

RTCA Special Committee 186, Working Group 5

ADS-B UAT MOPS Maintenance

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Discussion of NAC_v Coding Requirements

Richard E. Jennings, FAA, and George T. Ligler, PMEI

Summary

A version of this Working Paper was presented to RTCA SC-186 WG-3 for their consideration in revising the DO-260A definition of how NAC_v was derived. In this original Working Paper, we addressed those revisions to DO-260A necessary to change encoding of NAC_v from being based on a relationship with HFOM/VFOM to being based on either: (1) a specific velocity accuracy output from the position sensor, or, (2) velocity accuracy testing results accomplished/published by the position sensor manufacturer. For the latter case, test procedures developed and standardized by RTCA SC-159 provide for a velocity accuracy test to characterize the 95% horizontal and 95% vertical velocity accuracies during normal maneuvers of GNSS equipment as specified in RTCA/DO-229D, RTCA/DO-____, and RTCA/DO-253B receiver MOPS for use as ADS-B position sources intended to support either NAC_v = 1 (<10 m/s) or NAC_v = 2 (<3 m/s). Test procedures to support higher levels of NAC_v are expected to be developed as more demanding ADS-B applications mature.

1. Introduction

Until recently, acceptable means to substantiate a navigation source's capability to support NAC_V were not clearly established in Global Positioning System (GPS) sensor minimum operational performance standards. In light of this deficiency, a "best-method" was originally established in §2.2.3.2.6.1.5 of RTCA DO-260A to utilize the HFOM/VFOM quality indicator as a surrogate for setting the NAC_V value. The rationale for this method was also documented in Appendix J of DO-260A. However, the use of HFOM/VFOM to set NAC_V is not considered acceptable, since it does not provide an appropriate indication of the true horizontal velocity error as established by the position sensor manufacturer.

To remedy this deficiency, the FAA requested RTCA SC-159 to develop test procedures for a velocity accuracy test to characterize the 95% horizontal and 95% vertical velocity accuracies during normal maneuvers of GNSS equipment as specified in RTCA/DO-229D, RTCA DO/____, and RTCA/DO-253B receiver MOPS. These tests can be used to substantiate Global Positioning System (GPS), GPS/Space-Based Augmentation System (SBAS), or GPS/Ground-Based Augmentation System (GBAS) equipment to support an ADS-B $NAC_V = 1$ requirement of horizontal velocity error less than 10 meters/second (95th percentile with HDOP of 1.5 or less) and vertical velocity error less than 50 feet/second (95th percentile, with VDOP of 3.0 or less). Additional test procedures were developed to substantiate equipment that supports a $NAC_V = 2$ requirement of horizontal velocity error less than 3 meters/second and vertical velocity error less than 15 feet/second. However, these tests are not adequate for demonstrating more stringent ADS-B NAC_V levels (i.e., NAC_V value of 3 or greater), but are expected to be developed as more demanding ADS-B applications mature.

Navigation equipment manufacturers can submit the results of this testing with their TSO application or as additional information if they have already received TSO approval, for acceptance as approved data. Manufacturers of navigation equipment that pass these tests should document their equipment's 95% figure of merit velocity accuracy in their installation manual (or provide a velocity accuracy quality metric output for direct use by the ADS-B equipment.) The velocity output has no explicit integrity beyond the 95% figure of merit for the stated HDOP and VDOP.

Note: FAA AIR-100 memorandum dated October 10, 2008 (documented in 1090-WP24-10) serves as an interim reference describing testing procedures acceptable to the FAA until the procedures are incorporated into more formal GPS MOPS guidance material.

