

NATIONAL TRANSPORTATION SAFETY BOARD

Office of Research and Engineering
Washington, D.C. 20594

August 29, 2018

Aircraft Performance ADS-B and EGPWS Study

by John O'Callaghan

Location: Atqasuk, AK

Date: April 11, 2018

Time: 08:18 Alaska Daylight Time (AKD)
(16:18 Universal Coordinated Time (UTC))

Aircraft: Cessna 208B, registration N814GV

NTSB#: ANC18LA031

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B. GROUP

Not Applicable

C. HISTORY OF FLIGHT

On April 11, 2018, about 08:19 AKD, a single-engine, turbine-powered Cessna 208B airplane, N814GV, impacted snow-covered terrain about two miles north of the Atqasuk Airport, Atqasuk, Alaska (PATQ). The airline transport pilot, the only occupant onboard, sustained minor injuries, and the airplane sustained substantial damage. The airplane was being operated by Hageland Aviation Services, Inc., doing business as Ravn Connect, Anchorage, Alaska, as a visual flight rules (VFR) cross-country cargo/mail flight under 14 Code of Federal Regulations Part 135. Visual meteorological conditions (VMC) existed at the flight's point of departure, and company flight-following procedures were in effect. The flight originated about 07:58, from the Utqiagvik (formerly Barrow) Airport, Utqiagvik Alaska (PABR), and it was destined for Atqasuk, which is located about 58 miles south.

At 08:23, the PATQ Automated Weather Observing System (AWOS) reported a visibility of ½ statute mile in light snow and freezing fog. Ceiling information was missing from the ASOS report, but in a written statement² to the NTSB the pilot stated

At approximately 3 to 4 miles out from PATQ, I recall a cloud layer at approximately 1000-1200 obscuring the village and runway. I formulated a transition from a VFR to an IFR approach plan; DUVFU, the IAP of the RNAV 6. I recall turning direct DUVFU and loading the RNAV 6 approach in the GPS. My intent was to secure a "pop up" clearance from Center, or from Barrow Flight Service if unable to contact Center.

As I reached to change frequencies to Center, the auto pilot disengaged and the aircraft immediately went into an un-commanded steep nose down attitude. I recall being IMC immediately and transitioning attention to the

¹ Local time at Atqasuk on the day of the accident was Alaska Daylight Time (AKD). AKD = UTC - 8 hours. Times in this *Study* are in AKD unless otherwise noted.

² See the public docket for this accident for a copy of the pilot's full written statement.

instruments to bring the aircraft back to level flight. I recall having the yoke back, the plane recovering, but impacting the ground before fully recovered.

This *Aircraft Performance ADS-B and EGPWS Study* presents the results of using Automatic Dependent Surveillance – Broadcast (ADS-B) Global Positioning System (GPS) position and speed data, GPS position and speed data recorded by the airplane's Enhanced Ground Proximity Warning System (EGPWS), the crash site location, surface and upper-air weather information, and performance data for the Cessna 208B to calculate N814GV's position, orientation, speed, and other performance parameters during the accident flight.

These calculations support the following observations:

- N814GV departed PABR runway 7 about 07:59, turned right to a ground track of about 196° (true) for PATQ, and climbed to about 2300 ft. above mean sea level (MSL).
- N814GV leveled at about 2300 ft. at about 08:04, and reached a stabilized groundspeed of about 165 kt. at about 8:06.
- At about 08:17:00, N814GV started a descent from 2300 ft., and a few seconds later made a slight right turn to a ground track of about 216°. During the descent, the groundspeed increased to about 181 kt., and the rate of descent peaked at about 1700 ft./min. The airplane descended below the 1900 ft. minimum altitude at DUVFU³ at about 08:17:17.
- N814GV descended below the floor of ADS-B coverage at about 08:18:28.⁴ The last ADS-B transmission from the airplane was at 08:18:27.8, when the airplane was descending through 850 ft. MSL at about 260 ft./min., at a groundspeed of 168 kt., and turning slightly to the right, with the ground track increasing through 220°.
- Multiple terrain-proximity alerts generated by the airplane's Honeywell EGPWS system shortly before the airplane impacted the ground (see below) triggered the system to retain 24 seconds of GPS-based speed and position information in its non-volatile memory prior to loss of power to the unit. This data was downloaded from the device at the Honeywell facility in Redmond, WA, as described in Reference 1.
- The first EGPWS data point was recorded at 08:18:55.8, or 28 seconds after the last ADS-B transmission. At this point the airplane was descending through 504 ft. MSL at 687 ft./min., the groundspeed was 159 kt., and the ground track was 241°.
- At 08:19:00, N814GV started to roll right, reaching a computed roll angle of about 29° at 08:19:11. Following a brief roll rate reversal, the roll angle increased to about 33° at 08:19:17. Correspondingly, the ground track angle increased from 242° at 08:19:00 to 276° at 08:19:17, passing through the 255° heading direct to DUVFU. The EGPWS recorded track angle at the end of the data was 289°.
- At 08:19:05, N814GV descended through 400 ft. MSL at about 500 ft./min. Shortly after, the descent rate increased, reaching about 2300 ft./min. at 08:19:18.

³ DUVFU is the intermediate fix waypoint for the PATQ RNAV (GPS) RWY 6 instrument approach procedure.

⁴ Per coverage maps provided by the FAA, the ADS-B floor near PATQ is between 500 and 1500 ft. MSL.

- At 08:19:15.8, the first of three EGPWS alerts was triggered. This was a “Mode 1 Pull Up” alert, and would have resulted in an aural “pull up!” warning in the cockpit.⁵
- Two additional EGPWS alerts were triggered at 08:19:16.8 and 08:19:18.8, consisting of “TCF Too Low Terrain” and “TAD Terrain Pull Up” alerts. These alerts would have resulted in aural “too low, terrain!” and “terrain, pull up!” warnings.
- Between 08:19:18.8 and the last EGPWS data point recorded at 08:19:19.8, the recorded rate of descent decreased from 2300 ft./min. to 1460 ft./min. The GPS altitudes recorded at these points were 132 and 82 ft. MSL, respectively. The last recorded groundspeed was 158.5 kt.

The data sources and calculations that support these observations are described in further detail in the sections that follow.

D. DETAILS OF THE INVESTIGATION

I. The Cessna 208B Grand Caravan

The Cessna 208B Grand Caravan (C208B) is a fixed-gear, high-wing airplane powered by a 675 SHP Pratt and Whitney PT6A-114A turboprop engine, and has a maximum ramp weight of 8,785 lbs. N814GV was manufactured in 2002 (per FAA registration records), and was configured with seating for the pilot, co-pilot, and 4 passengers, as well as a belly cargo pod.

Figure 1 presents pre-accident photographs of N814GV. Figure 2 presents three-view diagrams of the C208B, taken from Reference 2. Table 1 provides some dimensions of the airplane, as well as the estimated weight of N814GV at the time of the accident (7,487 lb., which is rounded up to 7,500 lb. for the performance analyses described in this *Study*).

Item	Value
<i>Reference dimensions (from Reference 2):</i>	
Wing area	279.4 ft. ²
Wing span	52.08 ft.
<i>Mass properties for N814GV:</i>	
Empty weight (from Reference 3)	5,254.5 lb.
Pilot	230 lb.
Fuel (75 gal. @ 6.7 lb./gal., measured at accident site)	502.5 lb.
Cargo (per loading manifest)	1,520 lb.
Estimated weight at time of accident	7,487 lb. (rounded to 7,500 lb. for Study)

Table 1. Relevant geometry and mass properties for N814GV.

Information about the airplane’s aerodynamic characteristics, such as the lift coefficient (C_L) as a function of angle of attack (α), are needed to estimate the airplane’s Euler angles (pitch, roll, and

⁵ The switch that directs aural alerts to either the pilot’s headset or the cockpit speaker was found in the “speaker” position after the accident.

heading) throughout the flight. The aerodynamic characteristics for the C208B were provided by Cessna⁶ (now Textron Aviation) during previous NTSB investigations involving this model airplane, and these data are used in this *Study*.

N814GV was ADS-B Out equipped, and ADS-B data from the airplane was recorded by the FAA and provided to the NTSB. This data was used along with recorded EGPWS data to compute the airplane performance information presented in this *Study*. Since there is no radar coverage in the area of the accident, the ADS-B and EGPWS data are the only sources of position data for the airplane. The ADS-B system, and the ADS-B data for N814GV, are described in Section D-III. The EGPWS data is described in Section D-IV.

II. Crash site information

The latitude and longitude coordinates of the crash site were recorded on-scene by NTSB investigators, as follows:

70° 29' 04.8" N, 157° 33' 24.4" W, elevation⁷ 70 ft. MSL

For performance work, it is convenient to express the position of the airplane in a Cartesian coordinate system centered on a relevant reference point. This *Study* uses a north vs. east coordinate system centered on the centerline of the PATQ runway 6 threshold. Latitude and longitude coordinates are converted into this Cartesian system using the WGS84 ellipsoid model of the Earth. The coordinates of the crash site relative to the runway threshold are:

North coordinate: 1.115 nm

East coordinate: -2.085 nm

Total distance from PATQ runway 6 threshold: 2.364 nm

III. Automatic Dependent Surveillance – Broadcast (ADS-B) data

The ADS-B data from N814GV is described and presented in this section, beginning with a brief description of the ADS-B system.

Introduction to the ADS-B system

According to a 2007 “Fact Sheet” published by the FAA,⁸ the “Next Generation Air Transportation System” (NextGen) program “is a wide ranging transformation of the entire national air transportation system - not just certain pieces of it - to meet future demands and avoid gridlock in the sky and in the airports. It moves away from legacy ground based technologies [such as radar] to a new and more dynamic satellite based technology.” A key component of NextGen is the surveillance of aircraft through the Global Positioning System (GPS) satellite constellation instead of by ground radar. This GPS-based surveillance is enabled through the “Automatic Dependent Surveillance – Broadcast” (ADS-B) system. As described in the FAA fact sheet,

Automatic Dependent Surveillance Broadcast (ADS-B) is, quite simply, the future of air traffic control. As the backbone of the NextGen system, it uses GPS satellite signals to provide air traffic controllers and pilots with much more accurate information that will help keep aircraft safely separated in the sky and on runways. Aircraft transponders receive GPS signals and use them to determine the aircraft's precise position in the

⁶ In Cessna document F-208B-1, “Model 208B Performance Documentation.”

⁷ This is the *Google Earth* terrain elevation at the measured latitude / longitude of the crash site.

⁸ See: http://web.archive.org/web/20150403151639/http://www.faa.gov/news/fact_sheets/news_story.cfm?newsid=8145

sky, which is combined with other data and broadcast out to other aircraft and air traffic control facilities. When properly equipped with ADS-B, both pilots and controllers will, for the first time, see the same real-time displays of air traffic, substantially improving safety.

After January 1, 2020, ADS-B Out equipment (that broadcasts the airplane's position to ATC and other aircraft) is required to be installed on all aircraft in the National Airspace System (NAS) operating above 10,000 ft. and within or above Class B and C airspace, with certain exceptions (see 14 CFR 91.225).

Presentation of the ADS-B data

To calculate performance parameters from the ADS-B data (such as groundspeed, track angle, pitch and roll angles, etc.), it is convenient to express the position of the airplane in rectangular Cartesian coordinates. As stated in Section D-II, the Cartesian coordinate system used in this *Study* is centered at the PATQ runway 6 threshold and its axes extend east, north, and up from the center of the Earth. The ADS-B latitude and longitude data are converted into this coordinate system using the WGS84 ellipsoid model of the Earth for plotting and performance calculations. The latitude and longitude of the PATQ runway 6 threshold are:

70° 27' 58.2503" N latitude; 157° 27' 11.8244" W longitude; elevation 100.8 ft.

Figures 3 & 4 show the ADS-B (and EGPWS) data plotted in terms of nautical miles north and east of the runway 6 threshold. Figure 3 shows the entire flight from PABR to the accident site over a *Google Maps* topographical map background. Figure 4 shows the last 3 minutes of flight over a grid background. The inset in Figure 4 shows detail from the end of the flight, depicting the relative positions of the airplane position, the PATQ runway, and the DUVFU and IRIQU waypoints. DUVFU and IRIQU are the intermediate fix (IF) and final approach fix (FAF) waypoints, respectively, for the PATQ RNAV (GPS) RWY 6 instrument approach procedure (see Figure 5) and are also shown in Figure 3. The labels in Figures 3 and 4 indicate the time and airplane altitude corresponding to the location of the labels along the flight path.

In addition to the latitude, longitude, and GPS altitude of the airplane, the ADS-B and EGPWS data also recorded the airplane's GPS-based groundspeed, ground track angle, and rate of climb.⁹ The position of the airplane during the last three minutes of flight was also computed by integrating this velocity data over time, per the theorems of Calculus, and as described in more detail in Section D-V. The resulting position and altitude are depicted by the lines labeled "Integrated path" in Figures 3 and 4, and "True (geometric) altitude" in Figure 7.

The north and east positions of the ADS-B and EGPWS data are shown as a function of time in Figure 6, along with the "integrated path" positions. The altitude of the airplane, as determined from the ADS-B and EGPWS data, is shown as a function of time in Figure 7, along with the integrated altitude. The time parameter recorded in the ADS-B data is in UTC time, and is converted to AKD for presentation in this *Study*.

The terrain elevation depicted in Figure 7 is digital elevation map (DEM) data downloaded from the United States Geological Survey (USGS) "The National Map" interactive web site (see <https://viewer.nationalmap.gov/basic/>).

⁹ The ADS-B data recorded the airplane's north-south and east-west velocities, which combine to define the total groundspeed and ground track angle. The EGPWS data recorded total groundspeed and ground track angle, which can be resolved into north-south and east-west velocities.

