

Date: February 4, 2025

To: John Brannen, Office of Aviation Safety

From: John O’Callaghan, Office of Research and Engineering

Subject: Airplane performance plots for CEN24FA160

John:

This memorandum transmits plots of radar-based flight path and airplane performance information for the Piper PA-46-350P (N451MA) accident in Hartsburg, Missouri, on April 16, 2024 (CEN24FA160). The plots present Automatic Dependent Surveillance – Broadcast (ADS-B) data and radar data concerning N451MA, and additional performance parameters computed from the radar data. The ADS-B data transmitted from the airplane ended at 12:03:32 Central Daylight Time (CDT) while the airplane was still flying relatively level at an indicated altitude of about 16,000 ft., before it started a descending left turn at about 12:04:05. However, returns from the airplane’s transponder (secondary radar returns) were received from the Columbia, Missouri (COU) Airport Surveillance Radar (ASR) sensor up to 12:05:50, and indicated a peak descent rate of about 17,000 feet/minute at 12:04:46. The radar data analysis presented here suggests that the airplane might have started to break apart at about this time. Primary radar returns that might be associated with components of the airplane that separated in flight were received between 12:05:00 and 12:06:10. The airplane was destroyed after impacting the ground near Hartsburg, and the distribution of the wreckage indicated that the airplane indeed broke apart in flight.

Description of ADS-B data

The ADS-B data for the airplane was provided by the Federal Aviation Administration (FAA) and includes:

- Time of the ADS-B messages in Universal Coordinated Time (UTC), at a frequency of approximately 1 report every second (1 Hz).
- Latitude, as determined by the airplane’s Global Navigation Satellite System (GNSS) receiver, recorded to the nearest hundredth of an arc-second.
- GNSS longitude, recorded to the nearest hundredth of an arc-second.

- GNSS altitude, recorded to the nearest 25 feet (i.e., within an uncertainty of ± 12.5 ft.). The GNSS altitude is the height above the WGS84 ellipsoid. Altitude above mean sea level (MSL) is obtained by subtracting the height of the geoid above the ellipsoid from the GNSS height. In this case, MSL altitude = GNSS altitude + 109 ft. (at the accident site, the geoid is 109 ft. below the ellipsoid).
- Pressure altitude to the nearest 25 feet.
- Avionics-reported¹ GPS-based north and east velocities recorded to the nearest knot.
- Avionics-reported barometric-based rate of climb recorded to the nearest foot per second.

As noted earlier, the ADS-B ended before the final descending turn, and so is not used in this analysis. It is not known why no ADS-B data was received from N451MA after 12:03:32 CDT. The plots below present the end of the ADS-B data along with the radar data used to analyze the airplane's final turn and descent.

Description of ARSR and ASR radar data

In general, two types of radar are used to provide position and track information, both for aircraft cruising at high altitudes between airport terminal airspaces, and those operating at low altitude and speeds within terminal airspaces.

Air Route Surveillance Radars (ARSRs) are long range (250 nm) radars used to track aircraft cruising between terminal airspaces. ARSR antennas rotate at 5 to 6 RPM, resulting in a radar return every 10 to 12 seconds. Airport Surveillance Radars (ASRs) are short range (60 nm) radars used to provide air traffic control services in terminal areas. ASR antennas rotate at about 13 RPM, resulting in a radar return about every 4.6 seconds. N451MA was tracked by the COU ASR and by ARSRs located in Kirksville, MO (IRK), Crocker, MO (QJN), Oskaloosa, KS (QBZ) and St. Louis, MO (STL). The returns corresponding to N451MA from these radar sites are presented in Figures 1 and 2 and discussed further below.

Primary and secondary radar returns

A radar detects the position of an object by broadcasting an electronic signal that is reflected by the object and returned to the radar antenna. These reflected signals are called *primary returns*. Knowing the speed of the radar signal and the time interval

¹ Here "avionics-reported" indicates that the recorded speed values were computed by the airplane's avionics and broadcast over the ADS-B system, as opposed to being computed on the ground using the GNSS latitude and longitude coordinates broadcast by the airplane.

between when the signal was broadcast and when it was returned, the distance, or range, from the radar antenna to the reflecting object can be determined. Knowing the direction the radar antenna was pointing when the signal was broadcast, the direction (or bearing, or azimuth) from the radar to the object can be determined. Range and azimuth from the radar to the object define the object's position. In general, primary returns are not used to measure the altitude of sensed objects, though some ARSRs do have height estimation capability. ASRs do not have height estimation capabilities.

The strength or quality of the return signal from the object depends on many factors, including the range to the object, the object's size and shape, and atmospheric conditions. In addition, any object in the path of the radar beam can potentially return a signal, and a reflected signal contains no information about the identity of the object that reflected it. These difficulties make distinguishing individual aircraft from each other and other objects (e.g., flocks of birds) based on primary returns alone unreliable and uncertain.

To improve the consistency and reliability of radar returns, aircraft are equipped with transponders that sense beacon interrogator signals broadcast from radar sites, and in turn broadcast a response signal. Thus, even if the radar site is unable to sense a weak reflected signal (primary return), it will sense the response signal broadcast by the transponder and be able to determine the aircraft position. The response signal can also contain additional information, such as the identifying "beacon code" for the aircraft, and the aircraft's pressure altitude (also called "Mode C" altitude). Transponder signals received by the radar site are called *secondary returns*.

N451MA was on an instrument flight plan and broadcasting a transponder beacon code of 6206.

Recorded radar data

Recorded data from the ASRs and ARSRs listed above was obtained from the FAA, and includes the following parameters:

- UTC time of the radar return, in hours, minutes, and seconds. CDT = UTC - 5 hours.
- Transponder beacon code associated with the return (secondary returns only).

