International Civil Aviation Organization

FIFTEENH MEETING OF THE ADS-B STUDY AND IMPLEMENTATION TASK FORCE (ADS-B SITF/15)

Bangkok, Thailand, 18 - 20 April 2016

Agenda Item 4: Review States' activities and interregional issues on implementation of ADS-B and multilateration

ADS-B FAILURES IN CERTAIN A330 AIRCRAFT

(Presented by Australia)

SUMMARY

This paper reports on instances of ADS-B service failures that have been reported on certain configurations of A330 aircraft (in particular). Technical detail within this report, specific to Qantas aircraft, has been supplied (with thanks) by Lewis Benham, Chief Avionics Engineer - QANTAS.

1. INTRODUCTION

1.1 Since the introduction of the mandate for ADS-B carriage at and above FL290, numerous reports of ADS-B failure in A330 aircraft have been reported by ATC in Australia.

1.2 While ADS-B failures have been observed in a range of aircraft, and typically at a higher rate than for an SSR transponder failure, the A330s appear to be over-represented in failure reports.

2. BACKGROUND

2.1 Air Traffic Control in Australia will typically report an aircraft ADS-B system failure when the following occurs:

- the aircraft does not display as an ADS-B track when expected, and
- after instructing the pilot to changeover transponders, the ADS-B data is still not available at the ATC position.

2.2 At the time of the reporting, the cause of the failure is typically unknown and requires further investigation. The "high level" causes of ADS-B failure, as seen by ATC, will be due to either:

- no ADS-B data is output from the aircraft, or
- ADS-B data is reporting the accuracy or integrity below prescribed thresholds – so the ADS-B track data is suppressed from the ATC display.

In the case of A330 aircraft, both scenarios have been observed.

3. FAILURE MODES AND INVESTIGATIONS

3.1 The absence of any ADS-B data has been observed on A330-200 series aircraft operated by China Southern Airlines. In cases where Airservices has been able to follow up with the airline, they have indicated, replacement of either the ATC transponder or the Multi-Mode Receiver. In one case of missing ADS-B data, the aircraft had departed with one transponder inoperative (as a permissible defect).

3.2 For these aircraft, there appears to be a link between a single transponder failure and no ADS-B out from the other transponder, but this is inconclusive. Limited additional information has been obtained from the aircraft operator, so detailed investigation of root cause is problematic.

3.3 In the case of the Qantas A330 ADS-B failures, these are associated with a reduction to zero '0' of the Navigational Integrity Category (NIC) in the DO-260A DF17 messages.

Appendix 1 provides a technical report prepared by Mr Lewis Benham – Chief Avionics Engineer at Qantas.

3.4 The report is in 2 parts – the first section prepared in May 2015, with the second section prepared in September 2015 following further investigations and increased understanding of the fault condition observed.

3.5 The report discusses the methods used to gather data to aid investigations, and serves to demonstrate the capabilities of modern aircraft to support data gathering, and the commitment of Qantas, Airbus and the avionics manufacturers to understanding the root causes, with a view to correction.

Appendix 2 provides a summary of these ADS-B events detected by Qantas, also prepared by Mr Lewis Benham.

3.6 The technical report draws a number of conclusions associated with the incorrect determination of NIC (via the use of the Horizontal Integrity Limit – HIL). Below is an edited summary of conclusions extracted from the report at Appendix 1.

1) Label 130 Horizontal Integrity limit (HIL) on the Multi-Mode Receiver (MMR) GPS ARINC 429 output bus to the ATC transponders is periodically unable to be used by the end user (receiver) systems connected to the bus (at least the transponder and the FDIMU/ACMS);

2) It would appear to only affect aircraft with Rockwell MMRs and ACSS ATC Transponders (at least within the Qantas fleet);

3) This is being seen on both GLU-925 and GLU-920 equipped Airbus A330 aircraft, but appears to be more prevalent with the GLU-925;

4) The condition affects Qantas B747-400 fleet (Rockwell GLU-920 MMR, ACSS XS-950 ATC transponder) as well although to a lesser extent;

5) In all but one case so far in 2015, the aircraft exhibiting NIC=0 in ADS-B transmission has overnighted in Sydney (YSSY);

6) Cycling the circuit breaker for the MMR (removing electrical power) does clear the condition. On occasion the condition will resolve itself in flight;

7) According to Honeywell, the A330 Flight Management function and Enhanced Ground Proximity Warning System (EGPWS) will not exhibit observable loss of function with the loss of HIL from all sources (both MMRs), as these functions predominantly rely on HFOM; and

8) A330 GPS Monitor screen does not show any observable degradation in the performance of the navigation computation in the GPS function. There are no other fault indications or annunciations, either for invalid HIL or inoperative ADS-B, or any other aircraft avionics which use GPS data (but may or may not use HIL).

