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Evaluation of GPS Altitude Accuracy of the LX9000 High Altitude Flight Recorder

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Revision History

Table 1: Summary of report revisions

Date	**Changes**
11/12/18	Initial document with 2018 post-flight calibration data
9/17/19	Formatted in Space Rendezvous Lab Technical Note

Scope

The Stanford University's Space Rendezvous Laboratory (SLAB) was asked to evaluate the performance of the GPS positioning for a LX9000HAFR high-altitude flight-recorder (FR) serial number 7RA. This report details the post-flight calibration procedure conducted on November 9, 2018. This follows Perlan's record-breaking flights from August and September of 2018.

Flight Recorder Validation

SLAB testbed features an IFEN NavX-NCS Professional GNSS satellite simulator that is capable of replicating GPS radiofrequency (RF) signals. The simulator was configured to emulate receiver performance on May 29, 2016 as that was consistently used for previous pre/post-flight calibrations in 2016 and 2017. For this date, GPS final orbit products were used to simulate the satellite trajectories, and actual broadcast ephemerides were sent to the receiver. Representative atmospheric path delays were also incorporated into the test, including both ionospheric and tropospheric effects.

An initial reference trajectory was created based on a spiral centered at 50.3° S, 72.3° W with a two-nautical-mile (NM) radius. The FR's position to be simulated is specified in WGS-84 which is aligned with the international terrestrial reference frame (ITRF-2000). This is an Earth-centered Earth-fixed (ECEF) reference frame. The x, y, and z coordinates, velocities, and accelerations are specified for each 0.1-second time step and fed into the simulator. This trajectory started at a static position two NM East of the reference position for the first two minutes, with zero altitude relative to the surface of the WGS-84 ellipsoid. Then the simulated aircraft accelerated northward to 60 knots and then upwards to 3,000 feet per minute. The reference trajectory included pauses at 1 km increments on ascent, where the vertical velocity was zeroed out for 30 seconds and then reset to an upwards value of 3,000 feet per minute. After reaching an altitude of 30 km, the simulated aircraft circled at that altitude for 30 seconds and then accelerated downward to 3,000 feet per minute. It continued this downward spiral until again reaching zero altitude. It then circled at zero altitude and 60 knots for one minute.

The reference altitude is shown in Figure 1. This altitude is obtained by taking the x, y, and z coordinates that were sent to the simulator and converting them to an equivalent latitude, longitude and altitude referenced to the WGS-84 ellipsoid.

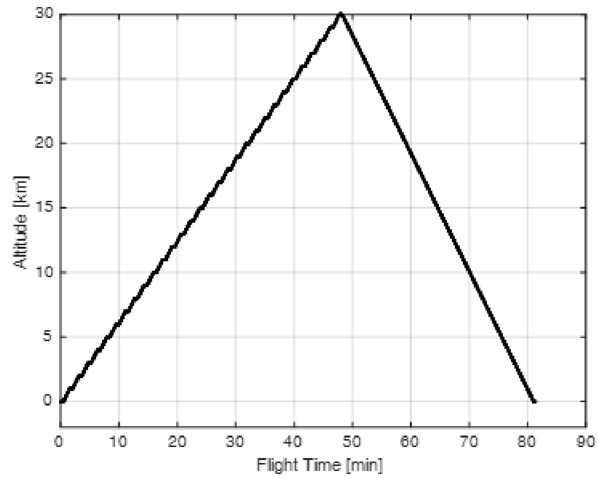

Figure 1: Simulated (reference) trajectory from GPS Time 1,148,515,200 seconds (Week 1899 Second 0)

The recorded trajectory from the FR for this simulation was then compared against the reference trajectory. The altitude error, calculated as recorded minus reference, is presented in Figure 2. The altitude from the FR was recorded into a file named 65TV7RA4.igc.

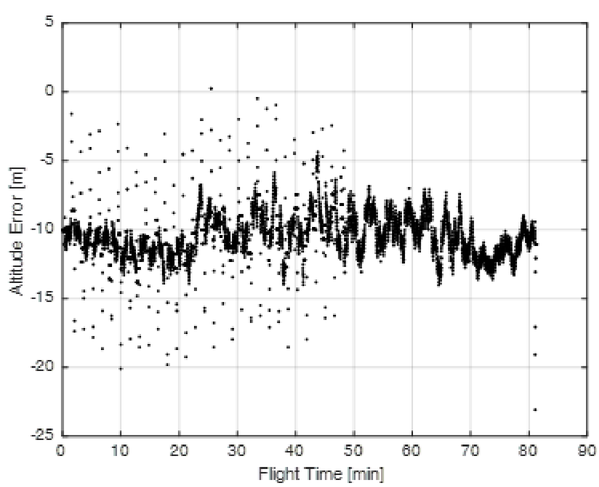

Figure 2: Altitude error in meters from GPS Time 1,148,515,200 seconds (Week 1899 Second 0). Error is calculated as recorded minus reference.

