Federal Aviation Administration

Memorandum

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To: ACO and Standards Staff Managers (see distribution list)

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Subject: Policy Reference for Approving Velocity Output Data from GPS (TSO-C129), GPS/SBAS (TSO-C145/146), and GPS/GBAS (TSO-C161) Equipment for use with ADS-B

BACKGROUND

The Federal Aviation Administration (FAA) is currently reviewing comments on proposed rulemaking to mandate Automatic Dependant Surveillance – Broadcast (ADS-B) for air traffic control separation services in the U.S. National Airspace System (NAS). ADS-B outputs various broadcast parameters such as latitude, longitude, and altitude from qualified onboard sources. ADS-B also needs a velocity input from a navigation source and knowledge of the navigation source's velocity accuracy and figure of merit to determine a corresponding Navigation Accuracy Category for Velocity (NAC_V). Until recently, acceptable means to substantiate a navigation source's capability to support NAC_V were not clearly established. This memorandum serves as an interim reference describing testing procedures acceptable to the FAA until the procedures are incorporated into more formal guidance material.

DISCUSSION

Attachment 1 to this memorandum defines acceptable tests for velocity accuracy and figure of merit. 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 support an ADS-B $NAC_V = 1$ requirement of horizontal velocity error less than 10 meters/second (95^{th} percentile with HDOP of 1.5 or less) and vertical velocity error less than 50 feet/second (95^{th} percentile, with VDOP of 3.0 or less). The attachment includes additional test procedures to substantiate equipment supports a $NAC_V = 2$ requirement of horizontal velocity error less than 3 meters/second and vertical velocity error less than 15 feet/second.

Navigation equipment manufacturers can submit this test data 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 the tests in attachment 1 should document their equipment's 95% figure of merit velocity accuracy in their installation manual. These tests are not adequate for demonstrating more stringent ADS-B NAC_V levels (i.e., NAC_V value of 3 or greater). The velocity output has no explicit integrity beyond the 95% figure of merit for the stated HDOP and VDOP.

Attachment

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Attachment 1

GNSS Sensor Velocity Accuracy and Figure of Merit Tests

The ADS-B Out Draft Advisory Circular (Paragraph 7d) states that 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.

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 1.

Table 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 *Note 1*	0.xx *Note 1*	0	0.25	0.xx *Note 1*	0.xx *Note 1*	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 *Note 1*	0.xx *Note 1*	0	0.2	0.xx *Note 1*	0.xx *Note 1*	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 *Note 1*	0.xx *Note 1*	0	0.25	0.xx *Note 1*	0.xx *Note 1*	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:

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

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

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

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 2.

<u>Table 2:</u> 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 *Note 1*	0.xx *Note 1*	0	0.25	0.xx *Note 1*	0.xx *Note 1*	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 *Note 1*	0.25	0	0	0.xx *Note 1*	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 *Note 1*	0.25	0	0	0.xx *Note 1*	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: $v_i = \left|V_i^{vertical\_truth} - V_i^{vertical}\right|$.

2.1 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

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

3. 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 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. 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 2.