National Transportation
Safety Board

Memorandum

Date: May 21, 2020

To: Jennifer Rodi
Deputy Regional Chief, Central Region
CEN20MA044 Investigator in Charge (IIC)

From: John O'Callaghan
National Resource Specialist – Aircraft Performance
CEN20MA044 Aircraft Performance Specialist

Subject: Plots of ADS-B data and performance estimates for CEN20MA044

Jennifer:

This memorandum transmits plots of flight path and airplane performance information for the Piper PA-31T Cheyenne II (N42CV) accident in Lafayette, Louisiana, on December 28, 2019 (CEN20MA044). The plots present Automatic Dependent Surveillance – Broadcast (ADS-B) data from N42CV, and performance parameters computed from the ADS-B data.

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[1] 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,

[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 GPS latitude and longitude coordinates broadcast by the airplane.

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 referred to here as the “recorded ground speed”). 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 Figure 1).

Additional performance parameters – such as the Euler angles (pitch, roll, and heading) and the engine power required – 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 rate of climb 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. As shown in Figure 2, the GPS altitude and barometric altitude do not agree perfectly, particularly during the airplane’s descent. GPS altitude has greater uncertainty than GPS latitude and longitude, and does not capture *changes* in altitude as accurately as barometrically measured altitude does. Consequently, in this memorandum the barometric pressure, smoothed using a running-average algorithm, is used for pitch angle, flight path angle, and angle of attack calculations. The barometric (indicated) altitude above sea level is computed by correcting the recorded pressure altitude for the 29.96” Hg altimeter setting near the time of the accident, based on the 15:53 UTC (09:53 CST) METAR from KLFT (the accident occurred at about 09:21:00 CST):

Time	Wind	Temp.	Altimeter	Visibility	Sky condition
09:53 CST	Variable / 5 kt.	20° C	29.96” Hg	0.74 sm / mist	Vertical visibility 200 ft. AGL
08:53 CST	120° / 5 kt.	19° C	29.97” Hg	0.74 sm / mist	Vertical visibility 200 ft. AGL

The resulting corrected barometric altitude is 37 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. While this parameter is very smooth, it clearly lags the actual rate of climb computed using the barometric altitude, and so is not used in the calculations presented here. The reason for this lag is unknown, but might be associated with the well-known lag in the barometric vertical speed indicator (VSI) instrument itself.[2]

[2] For example, Chapter 8 of the *Pilot’s Handbook of Aeronautical Knowledge* published by the FAA (see https://www.faa.gov/regulations_policies/handbooks_manuals/aviation/phak/media/10_phak_ch8.pdf) states the following regarding barometric VSIs: *“The trend information is the direction of movement of the VSI needle. For example, if an aircraft is maintaining level flight and the pilot pulls back on the control yoke causing the nose of the aircraft to pitch up, the VSI needle moves upward to indicate a climb. If the pitch attitude is held constant, the needle stabilizes after a short period (6–9 seconds) and indicates the rate of climb in hundreds of fpm. The time period from the initial change in the rate of climb, until the VSI displays an accurate indication of the new rate, is called the lag. Rough control technique and turbulence can extend the lag period and cause erratic and unstable rate indications.”*

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.

The wind speed and direction, as well as the airplane weight and lift and drag coefficients as a function of α, are required to compute additional performance parameters such as the Euler angles and power required. A wind of 5 kt. from 120° (true) is used here based on the 08:53 KLIT METAR. A weight of 9,070 lb. is used based on preliminary information provided by the Operations Group Chairman. After the performance analysis presented in this memorandum was completed, the fuel weight was determined to be about 200 lb. lighter than originally estimated, and so the actual gross weight for the flight was about 8,870 lb. Accounting for this reduced weight would lower the computed power required and angle of attack presented in this memorandum slightly, but would not materially affect the findings or conclusions.

The NTSB Aircraft Performance Specialist requested the required aerodynamic information about the PA-31T from Piper Aircraft Inc. Piper responded that "our engineering department has looked back into the records for this aircraft type and so far have been unable to find the data you requested. They suspect this may be due to the FAA requiring only pass/fail records for certain performance figures at the time of the type's certification." Consequently, the flaps and gear up lift and drag coefficients of the airplane are estimated based on textbook methods using information available in the Airplane Flight Manual (AFM).[3]

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 grid background (Figure 1a) and a *Google Earth* background (Figure 1b). The altitude labels in these Figures are the barometric (indicated) altitude in feet above mean sea level (MSL). Note that the smoothed ADS-B track matches the recorded track very well, but the track obtained by integrating the recorded ADS-B north and east speeds deviates from the recorded track by about 0.03 nm (180 ft.) to the outside of the descending left turn near the end of the flight.

Figures 1a-b also depict the location of microphones that recorded the sound of the airplane passing overhead, as described in the Powerplants Factual Report for this accident.

Figure 2 presents the GPS and barometric altitude data recorded in the ADS-B file, along with the results of smoothing this data while respecting the ±12.5 ft. uncertainty bands in that data. The

[3] Piper Aircraft Inc., *PA-31T Cheyenne II Pilot's Operating Handbook and FAA Approved Airplane Flight Manual*, PA-31T Report # 2210, approved September 14, 1979.

altitude obtained by integrating the recorded rate of climb is also shown. The integration results in a very smooth altitude trace, but lags the recorded barometric and GPS altitudes by 2 to 6 seconds.

Figure 3 presents the speed calculations based on the ADS-B data, along with the recorded ground speed. As described above, the ground speed computed from the raw ADS-B position data has unrealistic, noisy "spikes" resulting from uncertainty in that data, while the recorded ground speed is very smooth. Likewise, the rates of climb based on the raw ADS-B barometric and GPS altitudes are relatively noisy, while the recorded rate of climb is very smooth; but Figure 3, like Figure 2, indicates that the recorded rate of climb lags the actual rate of climb significantly. The rate of climb computed from the smoothed barometric altitude respects the uncertainty bands in that data, while reducing the noise in the data. Figure 3 indicates that the rate of descent was about 2,300 ft./min. at the end of the data.

