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AIRCRAFT PERFORMANCE & SIMULATION STUDY

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A. ACCIDENT

Location: Urbana, Ohio
Date: August 20, 2021
Time: 14:40 Eastern Daylight Time (EDT)
18:40 Coordinated Universal Time (UTC)
Airplane: Daher TBM 700A, registration N700DT

B. AIRCRAFT PERFORMANCE GROUP

Chairman: John O'Callaghan
National Transportation Safety Board (NTSB), RE-60
Washington, D.C.

Members: N/A

C. SUMMARY

C.1. Introduction

On August 20, 2021, about 14:40 eastern daylight time, a Daher TBM 700A airplane, N700DT, was destroyed when it was involved in an accident near Urbana, Ohio. The pilot sustained fatal injuries. The airplane was operated as a Title 14 Code of Federal Regulations Part 91 personal flight.

Preliminary air traffic control information revealed the airplane was enroute from the Erie-Ottawa Airport (KPCW), Port Clinton, Ohio, to the Cincinnati Municipal Airport (KLUK), Cincinnati, Ohio. The airplane departed runway 9 at KPCW and climbed to flight level 200 before beginning to descend. The airplane was southbound, descending to 12,000 ft mean sea level (MSL), and established communications with the assigned terminal radar approach control controller. The controller cleared the pilot to descend to 10,000 ft msl and proceed direct to KLUK. While descending through 13,000 ft msl, the airplane entered a left turn. The controller observed the left turn and asked the pilot if everything was all right; there was no response from the pilot. Radar contact was subsequently lost with the airplane. The controller's further attempts to establish communications were unsuccessful.

A witness, located about 2 miles south of the accident location, stated that he observed the airplane at a high altitude in a nose-dive descent toward the terrain. He reported the airplane was not turning or spinning; it was headed straight down. The witness observed no signs of distress, such as smoke, fire, or parts coming off the airplane, and he stated the airplane's engine was at full throttle. The witness lost sight of the airplane as it descended behind some trees.

The accident site was located 1 nm northwest of the last radar contact. The accident site showed the airplane impacted trees, two powerlines, and the terrain in a left-wing low attitude. The initial ground scar, located in a residential yard, contained separated components of the left wing. The airplane crossed a highway, struck trees and a ditch, and then continued into mature potato and soybean fields. The airplane wreckage was scattered over a distance of about 2,050 ft along a magnetic heading of 275°.

C.2. Objective and scope of the *Aircraft Performance & Simulation Study*

The objective of this *Aircraft Performance & Simulation Study* is to determine and analyze the motion of the airplane and the physical forces that produce that motion. In particular, the *Study* attempts to define the airplane's position and orientation during the relevant portion of the flight, and determine the airplane's response to control inputs, external disturbances, and other factors that could affect its trajectory.

The data used to determine and analyze the airplane motion includes the following:

- Air Traffic Control (ATC) surveillance data (both radar and satellite-based).
- Data recorded on a Garmin GTN 750 Global Positioning System (GPS) device.
- Wreckage location and debris field evidence.
- Weather information.
- Airplane performance information in the Pilot's Operating Handbook (POH).
- Output from aircraft performance analysis programs and simulations.

The airplane was not equipped (and was not required to be equipped) with a Flight Data Recorder (FDR) or Cockpit Voice Recorder (CVR). Consequently, no measures of the control inputs or engine power during the flight are available. However, the airplane was equipped with a Garmin GTN 750 navigator that recorded many performance parameters of interest, including altitude, position, ground speed and airspeed, Euler angles (heading, pitch, and roll), and vertical and lateral load factors (longitudinal load factor was not recorded). The recovery of this information from the GTN 750 is described in the *Global Positioning System Devices Specialist's Factual Report* for this accident (Reference 1).

In this *Study*, The information listed above is used to define the trajectory of N700DT during its descent from 20,000 ft. MSL, and sudden left turn and dive as it descended through 13,000 ft. MSL. An NTSB simulation incorporating aerodynamic, flight controls, and engine models of the TBM 700 provided by SIMCOM is then used to find a set of simulator flight control and throttle inputs that result in a simulated trajectory that approximately matches the trajectory defined by the recorded data. The control forces required to achieve the resulting flight control inputs are also computed.

C.3. Summary of results

The GTN 750 data indicates that at about 14:38:20, as N700DT was descending through about 13,000 ft. MSL, the roll rate abruptly changed from zero to about -7° /sec. (rolling left wing down). The airplane continued rolling left at this rate until about 14:38:37, when the roll angle reached about -110° (left) and the roll rate momentarily dropped back to zero.¹ The roll angle then started to return towards wings-level, reaching -62° (left) at 14:38:49.7, when the return paused and the roll angle remained relatively constant, reading -63.6° when the GTN 750 data ends at 14:38:51.7. During the initial roll to the left, the pitch angle decreased from about -4.5° at 14:38:20 to -31.5° at 14:38:37, and continued to decrease even as the roll angle lessened, reaching -53° at 14:38:45 (when the roll angle was returning through -80° (left)). Thereafter the pitch angle started to increase, reaching -45° at 14:38:51.7 (the end of the data).

The GTN 750 data ends at an altitude of about 4,200 ft. MSL, or 3,200 ft. above the terrain elevation of about 1,000 ft. MSL. At the end of the data, the descent rate was about 30,000 ft./minute, but was apparently decreasing. The airplane was about 1 nm away from the impact site when the GTN 750 data ended, and simulations indicate that it would have taken about another 11 seconds to cover this distance. Consequently, the GTN 750 data ends about 11 seconds before impact. According to the NTSB GPS Devices Specialist for this accident, it is very common for data recorded in avionics devices to end before impact because of the buffering process used in writing the data to storage media; the data loss can range from a few seconds up to a minute.

A simulation of the TBM 700 was used to determine flight control and throttle inputs that result in an approximate "match" of the GTN 750 data. A "match" results when the differences between the trajectory (position, speed, and attitude) of the simulated airplane and the trajectory recorded in the GTN 750 data are smaller than desired tolerances. Unlike the tolerances defined in 14 Code of Federal Regulations (CFR) Part 60 for the qualification of pilot training simulators, the "desired tolerances" for this exercise are not precisely defined or rigorous. Uncertainties and errors associated with the simulation models, recorded data, winds, and airplane loading have to be considered, so that determining whether the simulation results are reasonably representative of the recorded data, and can provide insight into airplane performance parameters that are not recorded (or into other circumstances of the accident) is largely a matter of engineering judgement. In this *Study*, comprehensive plots comparing the simulator results with the recorded data are provided to facilitate such judgement.

¹ The angular rates cited here are the body-axis pitch, roll, and yaw rates; at large pitch and roll angles, these can be substantially different from the rates of change of the pitch, roll, and heading angles (see Equations [1] and 2] in Section D.7, and Figures 11, 12, 22, and 23).

Three different simulation scenarios are evaluated in this *Study*, titled “Controls,” “Imbalance,” and “Recovery.” The Controls and Imbalance scenarios simulate the initial roll and dive of N700DT up to the end of the GTN 750 data (from 14:38:06 to 14:38:52). The Recovery scenario continues the simulation past the end of the GTN 750 data and attempts to apply flight control inputs that make the airplane match an impact point and attitude consistent with evidence from the accident site.

The Controls scenario was performed using a symmetrical airplane loading (the center of gravity (CG) is on the airplane centerline). Based on the results, which showed very little yoke (column) and wheel force required during the initial roll and dive, the Imbalance and Recovery scenarios were performed assuming a 420 lb. fuel imbalance (left wing heavier). This imbalance results in a match of the initial roll when zero wheel force is applied, and simulates a situation in which the autopilot is holding wheel force against the fuel imbalance until 14:38:20.5, but then disconnects for some reason. (As discussed below, oscillations in the recorded normal load factor (*nlf*) near 14:38:20.5 might have been sufficient to cause an autopilot disconnect.) Assuming that the human pilot does not intervene, the wheel force after the autopilot disconnect remains zero.

Two different control strategies during the initial roll and dive are used in the three simulation scenarios. In the Controls scenario, a “math pilot” generates simulator flight control inputs to match either the pitch angle (or *nlf*, at large roll angles) and roll angle recorded on the GTN 750. In the Imbalance scenario, the math pilot operates in the same way as in the Controls scenario until 14:38:20.5, at which point it switches to generating flight control inputs that make the resulting flight control forces zero. In the Recovery scenario, the math pilot operates in the same way as in the Imbalance scenario until 14:38:37 (the start of the “recovery” recorded in GTN 750 data), and thereafter generates flight control inputs to approximately match the impact conditions, a scenario that requires the human pilot to apply force on the controls.

The initial conditions and trim and control strategies for the simulation scenarios are described with other details in Section D.6. The results of the simulations are presented in Figures 6-28 and discussed throughout this *Study*.

In this accident, an important but unknown factor is the behavior of the human pilot and his activity (or lack thereof) on the flight controls during the initial roll and dive. Notably, the pilot responded normally to an ATC communication at 14:36:42, only 98 seconds before the roll rate starts to increase at 14:38:20.5. However, it is hard to reconcile an alert and attentive pilot with the steady roll-off and descent that followed. Consequently, the finding (from simulation) that the initial part of the maneuver can be approximately duplicated with zero control forces (together with either an aerodynamic or loading asymmetry and a disengaged autopilot) is intriguing, and, considering the irregularity of the maneuver itself, suggests that the pilot might have been momentarily incapacitated or distracted between 14:38:21 and 14:38:37.

However, the large yoke and wheel forces that the Recovery simulation scenario indicates are necessary to duplicate the start of the roll recovery recorded in the GTN 750 data, and to maneuver the airplane to the impact point (arriving there at the heading and relatively shallow descent angle indicated by the wreckage evidence), suggest a human pilot active on the flight controls, at least after 14:38:37.

There is insufficient information available to discern whether or not a fuel asymmetry was in fact present, or whether the pilot was in fact incapacitated or distracted for at least part of the roll and dive maneuver. The simulations described in this *Study* only present some physical possibilities for achieving the trajectory recorded by the GTN 750 data, and the impact geometry indicated by the crash site evidence, that are consistent with the airplane's capabilities.

D. DETAILS OF THE INVESTIGATION

D.1. The Daher TBM-700A airplane

The Daher (formerly SOCATA) TBM 700A is a pressurized, single-engine turboprop light airplane seating up to six people, powered by a Pratt & Whitney Canada PT6A-64 free-turbine turboprop engine producing 700 SHP, with a maximum takeoff weight of 6,579 pounds.

Figure 1 shows a 3-view image of the airplane, taken from the Daher TBM 700 Pilot's Operating Handbook (POH), U.S. Version (Reference 2).

The airplane weight assumed in this *Study* is 5,600 pounds at a longitudinal CG location of 22.5% mean aerodynamic chord (MAC), based on loading information provided by the NTSB Investigator In Charge (IIC) (see Table 1). The fuel weight corresponds to the estimated amount of fuel on board at the time of the accident.

Item	Weight (lb.)	Arm (in.)	Moment (in.-lb.)
Empty	4314.01	184.9	797847
Pilot	140	180.5	25270
Baggage	25	303	7575
Fuel	1121	189.8	212766
Total	5600	186.3	1043457
CG, %MAC	22.5		

Table 1. Weight and balance buildup for N700DT at the time of the accident.

D.2. Wreckage location and condition

The initial impact point is recorded in the preliminary report of this accident (Reference 4) at the following coordinates:

40° 03' 59.270" N Latitude / 83° 46' 28.207" W Longitude / Elevation 1,005 ft. MSL

These coordinates were confirmed by comparing *Google Earth* imagery with the photograph of the accident site shown in Figure 2. The elevation was also determined using *Google Earth*. As noted above, after the initial impact the airplane crossed a highway, struck trees and a ditch, and then continued into mature potato and soybean fields. The airplane wreckage was scattered over a distance of about 2,050 ft. along a magnetic heading of 275°. The long debris field is consistent with impact at a high speed and a relatively shallow flight path angle; had the airplane impacted at a steep angle, the debris field would have been considerably shorter.

D.3. Automatic Dependent Surveillance - Broadcast (ADS-B) data

N700DT's Global Navigation Satellite System (GNSS)-based position throughout the accident flight is recorded in the GTN 750 data (up until about 11 seconds before impact). The airplane was also tracked by ATC, using both ground-based radar and the GNSS-based ADS-B system. Since the GNSS positions recorded in the GTN 750 and the ADS-B data are more accurate and frequent than radar data, only these sources are used to determine N700DT's position in this *Study* (though the ADS-B data is compared to data from the Dayton Airport Surveillance Radar (DAY ASR) in Figure 4). The ADS-B data is presented here as a confirmation of the positions recorded by the GTN 750, and to illustrate that the ADS-B data stream contains unexplained dropouts, and ceased entirely about 83 seconds before the end of the GTN 750 data. The reasons for these lapses are unknown.

ADS-B capability enables aircraft to broadcast their three-dimensional position (latitude, longitude, and altitude) to other ADS-B equipped aircraft and to ADS-B ground stations.² ADS-B data broadcast from N700DT was received and recorded by Federal Aviation Administration (FAA) ADS-B ground stations. For unknown reasons, the ADS-B data stream from N700DT ended at 14:37:28, when the airplane was descending through 14,100 ft. MSL, about 4.9 nm north of the accident site. In addition, gaps in the ADS-B stream occurred between 14:35:42 and 14:35:58, and between 14:31:06 and 14:32:58. Gaps of 14 to 16 seconds duration also occurred at 14:13:17, 14:17:01, 14:21:22, and 14:26:25 (that is, about every 4 to 5 minutes).

² For more information about ADS-B, see https://www.faa.gov/air_traffic/technology/adsb.

ADS-B latitude and longitude are determined using GNSS signals, including those from GPS satellites, and altitudes determined both barometrically and by GNSS are included in ADS-B messages. The GNSS positions are very accurate compared to radar data; radar range uncertainty alone (without even considering azimuth uncertainty) is about $\pm 1/16$ nm, or ± 380 ft., and GNSS positions are generally accurate to within 60 ft. (see Reference 3). Furthermore, ADS-B data are available at a higher frequency than radar data: typically at 1 sample/second for ADS-B, and at best, 1 sample every 4.5 seconds for radar. The uncertainties associated with the DAY ASR data, after correcting for a bias error from the ADS-B data, are plotted in Figure 4 as the "DAY ASR uncertainty boxes."

The recorded ADS-B data includes the following parameters:

- UTC time of the ADS-B report, in hours, minutes, and seconds. EDT = UTC - 4 hours.
- Aircraft identifying information.
- Latitude and longitude, to a resolution of 0.01 arc-seconds (≈ 1 ft.)
- Pressure altitude in feet, to the nearest 25 ft. (an uncertainty band of ± 12.5 ft.)
- Geometric (GNSS) altitude in feet, to the nearest 25 ft. The GNSS altitude is the height above the WGS84 ellipsoid, which differs from MSL altitude by the height of the geoid.³ At the accident site, 112 ft. should be added to GNSS altitude to give MSL altitude.⁴
- North-south and east-west components of ground speed, to a resolution of 1 kt.
- Rate of climb, to a resolution of 1 ft./min.
- Numerous parameters documenting the quality and accuracy of each reported GNSS position.