- Transponder reported altitude in hundreds of feet associated with the return (secondary returns only). The transponder reports pressure altitude in feet MSL. The resolution of this data is ± 50 ft.
- Slant Range from the radar antenna to the return, in nm. The accuracy of this data is $\pm 1/16$ nm or about ± 380 ft.
- Azimuth relative to magnetic north from the radar antenna to the return, in degrees. The accuracy of azimuth data is about $\pm 0.2^\circ$.
- Latitude and longitude coordinates of the radar return.

In this analysis, the radar antenna locations are used along with the recorded range and azimuth data to compute the nominal latitude and longitude of the radar returns (which are consistent with the recorded latitude and longitude data), and the uncertainty in the positions of the returns associated with the uncertainty in the range and azimuth data. The computed latitude and longitude coordinates are converted to east and north coordinates from the accident site using the WGS84 ellipsoid model of the earth, and are presented in Figures 1 and 2. The latitude and longitude coordinates of the accident site are:

38° 42' 57.760" N, 092° 18' 05.904" W, elevation 596 ft.

Curve-fit of combined secondary returns

The "uncertainty boxes" in Figure 1 depict the areas in which it is possible to place the airplane given the uncertainties in the range and azimuth of each radar return. If the "nominal" locations of the returns, corresponding to zero range and azimuth error, are used to compute the airplane's ground speed, the result is unrealistically "noisy" and indicates that the range and azimuth errors are not in fact zero. To obtain more realistic, "smooth" ground speeds that respect the uncertainty boxes of the radar data, a cubic spline curve-fit of the data combined from all the radar sensors was performed. This curve-fit is depicted by the thick red line in Figure 1, and by the thin black line in Figure 2. The north and east coordinates of the curve fit are shown as a function of time in Figure 3. The primary returns from the COU and IRK radars are depicted by the solid blue and green symbols, respectively.

The Mode C pressure altitude of the combined secondary returns, which has an uncertainty of ± 50 ft., is also smoothed with a curve fit, as shown in Figure 4. The fit is constrained to respect the ± 50 ft. uncertainty bands.

The curve-fit position and altitude data is used to compute additional airplane performance parameters during the final descending turn, as described below.

Additional performance parameters computed from curve-fit radar data

The position of an airplane as a function of time defines its velocity and acceleration vectors. In coordinated flight, these vectors 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 additional information about the wind and the airplane. Specifically, the wind speed and direction, as well as the airplane weight and lift coefficient (C_L) as a function of α , are required to compute the Euler angles.

Winds aloft from a High Resolution Rapid Refresh (HRRR) atmosphere model for 12:00 CDT near the accident site, provided by an NTSB meteorologist, are used in the performance calculations (see Figure 5). A weight of 3,848 lb. is assumed per the weight and balance estimate provided during the investigation, which assumes the airplane was topped off with fuel at KMSN.

The lift curve (C_L vs. α) for the airplane is estimated based on textbook methods and the geometry and performance data published in the Airplane Flight Manual (AFM).

Results

The ADS-B data, radar data, and results of the performance calculations are presented in Figures 1-8. Figures 1 and 2 present a birds-eye view of the flight path of the airplane; Figure 1 presents the data from all the radars over a grid background, and Figure 2 presents a detail view of the curve-fit of the combined radar data over a simple map background. The position of the airplane is presented as north and east coordinates from the accident site. The altitude labels in Figure 2 are the Mode C pressure altitude in feet above mean sea level (MSL).

Figure 3 plots the north and east coordinates of the curve-fit position of the airplane as a function of time. The north and east coordinates of the COU and IRK primary returns are depicted by the solid symbols.

Figure 4 plots altitude vs. time. The ADS-B geometric altitude is depicted as a black line that ends at 12:03:32, the curve-fit of the combined Mode C pressure altitude data is

depicted by the red line, and the indicated altitude corresponding to the curve-fit pressure altitude and an altimeter setting of 29.67 "Hg is depicted by the green line. The true altitude estimated from the curve-fit pressure altitude and the temperature altitude profile shown in Figure 5 is depicted by the blue line. Note that the altitude drops increasingly rapidly after 12:04:05, but exhibits a "kink" between 12:04:50 and 12:04:55. This "kink" appears shortly after the computed airspeed peaks and then suddenly starts to decrease, and together with the airspeed behavior suggests that the in-flight breakup of the airplane might have started around this time.

Figure 5 presents the wind direction, wind speed, and static air temperature as a function of altitude from the 12:00 CDT HRRR model sounding obtained from the NTSB meteorologist.

Figure 6 plots several airplane speeds, including ground speed, true airspeed, calibrated airspeed, and vertical speed (rate of climb). The ground speed and vertical speed recorded at the end of the ADS-B data are depicted by the thick black lines. The ground speed obtained from the curve-fit of the radar data is depicted by the thin black line in the top plot of Figure 6. The true and calibrated airspeeds computed using the ground speed from the curve-fit combined with the winds aloft from the HRRR model are depicted by the blue and red lines, respectively. The V_{NE} of 200 KCAS published in the AFM is depicted by the dashed red line; note that the peak calibrated airspeed computed from the data is 240 KCAS, or 40 knots above V_{NE} .

The rate of climb obtained by taking the time derivative of the computed true altitude is depicted by the black line in the bottom plot of Figure 6. Note that the rate of climb reaches a value of about -17,000 ft./min., or about -168 knots, at about 12:04:46 before diminishing suddenly to -8,000 ft./min. at 12:04:52. Also about this time, the computed airspeed reaches its peak of 240 KCAS and starts to decrease suddenly. The reversals in the rate of change of airspeed and vertical speed at 12:04:46 suggest that the airplane might have started to break up at this time, with an associated large increase in drag. The airspeed and rate of climb eventually stabilized at about 100 KTAS and -10,000 ft./min. after 12:05:15.