Figure 4 presents the calculation of several flight angle parameters. The top plot presents pitch angle, flight path angle, and angle of attack; the middle plot presents the roll angle; and the bottom plot presents heading and track angle.

The top plot of Figure 4 also presents a parameter labeled "apparent pitch." This is the angle that the total load factor vector (sometimes called the "gravitational-inertial force" or GIF vector) makes with the vertical axis of the airplane, and is one contributor to the attitude a pilot would "feel" the airplane to be in, based on his vestibular / kinesthetic perception of the components of the load factor vector in his own body coordinate system. It is assumed in this case that the pilot perceives attitude by equating the GIF vector with the gravity vector, and resolving his attitude relative to that vector. Because the vestibular / kinesthetic system cannot distinguish load factors resulting from airplane accelerations from load factors resulting from the components of the gravity vector along the body axes, in accelerated flight it is possible for a pilot to misperceive his attitude if he relies on his vestibular / kinesthetic sense alone. This phenomenon is known as the "somatogravic illusion," and can lead to spatial disorientation.

In reality, reducing the vestibular / kinesthetic pitch angle "felt" by the pilot to the angle of the GIF vector (the GIF angle) is an over-simplification; other factors affect a pilot's vestibular / kinesthetic perception of pitch (such as angular rates and accelerations). Nonetheless, the GIF angle is an important contributor to the pilot's perception, and large differences between the actual pitch angle and the GIF angle can indicate times of potential vulnerability to spatial disorientation when in instrument meteorological conditions (IMC). Figure 4 indicates that during the N42CV accident flight, the "apparent pitch" could have been up to 12° higher than the actual pitch angle, and have been positive when the actual pitch angle was negative.

The line labelled "Flaps up α for C_{LMAX} = 10.8°" in the top plot of Figure 4 indicates the angle of attack at which the maximum flaps-up lift coefficient is obtained, based on the lift curve estimated for the airplane, and the stall speed data published in the AFM. The maximum calculated angle of attack is about 8°, so the calculation indicates that the airplane remained below the flaps-up stall angle of attack during the period of recorded data. This result is consistent with the lift coefficient calculation presented in Figure 6.

The middle plot of Figure 4 indicates that starting at about 09:20:13 and at a roll angle of about 13° right, the airplane started an approximately continuous roll towards the left, at an average roll rate of about 2 degrees / second, reaching a roll angle of 75° left at about 09:20:57.

Figure 5 presents the vertical and longitudinal load factors computed for the flight. The longitudinal load factor computed using the smoothed ground speed reflects the oscillations (accelerations) in that parameter. The longitudinal load factor computed using the recorded ground speed is much smoother; these characteristics are reflected in the two calculations of the "apparent pitch angle" in Figure 4, described above. Figure 5 indicates that during the descending left turn, the vertical load factor exceeded 3 G's at about 09:20:53.

The top plot of Figure 6 presents the computed horsepower required throughout the flight, based on drag characteristics estimated from the geometry of the airplane, and engine power and flaps-up rate of climb data published in the AFM. The estimated total shaft horsepower (SHP) produced by the engines is shown in Figure 6 as well, based on an estimated 86% propeller efficiency. The per-engine SHP (assuming both engines were producing equal power) is also shown; the per-engine SHP varies between 300 and 600 SHP until 09:20:55 (about 5 seconds before the end of the data), when it drops precipitously, consistent with a drop in ground speed. The large negative horsepower shown in the calculation after 09:20:56 indicates much larger drag on the airplane than assumed in the calculation; the source of this drag is unknown, but might result from drag on the propellers following a sudden reduction in power to the engines.

The bottom plot of Figure 6 shows the computed lift coefficient throughout the flight, assuming a weight of 9,070 pounds and a wing area of 229 ft^2. The maximum possible flaps-up lift coefficient, based on the stall speeds published in the AFM, is 1.22, as shown in the plot. The highest lift coefficient obtained on the flight was 1.0, and so the airplane did not experience an aerodynamic stall during the period of recorded data.

Figure 7 presents a 3-dimensional view of the flight path in the *Google Earth* computer program, with satellite imagery of the terrain under the flight path. The airplane models in the Figure are not to scale, but enlarged to show the airplane attitude more clearly. The blue data labels present information formatted as follows: Time, CST / Altitude, ft. MSL / Airspeed, KCAS / Rate of climb, ft./min.

Conclusions

ADS-B data for the flight starts at 09:20:05 as the airplane was climbing through 150 ft. MSL, or 110 ft. above ground level (AGL). The peak altitude recorded was 925 ft. MSL, from about 09:20:37 to 09:20:40, after which the airplane entered a continuous descent to the ground. The last ADS-B data point was at 09:20:59, as the airplane descended through 230 ft. MSL at a calculated flight path angle of about -7°.

The calculations and Figures presented in this memorandum indicate that after departing runway 22L, the airplane turned slightly to the right toward the assigned heading of 240° and climbed at a rate that varied between 1,000 and 2,400 ft./min., while accelerating from about 151 knots to 165 knots calibrated airspeed (KCAS). At 09:20:13, the airplane started rolling back towards wings level. At 09:20:20, the airplane rolled through wings level in a continued roll towards the left. At this time, the airplane was tracking 232°, the altitude was 474 ft. MSL, and the speed stabilized for about 10 seconds at 165 KCAS before increasing further. The airplane continued to roll steadily to the left, at an average roll rate of about 2 degrees per second. At the peak altitude of 925 ft. MSL at 09:20:40, the roll angle was about 35° left, the track angle was about 200°, and the airspeed was about 169 KCAS. The airplane then started to descend while the left roll continued, and the airplane reached a roll angle of 75° left at 09:20:57, while it descended through 320 ft. MSL, at about 2,500 ft./min. At 09:20:55, the airspeed peaked at about 197 KCAS, and then started dropping. The ADS-B data ends at 09:20:59, at an altitude of 230 ft. MSL, a calculated airspeed of 176 KCAS, and a calculated rate of descent of about 2,300 ft./min.