The ADS-B data is presented in Figures 3-5, and compared to the GNSS position data recorded on the GTN 750. In this *Study*, the position of the airplane is described by its east and north coordinates relative to a reference point about 0.19 nm north of the impact point (the reference was originally intended to be the impact point itself, but moved as a result of a subsequent correction to the latitude and longitude of the impact point). Latitude and longitude coordinates are transformed into east and north coordinates from the reference point using the WGS84 ellipsoid model of the earth, and the coordinates of the reference point:

40° 04' 09.858" N latitude / 83° 46' 23.5236" W longitude / elevation 1,050 ft. MSL

³ "The geoid ... is the shape that the ocean surface would take under the influence of the gravity of Earth, including gravitational attraction and Earth's rotation, if other influences such as winds and tides were absent." (Wikipedia.org, accessed 10/10/2022.)

⁴ Per <https://geographiclib.sourceforge.io/cgi-bin/GeoidEval>, the geoid at the accident site is about 34 m (112 ft.) below the surface of the WGS84 ellipsoid.

D.4. Garmin GTN 750 data

According to Reference 1,

The Garmin GTN 750 is a panel-mounted GPS receiver featuring an 800 x 600 pixel, 6.9 inch color liquid crystal (LCD) display. It has a GPS/SBAS engine and is TSO C146c certified for primary domestic, oceanic, and remote navigation including enroute, terminal, and non-precision approaches, and approaches with vertical guidance, such as LPV and [LNAV]/VNAV. The unit can simultaneously give aviators vital approach information and weather and traffic data in relation to their position on a large, color moving map display. Its color moving map features a built-in database that shows cities, highways, railroads, rivers, lakes, and coastlines. The unit has a slot on the front for a Jeppesen database containing all airports, VORs, NDBs, intersections, FSSs, approaches, DPs/STARs and SUA information. A flight plan composed of multiple waypoints, including user-defined waypoints, can be programmed in the unit. The GTN 750 also includes a TSO'd airborne VHF communications transceiver and TSO'd airborne VOR/Localizer and Glideslope receivers. The unit contains an internal SD card storing flight log data, which can be accessed through the slot in the right side of the unit.⁵

...

The downloaded data from Garmin GTN 750 ... contained 58 sessions, ranging from January 15, 2021, to August 20, 2021. The last session was identified as the event flight. The session was approximately 27 minutes and 21 seconds, recorded from 14:11:30 to 14:38:51 EDT on August 20, 2021. The data were recorded at a 1 second-per-sample rate.

Airplane performance parameters from the GTN 750 are used in this *Study* to set the simulation initial conditions, to provide trajectory and speed targets for the simulation math pilot, and to estimate winds aloft. The relevant parameters are presented in the various Figures discussed throughout the *Study*. GNSS time is recorded in the GTN 750 data, and is aligned with the GNSS time recorded in the ADS-B data.

D.5. Meteorological data

An NTSB meteorologist provided winds aloft data for area of the accident at 15:00 EDT based on a High-Resolution Rapid Refresh (HRRR) model sounding. These winds are compared to the winds recorded in the GTN 750 data in Figure 28. The winds used in the simulations are based on those recorded in the GTN 750 data.

The preliminary report for this accident (Reference 4) notes that visual meteorological conditions (VMC) prevailed at the time of the accident, with the lowest cloud condition

⁵ SBAS = satellite based augmentation system; TSO = technical service order; LPV = localizer performance with vertical guidance; LNAV/VNAV = lateral navigation / vertical navigation; VOR = very high frequency omnidirectional range; NDB = non-directional beacon; FSS = flight service station; DP = departure procedure; STAR = standard terminal arrival; SUA = special use airspace.

being scattered clouds at 4,000 ft. above ground level (AGL), visibility 10 statute miles, and an altimeter setting of 30.01 "Hg (conditions reported at 14:55 EDT from Grimes Field Airport, Urbana, Ohio (I74), located 2.5 nm from the accident site).

D.6. Simulations

As noted, simulations of N700DT's final left roll and dive were performed to generate control and throttle inputs that produce trajectories consistent with the GTN 750 data, the crash site location, and the capabilities of the airplane. The resulting control and throttle inputs can potentially provide additional insight into the circumstances of the accident, though it should be noted that other inputs, which produce similar but slightly different trajectories, could also be generally consistent with the recorded data.

Mathematical simulator models of the Daher TBM 700 aerodynamics, flight control system, and powerplant were provided to the NTSB by SIMCOM (a flight simulator manufacturer and pilot training provider),⁶ and incorporated into the NTSB's own MATLAB-based simulation engine. These models are the same as those underlying SIMCOM's TBM 700 Level 5 Flight Training Device (FTD). In keeping with the Level 5 qualification, the models used by the FTD are generic representations of a class of airplane, with the generic parameters underlying the models "tuned" to represent the TBM 700. However, there is no requirement to demonstrate that the resulting FTD performance matches flight test data. Higher FTD levels (6 and 7) use "airplane-specific" aerodynamic and other models that yield performance that must match flight-test data within specified tolerances.⁷

As described in Section C.3, three simulation scenarios are evaluated in this *Study*: the "Controls," "Imbalance," and "Recovery" scenarios. The fuel loading and control strategies for each scenario are summarized in Table 2. The initial conditions and initial trim strategies for each scenario are summarized in Tables 3 and 4, respectively. The math pilot strategies for each scenario and airplane axis are summarized in Table 5.

Scenario	Fuel loading	Control strategy
Controls	560 lb. in both tanks (Symmetric)	Math pilot generates flight control inputs to match pitch, roll, and approximate n_y recorded on GTN 750
Imbalance	770 lb. left tank 350 lb. right tank (420 lb. imbalance)	As in Controls scenario until 14:38:20.5, then math pilot generates flight control inputs that make the resulting yoke, wheel, and pedal forces zero
Recovery	770 lb. left tank 350 lb. right tank (420 lb. imbalance)	Same as Imbalance until 14:38:37. Thereafter, the math pilot applies yoke, wheel, and throttle as required to approximately match impact conditions.

Table 2. Simulation scenarios performed in this *Study*.

⁶ See www.simulator.com.

⁷ For more information about the differences between FTD levels, see Appendix B to 14 CFR Part 60.

Item	Value
Airplane gross weight	5,600 lb.
Flaps / gear	up / up
Time	14:38:06 EDT
Altitude	13,290 ft. MSL
North position relative to reference point	1.614 nm
East position relative to reference point	-0.354 nm
Airspeed	232 KCAS
Rate of climb	-1,578 ft./min.
Heading	184° true
Accelerations	All linear and angular accelerations set to 0

Table 3. Simulation initial conditions (all scenarios).

Body axis	Control used for trim		
	Controls scenario	Imbalance scenario	Recovery scenario
x: linear acceleration (fore/aft)	Throttle	Throttle	Throttle
y: linear acceleration (side to side)	Heading (alters β)	Heading (alters β)	Heading (alters β)
z: linear acceleration (up/down)	Pitch (alters α)	Pitch (alters α)	Pitch (alters α)
x: angular acceleration (roll)	Wheel	Wheel	Wheel
y: angular acceleration (pitch)	Yoke	Yoke	Yoke
z: angular acceleration (yaw)	Pedal	Pedal	Pedal
Yoke (column) force	Trim to 0 force with elevator tab at start of simulation	Not trimmed; elevator tab set for best match of pitch & altitude after column force = 0 at 14:38:20.5	Not trimmed; elevator tab set for best match of pitch & altitude after column force = 0 at 14:38:20.5
Wheel force	Not trimmed Aileron tab = 0°	Not trimmed Aileron tab = 1.04° ⁸	Not trimmed Aileron tab = 1.04°
Pedal force	Not trimmed Rudder tab = 0°	Trim to 0 force with rudder tab at start of simulation	Trim to 0 force with rudder tab at start of simulation

Table 4. Initial trim strategies for each simulation scenario. α = angle of attack; β = sideslip angle.

Additional explanation of the yoke (column), wheel, and pedal force trim strategies is in order. In the Controls scenario, only the column force is trimmed to zero (with elevator trim tab) at the start of the simulation; the wheel and pedal forces are not trimmed, and the aileron and rudder trim tabs are left at 0°. This results in some wheel and pedal force at the start of the simulation, as shown in Figure 15. The need for non-zero wheel input (and wheel force) to trim the roll acceleration arises from an inherent aerodynamic asymmetry in the aerodynamic model; the model contains a “baseline” rolling moment coefficient to the left, which at the simulation initial conditions must be countered with about 4° of right wheel.

⁸ This is the value of aileron trim tab that will trim the inherent roll asymmetry in the aerodynamic model with zero fuel imbalance (with non-zero wheel angle, but zero wheel force).

In the Imbalance and Recovery scenarios, the elevator trim tab is set to a value that results in the best match of pitch and altitude during the period after 14:38:20.5 when the yoke is driven so as to produce zero column force (simulating a stick-free condition). Note in Figures 15 and 26 that this results in about 2 lb. of yoke to trim pitch at the start of the simulations.

The aileron trim tab in the Imbalance and Recovery scenarios is set to 1.04° ; this is the value that will trim the inherent roll asymmetry in the aerodynamic model with zero wheel force (and with a symmetric fuel loading). This value was determined by assuming the following sequence of events:

- With the CG on the centerline (symmetric fuel loading), the trim is set to keep the wings level against the “baseline” rolling moment coefficient. This requires 1.04° of aileron trim tab (at the simulation initial conditions).
- The autopilot is turned on after the aileron trim is set.
- The airplane burns fuel out of the right wing tank only, allowing a fuel asymmetry to develop. Per the TBM 700 POH, the airplane burns about 385 lb. of fuel per hour in normal cruise at 20,000 ft.; at this rate, it would take 1.1 hours to burn 420 lb. from one tank (the usable fuel capacity of each tank is about 915 lb.)
- The autopilot applies increasing right wheel to counter the developing fuel asymmetry, and holds the resulting wheel force. Hence, over time, the autopilot holds increasing wheel force against the fuel asymmetry, but with the initial 1.04° of aileron trim tab present.
- At 14:38:20.5, the autopilot disconnects, but the human pilot doesn’t intervene. As a result, the control forces go to zero, and due to the fuel asymmetry, the airplane starts to roll left.

In the Imbalance and Recovery scenarios, the initial pedal force is trimmed to zero with rudder trim tab.

The results of the Imbalance scenario show that, with the control forces kept at zero, at about 14:38:37 the simulation diverges from the GTN 750 data, and does not duplicate the start of the recovery of the roll angle back towards the right recorded at that time. Consequently, in the Recovery scenario, at 14:38:37 the math pilot switches from targeting zero control forces to finding control inputs that match the GTN 750 data (until its end at 14:38:52), and that thereafter continue a trajectory that ultimately matches the impact conditions.

The Imbalance and Recovery scenarios assume that the autopilot is initially engaged and is holding wheel force to the right to counter a fuel asymmetry, but then suddenly disengages at 14:38:20.5, releasing the wheel and initiating the roll to the left. It is

reasonable to wonder what might cause such a sudden autopilot disconnect. One possibility is suggested by the normal load factor (*nlf*) increase recorded by the GTN 750 at 14:38:19.5, just before the start of the left roll.

According to Daher, the autopilot will disconnect when the *nlf* falls outside a range of 0.3 to 1.6 G. In notes summarizing a teleconference with the NTSB and the Bureau d'Enquêtes et d'Analyses (BEA) of France during the investigation, Daher wrote:

The [older model autopilot installed on N700DT] was more sensitive to turbulence. The vertical acceleration range that allows A/P operation is 0.3G-1.6G (within this range, the A/P keeps on working, above and below it will disconnect). By experience the [newer model autopilot not installed on N700DT] is less sensitive to G. Some spikes of vertical acceleration are recorded [in the accident GTN 750 data] from 14:38:19, when *Nz* [normal load factor] increased to 1.41G. Then roll started to increase to the left. The group discussed ... the potential disengagement of the A/P at that time due to turbulence, and the possible roll departure following that. The A/P has its own gyro sensors, it is not using the Garmin accelerations, so the recorded parameters available do not allow to be fully representative of the A/P condition.

Figure 13 shows the increase in the GTN 750 *nlf* to 1.4 G's just after 13:38:19, and a drop in lateral load factor (*n_y*) to -0.06 G's at about the same time. The sample rate of this data is 1 Hz, and so it is possible that the *nlf* could have deviated above 1.6 G's briefly without being recorded. The disturbances in *nlf* do not appear to be associated with changes in the pitch angle, and so might instead be the result of changes in angle of attack (α) due to localized vertical wind gusts (that is, turbulence). These observations make the scenario of an inadvertent autopilot disconnect resulting from a turbulence encounter more plausible.

While it is not certain that the autopilot was on preceding the *nlf* increase at 14:38:19.5, the roll behavior recorded in the GTN 750 during the descent from 21,000 ft. suggests that it was. In the turns that started at 14:32:17, 14:33:39, and 14:36:53, the sustained roll angles (ϕ) recorded by the GTN 750 are about 25°, and the roll rates (*P*) entering and exiting the turns peak at about 4.6°/sec., consistent with the autopilot authority limits of 25° and 5°/sec., respectively.⁹ Further, the descent rate from 21,000 ft. is relatively constant at about -1,600 ft./min., varying between 1,500 and 1,700 ft./min. with oscillations between -1,150 and -1,850 ft./min. during turns. Though this descent rate performance could also be consistent with hand-flying the airplane, the recorded roll behavior (that corresponds so well with the autopilot roll authority limits) suggests that the autopilot was indeed on. Engaging the autopilot would also be consistent with normal operations in this flight phase.

⁹ These are the autopilot roll authority limits cited in Daher's notes on the teleconference with the NTSB.

D.7. Simulation results

The results of the Controls and Imbalance scenarios are presented in Figures 6-16. The results of the Recovery scenario are presented in Figures 17-27. In both sets of Figures, simulation parameters are compared with the corresponding GTN 750 parameters, as discussed below.

Figure 3 presents a plan view of the last 7 minutes of flight over a map background, depicting N700DT's descent from 21,000 ft. MSL to the accident site, as recorded by the GTN 750 data.

Figure 4 presents a plan view of the last 2 minutes of flight over a grid background. In addition, the GTN 750 positions are compared to the DAY ASR returns, after the latter are shifted to best match the ADS-B data (the required shift is evidence of a bias error between the radar and ADS-B data); the radar data are shifted about 490 ft. south and 123 ft. east.

Figure 4 also depicts the location from which the last ATC transmission from N700DT was broadcast (between 14:36:42 and 14:36:46, as the airplane was descending through 15,300 ft. MSL about 8 nm north of the accident site). The context of this transmission, as transcribed from the recorded ATC audio by the author, is as follows:

Time (EDT)	Transmission source	Transmission content
14:35:36	N700DT	And Columbus Approach, good afternoon 700DT with you descending 11,000.
14:35:41	MR	TBM 700DT Columbus Approach good afternoon sir the Dayton altimeter is 30.00 descend and maintain 10,000
14:35:48	N700DT	Down to 10,000 700DT
14:36:18	MR	And TBM 700DT at 10,000 ft. you're clear direct Lunken, however a disclaimer - I might have to vector you around some parachute jump zones
14:36:29	N700DT	OK 700DT understand direct Lunken, but there's a disclaimer
14:36:33	MR	At 10,000 ft., yes sir, clear direct Lunken but there's a couple of parachute jump zones up near Midtown airport and Waynesville airport if you're familiar - I'll have vector you around those if - once you're direct
14:36:42	N700DT	OK, direct Lunken at 10,000 ft. and then we'll listen to you thanks November Delt Tango
14:36:46	MR	Thank you

Table 5. Radio communications between the Middletown Radar (MR) sector of Columbus ATC tower (CMH) and N700DT, as transcribed from recorded ATC audio.

