National Transportation Safety Board

Memorandum

Date: January 12, 2021

To: Timothy Sorensen
Senior Aviation Accident Investigator, Central Region
CEN20LA201 Investigator in Charge (IIC)

From: John O'Callaghan
National Resource Specialist – Aircraft Performance
CEN20LA201 Aircraft Performance Specialist

Subject: ADS-B and Appareo Stratus data analysis for CEN20LA201

Timothy:

This memorandum transmits plots of Automatic Dependent Surveillance – Broadcast (ADS-B) and Appareo Stratus 3i flight path and airplane performance information for the Piper PA-28-235 Cherokee (N8991W) accident in Carlinville, Illinois, on May 31, 2020 (CEN20LA201). The plots present ADS-B and Stratus data from N8991W, and additional performance parameters computed from these data.

Description of Appareo Stratus 3i data

A Stratus 3i ADS-B receiver carried on N8991W was recovered from the airplane sent to the NTSB recorder laboratory in Washington, D.C. for readout, as documented in Reference 1. Reference 1 describes the Stratus device as follows:

> The Appareo Stratus 3i is a wireless non-certified portable receiver capable of providing pilots with Wide Area Augmentation System (WAAS) GPS position, weather and traffic information. The device receives Automatic Dependent Surveillance Broadcast (ADS-B) and records position, speed, attitude, and uncorrected barometric altitude data during flight. The device communicates wirelessly with compatible devices, such as an iPad running compatible applications, such as *ForeFlight* to display all acquired information.

Data from the Stratus is presented in the Figures below as plots with the "Stratus" labels. Of note, Figure 6c depicts jumps in the normal load factor (nlf) from 3.92 G's at 15:46:05.3 to -3.84 G's at 15:46:05.5, from -3.87 G's at 15:46:05.9 to 3.42 G's at 15:46:06.1, and from 3.95 G's at 15:46:07.1 to -3.85 G's at 15:46:07.3. These jumps are self-evidently physically unrealistic, and inconsistent with the nlf computed using other data recorded on the Stratus device.[1]

[1] The longitudinal, lateral, and normal load factors (n_x, n_y, and *nlf*, respectively) can be computed from the components of the airplane's speed along its three axes, and from the recorded Euler angles (pitch, roll, and heading).

Consultations with Appareo (the manufacturer of the Stratus 3i) indicated that the device has an nlf limit of ±3.8 G's, and that normal load factors beyond these limits would be expected to be "railed," i.e., held at the ±3.8 G limit value. The observed jumps occur near this limit, but instead of being "railed," the recorded value appears to change sign. Additional data from the accident Stratus device was provided to Appareo for review. In an email dated December 21, 2020, Appareo informed the NTSB that based on the data for this event, they concluded that

> Our rail detection doesn't appear to work, but the part looks to be railed, that is pretty plain to see. We are unsure why the value is transitioning negative, but it's likely mishandled somewhere in our product somewhere … in summary, we believe the acceleration went above 4g's and the negative acceleration transition is incorrect.

This conclusion is consistent with the nlf values computed using other data, which as shown in Figure 6b reach 4.72 G's at 15:46:05.9.

Description of ADS-B data

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

- Time of the ADS-B position message from the airplane in UTC time, at a frequency of approximately 1 report every second (1 Hz);
- Latitude, as determined by the airplane's Global Positioning System (GPS) receiver, recorded to the nearest hundredth of an arc-second;
- GPS longitude, recorded to the nearest hundredth of an arc-second;
- GPS altitude, recorded to the nearest 25 feet (i.e., within an uncertainty of ±12.5 ft.);
- Pressure altitude to the nearest 25 feet;
- Avionics-reported[2] 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.

Although the ADS-B GPS 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 this spurious noise in the ground speed and other calculated parameters presented in this memorandum, the GPS positions were smoothed by applying a running-average smoothing algorithm. The north and east velocities recorded in the ADS-B file are themselves filtered by the airplane's avionics prior to broadcast over the ADS-B system, and so a very smooth ground speed can be obtained by combining these velocities (the result is shown in Figure 4 as the "Ground speed from ADS-B velocities"). However, this recorded ground speed is not perfectly consistent with the recorded ADS-B latitude and longitude positions; when the north and east velocities are integrated over time, the resulting flight path does not match the recorded flight path perfectly (see the "Integrated ADS-B velocities" curve in Figure 1).

[2] 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 GPS latitude and longitude coordinates broadcast by the airplane.

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. Consequently, most plots in this memorandum present these additional parameters computed using both the "smoothed" ground speed resulting from the running-average smoothing algorithm (which is not as smooth as the "recorded" ground speed, but is more consistent with the recorded positions), and the recorded ground speed (which is smoother than the "smoothed" ground speed, but less consistent with the recorded positions). The recorded and "smoothed" ADS-B ground speeds are plotted in Figure 4.

The rate of climb (vertical speed) can be computed from the recorded GPS and pressure altitudes, though the 25 ft. resolution of the data also results in spurious spikes or noise in the results. This noise can be reduced by smoothing the ADS-B altitude, as shown in Figure 3. The geometric altitude, smoothed using a running-average algorithm, is used for pitch angle and flight path angle calculations. The barometric (indicated) altitude above sea level is computed by correcting the recorded pressure altitude for the 30.26" Hg altimeter setting near the time of the accident, based on the meteorological information published in the preliminary report (Reference 2). The resulting barometric altitude is 313 ft. higher than the recorded pressure altitude.

Rate of climb as reported by the airplane's avionics is also recorded in the ADS-B data file. This parameter is very smooth compared to the rate of climb computed directly from the altitude data. The recorded rate of climb is integrated over time to obtain altitude; the result is shifted to match the recorded altitude, as shown in Figure 3.

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 based on a High Resolution Rapid Refresh (HRRR) sounding model were provided by an NTSB meteorologist and are plotted in Figure 7. A weight of 2,806 lb. is assumed based on the weight and balance estimate you provided in the "Wt&Bal Calc -- N8991W.xlsx" Excel file.

The lift curve (C_L vs. α) for the airplane is based on data for the PA-28-140 obtained during a previous investigation. However, the pitch angles obtained using this lift curve are about 6° higher than those recorded on the Stratus device while the airplane is in level flight, and so the lift curve used here is shifted by 6° so as to match the recorded pitch angles. Note that the Stratus pitch angles appear to be erroneously low; for example, at 15:43:20, while the airplane is flying level, the recorded pitch angle is -5.3°. Adding 6° to this pitch angle (to match the original PA-28-140 lift curve) would make the pitch angle in this condition +0.7°, which is a more realistic value.

Results

The ADS-B data and results of the performance calculations are presented in Figures 1-6. Figure 1 presents a birds-eye view of the flight path of the airplane, over a simple grid background (Figures 1a & 1b) and a *Google Earth* background (Figures 1c & 1d). The position of the airplane is presented as north and east coordinates from the impact site. The altitude labels in these Figures are the ADS-B geometric altitude in feet above mean sea level (MSL). Note that the Stratus and ADS-B positions agree well; the smoothed ADS-B track agrees very well with both the Stratus and ADS-B tracks until about 15:45:55, as the airplane was descending through about 4,830 ft., when the smoothed track starts to shift inside the recorded right turn slightly. The track resulting from the integrated ADS-B speeds matches the recorded positions well while the maneuvering is gentle, but deviates more from the recorded track as the right turn steepens, and deviates significantly from the recorded track past 15:46:00.

Figure 2 plots the north and east coordinates of the airplane as a function of time, for the as-recorded Stratus and ADS-B positions, the smoothed ADS-B positions, and the integrated ADS-B velocities.

Figure 3 plots the airplane's geometric altitude vs. time, as recorded by the Stratus device and in the ADS-B data. Interestingly, while the airplane is level at about 5,500 ft. the Stratus geometric altitude is about 100 ft. higher than the ADS-B geometric altitude. The ADS-B pressure and barometric altitudes are also plotted, as well as the altitude resulting from integrating the ADS-B rate of climb.

Figure 4 plots several airplane speeds, including ground speed, total inertial speed (the combination of ground speed and vertical speed), and calibrated airspeed. The ground speeds presented are those recorded by the Stratus 3i and in the ADS-B data, and computed from the smoothed ADS-B positions. The "Ground speed from ADS-B velocities" (blue line) and "Ground speed from integrated ADS-B velocities" should theoretically be identical, but differ slightly in the areas that the ground speed is changing quickly because of numerical effects when integrating and then differentiating discrete data. The blue line is computed by combing the recorded ADS-B north and east velocities. The red line is computed by first integrating the ADS-B north and east velocities to get positions, and then differentiating these positions to get velocities. If the ADS-B data were sampled at a higher rate, then the numerical effects and differences between the red and blue lines would diminish.

Calibrated airspeed is computed by combining total inertial speed with the winds aloft plotted in Figure 7 and accounting for the difference between true airspeed and calibrated airspeed with altitude. Results using both the ground speed from the smoothed ADS-B positions and the integrated ADS-B velocities are shown in Figure 4.

Figure 5 shows the Euler angle calculations. As noted above, the lift curve was adjusted so that the computed pitch angle matches the pitch angle recorded by the Stratus 3i, but this pitch angle appears low. Based on the original lift curve for the PA-28-140 obtained during a previous investigation, the actual pitch angle when level might be about 6° higher than that recorded on the Stratus 3i and plotted in Figure 5. Interestingly, during the airplane's descent the Stratus pitch angle is higher than the pitch angle computed from the velocity and position data. This could be the result of an erroneous pitch angle recorded by the Stratus, or an insufficiently steep lift curve slope assumed for the Euler angle calculations. Given the suspiciously low pitch angle values recorded by the Stratus during level flight, there might be something amiss with the Stratus pitch angle data more generally, and the computed pitch angles might be more accurate.

Figure 6 plots the load factors recorded by the Stratus 3i, the load factors computed from the velocities and Euler angles recorded on the Stratus, and the load factors computed based solely on the flight track, assuming coordinated flight (zero lateral load factor n_y). The nlf recorded by the Stratus is limited to ±3.8 G's, and the recorded jumps between +3.8 G's and -3.8 G's are spurious, as noted above. The maximum nlf computed using velocities and Euler angles recorded on the Stratus is 4.72 G's.