The lift coefficient calculations for the flight indicate that the airplane remained below the maximum possible lift coefficient, and so it did not stall during the period of recorded data. Power required calculations indicate that during the initial climb, the average shaft horsepower per engine was between 500 and 600 SHP, and that just before the sudden drop in airspeed at 09:20:55 the average SHP per engine was about 500 SHP. During the final descent, the calculated SHP values are negative, indicating that more drag was on the airplane than accounted for by the simple drag model developed from textbook methods and information in the AFM. The source of this drag is unknown, but might result from drag on the propellers following a sudden reduction in power to the engines.

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

Regards,

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John O’Callaghan

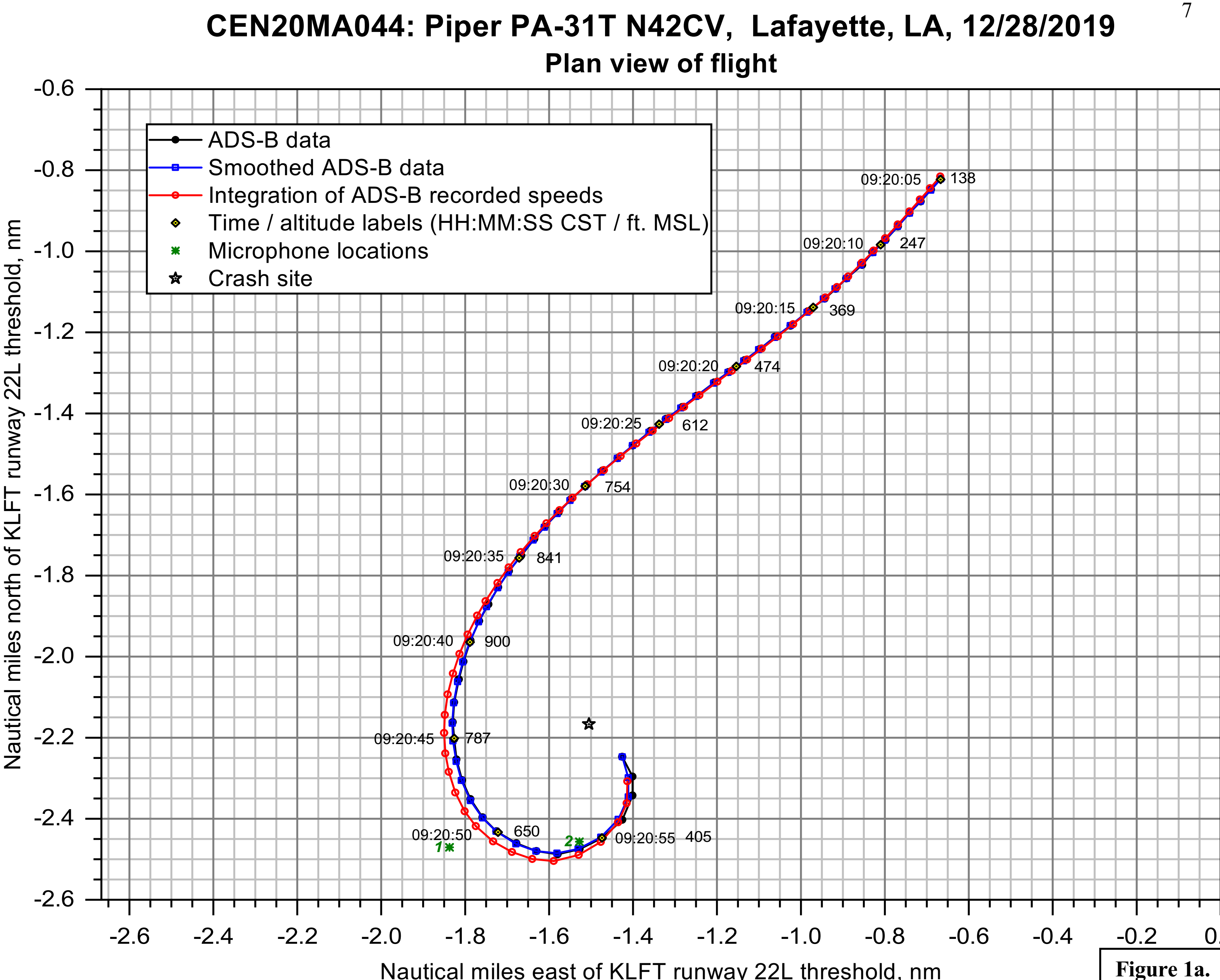

CEN20MA044: Piper PA-31T N42CV, Lafayette, LA, 12/28/2019
Plan view of flight
ADS-B data
Smoothed ADS-B data
Integration of ADS-B recorded speeds
Time / altitude labels (HH:MM:SS CST / ft. MSL)
Microphone locations
Crash site
09:20:05 138
09:20:10 247
09:20:15 369
09:20:20 474
09:20:25 612
09:20:30 754
09:20:35 841
09:20:40 900
09:20:45 787
09:20:50 650
09:20:55 405
1
2
Nautical miles north of KLFT runway 22L threshold, nm
Nautical miles east of KLFT runway 22L threshold, nm
-0.6
-0.8
-1.0
-1.2
-1.4
-1.6
-1.8
-2.0
-2.2
-2.4
-2.6
-2.6
-2.4
-2.2
-2.0
-1.8
-1.6
-1.4
-1.2
-1.0
-0.8
-0.6
-0.4
-0.2
0.0

Figure 1a.