Figure 7 presents the Euler angle calculations, and indicates that the descending left turn depicted in Figures 1, 2, and 4 started at about 12:04:05 with an initial left roll to between 25 and 29° and a drop in pitch from about 0° to about -5°. At 12:04:29, the left roll increased through 30° and reached 70° at 12:04:36. At the same time, the pitch angle decreased to about -17°. The roll angle remained between 65° and 70° left while the pitch continued to drop. At 12:04:46, the pitch angle was about -34°, the airspeed had climbed to 240 KCAS (40 knots above V_{NE}), and the rate of climb reached -17,000 ft. / min. As noted above, the airplane likely started to break apart at about this time. After 12:05:02, the flight path angle of the airplane relative to the airmass (γ_A) was

about -90° , or straight down. (Because the airplane drifted with the strong wind, the flight path angle relative to the Earth (γ_E) was only between -60° and -65° .)

Figure 8 plots the computed longitudinal and normal load factors (n_x and nlf). The large negative spike in n_x between 12:04:46 and 12:04:50 indicates a very large deceleration that could be consistent with a large increase in drag resulting from the airplane starting to break apart. The brief nlf peak of 2 Gs at 12:04:38 is consistent with the increase in roll angle to 70° left as the nose was dropping.

Summary

The airplane performance described by the radar data analysis in this memorandum suggests that shortly after 12:04:05 CDT, N451MA started a descending, left turn that steepened to a 70° roll angle while the pitch angle dropped to -17° and then further dropped to -34° , as the airplane accelerated past V_{NE} and reached a descent rate of about $-17,000$ ft./min. The sudden reversal in the rate of increase of airspeed and rate of climb at 12:04:46, at an airspeed of 240 KCAS (40 knots above V_{NE}), suggests that the airplane started to break up in flight at about this time.

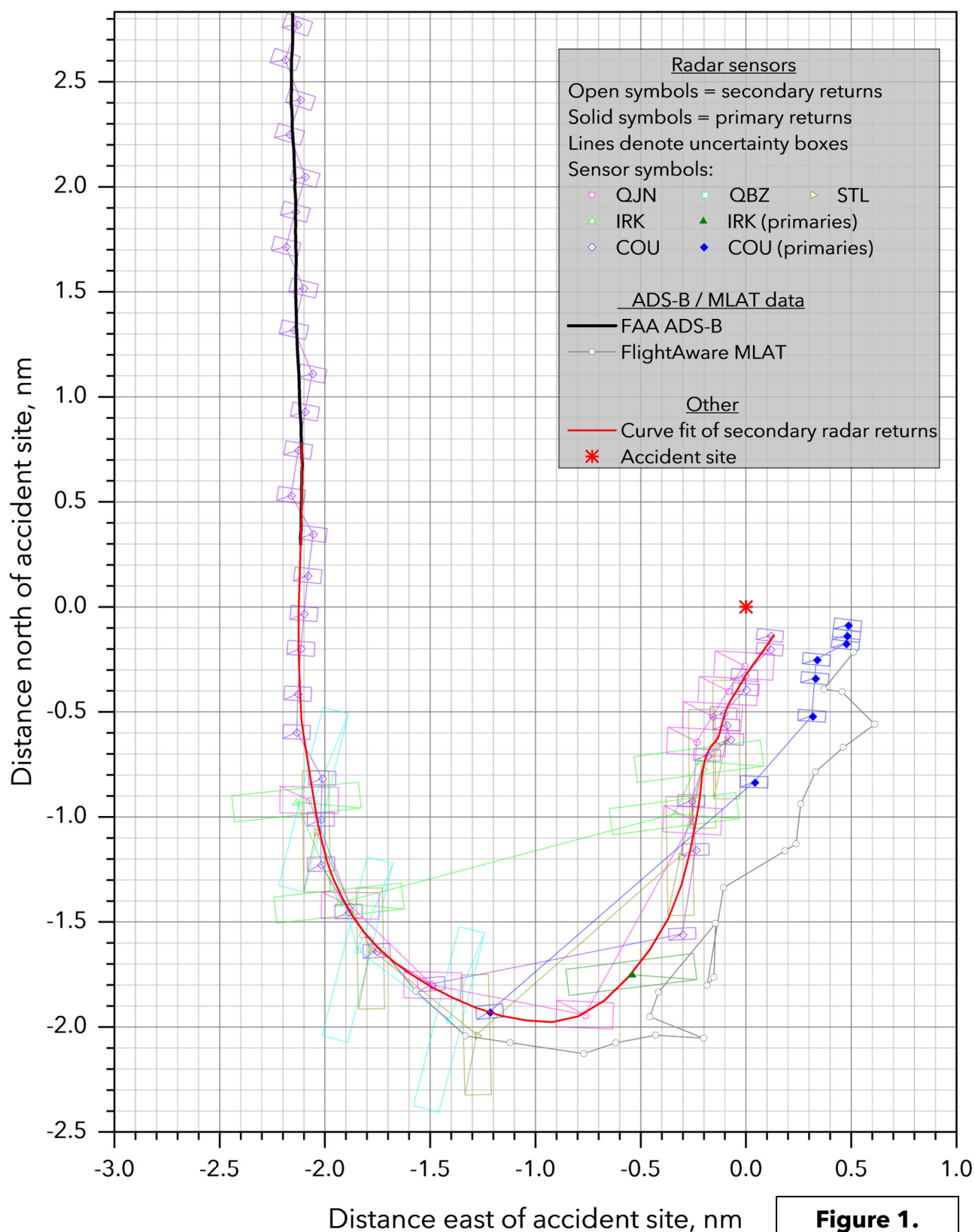
Please let me know if you have any questions about the contents of this memorandum.