IV. Enhanced Ground Proximity Warning System (EGPWS) data

System description

N814GV was equipped with a Honeywell KGP 560 General Aviation Enhanced Ground Proximity Warning System (EGPWS). The “Introduction” section of the KGP 560 *Pilot’s Guide* (Reference 4) describes the system as follows:

The Bendix/King KGP 560 & KGP 860 General Aviation Enhanced Ground Proximity Warning System (GA-EGPWS) brings state-of-the-art technology in Terrain Display, Situational Awareness, Terrain Alerting and Warning, and Obstacle Alerting and Warning to the General Aviation pilot. The KGP 560 & KGP 860 GA-EGPWS is an affordable, extremely lightweight, compact and rugged computer that is easily installed in single- and multi-engine piston aircraft as well as small turboprops and other aircraft.

Based on 30 years experience in the development and advancement of Ground Proximity Warning Systems for Air Transport, Regional and Commuter Airlines, Military aircraft and Corporate aviation, Honeywell brings this vital safety technology to all segments of General Aviation. Using our proprietary world-wide terrain database, obstacle database, runway database, state-of-the-art GPS technology, and proven Terrain Display with Alerting and Warning functions, the system provides the General Aviation pilot with superior situational awareness with respect to terrain and known obstacles. In addition, the system contains the most advanced alerting and warning functionality to warn the pilot of danger with respect to terrain, man-made obstacles and other primary scenarios associated with the dangers of Controlled Flight Into Terrain (CFIT).

Use of a terrain display is optional, but recommended in order to enhance full situational awareness. If a terrain display is not installed in the system, all alerts and warnings are still present.

N814GV was *not* equipped with a terrain display.

Alignment of EGPWS time with ADS-B time

The ADS-B data records a time parameter based on a GPS clock aligned with UTC time. Consequently, the “real-world” clock time at which the ADS-B data was recorded is captured in the data itself. The EGPWS data also records a time parameter, but this is expressed as an “operating time” that is not related to any real-work clock time. To combine the ADS-B and EGPWS data, the time relationship between these data sets must be established. This can be done if a common event is recorded in both sets; however, as noted above, there is a 28 second gap between the last ADS-B record and the first EGPWS record, so the records do not overlap, and there is no common event in the two sets.

Fortunately, the EGPWS also records a takeoff and a landing record during each flight, based on the airplane climbing or descending through a predetermined height above the ground. Since in this case the takeoff is also captured in the ADS-B data, the latitude and longitude of the takeoff record in the EGPWS serves as a common event between the data sets. The real-world clock time corresponding to the operating time of the EGPWS takeoff record is the ADS-B time at which the ADS-B latitude and longitude match the latitude and longitude of the EGPWS takeoff record.

The location of the EGPWS takeoff and landing records are noted in Figure 3. The corresponding time alignment with the ADS-B data is as follows:

12315:25:25.0 EGPWS operating time = 08:04:14.79 AKD ADS-B time

[1]

Recorded alerts

Three terrain-proximity alerts generated by the EGPWS shortly before the airplane impacted the ground triggered the system to retain 24 seconds of GPS-based speed and position information (along with additional system information) in its non-volatile memory prior to loss of power to the unit. This data was downloaded from the device at the Honeywell facility in Redmond, WA, as described in Reference 1. The EGPWS data, and additional parameters computed using that data, are presented in the various Figures throughout this *Study*.

The three terrain-proximity alerts generated by the EGPWS are listed in Table 2:

Time, AKD	Alert label	<i>KGP 560 Pilot's Guide (Reference 4) Section</i>
08:19:15.79	EGPWS MODE 1 PULL UP	Excessive Rate of Descent Alerting and Warning
08:19:16.79	EGPWS TCF TOO LOW TERRRAIN	Runway Field Clearance Floor (RFCF)
08:19:18.79	EGPWS TAD TERRAIN PULL UP	Look-Ahead Alerting and Warning

Table 2. Recorded EGPWS alerts.

The occurrence times of the EGPWS alerts are depicted in the data plots in this *Study* as vertical lines that intersect the horizontal time axes of the plots at the occurrence times. Each line is labeled with its corresponding alert.

The meaning of these alerts, and the conditions that trigger them, are described in the corresponding *KGP 560 Pilot's Guide* sections listed in Table 2. The relevant portions of the *Guide* are cited here:

1. EXCESSIVE RATE OF DESCENT ALERTING AND WARNING (Reference 4 pp. 17-18)

The KGP 560/860 GA-EGPWS uses both GPS Vertical Velocity and pressure altitude to compute vertical velocity information when the aircraft does not provide specific air data for this purpose. In either case, when the aircraft is descending toward terrain at a high rate for its relative altitude above terrain, the system will provide alerting and warning to the pilot. This function is always active. ...

Initially, the voice alert "Sink Rate" will be heard, and the yellow caution alert annunciator lamp will illuminate. If the aircraft continues in the high rate of descent, the "Sink Rate-Sink Rate" voice alert will be repeated at an increasing frequency.

Should the aircraft penetrate the warning boundary, the voice alert "Pull Up" will be heard continuously and the red warning annunciator lamp will illuminate.

In both cases, as the pilot reacts to decrease the high rate of descent and the aircraft flight path exits the alerting/warning envelope, the annunciator lamp will extinguish and the voice alerts will cease.

Sometimes, the alerting and warning functionality for excessive rate of descent may be overridden by the terrain "Look-Ahead" functionality. This is normal as the "Look-Ahead" function has a higher priority in the system alerting/warning logic.

Reference 4 also provides a graph of the protection envelope for Excessive Rate of Descent scenarios. This graph is reproduced here as Figure 9, overlaid with the corresponding data for N814GV (the height of N814GV above the ground is computed by subtracting the terrain elevation from the true altitude, both of which are shown in Figure 7). The top graph in Figure 9 is the full-scale graph presented in Reference 4; the bottom graph is a detail of the area below 600 ft. AGL, and includes time labels on the N814GV data.¹⁰ Note that at 08:19:14, the N814GV data

¹⁰ N814GV data using both the 1 Hz and 2 Hz rate of climb parameters from Figure 8 are shown in Figure 9. Only the 2 Hz data is labeled in the bottom plot of Figure 9. These data are described in Section D-V.

is outside both the “Sink Rate” and “Pull Up” areas, but that the data crosses the “Pull Up” area boundary shortly after 08:19:14.5. Per Table 2, the “MODE 1 PULL UP” alert was recorded about a second later, at 08:19:15.79. As described by Honeywell,¹¹ the system must confirm that the airplane is inside a MODE 1 warning envelope for at least 0.8 seconds before a warning is issued, and that, because of the cycle time of the alert logging process, an alert may be logged up to 1 second later than the time the aural alert was activated in the cockpit. Hence, the EGPWS MODE 1 PULL UP performance depicted in Figure 9 is consistent with the behavior of the system as described in Reference 4.¹²

2. RUNWAY FIELD CLEARANCE FLOOR (RFCF) (Reference 4 pp. 16-17)

The KGP 560/860 GA-EGPWS provides additional alerting protection for situations where aircraft descend to an altitude that is too low considering the aircraft’s distance from a known runway. This is called the Runway Field Clearance Floor (RFCF).

NOTE: This alert function is ONLY active when the aircraft is within 5 nm of a known runway in the system database.

Using the aircraft distance to a known runway and Geometric Altitude, the system establishes a “floor” of protection below the aircraft. Penetration of this floor will cause the yellow caution alert annunciator lamp to illuminate, and the voice alert “Too Low, Too Low” to be heard. If aircraft altitude continues to descend, the voice alert will be heard again, and at an increasing frequency.

When the pilot reacts to the alert and climbs back above the RFCF for the current distance from the known runway, the annunciator lamp will extinguish and the voice alerts will cease.

[Figure 10] is a graphical representation of the Runway Field Clearance Floor in both the “TSO” and “optional alerting and warning parameters outside the TSO” configurations.

Figure 10 shows N814GV entering the RFCF envelope at about 08:19:14.0, and Table 2 indicates that the RFCF warning was logged at 08:19:16.8, or 2.8 seconds later. According to Honeywell, the system must confirm that the airplane is inside the RFCF warning envelope for at least 1 second before a warning is issued, and this alert may be logged up to a second after the alert aural alert was activated. Hence, the performance depicted in Figure 10 is consistent with the behavior of the system as described in Reference 4.

3. “LOOK-AHEAD” ALERTING AND WARNING (Reference 4 pp. 15-16)

Using aircraft position, altitude and flight path information, the system provides an envelope of protection for the aircraft that is independent from the Terrain Awareness Display. This “Look-Ahead” function compares the aircraft flight path to terrain and obstacle database information, and distance to known runways.

[Figure 11] is a general representation of the “Look-Ahead” functionality.

When the “Look-Ahead” function detects a terrain or obstacle threat approximately one minute ahead of the aircraft, the voice alert “Caution Terrain, Caution Terrain” (or “Caution Obstacle, Caution Obstacle”) is given, and a bright, solid yellow “threat area” is shown on the Terrain Display. Should the aircraft flight path continue toward the threat area, the alert message will repeat approximately every 7 seconds.

¹¹ In a teleconference with NTSB staff on July 24, 2018.

¹² One aspect of the EGPWS alerts listed in Table 2 that is not immediately clear is why the MODE 1 PULL UP alert, which has the highest priority in the system, was not repeatedly logged until the end of the data, since the airplane remained within the “PULL UP” envelope during this time. In a teleconference with NTSB staff to discuss the EGPWS performance, Honeywell noted that MODE 1 alerts are cut off at a height of 50 ft. AGL, and that the terrain around PATQ in the EGPWS database is rounded to 100 ft. (about 25-50 ft. higher than the actual terrain). Considering this information, the MODE 1 warning may have ceased, and allowed the subsequent RFCF and TAD alerts to activate, because the system computed that the airplane had exited the bottom of the MODE 1 envelope.

If the aircraft flight path approaches to within approximately 30 seconds of a threat area, the voice message “Terrain Ahead” (or “Obstacle Ahead”) or optionally “Terrain Terrain, Pull Up” (or “Obstacle-Obstacle, Pull Up”) will be given continuously and the threat area on the Terrain Display will be shown in a bright, solid red color.

In either case, when the pilot reacts and changes the aircraft flight path to one that will safely avoid the detected threat area, the voice alerts will cease and the threat area(s) shown on the Terrain Display will be removed.

According to Honeywell, the look-ahead warning is desensitized as the airplane approaches an airport, so that by the time the airplane is within 2 nm of a runway, the look-ahead time is reduced to 15 to 20 seconds (vs. the full look-ahead time of 60 seconds).

V. Airplane performance calculations based on recorded ADS-B and EGPWS data

Horizontal trajectory (north and east positions, groundspeed, and ground track)

The latitude and longitude coordinates in both the ADS-B and EGPWS data are based on GPS positions, and are very accurate compared to radar data (range uncertainty in radar data alone is about $\pm 1/16$ nmi, or ± 380 ft., and GPS positions are generally accurate to within 60 ft. (see Reference 5). Nonetheless, small uncertainties or inaccuracies in the positions result in unrealistic spikes or “noisiness” in groundspeed and ground track computed from the first time-derivatives of the GPS data, which propagate into noisy heading and pitch angle calculations. In addition, there is a 28-second gap in the GPS position data near the end of the flight, corresponding to the time between when N814GV descended below the altitude floor of the ADS-B coverage, and the start of the EGPWS data. To produce a horizontal trajectory for performance calculations that contains kinematically consistent position, speed, and track data, including during the 28-second gap in the GPS data, the groundspeed and ground track data recorded in the ADS-B and EGPWS data were mathematically integrated over time (per the theorems of Calculus).

The ADS-B and EGPWS groundspeeds and ground track angles are smooth (the result of filters in the system algorithms that compute these parameters), and so were integrated directly to produce smooth north and east positions during the times data is available. The groundspeed and track angle during the 28-second data gap was estimated by interpolating between the end of the ADS-B data and the start of the EGPWS data. The interpolation was adjusted as required to make the airplane position resulting from integrating the interpolated groundspeed and track approximately match the position at the start of the EGPWS data.

Once the airplane north and east positions were computed from groundspeed and track angle, the first derivatives of those positions with time were computed to reproduce the groundspeed and track angle. Theoretically, the original speed and track that was used to compute the positions (through mathematical integration), and the “reproduced” speed and track computed from those positions (through mathematical differentiation), should be identical. In practice, however, because of the limited sample rate of the data and the methods used to numerically integrate and differentiate these discrete samples, there are slight differences in the two speeds and angles when these are changing rapidly (e.g., in the last few seconds of flight); the speeds and angles computed by differentiation of the integrated position are “smoother” (exhibit smaller oscillations or changes) than the recorded speeds and angles (see Figure 8b)¹³. If the sample rate of the recorded data were increased, these differences would be reduced (as the times

¹³ Several Figures in this *Study* have an “a” and a “b” version, which present the same information but at different scales, or with different background images. When the *Study* refers to a Figure with two or more versions without specifying the version, all versions are meant to be included in the reference.

between samples approach zero, so do the differences between the recorded and computed speeds and angles). The groundspeed and ground track obtained by differentiating the integrated positions with respect to time were used for the subsequent calculations of airspeed and Euler angles described below.

Vertical trajectory (altitude and rate of climb)

The ADS-B and EGPWS data also contain altitude information. Specifically, the ADS-B data contains both barometric pressure altitude and GPS altitude parameters, and the EGPWS data contains only GPS altitude. Both data sets include GPS-based rate of climb parameters. Analogously to the latitude, longitude, and groundspeed data, the recorded rate of climb is smooth (filtered before it is recorded), but the rate of climb computed from the recorded altitudes is noisy. To produce vertical trajectory for performance calculations that contains kinematically consistent altitude and rate of climb data, including during the 28-second gap in the GPS data, the rates of climb recorded in the ADS-B and EGPWS data were mathematically integrated over time. The rate of climb during the 28-second data gap was estimated by interpolating between the end of the ADS-B data and the start of the EGPWS data. The interpolation was adjusted as required to make the integrated altitude approximately match the altitude at the start of the EGPWS data.

