



Date: August 28, 2023

To: Zoë Keliher, Office of Aviation Safety

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

Subject: Airplane performance plots for WPR22FA197

Zoë:

This memorandum transmits plots of several airplane performance parameters for the Cessna 208B Supervan 900 (N7581F) skydiving flight accident in Oceanside, California (KOKB), on June 3, 2022 (WPR22FA197). The plots are based on Automatic Dependent Surveillance - Broadcast (ADS-B) data for the accident flight and winds aloft data (there is no Flight Data Recorder or other on-board recorded data available for N7581F). Performance parameters obtained from an engineering simulation of the descent of the airplane after the skydivers exited the airplane are also presented, and compare well with the parameters computed from the ADS-B and wind data.

Of particular interest is engine thrust developed during the descent. The engine power (power lever) and propeller speed (propeller RPM control lever) settings on N7581F are unknown. However, the thrust on the accident descent is compared with the thrust developed during N7581F's three previous descents, and with the thrust developed during descents on other aircraft for which the power settings are known. These comparisons indicate that the negative thrust coefficients developed during the accident descent and the three previous descents performed in the airplane are similar. The coefficients are also similar to those developed on the descents for which the power settings are known to have been kept within the operating limitations of the engine (that is, the power lever kept at or above the "flight idle" gate in flight). In addition, at the end of the accident descent the thrust coefficient recovers from a negative value to approximately zero or positive values, as it does on the other flights examined. However, following this recovery, the computed thrust coefficient on the accident flight oscillates, decreasing back to (and subsequently recovering from) negative values that approach those achieved during the descent. The reasons for this thrust oscillation are unknown.

ADS-B data

The ADS-B data for N7581F was provided by the Federal Aviation Administration (FAA) and consisted of:

- 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 + 114 ft. (at KOKB, the geoid is 114 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.

The recorded ADS-B positions defining the airplane's flight path during the last five minutes of the accident flight (corresponding to the descent from about 11,000 ft. MSL) are plotted as north and east coordinates relative to the KOKB runway 25 threshold in Figure 1. The labeled points indicate the ADS-B time in HH:MM:SS PDT, and the GNSS altitude in feet MSL. The north and east coordinates of the airplane are plotted vs. time in Figure 2.

Figure 3 plots the ADS-B GNSS and pressure altitudes vs. ADS-B time (the GNSS altitude is corrected for the geoid height, and the pressure altitude is corrected for an altimeter setting of 29.85 " Hg).²

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.

² Several Figures in this *Memorandum* have an "a" and a "b" version, which present the same information but at different scales. When the *Memorandum* refers to a Figure with two or more versions without specifying the version, all versions are meant to be included in the reference.

Winds aloft data

Winds aloft are based on a High Resolution - Rapid Refresh (HRRR) model sounding for 15:00 PDT over KCRQ (McClellan / Palomar Airport, Carlsbad, CA, about 6 nm southeast of KOKB), obtained from a National Oceanographic and Atmospheric Administration (NOAA) website.³ The wind speed, wind direction, and air temperature as a function of altitude from this model are plotted in Figure 4.

Additional performance parameters computed from ADS-B data

The north-south and east-west components of ground speed computed by on-board avionics are included in the ADS-B messages broadcast from the airplane. These speed components can be combined to produce total ground speed and ground track angle. This total ADS-B ground speed is plotted in the top plot of Figure 5. The true and calibrated airspeeds computed by combining the ADS-B ground speed with the winds and temperatures aloft data are also plotted. The ADS-B messages also include the vertical speed component (rate of climb), which is presented in the bottom plot of Figure 5.

Knowing the airplane's true airspeed and track angle, its pitch (θ), roll (ϕ), and heading (ψ) angles (i.e., the Euler angles) can be estimated as long as the following are true:

- The lift coefficient (C_L) of the airplane as a function of angle of attack (α) is known;
- The gross weight of the airplane is known;
- The sideslip angle and lateral acceleration are negligible (i.e., coordinated flight).

For this case, the C208B flaps-up lift curve (C_L vs. α) was extracted from the NTSB's simulation model of the C208B (described further below) for the Euler angle calculation (the flaps were found up in the wreckage). In addition, a gross weight of 5,867 lb. is used, based on the empty weight indicated in N7581F's records, the pilot and passenger weights, an assumed 100 gallons of fuel, and an assumed 26 pounds for miscellaneous items.

To compute the engine thrust and associated thrust coefficient (C_T), the drag coefficient (C_D) of the airplane is required. The C_D is computed as the C_D of the cargo pod-equipped C208B obtained from the simulation model, minus the C_D contribution of the cargo pod as provided by Textron. The C_T is computed as:

$$C_T = \frac{2T}{\rho(V^2)S}$$

³ See <https://www.ready.noaa.gov/READYamet.php>.

Where T = thrust, ρ = air density, V = true airspeed, and S = wing area. During the descent, the C_T is a better indicator than the absolute thrust of changes to the airplane's aerodynamic drag characteristics resulting from different combinations of the propeller and engine configuration, just as in cruise the C_D is a better indicator of the airplane's "aerodynamic cleanness" than the absolute drag.

The computed Euler angles and flight path angle (γ) during the descent are plotted in Figure 6, and the components of the airplane's acceleration (the load factors) are plotted in Figure 7. T and C_T are plotted in Figure 8. The calculations are for flaps up.

Figure 9 compares the T and C_T for the accident descent with three previous descents in N7581F. Figure 10 compares the accident descent with descents performed on two other C208B Supervan 900 airplanes, for which the power lever and propeller control lever settings are known.

The additional descents plotted in Figure 10 were flown in N420DZ and N703DC by the President of Texas Turbines, the company that performs the "Supervan" conversions on Cessna 208B airplanes. Texas Turbines is a party to the N7581F investigation. The descent in N420DZ was flown as part of a normal skydiving operation. The descents in N703DC were performed to document how the airplane would perform with the engine control levers set as shown in Table 1.

Figure 10 data label	power lever position	Propeller RPM Control Lever position
N703DC spd lvr high	Flight idle	"High"
N703DC spd lvr low	Flight idle	"Low"

Table 1. Engine control lever positions for N703DC descents plotted in Figure 10.

Figure 9 indicates that the negative thrust and C_T achieved during the accident descent is similar to the values achieved on N7581F's previous three descents, suggesting that all four descents were performed in a similar manner. Figure 10 indicates that the negative C_T achieved during these descents is comparable to the negative C_T achieved during the descents in N420DZ and N703DC, in which the power lever is known to have been at or above the "flight idle" gate. In Figure 10, the N420DZ C_T matches the N703DC "spd lvr high" C_T rather well (the N703DC "spd lvr low" descent was terminated relatively early so as not to allow the propeller RPM to decrease excessively). The N420DZ and N703DC "spd lvr high" C_T values are similar to the C_T values achieved on N7581F's accident descent.

Figures 8-10 indicate that at about 13:44:40, N7581F's C_T increases back to about zero, and increases above zero to about 0.4 (corresponding to a forward thrust of about 500 lb.) at about 13:46:10. However, the C_T drops back down to -0.12 (corresponding to a negative thrust of about -1,000 lb.) at 13:46:45. C_T increases back to 0.1 at about 13:46:52, decreases to -0.15 at 13:46:59, and increases back to about zero at 13:47:09. These C_T oscillations are reflected in the speed and longitudinal load factor

oscillations depicted in Figures 5 and 7, but the reasons for these oscillations are unknown.

Engineering simulation of accident descent

To confirm the consistency of the Euler angles and thrust levels calculated from the ADS-B and winds aloft data with the performance capabilities of the airplane, a six degree-of-freedom (6-DOF) simulation of the accident descent was performed. The objective of the simulation was to obtain a physics-based computation of the airplane's trajectory and orientation that is consistent with the performance capabilities of the Cessna 208B, and with the ADS-B and wind information described above.

The aerodynamic, propulsion, and flight controls models for the simulation were obtained from Kohlman Systems Research (KSR). KSR's models for the C208B meet the qualification standards for a Level D Full Flight Simulator specified in 14 Code of Federal Regulations (CFR) Part 60. Note that in the simulation performed here, the propulsion model is simplified so that the engine thrust reacts instantaneously to changes in power lever position; engine dynamics are not modeled, though the total steady-state forward thrust at a given flight condition and power lever position is modeled. Any additional drag resulting from abnormal power lever positions (e.g., the power lever below the "flight idle" gate), if required, is modeled artificially by introducing multipliers on the normal reverse thrust that can be obtained on the ground; the drag or reverse thrust is not the result of any physical modeling of the aerodynamics of the propeller blade in this condition.

Furthermore, the KSR simulation models the Pratt & Whitney PT-6A engine and McCauley propeller installed on the C208B as produced by Textron, not the Honeywell TPE331 engine and Hartzell propeller installed in the accident airplane. Hence, only the net thrust output by the simulation is relevant in this case. The engine model can be considered a "black box" that simply generates the thrust required to match the airplane trajectory recorded by the ADS-B data; the simulation model parameters that describe the internal engine and propeller performance are not applicable.

The simulation uses a "math pilot" to generate flight control and power lever inputs that result in an approximate matches of the ADS-B trajectory. The high-frequency oscillations or "noise" in the simulated thrust (the red lines in Figure 8) are not real, but the result of the math pilot instantaneously modifying thrust in reaction to the computed acceleration at each point computed from the ADS-B data. The noise in the resulting thrust could likely be made "smoother" with appropriate tuning of the math pilot gains; however, the results as they are suffice to confirm the thrust levels computed directly from the ADS-B data and the C_D described above (the simulation C_D was also decremented by the C_D contribution of the cargo pod).

The results of the simulation are presented in Figures 1-8 together with the corresponding parameters computed from the ADS-B and wind data. The generally good agreement between the simulated and computed positions, speeds, Euler angles, and thrust levels indicates that the performance parameters computed from the ADS-B data and winds are consistent with the performance capabilities of the airplane.