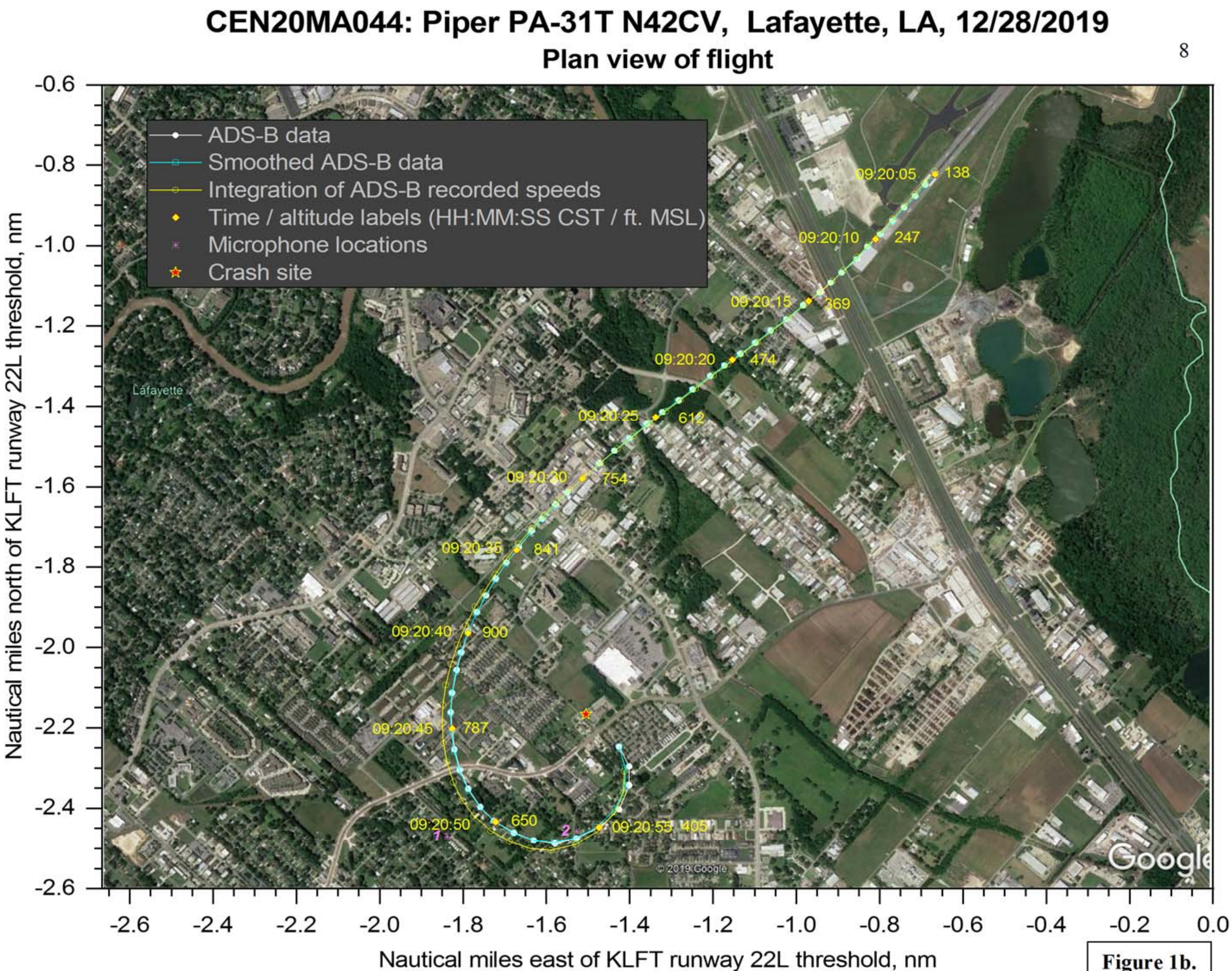

CEN20MA044: Piper PA-31T N42CV, Lafayette, LA, 12/28/2019
Plan view of flight
ADS-B data
Smoothed ADS-B data
Integration of ADS-B recorded speeds
Time / altitude labels (HH:MM:SS CST / ft. MSL)
Microphone locations
Crash site
09:20:05 138
09:20:10 247
09:20:15 369
09:20:20 474
09:20:25 612
09:20:30 754
09:20:35 841
09:20:40 900
09:20:45 787
09:20:50 650
09:20:55 405
1
2
Lafayette
© 2019 Google
Google
Nautical miles north of KLFT runway 22L threshold, nm
Nautical miles east of KLFT runway 22L threshold, nm
-0.6
-0.8
-1.0
-1.2
-1.4
-1.6
-1.8
-2.0
-2.2
-2.4
-2.6
-2.6
-2.4
-2.2
-2.0
-1.8
-1.6
-1.4
-1.2
-1.0
-0.8
-0.6
-0.4
-0.2
0.0

Figure 1b.

