Pterosoar Position and Altitude Verification

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Section 1: Introduction

Pterosoar is intended for operations at McGill University, which is within the CYUL Class C airspace. As a result, for compliance with the CARs and Standard 922 (relevant sections included in Section 2), position and altitude verification testing were conducted. Test methodology and results are presented in Section 3. Pterosoar has demonstrated that it meets the position and accuracy requirements outlined in the CARs and Standard 922.

This verification testing was conducted using the Here3 GPS. Pterosoar has the option of using the add-on RTK base station from Here that is designed to work with the Here3. No modifications to the drone itself are required for RTK mode. In RTK mode, Here states a GPS accuracy improvement of two orders of magnitude over the standard Here3.

Section 2: Regulatory References

CARs

901.69 (1) Subject to subsection (2), no pilot shall operate a remotely piloted aircraft system under this Division to conduct any of the following operations unless a declaration under section 901.76 has been made in respect of that model of system and the certificate of registration issued in respect of the aircraft specifies the operations for which the declaration was made:

(a) operations in controlled airspace;

(b) operations at a distance of less than 100 feet (30 m) but not less than 16.4 feet (5 m) from another person except from a crew member or other person involved in the operation, measured horizontally and at any altitude; or

(c) operations at a distance of less than 16.4 feet (5 m) from another person, measured horizontally and at any altitude.

901.76 (1) For each model of remotely piloted aircraft system that is intended to conduct any of the operations referred to in subsection 901.69(1), the manufacturer shall provide the Minister with a declaration in accordance with subsection (2), except in the case of a model referred to in subsection 901.69(2) and that is intended to conduct any of the operations referred to in that subsection.

(2) The manufacturer's declaration shall

(a) specify the manufacturer of the remotely piloted aircraft system, the model of the system, the maximum take-off weight of the aircraft, the operations referred to in subsection 901.69(1) that the aircraft is intended to undertake and the category of aircraft, such as a fixed-wing aircraft, rotary-wing aircraft, hybrid aircraft or lighter-than-air aircraft;

(b) indicate that the manufacturer

(i) declares that it meets the documentation requirements set out in section 901.78, and

(ii) has verified that the system meets the technical requirements set out in Standard 922 — *RPAS Safety Assurance* applicable to the operations referred to in subsection 901.69(1) for which the declaration was made.

(3) The manufacturer's declaration is invalid if

(a) the Minister has determined that the model of remotely piloted aircraft system does not meet the technical requirements set out in the standard referred to in subparagraph (2)(b)(ii); or

(b) the manufacturer has notified the Minister of an issue related to the design of the model under section 901.77.

901.79 (1) A manufacturer that has made a declaration to the Minister in respect of a model of remotely piloted aircraft system under section 901.76 shall keep, and make available to the Minister on request,

(a) a current record of all mandatory actions in respect of the system; and

(b) a current record of the results of, and the reports related to, the verifications that the manufacturer has undertaken to ensure that the model of the system meets the technical requirements set out in the standard referred to in subparagraph 901.76(2)(b)(ii) applicable to the operations for which the declaration was made.

(2) The manufacturer shall keep the records referred to in subsection (1) for the greater of

(a) two years following the date that manufacturing of that model of remotely piloted aircraft system permanently ceases, and

(b) the lifetime of the remotely piloted aircraft that is an element of the model of system referred to in paragraph (a).

Standard 922 – RPAS Safety Assurance

922.04 Operations in Controlled Airspace

Information Note: These technical requirements are applicable to RPAS declarations for operations referred to in paragraph 901.69(1)(a) of the CARs.

Information Note: The required accuracy for operations within controlled airspace is identified for purposes of communications with other users of the airspace (e.g. control tower) in order to provide a minimum confidence related to the altitude and position reports from an RPAS pilot.

Required Accuracy

(1) The remotely piloted aircraft system must have a lateral position accuracy of at least +/- 10 m while operating within the controlled airspace.

(2) The remotely piloted aircraft system must have an altitude accuracy of at least +/- 16 m while operating within the controlled airspace.