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

Regards,

John O'Callaghan
National Resource Specialist - Aircraft Performance

WPR22FA197: Cessna 208B Supervan 900, N7581F, Oceanside, CA, 06/03/2022

Plan view of flight path relative to KOKB runway 25 threshold

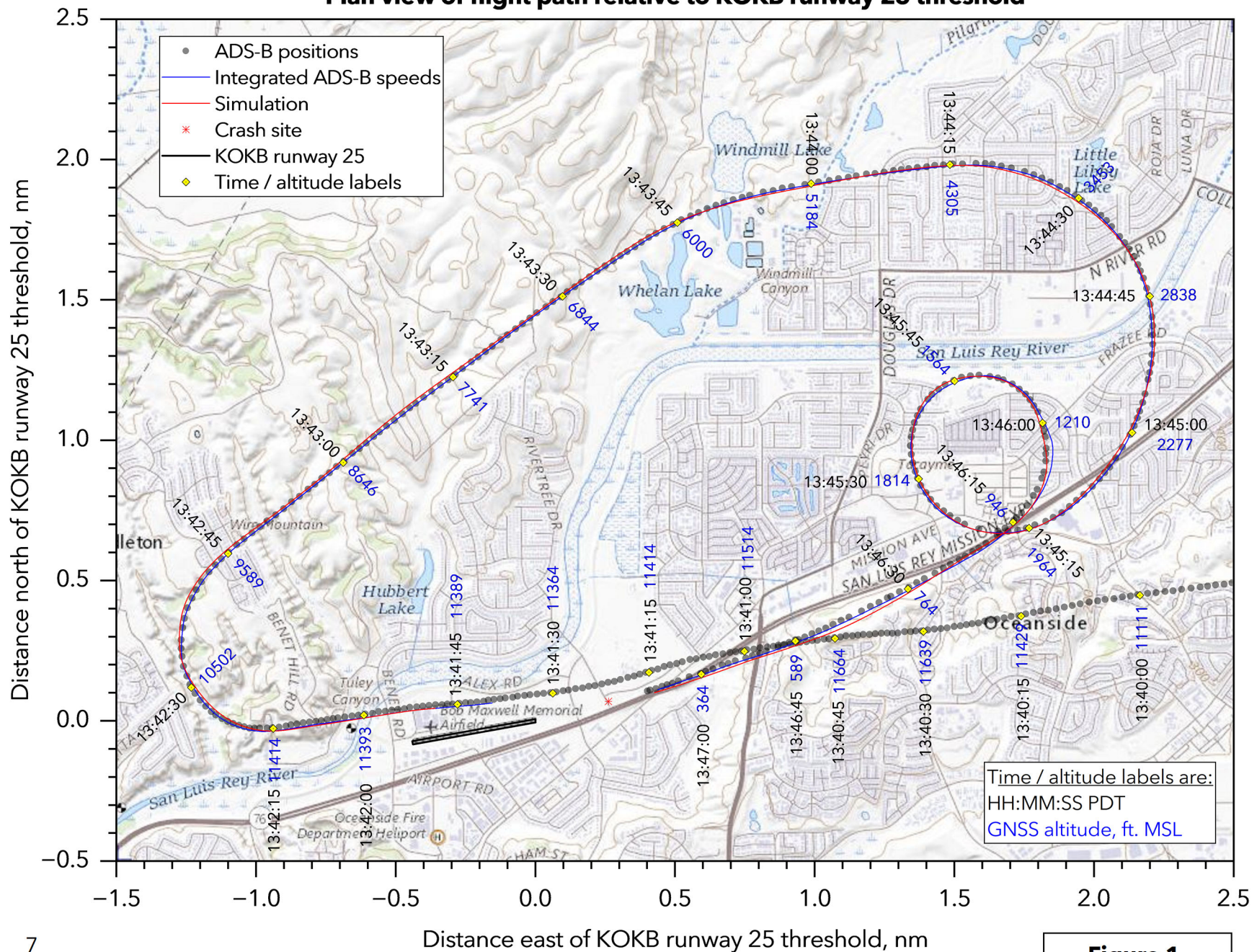
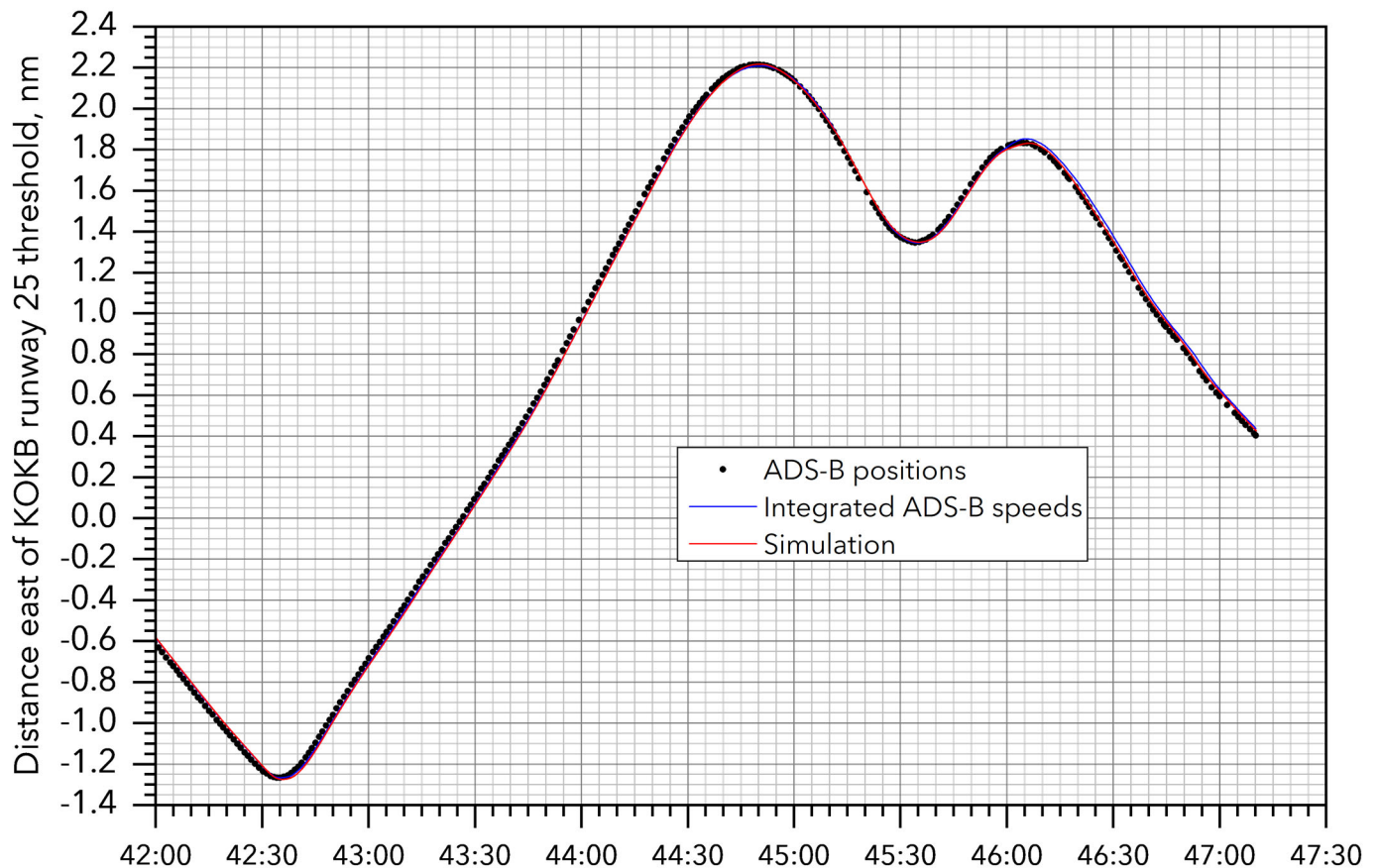
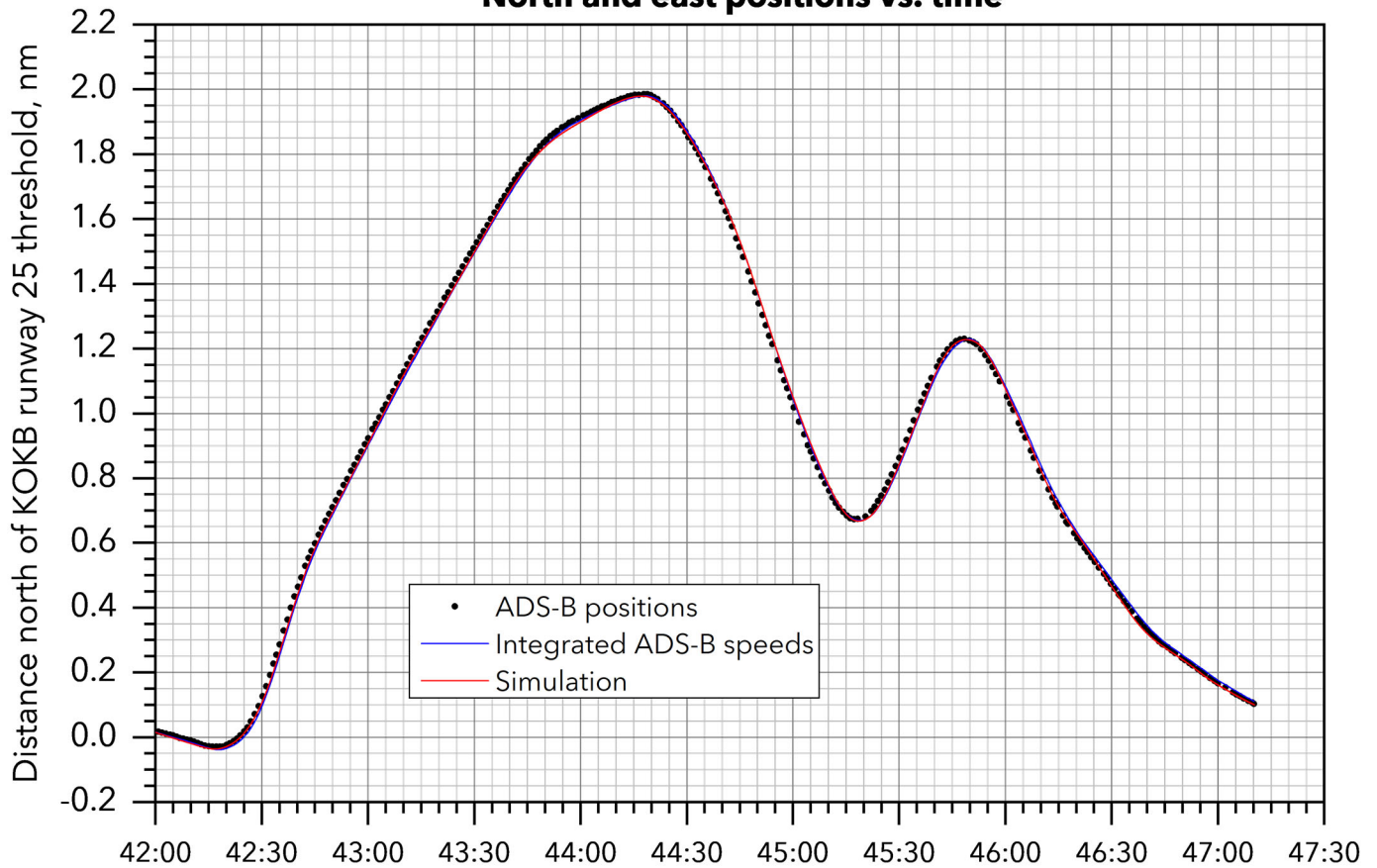


Figure 1.

