

# Portable device to assess dynamic accuracy of global positioning system (GPS) receivers used in agricultural aircraft

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**Abstract:** A device was designed to test the dynamic accuracy of Global Positioning System (GPS) receivers used in agricultural aircraft and other aerial vehicles. The system works by directing a sun-reflected light beam from the ground to the aircraft using mirrors. A photo detector points downward from the aircraft to detect the light beam, and photo detection circuitry triggers an event in the guidance system data file at the aircraft's location corresponding to the precisely georeferenced position on the ground. Construction details are presented on the mirror-based light reflection system and photo-electronic circuitry designed to trigger an event in the guidance system's log file. An example application evaluated the horizontal accuracy of a stand-alone GPS receiver by matching dynamic data with data from the aircraft's guidance system. Results indicated a 2.16 s lead in position registered by the stand-alone receiver over that registered by the aircraft's guidance system GPS receiver, which had been previously evaluated to be within 0.13 s of Real-Time Kinematic (RTK)-referenced time and position.

**Keywords:** GPS receiver accuracy, agricultural aircraft, aerial application, remote sensing, georeferencing, UAV

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## 1 Introduction

Aerial vehicles used for crop spraying and remote sensing rely on Global Positioning System (GPS) receivers for swath guidance, locating field boundaries for termination of spray, camera triggering, triggering remote sensing cameras, and support of integrated guidance functions that are essential components of Unmanned Aerial Vehicles (UAVs). Swathing systems for agricultural aircraft have recently been adapted for use in variable-rate aerial application of field-applied chemicals such as insecticides, cotton growth regulators, and defoliants<sup>[1]</sup>. These swathing systems typically use

GPS receivers to supply positioning information needed for automatic flow control and pilot guidance. Agricultural aircraft typically travels at speeds of up to 70 m/s, necessitating rapid response to changing flow requirements for variable-rate application<sup>[2]</sup>. These requirements may also involve simply shutting off flow when the aircraft arrives near a field border to prevent off-target application of spray. Errors in application involve GPS positioning error, control system response lags, and spray pump lags caused by the need to overcome static condition of the spray mix<sup>[3]</sup>.

Because of difficulty in matching GPS records to known position at high ground speeds, it was determined that quantifying dynamic GPS positioning error in agricultural aircraft would require special methodologies. These methods would need to exploit the capabilities inherent in the aircraft GPS receiver for rapid logging of liquid flow, which is a requirement for pinpointing field locations that correspond to flow events<sup>[3]</sup>. If the airplane's position could be recorded the instant the plane

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flew over an accurately defined position reference, deviations from ground reference due to positioning error could be quantified separately from errors due to the other flow control factors. This could be useful when automatically adjusting liquid flow according to field position. Then, sources of error could be analyzed and corrective measures could be taken where feasible.

To determine accuracy of the GPS receiver used in the aircraft's guidance system, a device was developed to be triggered over a ground location pinpointed by Real-Time Kinematic (RTK)-GPS and simultaneously transmit a record to the guidance system's log file. Position of the triggered event was logged to 1/100 s in the data file as interpolated within the receiver's position updating interval at constant ground speed. Use of this triggering device to determine accuracy of the AgJunction Satloc<sup>®</sup> Airstar M3 GPS-based guidance system has previously been accomplished by Smith and Thomson<sup>[4]</sup>. Results indicated that position latency was positive for N-S flight directions and negative for E-W flight directions. The magnitude of these latencies was less than 9 m at nominal ground speed of 60 m/s. GPS ground speed calibration results revealed errors ranging from 0.01% to 0.11% over a wide range of ground speeds.

In addition to the on-board swath systems, many new applications require the use of outboard GPS receivers to trigger remote sensing cameras or other devices. These GPS receivers need to be evaluated for their suitability in aircraft applications such as automatically triggered multispectral cameras<sup>[5]</sup>. This paper describes mechanical design of the light beam reflecting system and electronics of a portable version of the triggering system. Example data obtained illustrates the system's utility for determining the accuracy of stand-alone GPS receivers used in parallel with the guidance GPS in an Air Tractor 402B aircraft.