The discussion above relating to the differences between the recorded and computed groundspeed also applies to the recorded and computed rate of climb. Near the end of the data where the recorded rate of climb is changing rapidly, the rate of climb obtained by taking the first time derivative of the integrated altitude is smoother than the recorded rate of climb; see the “1 Hz” computed rate of climb in Figure 8b. If the sample rate of the data is artificially increased by interpolating between samples using a cubic spline curve fit, then the computed rate of climb matches the recorded data more closely, as shown by the “2 Hz” computed rate of climb in Figure 8b. These differences affect subsequent calculations that use the rate of climb data, including the flight path angle and pitch angle calculations, as shown below.

Airspeed, attitude, and flight angle calculations

The position and altitude obtained by integrating the recorded ADS-B and EGPWS groundspeed, ground track, and rate of climb data were used to compute additional performance information, including airspeeds, flight path angle, angle of attack, Euler angles (heading, pitch, and roll), and angular rates. If the position (latitude, longitude, and altitude) of an airplane is known as a function of time, then its orientation (i.e., the Euler angles) can also be estimated as long as the following are true:

- The motion of the air mass relative to the Earth, i.e., the wind, is known;
- The lift coefficient of the airplane as a function of angle of attack is known;
- The gross weight of the airplane is known;
- The sideslip angle and lateral acceleration are negligible (i.e., coordinated flight).

The winds aloft in the vicinity of PATQ for the performance calculations were taken from a run of the Global Data Assimilation System (GDAS) model valid at 0700 AKD on 4/11/2018 for latitude 70.49°N and longitude 157.50°W (see Reference 6). The wind speed and direction, and static air temperature, from this model are plotted as a function of altitude in Figure 12.

Selected one-minute PATQ Automated Weather Observing System (AWOS) reports surrounding the time of the accident (taken from Reference 6) are shown in Table 3:

Parameter \ Report	PATQ ASOS 08:13 AKD	PATQ ASOS 08:18 AKD	PATQ ASOS 08:23 AKD
Sky condition ¹⁴	<i>Missing from report</i>	<i>Missing from report</i>	<i>Missing from report</i>
Visibility	1 statute mile in light snow and mist	$\frac{3}{4}$ statute mile in light snow and mist	$\frac{1}{2}$ statute mile in light snow and freezing fog
Winds	340° @ 4 kt.	340° @ 3 kt.	340° @ 3 kt.
Temperature / Dew Point	-19°C / -21°C	-19°C / -21°C	-18°C / -21°C
Altimeter setting	29.65 "Hg	29.64 "Hg	29.64 "Hg

Table 3. Weather observations at PATQ surrounding the time of the accident.

As noted above, aerodynamic data for the Cessna was provided by Textron Aviation during previous investigations. A gross weight of 7,500 lb. (see Table 1) is assumed in the performance calculations. The flaps are up in photos of the airplane at the accident site (see Figure 13), so this *Study* assumes that the flaps were up at the time of the accident.

The position of an airplane as a function of time defines its velocity and acceleration components. In coordinated flight, these components lie almost entirely in the plane defined by the airplane's longitudinal and vertical axes. Furthermore, any change in the *direction* of the velocity vector is produced by a change in the lift vector, either by increasing the magnitude of the lift (as in a pull-up), or by changing the direction of the lift (as in a banked turn). The lift vector also acts entirely in the aircraft's longitudinal-vertical plane, and is a function of the angle between the aircraft longitudinal axis and the velocity vector (the angle of attack, α). These facts allow the equations of motion to be simplified to the point that a solution for the airplane orientation can be found given the additional information about wind and the airplane lift curve (i.e., C_L vs. α). The results of the performance calculations based on the integrated position data described above are presented below.

Results: position and altitude

The north and east positions of N814GV are presented in a plan view in Figures 3 and 4, and as a function of time in Figure 6. These Figures present the recorded ADS-B EGPWS data, and the positions obtained by integrating the speed information recorded by those devices, as described above.

True (geometric), pressure, and density altitudes are presented as a function of time in Figure 7. The types and sources of the altitude data presented in this Figure are as follows:

- **ADS-B GPS altitude:** the GPS altitude recorded in the ADS-B data. This is true (geometric) MSL altitude.
- **ADS-B pressure altitude:** the barometric pressure altitude recorded in the ADS-B data, based on the standard-day altimeter setting of 29.92 "Hg. The barometric pressure altitude is the altitude in the standard atmosphere corresponding to the atmospheric static pressure at each point in the data.
- **EGPWS GPS altitude:** the GPS altitude recorded in the EGPWS data. This is true (geometric) MSL altitude.

¹⁴ As described in Reference 6, sky condition was missing from all documented PATQ one-minute observations because the ceilometer was out of service.

- **True (geometric) altitude:** the MSL altitude obtained by integrating the ADS-B and EGPWS GPS-based rate of climb data, as described above.
- **Pressure altitude:** the pressure altitude corresponding to the static pressure in the GDAS sounding model, at the geometric altitudes corresponding to the integrated true altitude. Note that this pressure altitude is about 20-30 ft. lower than the ADS-B pressure altitude.
- **Indicated altitude:** this is the pressure altitude based on the GDAS model, corrected for an altimeter setting of 29.64 "Hg. It is the altitude that would have been displayed on the airplane's altimeter. The indicated altitude based on the ADS-B pressure altitude would be about 20-30 ft. higher.
- **Density altitude:** the altitude in the standard atmosphere corresponding to the static air density at each point in the data. The air density is computed using the static pressure and temperature in the GDAS model at the geometric altitudes corresponding to the integrated true altitude. Note that because of the extremely cold temperature, the density is much higher than standard, resulting in a density altitude significantly below sea level. The density altitude scale is on the right side of the plot.

Figure 7 also depicts the 1900 ft. MSL minimum altitude at DUVFU, the IF for the PATQ RNAV (GPS) RWY 6 instrument approach (see Figure 5). Note that N814GV started its descent from 2300 ft. at about 08:17:00, and descended through 1900 ft. at about 08:17:17. The descent to the ground was continuous, and at no time did the airplane arrest its descent or climb back to the minimum altitude of 1900 ft. required at DUVFU.

Results: speed and rate of climb

Figure 8 shows the results of the speed and rate of climb calculations. The ADS-B and EGPWS recorded groundspeeds are depicted by the black circle and green diamond symbols, respectively; the groundspeed computed by differentiating the airplane positions obtained by integrating the recorded groundspeed is shown by the black line. As discussed above, the computed groundspeed should be theoretically identical to the recorded groundspeed, but differs slightly from the recorded groundspeed because of the effects of numerical integration and differentiation with relatively low sample-rate data.

Likewise, the bottom graph in Figure 8 compares the ADS-B and EGPWS recorded rates of climb (and descent) with the rate of climb computed by differentiating the altitude obtained by integrating the recorded rate of climb. As noted above, the computed rate of climb obtained from data interpolated to 2 Hz matches the last few seconds of recorded data better than the (as recorded) 1 Hz data. Note that the rate of descent increases from about 500 ft./min. to about 2300 ft./min. between 08:19:05 and 08:19:18, with a steepening in the rate of increase at about 08:19:10. At 08:19:18, the rate of descent rapidly decreases back to 1460 ft./min. at the end of the data at 08:19:19.8, following the EGPWS alerts at 08:19:15.8 and 08:19:16.8.

The top graph in Figure 8 also presents the true and calibrated airspeeds resulting from the combination of the computed groundspeed with the wind data shown in Figure 12.

Note that both the speeds and rate of climb shown in Figure 8 during the 28-second gap between the recorded ADS-B and EGPWS data are smooth, showing a steady deceleration in speed and a relatively consistent rate of descent of between 300 and 900 ft./min. These results are not consistent with an abrupt increase in speed and rate of descent, as would be expected from a sudden, uncommanded dive.

Results: flight angles and angular rates

Figure 14 presents the following flight angles calculated from the trajectory obtained from integrating the ADS-B and EGPWS recorded groundspeed, track angle, and rate of climb, as described above:

- Flight path angle (from both the 1 Hz and 2 Hz trajectory solutions)
- Pitch angle (from both the 1 Hz and 2 Hz trajectory solutions)
- Angle of attack (from both the 1 Hz and 2 Hz trajectory solutions)
- Roll angle (1 Hz solution only; 2 Hz solution unrealistically noisy)
- Drift angle
- True and magnetic heading
- True ground track

The angle of attack in Figure 14 remains below 4° everywhere, indicating that the airplane was not operating near stall. The pitch angle decreases from about 0° to about -5° between 08:19:09 and 08:19:16, consistent with the increase in the rate of descent and decrease in the corresponding flight path angle (from about -3.5° to about -8°) during that time. The flight path angle and pitch angle increase rapidly by 2° to 3° starting around 08:19:18, a few seconds after the first two EGPWS alerts.

Figure 14 also presents the recorded ADS-B and EGPWS ground track angles, and the recorded EGPWS roll angle. The EGPWS roll angle (green line and circles) lags behind the computed roll angle (black line), likely due to filtering algorithms within the EGPWS software (the EGPWS roll angle is computed from speed and the rate of change of the track angle, and not sensed directly). In any case, both the recorded and computed roll angles show the airplane entering a steepening right turn (from a relatively shallow right turn) at about 08:19:00. The computed roll angle reaches a maximum roll 33° at about 08:19:17, before decreasing to about 10° at the end of the data at 08:19:19.8. The computed roll angle is sensitive to the rate of change of ground track, and hence to the uncertainties associated with the low sample rate of the data described above. However, the final resting attitude of the airplane on its back, with the wings relatively intact (see Figure 13), is additional evidence that the right roll was in fact reducing towards the end of the data; if the airplane had maintained a significant right roll angle at impact, the right wing would have contacted the ground first, damaging that wing and likely causing the airplane to cartwheel. The images in Figure 13 indicate that this did not occur.

During the final right turn, the airplane turned past the heading direct to DUVFU (about 255°), reaching a heading of about 290° at the end of the data.

The angular rates associated with some of the flight angles plotted in Figure 14 are presented in Figure 15. The body-axis pitch rate starts to increase at about 08:19:14 consistent with the steepening of the roll angle¹⁵, but the rate of change of pitch angle starts to increase significantly a little later, at 08:19:16, about the time of the first EGPWS alert. The roll rate also starts to reverse abruptly at about this time.

¹⁵ The component of angular velocity along the body y-axis (the pitch rate) increases with roll angle during a turn.

E. CONCLUSIONS

This *Aircraft Performance ADS-B and EGPWS Study* presents the results of using ADS-B position and speed data, EGPWS position and speed data, the crash site location, surface and upper-air weather information, and Cessna 208B performance data to calculate N814GV's position, orientation, speed, and other performance parameters during the flight. The results of these calculations are summarized in the "History of Flight" Section above, and described in detail in the body of the *Study*.

Regarding the descent of the airplane from its cruising altitude of 2300 ft. and subsequent impact with terrain, the *Study* indicates that:

- At about 08:17:00, N814GV started a descent from 2300 ft., and a few seconds later made a slight right turn to a ground track of about 216°. During the descent, the groundspeed increased to about 181 kt., and the rate of descent peaked at about 1700 ft./min.
- The airplane descended below the 1900 ft. minimum altitude at DUVFU at about 08:17:17. The descent to the ground was continuous, and at no time did the airplane arrest its descent or climb back to the minimum altitude of 1900 ft. required at DUVFU.
- The interpolated speed and rate of climb during the 28-second gap between the recorded ADS-B and EGPWS data are smooth, showing a steady deceleration in speed and a relatively consistent rate of descent of between 300 and 900 ft./min. These results are not consistent with an abrupt increase in speed and rate of descent, as would be expected from a sudden, uncommanded dive.
- At about 08:18:56, the airplane was descending through 504 ft. MSL at 687 ft./min., the groundspeed was 159 kt., and the ground track was 241°.
- At 08:19:00, N814GV started to roll right, reaching a computed roll angle of about 29° at 08:19:11. Following a brief roll rate reversal, the roll angle increased to about 33° at 08:19:17, before decreasing to about 10° at the end of the data at 08:19:19.8.
- During the right turn, the ground track angle increased from 242° at 08:19:00 to 276° at 08:19:17, passing through the 255° heading direct to DUVFU. The EGPWS recorded track angle at the end of the data was 289°.
- At 08:19:05, N814GV descended through 400 ft. MSL at about 500 ft./min. Shortly after, the descent rate increased, reaching about 2300 ft./min. at 08:19:18.
- At 08:19:15.8, the first of three EGPWS alerts was triggered. This was a "Mode 1 Pull Up" alert, and would have resulted in an aural "pull up!" warning in the cockpit.
- Two additional EGPWS alerts were triggered at 08:19:16.8 and 08:19:18.8, consisting of "TCF Too Low Terrain" and "TAD Terrain Pull Up" alerts. These alerts would have resulted in aural "too low, terrain!" and "terrain, pull up!" warnings.

- Between 08:19:18.8 and the last EGPWS data point recorded at 08:19:19.8, the recorded rate of descent decreased from 2300 ft./min. to 1460 ft./min. The GPS altitudes recorded at these points were 132 and 82 ft. MSL, respectively. The last recorded groundspeed was 158.5 kt.
- The angle of attack remained below 4° during the descent, indicating that the airplane was not operating near stall. The pitch angle decreased from about 0° to about -5° between 08:19:09 and 08:19:16, consistent with the increase in the rate of descent and decrease in the corresponding flight path angle during this time. The flight path angle and pitch angle increased rapidly by 2° to 3° starting around 08:19:18, a few seconds after the first two EGPWS alerts.
- The body-axis pitch rate started to increase at about 08:19:14 consistent with the steepening of the roll angle, but the rate of change of pitch angle started to increase significantly a little later, at 08:19:16, about the time of the first EGPWS alert. The roll rate also started to reverse abruptly at about this time.
- The three EGPWS alerts triggered during the flight and recorded in the EGPWS data are consistent with the system performance descriptions provided in the EGPWS *Pilot's Guide* (Reference 4).