Figure 5 plots the altitude of N700DT vs. time during the last 7 minutes of flight, depicting its descent from 21,000 ft. MSL and sudden dive starting at about 14:38:25. The pressure altitude recorded in the GTN 750 data matches the “Mode C” pressure altitude included in the DAY ASR returns within their ± 50 ft. uncertainty band. As shown, the difference between the GNSS-based geometric altitude above sea level and the pressure altitude increases with altitude. The approximately 1,000 ft. MSL elevation of the terrain underneath the airplane is also depicted, as determined from Shuttle Radar Topography Mission (SRTM) elevation data provided by the United States Geological Survey (USGS).¹⁰

Figures 6a and 6b depict enlarged plan views of N700DT’s final turn and dive over map and grid backgrounds, respectively, including the results of both the Controls and Imbalance simulation scenarios. Figures 17a and 17b are similar plots that include the results of the Recovery scenario. Note that the Controls scenario matches the recorded GTN 750 best, as the math pilot is targeting that data throughout the simulation, whereas in the Imbalance and Recovery scenarios the math pilot is targeting zero control forces during much of the simulation. Nonetheless, the Recovery scenario shows that the GTN 750 data can be matched fairly well with zero control forces up until the start of the roll recovery, and that the impact location and heading can be matched relatively well using customized control inputs thereafter.

Figure 7 shows altitude vs. time during the last minute of flight (which covers the left turn and final dive), together with the Controls and Imbalance simulation scenario matches. The equivalent Figure for the Recovery scenario is Figure 18. The simulations are set up to match the GTN 750 geometric altitude.

Figure 8 shows the north and east coordinates from the reference point vs. time during the last minute, together with the Controls and Imbalance scenario matches. The equivalent Figure for the Recovery scenario is Figure 19.

Figure 9 shows the ground speed, true airspeed, calibrated airspeed, and rate of climb during the last minute, together with the Controls and Imbalance scenario matches. The equivalent Figure for the Recovery scenario is Figure 20. Note that the Controls scenario matches the GTN 750 airspeeds fairly well, but does not match the ground speed as well. This suggests an error in the wind modeling at the points in question; for example, a greater tailwind after 14:38:30 would improve the ground speed match in this scenario.

The Imbalance and Recovery scenarios match the GTN 750 ground speed better than the GTN 750 airspeed. The different airspeed behavior between the Controls scenario and the Imbalance and Recovery scenarios is the result of different assumptions for

¹⁰ See <http://viewer.nationalmap.gov/viewer/>.

engine power; in the Controls scenario, the power is pulled back early in the dive, whereas in the other scenarios it is not pulled back until the start of the roll recovery (consistent with the assumption of no pilot activity on the controls until this point). Clearly, the Controls scenario matches the GTN 750 airspeed better than the other scenarios, suggesting that the power might indeed have been reduced early in the dive.

Figure 10 presents several longitudinal and lateral / directional flight angles for the last minute of flight, together with the Controls and Imbalance scenario matches. The equivalent Figure for the Recovery scenario is Figure 21. The top plots of the Figures present pitch angle (θ) and flight path angle (γ), the middle plots present roll angle (ϕ) and sideslip angle (β), and the bottom plots present true heading (ψ).

Note in Figure 10 that the math pilot in the Controls scenario manages to match the GTN 750 roll angle well throughout the simulation. The Imbalance scenario, in which the math pilot is targeting zero wheel force, matches the roll to the left up to about -100° well, but does not capture the roll recovery that starts at about -110° and instead continues rolling left, indicating that it is likely that in the actual accident wheel force was applied at this point in order to arrest the roll towards the left.

As shown in Figure 21, the roll recovery is captured in the Recovery scenario as the math pilot switches (at 14:38:37) from targeting zero wheel force to once again targeting roll angle. After the GTN 750 data ends at 14:38:52, the math pilot targets a roll angle that is constructed manually (by trial and error) so as to fly the airplane to the impact point, arriving there on the correct heading and in a shallow, slightly left-wing down dive (consistent with the evidence at the site). In order to accomplish this, the “hesitation” in the roll angle recovery at -60° observed at the end of the GTN 750 data is held for about 10 seconds, from 14:38:49 to 14:38:59, and then the roll is abruptly ramped to about -13° at 14:39:02, the time of impact in the simulation. The pitch angle continues to recover throughout, and is approximately 0° at impact, consistent with the very long debris path.

Figure 11 presents the body-axis angular rates (i.e., the components of the angular velocity vector along the airplane’s longitudinal (x), lateral (y), and vertical (z) axes) during the last minute of flight, together with the Controls and Imbalance scenario matches. Figure 12 presents the corresponding rates of change of the Euler angles. The equivalent Figures for the Recovery scenario are Figures 22 and 23.

The body-axis angular rates are related to the rates of change of the Euler angles as follows:

$$\begin{Bmatrix} P \\ Q \\ R \end{Bmatrix} = \begin{bmatrix} -\sin \theta & 0 & 1 \\ \sin \phi \cos \theta & \cos \phi & 0 \\ \cos \phi \cos \theta & -\sin \phi & 0 \end{bmatrix} \begin{Bmatrix} \dot{\psi} \\ \dot{\theta} \\ \dot{\phi} \end{Bmatrix} \quad [1]$$

where P , Q , and R are the body-axis roll, pitch, and yaw rates, respectively, and ψ , θ , and ϕ are the heading, pitch, and roll angles, respectively. The inverse of Equation [1] is

$$\begin{Bmatrix} \dot{\psi} \\ \dot{\theta} \\ \dot{\phi} \end{Bmatrix} = \begin{bmatrix} 0 & \sin \phi / \cos \theta & \cos \phi / \cos \theta \\ 0 & \cos \phi & -\sin \phi \\ 1 & \tan \theta \sin \phi & \tan \theta \cos \phi \end{bmatrix} \begin{Bmatrix} P \\ Q \\ R \end{Bmatrix} \quad [2]$$

Note that when $\phi = 0$, $Q = \dot{\theta}$, and when $\theta = 0$, $P = \dot{\phi}$, but in general the body-axis pitch and roll rates are not simply equivalent to the rates of change of the pitch and roll angles. This is apparent in Figures 11, 12, 22, and 23, which show that between 14:38:20 and 14:38:45 $\dot{\theta} < 0$ while $Q > 0$, and that between 14:38:38 and 14:38:51 $\dot{\phi} > 0$ while $P < 0$.

Figure 13 presents the body-axis load factors during the last minute of flight, together with the Controls and Imbalance scenario matches. The equivalent Figure for the Recovery scenario is Figure 24. After 14:38:29 in the Controls scenario and after 14:38:37 in the Recovery scenario, the math pilot manipulation of the yoke (column) switches from targeting pitch angle (in the Controls scenario) or zero column force (in the Recovery scenario) to targeting nlf . (At high roll angles, changing the body-axis pitch rate (Q) by action on the column has a reduced effect on the change of pitch angle; see Equation [2].) Note that the nlf oscillations in the GTN 750 data between 14:38:18 and 14:38:26 are not duplicated in the Controls scenario, even though the pitch angle is matched relatively well; as discussed above, this could be evidence of real-world turbulence that is not modeled in the simulation.

In all scenarios, except in the Imbalance scenario after 14:38:20.5 and in the Recovery scenario between 14:38:20.5 and 14:38:37 (when the math pilot targets zero pedal force), the math pilot uses pedal to approximately match the average lateral load factor (n_y) in the GTN 750 data. The abrupt changes in the simulation longitudinal load factor (n_x) in Figures 13 and 24 result from abrupt throttle changes (see Figures 16 and 27).

The simulation flight control inputs and associated flight control surface deflections used in the Controls and Imbalance scenarios are plotted in Figure 14. The equivalent Figure for the Recovery scenario is Figure 25. The control forces corresponding to these inputs are plotted in Figure 15 for the Controls and Imbalance scenarios, and in Figure 26 for the Recovery scenario.

As noted above, the Controls scenario assumes a symmetric fuel loading, but does not use aileron trim to trim out the baseline roll asymmetry in the aerodynamic model; consequently, it takes about 4° of right wheel and about 3.5 lb. of wheel force to trim wings-level at the start of the simulation. However, the wheel force then needed to match the roll during the initial roll and dive is very small (less than 1 lb.) This observation raises the possibility that the baseline roll asymmetry - by itself - might be

sufficient to roll the airplane as recorded (assuming a symmetric fuel load, zero aileron trim, and zero wheel force). However, simulations of such a scenario generate a roll significantly lower than that recorded in the GTN 750 data, indicating that, with zero wheel force applied, additional rolling moment – such as from a fuel asymmetry – is required to match the recorded roll rate. This reasoning leads to the Imbalance simulation scenario.

In the Imbalance scenario, the baseline roll asymmetry is trimmed out with 1.04° of aileron trim tab, and a fuel imbalance of 420 lb. is required to match the roll rate recorded in the GTN 750 data, assuming zero wheel force. If the aileron trim were kept at 0°, the baseline roll asymmetry would contribute to the left rolling moment, and a smaller fuel imbalance would match the recorded roll rate.

In the Recovery scenario, Figure 26 indicates that after 14:38:37, about 8 lb. of right wheel force is required to arrest the left roll rate, roll the airplane back to -60°, and maintain that roll angle until about 14:38:54. During this time, the airplane pitch is also recovering after having reached -53° at 14:38:45. After 14:38:54 the wheel force starts to increase, and does so abruptly at 14:38:58, reaching 47 lb. at 14:39:01 as the airplane rolls hard right so as to be at only about -13° roll angle at impact. In the meantime, the yoke (column) force also increases substantially, both to pull the airplane around to the required westerly impact heading, and to reduce the pitch angle to approximately 0° to be consistent with the shallow descent angle at impact evidenced by the long debris field (the *nlf* peaks at 5 G in this scenario; see Figure 24). These large wheel and column forces suggest that in this scenario the human pilot is required to be active on the flight controls, at least after 14:38:37. (If the “Controls” scenario were to be continued beyond the end of the GTN 750 data, similar control inputs and forces would be required to match the impact conditions.)

The thrust and power applied to the airframe in the Controls and Imbalance scenarios are plotted in Figure 16. The equivalent Figure for the Recovery scenario is Figure 27. The thrust is output from the simulation engine model, and the horsepower is then computed by multiplying the thrust by the true airspeed. The simulation thrust is controlled by making throttle adjustments in the engine model, but because in the model increases in engine power beyond a certain point do not result in a significant increase in thrust, it is less useful to use the engine power computed by the model, or the throttle position, as a measure of the thrust and power actually delivered to the airframe. As noted above, throughout the Controls scenario the throttle is adjusted to approximately match the position and airspeed recorded in the GTN 750 data. In the Imbalance and Recovery scenarios, the throttle is not adjusted during the time that the math pilot is targeting zero control forces, in order to be consistent with the assumption of an inactive human pilot during this time. In the Recovery scenario, the throttle is reduced to idle after 14:38:37, consistent with the proper action to recover from a dive.

E. CONCLUSIONS

The material in this *Study* supports a number of observations regarding the performance of N700DT during its descent from 21,000 ft. MSL, sudden left roll starting at about 14:38:20 as it descended through 13,000 ft., and final dive and impact with terrain. Several performance parameters for the accident flight were recorded by the installed Garmin GTN 750 GPS device up until the data ends about 3,200 ft. above the terrain, an estimated 11 seconds before impact.

N700DT began its descent from 21,000 ft. at about 14:33:00, while flying at 183 KCAS (256 KTAS) about 25 nm north and 7 nm east of the accident site. The descent rate was relatively constant at about -1,600 ft./min., varying between 1,500 and 1,700 ft./min., with oscillations between -1,150 and -1,850 ft./min. during turns. During the descent, the airspeed increased to 220 KCAS at 14:35:00, and then at 14:35:40 increased further, reaching 235 KCAS (285 KTAS and 295 knots ground speed) at 14:38:20 and 13,000 ft. MSL, just before the start of the left roll and final dive. Turns during the descent were consistent with the autopilot roll authority limits of 25° roll angle and 5°/sec. roll rate.

The position data recorded by the GTN 750 is consistent with recorded ADS-B and ASR data for N700DT. For unexplained reasons, there are periodic 14 to 16 second gaps in the ADS-B data every 4 to 5 minutes during the flight, and the ADS-B data stops entirely at 14:37:28, about 83 seconds before the end of the GTN 750 data, as the airplane was descending through 14,100 ft. MSL, about 4.9 nm north of the accident site. The reasons for these lapses in the ADS-B data are unknown.

At 14:36:42, 98 seconds before the start of the final roll and dive, as N700DT was descending through 15,300 ft. MSL about 8 nm north of the accident site, the pilot made a final radio transmission to ATC. The content of this communication was appropriate and unremarkable.

At 14:38:20.5, N700DT started rolling left at about -7°/sec. (faster than the autopilot authority). The airplane continued rolling left at this rate until the roll angle reached about -110°, when the roll rate momentarily dropped back to zero. The roll angle then started to return towards wings-level, reaching -62° (left) at 14:38:49.7, and then remained relatively constant until the end of the GTN 750 data at 14:38:51.7. During the roll maneuver, the pitch angle decreased from about -4.5° at 14:38:20 to -31.5° at 14:38:37, and continued to decrease even as the roll angle lessened, reaching -53° as the roll angle was returning through -80° (left). Thereafter the pitch angle started to increase, reaching -45° at the end of the data.

The "Recovery" simulation scenario provides an estimate of performance parameters beyond the end of the GTN 750 data, that are consistent with the final recorded data

points and with the airplane heading, bank angle, and flight path angle evidenced by the impact point and long debris path. This scenario indicates that substantial wheel and column forces are required to maneuver the airplane from the state indicated by the end of the GTN 750 data to the impact point, under the required impact conditions.

The "Recovery" scenario also indicates that the initial part of the maneuver can be approximately duplicated with zero control forces applied, together with either an aerodynamic or loading asymmetry and a disengaged autopilot, though the "Controls" scenario indicates that a better match of airspeed is obtained by partially reducing the power after the start of the roll maneuver. Nonetheless, the low control forces required and the irregularity of the maneuver itself suggest that the pilot might have been momentarily incapacitated or distracted between 14:38:21 and 14:38:37. However, as just noted, the simulations also indicate that the pilot would have had to apply substantial wheel and column forces after 14:38:37 in order to maneuver the airplane to the accident site.

A turbulence encounter that produces an *nlf* of more than 1.6 Gs can disengage the autopilot. The GTN 750 data indicates that such an encounter might have occurred prior to the start of the left roll at 14:38:20.5. If the autopilot were holding wheel force against a 420 lb. fuel imbalance at the time it disconnected, a roll rate matching that recorded in the data would develop, unless the human pilot intervened by applying force on the control wheel. A 420 lb. fuel imbalance could result from burning fuel from only one tank for about 1.1 hours in cruise flight.