## 2 Materials and methods

### 2.1 Development of triggering device

To meet needs for determining ground position accurately, a method was conceptualized to detect a vertical beam of light at an RTK-specified GPS position

and use this beam to trigger a positioning event in the log file of the aircraft's GPS receiver. While conceptualizing this system, a method by which a high intensity light beam directed upward across from a stand-alone sensitive detector was investigated, but light intensity was not bright enough to overcome interference from much brighter daylight. In the end, a ground-based spotting system was developed using two strategically placed mirrors to reflect sunlight to the belly of the aircraft when the plane passes over a ground reference point. This method proved to be successful and assured adequate light intensity with an ample field of transmission to allow for the pilot being slightly off-center in flight. A diagram of the concept is illustrated in Figure 1.

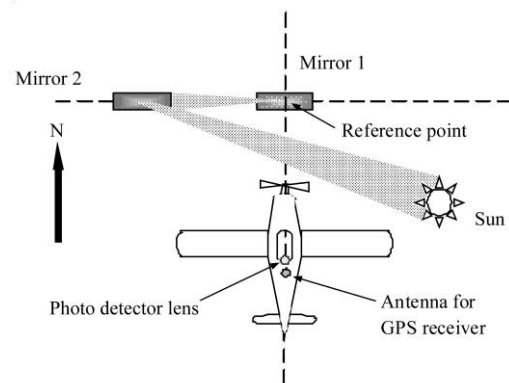


Figure 1 System for determining GPS position error for agricultural aircraft. Mirror 2 is adjusted so that the reflected light impinges on Mirror 1, which is then reflected upward to the belly of the aircraft, triggering an event in the GPS log file

Figure 2 illustrates how the light reflecting system was implemented in practice. Protocol for adjustment is indicated below:

- 1) A person sitting on the truck adjusts Mirror 2 so that the reflection impinges on Mirror 1.
- 2) To assure accuracy of the positioning evaluation device, the light beam impinging on the aircraft's sensor must be exactly vertical. A reference device to accomplish this uses a plumb-bob attached to a horizontal plate fastened to a long pole (Figure 3). The plate is adjusted horizontally until the plumb-bob is exactly over the geo-located point on the ground.
- 3) Mirror 1 (Figure 4) is adjusted until the light beam is centered on the horizontal plate. Thumbscrews are then tightened on Mirror 1.

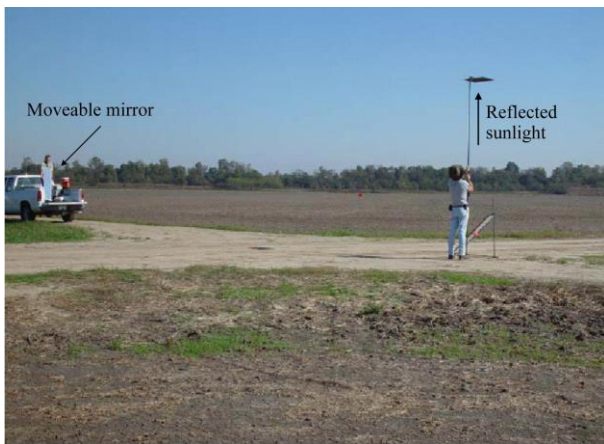


Figure 2 Mirror-based system to reflect sunlight to the aircraft. The moveable mirror is referenced as Mirror 2; the mirror over which the aircraft flies is Mirror 1