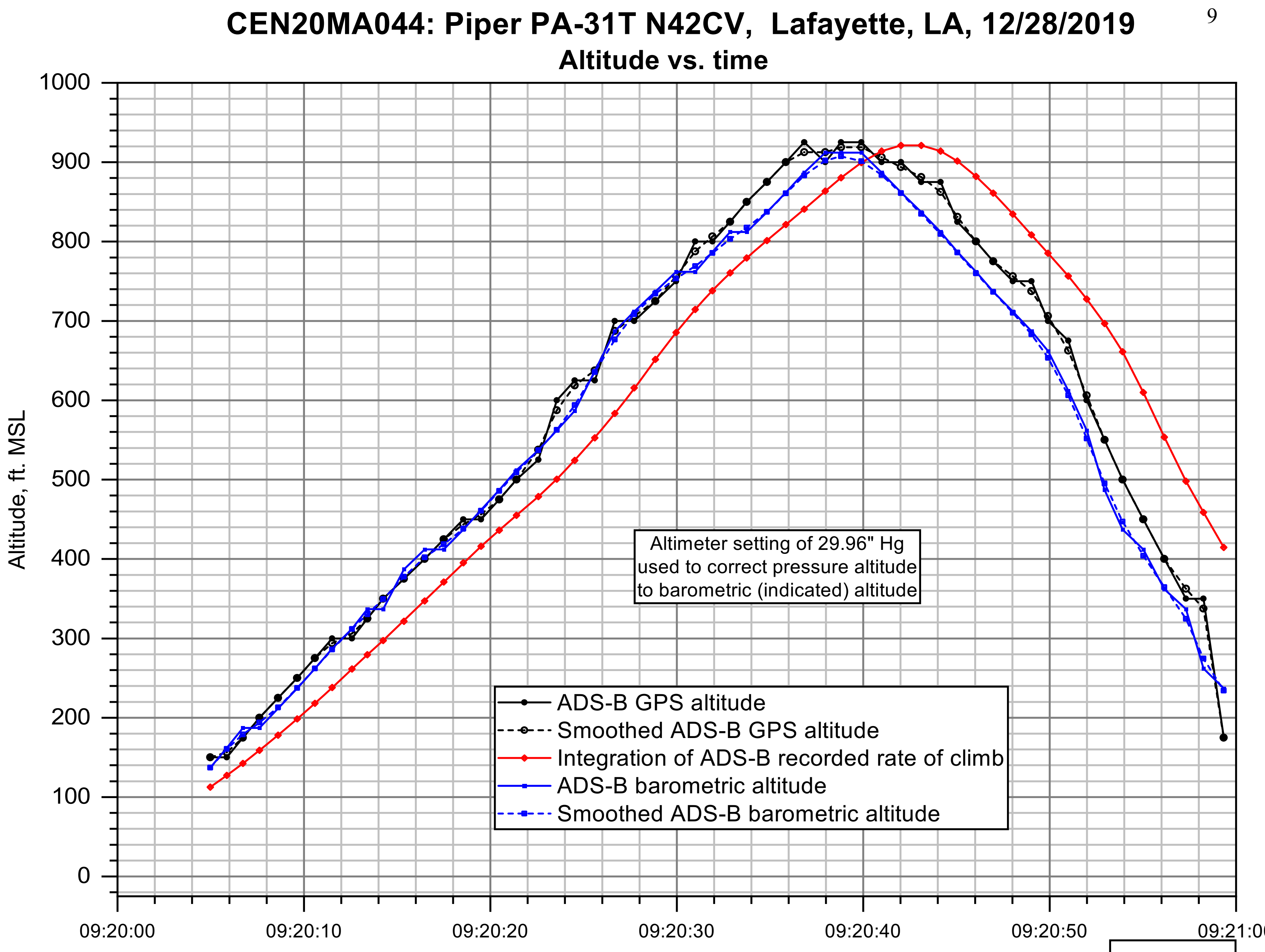
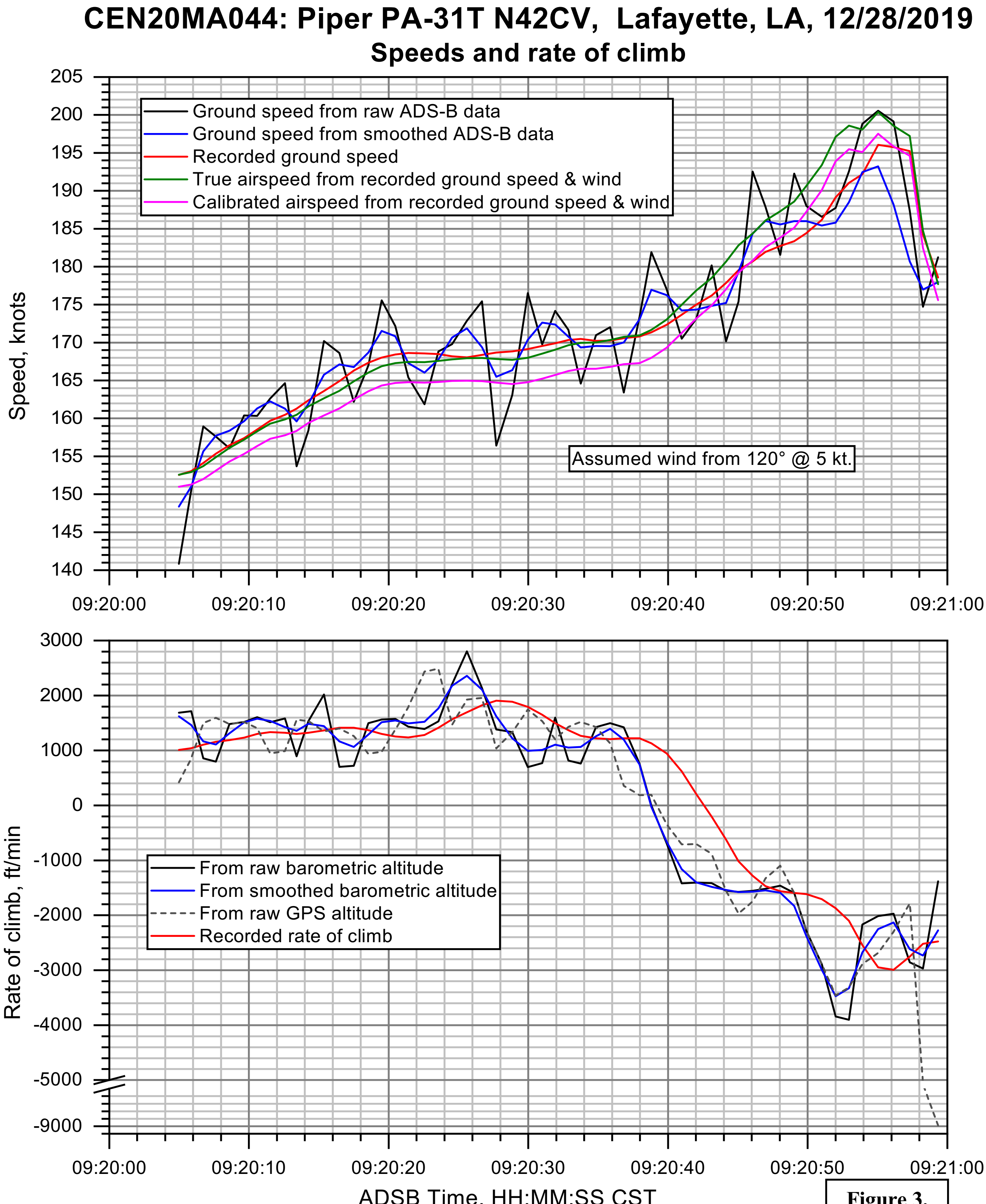

CEN20MA044: Piper PA-31T N42CV, Lafayette, LA, 12/28/2019
Altitude vs. time
Altitude, ft. MSL
1000
900
800
700
600
500
400
300
200
100
0
09:20:00
09:20:10
09:20:20
09:20:30
09:20:40
09:20:50
09:21:00
ADSB time, HH:MM:SS CST
Altimeter setting of 29.96" Hg used to correct pressure altitude to barometric (indicated) altitude
ADS-B GPS altitude
Smoothed ADS-B GPS altitude
Integration of ADS-B recorded rate of climb
ADS-B barometric altitude
Smoothed ADS-B barometric altitude

Figure 2.