2. Proposed Changes to DO-282A

a. Originally Proposed changes to DO-260A §2.2.3.2.6.1.5:

The definition of NAC_V in DO-260A §2.2.3.2.6.1.5 was originally set up based on using HFOM. The changes proposed in the version of this Working Paper presented to WG-3 remove those connections to HFOM/VFOM, retain the table defining the actual NAC_V values, and propose the addition of the following *Note*:

Note: Subsequent to revision A of the 1090 MHz ADS-B MOPS, the Federal Aviation Administration requested RTCA SC-159 to develop test procedures for a velocity accuracy test to characterize the 95% horizontal and 95% vertical velocity accuracies during normal maneuvers of GNSS equipment, as specified in RTCA/DO-229D, RTCA/DO-____, and RTCA/DO-253C receiver MOPS, which do not provide a specific velocity accuracy output. These tests can be used to substantiate Global Positioning System (GPS), GPS/Space-Based Augmentation System (SBAS), or GPS/Ground-Based Augmentation System (GBAS)

equipment to support an ADS-B $NAC_V = 1$ requirement of horizontal velocity error less than 10 meters/second (95th percentile with HDOP of 1.5 or less) and vertical velocity error less than 50 feet/second (95th percentile, with VDOP of 3.0 or less). Additional test procedures were developed to substantiate equipment that supports a $NAC_V = 2$ requirement of horizontal velocity error less than 3 meters/second and vertical velocity error less than 15 feet/second. However, these tests are not adequate for demonstrating more stringent ADS-B NAC_V levels (i.e., NAC_V value of 3 or greater), but are expected to be developed as more demanding ADS-B applications mature. The results of these tests can be used to substantiate the setting of a NAC_V value to be used when ADS-B position and velocity are provided by the GPS equipment, presuming that that equipment does not have a specific velocity accuracy output.

b. Proposed changes to DO-282A Section 2.2.4.5.4.10:

The definition of NAC_V in DO-282A was never related to the use of HFOM. Therefore, the Working Group is requested to review and consider whether it is appropriate to revise and add the above *Note* into DO-282B, §2.2.4.5.4.10.

c. Proposed changes to DO-260A Appendix J and possibly to DO-282B:

The original Appendix J to DO-260A expressed in detail the relationship of NAC_V and HFOM/VFOM. In this Working Paper as presented to WG-3, it was proposed to delete the existing DO-260A, Appendix J, and replace it with the following materials which were taken from the FAA AIR-100 memorandum dated October 10, 2008 (documented in 1090-WP24-10), which served as an interim reference describing testing procedures acceptable to the FAA, until the procedures are incorporated into more formal GPS MOPS guidance material.

Working Group 5 is requested to review the following materials to determine if they are appropriate to use in some fashion in the proposed DO-282B.

J. Determining the Navigation Accuracy Category for Velocity (NAC_V)

J.1 Purpose and Scope

This Appendix describes the manner in which GNSS position sources which do not output velocity accuracy can be characterized so that a velocity accuracy value associated with the position source can be input into ADS-B equipment as part of the installation process.

J.2 Rationale for Table 2-46, “Determining NAC_V Based on Position Source Declared Horizontal Velocity Error”

Until recently, acceptable means to substantiate a navigation source’s capability to support NAC_V were not clearly established in Global Positioning System (GPS) sensor minimum operational performance standards. In light of this deficiency, a “best-method” was established in Section 2.2.3.2.6.1.5 of RTCA DO-260A to utilize the HFOM/VFOM quality indicator as a surrogate for setting the NAC_V value. The rationale for this method was documented in Appendix J of DO-260A. However, the use of HFOM/VFOM to set NAC_V is not considered acceptable, since it does not provide an appropriate indication of the true horizontal velocity error as established by the position sensor manufacturer.

To remedy this deficiency, the FAA requested RTCA SC-159 to develop test procedures for a velocity accuracy test to characterize the 95% horizontal and 95% vertical velocity accuracies during normal maneuvers as specified in RTCA/DO-229D and RTCA/DO-253B receiver MOPS. These tests can be used to substantiate Global Positioning System (GPS), GPS/Space-Based Augmentation System (SBAS), or GPS/Ground-Based Augmentation System (GBAS) equipment to support an ADS-B $NAC_V = 1$ requirement of horizontal velocity error less than 10 meters/second (95th percentile with HDOP of 1.5 or less) and vertical velocity error less than 50 feet/second (95th percentile, with VDOP of 3.0 or less). Additional test procedures were developed to substantiate equipment that supports a $NAC_V = 2$ requirement of horizontal velocity error less than 3 meters/second and vertical velocity error less than 15 feet/second. However, these tests are not adequate for demonstrating more stringent ADS-B NAC_V levels (i.e., NAC_V value of 3 or greater), but are expected to be developed as more demanding ADS-B applications mature.