There is insufficient information available to discern whether or not a fuel imbalance was in fact present, or whether the pilot was in fact incapacitated or distracted for at least part of the roll and dive maneuver. The simulations described in this *Study* only present some physical possibilities for achieving the trajectory recorded by the GTN 750 data, and the impact geometry indicated by the crash site evidence, that are consistent with the airplane's capabilities.

Submitted by:

John O'Callaghan
National Resource Specialist – Aircraft Performance

F. REFERENCES

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4. National Transportation Safety Board, Office of Aviation Safety, *Preliminary Report: TBM 700A, N700DT, Urbana, Ohio, August 20, 2021, NTSB accident #CEN21FA376*.

G. GLOSSARY

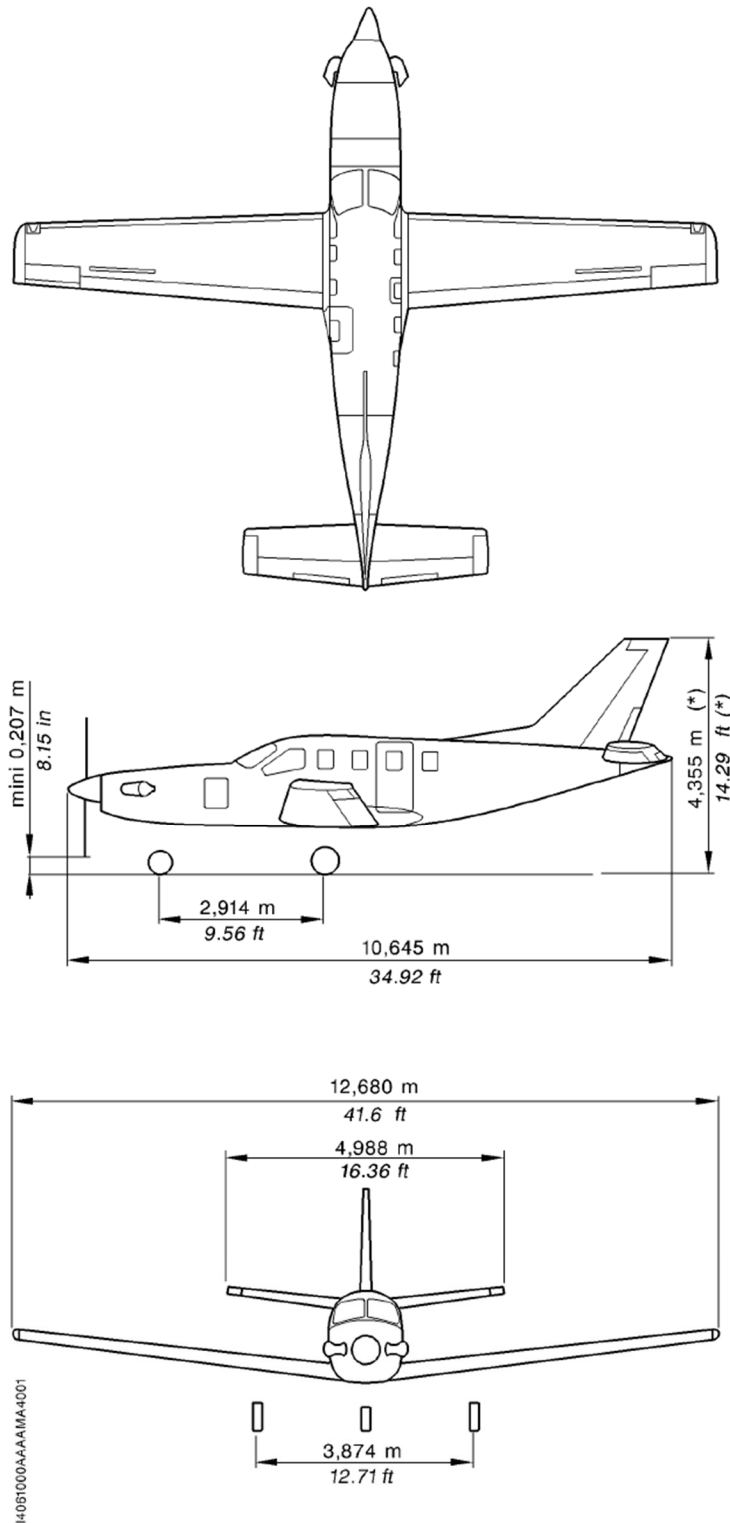
Acronyms

ADS-B	Automatic Dependent Surveillance – Broadcast
AFM	Airplane Flight Manual
AGL	Above ground level
ASR	Airport Surveillance Radar
ATC	Air Traffic Control
CFR	Code of Federal Regulations
CG	Center of Gravity
CVR	Cockpit Voice Recorder
DAY	Dayton Airport Surveillance Radar
EDT	Eastern Daylight Time
FAA	Federal Aviation Administration
FDR	Flight Data Recorder
FTD	Flight Training Device
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
"Hg	Inches of mercury
IIC	NTSB Investigator In Charge
KLUK	Cincinnati Municipal Airport, Cincinnati, Ohio
KCAS	Knots calibrated airspeed
KIAS	Knots indicated airspeed
KPCW	Erie-Ottawa Airport, Port Clinton, Ohio
KTAS	Knots true airspeed
MSL	Mean Sea Level
NTSB	National Transportation Safety Board
POH	Pilot's Operating Handbook
UTC	Universal Coordinated Time

Symbols

α	Angle of attack
β	Sideslip angle
γ	Flight path angle
θ	Pitch angle
ϕ	Roll angle
ψ	Heading angle
n_{lf}	Normal load factor
n_y	Longitudinal load factor
n_y	Lateral load factor
P	Body-axis roll rate (angular velocity about the x axis)
Q	Body-axis pitch rate (angular velocity about the y axis)
R	Body-axis yaw rate (angular velocity about the z axis)

FIGURES



* Airplane on line of flight with extended FWD shock-absorber

Figure 1.2.1 (1 / 2) - THREE VIEW DRAWING - **TBM700A**

Figure 1. 3-view of the Daher TBM 700A airplane (from Reference 2).

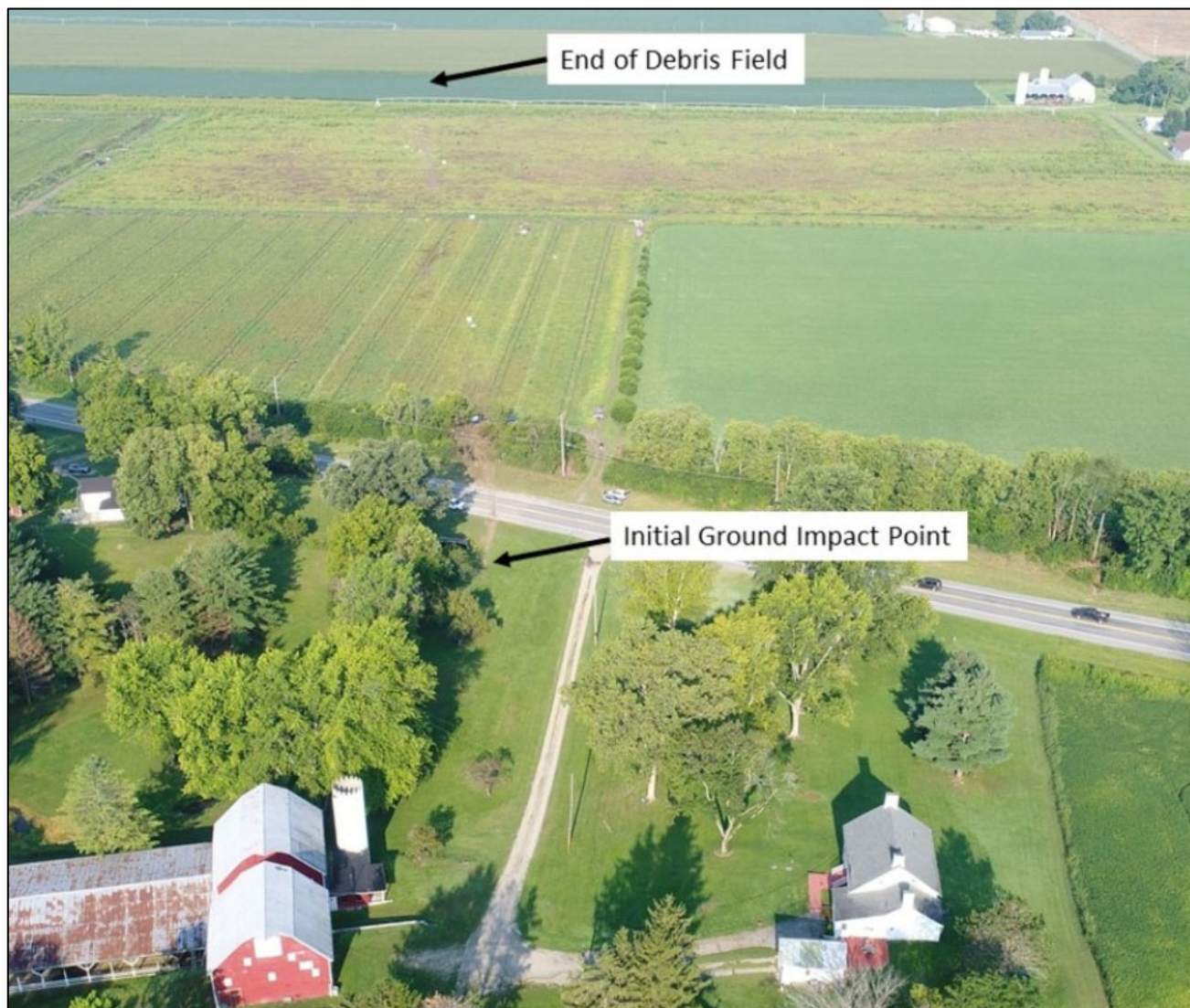


Figure 2. Aerial photograph of the impact point and debris field, from Reference 4.

CEN21FA376: Socata TBM-700, N700DT, Urbana, OH, 08/20/2021

Plan view of last 7 minutes of flight

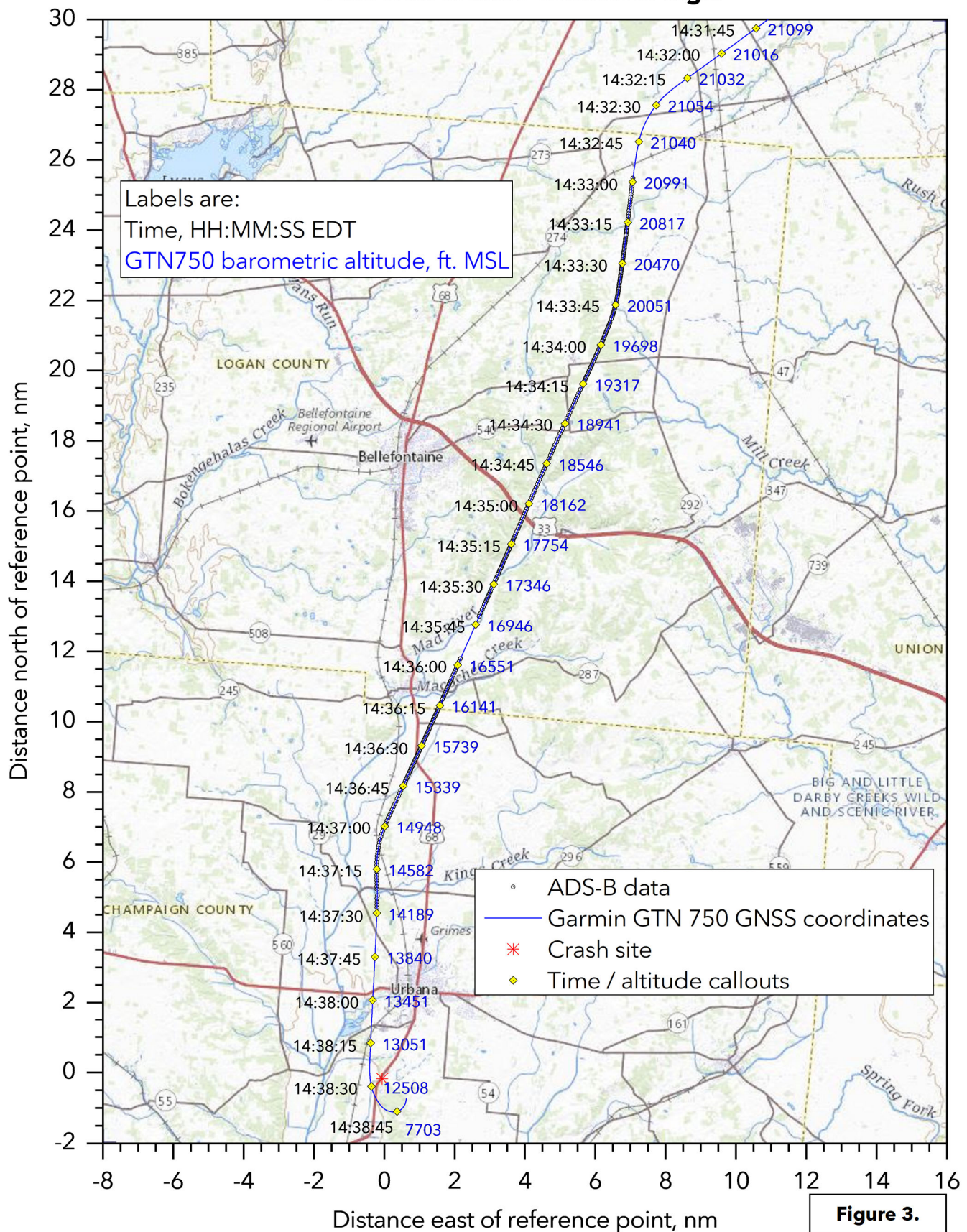


Figure 3.