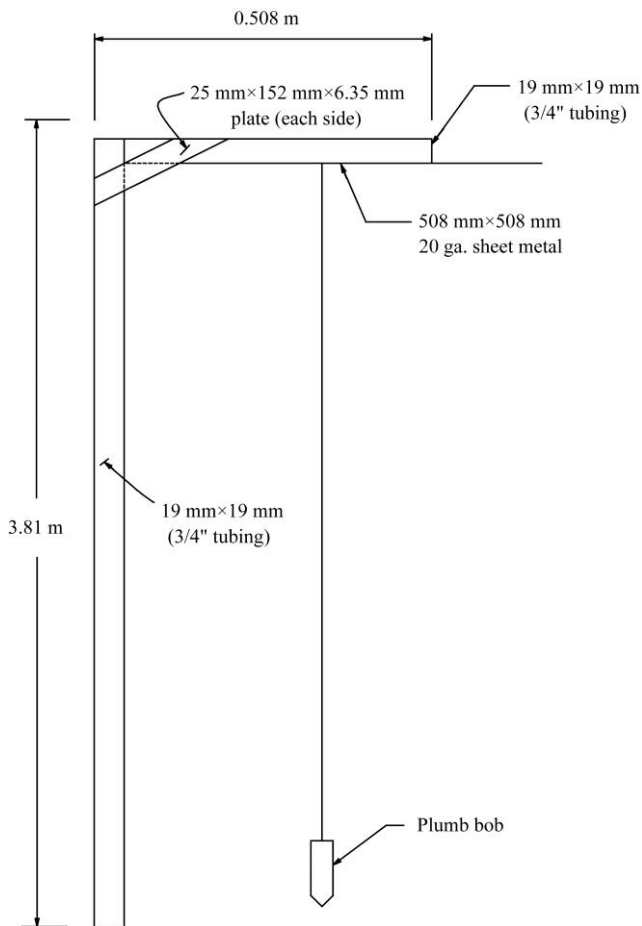


Figure 3 Centering plate and plumb-bob used to assure vertical beam to the aircraft

## 2.2 Global positioning system

An Air Tractor 402B agricultural aircraft was used as the test vehicle. This aircraft is equipped with the AgJunction Satloc<sup>®</sup> Airstar M3 swathing system using Wide Area Augmentation System (WAAS) differential correction for aircraft guidance and support of map-based flow control. The normal data logging interval for our

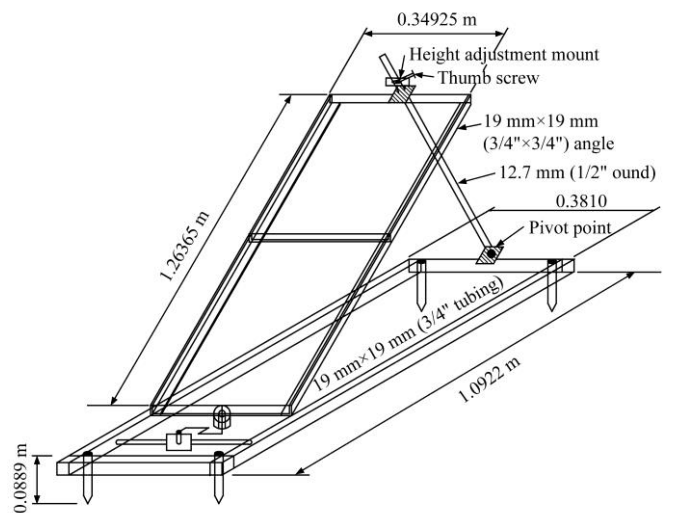


Figure 4 Mirror and stand used for directing light beam to the aircraft

setup was 0.2 s and the time associated with these records was recorded to the nearest second. However, extra records are inserted in response to a triggered event, in this case from a pressure switch that detects commencement of flow to the spray boom. These time records have a 0.01 s precision.

## 2.3 Light detection circuitry

A light-detection circuit (Figure 5) was designed to trigger a logged positioning event in place the pressure switch used to log commencement of flow. In this case, light detection could terminate the simulated spray (open relay) as well as initiate spray (close relay). Since only one reference point was used for position latency measurements, the circuit was designed to automatically reset 14.45 s after it was triggered in preparation for the next pass over the reference point. A check of GPS ground speed could also be made by using two reference points positioned a known distance apart. Circuit operation was initiated by flying over a reference point so that the vertical light beam triggered the photo detector (Q1, Figure 5) and caused a three-second pulse to be applied to the control “flip-flop” (U7B) by the “one-shot” (U8A). The rising edge of this pulse toggled the state of the “flip-flop”, which caused the relay (K1) to close and allowed counter U3 to begin counting. The “AND” gate (U4A) changed state at a count of 896 (equivalent to 14.45 s for a 62 Hz clock), and automatically reset the state of the control “flip-flop” at that time. This “reset” state of the flip-flop opened the relay, reset the U3