The maximum lift coefficient C_L achieved during the final minutes of the flight was 1.02 at 15:45:38.1. Based on the flaps-up stall speed and maximum gross weight published in Reference 3 (70 mph and 2,900 lb., respectively), the maximum flaps-up C_L is 1.36; consequently, the C_L remained below stall throughout the accident.

Conclusions

The results plotted in Figures 1-6 are consistent with the following sequence of events during the accident flight:

At 15:43:00, N8991W was flying level at about 5,400 ft. MSL and 100 kt. calibrated airspeed (about 110 kt. ground speed) towards the northeast. Starting at about 15:43:20, the airplane rolled about 15° left, entering a left turn while remaining level between 5,400 and 5,500 ft. During the turn, the airspeed varied between 90 and 106 knots calibrated airspeed (KCAS).

At about 15:45:00, N8991W was heading southwest at 5,525 ft. when the roll angle steepened to about 50° left. The left turn tightened accordingly, and the airplane climbed slightly, to 5,600 ft.

At 15:45:25, N8991W started rolling back towards the right, rolling through wings-level at 15:45:30, and reaching a roll angle of 60° right at 15:45:38. The airplane reached a peak altitude of 5,685 ft. at 15:45:38, and then began a continuous descent. Between 15:45:32 and 15:45:38, the airspeed dropped from 95 KCAS to about 85 KCAS, and then increased continuously as the airplane descended.

At 15:45:54, the roll angle started to steepen, reaching 90° right at 15:46:01, and a maximum of 110° right at 15:46:07. Between 15:45:38 and 15:46:07, the altitude decreased from 5,685 ft. to 2,850 ft., the rate of descent increased from 0 ft./min. to over 18,700 ft./min., and the calibrated airspeed increased from 85 KCAS to over 200 KCAS. During this same interval, the pitch angle recorded on the Stratus decreased from 10° to -52°, and reached a minimum of -63° just before the end of the data.

N8991W exceeded the PA-28-235 never-exceed speed (V_{NE} = 197 mph = 171 KCAS, per Reference 4) at about 15:46:05. The maximum computed nlf of 4.72 G's was reached about a second later.

The ADS-B data and recorded Stratus data both end between 15:46:09 and 15:46:10, where the altitude is between about 2,000 and 2,500 ft. MSL, or between 1,400 and 1,900 ft. above the terrain elevation of approximately 600 ft. MSL. Further, at the end of the data the track of the airplane is headed away from the impact location. It is not known how the airplane maneuvered from its position at the end of the recorded data to the impact site; however, at the end of the data the airplane was in a steep, spiral dive, about 30 to 40 knots above V_{NE}, and pulling an unknown amount of nlf (both the Stratus and computed load factors are not reliable at the very end of the data), though seconds earlier the calculated nlf reached 4.72 G's. As reported by Appareo and discussed above, the nlf of -3.8 G's recorded by the Stratus at the end of the data is erroneous, but indicates that the actual nlf was above 4 G's.

These findings are consistent with an in-flight breakup of the airframe due to excessive stresses resulting from airspeeds well above V_{NE} and high load factors developed during a steep, spiral dive. The condition and distribution of the wreckage at the accident site might provide additional evidence of such a breakup.

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

Regards,

____

John O'Callaghan

References

1. National Transportation Safety Board, Office of Research and Engineering, *Electronic Device Specialist's Factual Report, Piper PA-28-235, N8991W, Carlinville, Illinois, May 31, 2020, NTSB # CEN20LA201* (Washington, D.C., October 6, 2020).
2. National Transportation Safety Board, Office of Aviation Safety, *Preliminary Report, Piper PA-28-235, N8991W, Carlinville, Illinois, May 31, 2020, NTSB # CEN20LA201*.
3. Piper Aircraft Corporation, *The Cherokee 235 Owner's Handbook,* Part # 753648, Issued April 1964, revised May 1968.
4. Piper Aircraft Corporation, *Airplane Flight Manual, Model PA-28-235, Report VB-170,* August 12, 1964.

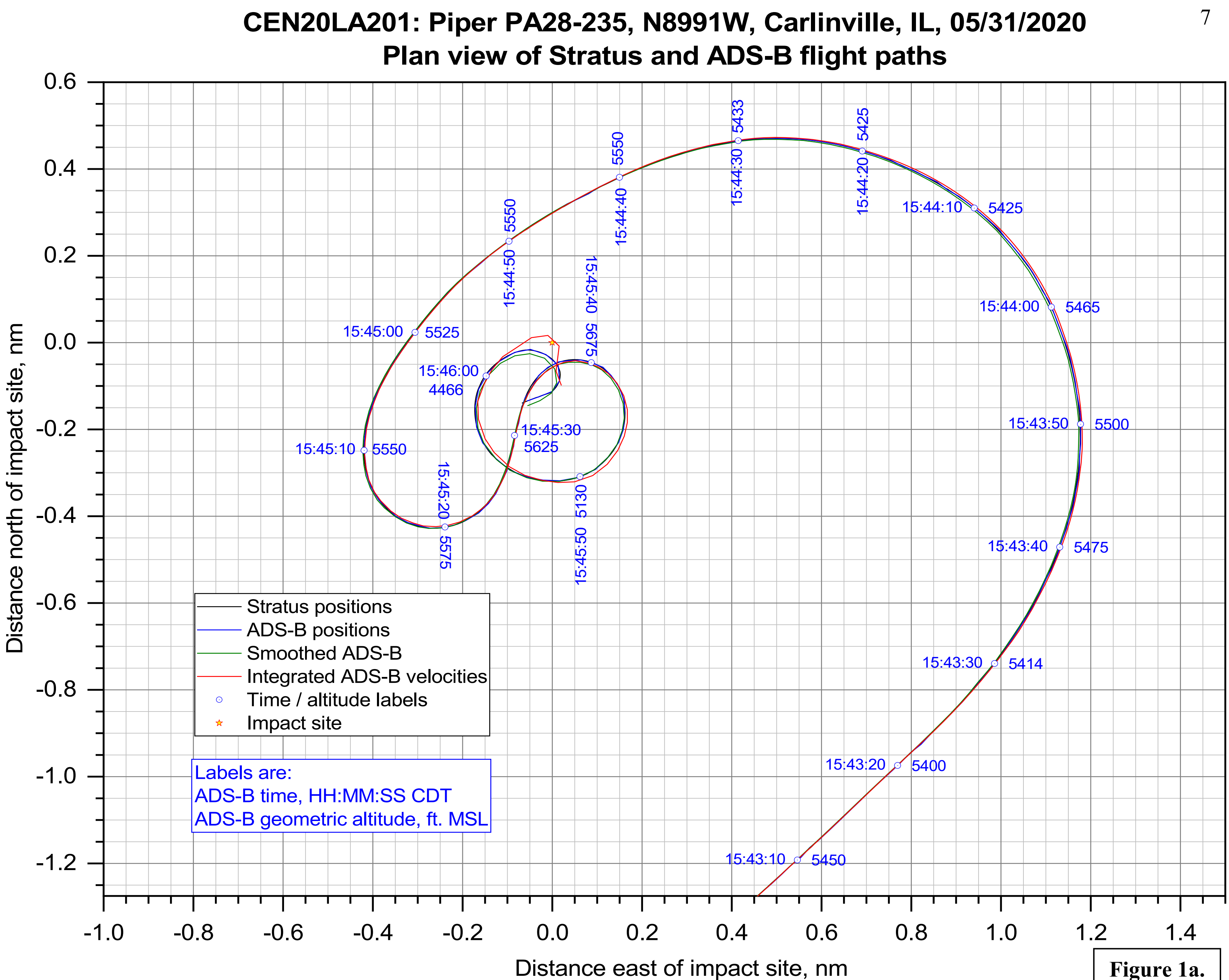

CEN20LA201: Piper PA28-235, N8991W, Carlinville, IL, 05/31/2020
Plan view of Stratus and ADS-B flight paths
Distance north of impact site, nm
Distance east of impact site, nm
Stratus positions
ADS-B positions
Smoothed ADS-B
Integrated ADS-B velocities
Time / altitude labels
Impact site
Labels are:
ADS-B time, HH:MM:SS CDT
ADS-B geometric altitude, ft. MSL
15:43:10 5450
15:43:20 5400
15:43:30 5414
15:43:40 5475
15:43:50 5500
15:44:00 5465
15:44:10 5425
15:44:20 5425
15:44:30 5433
15:44:40 5550
15:44:50 5550
15:45:00 5525
15:45:10 5550
15:45:20 5575
15:45:30 5625
15:45:40 5675
15:45:50 5130
15:46:00 4466

Figure 1a.