CEN21FA376: Socata TBM-700, N700DT, Urbana, OH, 08/20/2021

Plan view of last 2 minutes of flight

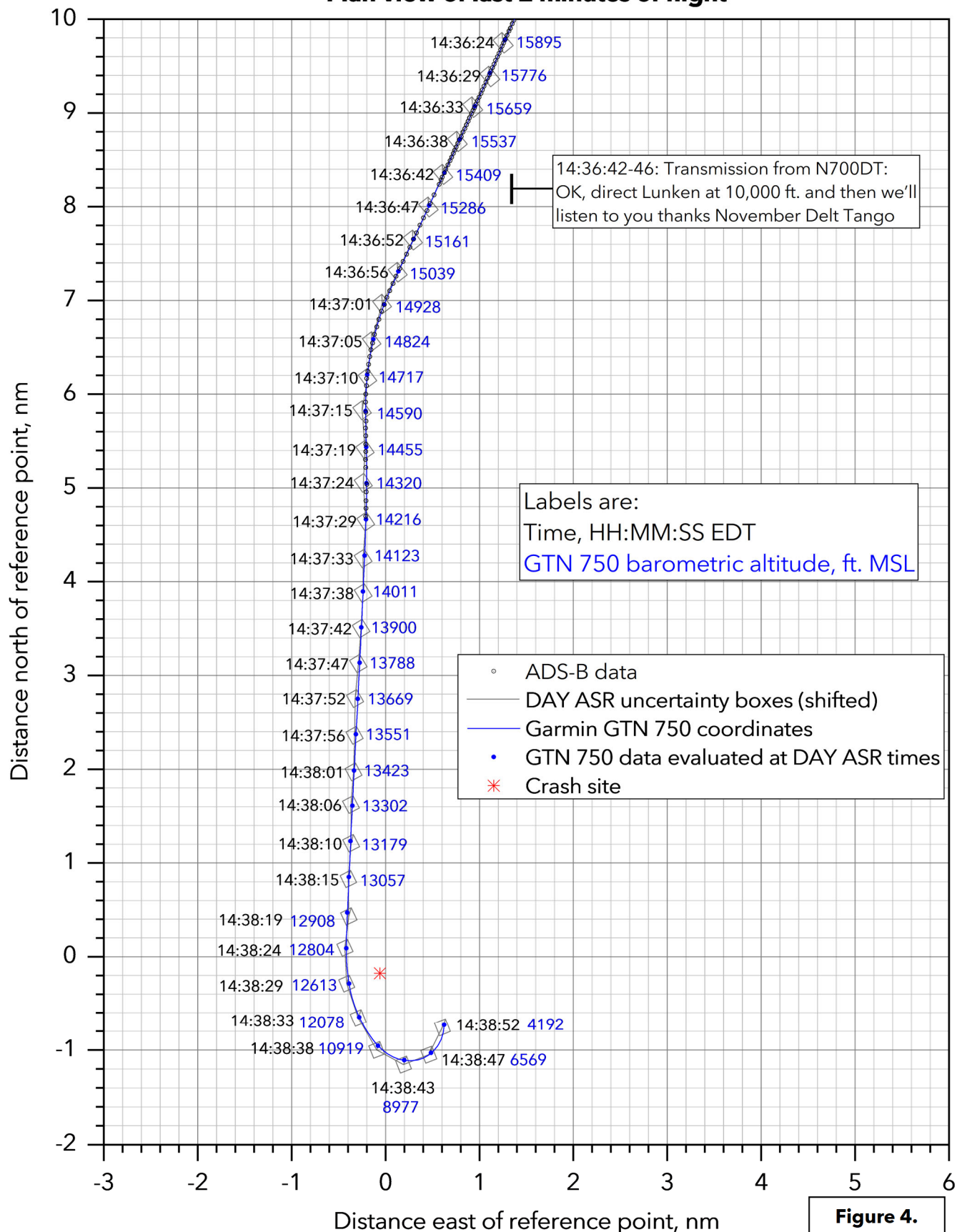
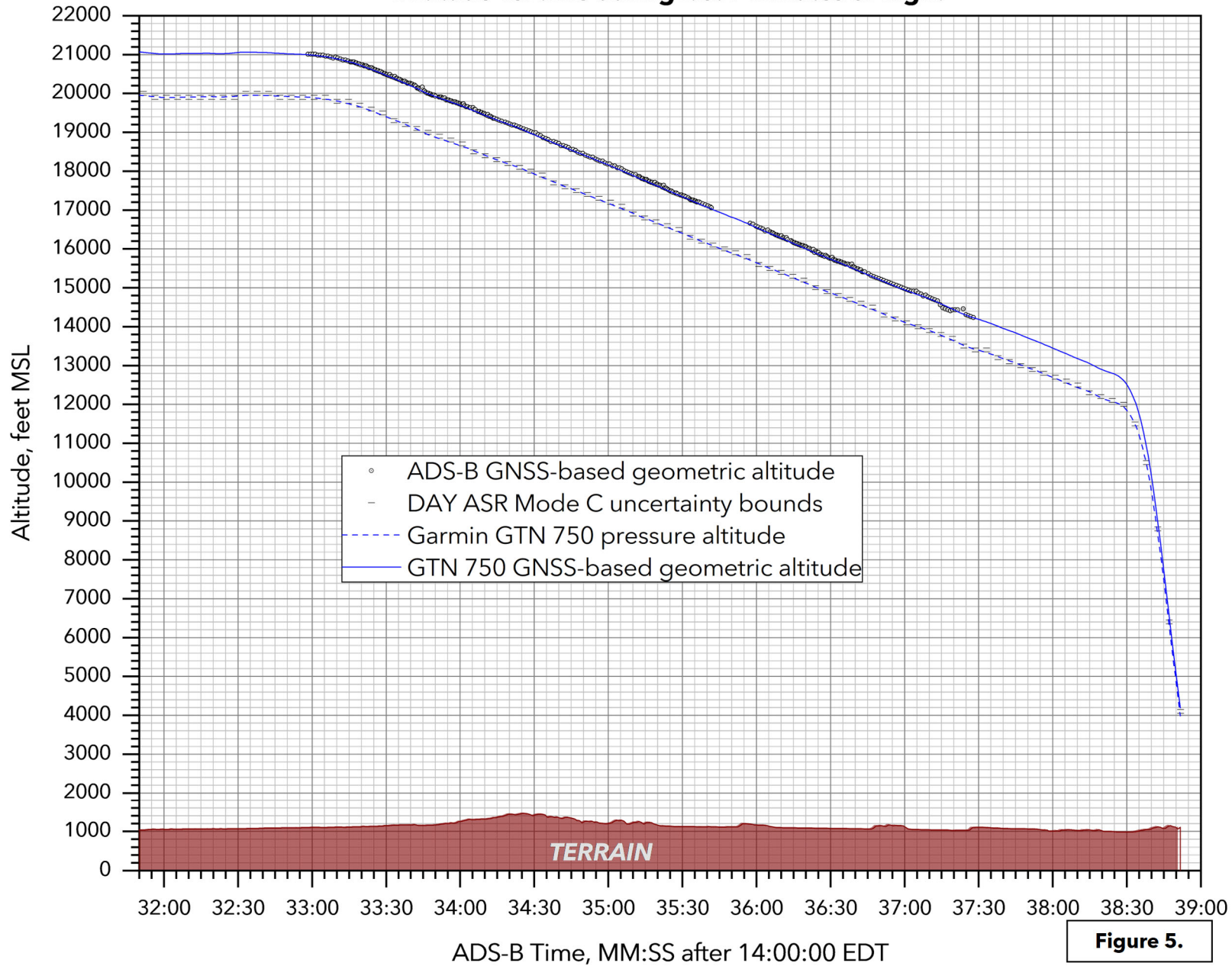


Figure 4.

CEN21FA376: Socata TBM-700, N700DT, Urbana, OH, 08/20/2021

Altitude vs. time during last 7 minutes of flight



CEN21FA376: Socata TBM-700, N700DT, Urbana, OH, 08/20/2021

Plan view of final dive

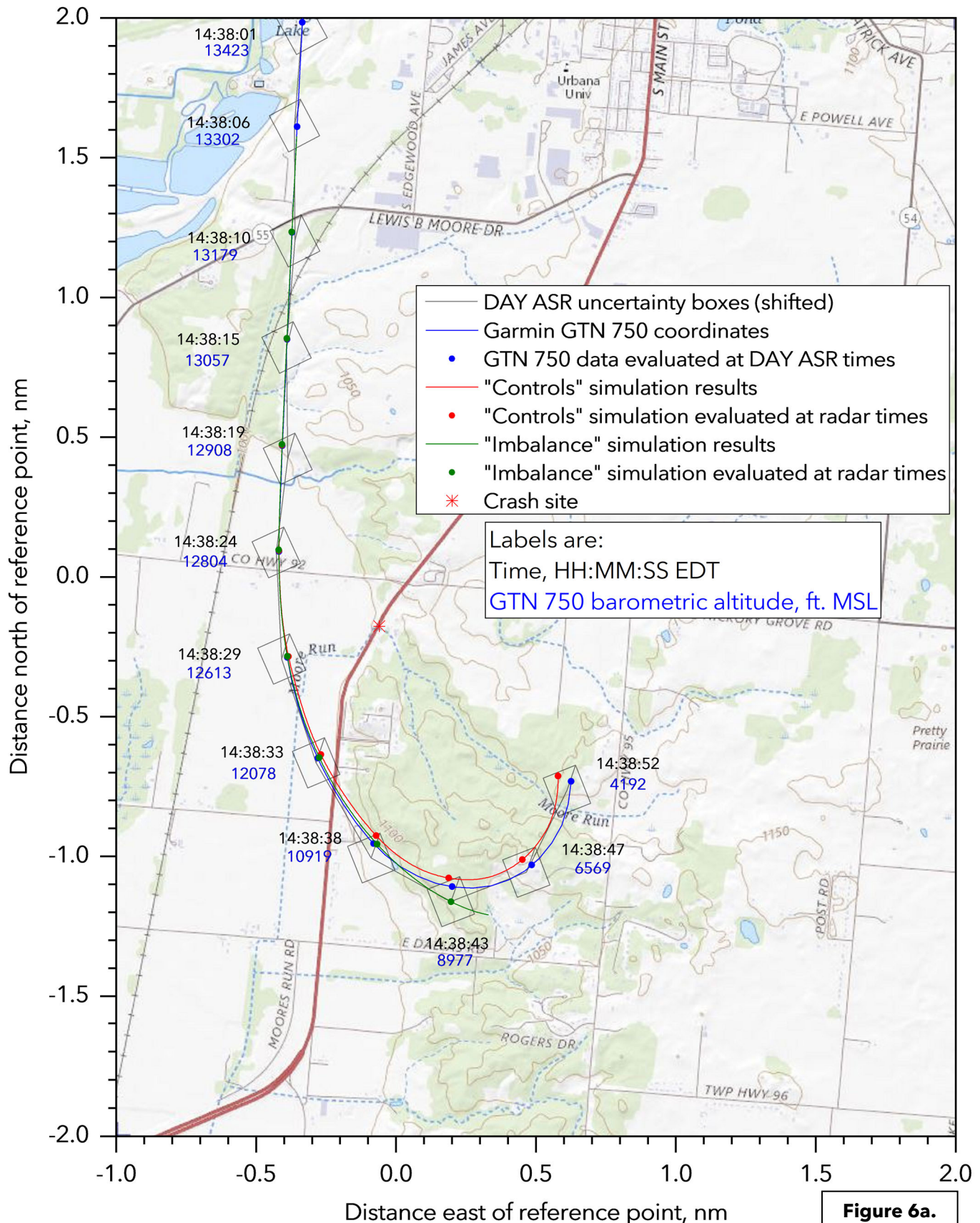


Figure 6a.

CEN21FA376: Socata TBM-700, N700DT, Urbana, OH, 08/20/2021

Plan view of final dive

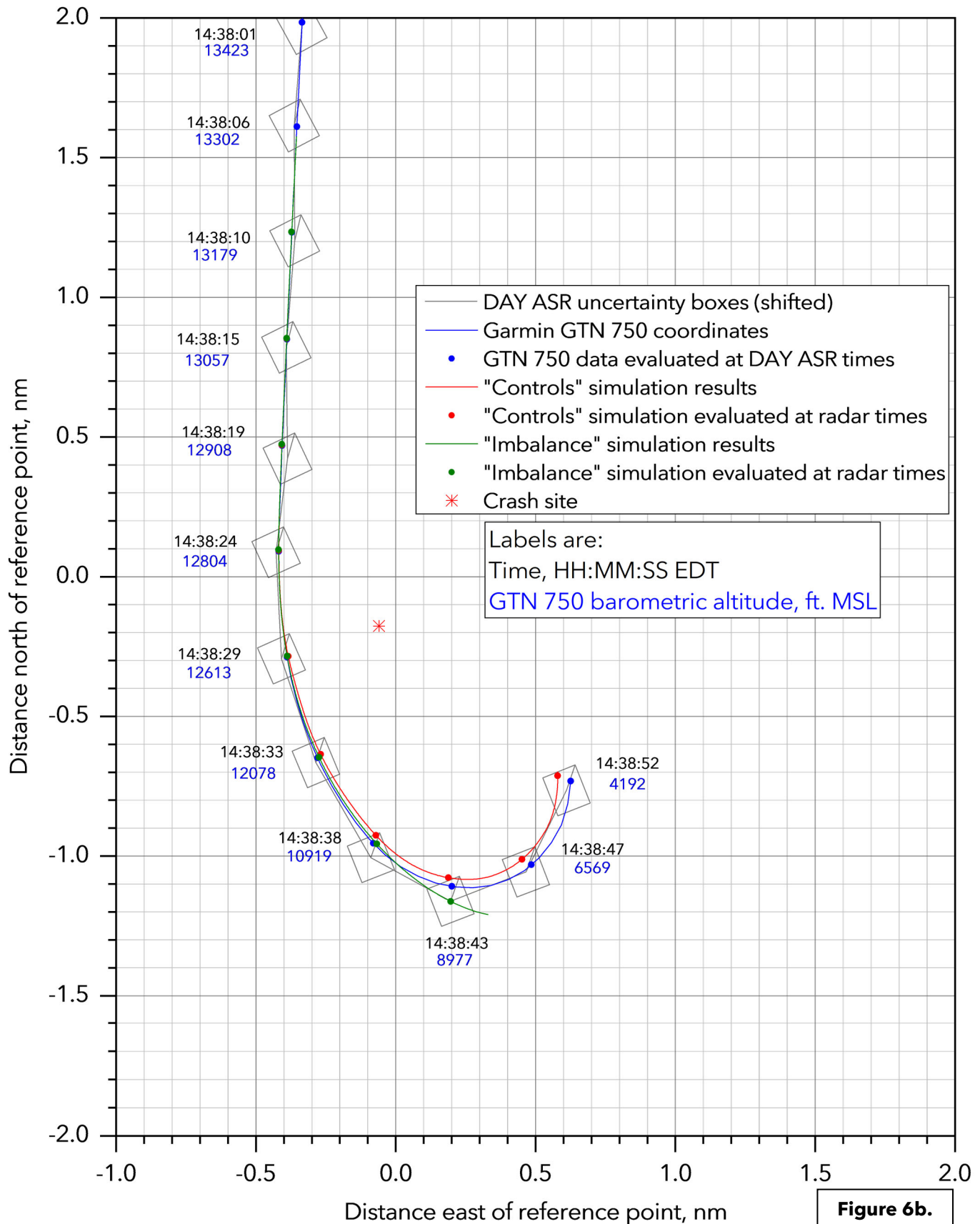
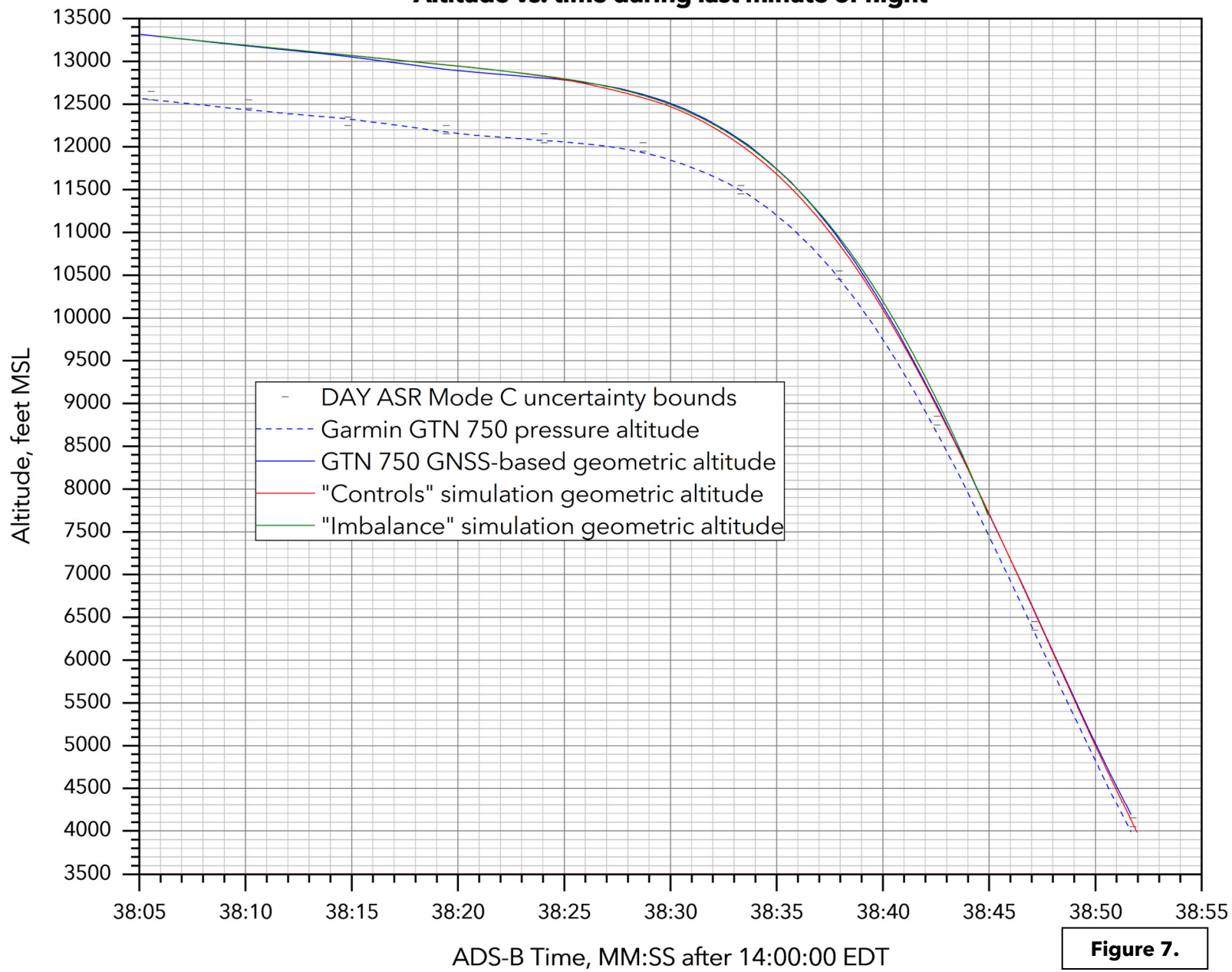