Regards,

John O'Callaghan
National Resource Specialist – Aircraft Performance

CEN24FA160: Piper PA-46-350P, N451MA, Hartsburg, MO 04/16/2024

Plan view of flight path during final descent



CEN24FA160: Piper PA-46-350P, N451MA, Hartsburg, MO 04/16/2024

9

Plan view of flight path during final descent (detail)

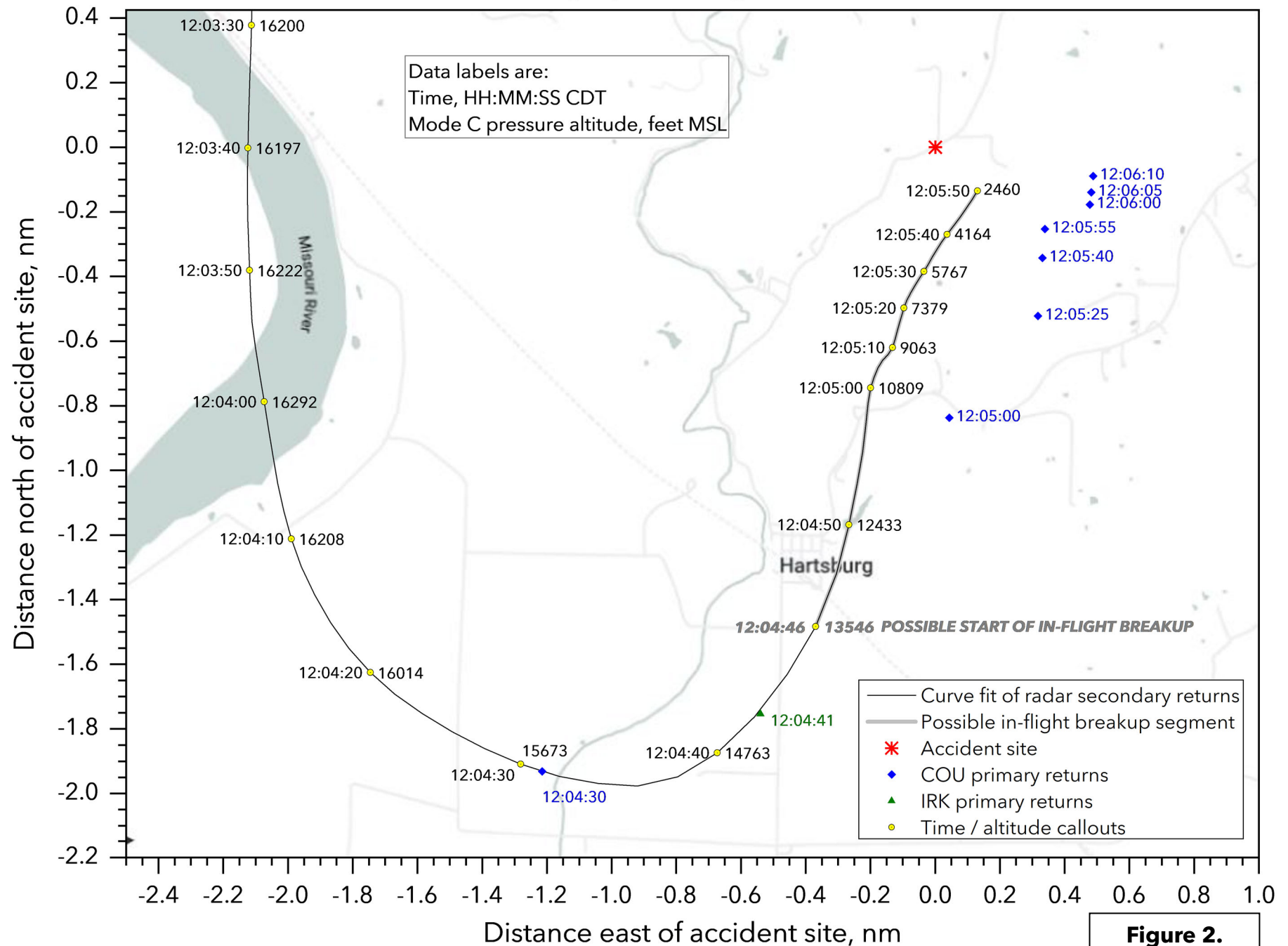
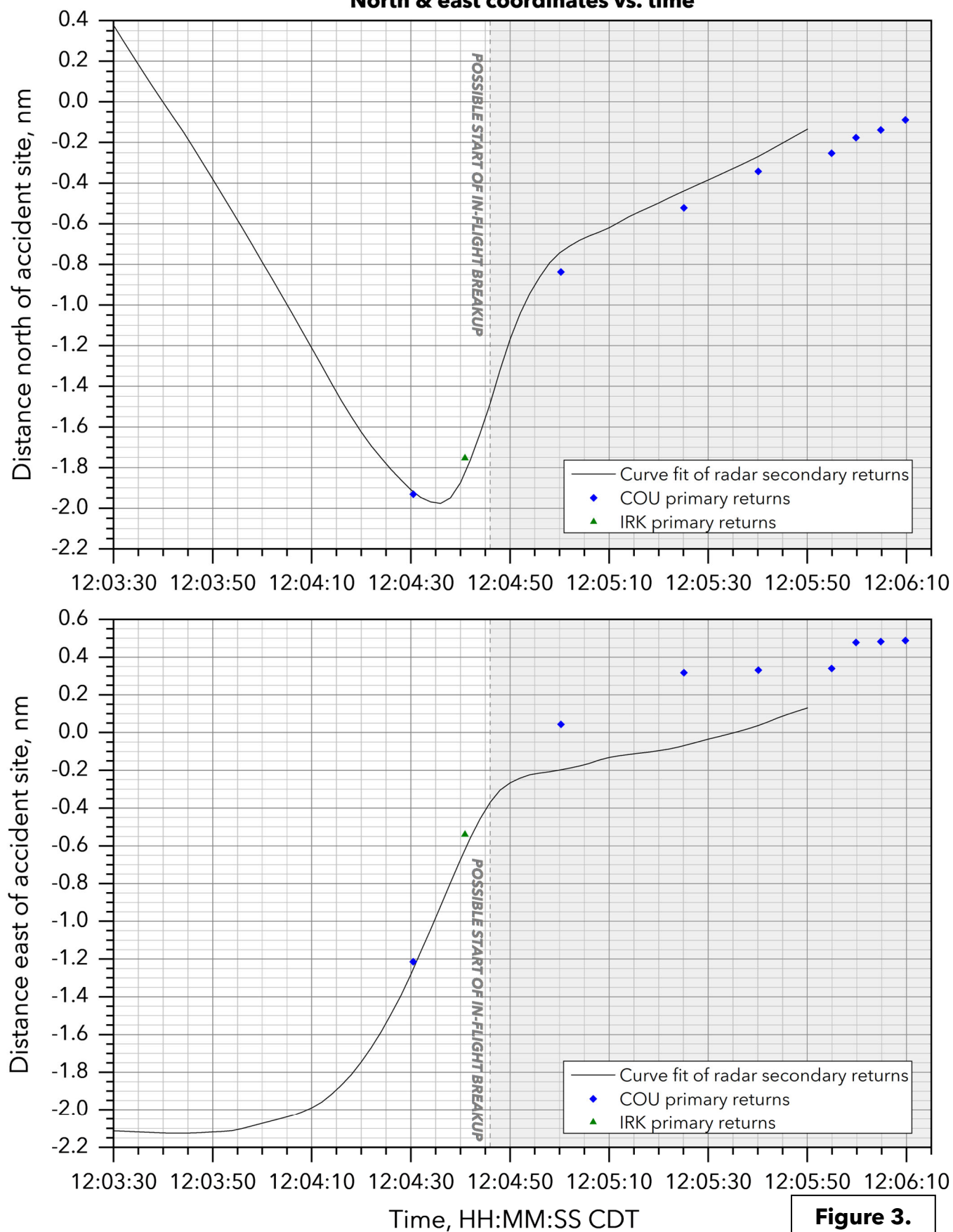


