

Date: May 1, 2024

To: Laura Abraham, Office of Aviation Safety

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

Subject: Airplane performance plots for CEN23FA220

Laura:

This memorandum transmits plots of Automatic Dependent Surveillance – Broadcast (ADS-B) flight path and airplane performance information for the Vans RV7 (N977RV) accident in Gibbon, Nebraska, on June 2, 2023 (CEN23FA220). The plots present ADS-B data from N977RV, and additional performance parameters computed from these data. The airplane was destroyed after impacting the ground following a sudden dive from about 12,000 ft. MSL, and the pilot was fatally injured.

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 + 82 ft. (at the accident site, the geoid is 82 ft. below the ellipsoid).
- Pressure altitude to the nearest 25 feet.
- Avionics-reported¹ GPS-based north and east velocities recorded to the nearest knot.

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.

- Avionics-reported barometric-based rate of climb recorded to the nearest foot per second.

Additional performance parameters computed from the ADS-B data – such as the Euler angles (pitch, roll, and heading) – depend on the ground speed, and will reflect any “noise” in that parameter. Although the ADS-B GNSS position of the airplane is provided at a relatively high sample rate (1 Hz) and accuracy (compared to radar data), computing ground speed from the data directly, without any filtering or other corrections, results in unrealistic noisiness or “spikes” in the result.

To reduce spurious noise in the ground speed and other calculated parameters presented in this memorandum, the north and east coordinates of the airplane relative to the crash site are computed by integrating the north and east components of ground speed recorded in the ADS-B data as a function of time. The recorded ground speed components are themselves filtered by the airplane’s avionics prior to broadcast over the ADS-B system, and so a smooth ground speed can be obtained by combining these velocities (the result is referred to here as the “recorded ADS-B ground speed”). In addition, for the performance calculations the integrated north and east positions are curve fit using a cubic spline smoothing algorithm evaluated at a consistent 1 Hz sampling interval. This step fills in gaps in the recorded data, and further ensures that smooth velocities and other performance parameters result from taking the time-derivatives of the positions. As shown in Figures 1 and 2, the resulting flight track (labeled “Curve fit of ADS-B ground speed integration”) matches the recorded flight track well. This curve fit flight track is used in the computation of additional performance parameters.

A similar approach is used to determine the altitude used for additional performance calculations. Figure 3 plots the ADS-B geometric and pressure altitudes vs. time, as well as a cubic spline curve fit of the pressure altitude resulting from integrating the vertical speed recorded in the ADS-B data (labeled “Curve fit of ADS-B vertical speed integration.”) This curve fit altitude is used along with the curve fit flight track to compute additional performance parameters.

Notice in Figures 2 and 3 that the ADS-B north, east, and geometric altitude parameters are plotted up to a time of about 09:06:51, but that the ADS-B pressure altitude data is plotted up to a time of about 09:06:59. The data is presented this way because most ADS-B parameters (but not pressure altitude) appear to become invalid after 09:06:51; the recorded geometric altitude becomes 0, and the position data shows the airplane track moving to the northwest of the data point at 09:06:51, whereas the crash site is to the southeast of that point (see the gray “x” symbols labeled “Questionable ADS-B points” in Figure 1). The recorded pressure altitude, which appears to be valid for a longer time, is used to compute the vertical component of the airplane’s airspeed after 09:06:51, as discussed below.

Additional performance parameters computed from ADS-B 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 09:00 CDT near the accident site, provided by an NTSB meteorologist, are used in the performance calculations (see Figure 4). A weight of 1,600 lb. is assumed, which is 200 lb. less than the maximum gross weight allowed by the RV7 design.

The lift curve (C_L vs. α) for the airplane is estimated based on textbook methods and the geometry and published cruise performance of the airplane. The resulting pitch angle is therefore also an estimate. The computed roll angle can be computed with more confidence, since it is not very sensitive to the airplane weight or lift curve.

Results

The ADS-B data and results of the performance calculations are presented in Figures 1-7. Figure 1 presents a birds-eye view of the flight path of the airplane, over a simple map background. The position of the airplane is presented as north and east coordinates from the crash site. The altitude labels in these Figures are the ADS-B pressure altitude in feet above mean sea level (MSL). The curve fit of the integrated ADS-B speeds is shown as the blue line. Note the ADS-B points depicted by gray "x" symbols that proceed to the northwest, away from the crash site, in a straight line at about 09:06:51; these points are labeled "Questionable ADS-B points" and are not part of the curve fit data or used in the performance calculations.