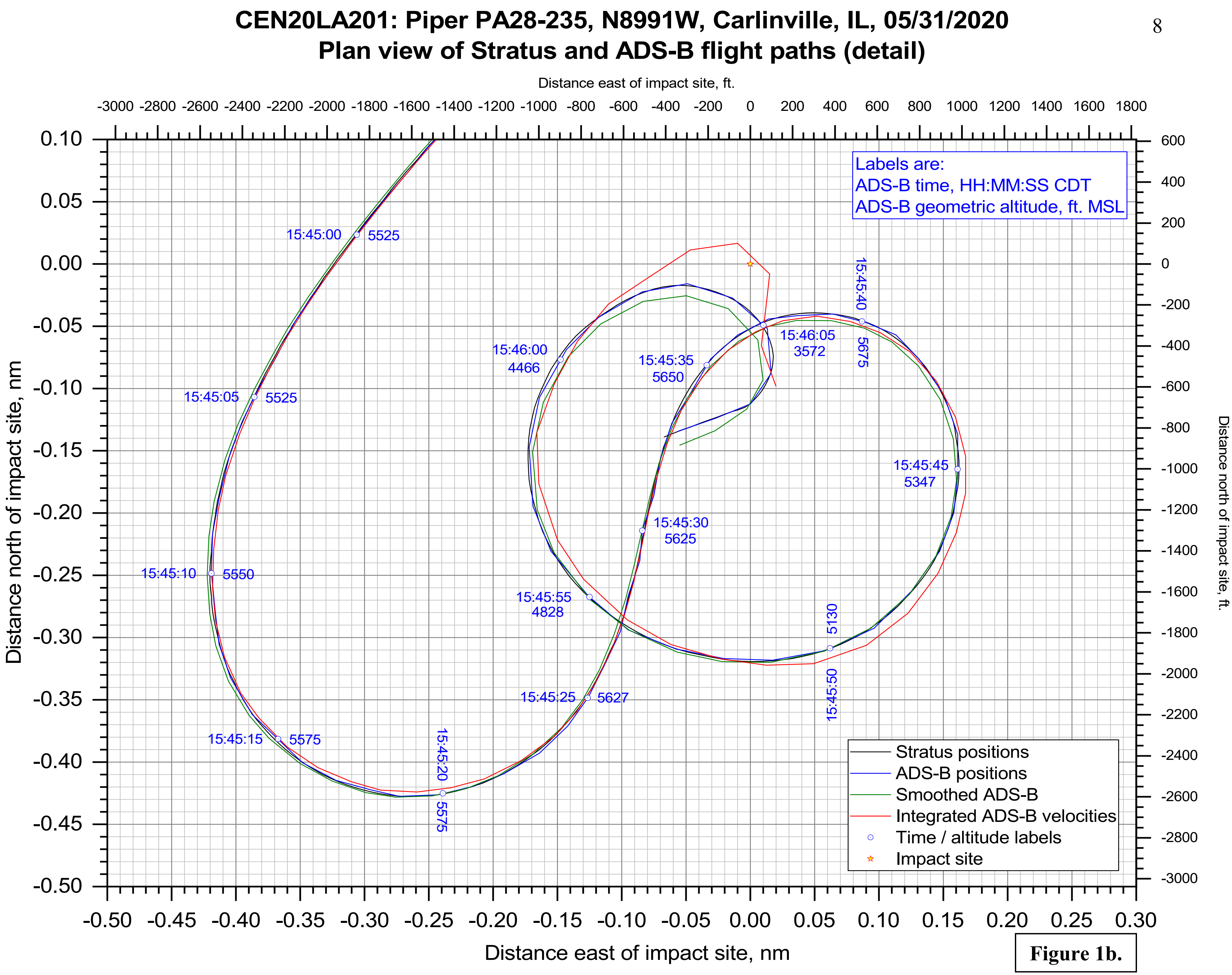

CEN20LA201: Piper PA28-235, N8991W, Carlinville, IL, 05/31/2020
Plan view of Stratus and ADS-B flight paths (detail)
Distance east of impact site, ft.
Distance north of impact site, nm
Distance north of impact site, ft.
Distance east of impact site, nm
Labels are:
ADS-B time, HH:MM:SS CDT
ADS-B geometric altitude, ft. MSL
15:45:00 5525
15:45:05 5525
15:45:10 5550
15:45:15 5575
15:45:20 5575
15:45:25 5627
15:45:30 5625
15:45:35 5650
15:45:40 5675
15:45:45 5347
15:45:50 5130
15:45:55 4828
15:46:00 4466
15:46:05 3572
Stratus positions
ADS-B positions
Smoothed ADS-B
Integrated ADS-B velocities
Time / altitude labels
Impact site

Figure 1b.

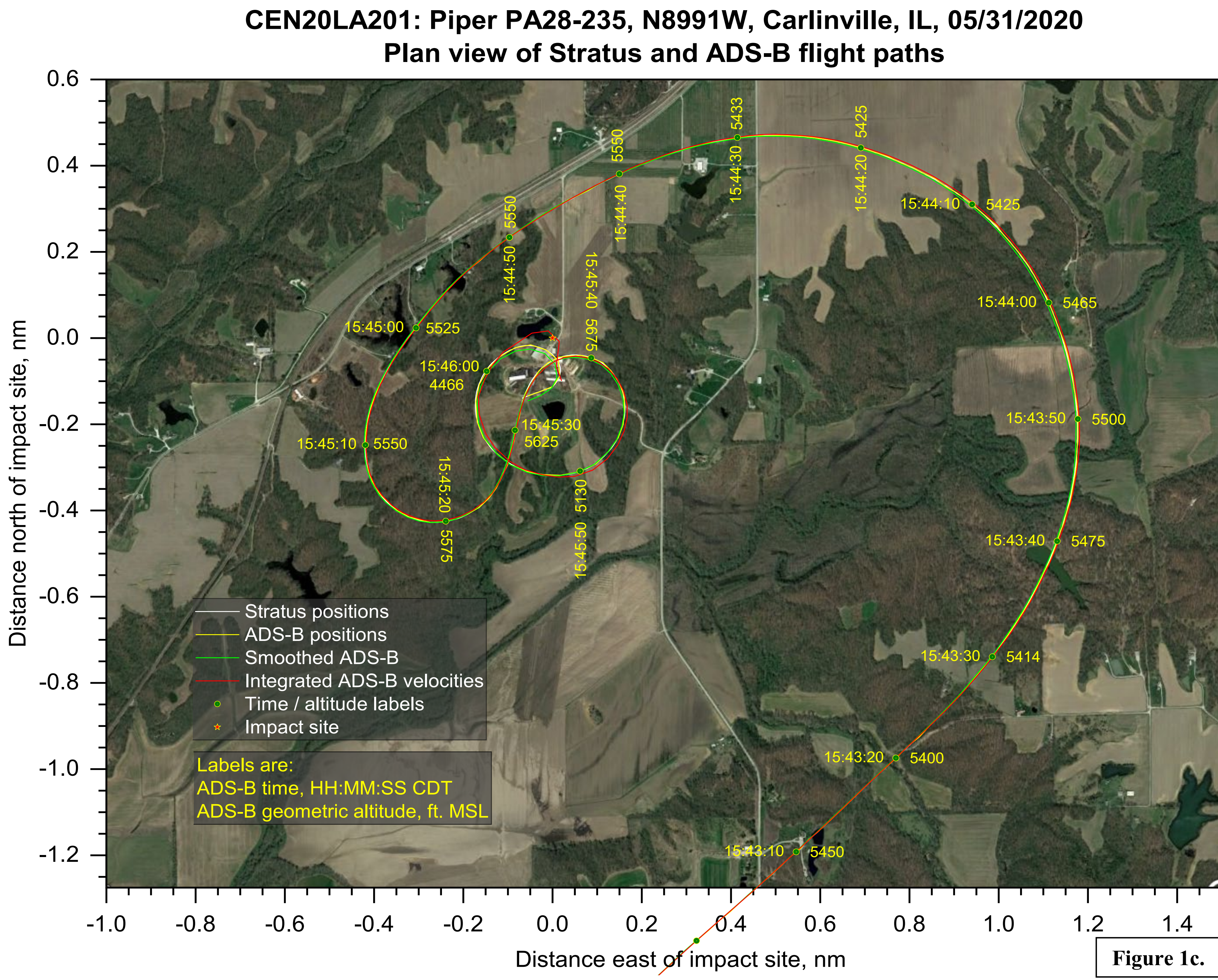
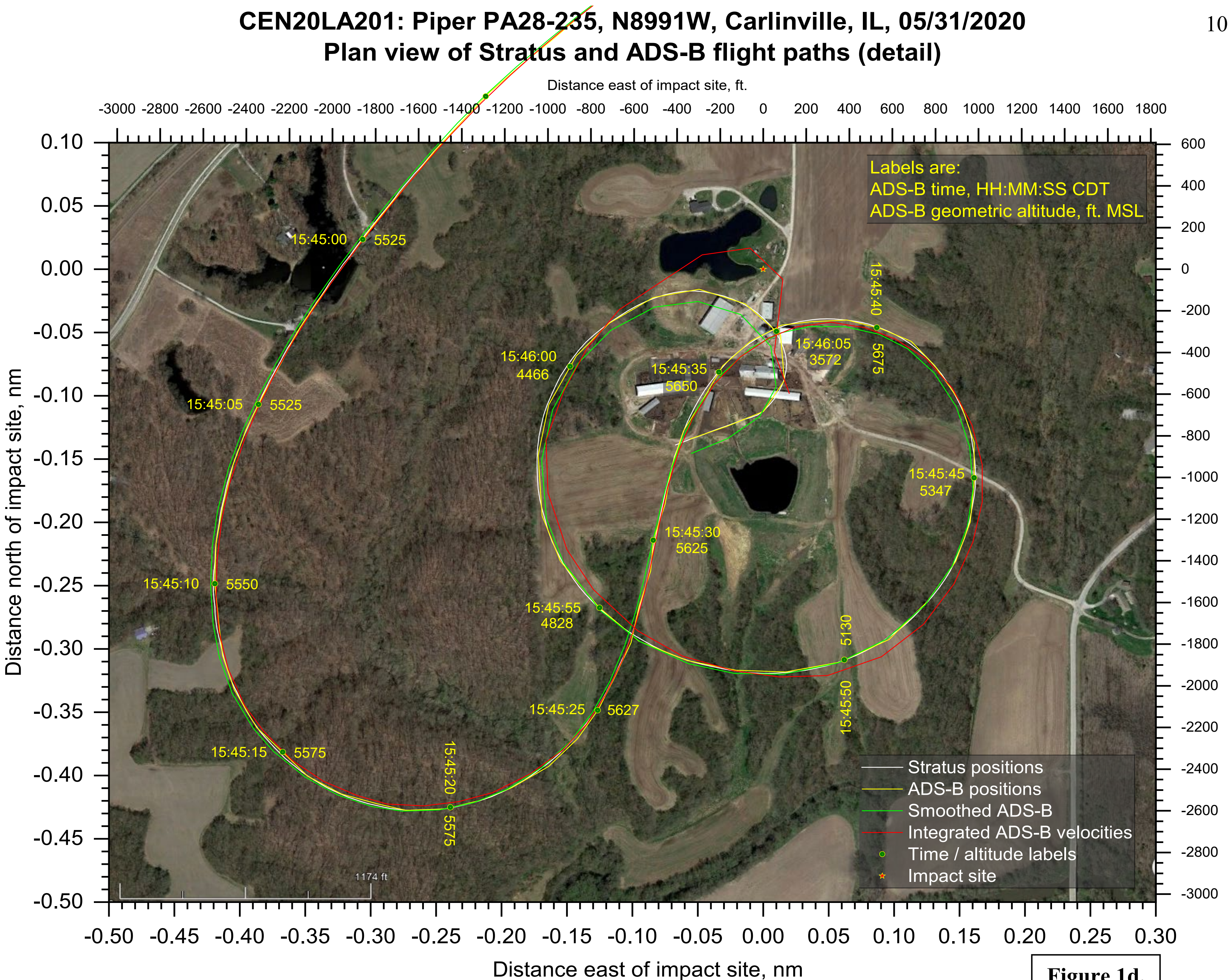

CEN20LA201: Piper PA28-235, N8991W, Carlinville, IL, 05/31/2020
Plan view of Stratus and ADS-B flight paths
Distance north of impact site, nm
Distance east of impact site, nm
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
-1.2
-1.0
-0.8
-0.6
-0.4
-0.2
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
15:43:10 5450
15:43:20 5400
15:43:30 5414
15:43:40 5475
15:43:50 5500
15:44:00 5465
15:44:10 5425
15:44:20 5425
15:44:30 5433
15:44:40 5550
15:44:50 5550
15:45:00 5525
15:45:10 5550
15:45:20 5575
15:45:30 5625
15:45:40 5675
15:45:50 5130
15:46:00 4466
Stratus positions
ADS-B positions
Smoothed ADS-B
Integrated ADS-B velocities
Time / altitude labels
Impact site
Labels are:
ADS-B time, HH:MM:SS CDT
ADS-B geometric altitude, ft. MSL

Figure 1c.