CEN20MA044: Piper PA-31T N42CV, Lafayette, LA, 12/28/2019
Speeds and rate of climb
Ground speed from raw ADS-B data
Ground speed from smoothed ADS-B data
Recorded ground speed
True airspeed from recorded ground speed & wind
Calibrated airspeed from recorded ground speed & wind
Assumed wind from 120° @ 5 kt.
Speed, knots
205
200
195
190
185
180
175
170
165
160
155
150
145
140
09:20:00
09:20:10
09:20:20
09:20:30
09:20:40
09:20:50
09:21:00
From raw barometric altitude
From smoothed barometric altitude
From raw GPS altitude
Recorded rate of climb
Rate of climb, ft/min
3000
2000
1000
0
-1000
-2000
-3000
-4000
-5000
-9000
ADSB Time, HH:MM:SS CST

Figure 3.

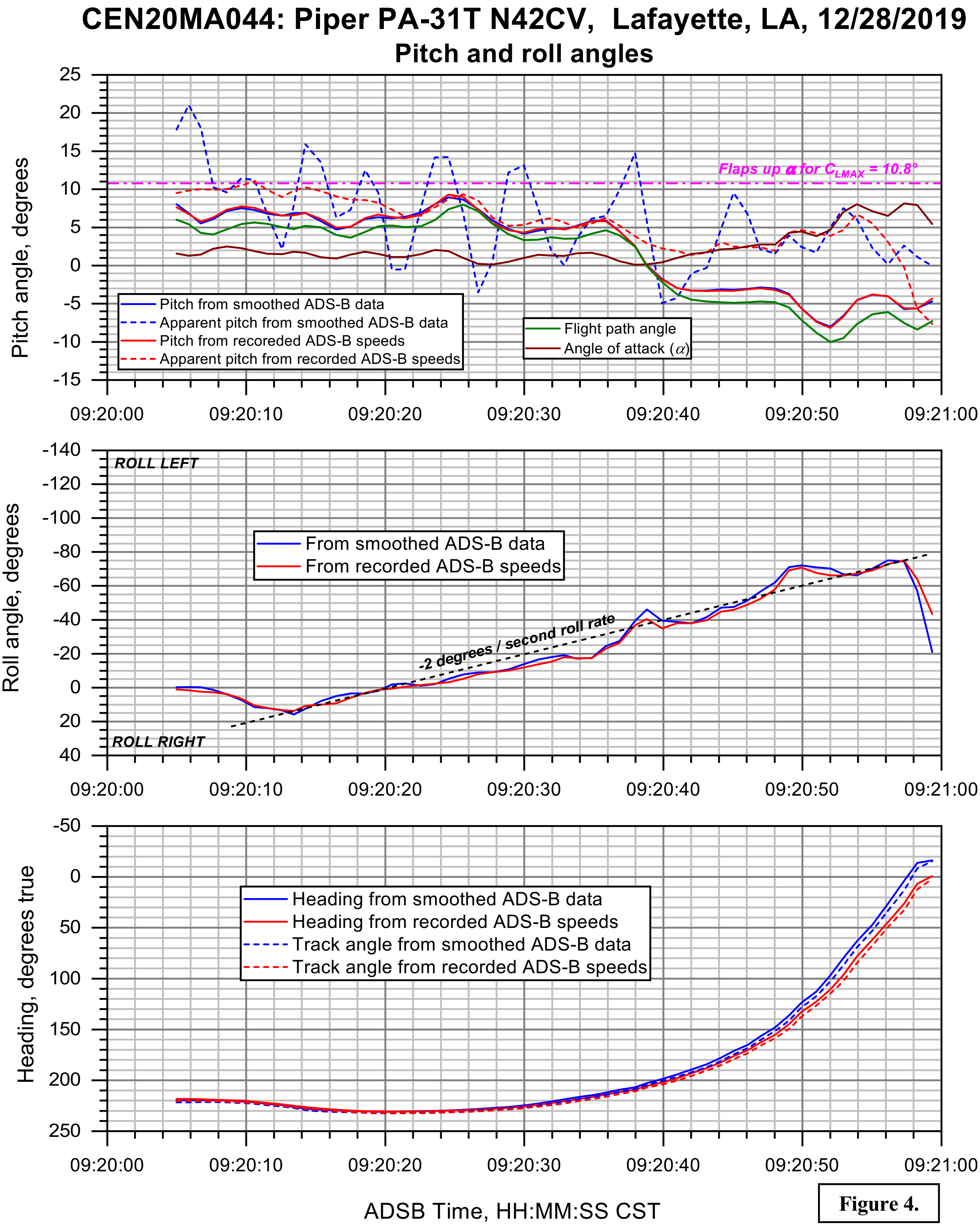

CEN20MA044: Piper PA-31T N42CV, Lafayette, LA, 12/28/2019
Pitch and roll angles
Pitch angle, degrees
Flaps up α for C_{LMAX} = 10.8°
Pitch from smoothed ADS-B data
Apparent pitch from smoothed ADS-B data
Pitch from recoreded ADS-B speeds
Apparent pitch from recorded ADS-B speeds
Flight path angle
Angle of attack (α)
Roll angle, degrees
ROLL LEFT
ROLL RIGHT
From smoothed ADS-B data
From recorded ADS-B speeds
-2 degrees / second roll rate
Heading, degrees true
Heading from smoothed ADS-B data
Heading from recorded ADS-B speeds
Track angle from smoothed ADS-B data
Track angle from recorded ADS-B speeds
09:20:00
09:20:10
09:20:20
09:20:30
09:20:40
09:20:50
09:21:00
ADSB Time, HH:MM:SS CST

Figure 4.