Figure 2 plots the north and east coordinates of the airplane as a function of time. The ADS-B position data is depicted by the gray circles, and the curve fits of the integrated ADS-B velocities are depicted by the blue lines.

Figure 3 plots the ADS-B altitudes vs. time. The geometric altitude is depicted as gray circles, the pressure altitude is depicted by the green diamonds, and the curve

fit of the integrated vertical speed is depicted as the blue line. Note that the altitude drops rapidly after 09:06:45, and that the geometric altitude is no longer valid after 09:06:51 (values of "0" are recorded), but that the pressure altitude remains valid until the end of the data at 09:06:59.

Figure 4 plots the wind direction, wind velocity, and static air temperature vs. altitude from the 19:00 CDT HRRR model obtained from the NTSB meteorologist.

Figure 5 plots several airplane speeds, including ground speed, true airspeed, calibrated airspeed, and vertical speed (rate of climb). The ground speed and vertical speed recorded in the ADS-B data are depicted by the gray circles. The ground speed obtained from the curve fit of the integrated ADS-B velocity components is depicted as the black line. 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 red and blue lines, respectively. The vertical speed obtained by taking the time derivative of the recorded ADS-B pressure altitude is depicted by the green line in the bottom plot of Figure 5. The absolute value of this rate of climb, expressed in knots, is depicted by the green line in the top plot of Figure 5, and provides the vertical component of true airspeed after 09:06:51, after the other ADS-B parameters become invalid. Note that this vertical component alone reaches a value of about -29,000 ft./min., or about 286 knots, at the end of the data.

Figure 6 presents the Euler angle calculations, and indicates that in the right turn depicted in Figure 1, the roll angle initially varied between 10° and 50°. At 09:06:18, the roll angle increased briefly to 90° as the flight path angle dropped to about -20°, before the roll angle recovered back to about 0° and the flight path angle increased to about -10°. The roll angle then progressively increased to about 60° at 09:06:37. At about 09:06:42, the roll angle again increased rapidly, passing through 90° and reaching 129° at 09:06:48. At the same time, the flight path angle decreased rapidly, reaching about -60° at 09:06:50.

Figure 7 plots the computed longitudinal and normal load factors. The computed normal load factor remains positive and below 2 G's until about 09:06:47. The maximum computed load factor is 2.46 G's at 09:06:48.

Please let me know if you would like to discuss the contents of this memorandum further.

Regards,

John O'Callaghan

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Plan view of flight path over accident area