CEN20LA201: Piper PA28-235, N8991W, Carlinville, IL, 05/31/2020
Plan view of Stratus and ADS-B flight paths (detail)
Distance east of impact site, ft.
Distance north of impact site, nm
Distance north of impact site, ft.
Distance east of impact site, nm
Labels are:
ADS-B time, HH:MM:SS CDT
ADS-B geometric altitude, ft. MSL
15:45:00 5525
15:45:05 5525
15:45:10 5550
15:45:15 5575
15:45:20 5575
15:45:25 5627
15:45:30 5625
15:45:35 5650
15:45:40 5675
15:45:45 5347
15:45:50 5130
15:45:55 4828
15:46:00 4466
15:46:05 3572
Stratus positions
ADS-B positions
Smoothed ADS-B
Integrated ADS-B velocities
Time / altitude labels
Impact site
1174 ft

Figure 1d.

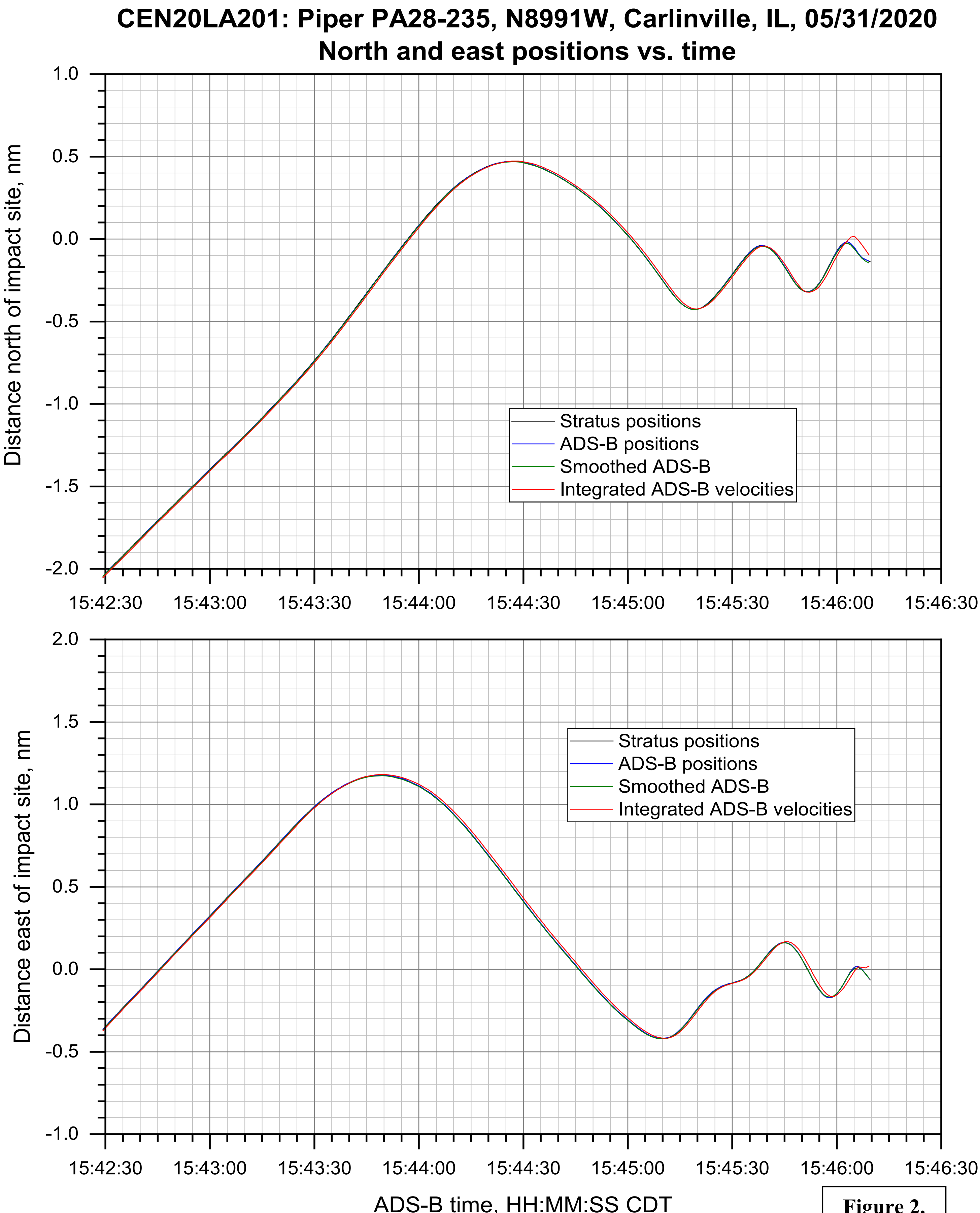

CEN20LA201: Piper PA28-235, N8991W, Carlinville, IL, 05/31/2020
North and east positions vs. time
Distance north of impact site, nm
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
Stratus positions
ADS-B positions
Smoothed ADS-B
Integrated ADS-B velocities
15:42:30
15:43:00
15:43:30
15:44:00
15:44:30
15:45:00
15:45:30
15:46:00
15:46:30
Distance east of impact site, nm
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
Stratus positions
ADS-B positions
Smoothed ADS-B
Integrated ADS-B velocities
15:42:30
15:43:00
15:43:30
15:44:00
15:44:30
15:45:00
15:45:30
15:46:00
15:46:30
ADS-B time, HH:MM:SS CDT

Figure 2.

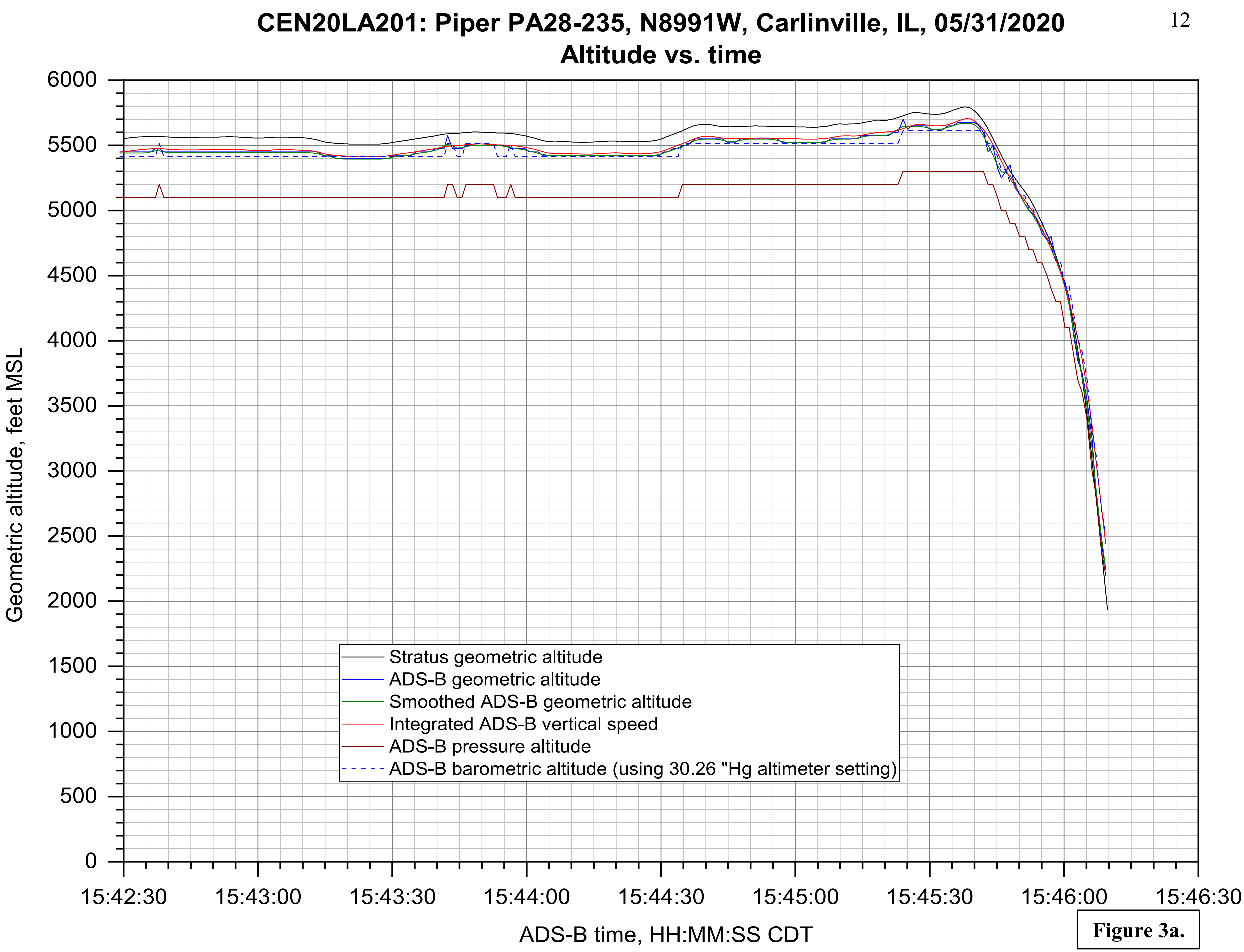

CEN20LA201: Piper PA28-235, N8991W, Carlinville, IL, 05/31/2020
Altitude vs. time
Geometric altitude, feet MSL
6000
5500
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
15:42:30
15:43:00
15:43:30
15:44:00
15:44:30
15:45:00
15:45:30
15:46:00
15:46:30
ADS-B time, HH:MM:SS CDT
Stratus geometric altitude
ADS-B geometric altitude
Smoothed ADS-B geometric altitude
Integrated ADS-B vertical speed
ADS-B pressure altitude
ADS-B barometric altitude (using 30.26 "Hg altimeter setting)

Figure 3a.