Figure 3 shows the reference altitude error as a function of the reference altitude. Note that there are spikes in the error that correspond to the times of transition in the simulated trajectory when it abruptly changes its upward velocity between 3,000 feet per minute and 0.

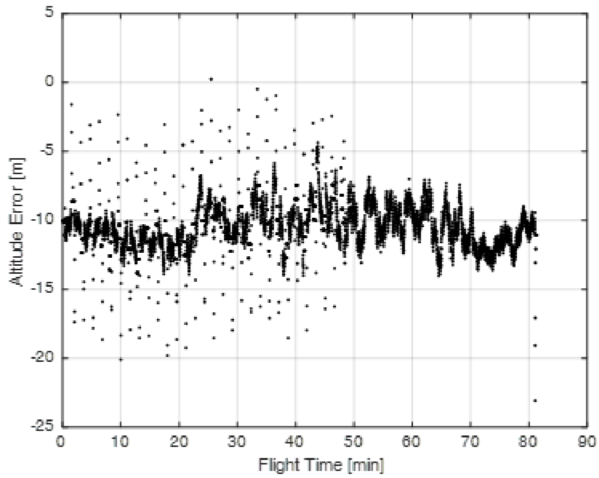

Figure 3: Altitude error as a function of reference altitude

Figure 4 shows the observed differences at the times when the upward velocity was zero. The first five seconds at each altitude step are removed to allow the receiver tracking to recover from the rapid acceleration in the simulated trajectory. The error bars reflect a two-sigma or 95% expected uncertainty. The tabulated version of this data is shown in Table 2.

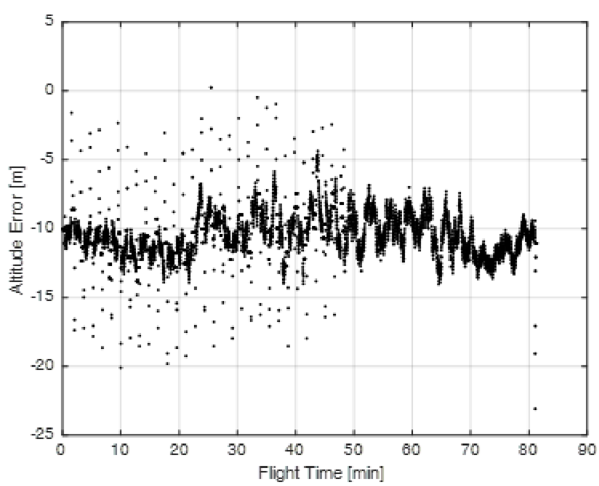

Figure 4: Altitude error showing error bars at 1km increments

Table 2: Tabulated corrections for FR 7RA

Test Organization:	Stanford University Space Rendezvous Lab		
Date of Testing:	11/9/18	**IGC filename:**	65TV7Ra4.igc
Head of Test Team:	Simone D'Amico		
Signal Generator Type:	IFEN NavX-NCS Professional		
SigGenSpecification:	https://www.ion.org/ptti/upload/files/1404_NavX-NCS-PRO_Datasheet_Letter.pdf		
Simulation Date:	5/29/2016		
HAFR Type:	LX9000	**Serial Number:**	7RA

Signal Generator Altitude [m]	IGC File [m]	Correction [m] to be applied to IGC File:
1.073	-9.063	-10.135
1001.61	992.818	-8.792
2001.356	1989.455	-11.901
3001.098	2990.591	-10.916
4000.841	3909.591	-11.25
5000.586	4987.905	-12.681
6000.331	5990.045	-10.286
7000.074	6988	-12.073
7999.816	7986.545	-13.27
8999.562	8988.545	-11.016
9999.306	9988.909	-10.397
10999.048	10988.364	-10.685
11998.791	11986.591	-12.427
12998.536	12986.591	-11.946
13998.281	13987.19	-11.091
14998.024	14987.909	-10.115
15997.767	15988.476	-9.29
16997.512	16987.727	-9.785
17997.257	17985.81	-11.448
18996.999	18987.545	-9.454
19996.741	19984.909	-11.833
20996.487	20988.909	-7.578
21996.232	21985.955	-10.756
22995.974	22985.955	-10.02
23995.974	23983.364	-12.354
24995.463	24987.182	-8.281
25995.207	25984.5	-10.707
26994.95	26985.524	-9.426
27994.693	27984.045	-10.647
28994.438	28986.227	-8.211
29994.438	29985.318	-8.865

Based on these results, the FR has been successfully validated post-flight as it is still producing valid GPS altitude to at least 30 km above the WGS-84 ellipsoid within 15m of error.