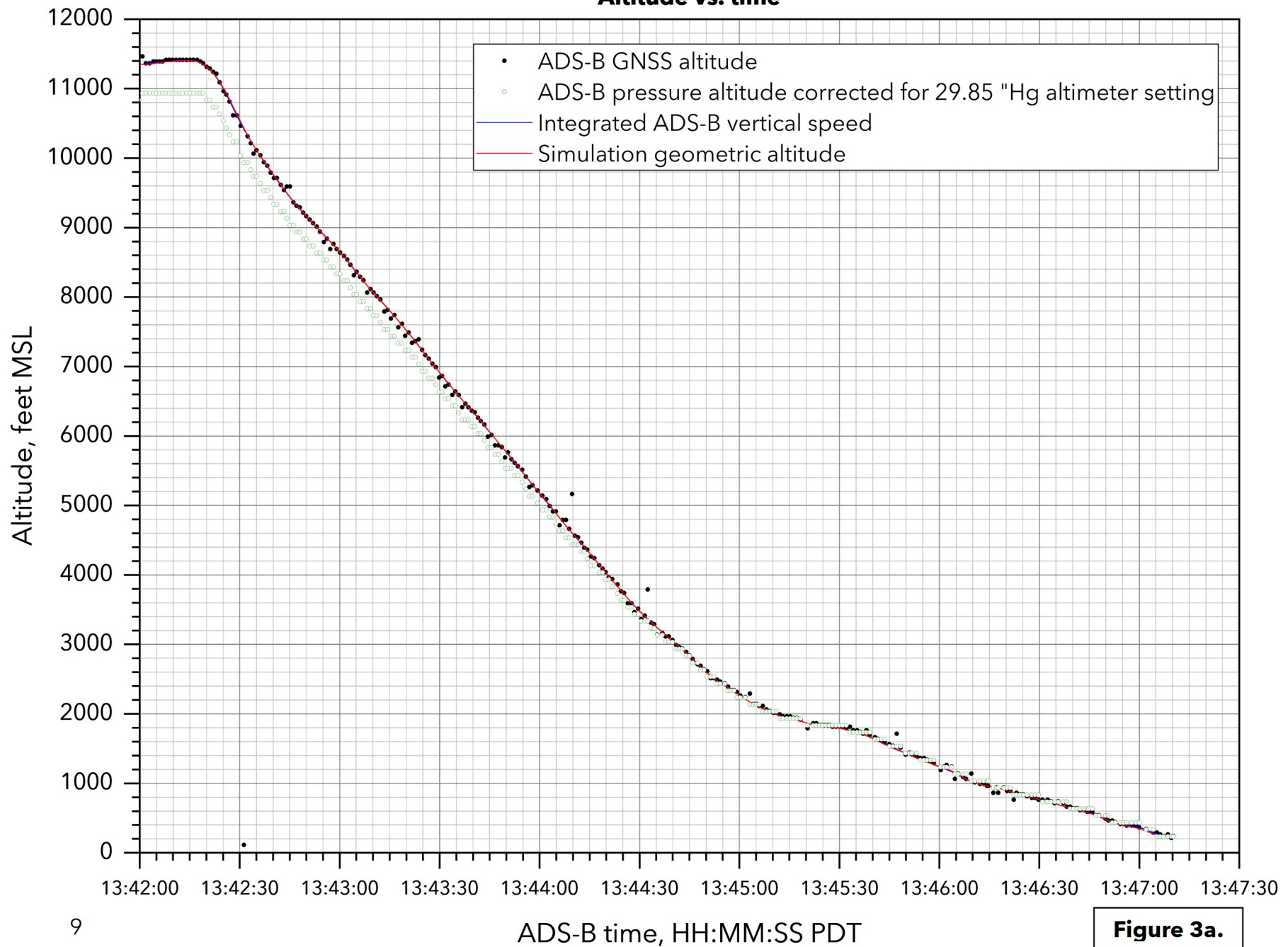
WPR22FA197: Cessna 208B Supervan 900, N7581F, Oceanside, CA, 06/03/2022

North and east positions vs. time



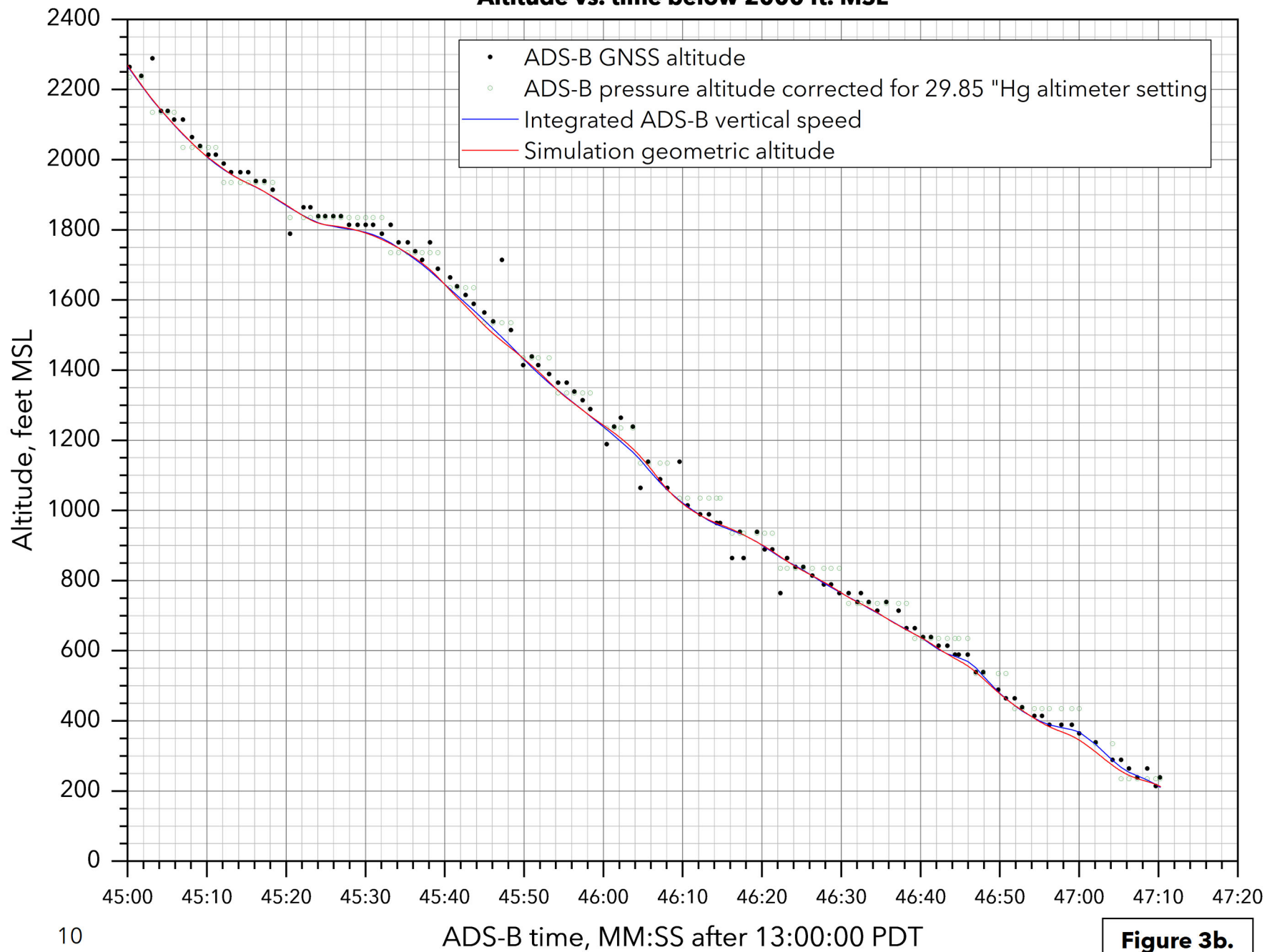
WPR22FA197: Cessna 208B Supercub 900, N7581F, Oceanside, CA, 06/03/2022

