RTCA SC-186 WG3

Washington, DC

16 June to 19 June 2009

Vertical Metrics in ASAS Applications

Revision 1 of WP28-24

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Summary

WP 27-15 addresses separating the vertical quality metrics from the horizontal quality metrics. This paper addresses the desire for vertical quality metrics in near term ASAS Applications. This second revision of the paper incorporates the consensus from meeting 27 and proposes an independent vertical position accuracy metric.

1. Introduction

WP ~~(TBD-Boeing??)~~27-15 addresses separating the vertical quality metrics from the horizontal quality metrics. If accepted, the vertical metrics will be unavailable. This paper addresses the desire for vertical quality metrics in near term ASAS Applications. This second revision of the paper incorporates the consensus from meeting 27 and proposes an independent vertical position accuracy metric.~~Future revision of this paper will propose a format for maintaining geometric altitude accuracy and vertical rate accuracy. Further investigation is needed to justify the quantization and transmit rates before making a proposal.~~

2. Discussion

ASAS MOPS Text

All five of the initial applications in ASAS MOPS allow for a mode of operation using geometric altitude when the geometric vertical accuracy of the ownship and ADS-B traffic is better than 45 meters.

ASAS MOPS Section 2.2.4.1 Enhanced Visual Acquisition (EVAcq) states that when pressure altitude is unavailable, geometric altitude may be used to compute a relative altitude with the target when the reported vertical accuracy is better than 45 meters for both the ownship and ADS-B traffic.

ASAS MOPS Section 2.2.4.2 Airport Surface Situational Awareness/Final Approach and Runway Occupancy Awareness (ASSA/FAROA) states that the application may be performed when either pressure altitude is valid or geometric vertical accuracy is better than 45 meters for ownship. ADS-B Traffic are considered valid for ASSA/FAROA when pressure altitude is valid or geometric vertical accuracy is better than 45 meters.

The preliminary requirements in ASAS MOPS Section 2.2.4.3 Conflict Detection (CD) state that ownship and traffic vertical position requirements may be met by geometric accuracy better than 45 meters.

ASAS MOPS Section 2.2.4.4 Enhanced Visual Approach (EVApp) states that ownship and traffic vertical position requirements may be met by geometric accuracy better than 45 meters.

ASAS MASPS DO-289 Conflict Detection Requirements Summary

DO-289 explores Conflict Detection in some detail and made recommendations on required and desired performance of the vertical metrics. Those recommendations are summarized in the table below.

	Required Performance	Desired Performance
Horizontal Position Accuracy	0.5 NM (NACp >= 5)	20 m (NACp >= 9)
Horizontal Velocity Accuracy	3 m/s (5.83 knots)(NACv >=2)	0.6 m/s (1.2 knots)(NACv >= 3)
Vertical Position Accuracy Baro	Existing Specifications	
Vertical Velocity Accuracy Baro	Existing Specifications	

Vertical Position Accuracy Geo	45 m (148 ft)(NACp >= 9)	10 m (32 ft)(NACp > 10)
Vertical Velocity Accuracy Geo	Baro Equivalent	60 fpm (DO-242A)(NACv=4)

It is interesting to note that DO-289 refers to pressure altimetry accuracy several times without actually documenting what the assumed performance is. I found the same issue with DO-242. Jonathon Hammer stated that the performance of the pressure altimetry was based on a model they created during the TCAS development to represent actual aircraft equipment. The model assumes that pressure altitude accuracy varies between 30 and 100 feet depending on the altitude.

Air Data Computer Performance

To get a data point on Air Data Computer performance, I looked up some numbers in ARINC 706-4.

ARINC 706-4 paragraph 4.10.1 requires Air Data Computer (ADC) altitude accuracy to be:

Accuracy	Altitude Range
15 ft	-1000 – 0 ft
20 ft	@ 10,000 ft
40 ft	@ 30,000 ft
80 ft	@ 50,000 ft

with intermediate altitudes meeting a linear interpolation between the given points.

ARINC 706-4 paragraph 4.10.4 requires ADC altitude rate accuracy to be 30 fpm. This is identical to the Inertial Vertical Speed Accuracy given in ARINC 738A-1.

Note that the equipment performance does not include the effects of aircraft installation or atmospheric phenomenon deviating from the standard model (e.g. temperature inversions). So the actual installed performance of the equipment will be worse than that given here. These numbers agree fairly well with the MITRE model.

The minimum performance specified in ICAO Annex 10 Volume IV is 125 ft. For reference the paragraph of interest is copied below.