CEN20MA044: Piper PA-31T N42CV, Lafayette, LA, 12/28/2019

Load factors

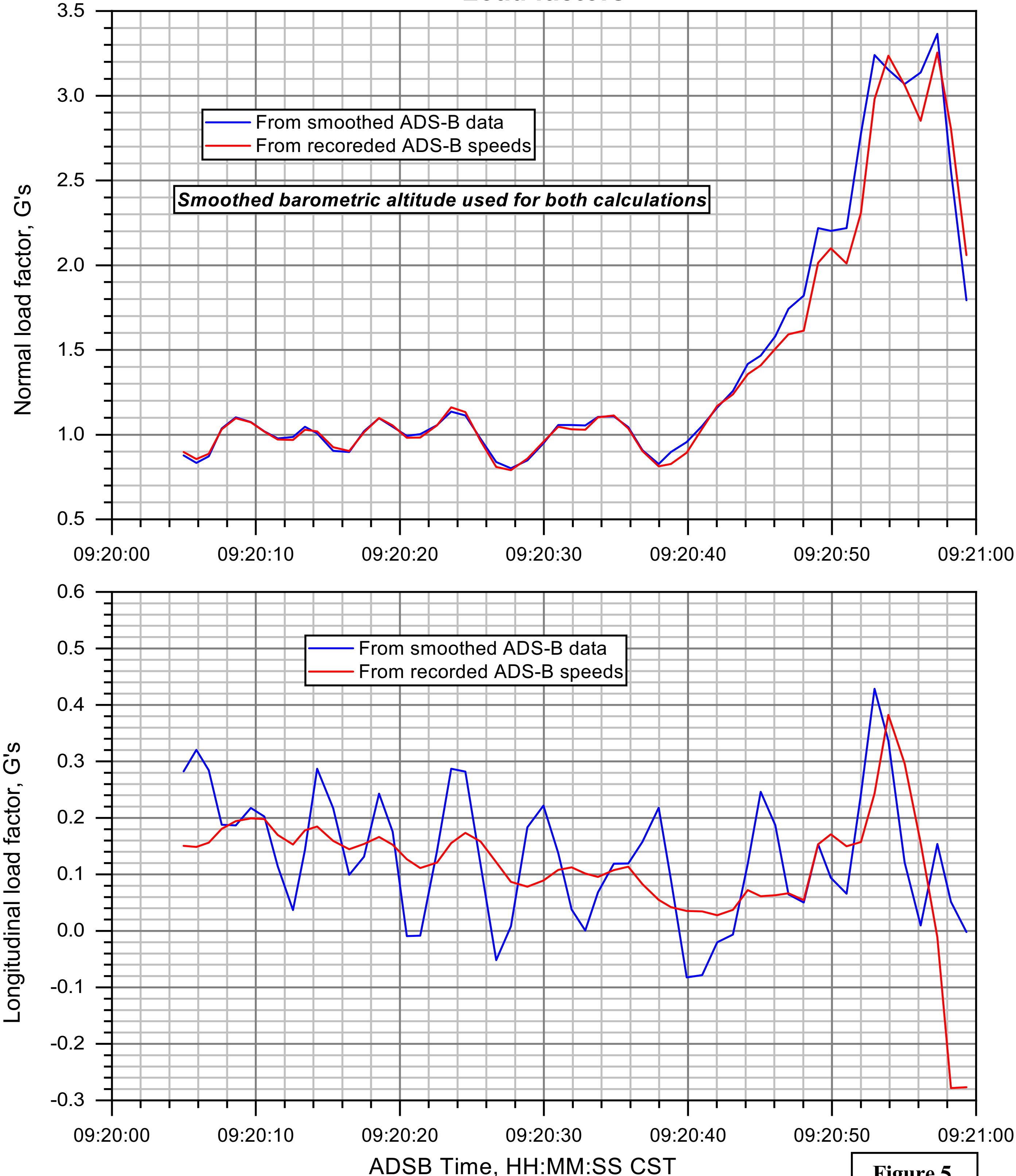


Figure 5.