Navigation equipment manufacturers can submit the results of this testing with their TSO application or as additional information if they have already received TSO approval, for acceptance as approved data. Manufacturers of navigation equipment that pass these tests should document their equipment’s 95% figure of merit velocity accuracy in their installation manual (or provide a velocity accuracy quality metric output for direct use by

the ADS-B equipment.) The velocity output has no explicit integrity beyond the 95% figure of merit for the stated HDOP and VDOP.

Note: *FAA AIR-100 memorandum dated October 10, 2008 serves as an interim reference describing testing procedures acceptable to the FAA until the procedures are incorporated into more formal GPS MOPS guidance material.*

J.3 Test to Determine Velocity Accuracy to Support Setting $NAC_V = 1$ or 2 .

The ADS-B installations with a position source capable of providing velocity accuracy should have the NAC_V derived from the position source, and the velocity accuracy should be validated during the position source manufacturer's certification testing. The following procedures, developed by RTCA SC-159, are one means of accomplishing this testing.

The purpose of GNSS velocity accuracy test is to characterize the 95% horizontal and 95% vertical velocity accuracies during normal maneuvers as specified in RTCA/DO-229D and RTCA/DO-253B receiver MOPS for equipment intended to support either $NAC_V = 1$ or $NAC_V = 2$. Test procedures for higher levels are expected to be developed as more demanding ADS-B applications mature.

The tests to verify velocity accuracy performance shall be run for each of the scenarios described below for all operating modes of the receiver where a valid position and/or velocity could be output by the receiver.

Note: *It is possible that a given receiver may use a different velocity algorithm when computing an unaugmented GPS position solution versus computing a solution augmented with differential corrections. In that case, this test must be repeated for both the augmented and unaugmented modes of operation. Even in the case where the velocity algorithm is the same whether in unaugmented or augmented mode, there are still enough variables like the software path, inputs, outputs etc., that it is required to repeat the test. However it is not required to repeat the test for different sub-modes of an unaugmented or augmented mode where the inputs, velocity algorithm and outputs are the same.*

J.3.1 Horizontal Velocity Accuracy Test Conditions Commensurate with $NAC_V = 1$

1. Ensure the simulator scenario has enough GPS satellites to provide a HDOP of 1.5 or less.
2. One satellite shall set at maximum power (including maximum combined satellite and aircraft antenna gain), and the other satellites shall be set at minimum power (including minimum antenna gain).
3. Broadband GNSS test noise ($I_{GNSS,Test}$) of spectral density as defined in DO-229D accuracy test section 2.5.8. Broadband external interference ($I_{ext,test}$) and thermal noise contribution from the sky and the antenna ($N_{sky,antenna}$) shall be simulated.
4. The airborne equipment shall be initialized with the appropriate position and time. It is assumed that the receiver has obtained a valid almanac for the simulator scenario to be tested prior to conducting the test.
5. Platform Dynamics for the horizontal velocity accuracy test shall be as defined in Table J-1.

Table J-1: Platform Dynamics for the Horizontal Velocity Accuracy Test

Time (s)		Dynamics	Start Jerk (g/s)				End Jerk (g/s)			
From	To		North	East	Down	Total	North	East	Down	Total
0	T	Static	0	0	0	0	0	0	0	0
T+1	T+71	0.58g longitudinal acceleration to 411 m/s	0.xx <i>Note 1</i>	0.xx <i>Note 1</i>	0	0.25	0.xx <i>Note 1</i>	0.xx <i>Note 1</i>	0	0.25
T+72	T+129	Straight un-accelerated flight	0	0	0	0	0	0	0	0
T+130	T+194	-0.45g longitudinal acceleration to 125 m/s	0.xx <i>Note 1</i>	0.xx <i>Note 1</i>	0	0.2	0.xx <i>Note 1</i>	0.xx <i>Note 1</i>	0	0.2
T+195	T+254	Straight un-accelerated flight	0	0	0	0	0	0	0	0
T+255	T+325	turn 180° with 0.58g lateral acceleration	0.xx <i>Note 1</i>	0.xx <i>Note 1</i>	0	0.25	0.xx <i>Note 1</i>	0.xx <i>Note 1</i>	0	0.25
T+326	T+420	Straight un-accelerated flight	0	0	0	0	0	0	0	0

Note 1: The components of the jerk in the North and East direction depend on the heading chosen in the scenario. The total jerk is the not to exceed vector combination of north, east, and down jerk components. The maximum total jerk to quickly achieve the desired dynamics should be used, but the jerk should not exceed the normal maneuver total jerk requirement of 0.25g/s.