3.1.1.7.12.2.4 The digitizer code selected shall correspond to within plus or minus 38.1 m (125 ft), on a 95 per cent probability basis, with the pressure-altitude information (referenced to the standard pressure setting of 1 013.25 hectopascals), used on board the aircraft to adhere to the assigned flight profile.

GNSS Vertical Performance

GNSS Vertical Performance varies as a function of satellite geometry, receiver assumptions (e.g. SA On/Off), receiver type (e.g. SBAS, GBAS, unaugmented), as well as a host of other factors. Honeywell performed a short study of GPS Vertical Performance using a 24 Satellite reference constellation as well as using an almanac from the current constellation. Refer to the attached paper

for details. Based on this short study, the performance you can expect from an SA Aware fleet is Vertical Accuracy (95%) better than 60 meters and Vertical Velocity Accuracy better than 0.6 m/s.

Desired Transmit Frequency

Vertical Metrics are only interesting when an aircraft is airborne. Therefore this paper recommends that the vertical metrics only be included in airborne formats. Since Conflict Detection is the most tactical of the applications currently defined to need vertical metrics. That is the application used to determine the required frequency. The CD Application in DO-289 states that the desired update rate for state data is 3 seconds and tolerated update rate is 10 seconds. It is unclear but assumed that the quality metrics are associated with state data with respect to update rate. So the update rate for the vertical metrics should not exceed 10 seconds. I asked Larry Bachman to do an analysis for me using a 2020 interference model to help determine the required transmit frequency. If the vertical metrics are transmit at 2.5 second intervals, they would support a 10 second update at 15 miles in the modeled 2020 air-to-air interference environment.

Existing Vertical Metrics

The following tables present the vertical metrics as they currently exist in DO-260A.

NAC_P	Navigation Accuracy Category for Position (DO-260A 2.2.3.2.7.1.3.11, 2.2.3.2.7.2.7) [DF17,DF18]	
	95% Horizontal/Vertical Accuracy	Comment
0	EPU ≥ 10 Nm (18.52 km)	Unknown Accuracy
1	EPU < 10 Nm (18.53 km)	RNP-10
2	EPU < 4 Nm (7.408 km)	RNP-4
3	EPU ≥ 2 Nm (3.704 km)	RNP-2
4	EPU < 1 Nm (1852 m)	RNP-1
5	EPU < 0.5 Nm (926 m)	RNP-0.5
6	EPU ≥ 0.3 Nm (555.6 m)	RNP-0.3
7	EPU < 0.1 Nm (185.2 m)	RNP-0.1
8	EPU < 0.05 Nm (92.6 m)	GPS (SA on)
9	EPU < 30 m and VEPU < 45 m	GPS (SA off)
10	EPU < 10m and VEPU < 15 m	WAAS
11	EPU < 3 m and VEPU < 4 m	LAAS
12-15	Reserved	

NAC_V	Navigation Accuracy Category for Velocity (DO-260A 2.2.3.2.6.1.5) [DF17,DF18]					
	$HFOM_R$ $VFOM_R$ Available		WAAS/LAAS		GPS Only	
	$HFOM_R$	$VFOM_R$	HFOM	VFOM	HFOM	VFOM
0	> 10 m/s	> 50 fps	> 49.5 m	> 248 ft	> 475 m	> 2335 ft
1	< 10 m/s	< 50 fps	≤ 49.5 m	≤ 248 ft	≤ 475 m	≤ 2335 ft
2	< 3 m/s	< 15 fps	≤ 14.5 m	≤ 73.3 ft	≤ 125 m	≤ 585 ft
3	< 1 m/s	< 5 fps	≤ 4.5 m	≤ 23.3 ft	Not	Used
4	< 0.3 m/s	< 1.5 fps	≤ 1 m	≤ 5.85 ft	Not	Used

Proposed Vertical Accuracy Quantization Changes

~~The existing vertical separation in the airspace ranges from 500 ft to 2000 ft depending on the altitude assigned. Based on 500 ft separation, it seems unlikely that there would be a use for a vertical accuracy metric as large as half of the 500 ft separation. However, since the SA Aware equipment performance is 200 feet or better 95 % of the time, it seems reasonable to make the largest quantization support SA Aware performance. Thus I propose that the largest Vertical Accuracy quantization be 200 feet or 60.96 meters. This differs from the current largest vertical metric of 45 m or 147.6 ft. The altitude resolution supported by the Mode S link is 25 feet. So it doesn't make sense to support any quantization smaller than 25 feet. This differs from the current smallest vertical metric of 4 m or 13.1 ft. In the table below, I propose to use three bits to support the new Geometric Vertical Accuracy metric.~~To support the existing ASAS MOPS requirements, I propose to use the currently reserved BAQ field in the Aircraft Operational Status message for a geometric vertical accuracy metric. The main section affected by this change is 2.2.3.2.7.2.8 in the current DO-260B draft material. I propose replacing the existing paragraph with the following paragraph.