counter to zero and inhibited counting on U3. Maximum propagation time required to close the relay after sensing the light beam was 175 micro-seconds. A second trigger could be achieved anytime between the dissipation of the initial 3-second pulse and the automatic reset. A second trigger would toggle the state of the “flip-flop” back to its “reset” state (relay open and counter inhibited) and cause the Satloc<sup>®</sup> system to insert an extra record into the data log containing the precise position and time associated with the second reference point. Time lapse required between two reference points and measured distance between the points could be

used to compute the average ground speed of the plane. Average GPS ground speed from the data log could be computed by numerically integrating the area under the Speed vs. Time curve and dividing by the elapsed time. This feature was used by Smith and Thomson<sup>[4]</sup> to verify ground speed calibration. The pilot was able to verify a triggered event by setting up the Satloc<sup>®</sup> system to display accumulated spray time on the light bar and observing an increase in the displayed value each time the light detector was triggered. The pilot could then signal a successful triggering back to the ground by radio or smoker.

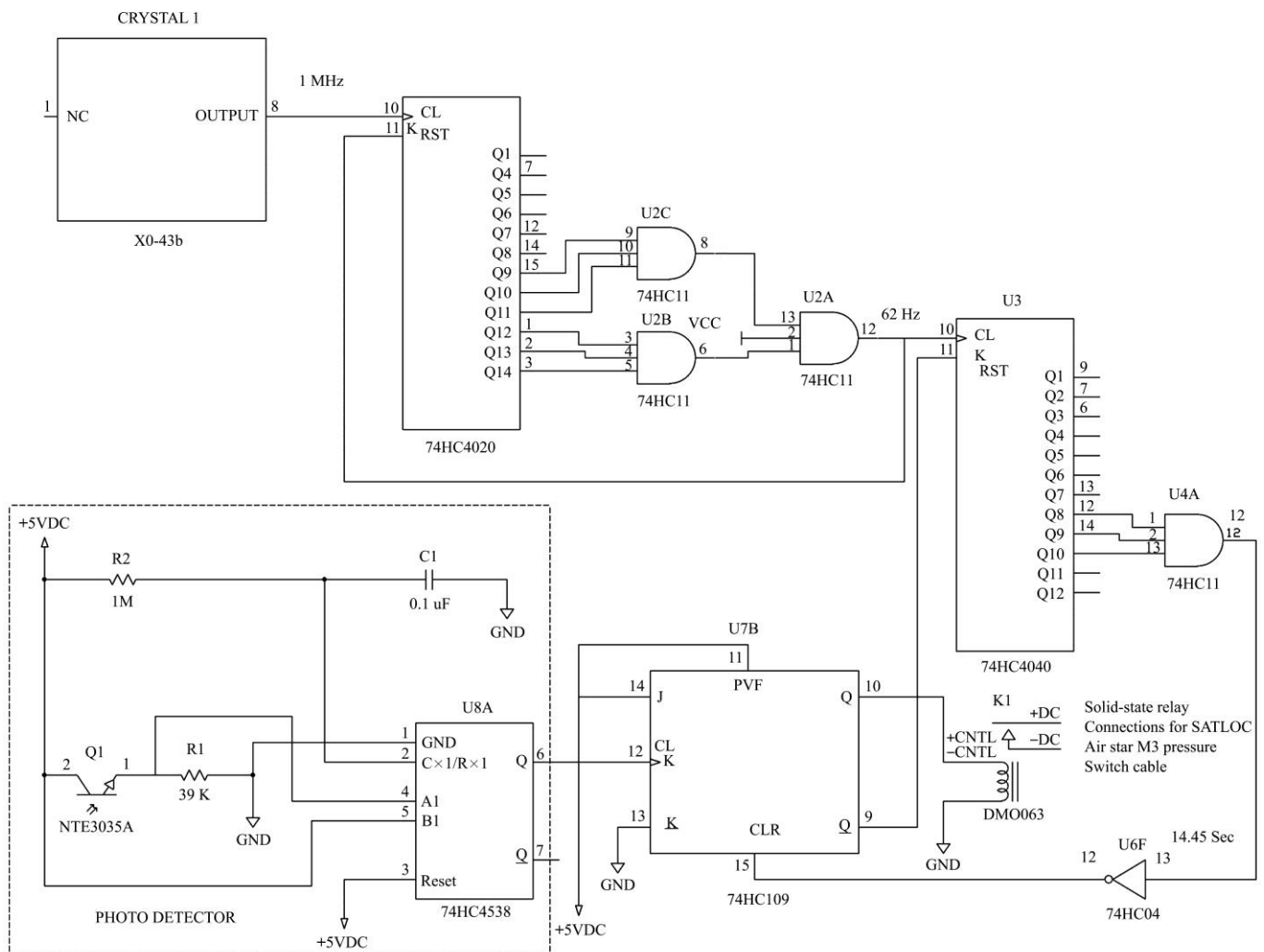


Figure 5 Light detection and triggering circuitry

**2.4 Evaluation of stand-alone GPS receiver accuracy**

Determination of stand-alone external GPS receiver accuracy first required evaluation of the Satloc<sup>®</sup> guidance receiver, used in parallel with an external receiver under test. This prerequisite evaluation was needed because of typical updating limitations of the external receivers (1-s

in our case) and the inability to use external triggers and log event records with most of these receivers. Satloc<sup>®</sup> guidance system accuracy was thus evaluated using the spotting device<sup>[4]</sup>, and these results could be used as a basis for comparison with data from stand-alone (external) GPS receivers. Results indicated that ground position

lagged the ground reference point by an average of  $-4.53$  m (SD =  $0.68$  m, SD – Standard Deviation) in the east-west directions and led the reference point in the north-south directions by an average of  $+7.88$  m (SD =  $0.52$  m) over 16 total runs (four in each direction). All tests over the five-week period exhibited these consistent, directionally dependent patterns. A position error of  $7.88$  m corresponds to a time error of  $0.13$  s at  $60$  m/s forward speed. This error was acceptable in our view, thus providing good basis by which to evaluate stand-alone GPS receivers.

