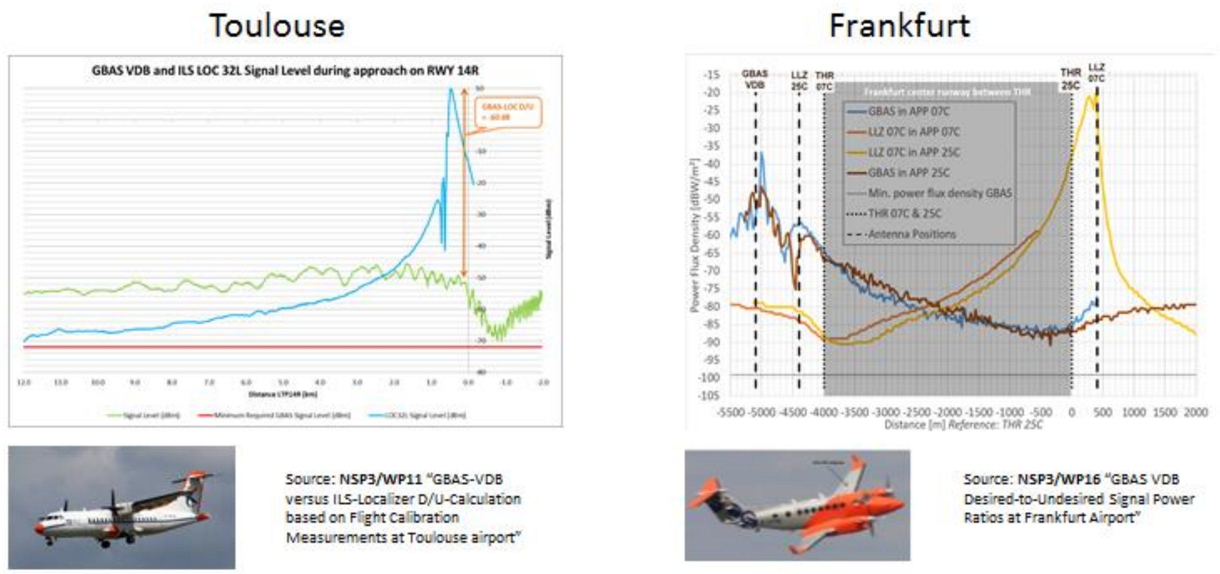
To complicate the measurement of the VDB signal further, the use of multiple VDB stations and the need to measure to threshold, there is the chance that the radiating signal will not come from in front of the aircraft (as would ILS normally), but rather than from the side or below. This will require calibration/characterisation of the VDB receiving antenna in both horizontal and vertical planes. The required resolution of the calibration is further discussed in section 5.

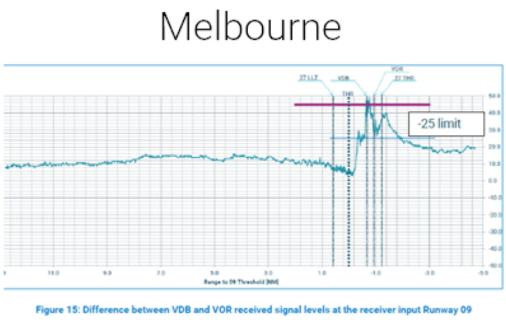
GPS interference measurements for FAST-D stations remains similar to FAST-C, although it may be necessary to ensure there are no interfering signals in the region 100' decision height to the equivalent of ILS Point E. This is most likely to be covered by ANSPs through the use of ground inspection techniques that are also able to locate the interfering source as they occur.

4. DESIRED TO UNDESIRED RATIOS

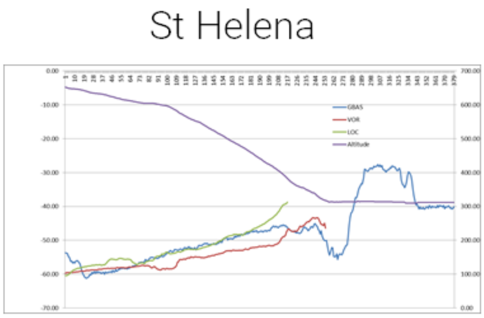
An area of study for ICAO over the last 2 years has been the development of adjacent channel interference requirements. Within RTCA and ICAO specifications, adjacent channel rejection is only specified up to the 3rd channel to be -46dB. However, with this figure in use (also for 3rd channel and beyond) SESAR studies showed that it would be virtually impossible to allocate GBAS frequencies for all sites within Europe. A body of work was undertaken to understand both the receiver's ability to reject levels greater than the -46 dB rejection ratio would suggest and also to define whether there was an issue with current navigational aids causing interference to GBAS signals (ILS or VOR as the Undesired).