3.7 The fault condition associated with the reduction of NIC to zero remains unresolved, however with increased understanding of the underlying system architecture and behavior, a solution may be forthcoming.

4. ACTION BY THE MEETING

The meeting is invited to :

a) note the information contained in this paper; and

b) discuss any relevant matters as appropriate

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Appendix 1

Qantas A330 ADS-B Failures

Author: Lewis Benham
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Qantas Airways

Version: 2.0
Date: 5th September 2015

Note: Refer to "Update on Investigation, September 2015 (v2.0 of this paper)" section for updated information. All of the text that follows is unchanged from v1.0 of this paper.

Introduction:

Qantas was one of the first airlines in the world to have and aircraft equipped with operational ADS-B, when we took delivery of VH-QPC in 2003, with Rockwell Collins GLU920 MMRs.

Australia was one of the first countries in the world to offer ATC separation services based upon ADS-B surveillance.

To be able to use ADS-B information for surveillance, and to be able to provide ATC separation services based upon that information, the integrity is required to be as good as or better than primary and secondary.

The GPS output parameter Autonomous Horizontal Integrity Limit (HIL), Label 130 on the ARINC 429 output buses, provides the required integrity, with the actual aircraft position having a 99.999% (or better) probability of being less that the HIL distance from the position reported in the ADS-B message (within latency limits as well).

Qantas Fleet Configuration:

A330 aircraft are equipped with a dual transponder and dual MMR configuration, however each transponder only receives GPS data from its onside MMR, thus if the GPS function in MMR #1 is unserviceable, then the #2 transponder must be used in Australian airspace.

Qantas A330 aircraft delivered from Airbus after October 2010, were equipped with ACSS XS-950 DO-260A transponders, RC GLU-925 MMRs and direct connection of the GPS output ARINC 429 bus from the MMR to the transponder (total 6 aircraft).

Qantas retrofitted the DO260A transponders and direct GPS bus to the first 24 A330 aircraft in our fleet (equipped with GLU920 MMRs) and this program was completed in May 2014.

Australian ADS-B Mandate:

On 12th December 2013, carriage of serviceable ADS-B equipment became mandatory for all flights at or above Flight Level 290 (29,000ft) in Australian territory.

Prior to that date procedural separation rules required 50nm separation between aircraft if either did not carry serviceable ADS-B. Separation between aircraft both carrying ADS-B is the same as for radar, 5nm.

Since that date, necessarily given that all aircraft flying at or above FL290 should have ADS-B and so all were expected to be able to continue with 5nm separation once leaving radar surveillance, the Australian ANSP, Airservices Australia (AsA), placed a very high importance on detecting and reporting any issues with ADS-B based surveillance, especially a complete loss of ADS-B capability for an aircraft which required reversion to procedural separation (50nm) between that aircraft and any surrounding aircraft.

Reports of Dual ADS-B Failures:

For some period of time in early 2014, Qantas was not aware of any issues either with ADS-B in general, nor with the Rockwell Collins MMRs as the GPS source nor the ACSS Mode S transponders and the ADS-B transmitting equipment.

Qantas was notified by AsA of an occurrence in February 2014 where a later model A330 aircraft (GLU925) had a failure of the ADS-B function on both transponders. Both ATC systems tested serviceable at the end of the flight, with no further reports of any problems.

Qantas was then notified by AsA of another occurrence in August 2014 where another later model A330 aircraft (GLU925) had a failure of the ADS-B function on both transponders. Again, both ATC systems tested serviceable at the end of the flight, with no further reports of any problems.

“Failure” of the ADS-B function for the purposes of ATC in Australia simply means that once the aircraft leaves radar coverage, there is no ADS-B data available to the ATC system for it to be able to continue surveillance of the aircraft. By examination of its raw ADS-B data records, AsA was able to determine that in fact their ADS-B ground receivers were receiving data from these aircraft at the time of these events. All ADS-B parameters were good, however the encoded Navigation Integrity Category (NIC) parameter (DO260A) was 0 (zero). ADS-B data with a NIC below about 4 is automatically discarded by the Australian ATC system as unusable for ATC surveillance, hence the observed ADS-B failure.

Data Monitoring:

Most modern transport category aircraft have a data acquisition and recording system to support both mandatory recording (flight data recorder) and non-mandatory recording (Quick Access Recorder, QAR) and condition monitoring. The Teledyne version is called the Aircraft Condition Monitoring System (ACMS) and we have the capability to modify this software to suit our needs.