Figure 2.

CEN24FA160: Piper PA-46-350P, N451MA, Hartsburg, MO 04/16/2024**North & east coordinates vs. time****Figure 3.**

Altitude during final descent

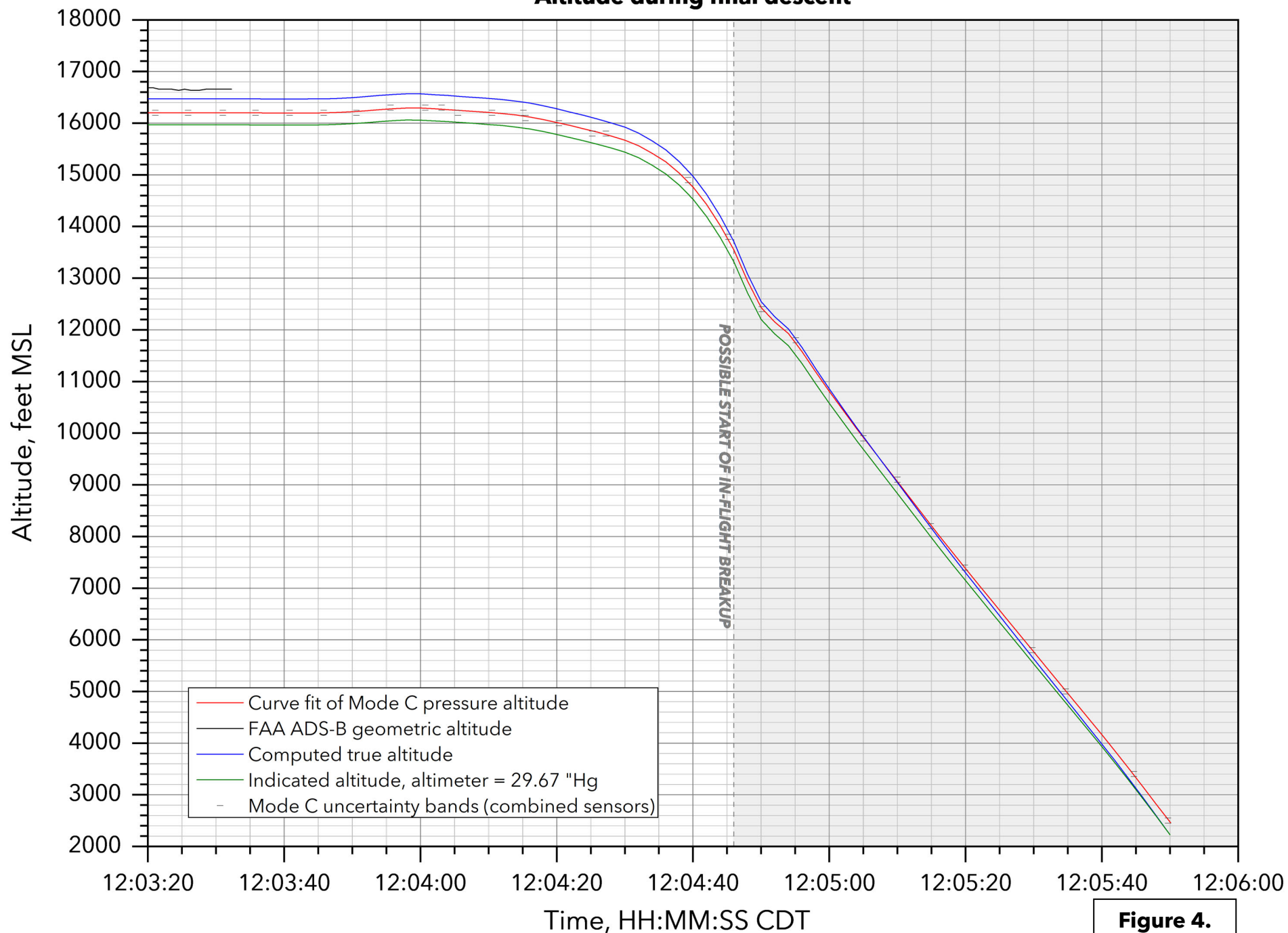


Figure 4.

CEN24FA160: Piper PA-46-350P, N451MA, Hartsburg, MO 04/16/2024

12

Winds aloft from 12:00 CDT HRRR model

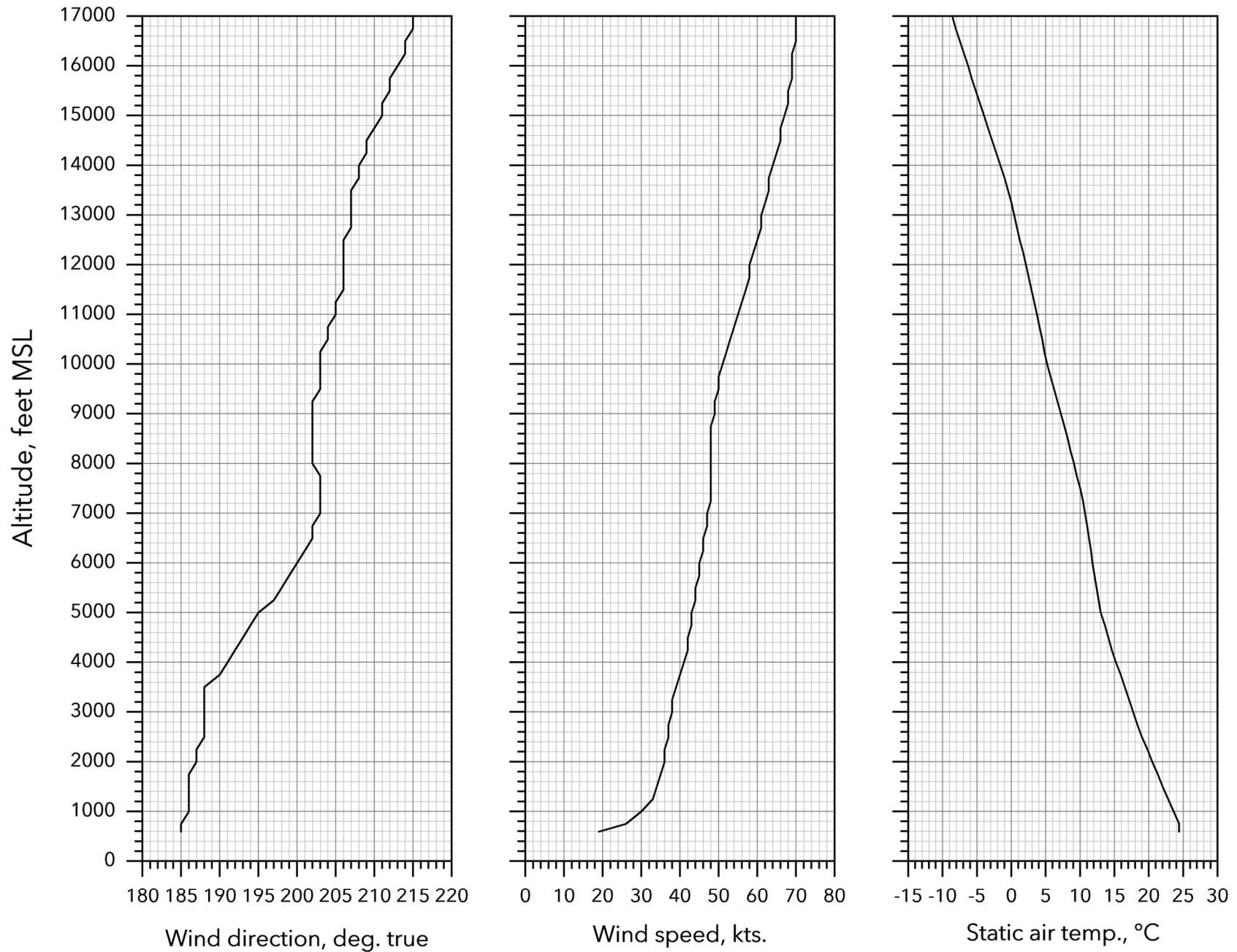


Figure 5.