Figure 6b.

CEN21FA376: Socata TBM-700, N700DT, Urbana, OH, 08/20/2021

Altitude vs. time during last minute of flight



CEN21FA376: Socata TBM-700, N700DT, Urbana, OH, 08/20/2021

North & east coordinates vs. time during last minute of flight

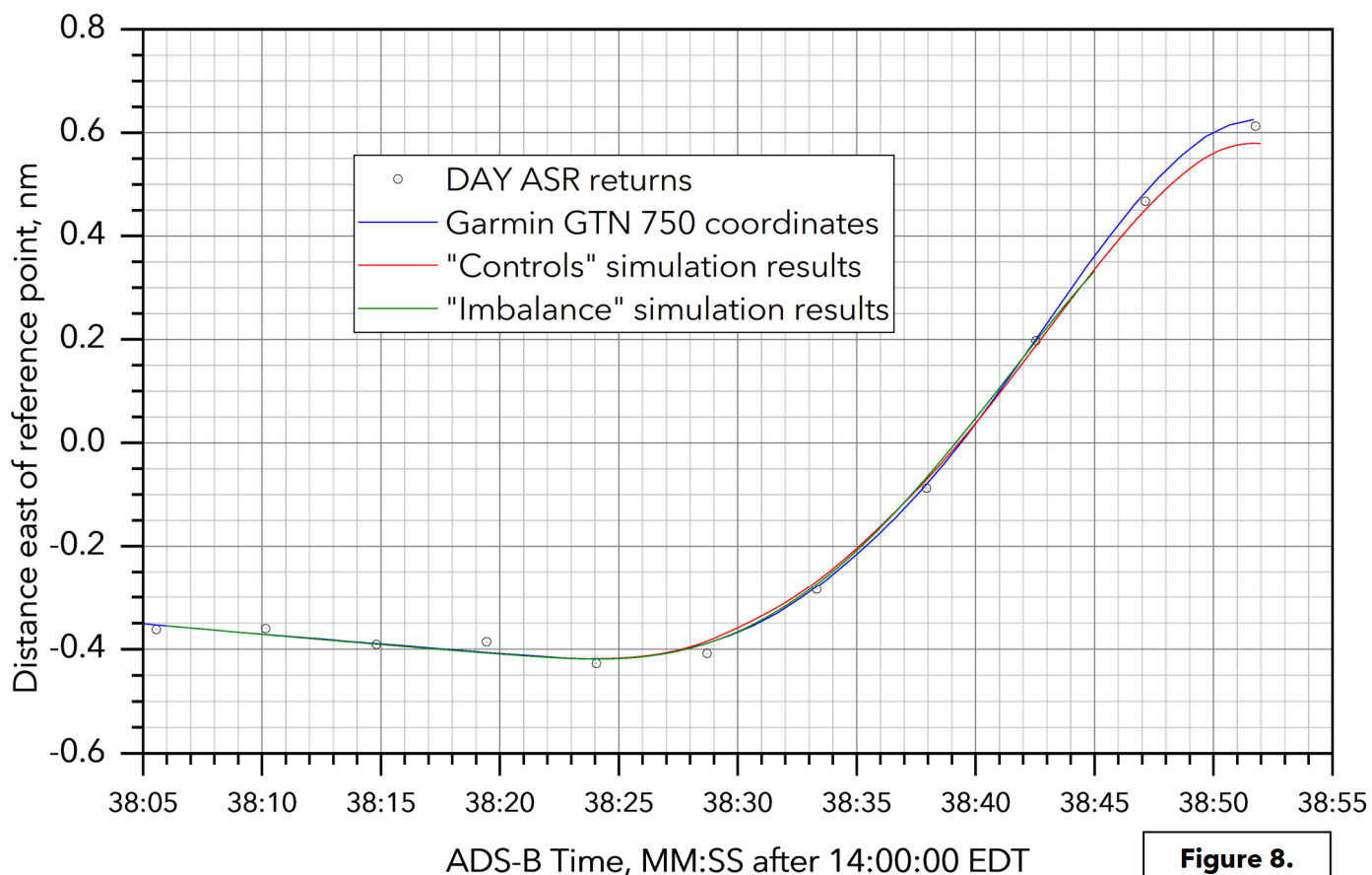
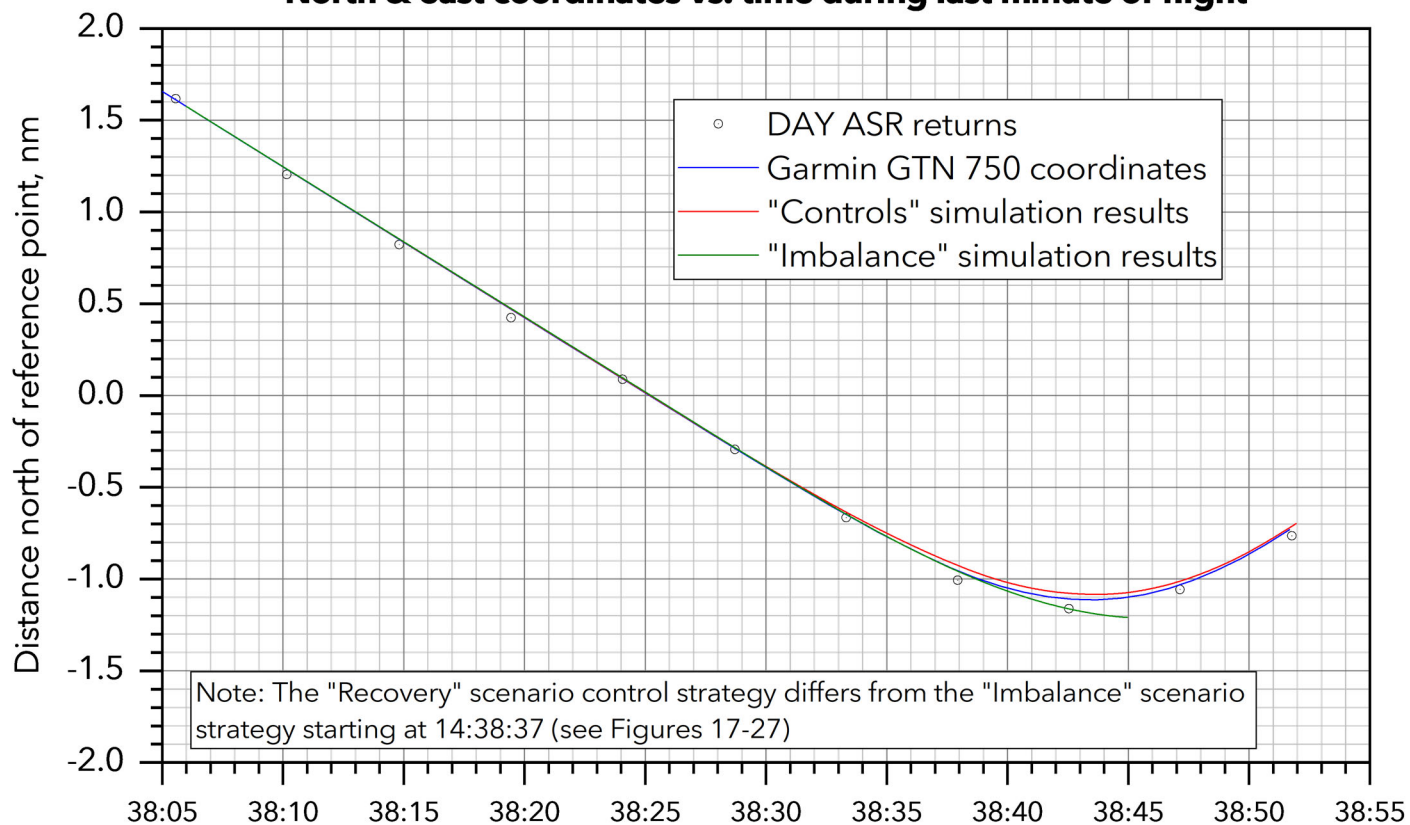


Figure 8.

CEN21FA376: Socata TBM-700, N700DT, Urbana, OH, 08/20/2021

Speed & rate of climb during last minute of flight

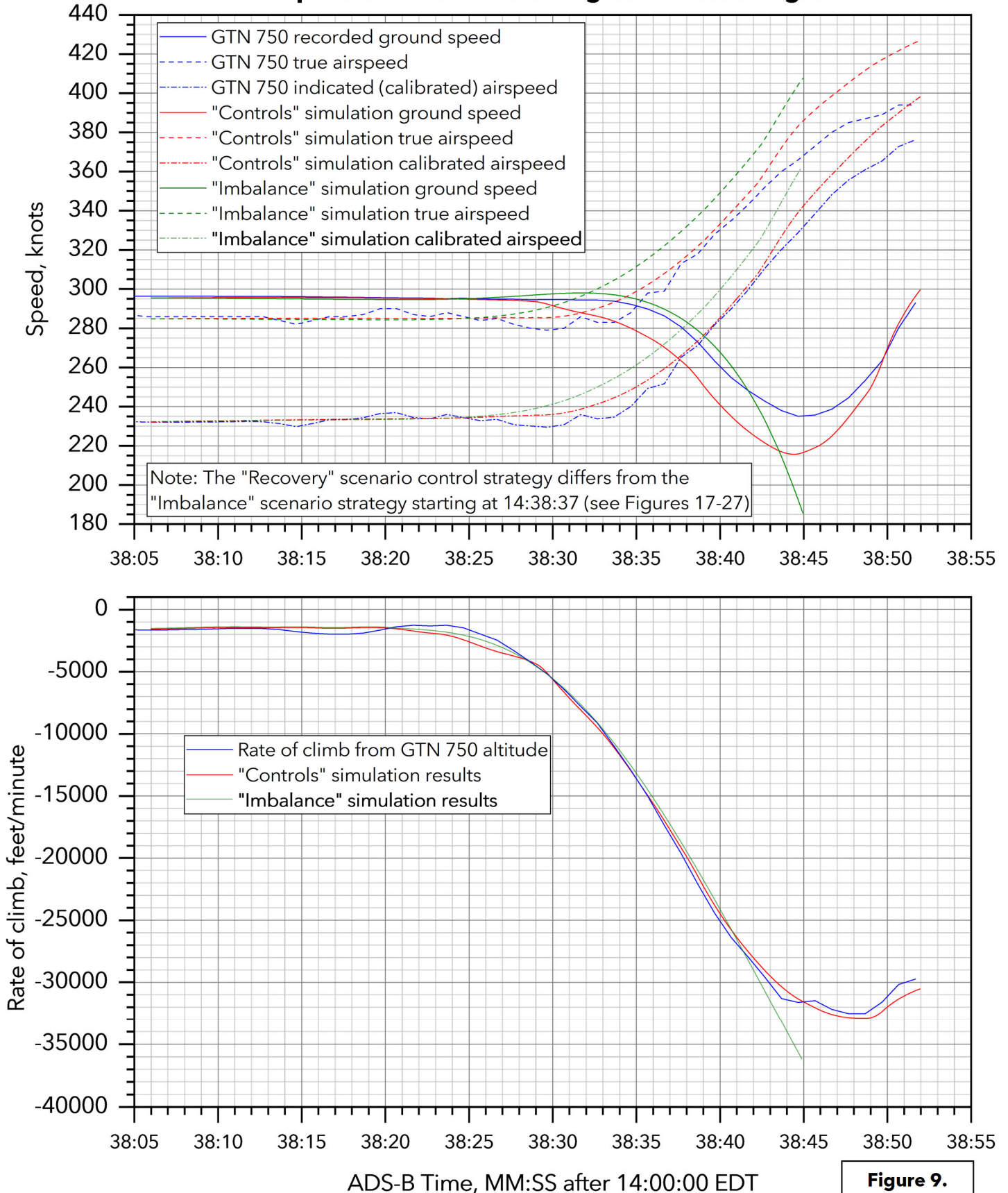


Figure 9.