Altitude vs. time



WPR22FA197: Cessna 208B Supercub 900, N7581F, Oceanside, CA, 06/03/2022

Altitude vs. time below 2000 ft. MSL



WPR22FA197: Cessna 208B Supervan 900, N7581F, Oceanside, CA, 06/03/2022

Winds aloft from 15:00 PDT KCRQ HRRR model

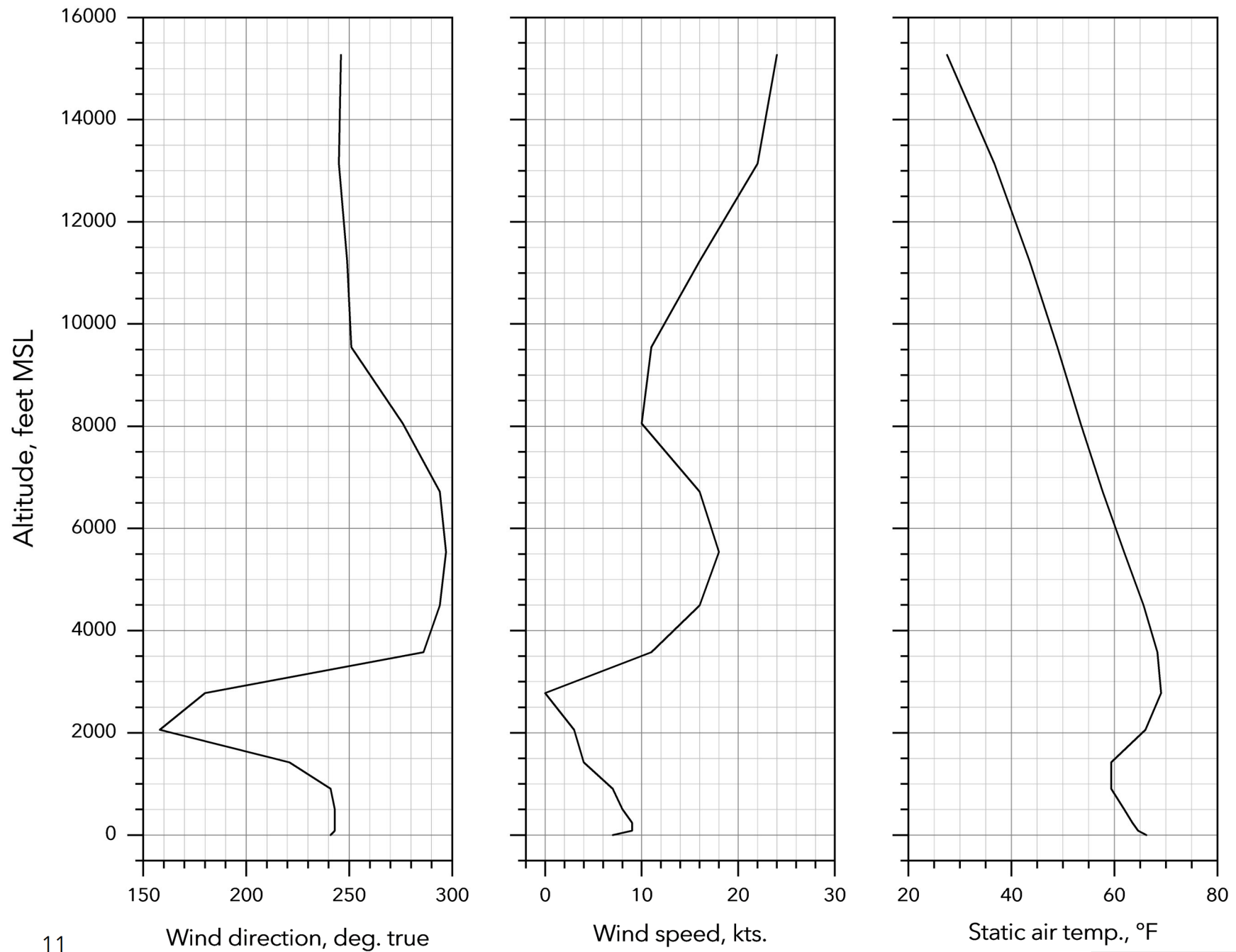


Figure 4.

WPR22FA197: Cessna 208B Supervan 900, N7581F, Oceanside, CA, 06/03/2022

Speed and rate of climb vs. time

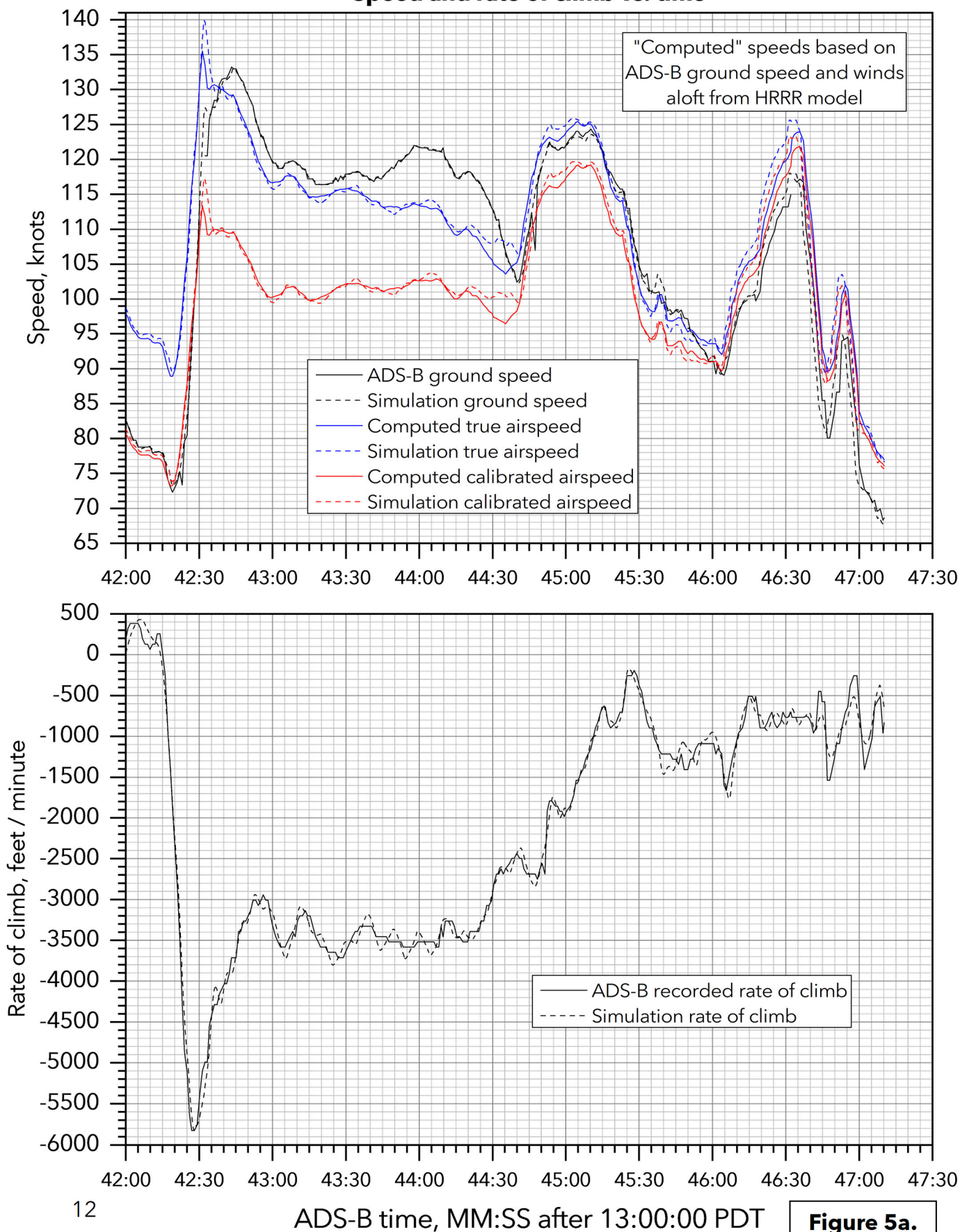
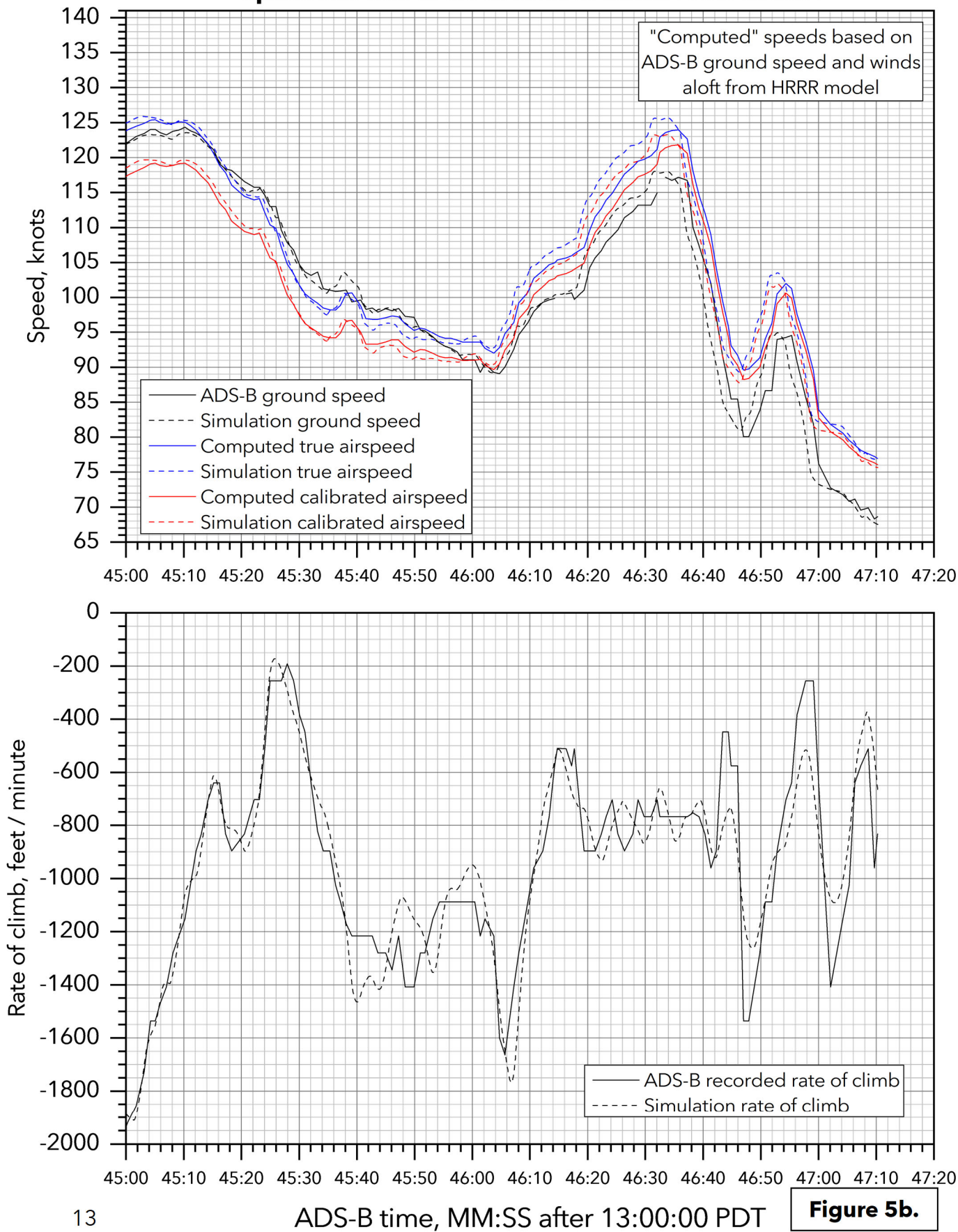


Figure 5a.