This sequence of events is consistent with a controlled descent from 2300 ft. to well below the 1900 ft. minimum altitude at DUVFU specified by the PATQ RNAV (GPS) RWY 6 instrument approach procedure. The lowering of the pitch angle (from about 0° to about -5°) and corresponding steepening of the flight path angle (from about -3.5° to about -8°) during the last 11 seconds of data (starting at an altitude of about 350 ft.) could be the result of the increasing roll angle without a compensating pull on the control column to maintain the pitch angle. The relatively abrupt increase in the pitch angle and flight path angles, and reduction in the roll angle, after 08:19:16 might be explained as a pilot response to the EGPWS alert issued at about that time.

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Office of Research and Engineering

F. REFERENCES

1. National Transportation Safety Board, Office of Aviation Safety, *Enhanced Ground Proximity Warning System Download, Cessna 208 N814GV, Atkasuk, AK, April 11, 2018*, NTSB Accident Number ANC18LA031 (Washington, DC: NTSB, May 12, 2018). (Contact NTSB at pubinq@ntsb.gov).
2. Cessna Aircraft Company (now Textron Aviation), *Cessna 208B G1000 Grand Caravan Information Manual Rev. 1*, Document 208BIMBUS-01, June 5, 2008.
3. Hageland Aviation Services, Inc., *N814GV S/N 208B0958 Weight and Balance / Seat Schedule*, dated March 20, 2017.
4. Honeywell International Inc., *KGP 560 & KGP 860 General Aviation Enhanced Ground Proximity Warning System Pilot's Guide*, Revision 5, dated July 2004.
5. International Civil Aviation Organization (ICAO), The Tenth Meeting of Automatic Dependent Surveillance – Broadcast (ADS-B) Study and Implementation Task Force (ADS-B SITF/10) Agenda Item 6: Review States' activities and interregional issues on trials and implementation of ADS-B and multilateration: ADS-B / GPS Accuracy (Presented by Australia). Singapore, 26-29 April 2011. Document available at: https://www.icao.int/APAC/Meetings/2011_ADS_B_SITF10/IP10_AUS%20AI.%206%20-%20GPS%20Accuracy.pdf
6. National Transportation Safety Board, Office of Aviation Safety, *Meteorology Weather Study, Cessna 208 N814GV, Atkasuk, AK, April 11, 2018*, NTSB Accident Number ANC18LA031 (Washington, DC: NTSB, May 23, 2018). (Contact NTSB at pubinq@ntsb.gov).

G. FIGURES



Figure 1. Pre-accident photographs of N814GV (© Air-Britain Photographic Images Collection).

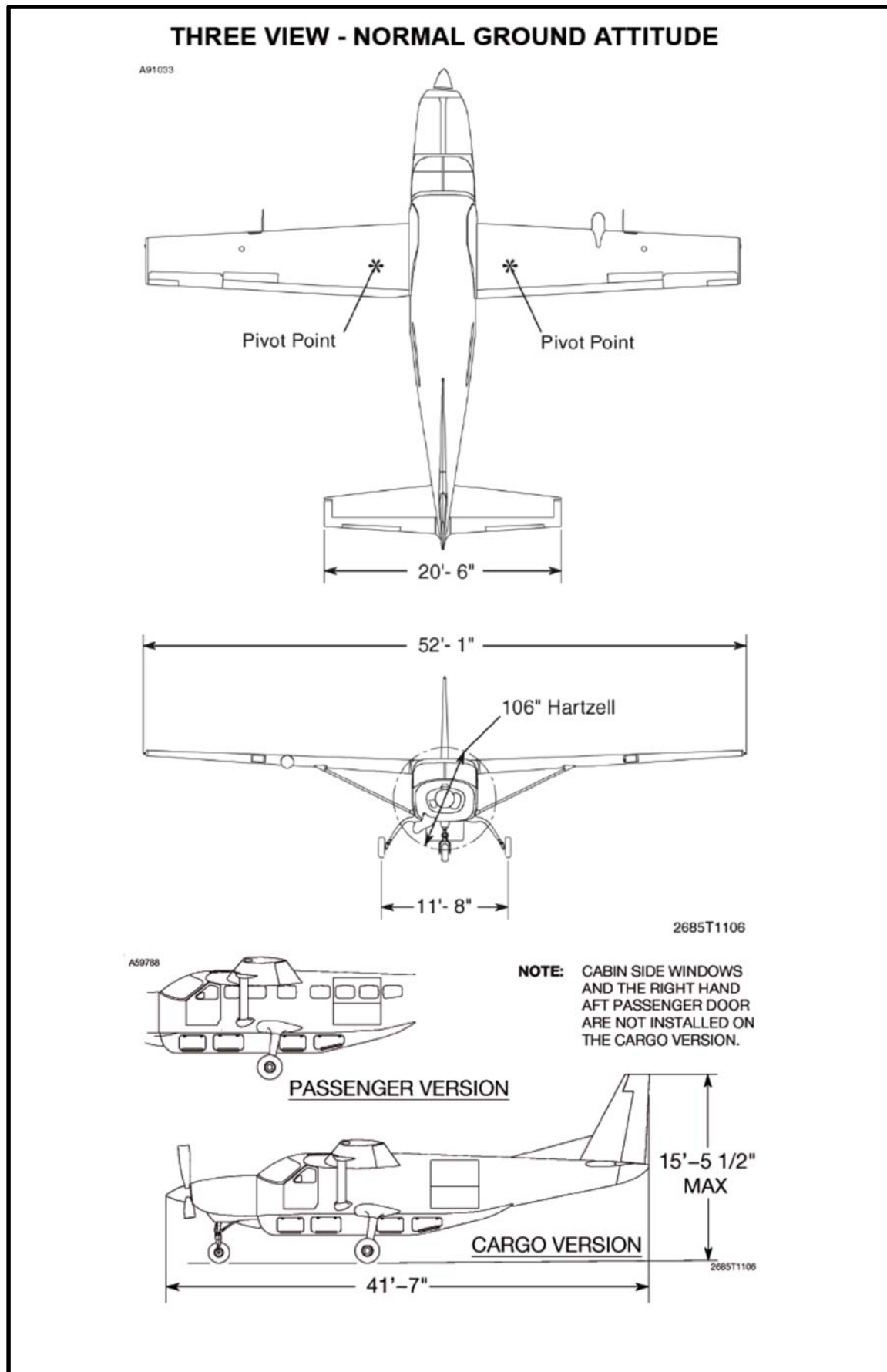


Figure 2. Three-view drawings of the Cessna 208B Grand Caravan^{EX}, from Reference 2.

ANC18LA031: Cessna 208B Caravan, N814GV, Atqasuk, AK, 04/11/2018

Plan view of flight

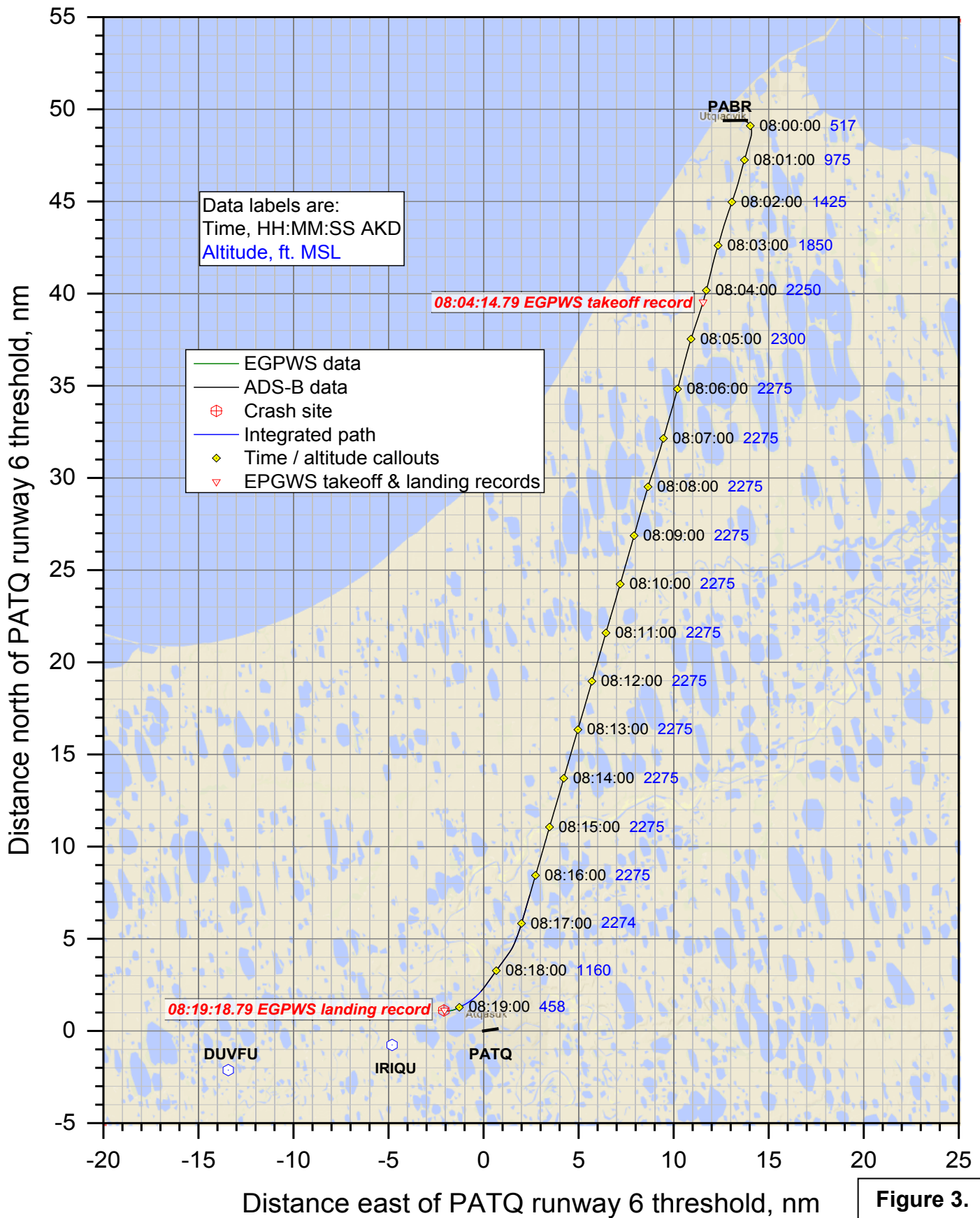


Figure 3.

ANC18LA031: Cessna 208B Caravan, N814GV, Atkasuk, AK, 04/11/2018

Plan view of final 3 minutes of flight

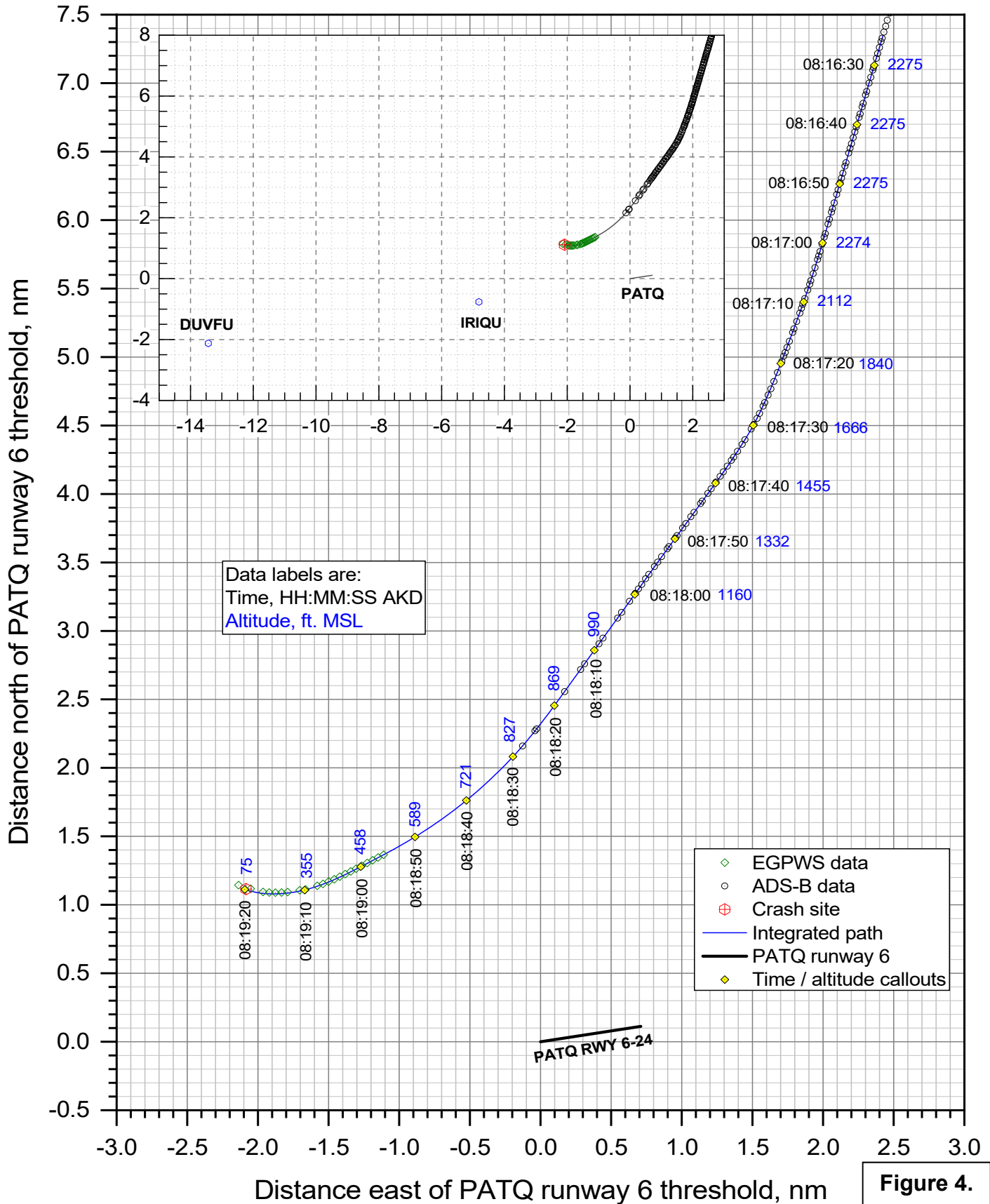


Figure 4.