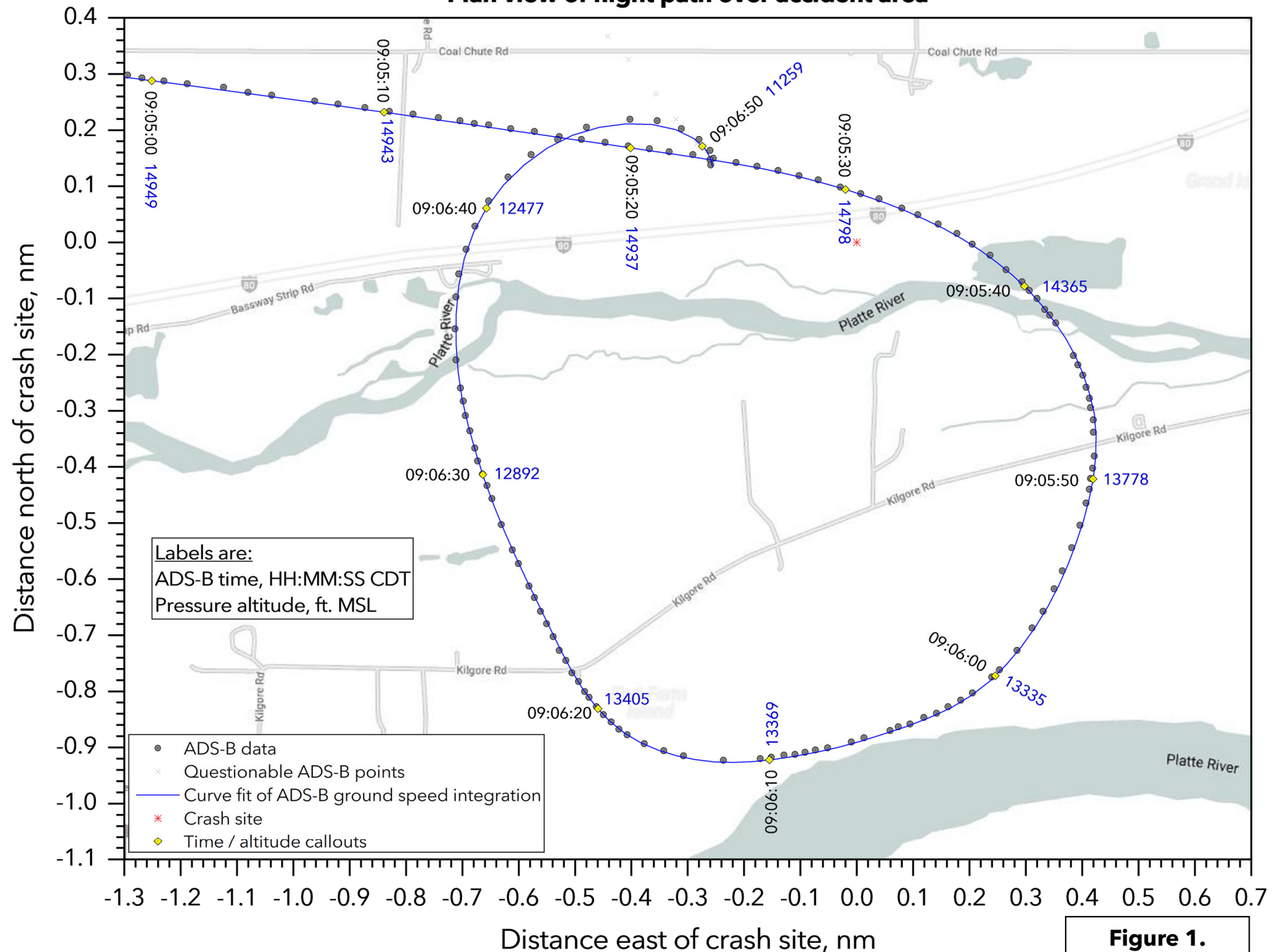


Figure 1.

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North & east coordinates vs. time