Results of simulation work by Boeing along with RTCA, and also through practical flight inspection, revealed that there are potential instances where the Undesired signal level from an ILS or VOR may cause an effect on the reception of VDB messages. As mentioned previously, the effect is more likely to be either not seen by a line aircraft receiver, or result in missed messages; accuracy or integrity of the GBAS signal is unaffected by such interference unless it has the potential to affect the time-to-alarm requirements. The analysis of results from several organisations was undertaken, which highlighted several difficulties in determining the exact ratios between ILS, VOR and GBAS, shown in Figure 8.





Source: **NATS 2017:** VDB Vs. Loc Vs. VOR Adjacent Channel Study (Melbourne- Airservices Australia/Aeropearl)



Source: **NATS 2017:** Review of results in St Helena (FCSL Ltd)

Figure 8: Results derived four Flight Inspection companies

The results highlight the need to standardise on presentation to some extent and also to provide the ANSP with clear indications as to the units of measurement (SiS or input level to the receiver). To produce the results above in some cases required use of Microsoft Excel tools to combine data from different runs. This leads to the desire for future systems to collect data from a single run, given that it is also impossible to fly the same position in space to determine the exact of the D/U ratio from two separate transmitters at the same time otherwise. Ideally, VDB, VOR and ILS need to be recorded at the same time, preferably using the same antenna where possible to eliminate sources of measurement error. Another issue encountered was combing runs from different runway directions as seen on the Frankfurt results as this is not a normal process for standard flight inspection systems which generally show data set against time or distance to a navigation aid (or threshold), rather than allocate a result to position in space. Most systems however normally have the WGS 84 co-ordinates available for the point recorded, so this can be used with some manipulation to generate common axis distance based results. Interestingly, in this respect exporting the data to Google Earth was very useful to help understand the data and validate the positioning of results as per Figure 9.

Figure 9: Google Earth representation of data

The results were of use in determining where the worse-case D/U ratio could be found; however they could not readily be used to determine the absolute D/U ratios at each site, given that the graphs do not indicate whether antenna patterns, frequency related losses and cable loss are taken into account for the arrival direction. This could also be different for each of the Navigation Aids inspected depending on how the flight inspection system works. The DFS results have the highest level of integrity, given it is the only aircraft that employed the used of 3D antenna patterns. However, even these may be questioned since the patterns are modelled and may not represent the true pattern to an accuracy required to determine

D/U ratios to 1 or 2 dB resolution. Never-the-less the signals from Toulouse and Frankfurt were correlated with results from modelling to a certain degree during an exercise by RTCA. Confidence in the results has allowed RTCA to define new D/U ratio figures for the 3rd to 40th adjacent channel and this new figure is being consulted with industry and ICAO at this moment in time. Adoption of the relaxed D/U ratio will allow frequency planning tools to allocate GBAS frequencies more readily. For future inspections, flight Inspection companies should consider if systems can be designed to report on potential D/U ratio infringements during inspection of GBAS VDB signals (e.g via individual VOR or ILS receivers or by wideband signal analysis since demodulation of the signal is not required for this check).

The review of sites by the ICAO/RTCA team is still ongoing, with definition of the different scenarios that might result in D/U ratios being observed close to the maximum allowable. The most likely of these is the 'localiser overflight' where an approaching aircraft on say runway 07 using GBAS as the approach aid overflies runway 25 ILS that is radiating. There is a short period where excessive ILS signal may be observed that could affect the received message rate. RTCA have considered relaxing the D/U ratio requirement specifically in this case (coupled to a specific level of ILS signal being received) and allow a reduced message failure rate. This would allow certification of a GBAS approach in a similar way to ILS, in that provided no harmful interference is experienced the GBAS can provide GAST-C support. Note that this technique is only proposed for the localiser overflight case. ANSPs can take advantage of this to reduce the interlock requirement between ILS and GBAS for CAT I operations. For flight inspection tasks, it may be of interest to consider recording 'opposite-end' ILS information at the same time of completing GBAS approaches to cross check the actual D/U ratio seen in the vicinity of the ILS. Whilst GBAS is not yet used in the Guided Take-off mode, this is being studied and may result in the need to also ensure same-end ILS/GBAS operation is acceptable. Another potential case to be aware of is the 'Roll-out Guidance case', where the ILS serving the landing runway is close to the opposite-end threshold as in the vicinity of ILS Point E, it has been observed that ILS signals can breach the D/U requirement if the GBAS is located near the landing threshold.