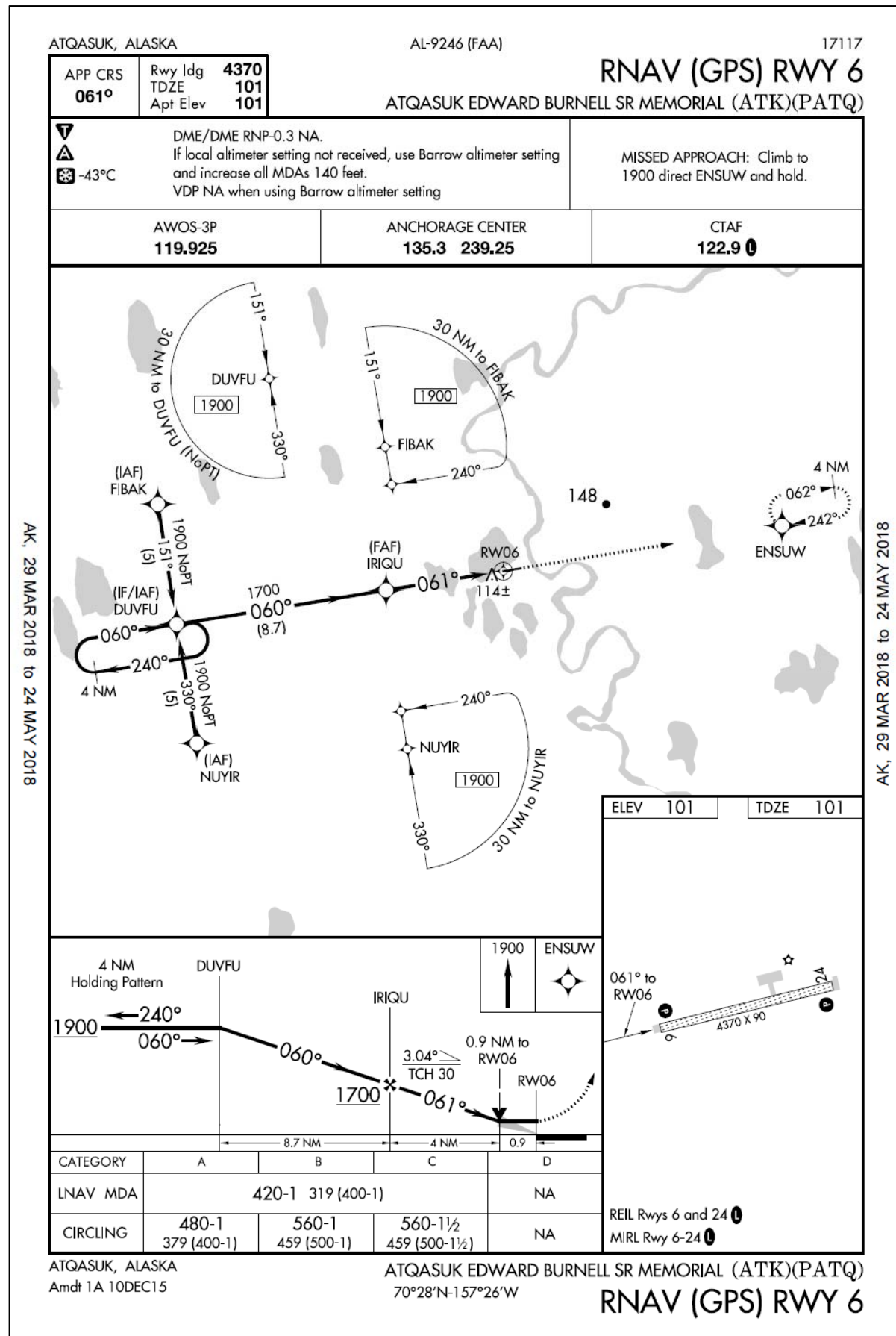


Figure 5. PATQ RNAV (GPS) RWY 6 approach plate.

ANC18LA031: Cessna 208B Caravan, N814GV, Atkasuk, AK, 04/11/2018

North & east coordinates during final 3 minutes of flight

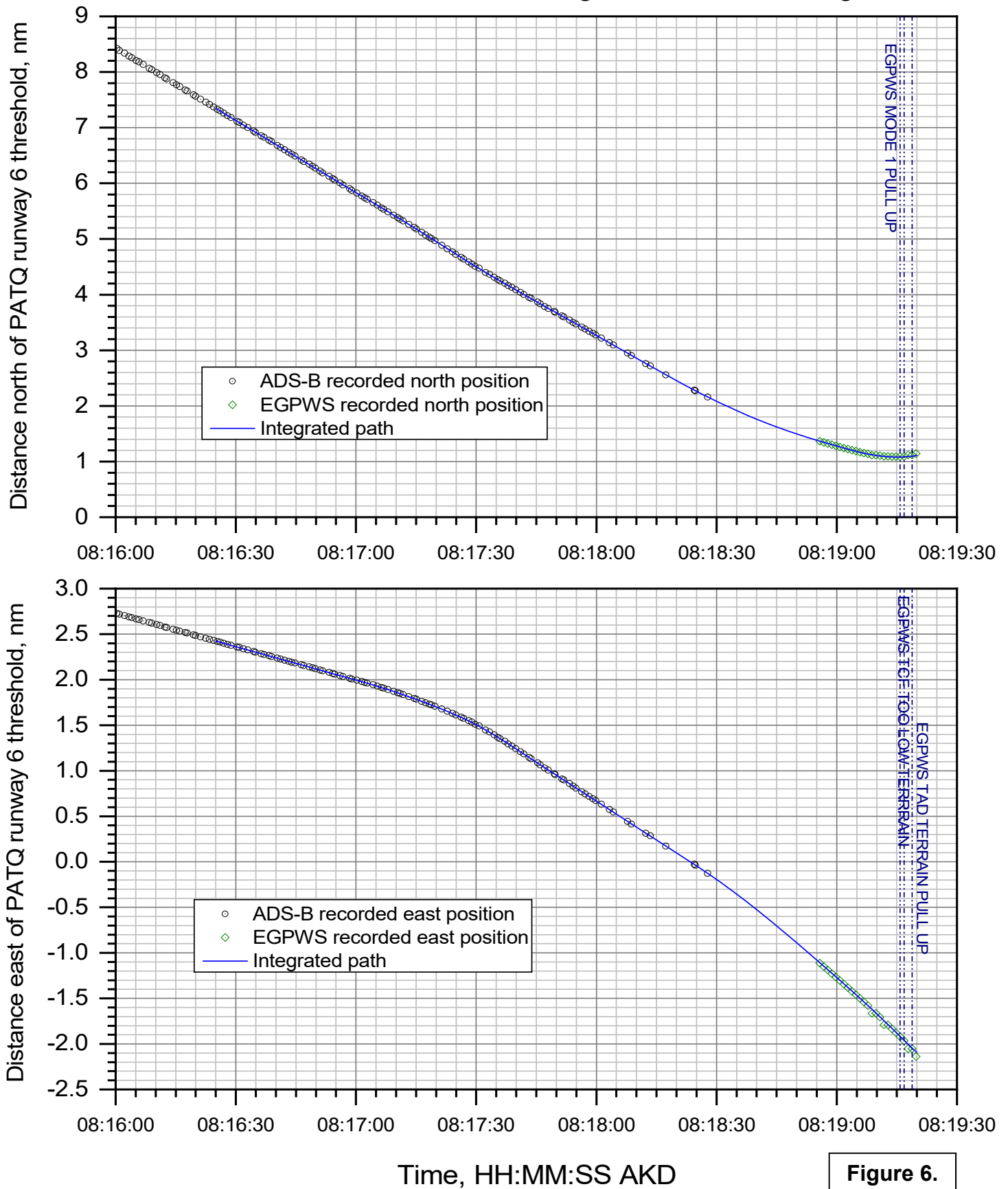


Figure 6.

ANC18LA031: Cessna 208B Caravan, N814GV, Atkasuk, AK, 04/11/2018

Altitude vs. time during final 3 minutes of flight

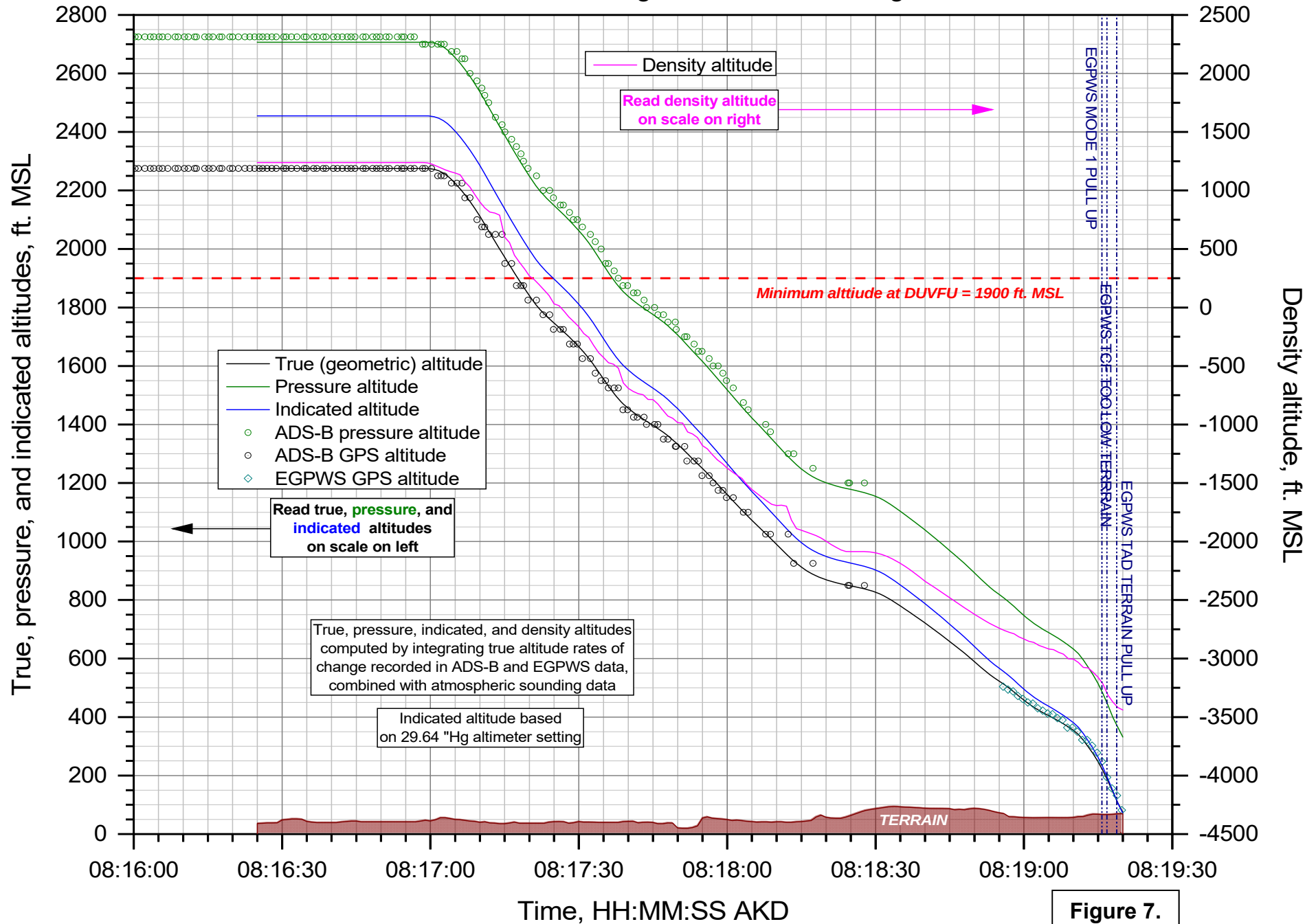
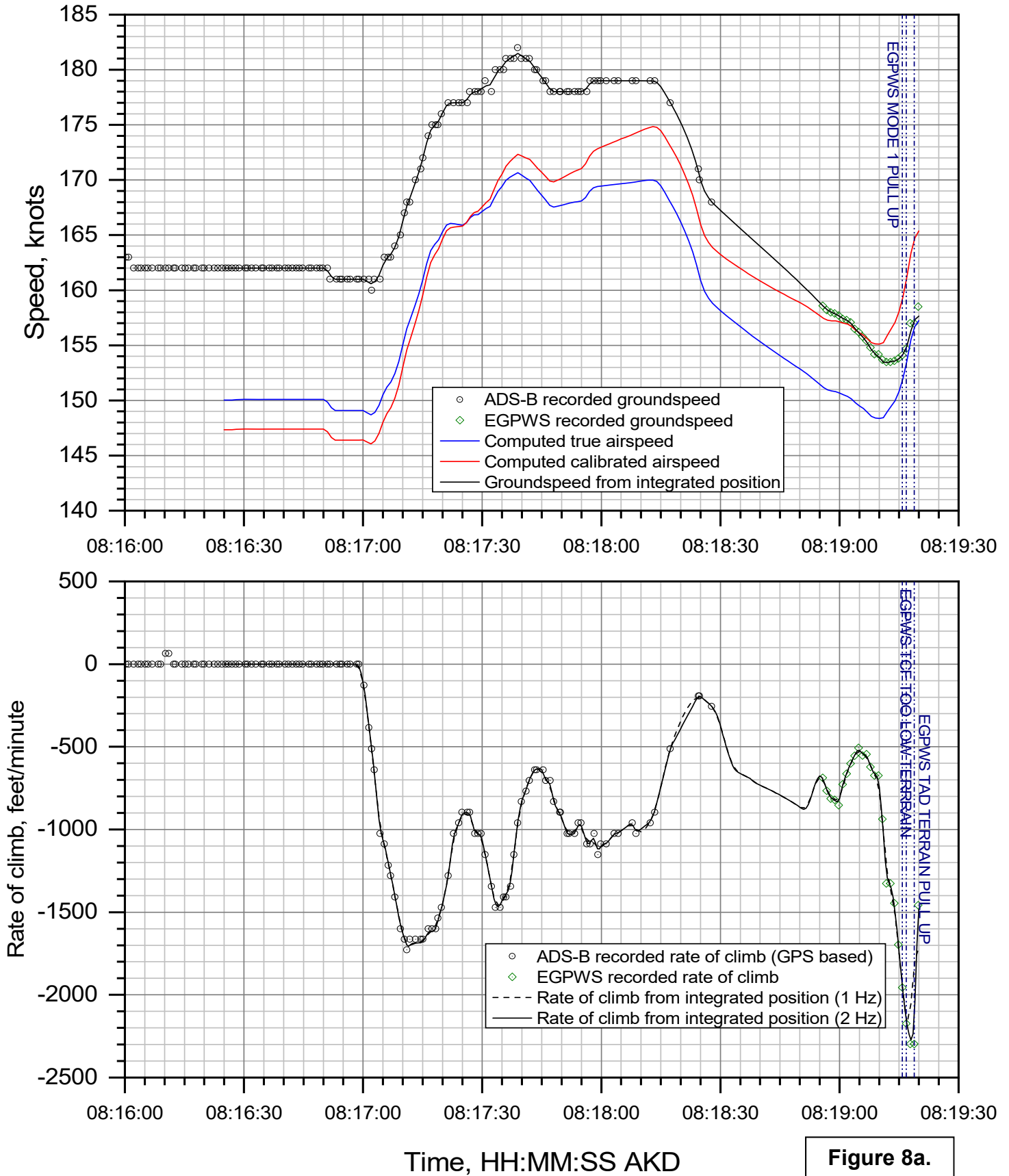