This software is hosted on the Flight Data Acquisition and Monitoring Unit (FDIMU) on all but the first 7 Qantas A330s. Fortunately, the MMR GPS output ARINC 429 bus architecture is such that the same bus which supplies GPS data direct from each MMR to each transponder is also connected to the FDIMU (both MMRs).

After the seconds dual ADS-B failure, we modified out ACMS software to acquire the Autonomous Horizontal Integrity Limit (HIL) parameter (Label 130) separately from each MMR and record it continuously on the QAR. The FDIMU also supports downlinking of snapshots of realtime via ACARS in response to an uplink request for the data.

At this stage it looked like more of a problem for GLU925 equipped aircraft, so we installed the modified ACMS software on all 6 of these aircraft in our fleet plus one trial GLU920 equipped aircraft.

Qantas was then notified by AsA of another occurrence in November 2014 where another later model A330 aircraft (GLU925) had a failure of the ADS-B function on both transponders. Again, both ATC systems tested serviceable at the end of the flight, with no further reports of any problems.

For this occurrence however we had been recording HIL continuously and it showed in the QAR data as continuously full scale (16nm) for both MMRs. To save recording space, data recorded on the QAR is recorded without any direct indication as to whether the data is valid or not, but if the source data is invalid for any reason in the ACMS then it is recorded as all 1's in the QAR data. Because HIL is always positive, then an all 1's equates to full scale of 16nm. Thus we inferred that the HIL label 130 on the GPS input bus from both MMRs was invalid.

Qantas was then notified by AsA of another dual ADS-B failure occurrence in December 2014 however this time it was on a GLU920 equipped aircraft. Again, both ATC systems tested serviceable at the end of the flight, with no further reports of any problems. This aircraft however was not equipped with the modified ACMS software.

Initial Analysis:

At this stage it was apparent that there was a systemic issue, however Qantas was only aware of the dual failure events. We then conducted a review of maintenance records between 1st January 2013 and 31st December 2014 (2 full years) and found 19 occurrences of ADS-B failures:

6 dual failure events	ADS-B reported inoperative by ATC on systems 1 and 2
12 single failure events	ADS-B reported inoperative on one system but operation was restored when the other transponder was selected
1 other event	intermittent operation

Normal procedures dictate that if the Captain is the "Pilot Flying" (PF) then autopilot 1 (A/P) will be used and transponder 1 (and thus MMR 1) will be used for ADS-B. If the First Officer is the PF then autopilot 2 will be used and transponder 2 (and thus MMR 2) will be used for ADS-B. So if there is a problem with HIL on MMR 2 but A/P 1 (and thus transponder 1 and MMR 1) is being used then as far as ADS-B is concerned that issue will be completely invisible.

Assuming that HIL failure on MMR 1 or MMR 2 is random and distributed equally and that use of A/P 1 or 2 is also random and distributed equally, we can infer that during the same period there have been an additional 12 single HIL failures but that these were invisible as described above.
Thus we have 24 single failures plus the 6 dual failures ie 12 individual failures, making a total of 36 individual HIL failure events during the two year period. During this period the Qantas A330 fleet conducted nearly 34,000 flights which equates to an average of one HIL failure event approximately every 950 flights.

For none of these events have there been any onboard failure annunciation either of failed systems or equipment, of any of the surveillance or navigation functions, eg ADS-B, transponder, flight management system (FMS) etc.

Realtime Monitoring:

Around the end of January 2015, we modified one of ground system which processes the ACARS message received from our aircraft (SITA Aircomserver) to automatically request a snapshot of the following data from the 7 aircraft equipped with the modified ACMS software twice per flight: just after takeoff and during descent prior to landing. The data requested initially was

- HIL from GPS (MMR) 1
- HIL from GPS (MMR) 2
- HFOM from MMR 1 if valid otherwise from MMR 2
- VFOM from MMR 1 if valid otherwise from MMR 2
- Altitude from MMR 1 if valid otherwise from MMR 2