2.2.3.2.7.2.8 "Geometric Vertical Accuracy Quantization (GVAQ)" Subfield in Aircraft Operational Status Messages

The "Geometric Vertical Accuracy Quantization (GVAQ)" subfield of Subtype=0 Aircraft Operational Status Message is a two-bit field ("ME" bits 49-50, Message bits 81-82) defined in the following Table 2-XX. This field shall be set by using the Vertical Figure of Merit (VFOM) (95%) from the GNSS position source used to encode the geometric altitude field in the Airborne Position Message.

Table 2-xx: "GVAQ" Subfield Encoding

Geometric Vertical Accuracy Quantization	Accuracy (m)~~in Feet~~
0	~~> 200~~Unknown or > 45
1	≤ 45~~200~~
2	~~150~~Reserved
3	Reserved~~100~~
~~4~~	~~50~~
~~5~~	~~25~~
~~6~~	~~RESERVED~~
~~7~~	~~RESERVED~~

Note: For the purposes of these MOPS (RTCA DO-260B) values for 0 and 1 are encoded. Decoding values for 2 and 3 should be treated as < 45 meters until future versions of these MOPS redefine the values.

Figure 2-11 needs to have BAQ=0 replaced with GVAQ.

Table 2-88 needs to have BAQ replaced with GVAQ. The columns of the table should be populated as follows: Column 3: Operational Status – "GVAQ", column 4: 49-50, column 5: 81-82, column 10: xxxxxxdL. The remaining columns stay the same.

Table 2-89 needs to have BAQ replaced with GVAQ.

Table 2-90 needs to have BAQ replaced with GVAQ.

Section 2.2.8.2.15 should be replaced with the following paragraph.

2.2.8.2.15 SV Quality – GVAQ

The ADS-B Report Assembly Function shall extract the GVAQ data from the Aircraft Operational Status Message (2.2.3.2.7.2.10) and map the value of the GVAQ field to the Mode Status Report in the format specified in Table 2-88.

Table 2-102 should have row 9d replaced as follows: SV Quality – GVAQ, No, Note 2.

Replace test section 2.4.3.2.7.2.8 with the following text.

2.4.3.2.7.2.8 Verification of the "Geometric Vertical Accuracy Quantization (GVAQ)" Subfield in Aircraft Operational Status Messages (2.2.3.2.7.2.9)

Step 1: Verification of GVAQ Transmission

Configure the ADS-B Transmitting Subsystem to transmit Aircraft Operational Status Messages by providing valid trajectory information at the nominal update rate.

Set the Vertical Figure of Merit (VFOM) field to each of the following values in Table 2-xx and verify that the corresponding encoding is set in the GVAQ field of the Aircraft Operational Status Message.

Table 2-xx GVAQ Validation Values

Row	VFOM (m)	GVAQ Encoding
1	INVALID	0
2	30.0	1
3	44.5	1
4	45.5	0
5	327.1	0

Step 2: Verification of GVAQ – Data Lifetime

Rerun Table 2-xx Row 2 from Step 1. Remove the data source input for GVAQ for a period of at least 2 seconds. Verify that the GVAQ field of the Aircraft Operational Status Message is set to Zero (binary 00).

Replace test section 2.4.8.2.15 with the following text.

2.4.8.2.15 Verification of the Mode Status Report – SV Quality – GVAQ (2.2.8.2.15)

Step 1: Initialization

Provide valid ADS-B Position and Velocity Messages to the ADS-B Receiving Subsystem such that the ADS-B Report Assembly Function enters the Track State and is outputting Reports to the Report Buffer. Verify that the Report Type Code (bits 7 through 4 of byte 0) is set to TWO (binary 0010) to indicate Mode Status Report.

Step 2: Verification of Mapping GVAQ Data to the (MS) Report – Version Two (2)

Provide valid Version Two (2) ADS-B Aircraft Operational Status Messages to the ADS-B Receiving Subsystem with valid TYPE Codes included in the messages. Verify that the GVAQ data from these messages is mapped bit for bit from the most recently received ADS-B Message to the Mode Status Report as specified in Table 2-88.