Figure 7.

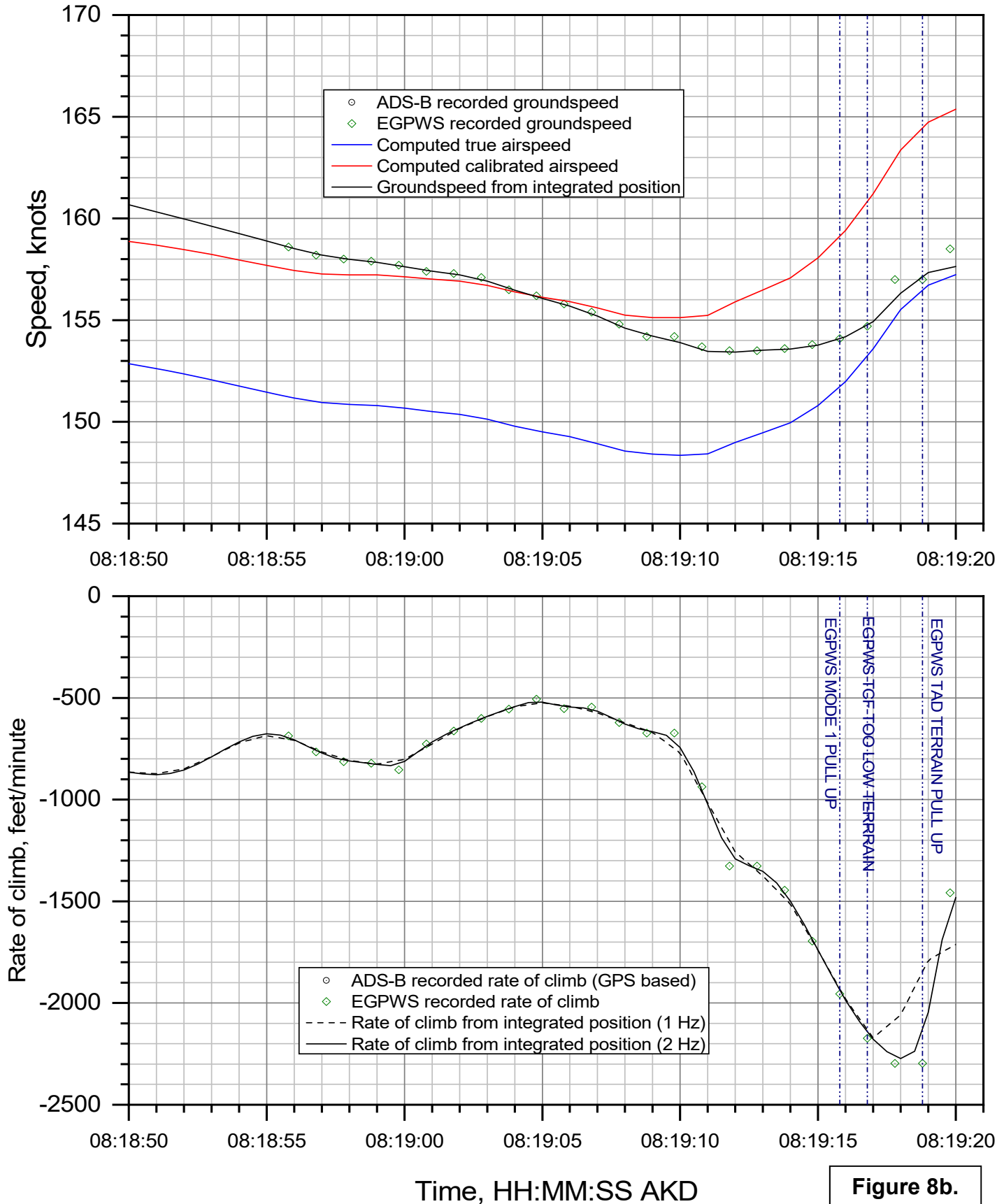
ANC18LA031: Cessna 208B Caravan, N814GV, Atkasuk, AK, 04/11/2018

Speeds & rate of climb during final 3 minutes of flight



ANC18LA031: Cessna 208B Caravan, N814GV, Atkasuk, AK, 04/11/2018

Speeds & rate of climb during final 3 minutes of flight (detail)



ANC18LA031: Cessna 208B Caravan, N814GV, Atkasuk, AK, 04/11/2018

EGPWS "Excessive Rate of Descent" protection envelope

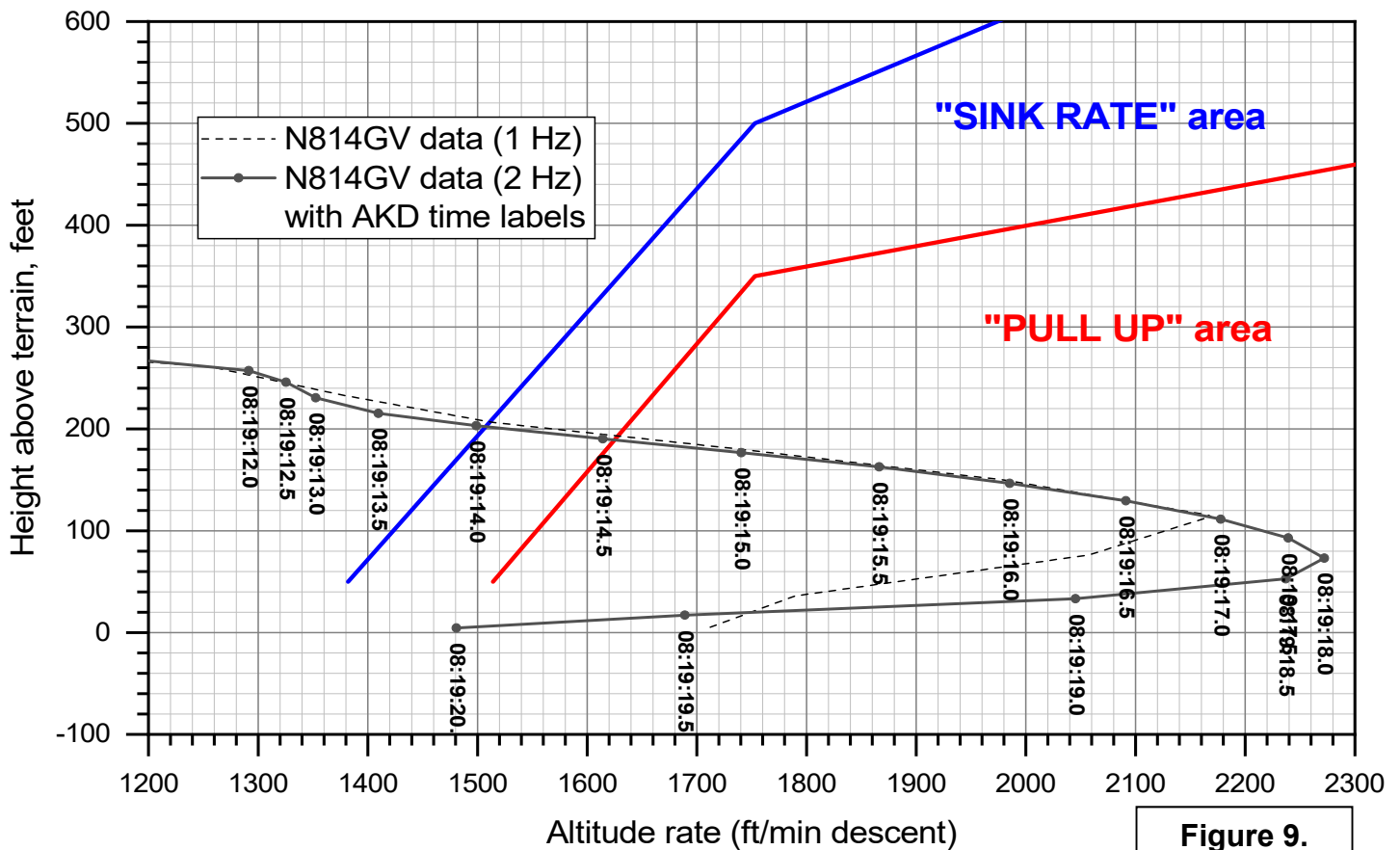
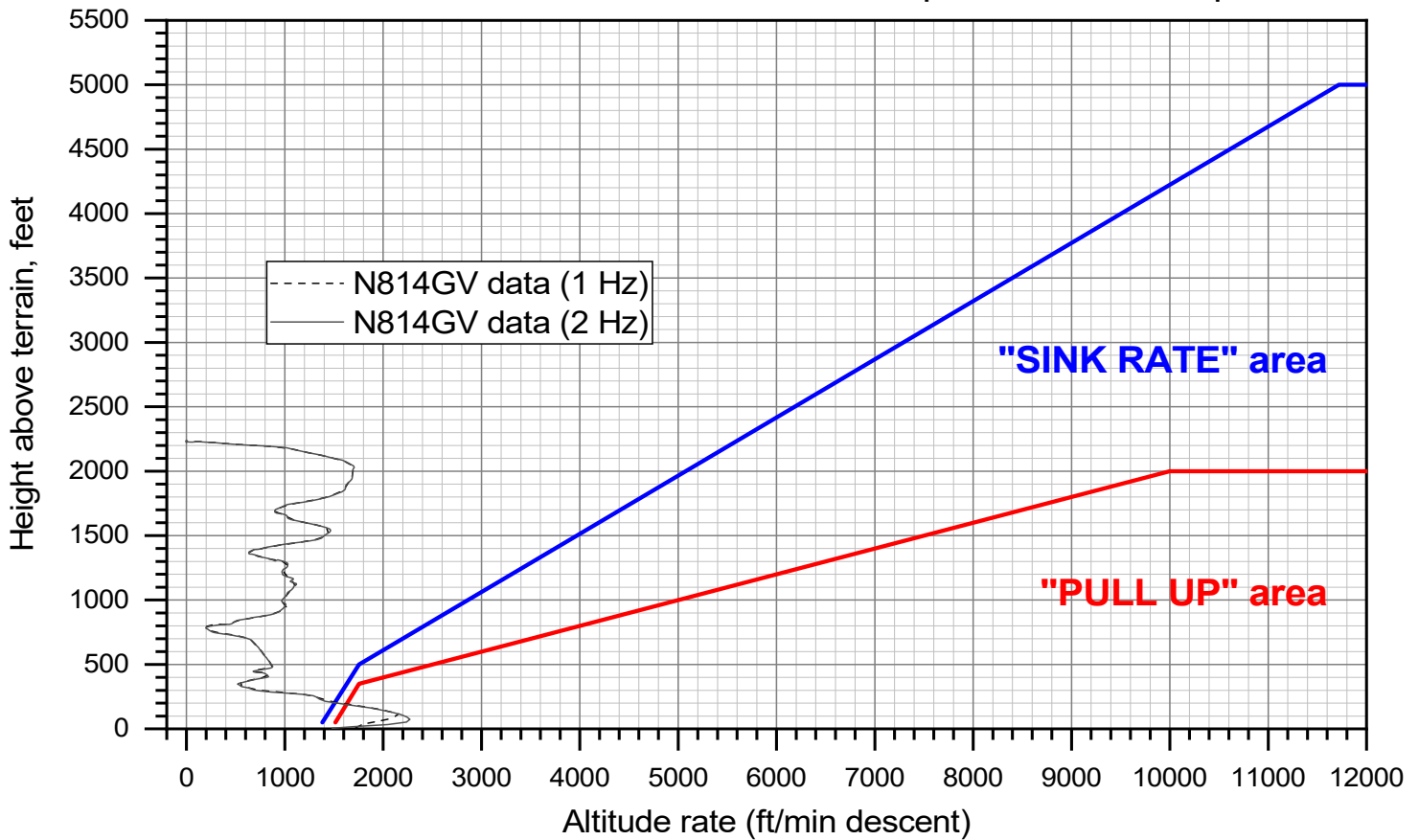


Figure 9.