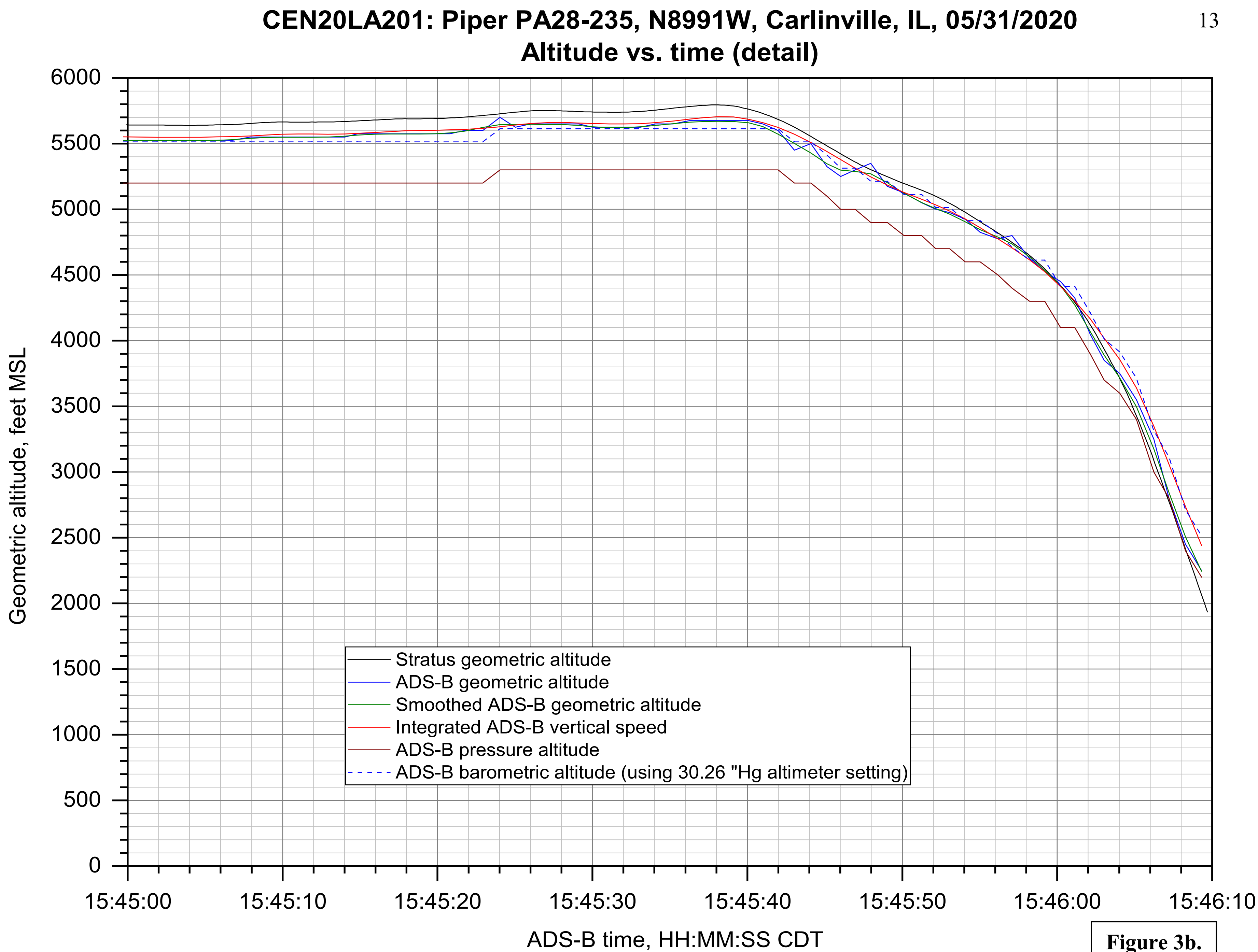

CEN20LA201: Piper PA28-235, N8991W, Carlinville, IL, 05/31/2020
Altitude vs. time (detail)
Geometric altitude, feet MSL
6000
5500
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
15:45:00
15:45:10
15:45:20
15:45:30
15:45:40
15:45:50
15:46:00
15:46:10
ADS-B time, HH:MM:SS CDT
Stratus geometric altitude
ADS-B geometric altitude
Smoothed ADS-B geometric altitude
Integrated ADS-B vertical speed
ADS-B pressure altitude
ADS-B barometric altitude (using 30.26 "Hg altimeter setting)

Figure 3b.

CEN20LA201: Piper PA28-235, N8991W, Carlinville, IL, 05/31/2020
Speeds vs. time

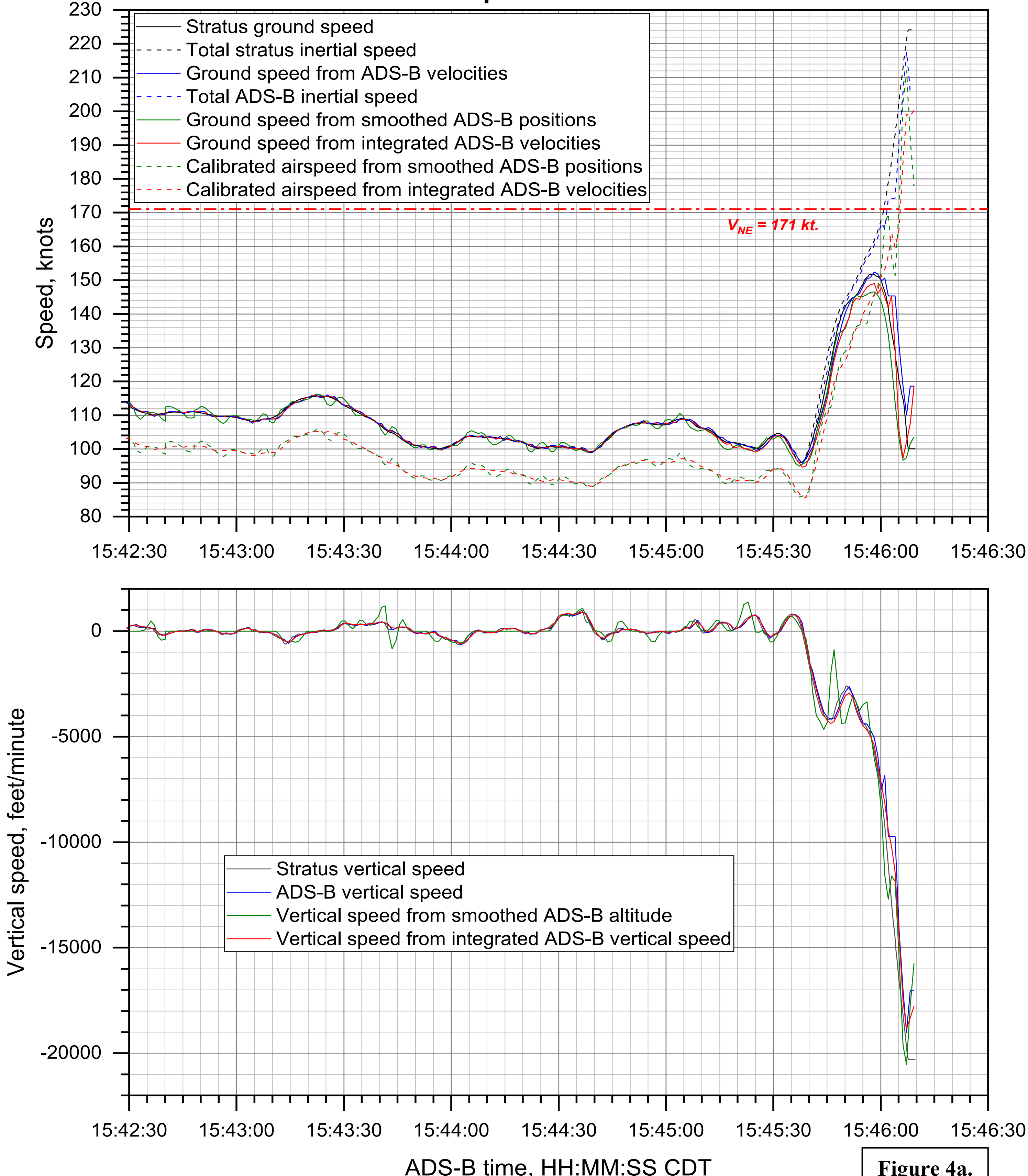
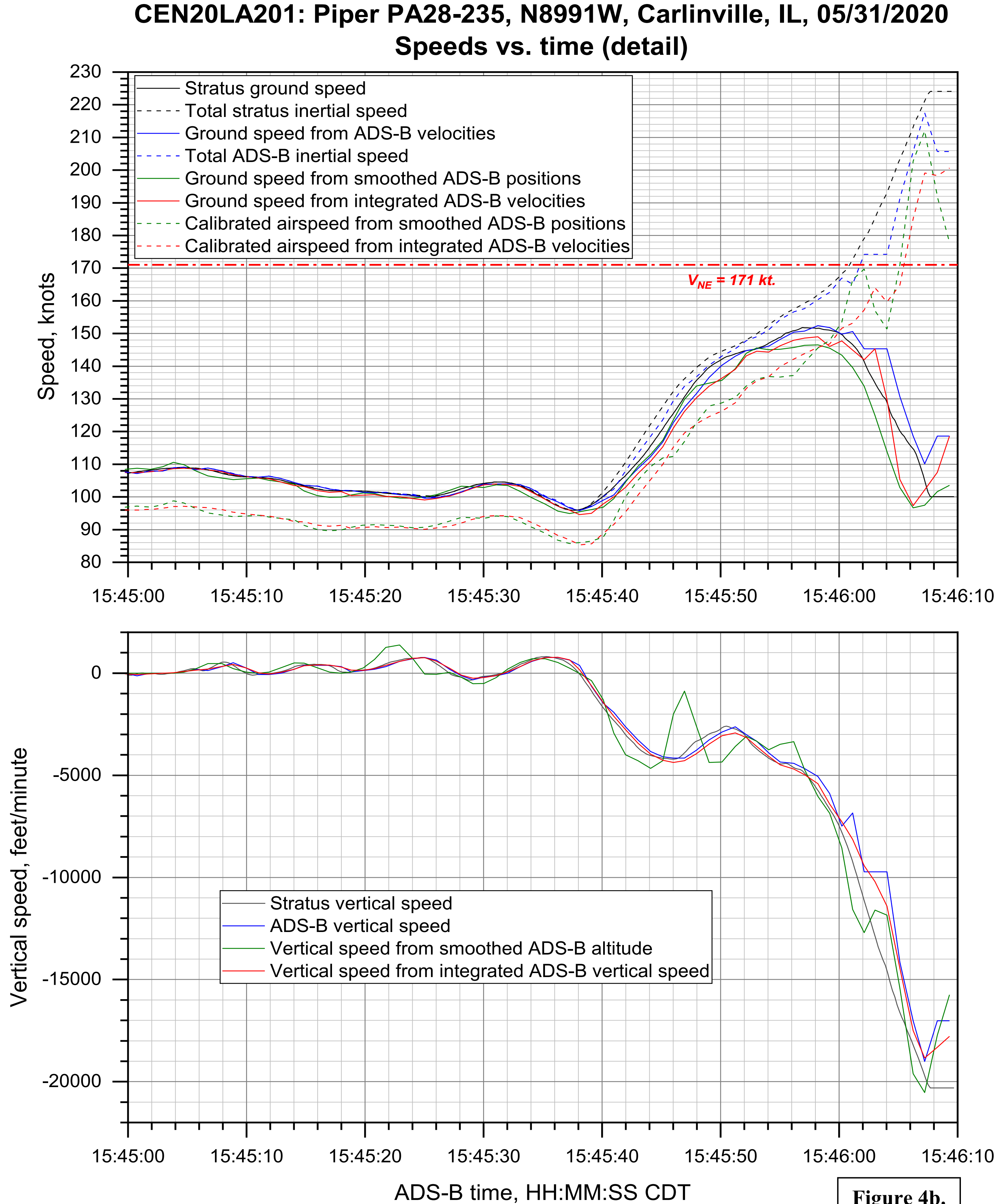