Then at the end of February 2015, one of the aircraft with the modified ACMS software that was being interrogated twice every flight by the ground system exhibited an invalid HIL from the #2 MMR. Shown here is a copy of the raw ACARS data. A semicolon indicates invalid data on that acquired label (130 in this case):

```
QU SYDAXQF
.QXSXMXS 281911
_DFD
FI QF0401/AN VH-EBO
DT QXS SYD1 281911 D24A
-  R76/A33076,1,1
.VH-EBOYSSYYMML28021910 30 24  29150.313146691QFA401     418CL00

       GPS1HIL   GPS2HIL   GPSHFOM   GPSVFOM    GPSALT

1717   229.000;;;;;;.;;;     4.000    22.000  2851.000
1718   229.000;;;;;;.;;;     4.000    22.000  2914.000
1719   229.000;;;;;;.;;;     4.000    22.000  2975.000
1720   229.000;;;;;;.;;;     4.000    22.000  3037.000
1721   229.000;;;;;;.;;;     4.000    22.000  3097.000
1722   229.000;;;;;;.;;;     4.000    22.000  3157.000
1723   229.000;;;;;;.;;;     4.000    22.000  3217.000
1724   229.000;;;;;;.;;;     4.000    22.000  3276.000
1725   229.000;;;;;;.;;;     4.000    22.000  3334.000
1726   229.000;;;;;;.;;;     4.000    22.000  3392.000
```

Each line is one second of data and the first column is simply a counter that corresponds to seconds.

The aircraft flew the following sectors in this condition and the invalid HIL for MMR #2 was also confirmed in the QAR data:

QFA0401/28Feb YSSY YMML
GPS1HIL: OK
GPS2HIL: {value = 16.xxxx} complete flight

QFA0485/28Feb YMML YPPH
GPS1HIL: OK
GPS2HIL: {value = 16.xxxx} complete flight

QFA0802/01Mar YPPH YMML
GPS1HIL: OK
GPS2HIL: {value = 16.xxxx} complete flight

QFA0769/02Mar YMML YPPH
GPS1HIL: OK
GPS2HIL: OK, only at the end of flight.

GPS1HIL " OK " means its value varies between 0.0280 NM and 0.0635 NM.

There was no report in the aircraft records of any fault with ADS-B, however note that for flights like SYD-MEL the entire flight is in radar coverage and so all ADS-B data from the aircraft is discarded by ATC. For flights like MEL-PER the first part of the flight is within radar coverage (until West of Adelaide), then across the Great Australian Bight where there is neither radar nor ADS-B ground station coverage, and only the very last part of the flight is within range of an ADS-B ground station, however the aircraft quickly enters range of the Perth airport radar and so again ADS-B data is discarded. Also if the Captain was the PF then A/P 1, this transponder 1, thus MMR 1 was being used so no fault would be observed.

After this event, the uplink request for data was change to the following parameters so that the A/P is used could be determined:

- HIL from GPS (MMR) 1
- HIL from GPS (MMR) 2
- Altitude from MMR 1 if valid otherwise from MMR 2
- A/P 1 engaged
- A/P 2 engaged

Recent Occurrences on VH-EBV:

Then in April 2015, our newest A330 VH-EBV exhibited failure of HIL from GPS #2 for 12 consecutive flights over 4 days.

In fact on the first of these flights, QF401 SYD-MEL, HIL was invalid from MMR #1 and from #2 bus as this flight is completely with radar coverage, again, all of the ADS-B data from the aircraft is discarded by ATC and so no failure of the ADS-B was reported to the pilots.

The raw ADS-B data is however stored by AsA and this was supplied to Qantas. This confirmed that NIC was zero for the first 2/3 of the flight. The ACARS report for that flight showed that A/P 1 was being used, so this indicated that HIL from MMR 1 rectified itself during the flight:

```
QU SYDAXQF
.QXSXMXS 112023
_DFD
FI QF0401/AN VH-EBV
DT QXS SYD2 112023 D52A
-  R76/A33076,1,1
.VH-EBVYSSYYMML11042022 22 16  29180.323156543QFA401     565CL00

       GPS1HIL   GPS2HIL    GPSALT    M10A03    M10A04
 557;;;;;;.;;;;;;;;;;.;;;  3083.000     1.000     0.000
 558;;;;;;.;;;;;;;;;;.;;;  3140.000     1.000     0.000
 559;;;;;;.;;;;;;;;;;.;;;  3197.000     1.000     0.000
 560;;;;;;.;;;;;;;;;;.;;;  3255.000     1.000     0.000
 561;;;;;;.;;;;;;;;;;.;;;  3314.000     1.000     0.000
 562;;;;;;.;;;;;;;;;;.;;;  3373.000     1.000     0.000
 563;;;;;;.;;;;;;;;;;.;;;  3432.000     1.000     0.000
 564;;;;;;.;;;;;;;;;;.;;;  3490.000     1.000     0.000
 565;;;;;;.;;;;;;;;;;.;;;  3546.000     1.000     0.000
 566;;;;;;.;;;;;;;;;;.;;;  3601.000     1.000     0.000
```

Now also a key point to observe in this report is that even though HIL is invalid from both MMRs, the GPS Altitude (whether from MMR 1 or MMR 2) is valid and reasonable to the navigation function within the GPS engine is still working normally.