CEN21FA376: Socata TBM-700, N700DT, Urbana, OH, 08/20/2021

Euler angles during last minute of flight

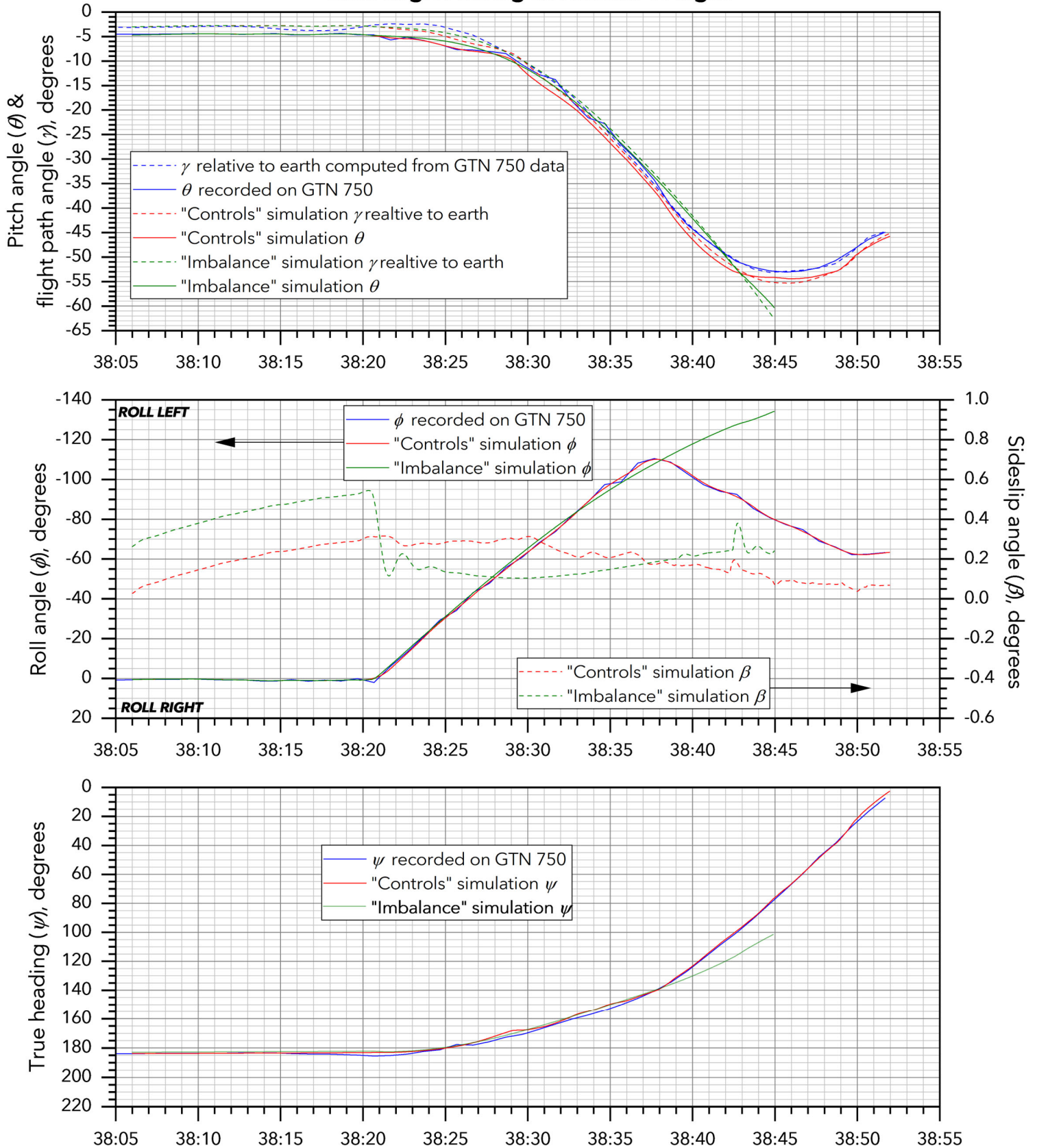


Figure 10.

CEN21FA376: Socata TBM-700, N700DT, Urbana, OH, 08/20/2021

Angular rates during last minute of flight

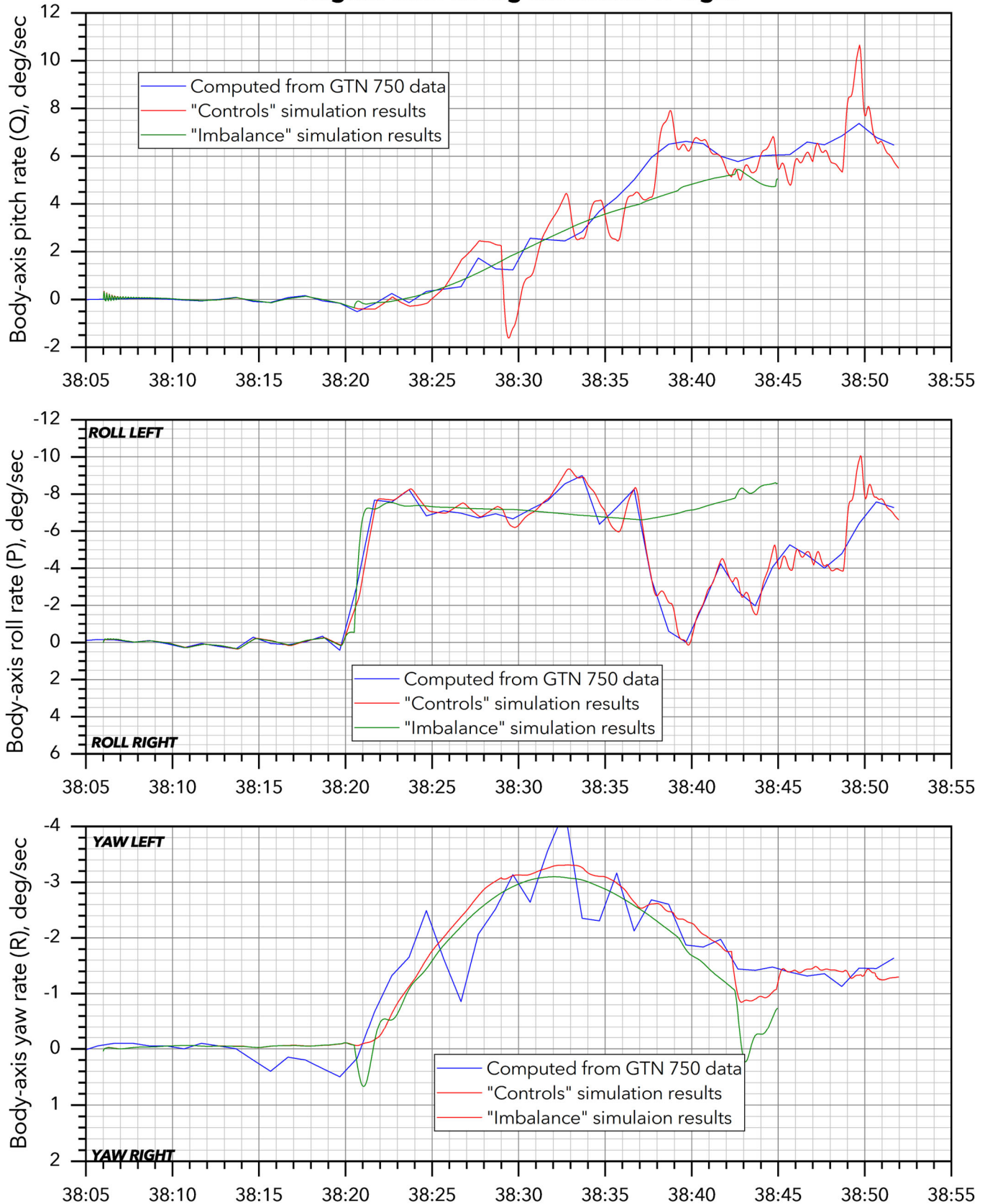
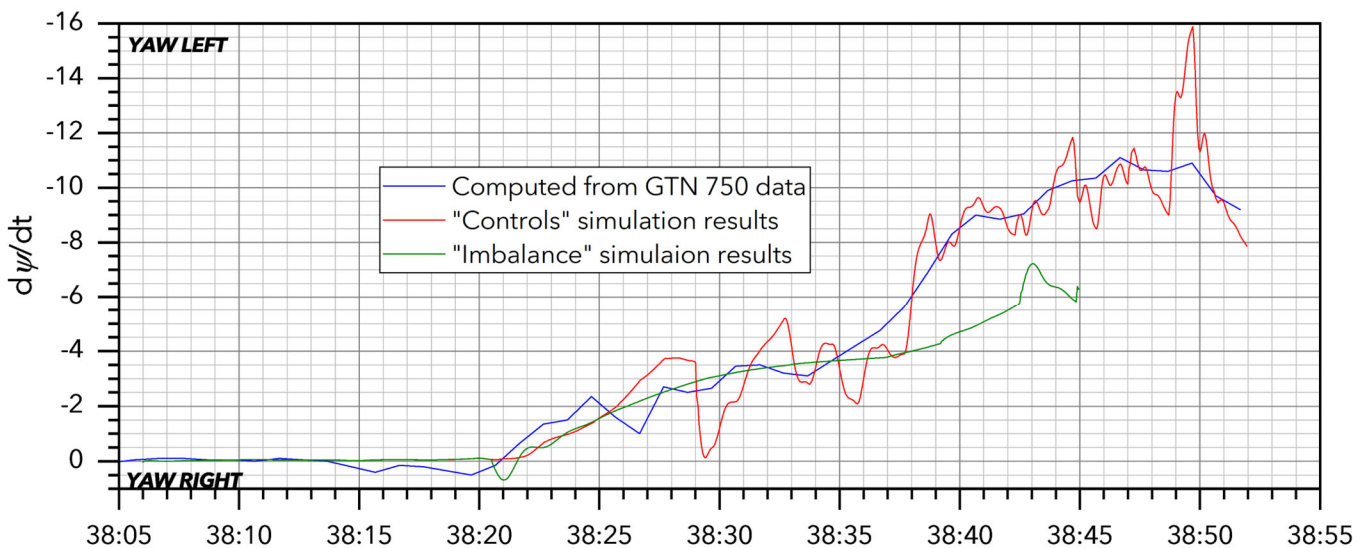
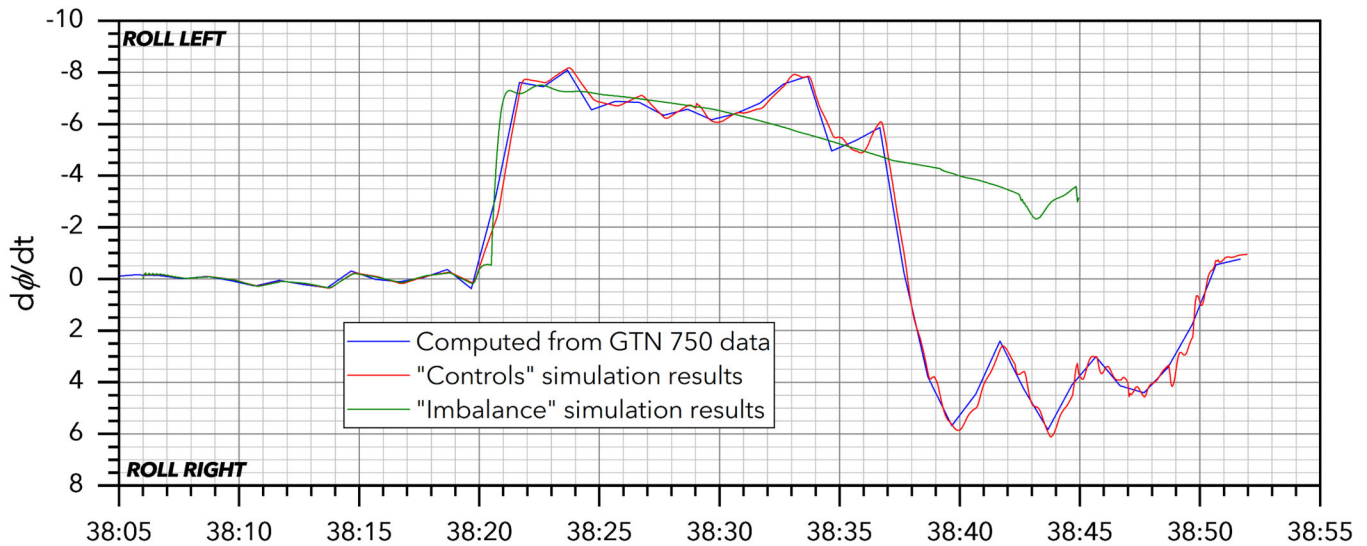
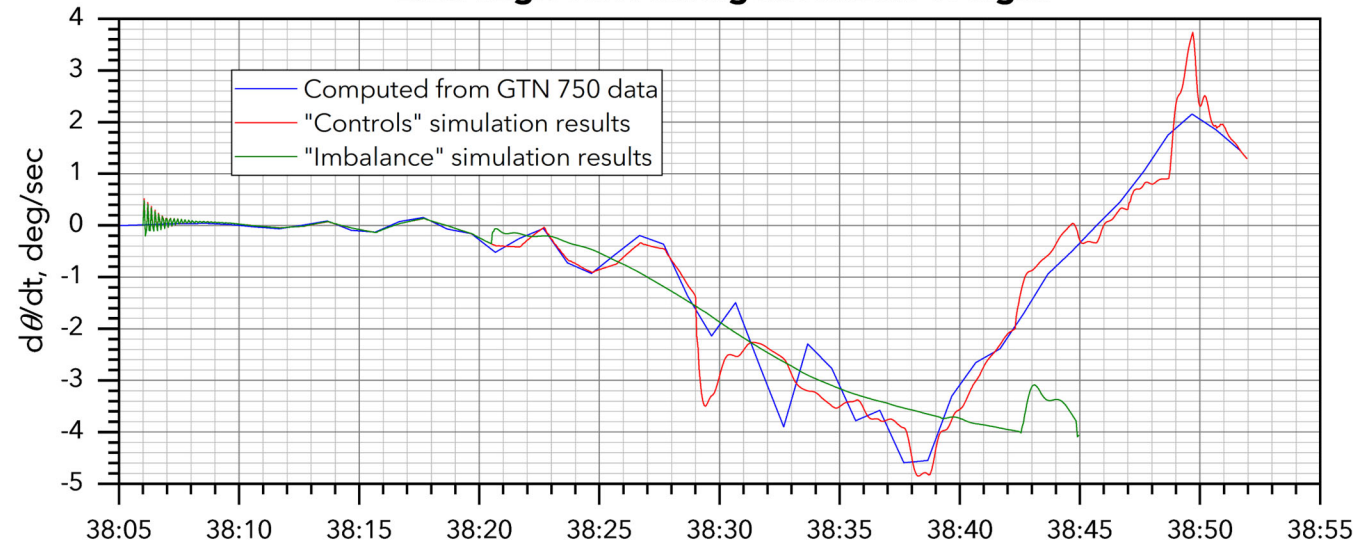


Figure 11.