Figure 4a.



CEN20LA201: Piper PA28-235, N8991W, Carlinville, IL, 05/31/2020
Speeds vs. time (detail)
Stratus ground speed
Total stratus inertial speed
Ground speed from ADS-B velocities
Total ADS-B inertial speed
Ground speed from smoothed ADS-B positions
Ground speed from integrated ADS-B velocities
Calibrated airspeed from smoothed ADS-B positions
Calibrated airspeed from integrated ADS-B velocities
V_{NE} = 171 kt.
Speed, knots
230
220
210
200
190
180
170
160
150
140
130
120
110
100
90
80
15:45:00
15:45:10
15:45:20
15:45:30
15:45:40
15:45:50
15:46:00
15:46:10
Stratus vertical speed
ADS-B vertical speed
Vertical speed from smoothed ADS-B altitude
Vertical speed from integrated ADS-B vertical speed
Vertical speed, feet/minute
0
-5000
-10000
-15000
-20000
ADS-B time, HH:MM:SS CDT

Figure 4b.

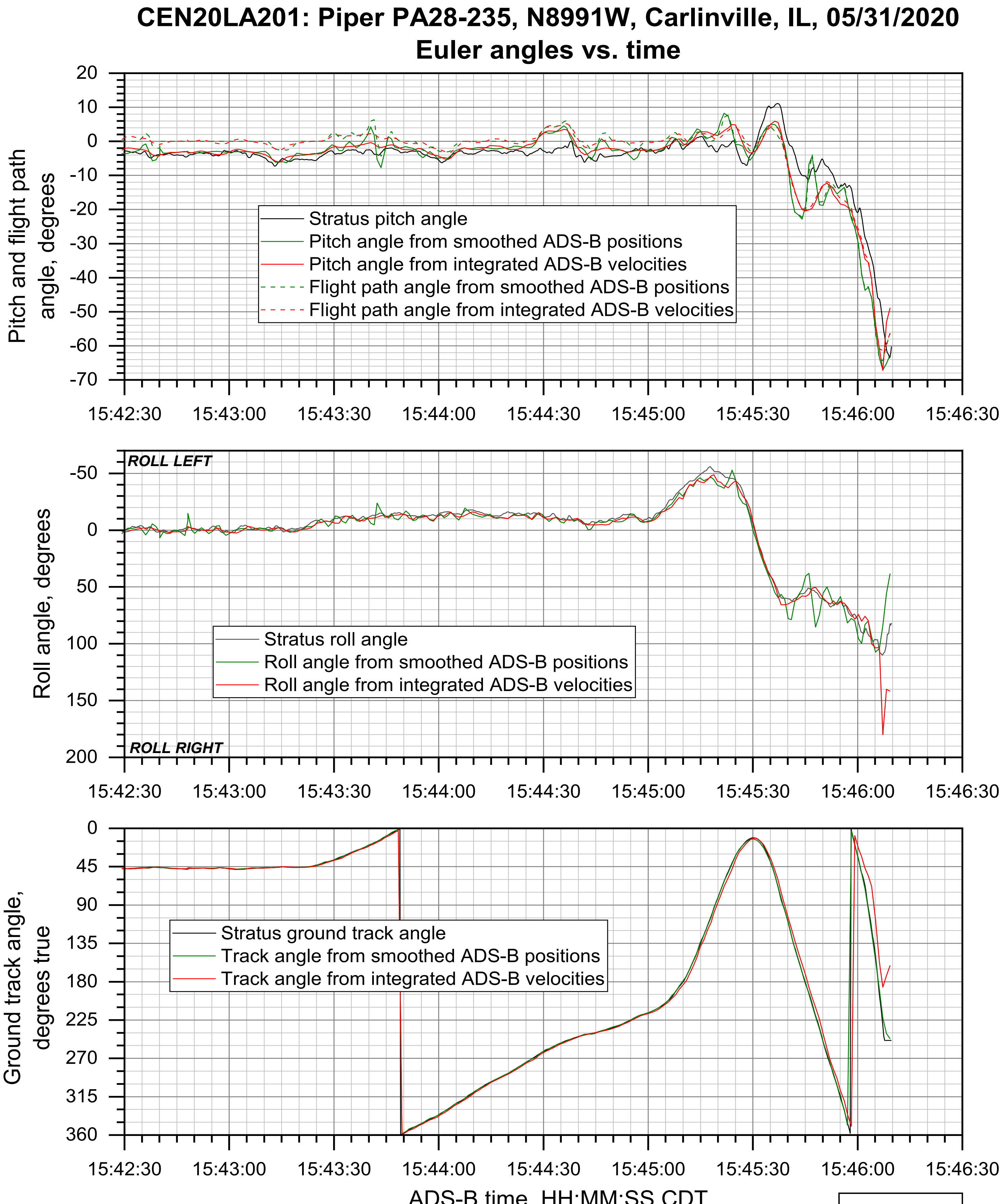

CEN20LA201: Piper PA28-235, N8991W, Carlinville, IL, 05/31/2020
Euler angles vs. time
Pitch and flight path angle, degrees
Stratus pitch angle
Pitch angle from smoothed ADS-B positions
Pitch angle from integrated ADS-B velocities
Flight path angle from smoothed ADS-B positions
Flight path angle from integrated ADS-B velocities
20
10
0
-10
-20
-30
-40
-50
-60
-70
15:42:30
15:43:00
15:43:30
15:44:00
15:44:30
15:45:00
15:45:30
15:46:00
15:46:30
Roll angle, degrees
ROLL LEFT
ROLL RIGHT
Stratus roll angle
Roll angle from smoothed ADS-B positions
Roll angle from integrated ADS-B velocities
-50
0
50
100
150
200
Ground track angle, degrees true
Stratus ground track angle
Track angle from smoothed ADS-B positions
Track angle from integrated ADS-B velocities
0
45
90
135
180
225
270
315
360
ADS-B time, HH:MM:SS CDT

Figure 5a.