Advisory Circular 922-01: Remotely Piloted Aircraft Systems Safety Assurance

6.1 Operations in controlled airspace

(1) **General.** For RPAS operating in controlled airspace CAR Standard 922.04 requires that design requirements are met to allow for communication of position and altitude to air traffic controllers and other participant aircraft with the specified level of accuracy. While it is acknowledged that accuracy requirements alone do not provide any additional robustness or system reliability objectives, the intent is to provide a minimum required accuracy for position and altitude such that other users of the airspace are accurately made aware of any potential hazard the RPA may pose.

(2) **Position Accuracy**. A system position accuracy of +/-10m has been identified as the minimum accuracy for position within controlled airspace. Most modern Global Navigation Satellite System (GNSS) technologies can easily achieve this accuracy nearly 100% of the time. Considerations should be taken to ensure that this accuracy can be maintained while in degraded modes of operation, and in all portions of the proposed operational space (e.g. considerations for buildings, trees, valleys etc.). The accuracy should be clearly identified in the limitations portions of the operating manual.

(3) **Altitude Accuracy**. A system altitude accuracy of +/- 16m has been identified as the minimum accuracy for altitude within controlled airspace. Most modern GNSS technology can achieve this accuracy using the WGS-84 geodetic datum. Consideration should be taken when designing altitude measurement systems that differences between ground level, sea level, and various geodetic datum are taken into account.

(4) **Errors**. Accuracy is a probabilistic measurement based on assumptions related to the quality and integrity in a constantly changing environment. It is important to understand the errors that may contribute to degradation of accuracy and take these into account as part of the overall design error budget. Examples of sources of errors adversely affecting accuracy are identified below.

(a) **Terrain Errors**. GNSS signals are also subject to errors caused by the terrain. Terrain masking of the signal, for example by a building or mountain, blocks the antenna on the RPAS from receiving the satellite signal. A GNSS signal reflected by the landscape such that the receiver now receives "additional" signals which can create confusion and may need to be processed out to avoid creating position errors.

(b) **Atmospheric Errors**. Atmospheric errors are caused by the Ionosphere and the Troposphere, which are both capable of refracting GNSS radio signals. Ionospheric Density is diurnally dependent, which means that it varies with time of day (or night). The density is affected by, among other factors, humidity, temperature and pressure. These variations adversely affects the "signal speed x time" equation built into GNSS position calculations. To correct for these errors, a number of steps are taken. Troposphere errors can be caused by moisture absorbing/refracting signal and cause errors up to 6m. Ionosphere errors can be caused by the atmospheric refraction of the GNSS signals and may be up to 40-60 m by day and 6-12 m at night. These errors can be mitigated by the use of multi-frequency receivers, selection of masking angle, and/or the use of augmentation systems (either ground-based, such as Local Area Augmentation System [LAAS], or space-based, such as European Geostationary Navigation Overlay Service [EGNOS]).

(c) **Satellite Errors**. These are errors resulting from poor or unexpected geometries related to the positions of the GNSS satellites in reference to an RPAS. Gravitational effects of the Sun and Moon may pull the SV from planned orbital path. Solar Radiation creates EMI prior to the signal hitting the atmosphere.

(d) **Geometric Dilution of Precision (DOP)**. DOP occurs when there is no adequate cross cut in the "fix" (i.e. all satellites are all too closely located to each other). The consequence is that all of the signals are vulnerable to same errors from the atmosphere. Errors can occur in the horizontal (H), the vertical (V) and in time (T).