CEN20MA044: Piper PA-31T N42CV, Lafayette, LA, 12/28/2019

Engine power required and lift coefficient

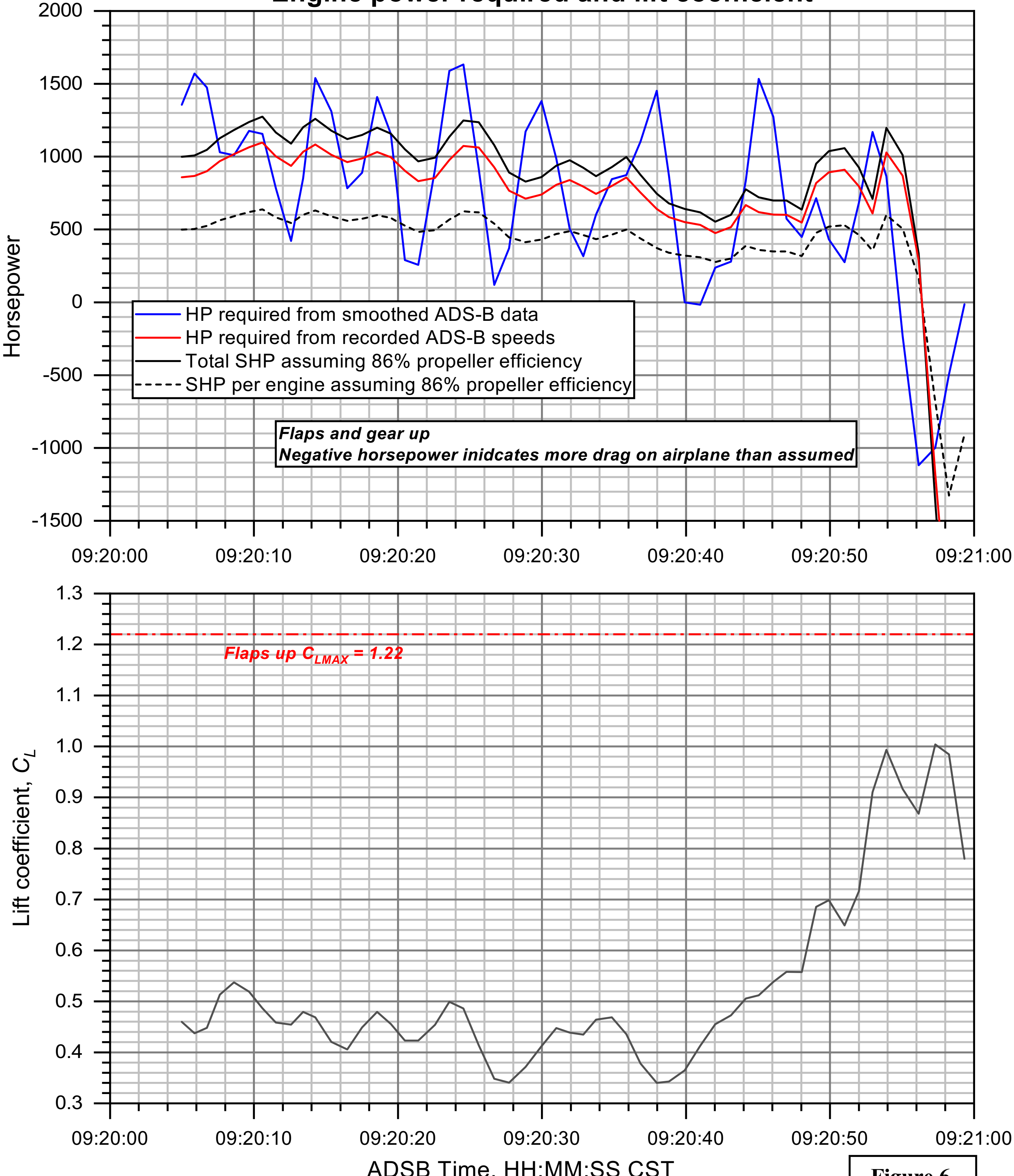


Figure 6.

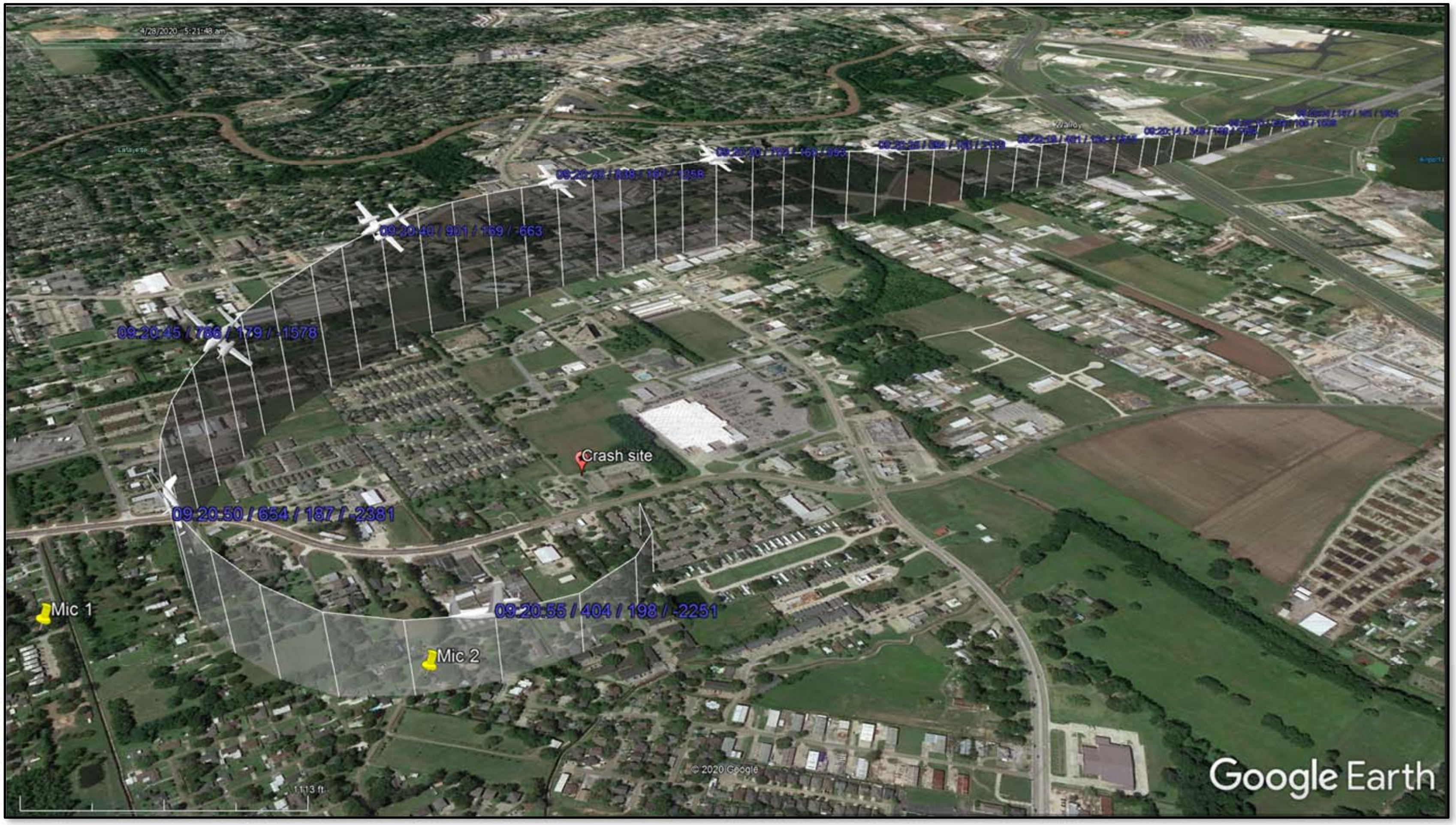


Figure 7. 3D view of flight path in *Google Earth.* The airplane models are not to scale, but enlarged to show the airplane attitude. The blue data labels provide information in the following format: Time, CST / Altitude, ft. MSL / Airspeed, KCAS / Rate of climb, ft./min.