WPR22FA197: Cessna 208B Supercub 900, N7581F, Oceanside, CA, 06/03/2022

Speed and rate of climb vs. time below 2000 ft. MSL



WPR22FA197: Cessna 208B Supervan 900, N7581F, Oceanside, CA, 06/03/2022

Euler angles vs. time

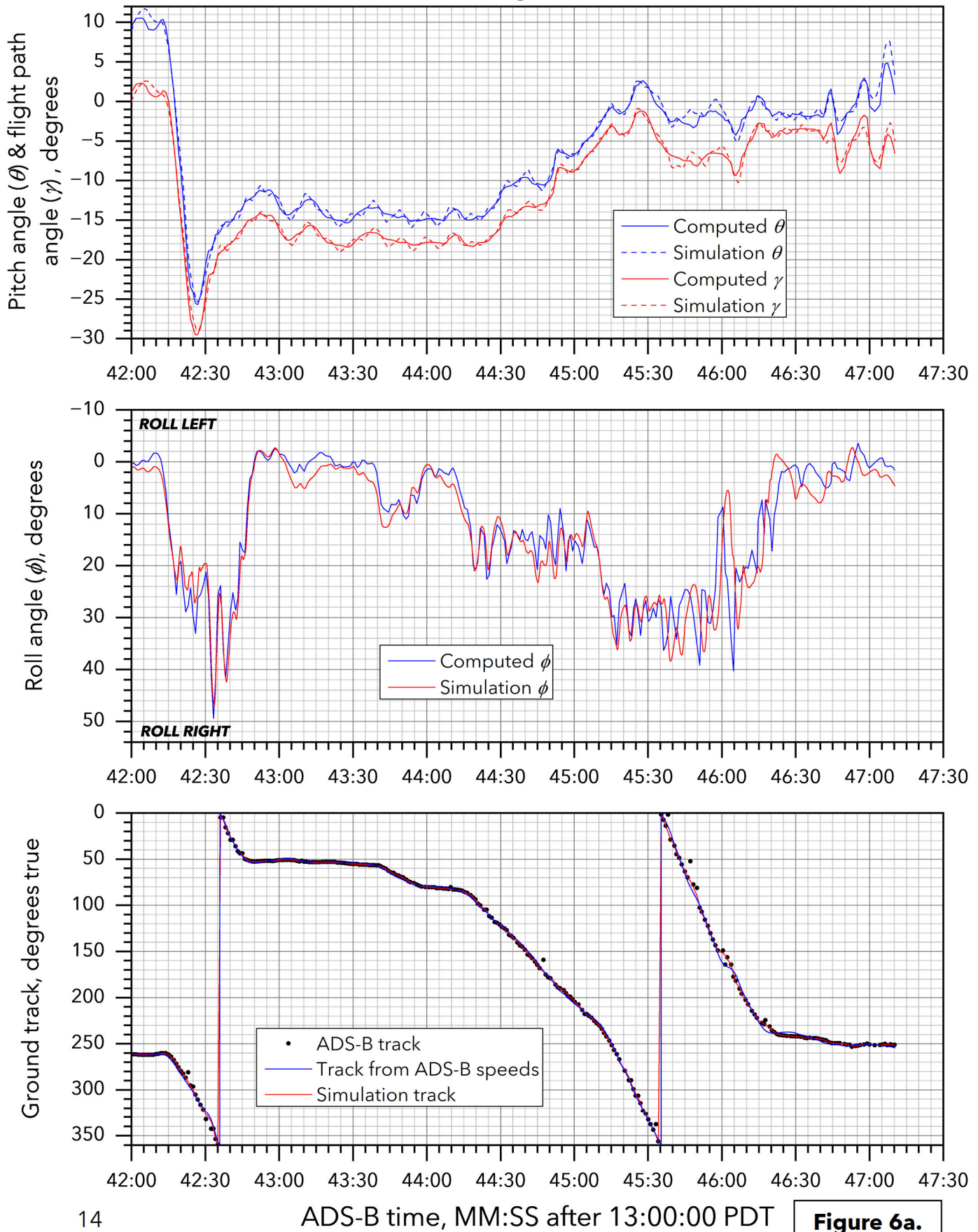
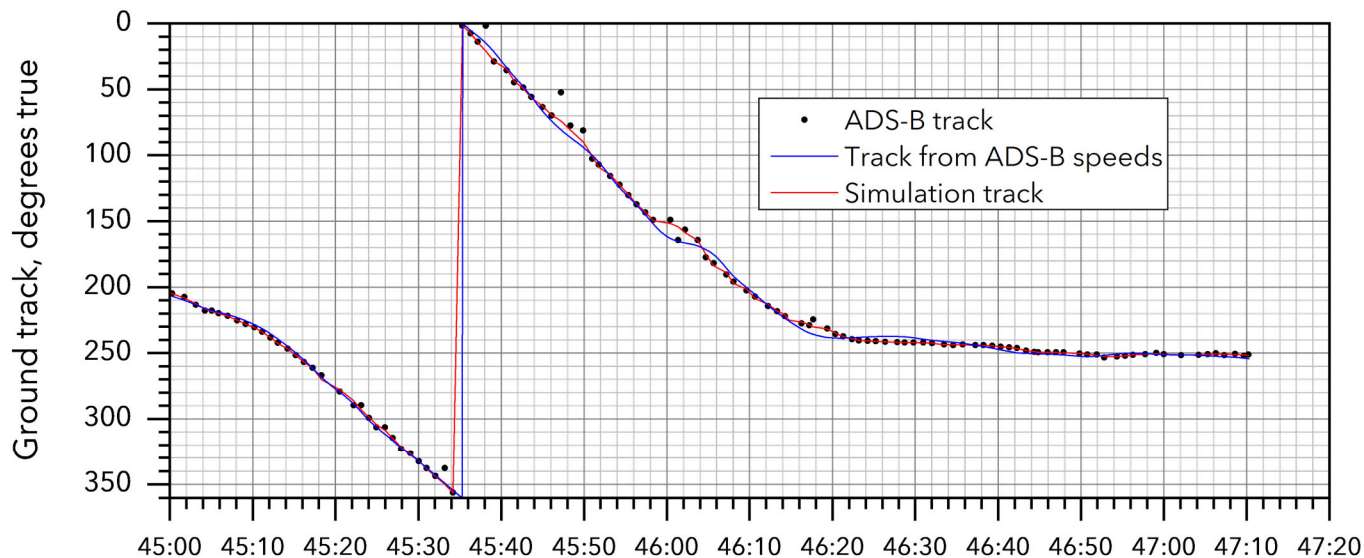
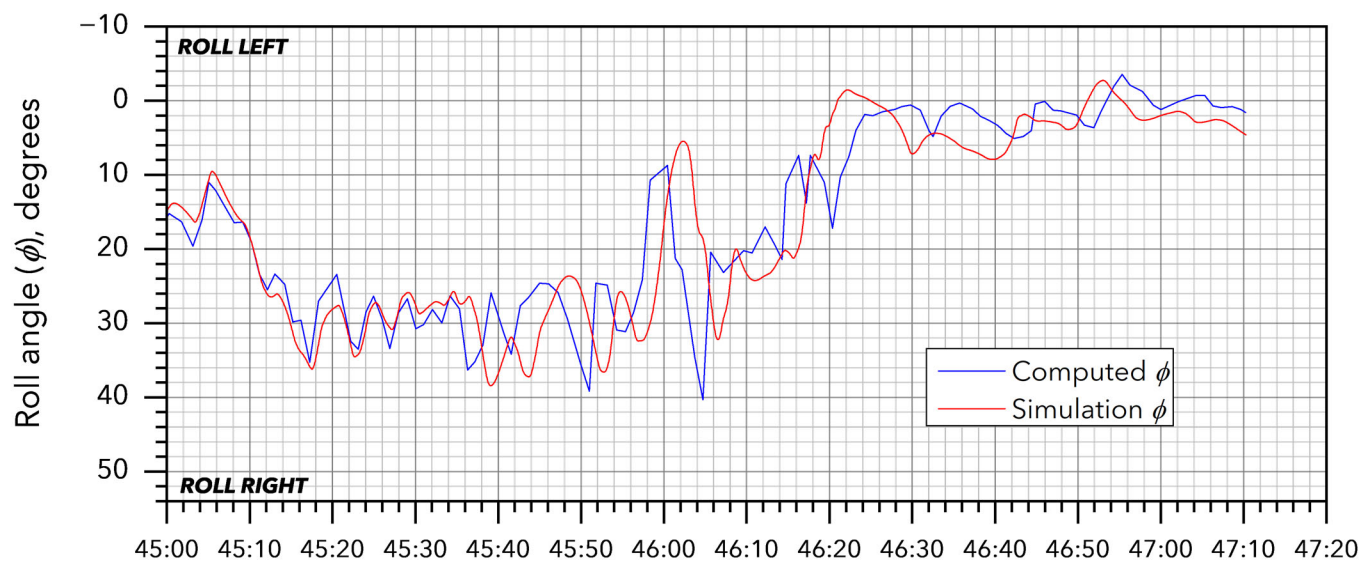
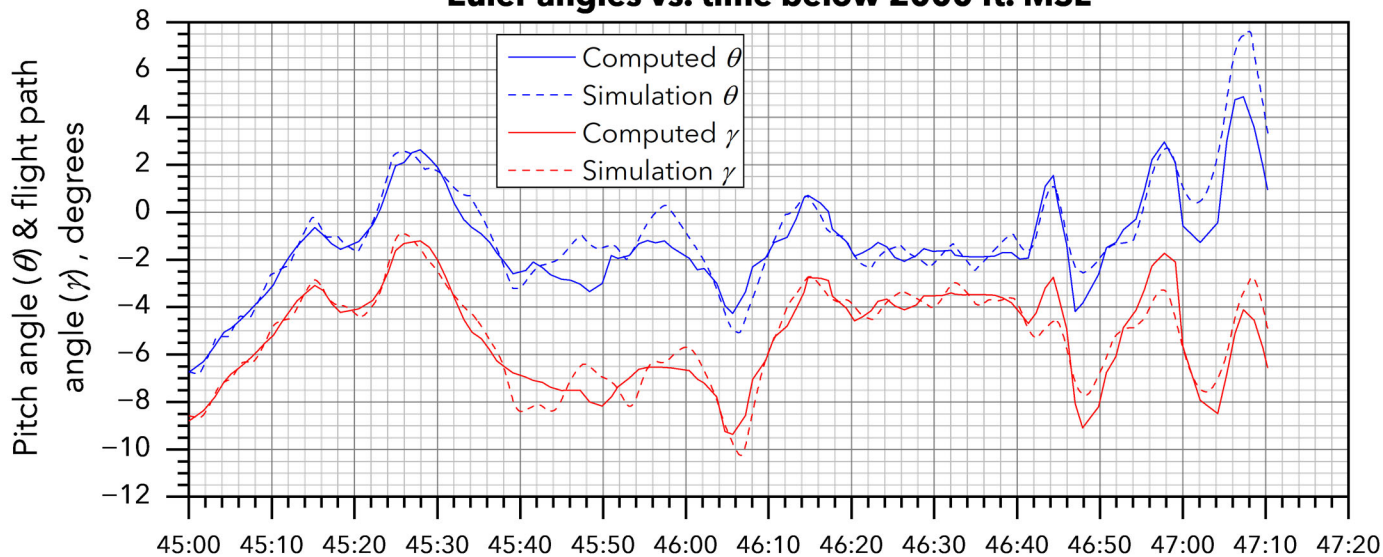


Figure 6a.