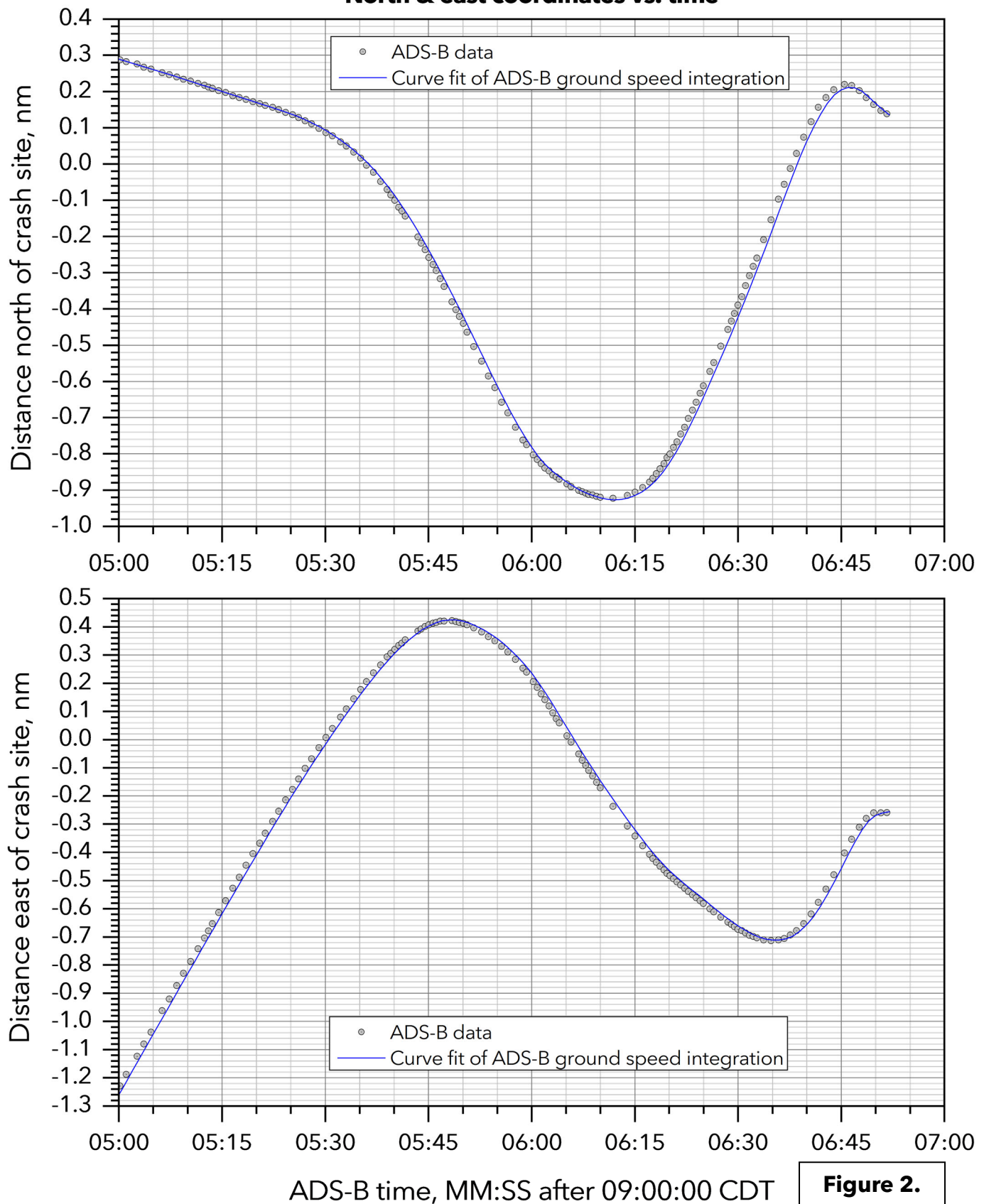
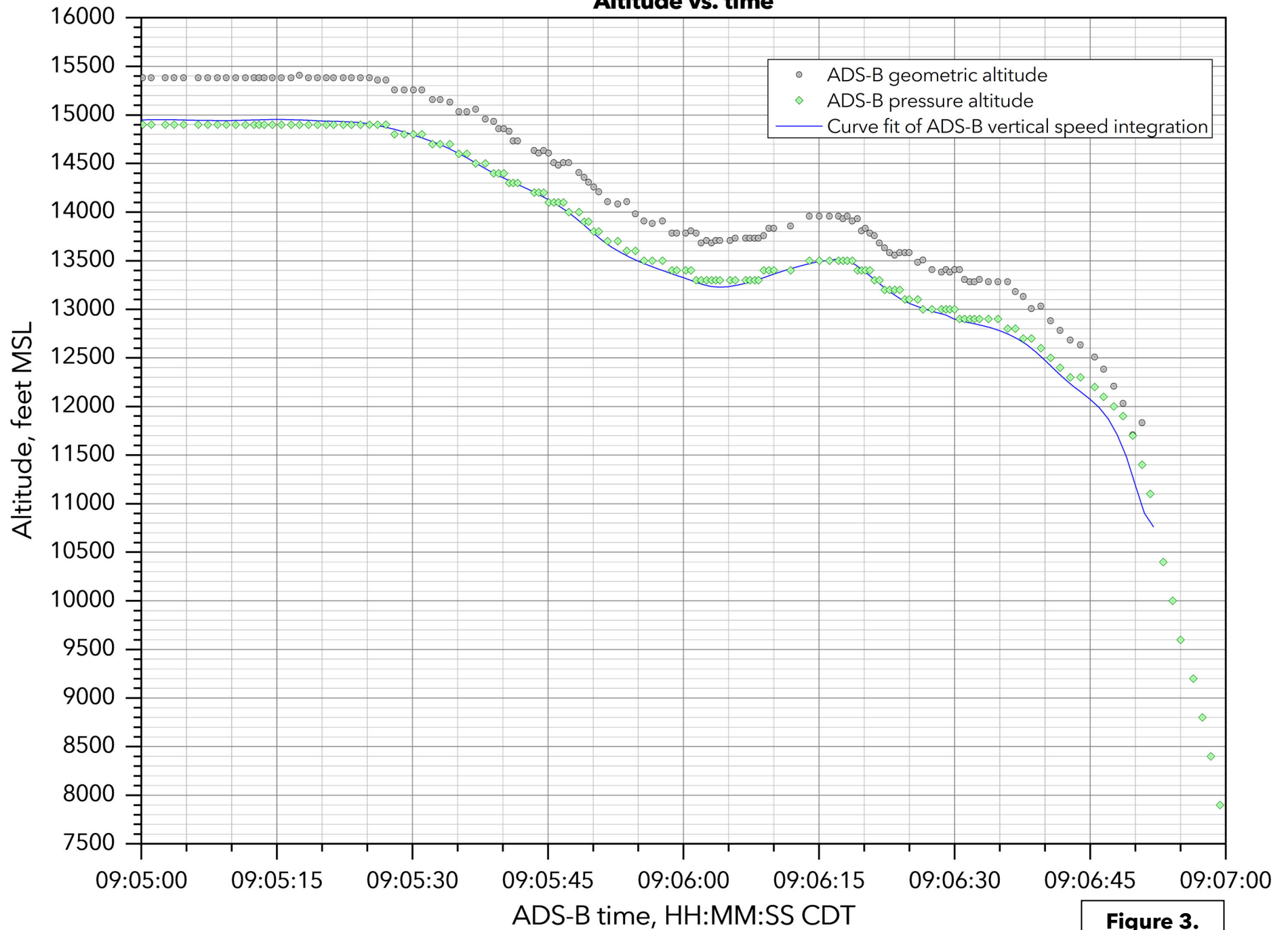