The subsequent Sector was MEL-PER and ATC reported ADS-B inoperative on system No. 2 but operations were normal on system No. 1 . The No. 2 transponder was tested and considered serviceable.

The aircraft then operated two more sectors PER-MEL and MEL-PER, both using A/P 2 but presumably almost always out of ADS-B ground station ranger or within ATC radar coverage.

The next sector was again MEL-PER and again A/P 2 and again ATC reported ADS-B inoperative on the No. 2 system. This time due to time constraints the aircraft was dispatched under the Minimum Equipment List (MEL) entry for ADS-B. This allows dispatch of the aircraft with ADS-B inoperative on

one transponder for 10 days, provided the other transponder is selected and used. This means then that until the MEL is cleared the No. 1 Transponder (and thus No. 1 MMR for GPS HIL) is selected and used regardless of which pilot and which A/P is being used, so the invalid HI from MMR No. 2 was them masked for the subsequent 7 flight, after which time it self-cleared.

The transponder was replaced and the MEL cleared on the 18th April.

VH-EBQ also suffered an event for 3 flights on 17th and 18th April, where HIL was invalid from both MMR No. 1 and No. 2, however the first two flights were between SYD and MEL and so completely in radar coverage. On the 3rd flight SYD-PER both HIL were again invalid at the start of the flight however HIL from the No. 1 MMR cleared itself during flight. The No. 2 A/P was being used and sure enough ATC reported to the pilots that ADS-B was inoperative on transponder No. 1 but was normal on transponder No. 1.

On 26th April 2015, again VH-EBV exhibited invalid HIL but this time from MMR No. 1. The first sector was MEL-PER but A/P was being used and so there was no report of any problem with ADS-B. On the return sector PER-SYD, A/P 1 was used and sure enough ATC reported to the pilots that ADS-B was inoperative on system No. 1 and but operations were normal when transponder 2 was selected.

Again the MEL was applied for the transponder system however there are significant implications of applying the MEL for the No. 1 transponder system on Airbus aircraft. Due to the electrical power configuration and the requirements of the Airbus Master MEL, the No. 1 Transponder is required to be operative for extended range operations (ETOPS), thus the aircraft became non-ETOPS. Significant portions of the MEL-PER flights are over water, so with this MEL applied, VH-EBV was non-ETOPS and so had to be flight planned over land which required and additional 4 tonnes of fuel per flight.

The aircraft operated 4 flights in this configuration and then the transponder was replaced on the evening of the 28th April and the MEL cleared.

On the morning of the 29th April on departure from SYD, HIL was invalid from both MMRs. The flight was SYD-PER which again is in radar coverage until West of ADL and then over the Great Australian Bight which is out of ADS-B ground station coverage and then transits ADS-B coverage but quickly enters PER radar coverage. There was no report written in the aircraft Technical log of any problems with ADS-B for this sector.

The return PER-SYD sector was a much more Northerly, mostly over the Nullarbor Plain, and as soon as the aircraft exited radar coverage on departure from PER, ATC reported to the pilots that ADS-B was inoperative on both systems 1 and 2.

Knowing the recent history of problems with the ADS-B function on this aircraft, the subsequent sectors for this flight were allocated to another aircraft and the two flights for the replacement aircraft were cancelled so that overnight troubleshooting could be accomplished. The ATC system was fully tested and due to unrelated intermittent issues the ATC control panel was replaced. As a precaution the No. 1 MMR was replaced. Thus HIL from the No. 1 MMR was then valid.

For an unknown reason the HIL from the No. 2 MMR (still the same unit) rectified itself during the course of the night's troubleshooting activities, possibly as a result of extended power off time but there is no proof that this is the case.

What is interesting to note is that whilst this is certainly a highly unusual and not very frequent situation, Horizontal Integrity Limit is the cornerstone of ADS-B operations. There is no annunciation however when HIL from either MMR is unable to support ADS-B operations, and also the ATC (transponder) system test on the Airbus A330 Aircraft Maintenance Manual (AMM) does not check that the value of HIL is either valid or reasonable.

As previously noted throughout all of this so far, there have been no fault annunciation on the aircraft and no reports of any issue with navigation of flight management.

Conclusions (V1.0 of this paper):

1. Label 130 Horizontal Integrity limit (HIL) on the MMR GPS ARINC 429 output bus to the ATC transponders is periodically unable to be used by the end user (receiver) systems connected to the bus (at least the transponder and the FDIMU/ACMS).