An experiment was conducted to evaluate positioning error of a Lowrance Airmap<sup>®</sup> 1000 GPS receiver, since it was being considered a potential candidate for triggering our remote sensing cameras. To accomplish evaluation of stand-alone GPS receivers, a GPS data acquisition program was written in QuickBasic 4.5 for an MS-DOS based HP200LX palmtop. The program was written to read any NMEA data string desired from the serial port, parse the data, and send position and time stamp data to an external CF memory card. Any GPS receiver could be connected to this palmtop and placed in the aircraft, along with an appropriate external antenna placed inside the windshield. In our case, positioning data were obtained from the \$GPRMC data string.

Four flights in four directions each (North, South, East, West) were conducted on four different days while operating the AgJunction Satloc<sup>®</sup> GPS system<sup>[6]</sup> on 04 April, 2003. The Airmap<sup>®</sup> GPS receiver and Palmtop were activated to acquire data and placed inside the cockpit. The airplane was flown at an approximate  $3.0$ -m height directly over a ground target referenced using a Rockwell Collins PLGR+ and verified using a Trimble MS750 RTK receiver with a Sitenet 900 base radio. The former used the military PPS (Precise Positioning Signal) to obtain a position fix<sup>[7]</sup> but has since been de-commissioned at our location. Runs conducted on the final day of testing were diagonal and indicated a composite of longitudinal and latitudinal accuracy (Northeast - NE, Southeast - SE, Southwest - SW, and Northwest - NW).

After the flights, time stamps from the Airmap<sup>®</sup>

receiver were matched with time stamps from the output file of the Satloc<sup>®</sup> and converted to text files using the Satloc<sup>®</sup> Mapstar<sup>®</sup> program so positioning error could be determined. In a similar fashion, differences in time could be determined by matching dynamic data from both GPS log files. Position Heading (or direction) was a good variable to verify matching as it changed continually during aircraft runs. Heading curves for the two GPS receivers were plotted in the spreadsheet and the two heading curves were superimposed. The corresponding times were then noted for the Satloc<sup>®</sup> guidance GPS and stand-alone GPS receiver being tested (in this case, the Lowrance Airmap<sup>®</sup>). Position information was then in the same row so differences in location could be determined.