5. MEASUREMENT UNCERTAINTY CONSIDERATIONS

Doc 8071 [2] covers the flight inspection of GBAS in a similar way to traditional navigational aids. Table II-4-4, presented at Figure 10, recommends that for VDB coverage measurement uncertainty a value of +/- 3dB is appropriate. This figure was derived during development of the GAST-C SARPS and should be achievable for modern flight inspection systems with accurate antenna calibration and mapping capabilities, coupled to attitude systems that can assist with the determination of the angle of arrival of the VDB signal. In the GAST-C case, it is only necessary to measure to 100' (half the decision height), which in general will put the aircraft 0.25 NM prior to threshold and at an altitude where the vertical angle of arrival from a VDB antenna (nominally 10-5m high) is close to 0 degrees or no more than a few more. Provided the GBAS is in front of the aircraft, typical ILS-type antenna corrections will suffice and potentially meet the measurement uncertainty recommendation.

Table II-4-4. Summary of minimum flight test requirements — GBAS

Parameter	*Annex 10 Volume I reference*	*Doc 8071 Volume II reference*	*Measurand*	*Tolerance/ Limit*	*Uncertainty*	*Periodicity*
FAS data	App.B 3.6.4.5	4.3.4	FAS path	Consistent with FAS design	N/A	C, Sp
Procedure Validation	(none)	5.3	N/A	N/A	Subjective	C, Sp
Resistance to Interference (Ranging Signal)	App. B 3.7	4.3.6	Interference signal level	< interference mask definitions	±3 dB	C, Sp
VDB Coverage GBAS/H field strength GBAS/E field strength Horizontal Vertical	3.7.3.5.4.4	4.3.7 to 4.3.10	Field strength	 >-99 dBW/m^2 to –35 dBW/m^2 >-99 dBW/m^2 to –35 dBW/m^2 –103 dBW/m^2 to –39 dBw/m^2	±3 dB	C, Sp
Message block header (GBAS identification only)	App. B 3.6.3.4.1	4.3.14	Facility Identification	Exact Match	N/A	C, Sp
Data content (operational)	App. B 3.6.4	4.3.15 to 4.3.16	Message Data Content	Exact Match	N/A	C, Sp
Position Domain Accuracy (optional)	(none)	4.3.17 to 4.3.18	Position	4 m vertical / 16m lateral	1m	C, Sp

Figure 10: Extract from DOC 8071 Volume II

The issue becomes relevant for both FAST-C and also for FAST-D stations when the VDB signal comes from an antenna towards the side of the runway. GBAS has the technical advantage over ILS in that the elements that constitute the ground sub-system can be installed virtually anywhere in the vicinity of the airfield and not necessarily in line with the runway as per ILS. Constraints do exist for the location of the VDB antenna due to the maximum allowable field strength at the aircraft receiver. Assuming nominal VDB power being transmitted (in order to ensure 23NM coverage and minimum field strength requirements are met), the VDB antenna must be at least 80m from the aircraft. Derivation of the resulting 100m minimum recommendation is subject of an ICAO paper that has been used to derive new SARPS guidance material to be published in the next version of Annex 10 therefore is not covered here. However, the result is as per the simplified Figure 11, where VDB antenna cannot be installed within the blue area. Conversely this means the antenna can be placed anywhere else.

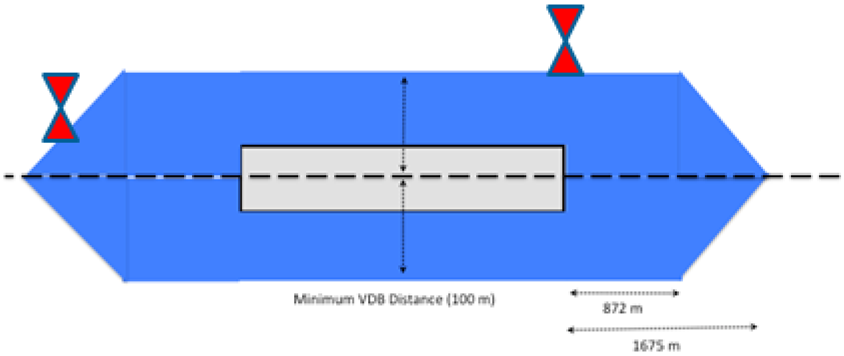


Figure 11: VDB location (new SARPS guidance)

This will result in the need to consider the angle of reception from each antenna independently. The main issue would be when evaluating the frame-to-frame variation when the aircraft (or vehicle) is between the antennae, or alongside. Typically aircraft travel at 140-180 knots on approach (if not landing) which equates to around 70-90 metres per second. Whilst abeam an antenna that is located 80m away, this will result in an effective angular change of 45 degrees per second. The measurement of the VDB signal must be taken over the average over the 42bits of the period of the synchronization and ambiguity resolution field slot in use ([1] 3.7.3.5.4.4.1.2), which equates to a figure of less than 20 mS. During this period, the angle to the VDB will change by 1 degree or more. Various examples of VHF antenna patterns available on the internet show that abeam, or especially behind the aircraft vary considerably, thus making the application of antenna pattern correction extremely complex and non-trivial. Whilst it is acceptable for ILS, VOR and other conventional navigation aids to use simple antenna pattern corrections, it is clear measurement of VDB signals requires a more complex approach, such as determining the change in correction to be applied throughout the average measurement period. It is perhaps also possible that the application of pattern correction must be applied as part of the measurement process (i.e. during calculation of the average signal) rather than a correction factor applied afterwards. Even a small change in antenna pattern during the measurement can result in errors in excess of the required measurement uncertainty. Consider a simple measurement uncertainty analysis as per Table 1:

Table 1: Typical Measurement Uncertainties

Source of Uncertainty	Uncertainty (dB)
Signal Measurement system	1
Antenna/feeder variation (non-pattern related)	1
Antenna characterisation	1.5
Pattern change during measurement	2
Root Sum Square	2.9

A paper covering the measurement of VDB along the runway is being presented at ICAO in April 2018 [5]. This paper highlights the difficulty in measuring the VDB signal accurately, since variations along the runway due to multipath constructive and destructive interference can cause variations of ± 6dB when driving along at 50 km/h; and up to ±12 dB when driving more slowly at 30 km/h. This could lead to the conclusion that traveling at speed (in a fixed wing aircraft) may not result in an accurate picture of the VDB Signal in Space when in a multipath environment. It is perhaps more likely that measurements in the vicinity of the runway will be performed using ground vehicles or UAVs in the future, where the characterisation of the antenna is less complex and speeds can be slower, thus providing more consistent results than using an aircraft.

6. CONCLUSION

Whilst GBAS provides an approach aid, in terms of flight inspection it can be considered more in terms of a communication/transport medium for the data which allows an aircraft receiver and FMS system to calculate and execute approaches. Since the signal in space is in the VHF band, the signal can be influenced by multipath (destructive and constructive) and line of sight issues; however these will affect the availability of the GBAS messages rather than the integrity or accuracy. Measurement of the Signal in Space needs to consider how the GBAS sub system is set up and consider:

- Multiple VDB sites
- Potential frame-to-frame variations
- VDB antenna layout with respect to the measurement system
- Potential for ILS or VOR influence on VDB (D/U ratios)
- Both minimum and maximum signal levels
- Aircraft pattern correction data
- Use of the system (e.g. GAST-C supporting decision heights as low as 100', roll out and departure guidance)

When presenting data to ANSPs and other 3rd parties, it should be clear from the results whether the Signal in Space measurement is the result of appropriate antenna calibration/characterisation and the measurement uncertainty associated with the data. The measurement uncertainty may well be a different value for each angle of arrival of the signal, and be linked to measurement system speed (over ground). Since GBAS VDB signals are sent at 0.5 Hz, but may contain 1-3 messages from the same VDB transmitter, the data capture system can run at a speed as low as 6 Hz (potentially 8), however the actual measurement of the signal level has to be performed at a high rate on the specific message being received to gain the average level as required. This may drive measurement requirements towards an external dedicated measuring system, coupled to a standard flight inspection system. Signal level measurement along the runway (within threshold regions) for FAST-D stations may well be better performed using vehicle or UAV mounted systems once ground measurement requirements are fully developed.

Since GBAS must ensure that no more than 1 in 1000 missed messages are encountered by the receiver (1 in 10 being discussed at ICAO for specific instances), this is perhaps a critical measurement parameter. Each message contains CRC (Cyclic Redundancy Checking) and one could consider that counting successful CRC checks vs. received messages would give an indication that there were no lost messages. As such, measurement system designers are encouraged to provide a means of counting and monitoring missed messages. Coupled to this, a system design that not only recognises a missed message, but also characterises why would be ideal, with the system being able to determine when a missed message could be expected through signal levels being outside specification (high or low), D/U ratios being exceeded for ILS or VOR at the same site or frame-to-frame changes are excess.

Noting that both excessive Frame-to-frame variations and D/U ratios may cause an aircraft receiver to miss messages, it would seem prudent on commissioning inspections to ensure either scenario does not exist at the site. This in turn requires flight inspection systems and aircraft to have accurately calibrated antennas covering the expected direction of arrival of signals. DOC 8071 [2] is being considered for update at this moment in time by ICAO, with papers being presented in April and again in October/November 2017. Any proposals to improve on the current recommendations in [2] should be forwarded to ICASC or to your national ICAO NSP (Navigation System Panel) representative during 2018.

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REFERENCES

[1] Annex 10: SARPS
[2] Doc 8071 Volume 2 5th Edition
[3] ICAO JWGs3_wp7_GBAS_approach_service_volume_3DRepresentation
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[5] ICAO NSP4_wp6_VDB Measurement Criteria_2017-10-06