2. The Semi-colon in the ACMS ACARS reports indicates that the label is present on the bus (it is being transmitted), without parity errors, but cannot be decoded or used by the ACMS. It is unable to be determined at this stage whether the HIL word actually contains real data or not.

3. It would appear due to the lack of navigation problems in the FMS (which presumably uses HFOM instead of HIL) and that GPS altitude parameter was valid when both HIL parameters were valid in the ACMS reports, that all other parameters on the GS bus are OK,

4. At this stage there is no observable pattern as to when the invalid HIL starts, other than it has not yet been observed to start in flight however it has been observed to self-rectify in flight.

5. No procedure has yet been determined to be able to reliably clear the condition.

6. There are no other fault indications or annunciations, either for invalid HIL or inoperative ADS-B, or any other aircraft avionics which use GPS data (but may or may not use HIL).

7. The Airbus A330 AMM ATC System test does not test the value of HIL.

8. This is being seen on both GLU-925 and GLU-920 equipped Airbus A330 aircraft, but appears to be more prevalent with the GLU-925.

9. This is not being on other GLU-925 (B737-800, A380) or GLU-920 (B747-400) equipped aircraft in the Qantas mainline fleet.

Update on Investigation, September 2015 (V2.0 of this paper)

Progress with this investigation has been slow, however a number of significant findings have been made in the 4 months since this paper was first issued on 1st May 2015.

Since 1st May 2015, Qantas has been able to detect an additional 19 events, for a total of 24 events logged so far in 2015, including a number of dual failures.

Events have also been observed on Qantas B747-400 aircraft, which are also equipped with Rockwell Collins MMRs and ACSS XS-950 ATC transponders. At this point Qantas has not yet raised a Service Request to ask for Boeing assistance on the B747-400 fleets for a few reasons: we are seeing the issue much less frequently on the B747-400 fleet; we have not yet seen a dual ADS-B "failure"; the B747-400 fleet rarely operates in a region where the Australian ADS-B surveillance is used for ATC separation services (principally either in radar coverage or in an oceanic region outside both radar and ADS-B surveillance).

In the early stages of the investigation we believed that the presence of an active GLS function on Qantas B737-800 and A380 fleets may have been a factor in these fleets not experiencing the same issue, however it would seem that that is purely circumstantial and not related. (See below for an explanation)

Qantas has established formal communications with Airbus, Rockwell and ACSS, and also the ACMS manufacturer Teledyne to assist with interpretation of the ACMS data.

Honeywell was asked about the response of the A330 Flight Management function in the Flight Management Guidance and Envelope Computer (FMGEC) and also the Enhanced Ground Proximity Warning System (EGPWS) to complete loss of Horizontal Integrity limit (HIL) from both MMRs. Honeywell Responded as follows:

> "Basically, if only HIL goes away (lack of update), there is little to no effect on EGPWS as long as, Non-Isolatable Satellite Failure (NISF, bit 11 of the HIL Label 130) is not set.
>
> The EGPWS normally uses GPS HFOM as the measure of GPS accuracy. The use of HIL as a measure of GPS accuracy was not deemed desirable since the conservative nature of its computation could have a negative effect on the system availability. The EGPWS though does take into account the GPS FDE algorithm results. The EGPWS will switch to using Horizontal Integrity Limit (HIL) as the measure of GPS accuracy if HIL bit #11, non-isolatable satellite failure (NISF) is set and HIL is valid. NISF being set with HIL still valid is an indication that the GPS receiver's RAIM/FDE algorithm has detected a bad satellite but it is unable to exclude it from the solution. Since HIL is still valid, the value of HIL will still bound the error due to this satellite being in the solution. HFOM should not be used in this case since a bad satellite has been detected. If HIL subsequently then goes invalid while NISF is still set, GPS data will be declared invalid and not used by the EGPWS. This ensures that the EGPWS does not use the GPS data if the possibility of a bad satellite being in the solution still exists. GPS data will remain invalid in this case until HIL returns to a valid state and the EGPWS can be sure that the bad satellite is no longer being used.
>
> GPS position data will NOT be used if GPS Latitude, Longitude, or HFOM are invalid.
>
> Note under normal operation, (NISF not set), HIL being invalid has no effect on the EGPWS operation. HIL will be set invalid anytime the receiver is unable to compute the FDE algorithm. This can occur fairly often, (FDE only required to be available 95% of the time), such that the availability of the EGPWS would be affected adversely if we required HIL to be valid.

> As far as the FMS is concerned it's using the Hybrid GPS / Inertial position from the 3 ADIR's and again HIL being lost by itself won't cause the FMS to deselect the preferred Hybrid GPS / Inertial position source."