WPR22FA197: Cessna 208B Supervan 900, N7581F, Oceanside, CA, 06/03/2022

Euler angles vs. time below 2000 ft. MSL



WPR22FA197: Cessna 208B Supervan 900, N7581F, Oceanside, CA, 06/03/2022

Load factors vs. time

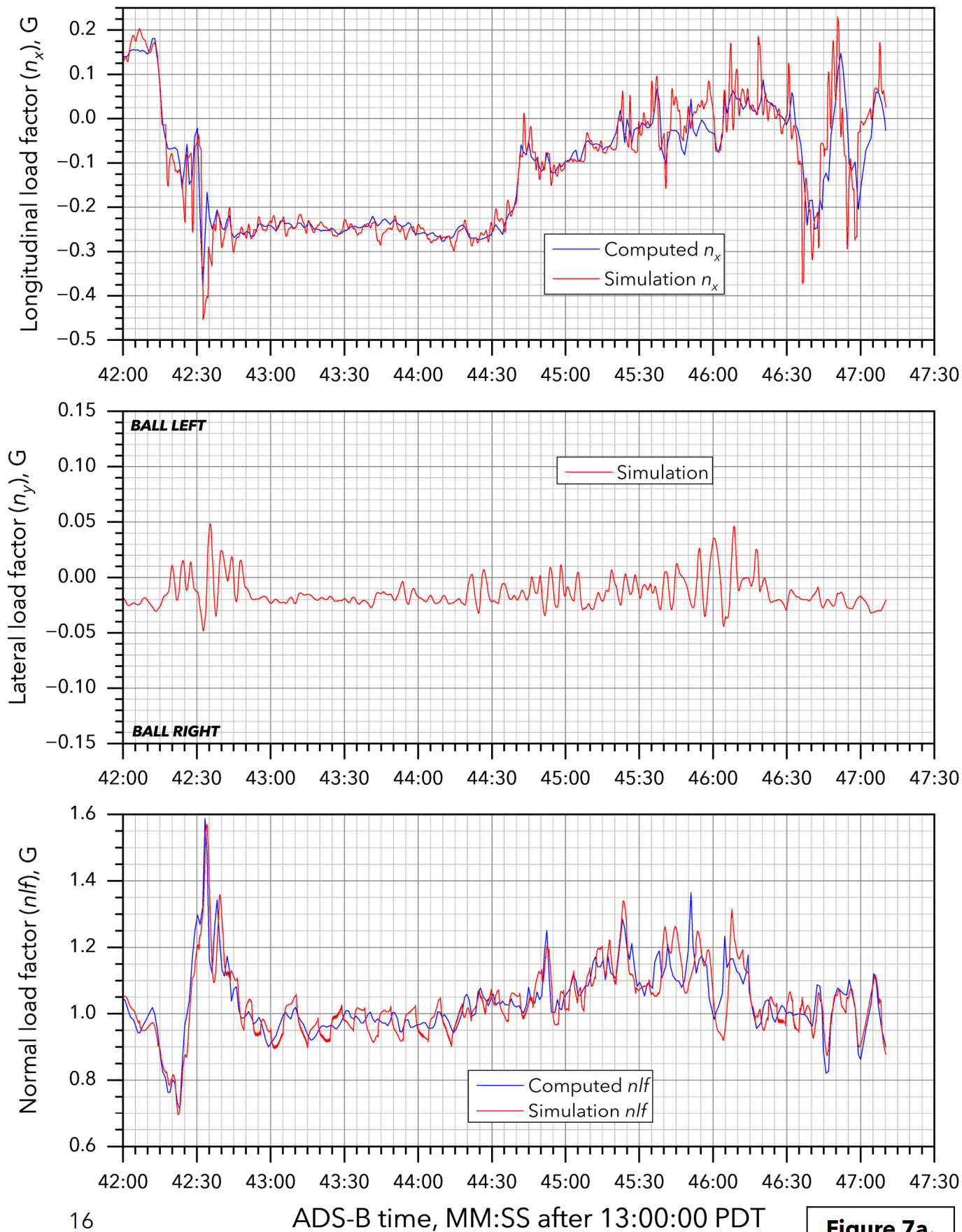
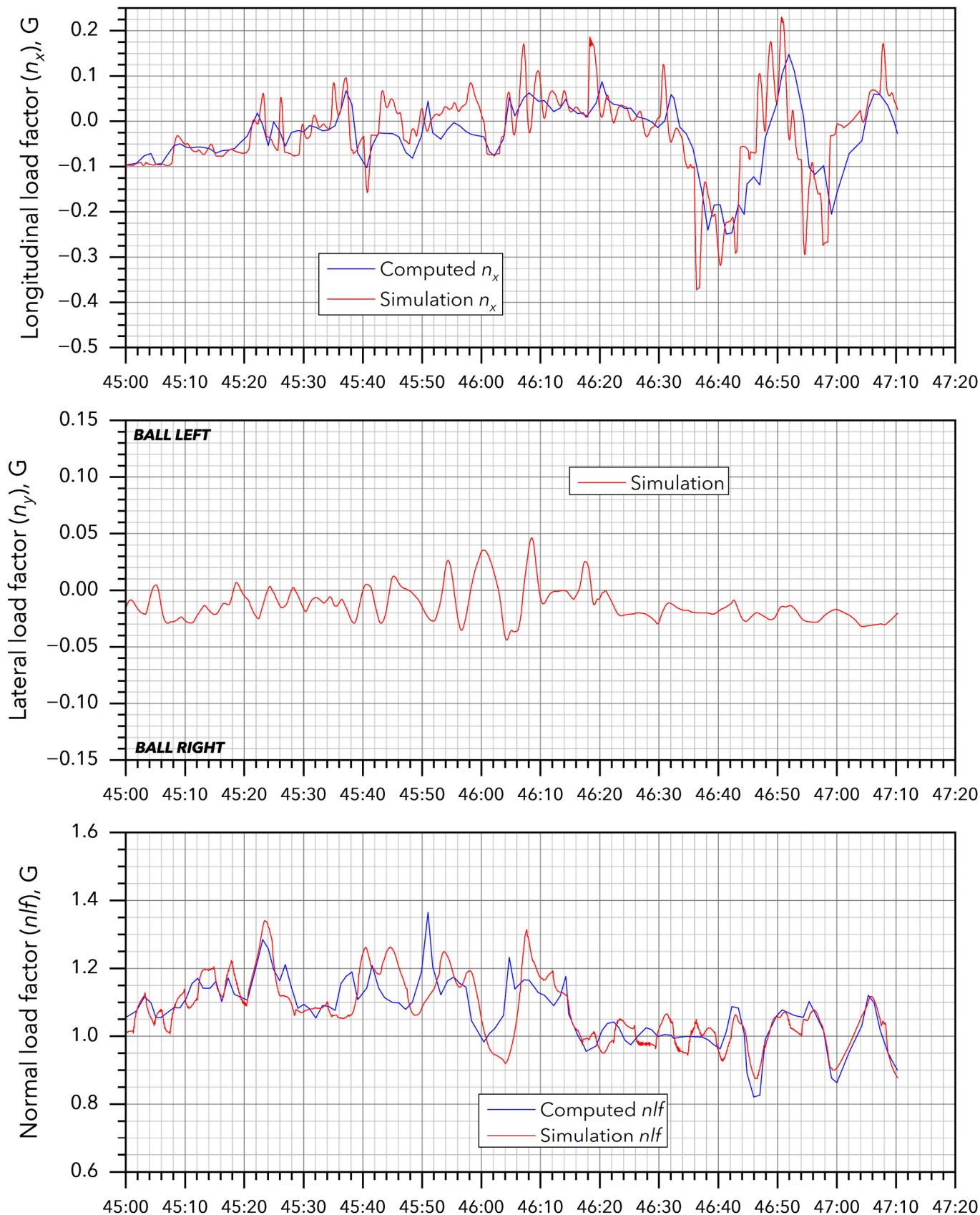


Figure 7a.