### 3 Results and discussion

Table 1 illustrates positioning accuracy data for diagonal runs for the stand-alone Lowrance Airmap<sup>®</sup> GPS receiver with reference to the Satloc<sup>®</sup> guidance system as an example.

**Table 1 Positioning accuracy of the Lowrance Airmap<sup>®</sup> GPS compared with the Satloc<sup>®</sup> for diagonal runs**

# of Runs obtained	Ave. GPS time difference/s	range/sec
3 (NW heading)	2.19	0.254
2 (SE heading)	2.08	0.11
3 (SW heading)	2.11	0.047
2 (NE heading)	2.25	0.002

The Airmap<sup>®</sup> GPS receiver showed an average lead of  $2.16$  s over the Satloc<sup>®</sup> at about  $63$  m/s ground speed (four directions). This corresponds to a position difference of  $140$  m, and results over all runs were quite consistent. The range of values for the two or three diagonal runs is also illustrated.

With characteristics of the GPS receiver now indicated, Huang et al.<sup>[8]</sup> evaluated the Lowrance Airmap<sup>®</sup> GPS receiver with a firmware update to automatically trigger a 3-CCD multispectral camera, MS 4100 (Geospatial Systems, Inc., West Henrietta, New York), via Dragonfly navigation software (TerraVerde Technologies, Inc., Stillwater, Oklahoma). This camera triggering scheme was successfully used for a study to assess crop injury caused by the drift from aerially

applied herbicide<sup>[5]</sup>. Position triggering was based on boundaries of an ArcGIS shapefile over corn, soybeans, and cotton that were intentionally stressed by application of glyphosate herbicide. The authors found that triggering over the field occurred consistently at the correct location. A position lead of about 2 s (Table 1) may have thus been desirable from a position triggering standpoint. Previous experience with camera triggering using an airworthy GPS receiver like the Lowrance unit indicates that a lead time of this magnitude should allow triggering at the correct location when an aircraft is within 90 m of the mapped area at a typical ground speed of 45 m/s<sup>[9]</sup>. A lead in triggering could also account for software delays inherent in triggering the multispectral camera for the plant injury study<sup>[5]</sup>.

#### 4 Summary and Conclusions

A device was developed for use in agricultural aircraft to determine position accuracy of GPS receivers used for aircraft swath guidance and stand-alone GPS receivers used to trigger imaging cameras. A vertically-directed light beam triggered an event in the log file of the guidance GPS receiver via a photocell and electronic circuitry as the aircraft flew over a fixed field position specified beforehand by RTK GPS receiver. The directed beam of light was created by an arrangement of mirrors to reflect sunlight vertically to the belly of the aircraft. An example experiment illustrated the system's utility in evaluating positioning accuracy of a stand-alone GPS receiver used to trigger cameras in parallel with the aircraft's guidance system. Positioning accuracy of the guidance system's GPS receiver had been evaluated within 0.13 s of the RTK-specified position to provide a basis for comparing stand-alone receivers. Results indicated an average lead of 2.16 s over the guidance GPS position at a 63 m/s ground speed over four diagonal runs. This corresponded to a position difference of 140 m, and this lead was deemed to be an advantage for triggering a multispectral camera.

The event triggering system described herein does have limitations when evaluating the dynamic accuracy of stand-alone GPS receivers. We were able to evaluate a stand-alone GPS receiver indirectly by comparison with

data from a guidance system GPS receiver; this was suitable for applications with our agricultural aircraft. However, additional modifications would be needed to evaluate stand-alone receivers without the benefit of a guidance system receiver to check against. Newer GPS receivers such as the Garmin 18X<sup>[10]</sup> have a 5 Hz option that allows more frequent updating, and this feature would be useful for determination of position at high ground speeds. A logic level pulse from the triggering device used herein (U7B, Figure 5) could toggle transmission of a data record from the output of a GPS receiver under test. Updating speed of 5 Hz translates to about a 13-m distance resolution at 65 m/s ground speed, but an interpolation scheme developed in microcontroller software and sequenced by the hardware clock could create additional records within that time frame if better resolution was required. This method should be suitable for any aerial vehicle that maintains a constant ground speed.

#### Acknowledgements

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