The MMR has 3 databus outputs. Outputs 1 and 2 feed the flight critical systems (such as flight management computers) via the Air Data Inertial Reference Units (ADIRUs), Output number 3 only feeds the less flight critical systems: ATC transponder, clock and Flight Data Interface and Management Unit (FDIMU, which hosts the ACMS software). It is possible that the condition we are observing only affects databus output number 3, but if it does affect buses 1 and 2 as well, the above explanation from Honeywell would explain why when we have a dual failure condition, that there is no indication of loss of function from the Flight Management System (FMS) or EGPWS.

Quite early on in the investigation we understood that the condition always started in Sydney. Towards the end of June we had a realisation that not only did the condition always start in Sydney, but always after the affected aircraft had had an overnight stop in Sydney. It is not possible to determine at this stage if the affected aircraft had had electrical power removed during the overnight stop or not.

This is true is all but one case observed so far this year. Refer to the spreadsheet log of events.

Qantas continued to log events throughout July and August.

At the request of Airbus we have been attempting to recover information in flight and post flight. We have recovered some screen shots of the MCDU "GPS Monitor" page whilst an aircraft is exhibiting the condition. Refer attached pictures. These do not indicate that any observable anomaly is present in the GPS information or navigation solution.

With the on-going monitoring of invalid HIL using the ACMS software, the following request was implemented through our Maintenance Operations Centre when the condition was reported on an A330 aircraft:

> If the Flt Crew report that the ADS-B is not working, or a bad HIL email is received, do the following at the next station-
> 1/ do BITE test of the effected MMR from the MCDU to confirm that it fails
> 2/ obtain GPS Report and GPS History (accessed via System Report/TEST pages)
> 3/ Obtain MMR TSD (accessed via CMS menu)
> 4/ cycle the MMR c/b
>
> Enter on the MCDU Keypad the correct Alpha Call-up into the scratchpad. Look at the Alpha Call-up List (Ref. AMM 31-36-00-001). The Parameter Alpha Call-up shows on the bottom of the display (scratchpad).
> enter GPS1HIL (for MMR-1) or GPS2HIL (for MMR-2)
>
> 5/ run MMR BITE test again to confirm it passes
>
> MMR C/Bs-
> COM NAV/MMR/1 | N68 | 742VU
> COM NAV/MMR/2 | H43 | 722VU
>
> The GPS HIL can be checked directly via the MCDU to verify that the invalid HIL condition has been cleared eg after a c/b cycle for the related MMR.
> Using AMM TASK 31-36-00-740-805-A Access to the Parameter call-up menus.
> Subtask 31-36-00-740-054-A B. Procedure to enter the Alpha Call-up via MCDU.

Through the above activities, we have established that:

(1) The BITE test of the MMR **<u>does not</u>** reliably detect the condition.

(2) Cycling the circuit breaker for the affected MMR **does** reliably clear the condition

Qantas and Rockwell held a teleconference at the end of May 2015, which was a very positive discussion. Rockwell Collins responded with a request to record additional information from the MMR on the QAR:

> "Rockwell Collins would like Qantas to program into your ACMS reporting tool to help our team with data related to your current ADS B Out / ATC fail issue you are experiencing.
>
> *The labels we would like to record are 076, 110, 111, 130, 150, 273, 274, 352, 354, and 370. If we can get just the raw hex, that would be best.*
>
> These data labels will help to provide additional information that the Engineering team can use to help with the root cause investigation. We have another customer currently providing us with these labels from their aircraft (similar configuration and similar issue) and Engineering is reviewing the data weekly to look for any emerging trends or data correlation. "

These were programmed into the ACMS for recording on the QAR. This version of ACMS software was installed on the Qantas A330-200 VH-EBG on 31st July. Initial indications are that the additional data from the MMR recorded on the QAR is useful. This software is only on one aircraft at this stage, and VH-EBG is a GLU-920 equipped aircraft and we very rarely see the invalid HIL condition on these aircraft. The software will be installed on all Qantas A330 aircraft in due course and this will provide addition data from the GLU-925 MMRs on later aircraft, and hopefully we will be able to capture data from a real invalid HIL event.

As part of this activity we created a new parameter in the ACMS software for the Non-Isolatable Satellite Failure (NISF) bit, bit 11 of label 130 word. The HIL parameter also acquired from the label 130 word was unchanged and is defined in the ACMS database as a Binary parameter (multiple bits in 2's complement format representing a value in engineering units that must be converted from binary to decimal floating point. In this case Horizontal Integrity Limit in nautical miles, with the 17 bits from bit 12 to bit 28 having a full scale range of 16nm, and bit 29 being the sign bit ('1' for negative values in 2's complement format). The NISF parameter, was defined as a "Discrete" parameter, being only 1 bit. It can only have a value of 1 or 0 and requires no conversion.