Figure 2.

Altitude vs. time



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Winds aloft from 19:00 CDT HRRR model

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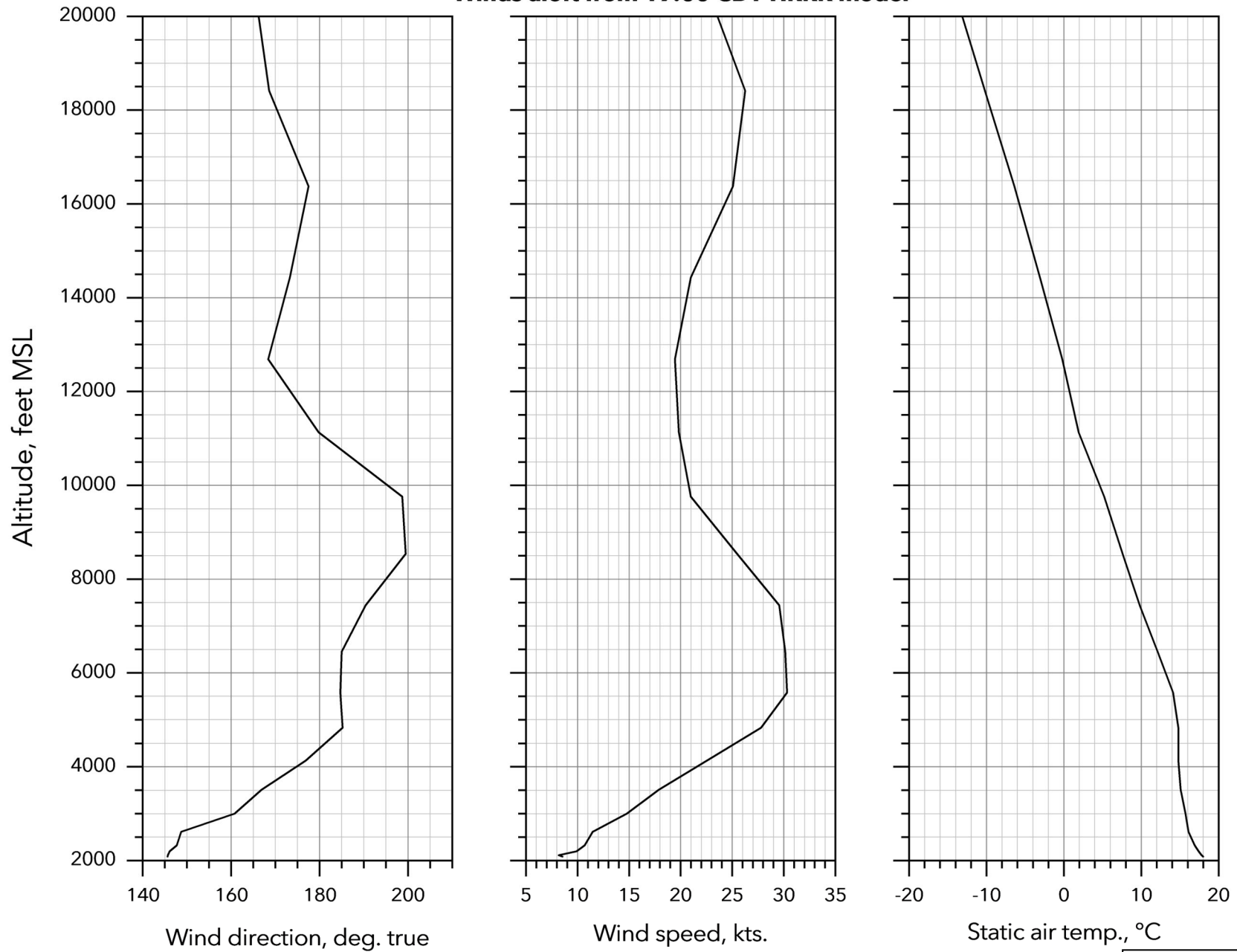