Note 2: The actual times may vary based on the simulator scenario control settings.

6. Signal and RF Interference conditions can be modified during static period to aid acquisition. Ensure the receiver enters the desired Operation mode before dynamics and appropriate signal and interference conditions are applied.

7. Use the simulator velocity truth data ($V_i^{east_truth}, V_i^{north_truth}$) and the GNSS receiver velocity data (V_i^{east}, V_i^{north}) to determine the horizontal velocity error h_i after the GNSS receiver has entered the desired Navigation mode with the specified signal and RF Interference conditions:

$$h_i = \sqrt{(V_i^{east_truth} - V_i^{east})^2 + (V_i^{north_truth} - V_i^{north})^2}$$

J.3.1.1 Pass/Fail determination

The 95% Horizontal Velocity accuracy statistic shall be computed using the formula given below. The equipment shall pass if the statistic is less than 10 m/s.

$$2 * \sqrt{\frac{\sum_{i=1}^N \left(\frac{1.5(h_i)}{HDOP_i} \right)^2}{N}}$$

Where:

h_i – is the horizontal velocity error (m/sec)

N – Number of sample points used

For this test, the number of samples shall include all samples where the receiver is in the desired Navigation mode and when in motion.

Note: The minimum of samples is 420 for 1 Hz solution and 2100 for 5 Hz solution (i.e., 5 420).*

The receiver velocity data and the $HFOM_V$ data shall be used to determine the percentage of samples bounded by the $HFOM_V$ as shown below. The test passes only if $TS_{h,b}$ is greater than or equal to 0.95.

$$TS_{h,b} = \frac{1}{N} \sum_{i=1}^N b_{h,i}$$

N = number of samples

$$b_{h,i} = \begin{cases} 1 & h_i \leq HFOM_V \\ 0 & h_i > HFOM_V \end{cases}$$

J.3.1.2 Vertical Velocity Accuracy Test Conditions Commensurate with $NAC_V = 1$

1. Ensure the simulator scenario has enough GPS satellites to provide a VDOP of 3.0 or less.
2. One satellite shall set at maximum power (including maximum combined satellite and aircraft antenna gain), and the other satellites shall be set at minimum power (including minimum antenna gain).
3. Broadband GNSS test noise ($I_{GNSS,Test}$) of spectral density as defined in DO-229D accuracy test section 2.5.8. Broadband external interference ($I_{ext,test}$) and thermal noise contribution from the sky and the antenna ($N_{sky,antenna}$) shall be simulated.
4. The airborne equipment shall be initialized with the appropriate position and time. It is assumed that the receiver has obtained a valid almanac for the simulator scenario to be tested prior to conducting the test.
5. Platform Dynamics for the vertical velocity accuracy test shall be as defined in Table J-2.

Table J-2: Platform Dynamics for the Vertical Velocity Accuracy Test

Time (s)		Dynamics	Start Jerk (g/s)				End Jerk (g/s)			
From	To		North	East	Down	Total	North	East	Down	Total
0	T	Static	0	0	0	0	0	0	0	0
T+1	T+71	0.58g longitudinal acceleration to 411 m/s	0.xx <i>Note 1</i>	0.xx <i>Note 1</i>	0	0.25	0.xx <i>Note 1</i>	0.xx <i>Note 1</i>	0	0.25
T+72	T+130	Straight and level un-accelerated flight	0	0	0	0	0	0	0	0
T+131	T+131+X	Climb, increasing the vertical climb rate from 0 to 21 m/s, then decrease the rate back to 0 m/s and repeat this increasing and decreasing pattern until the time out.	0	0	0.xx <i>Note 1</i>	0.25	0	0	0.xx <i>Note 1</i>	0.25
T+132+X	T+192+X	Straight and level un-accelerated flight	0	0	0	0	0	0	0	0
T+193+X	T+193+2X	Descend, increasing the vertical descent rate from 0 to 21 m/s, then decrease the rate back to 0 m/s and repeat this increasing and decreasing pattern until the time out.	0	0	0.xx <i>Note 1</i>	0.25	0	0	0.xx <i>Note 1</i>	0.25
T+194+2X	T+274+2X	Straight and level un-accelerated flight	0	0	0	0	0	0	0	0