During testing of the new parameter it was found that whilst the HIL parameter was valid (normal condition) the NISF parameter was showing invalid in the same way that the HIL parameter shows as invalid when the ATC transponder is broadcasting NIC=0. This could not be explained at the time.

Towards the end of August, whilst conducting an investigation on an unrelated topic, a definition of the ARINC 429 word Sign Status Matrix (SSM) was found in an Interface Control Document (ICD) that Triggered another realisation. The SSM are bits 30 and 31 of each ARINC 429 word which are used to represent the validity of the data contained within the word. The definition is as follows:

ARINC 429 Word Type	SSM State for "Normal"	SSM State for "Failure Warning"
Binary	11	00
Discrete	00	11

An end user avionic computer is supposed to treat the data in the word according to the state of the SSM and only use the data if "Normal" condition is indicated by the SSM.

A check of ARINC Specification 420 “Digital Information Transfer System” (DITS) for the transfer of information between avionic computers on commercial aircraft confirms the above definition (refer to section 2.1.5.2 and 2.1.5.3 of the subject ARINC Specification).

Qantas and Rockwell surmise at this point that perhaps there is an integration problem between the Rockwell MMR and the ACSS XS-950 ATC transponder (and the Teledyne FDIMU) in terms of the application and the interpretation of the Sign Status Matrix for Binary and Discrete data with the same ARINC 429 Word (Label 130 in this case) given that the NISF bit in label 130 word could be considered discrete data whereas the HIL is definitely binary data.

This also could provide an alternative explanation for the absence of the condition on Qantas B737-800 and A380 fleets both of which have Rockwell MMRs. The Qantas B737-800 fleet has Rockwell ATC Transponders, and the A380 fleet of course has the Honeywell Aircraft Environment Surveillance Systems (AESS). Qantas speculates that Rockwell may have performed integration testing of its own MMRs with its own transponders (or otherwise applied a consistent implementation and interpretation of the SSM for label 130), and the AESS uses the A380 Aircraft Data Communications Network (ADCN) to obtain HIL data from the MMR (this does not use the ARINC 429 protocol and so does not involve the use of status indications such as SSM).

Summary (V2.0):

1. In all but one case so far in 2015, the aircraft exhibiting NIC=0 in ADS-B transmission has overnighted in Sydney (YSSY)

2. It would appear to only affect aircraft with Rockwell MMRs and ACSS ATC Transponders (at least within the Qantas fleet)

3. The condition affects Qantas B747-400 fleet (Rockwell GLU-920 MMR, ACSS XS-950 ATC transponder) as well although to a lesser extent.

4. According to Honeywell, the A330 Flight Management function and EGPWS will not exhibit observable loss of function with the loss of HIL from all sources (both MMRs).

5. A330 GPS Monitor screen does not show any observable degradation in the performance of the navigation computation in the GPS function.

6. Cycling the circuit breaker for the MMR (removing electrical power) does clear the condition.

7. Label 130 contains both Binary and Discrete data

8. ARINC Specification 429 defines opposite states for the SSM for words that contain binary data and words that contain discrete data.

Lewis Benham
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Appendix 2
Summary of Qantas ADS-B Events
Fleet: A330

Year	Fleet Size	ATC Reports[1]	ACMS Reports[2]	Dual Failures
2013	30	29	---	3
2014	30	29	---	3
2015	29	19	19	5
2016 (Q1)	28	4	14	2

Fleet: B747-400

Year	Fleet Size	ATC Reports[1]	ACMS Reports[2]	Dual Failures[3]
2013	15	8	---	0
2014	13	4	---	0
2015	12	10	18	0
2016 (Q1)	11	1	3	0

Notes:

1 Number of flights where it was recorded in aircraft technical log that Air Traffic Control (ATC) had advised the pilots that the ADS-B function is inoperative.

2 Number of flights where the loss of ADS-B surveillance capability was detected by Aircraft Condition Monitoring System (ACMS) monitoring of Horizontal Integrity Limit (HIL) from the Multi-Mode Receiver (MMR). This monitoring did not commence until early 2015.

3 On the Qantas B747-400 fleet there have been no dual failure events detected or reported to date.

4 The rate of ATC reports has reduced noticeably since mid-2015 due to the ACMS monitoring capability. Qantas Maintenance Operations Centre actively monitors the ACMS reports and will request Line Maintenance crews to cycle the MMR circuit breaker(s) (which will clear the condition) prior to the event proceeding long enough for an ATC report to occur.

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