Section 3: Test Methodology, Data, and Analysis/Results

Test Methodology

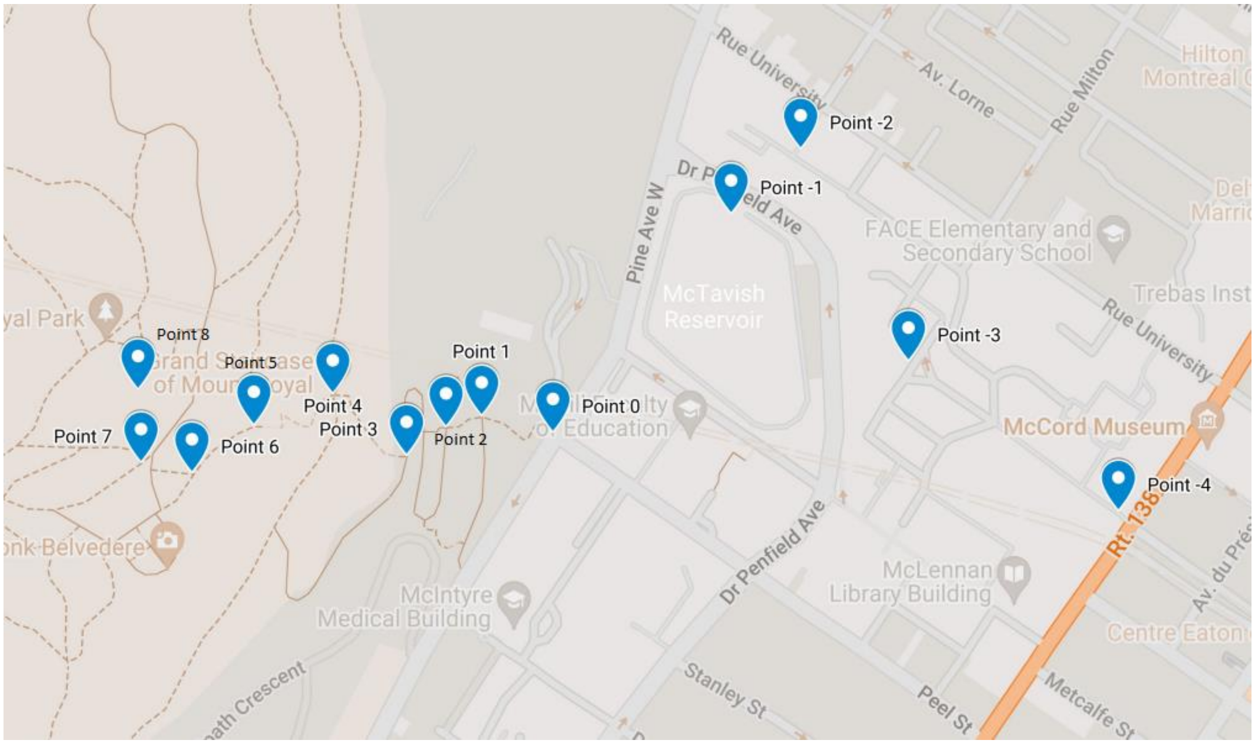
Pterosoar was hand-carried to 13 locations at the McGill downtown campus and up Mount Royal, see the below map outlining the test points. At each location, the GPS position, GPS altitude, and barometric altitude were recorded.

GPS position was checked against Google maps, and altitudes were checked against a topographic map of Montreal located at https://en-ca.topographic-map.com/maps/fwea/Montreal/. This topographic map uses a data set published in Geophysical Research Letters Volume 44, 2017.[1]

1. Yamazaki D., D. Ikeshima, R. Tawatari, T. Yamaguchi, F. O'Loughlin, J.C. Neal, C.C. Sampson, S. Kanae & P.D. Bates. A high accuracy map of global terrain elevations. Geophysical Research Letters, vol.44, pp.5844-5853, 2017. https://agupubs.onlinelibrary.wiley.com/doi/full/10.1002/2017GL072874

The test points covered an altitude band of 501ft, which exceeds the 400ft AGL altitude limitation for RPAS.

Note: GPS altitude is the MSL altitude. The Pterosoar flight controller reports barometric altitude relative to where the flight controller was powered on.



Pterosoar GPS/altitude verification test locations

Data

Position and altitude verification test data is presented in the below tables.

Position Verification					
Point #	Map lat	Map long	GPS lat	GPS long	GPS Error (m)
-4	45.50388	-73.57485	45.50393	-73.57495	9.8
-3	45.50522	-73.57748	45.50514	-73.57730	16.6
-2	45.50710	-73.57889	45.50712	-73.57901	9.6
-1	45.50651	-73.57974	45.50654	-73.57963	9.2
0	45.50457	-73.58200	45.50458	-73.58194	4.8
1	45.50472	-73.58290	45.50475	-73.58288	3.7
2	45.50462	-73.58335	45.50455	-73.58332	8.1
3	45.50437	-73.58385	45.50432	-73.58378	7.8
4	45.50492	-73.58478	45.50500	-73.58483	9.7
5	45.50464	-73.58578	45.50458	-73.58585	8.6
6	45.50422	-73.58657	45.50417	-73.58658	5.6
7	45.50430	-73.58716	45.50424	-73.58710	8.2
8	45.50496	-73.58725	45.50495	-73.58736	8.7