ANC18LA031: Cessna 208B Caravan, N814GV, Atkasuk, AK, 04/11/2018

EGPWS "Runway Field Clearance Floor" protection envelope

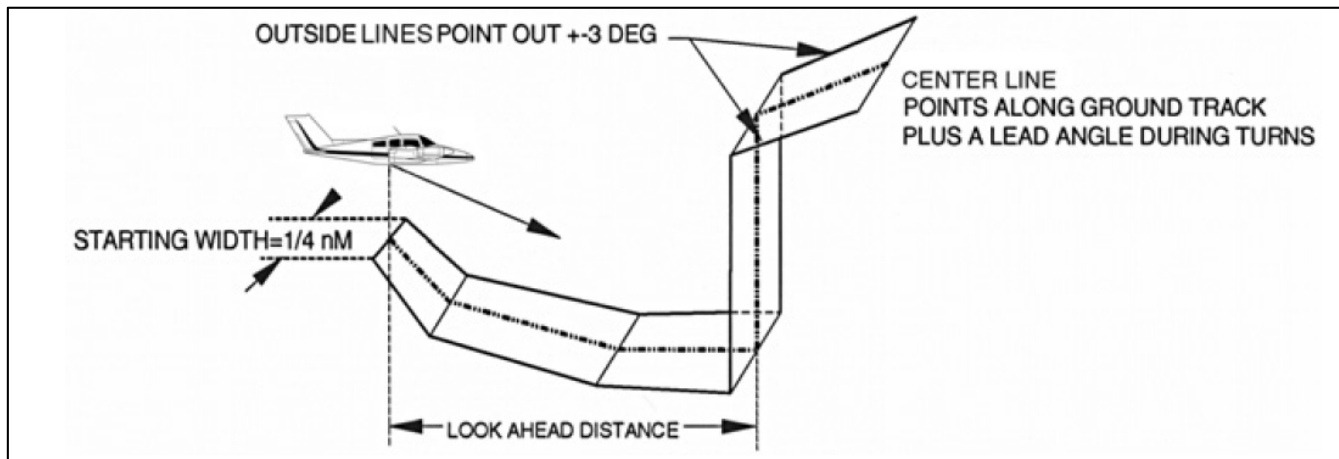
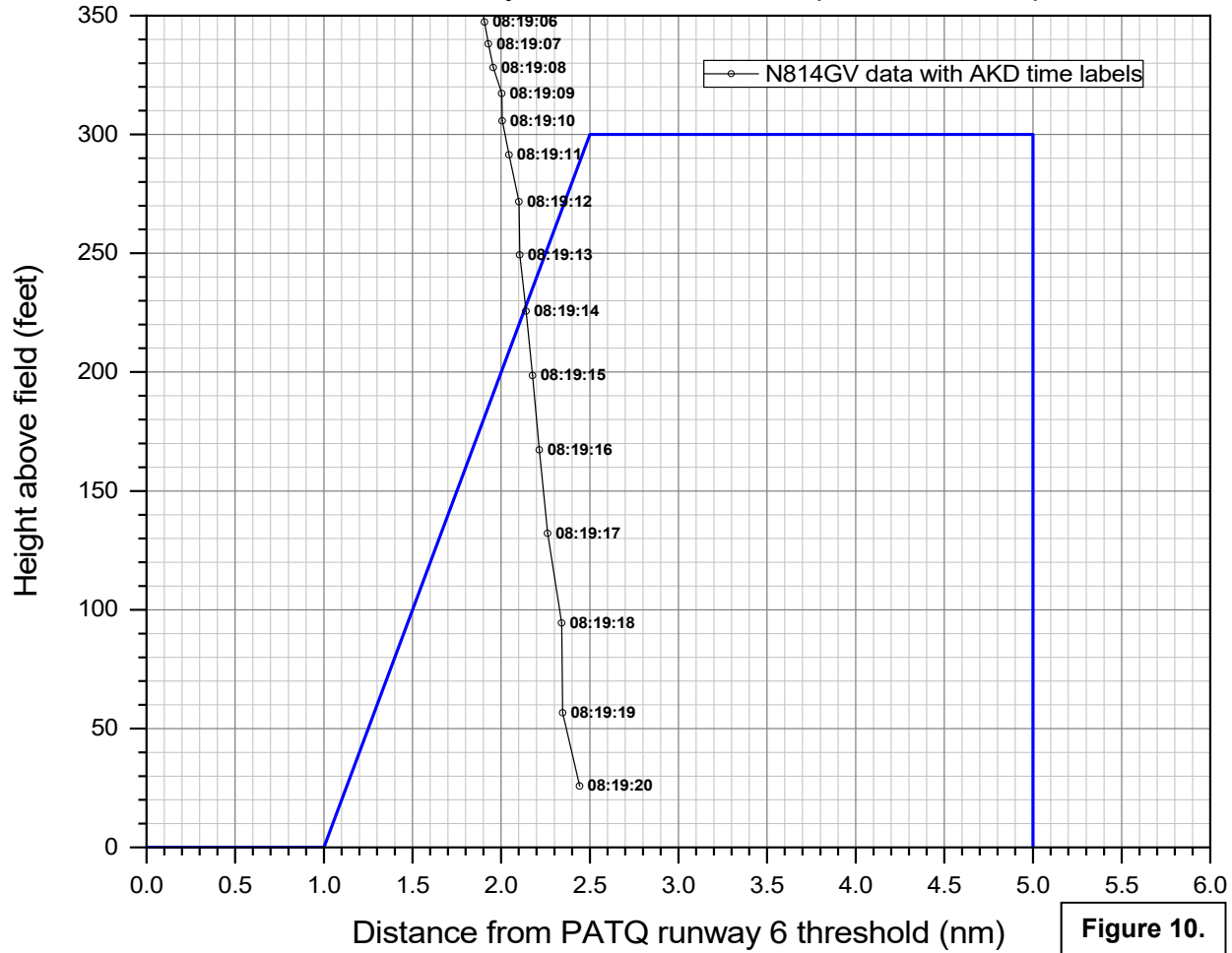
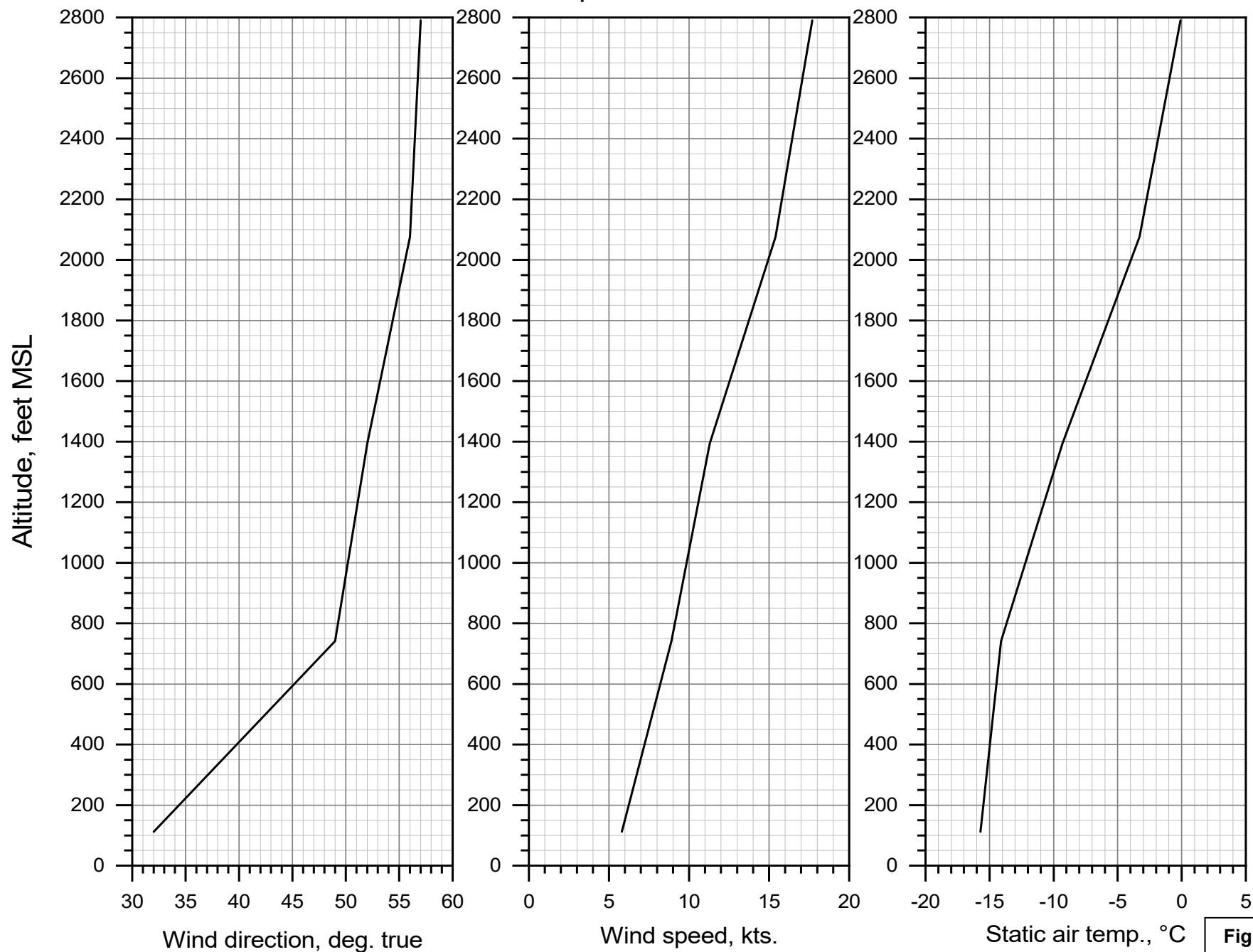


Figure 11. EGPWS "Look Ahead" Alerting and Warning schematic (from Reference 4).

ANC18LA031: Cessna 208B Caravan, N814GV, Atkasuk, AK, 04/11/2018

Winds and temperature aloft from GDAS model

**Figure 12.**

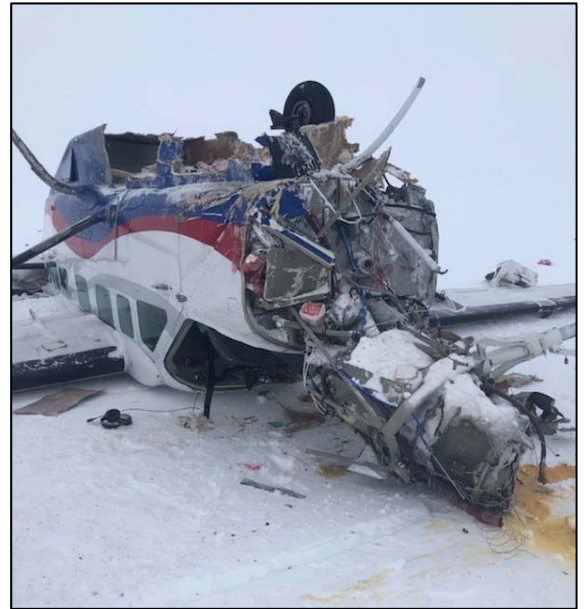


Figure 13. Post-accident photographs of N814GV (courtesy of NTSB Investigator-In-Charge).

ANC18LA031: Cessna 208B Caravan, N814GV, Atkasuk, AK, 04/11/2018

Euler angles during final 3 minutes of flight

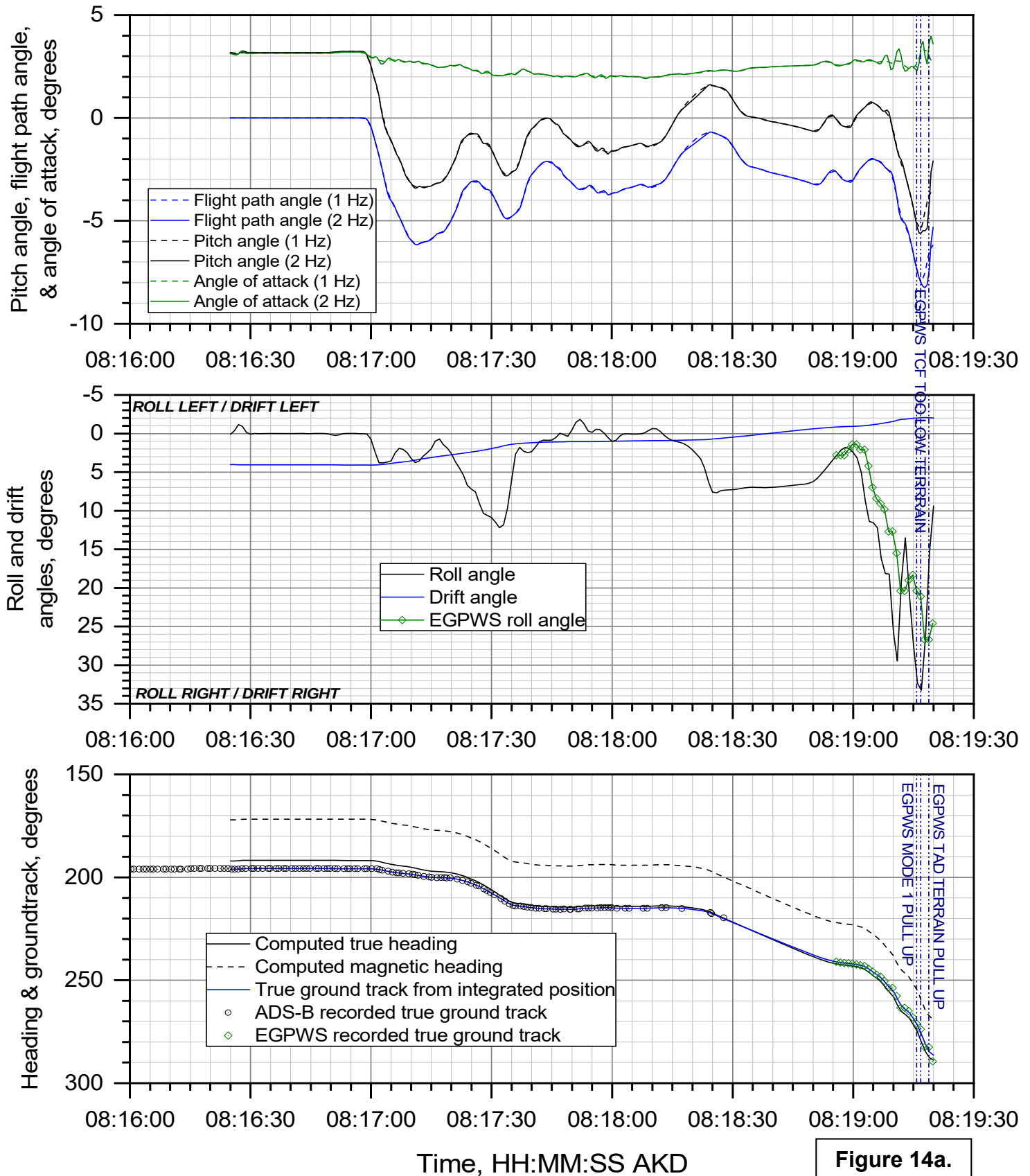


Figure 14a.