Figure 4.

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Speeds vs. time

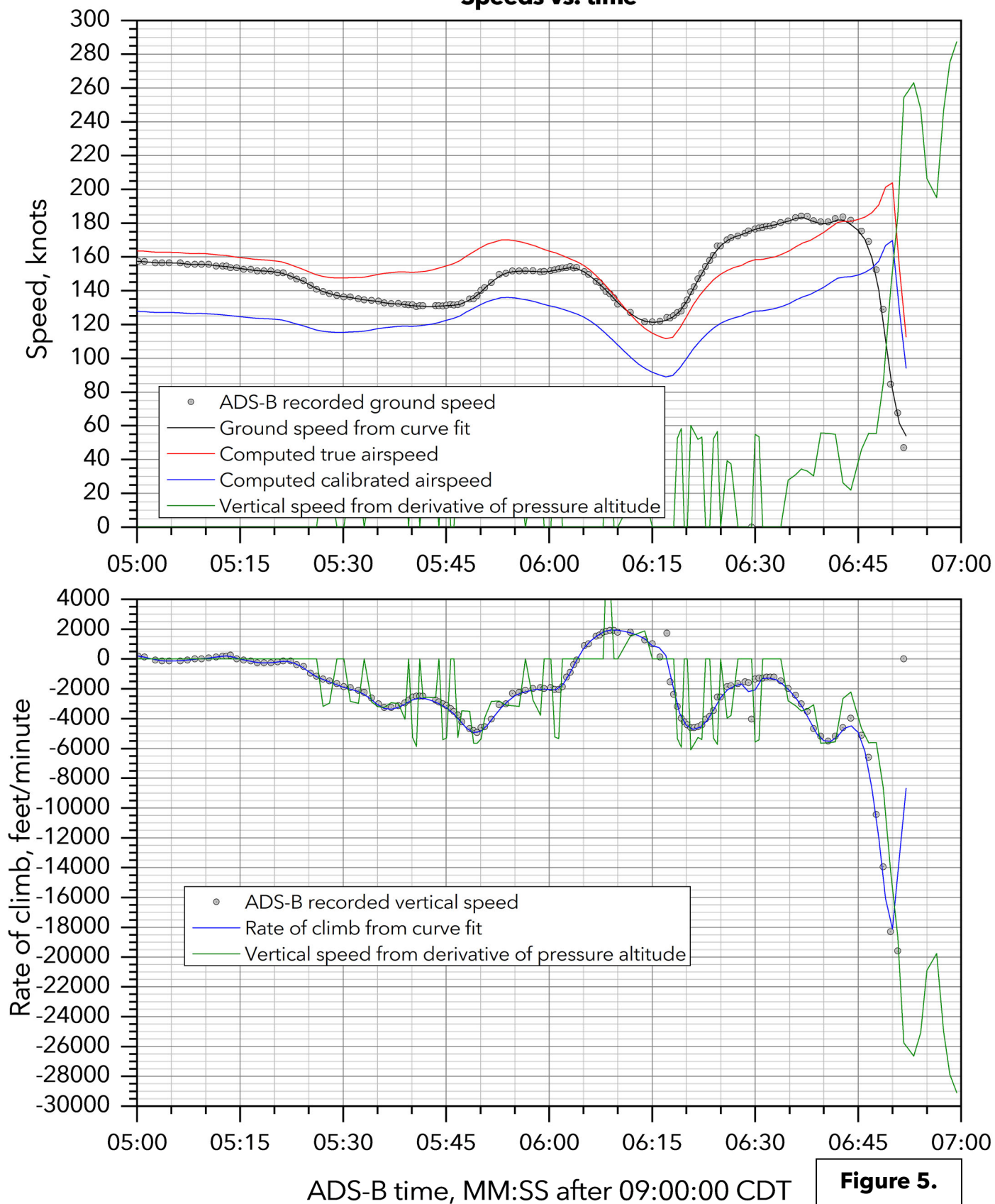
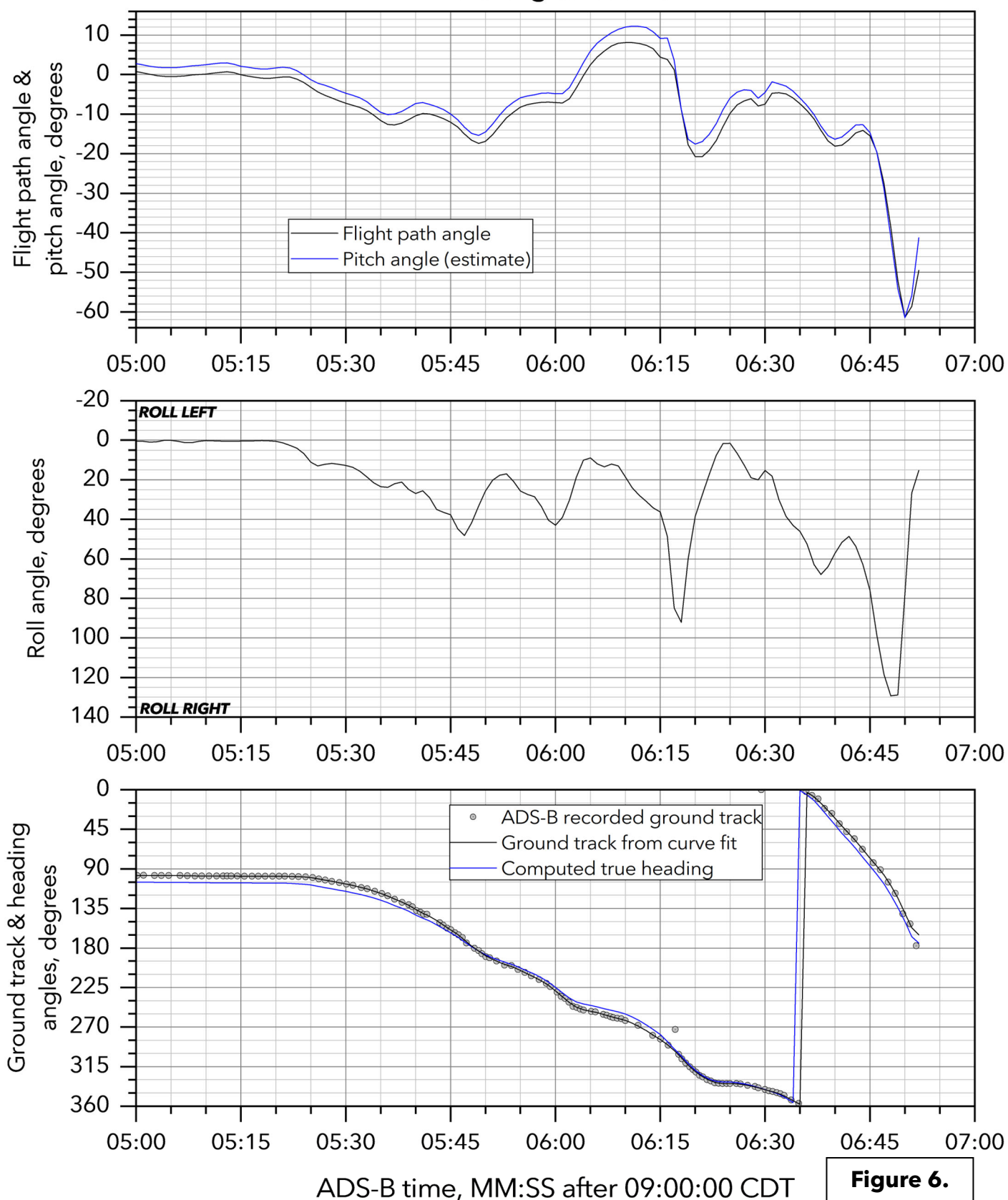


Figure 5.