Step 3: Verification of Data Not Available – Version Two (2)

Provide valid Version Two (2) ADS-B Aircraft Operational Status Messages to the ADS-B Receiving Subsystem with valid TYPE Codes included in the messages. Allow 24 seconds to pass without an update and verify that the GVAQ field of the ADS-B Mode Status Report is set to ALL ZEROs.

Step 4: Verification of Previous Versions

No specific test procedure is required to validate the requirements for previous link versions as this field was reserved.

Replace section A.1.4.10.8 with the following paragraph.

A.1.4.10.8 Geometric Vertical Accuracy Quantization (GVAQ)

The "Geometric Vertical Accuracy Quantization (GVAQ)" subfield of Subtype=0 Aircraft Operational Status Message is a two-bit field ("ME" bits 49-50, Message bits 81-82) defined in the following Table A-XX. This field shall be set by using the Vertical Figure of Merit (VFOM) from the GNSS position source used to encode the geometric altitude field in the Airborne Position Message.

Table A-xx: "GVAQ" Subfield Encoding

Geometric Vertical Accuracy Quantization	Accuracy (m)
0	Unknown or > 45
1	≤ 45
2	Reserved
3	Reserved

In Figure A-10, replace the BAQ=0 text with GVAQ.

Something will need to be done for the BAQ entries in Table F-1. WG3 should discuss this issue and decide how to treat changes to the MASPS in this table.

Replace the text in Row 9d of Table H-3 as follows: SV Quality – GVAQ, Aircraft Operation Status Message.

Table N-5 references BAQ but appears to be correct and should stay the same.

Proposed Vertical Velocity Quantization

The ~~existing~~ vertical velocity quality of all existing sensors support the required accuracy of the CD application. WG3 decided that at this point there is no clear need to have a vertical velocity metric transmitted on the link. The link already transmits whether it is sending a barometric or geometric altitude rate. ~~quantization is puzzling at best. What any application can do with 50 ft/s or 3000 fpm of error is questionable. It is unclear what system performs this poorly. Air Data Computers and Inertial Reference Systems provide vertical rate accuracies of about 30 fpm. Even the largest number from the SA Aware sensor study was on the order of 10 feet per second. It seems like the vertical rate quantization could use some tinkering. I propose to use three bits to support the new Vertical Velocity quantization in the table below.~~

~~Vertical Velocity Accuracy Quantization~~	~~Accuracy in ft/s~~	~~Accuracy in m/s~~	~~Accuracy in fpm~~	~~Comment~~
~~0~~	~~> 15~~	~~>4.57~~	~~> 900~~	~~Unknown~~
~~1~~	~~15~~	~~4.57~~	~~900~~	
~~2~~	~~10~~	~~3.05~~	~~600~~	
~~3~~	~~5~~	~~1.52~~	~~300~~	
~~4~~	~~2~~	~~0.61~~	~~120~~	~~SA Aware~~
~~5~~	~~1~~	~~0.30~~	~~60~~	~~Augmented GNSS~~
~~6~~	~~0.5~~	~~0.15~~	~~30~~	~~ADC, INS~~
~~7~~				~~Reserved~~

~~It would be helpful to have SC-159 comment on the existing equipment to determine what vertical velocity accuracy can be expected.~~

~~**Desired Transmit Frequency**~~

~~Vertical Metrics are only interesting when an aircraft is airborne. Therefore this paper recommends that the vertical metrics only be included in airborne formats. Since Conflict Detection is the most tactical of the applications currently defined to need vertical metrics. That is the application used to~~

~~determine the required frequency. The CD Application in DO-289 states that the desired update rate for state data is 3 seconds and tolerated update rate is 10 seconds. It is unclear but assumed that the quality metrics are associated with state data with respect to update rate. So the update rate for the vertical metrics should not exceed 10 seconds. I asked Larry Bachman to do an analysis for me using a 2020 interference model to help determine the required transmit frequency. If the vertical metrics are transmit at 2.5 second intervals, they would support a 10 second update at 15 miles in the modeled 2020 air-to-air interference environment.~~

3. Recommendations

WG3 is advised to consider the desire for vertical quality metrics in the ASAS MOPS. WG3 is asked to consider the proposals for adding Geometric Altitude Accuracy ~~and Vertical Velocity Accuracy~~ field~~s~~ for inclusion in ~~Change 3 to~~ DO-260B~~A~~.