GPS position verification test data

Altitude Verification						
Point #	Map alt (m, MSL)	GPS alt (m, MSL)	GPS alt error (m)	Map relative alt (m)	Baralt relative alt (m)	Baralt error (m)
-4	54	58.2	4.2	-46	-52.8	6.8
-3	61	60.8	0.2	-39	-44.2	5.2
-2	70	71.6	1.6	-30	-36.5	6.5
-1	76	76.3	0.3	-24	-22.9	1.1
0	100	100.9	0.9	30	37.7	7.7
1	111	111.6	0.6	41	54.4	13.4
2	118	118.7	0.7	48	58.9	10.9
3	122	122.1	0.1	52	69.1	17.1
4	140	142.6	2.6	70	83.2	13.2
5	167	172.4	5.4	97	123.7	26.7
6	193	193.6	0.6	123	138.6	15.6
7	199	201.6	2.6	129	143.4	14.4
8	207	206.4	0.6	137	150.7	13.7

GPS and barometric altitude verification data

Analysis/Results

GPS Position

GPS position error was calculated by the great-circle distance between the map data point and the GPS data point using the haversine formula.

Data point -3 was taken directly in front of the Arts building at the McGill downtown campus. It is likely that terrain masking as discussed in AC922-01 (and presented in Section 2) in the form of buildings blocking the GPS signal occurred.

Removing data point -3 due to the poor GPS environment, the GPS position accuracy was measured to be, to a 95% confidence level, 7.8m +/- 1.3m.

The measured GPS position error meets the 10m requirement of CAR 901.69, 901.76, and Standard 922.

Points -4, -2, and 4 also have relatively high GPS position errors. Point -4 is located at the McGill downtown main gate on Rue Sherbrooke and point -2 is located adjacent to the Rutherford physics building at the McGill downtown campus; both are in a somewhat similarly poor GPS environment to point -3 (but do have better sky visibility). Point 4 is directly next to the Mount Royal grand staircase, located on a nearly sheer cliff-face of the mountain. Terrain masking was likely occurring at these points. The need to consider terrain masking of the GPS signal is included in the Pterosoar operations manual as a result of this testing.

GPS Altitude

GPS altitude error was calculated by the difference between the map altitude and the GPS altitude.

The average GPS altitude error was measured to be, to a 95% confidence level, 1.6m +/- 1.0m.

The measured GPS altitude error meets the 16m requirement of CAR 901.69, 901.76, and Standard 922.

Barometric Altitude

Barometric altitude error was calculated by the difference between the map relative altitude and the barometric relative altitude

The average barometric altitude error was measured to be, to a 95% confidence level, 11.6m +/- 3.9m.

The measured barometric altitude error meets the 16m requirement of CAR 901.69, 901.76, and Standard 922.

> **Note**: For points -4, -3, -2, -1: the flight controller was reset at point 0, so the map and barometric relative altitudes are relative to point 0.
>
> For points 0 to 8: the flight controller was reset at point -2, so the map and barometric relative altitudes are relative to point -2.

Points -4 to -1 have lower errors than the remaining points. These points were re-taken at the end of testing due to data quality concerns, and the flight controller (and baralt) was reset at point 0. These points were measured over a short time period of approximately 20 minutes. The other data points were measured during a climb up Mount Royal over approximately 2 hours. It is likely that the local barometric pressure (i.e. the local altimeter setting) was changing over the 2 hour period of points 0 to 8, but would not have changed as much during the 20 minute period of points -4 to -1. As a result, there is lower error for points -4 to -1. The Pterosoar operations manual includes a note to update the QNH barometric altimeter parameter or cycle flight controller power prior to each flight during extended operations as a result of this testing.

Point 5 appears anomalous (as does data point 3 to a lesser degree; the same analysis applies). It is possible a gust of wind affected the flight controller's MS5611 barometric pressure sensor, or there may have been a momentary lapse of the sensor. Removing point 5 as an anomalous data point, the barometric altimeter error was measured to be, to a 95% confidence level, 10.5m +/- 3.1m. This meets the 16m requirement of CAR 901.69, 901.76, and Standard 922.

Conclusions

Pterosoar has demonstrated that it meets and in fact surpasses the position and altitude requirements of the CARs and Standard 922. This report will be kept on file in accordance with CAR 901.79.