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Euler angles vs. time


Figure 6.

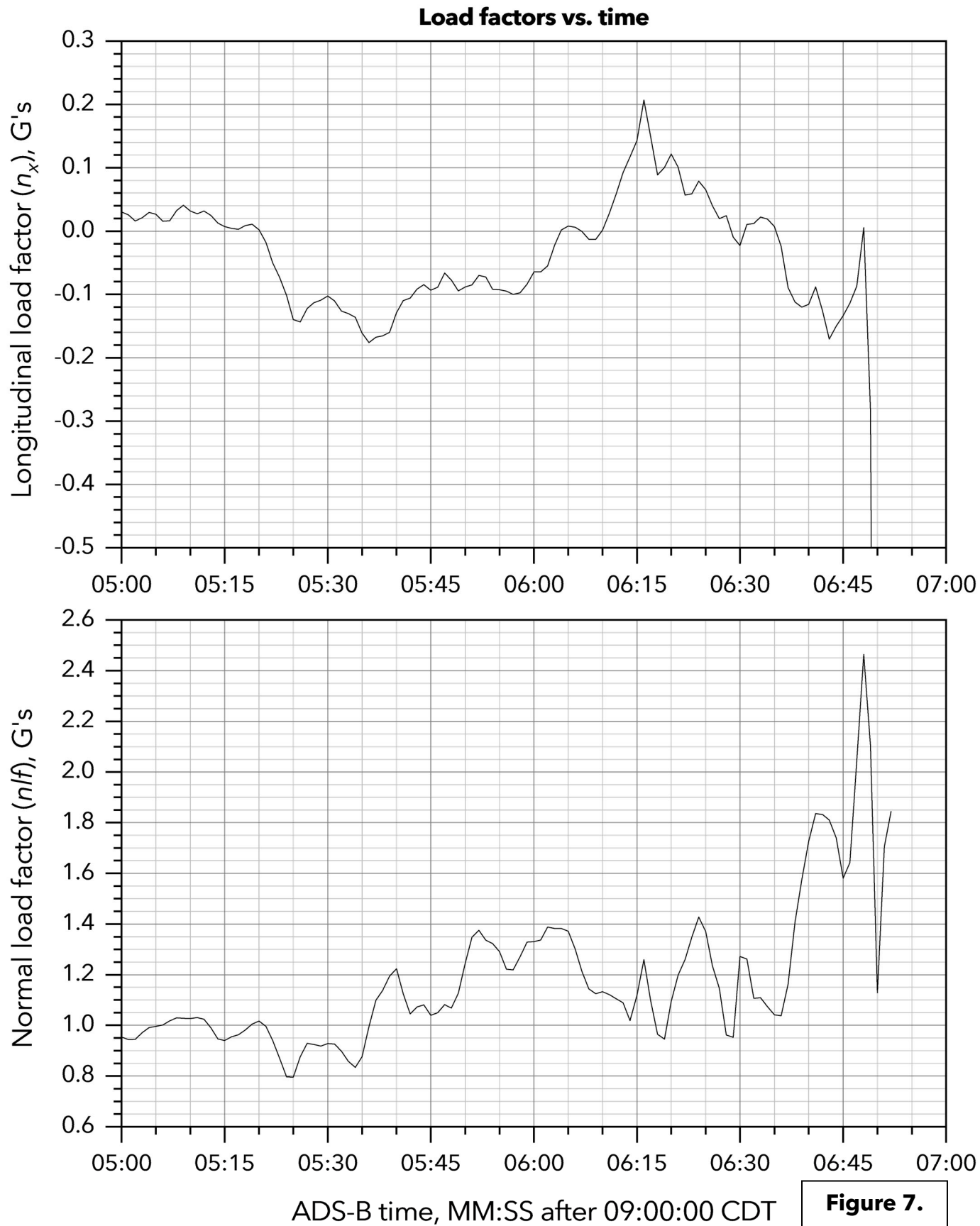


Figure 7.