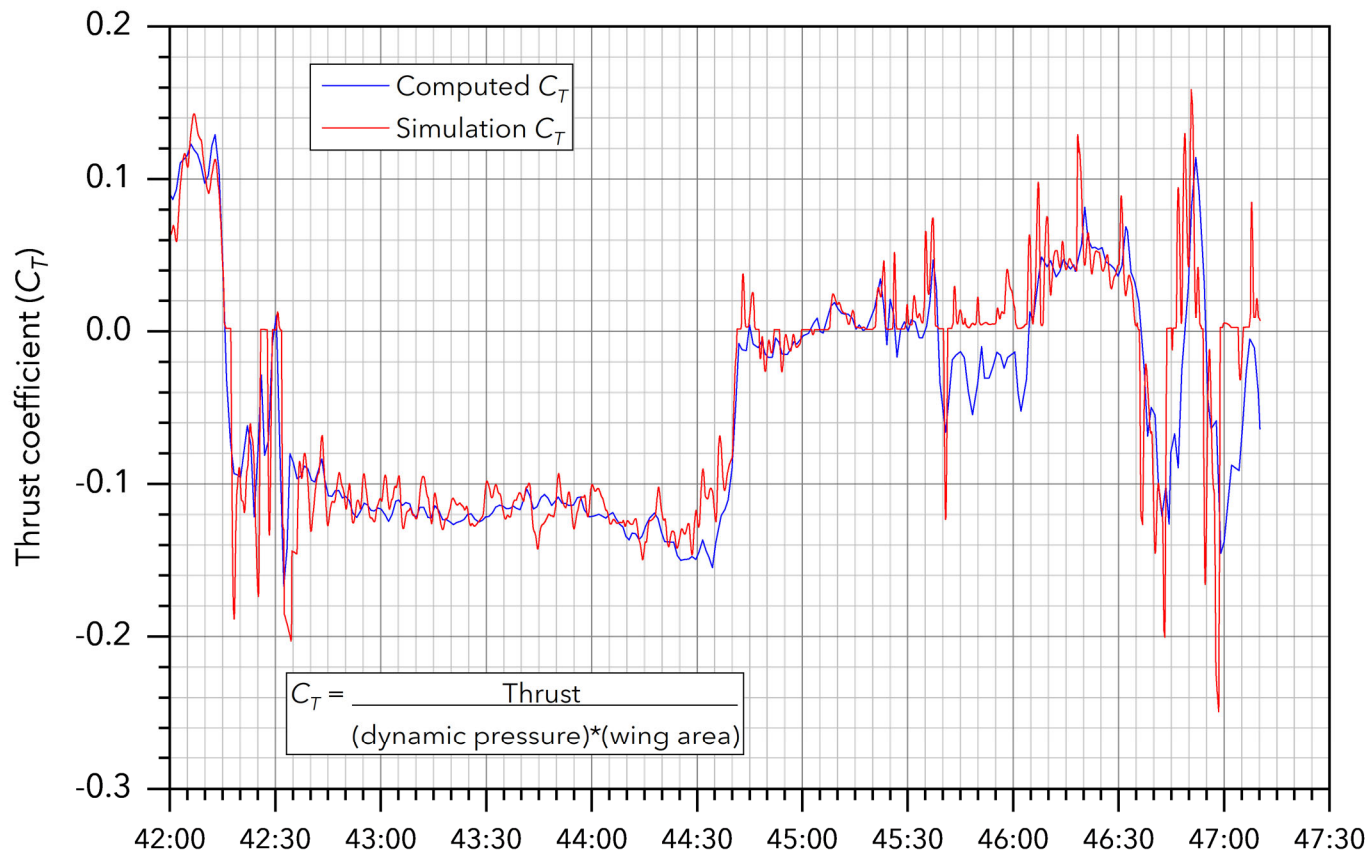
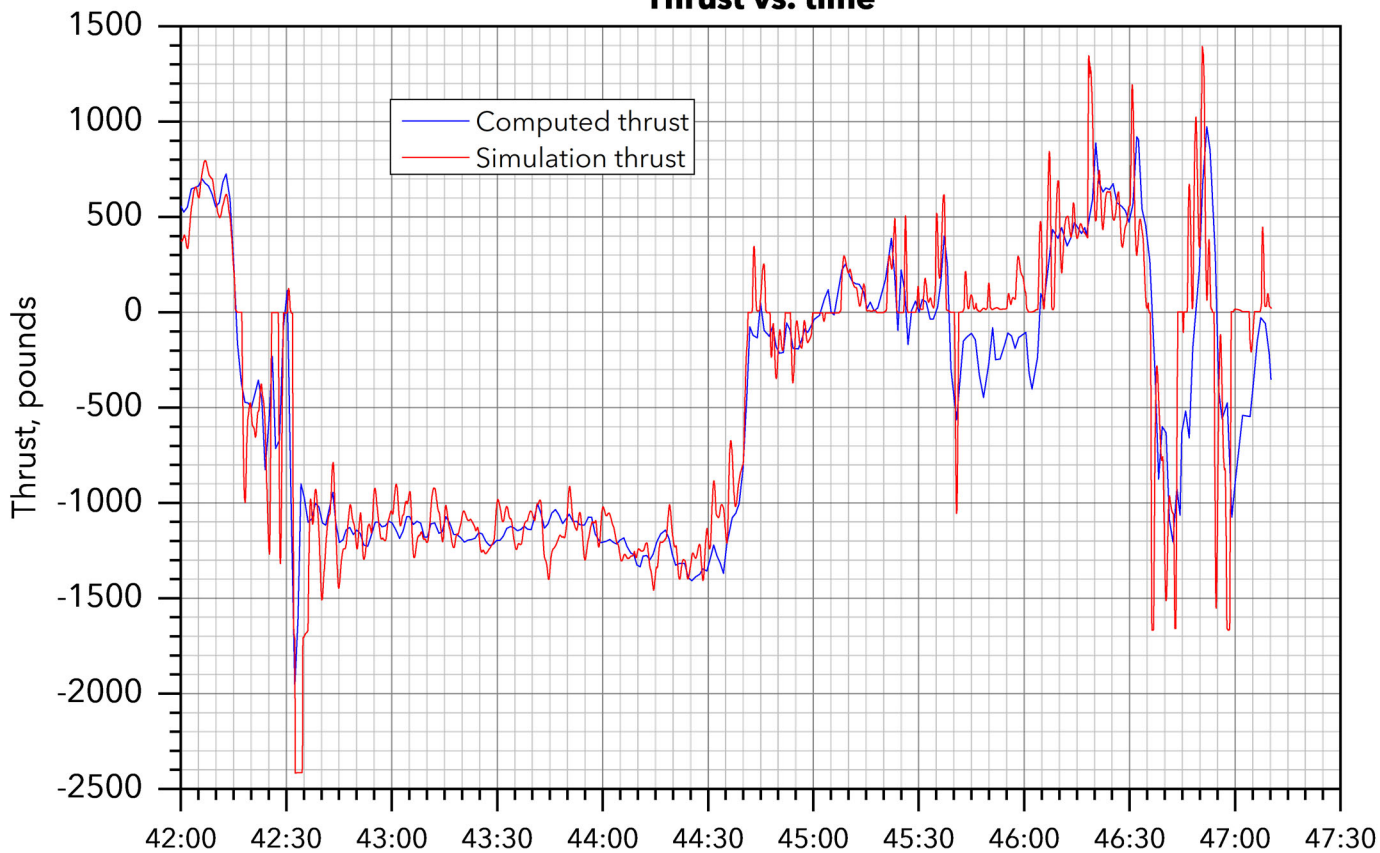
WPR22FA197: Cessna 208B Supervan 900, N7581F, Oceanside, CA, 06/03/2022

Load factors vs. time below 2000 ft. MSL



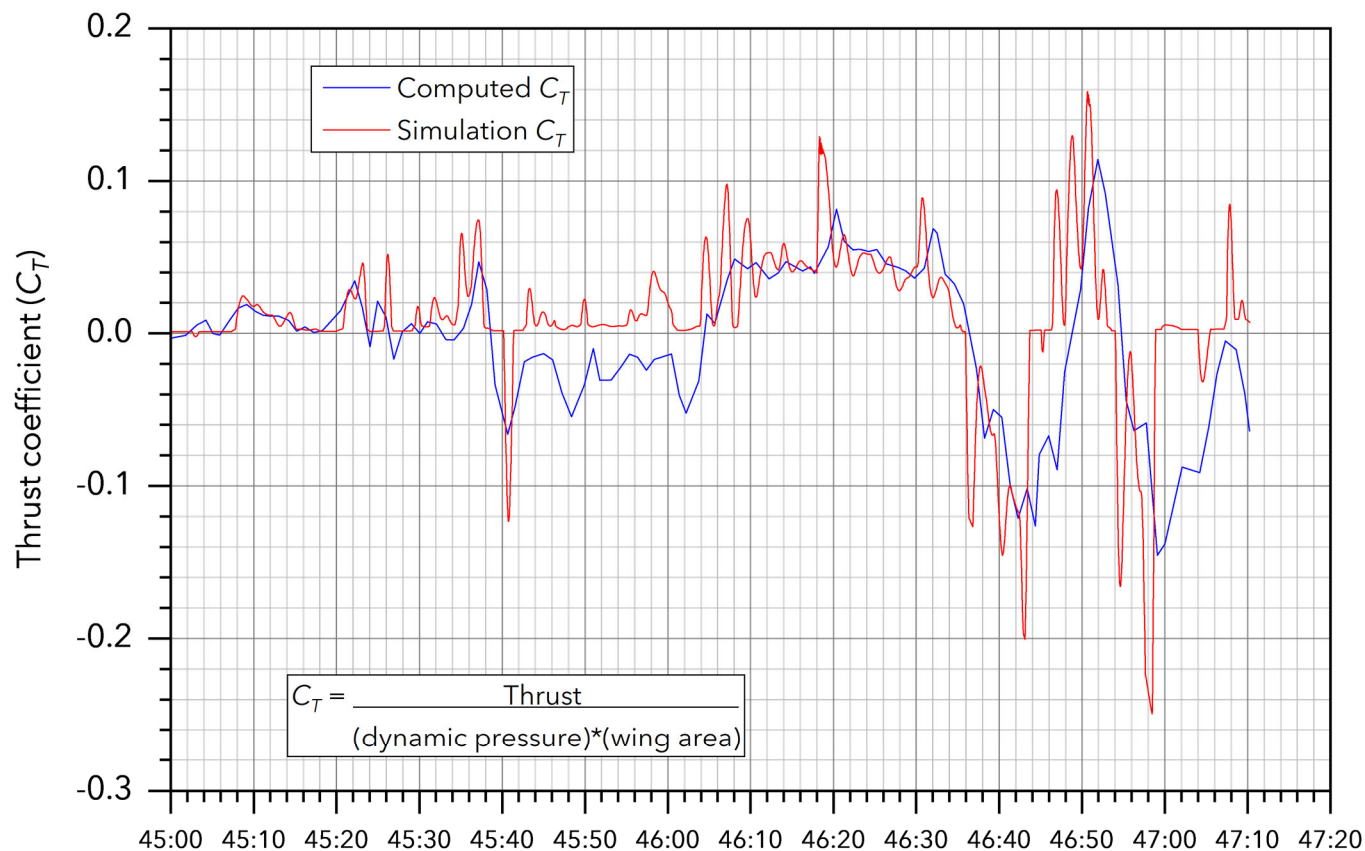
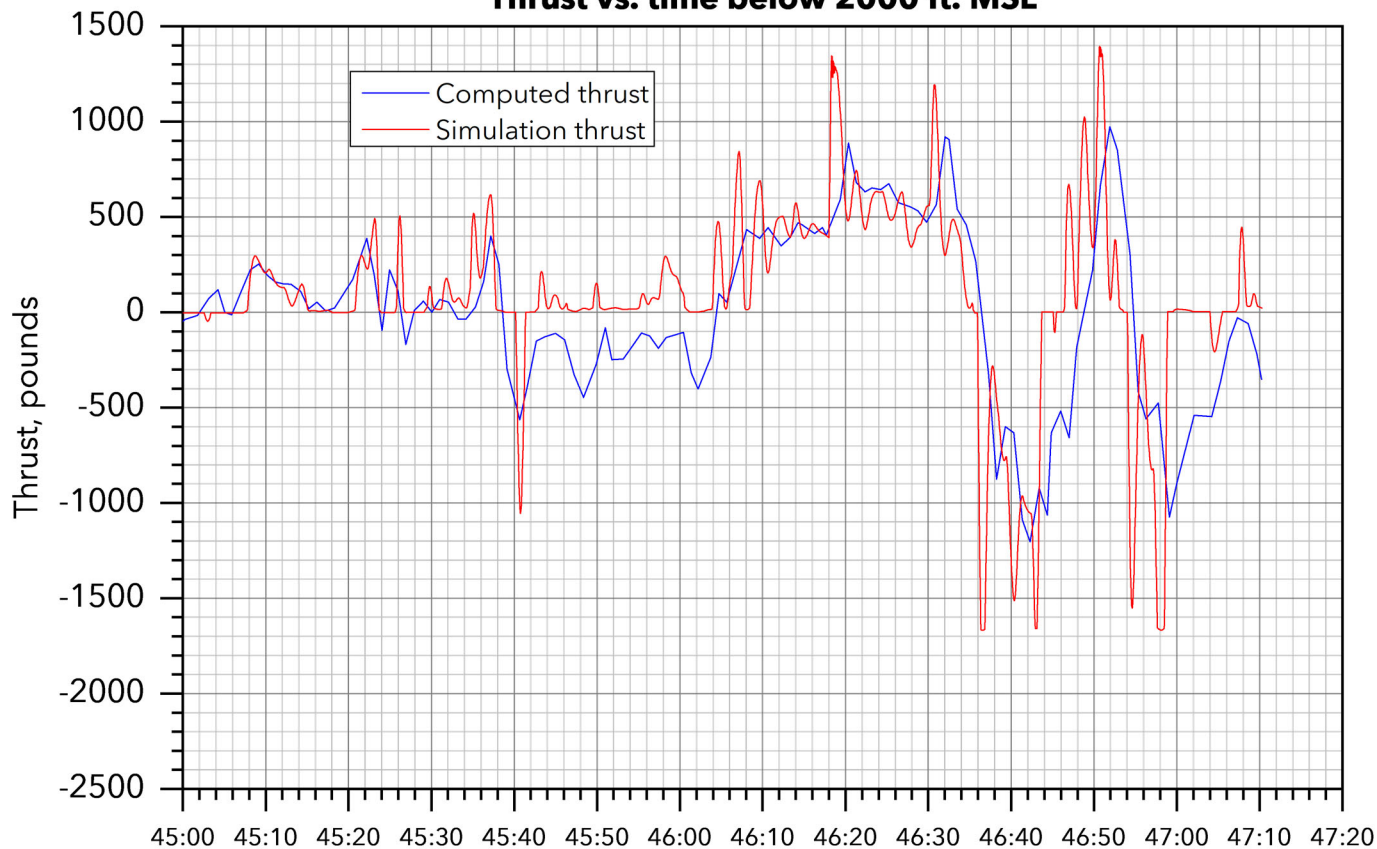
WPR22FA197: Cessna 208B Supervan 900, N7581F, Oceanside, CA, 06/03/2022