Note 1: The components of the jerk in the North and East direction depend on the heading chosen in the scenario. The total jerk is the not to exceed vector combination of north, east, and down jerk components. The maximum total jerk to quickly achieve the desired dynamics should be used, but the jerk should not exceed the normal maneuver total jerk requirement of 0.25g/s.

Note 2: The actual times may vary based on the simulator scenario control settings.

Note 3: The value of X must be at least 63 seconds to have enough samples during vertical acceleration.

6. Signal and RF Interference conditions can be modified during static period to aid acquisition. Ensure the receiver enters the desired Operation mode before dynamics and appropriate signal and interference conditions are applied.

7. Use the simulator velocity truth data ($V_i^{vertical_truth}$) and the GNSS receiver velocity data ($V_i^{vertical}$) to determine the vertical velocity error (v_i) after the GNSS receiver has entered the desired Navigation mode with the specified signal and RF Interference conditions: $v_i = |V_i^{vertical_truth} - V_i^{vertical}|$.

J.3.1.3 Pass/Fail determination

The 95% Vertical Velocity accuracy statistic shall be computed using the formula given below. The equipment shall be considered pass only if the statistic is less than 50 ft/s.

$$2 * \sqrt{\frac{\sum_{i=1}^N \left(\frac{3(v_i)}{VDOP_i} \right)^2}{N}}$$

Where:

v_i - is the vertical velocity error (ft/sec)

N – Number of sample points used

For this test, the number of samples shall include all samples where the receiver is in the desired Operation mode

Note: The minimum of samples is 420 for 1 Hz solution and 2100 for 5 Hz solution.

The receiver velocity data and the $VFOM_V$ data shall determine the percentage of samples bounded by the $VFOM_V$ as shown below. The test passes if $TS_{v,b}$ is greater than or equal to 0.95.

$$TS_{v,b} = \frac{1}{N} \sum_{i=1}^N b_{v,i}$$

N = number of samples

$$b_{v,i} = \begin{cases} 1 & v_i \leq VFOM_V \\ 0 & v_i > VFOM_V \end{cases}$$

J.3.2 Additional Tests to Demonstrate Accuracy Commensurate with $NAC_V = 2$

The following procedure is one acceptable means for equipment capable of better accuracy performance to demonstrate compliance with the horizontal velocity error requirement of less than 3 m/s.

1. Run the scenario in Table J-1 with all satellites set at high power and no RF interference.
2. This accuracy evaluation shall only include those data samples collected during the acceleration period.
3. Find the particular h_i (noted as T_{acc}) so that 95% of h_i samples are less than or equal to T_{acc} .
4. Re-run the scenario in Table 1 with the same satellite and RF interference conditions as the 10 m/s ($NAC_V=1$) test.
5. This time only the data samples during the non-acceleration period with the specified signal and RF Interference conditions are used.

$$6. \quad \text{Compute } T_{non_acc} = 2 * \sqrt{\frac{\sum_{i=1}^{N_{non_acc}} \left(\frac{1.5(h_{i_non_acc})}{HDOP_{i_non_acc}} \right)^2}{N_{non_acc}}}$$

where $HDOP_{i_non_acc}$ and N_{non_acc} are the HDOP values for each sample i and the total number of samples (non-acceleration period), respectively.

7. The test passes only if $T_{acc} + T_{non_acc}$ is less than 3 m/s.
8. The velocity FOM is evaluated in the same way as for the 10 m/s test, i.e. the samples during acceleration and non-acceleration periods of the above 2 runs are evaluated together against the 0.95 threshold.

The vertical velocity requirement of 15 ft/s should be tested using the exact same philosophy as the test of 3 m/s above but with the scenario in Table J-2.