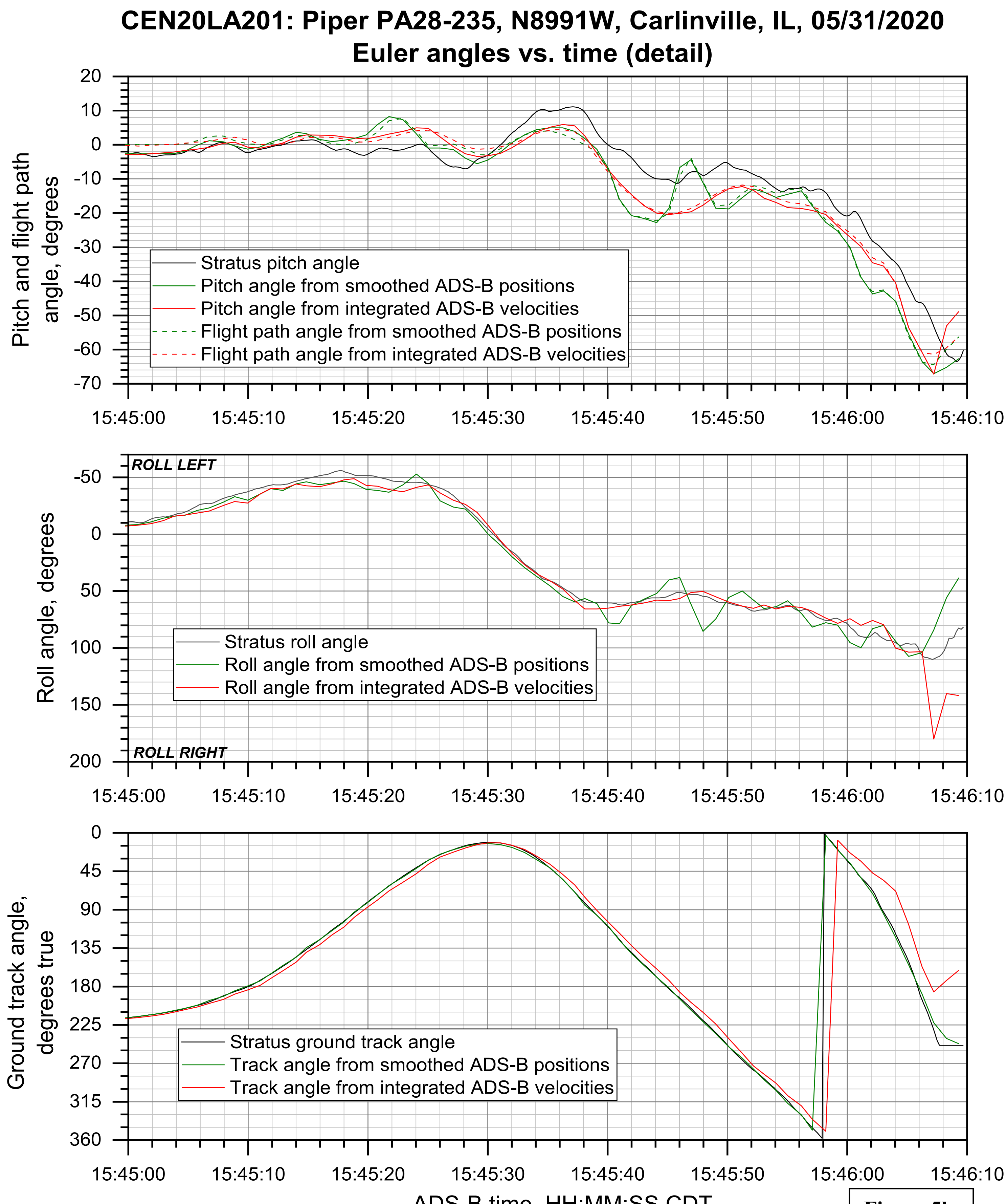

CEN20LA201: Piper PA28-235, N8991W, Carlinville, IL, 05/31/2020
Euler angles vs. time (detail)
Pitch and flight path angle, degrees
20
10
0
-10
-20
-30
-40
-50
-60
-70
Stratus pitch angle
Pitch angle from smoothed ADS-B positions
Pitch angle from integrated ADS-B velocities
Flight path angle from smoothed ADS-B positions
Flight path angle from integrated ADS-B velocities
15:45:00
15:45:10
15:45:20
15:45:30
15:45:40
15:45:50
15:46:00
15:46:10
Roll angle, degrees
ROLL LEFT
ROLL RIGHT
-50
0
50
100
150
200
Stratus roll angle
Roll angle from smoothed ADS-B positions
Roll angle from integrated ADS-B velocities
Ground track angle, degrees true
0
45
90
135
180
225
270
315
360
Stratus ground track angle
Track angle from smoothed ADS-B positions
Track angle from integrated ADS-B velocities
ADS-B time, HH:MM:SS CDT

Figure 5b.

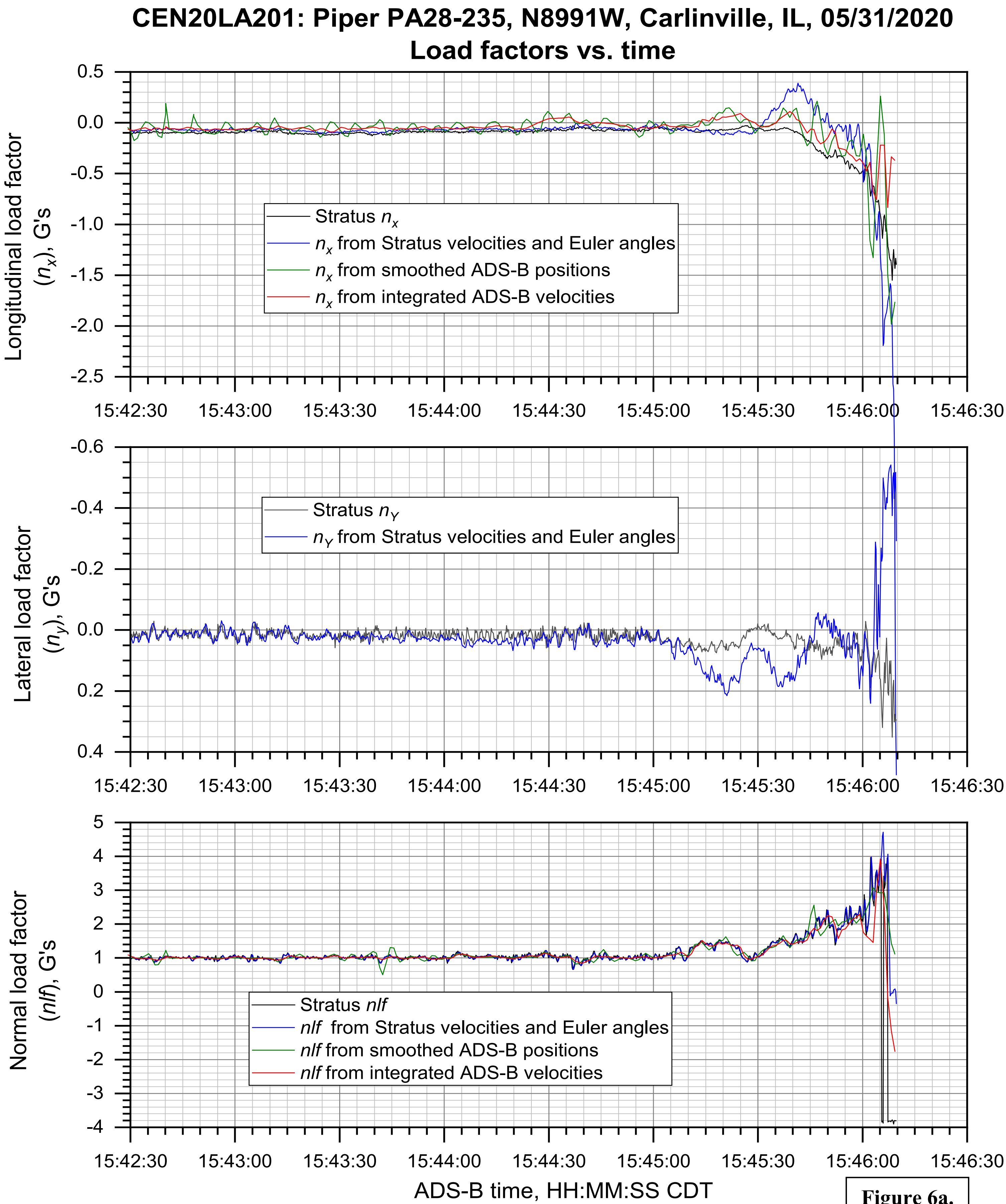

CEN20LA201: Piper PA28-235, N8991W, Carlinville, IL, 05/31/2020
Load factors vs. time
Longitudinal load factor (n_x), G's
Stratus n_x
n_x from Stratus velocities and Euler angles
n_x from smoothed ADS-B positions
n_x from integrated ADS-B velocities
Lateral load factor (n_y), G's
Stratus n_Y
n_Y from Stratus velocities and Euler angles
Normal load factor (nlf), G's
Stratus nlf
nlf from Stratus velocities and Euler angles
nlf from smoothed ADS-B positions
nlf from integrated ADS-B velocities
15:42:30
15:43:00
15:43:30
15:44:00
15:44:30
15:45:00
15:45:30
15:46:00
15:46:30
ADS-B time, HH:MM:SS CDT

Figure 6a.