CEN24FA160: Piper PA-46-350P, N451MA, Hartsburg, MO 04/16/2024

Speeds & rate of climb vs. time

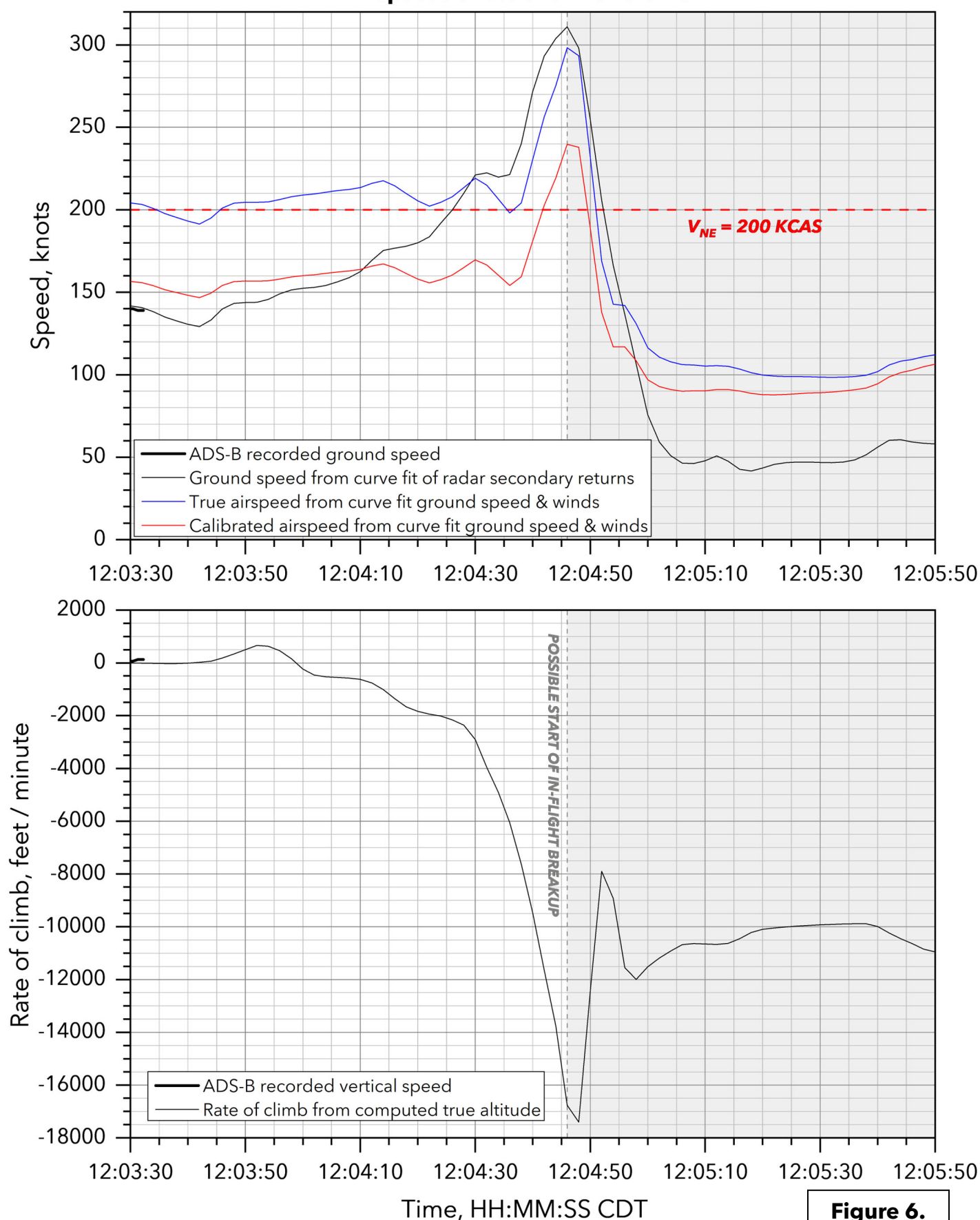
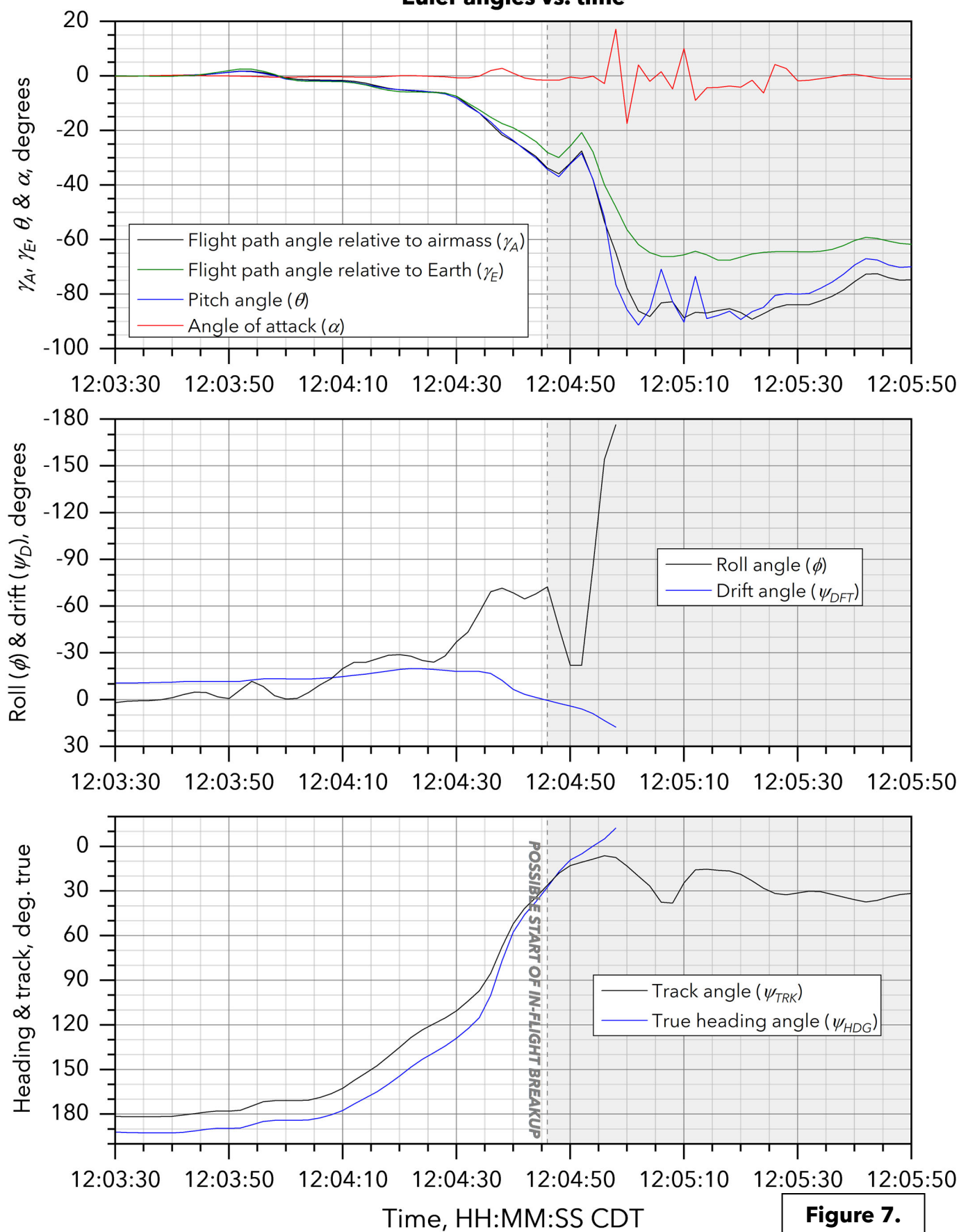
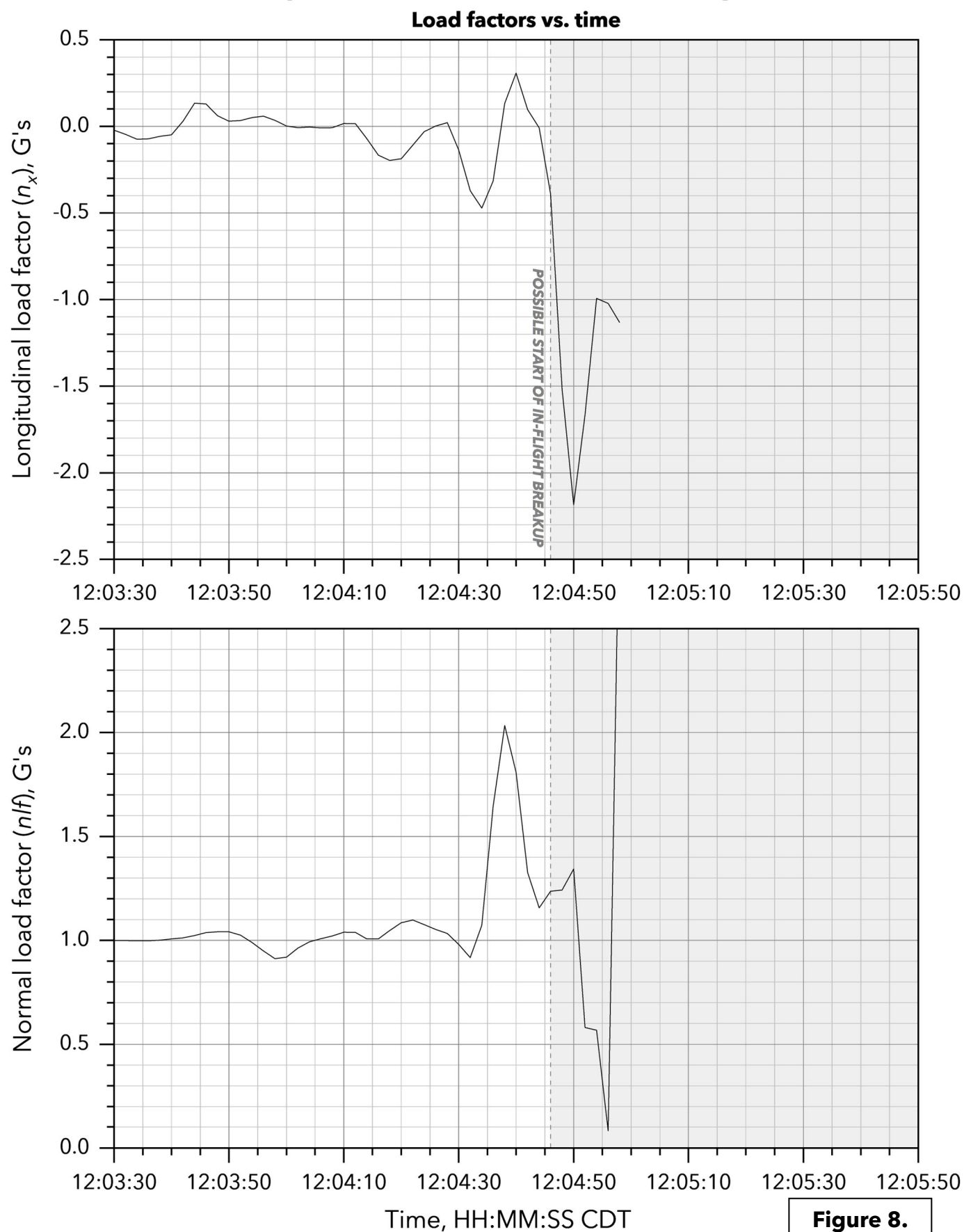


Figure 6.

CEN24FA160: Piper PA-46-350P, N451MA, Hartsburg, MO 04/16/2024

Euler angles vs. time


Figure 7.

CEN24FA160: Piper PA-46-350P, N451MA, Hartsburg, MO 04/16/2024**Figure 8.**