ANC18LA031: Cessna 208B Caravan, N814GV, Atkasuk, AK, 04/11/2018

Euler angles during final 3 minutes of flight (detail)

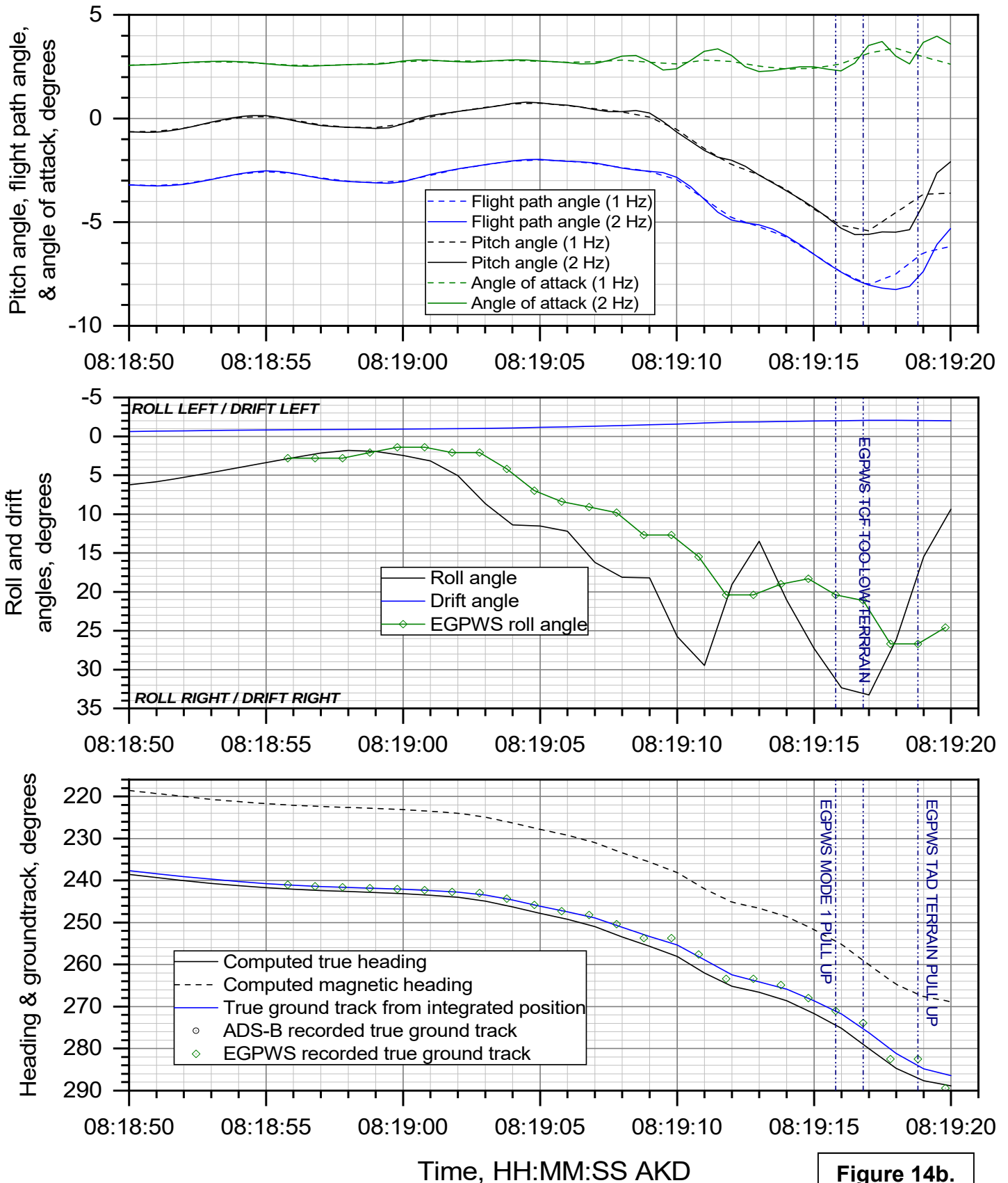
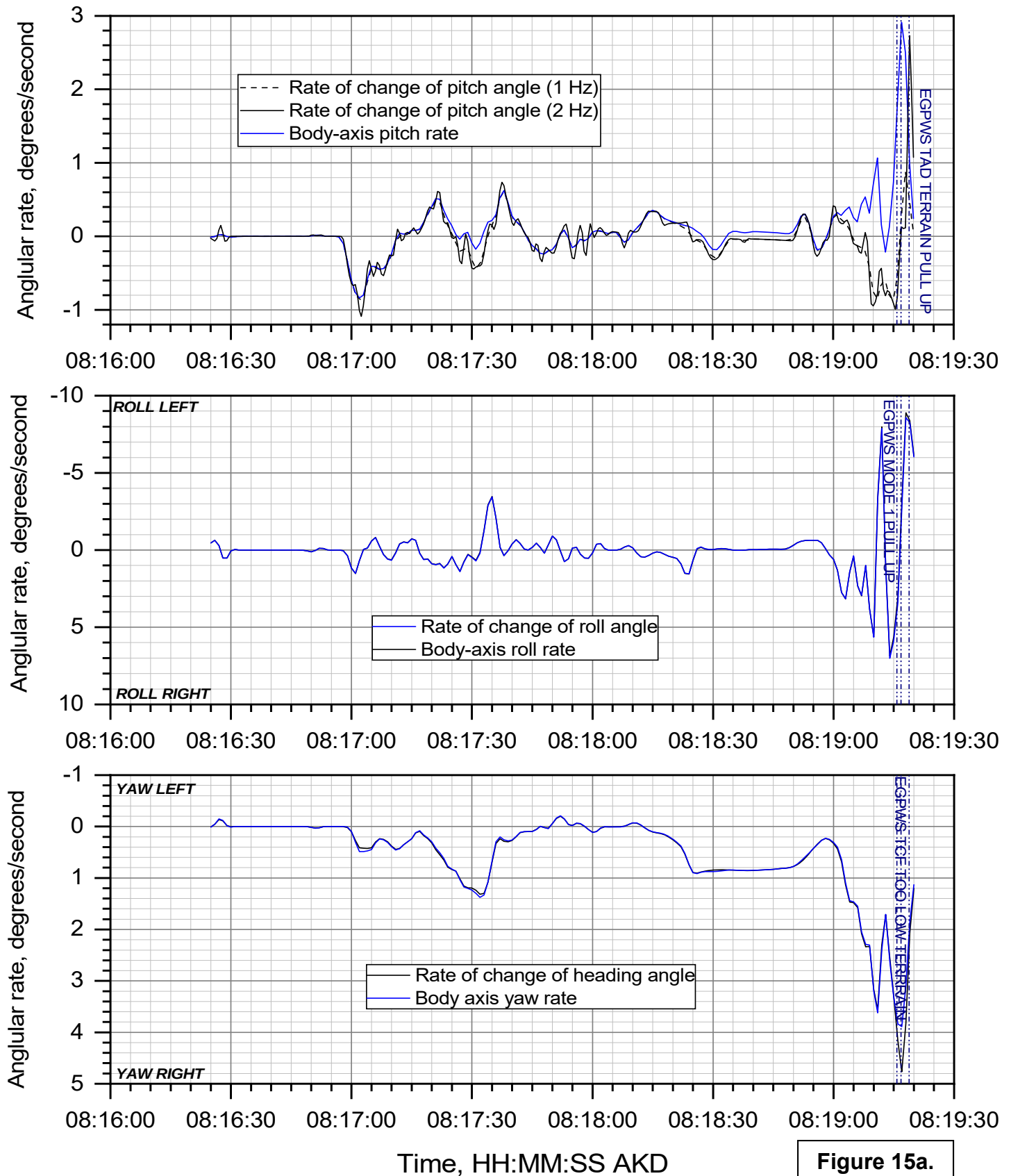


Figure 14b.

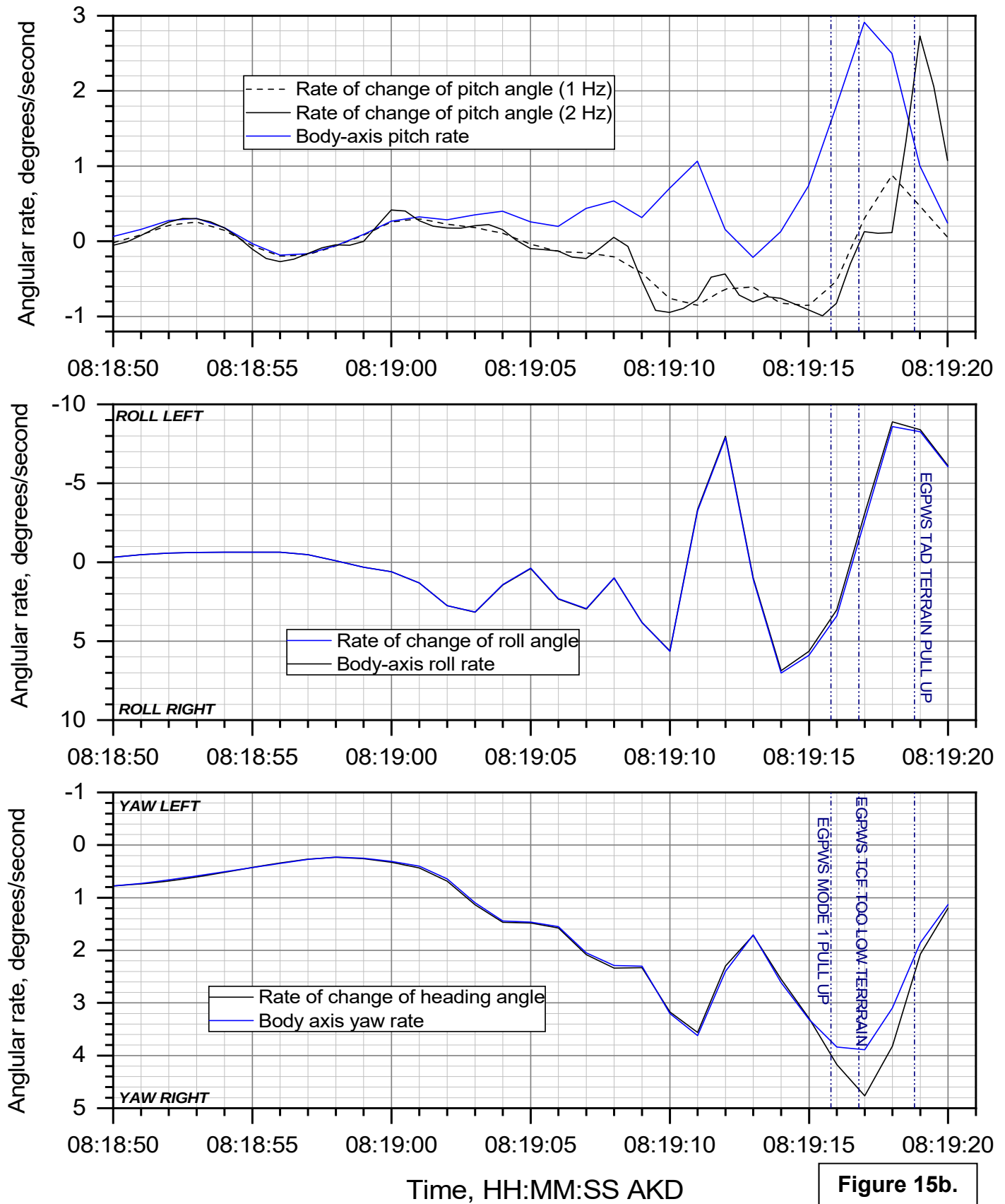
ANC18LA031: Cessna 208B Caravan, N814GV, Atqasuk, AK, 04/11/2018

Angular rates during final 3 minutes of flight


Figure 15a.

ANC18LA031: Cessna 208B Caravan, N814GV, Atqasuk, AK, 04/11/2018

Angular rates during final 3 minutes of flight (detail)


Figure 15b.

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