Thrust vs. time



WPR22FA197: Cessna 208B Supervan 900, N7581F, Oceanside, CA, 06/03/2022

Thrust vs. time below 2000 ft. MSL



Net thrust and thrust coefficient (C_T) computed from N7581F ADS-B data, compared to previous N7581F descents

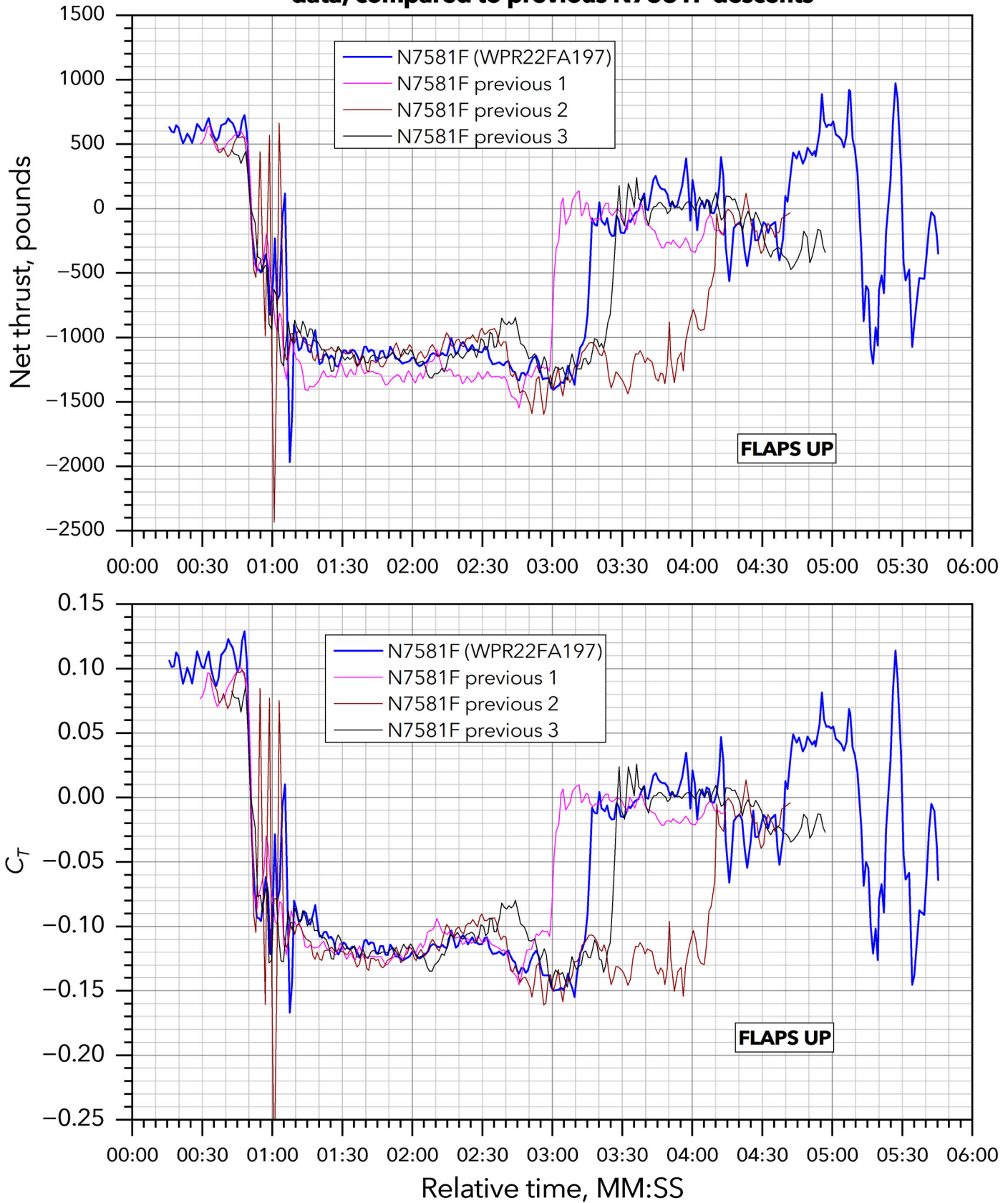


Figure 9.

Net thrust and thrust coefficient (C_T) computed from N7581F ADS-B data, compared to known descents in other airplanes

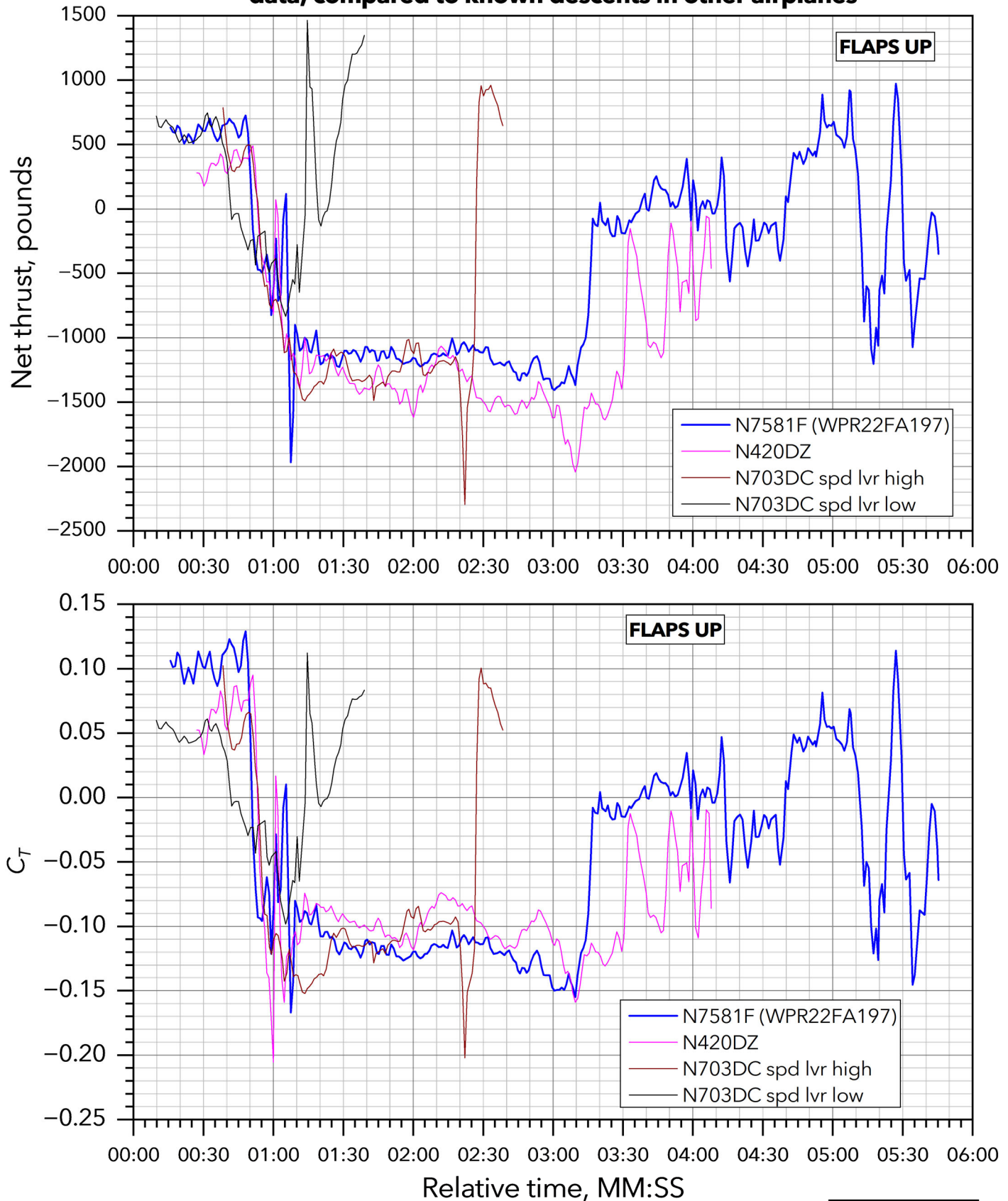


Figure 10.