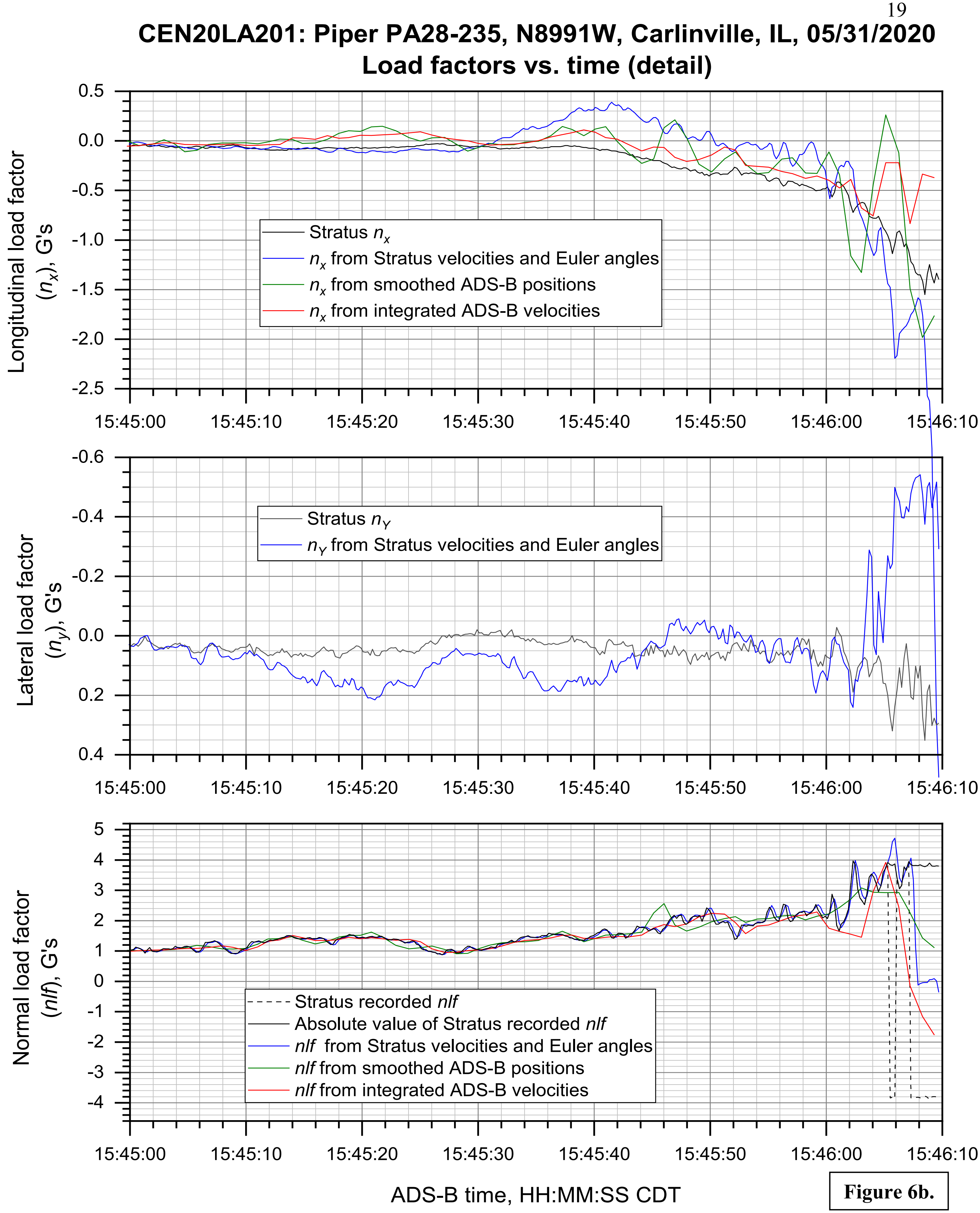

CEN20LA201: Piper PA28-235, N8991W, Carlinville, IL, 05/31/2020
Load factors vs. time (detail)
Longitudinal load factor (n_x), G's
Stratus n_x
n_x from Stratus velocities and Euler angles
n_x from smoothed ADS-B positions
n_x from integrated ADS-B velocities
Lateral load factor (n_y), G's
Stratus n_Y
n_Y from Stratus velocities and Euler angles
Normal load factor (nlf), G's
Stratus recorded nlf
Absolute value of Stratus recorded nlf
nlf from Stratus velocities and Euler angles
nlf from smoothed ADS-B positions
nlf from integrated ADS-B velocities
15:45:00
15:45:10
15:45:20
15:45:30
15:45:40
15:45:50
15:46:00
15:46:10
ADS-B time, HH:MM:SS CDT

Figure 6b.

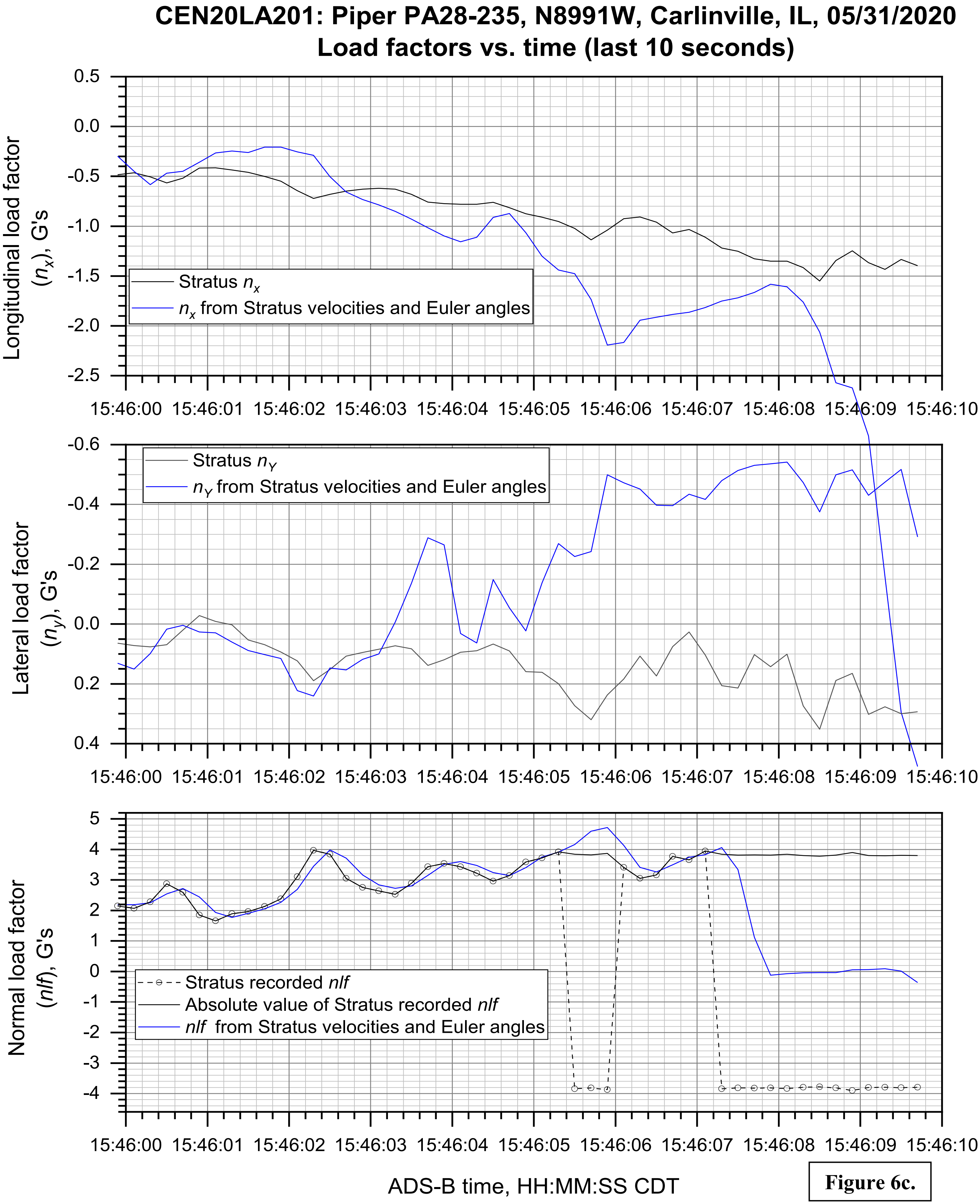

CEN20LA201: Piper PA28-235, N8991W, Carlinville, IL, 05/31/2020
Load factors vs. time (last 10 seconds)
Longitudinal load factor (n_x), G's
Stratus n_x
n_x from Stratus velocities and Euler angles
Lateral load factor (n_y), G's
Stratus n_Y
n_Y from Stratus velocities and Euler angles
Normal load factor (nlf), G's
Stratus recorded nlf
Absolute value of Stratus recorded nlf
nlf from Stratus velocities and Euler angles
15:46:00
15:46:01
15:46:02
15:46:03
15:46:04
15:46:05
15:46:06
15:46:07
15:46:08
15:46:09
15:46:10
ADS-B time, HH:MM:SS CDT

Figure 6c.

CEN20LA201: Piper PA28-235, N8991W, Carlinville, IL, 05/31/2020

Winds aloft from High Resolution Rapid Refresh (HRRR) sounding model for accident site

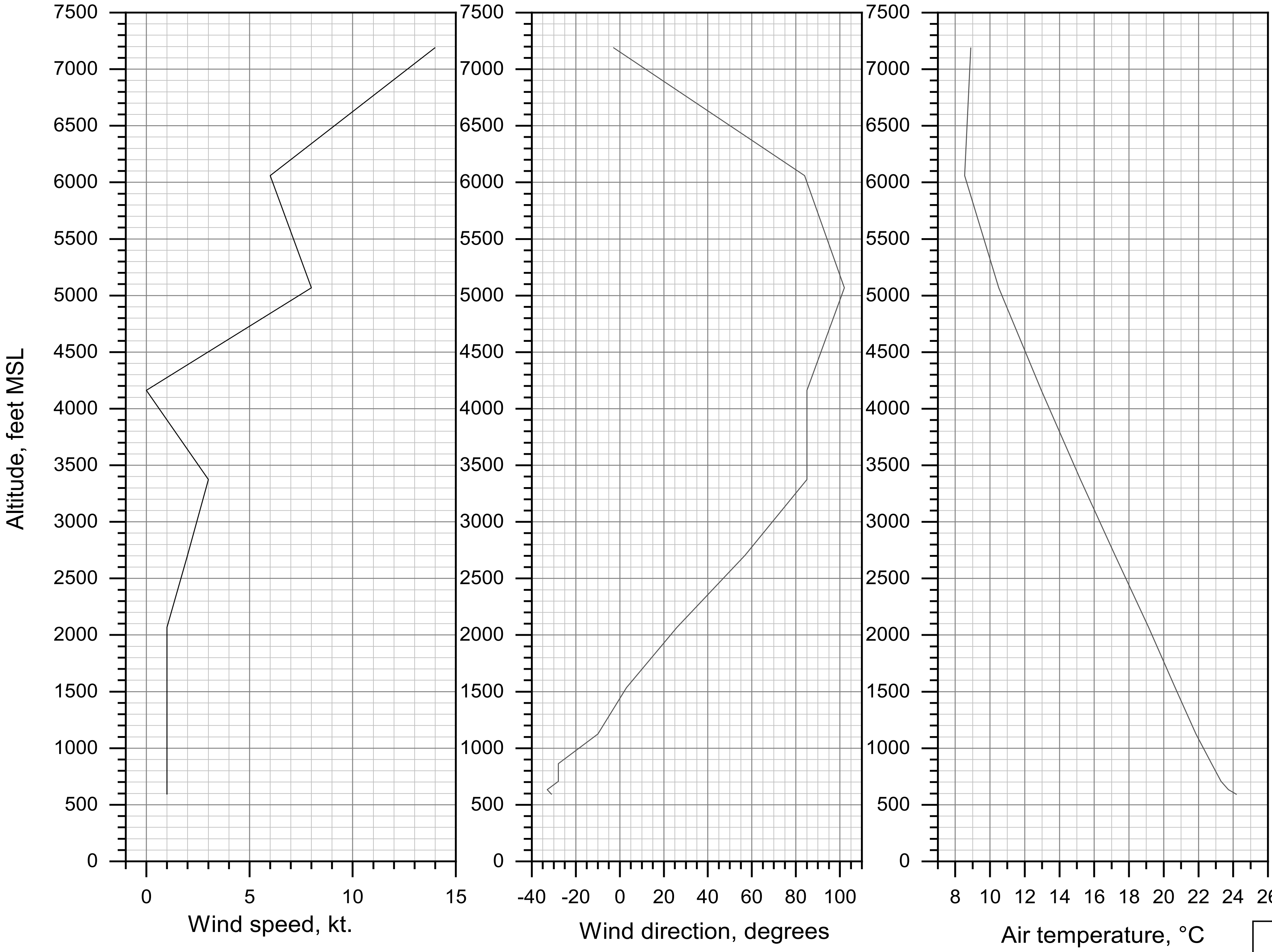


Figure 7.