CEN21FA376: Socata TBM-700, N700DT, Urbana, OH, 08/20/2021

Euler angle rates during last minute of flight



ADS-B Time, MM:SS after 14:00:00 EDT

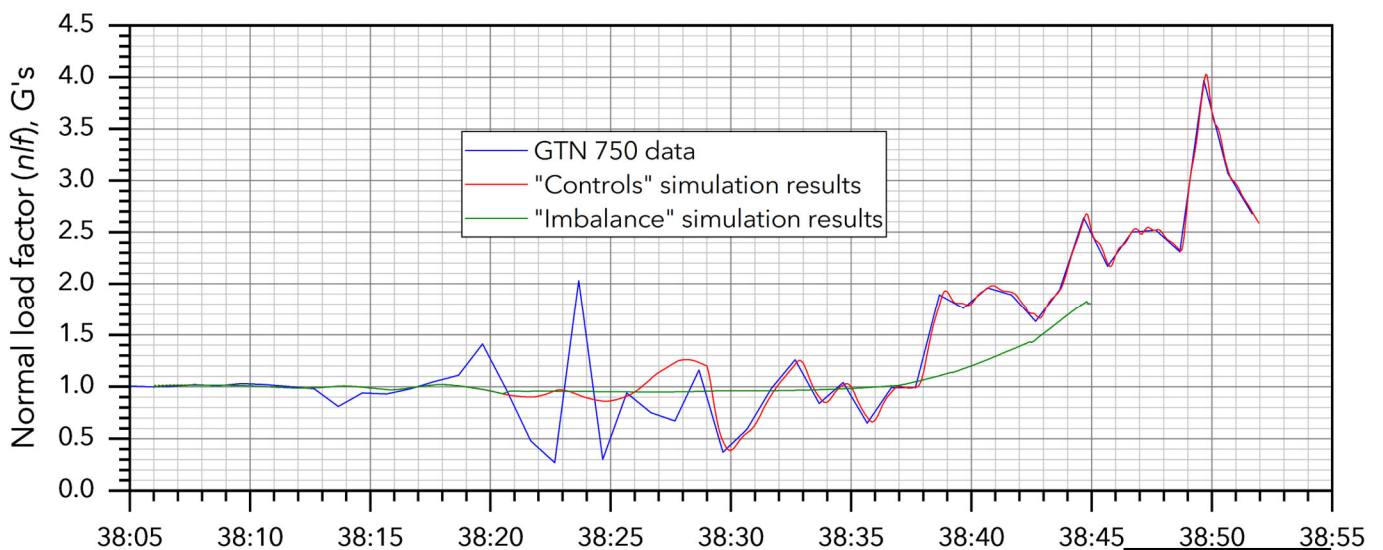
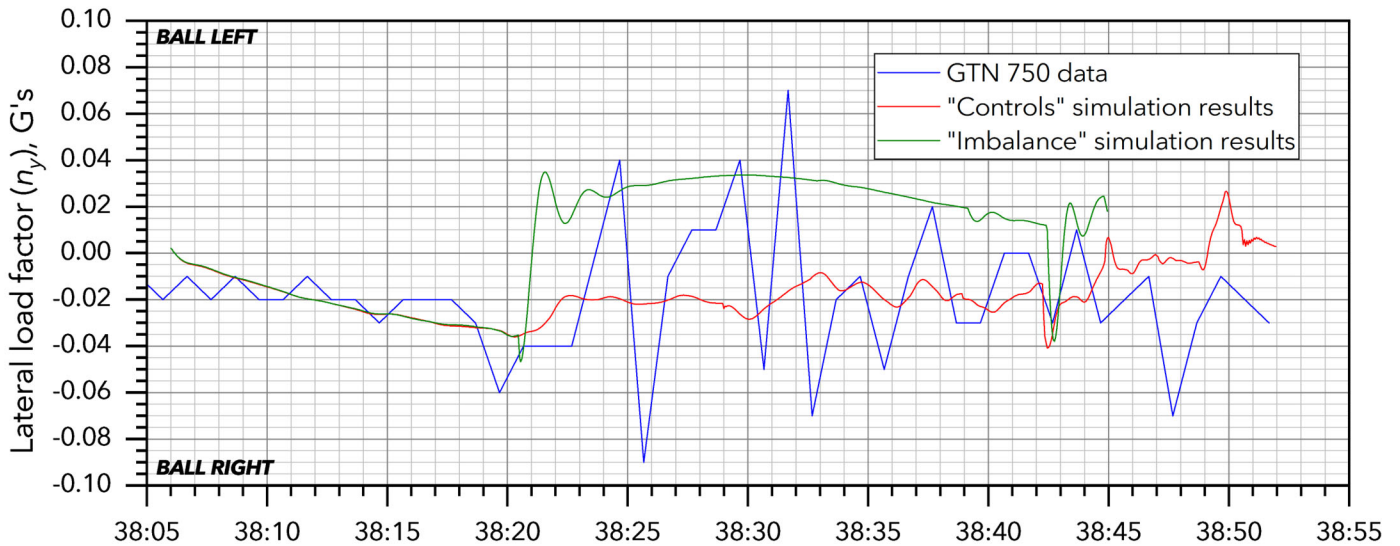
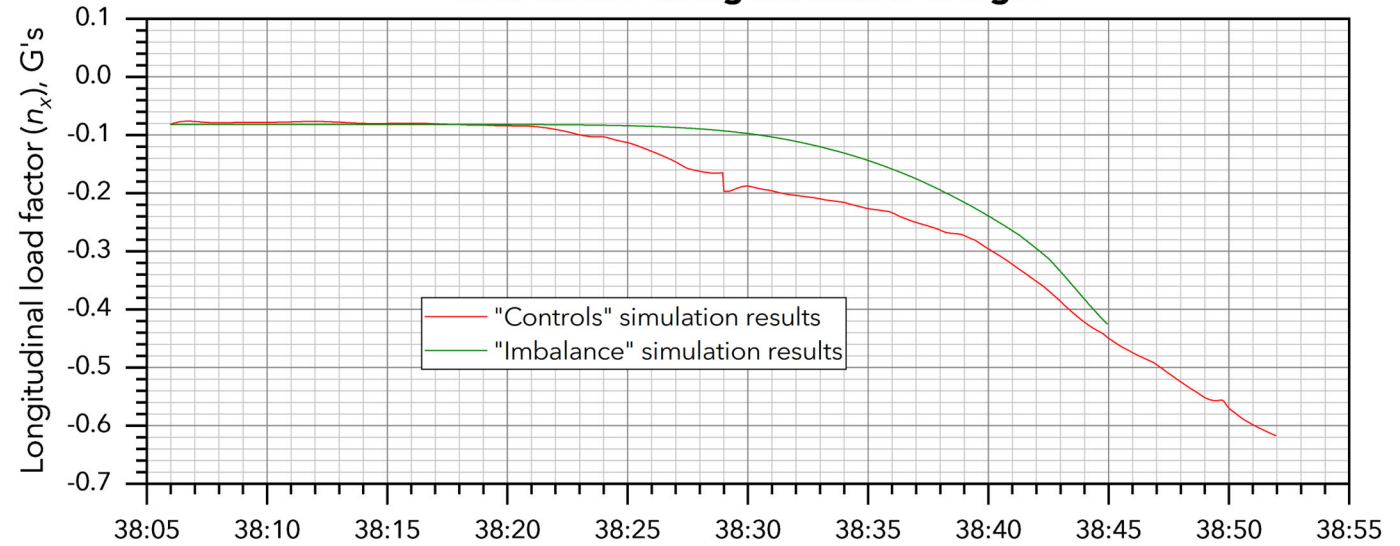
AIRCRAFT PERFORMANCE & SIMULATION STUDY

Figure 12.

CEN21FA376
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CEN21FA376: Socata TBM-700, N700DT, Urbana, OH, 08/20/2021

Load factors during last minute of flight



ADS-B Time, MM:SS after 14:00:00 EDT

AIRCRAFT PERFORMANCE & SIMULATION STUDY

Figure 13.

CEN21FA376
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CEN21FA376: Socata TBM-700, N700DT, Urbana, OH, 08/20/2021

Flight controls during last minute of flight

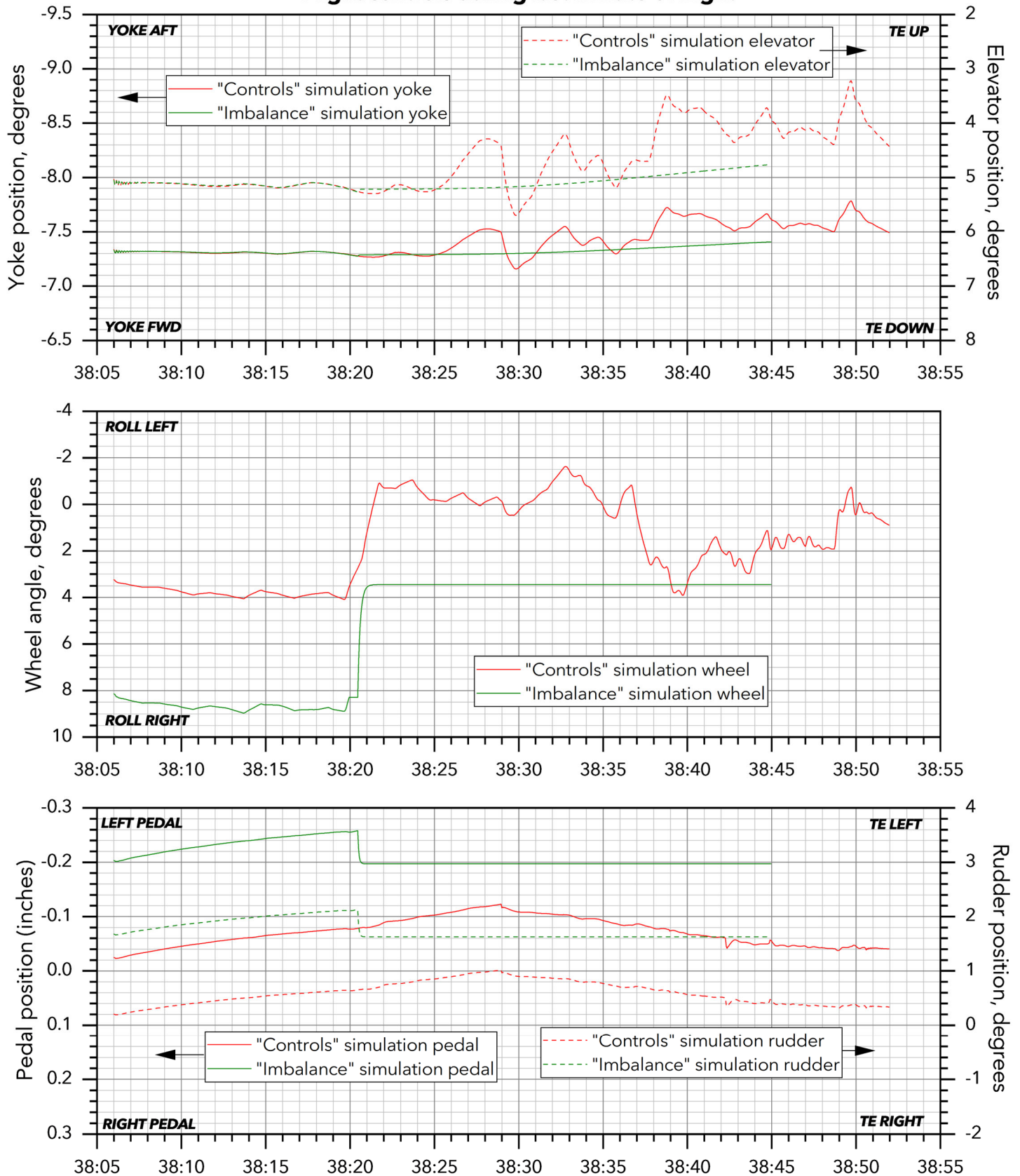


Figure 14.

CEN21FA376: Socata TBM-700, N700DT, Urbana, OH, 08/20/2021

Control forces during last minute of flight

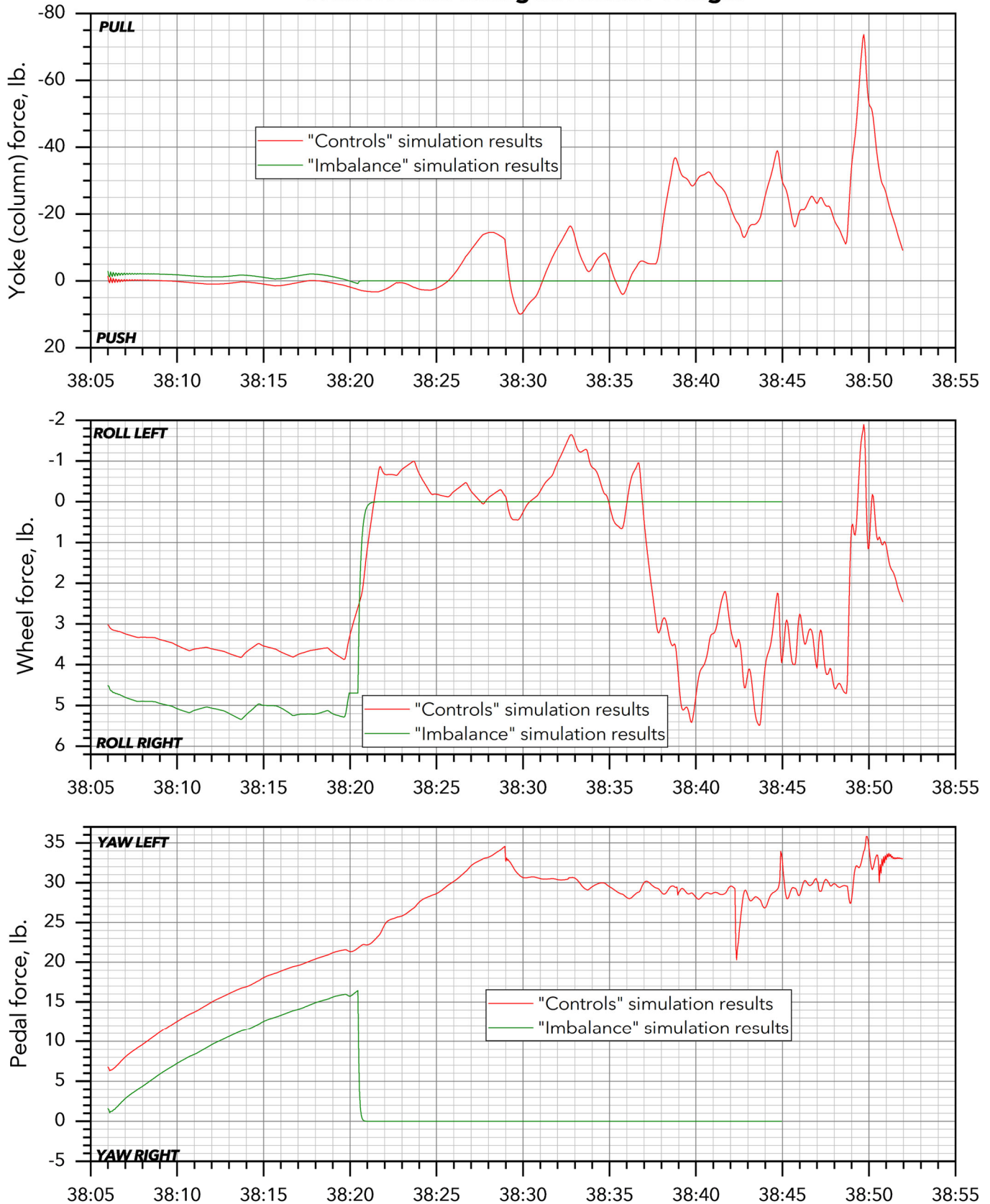
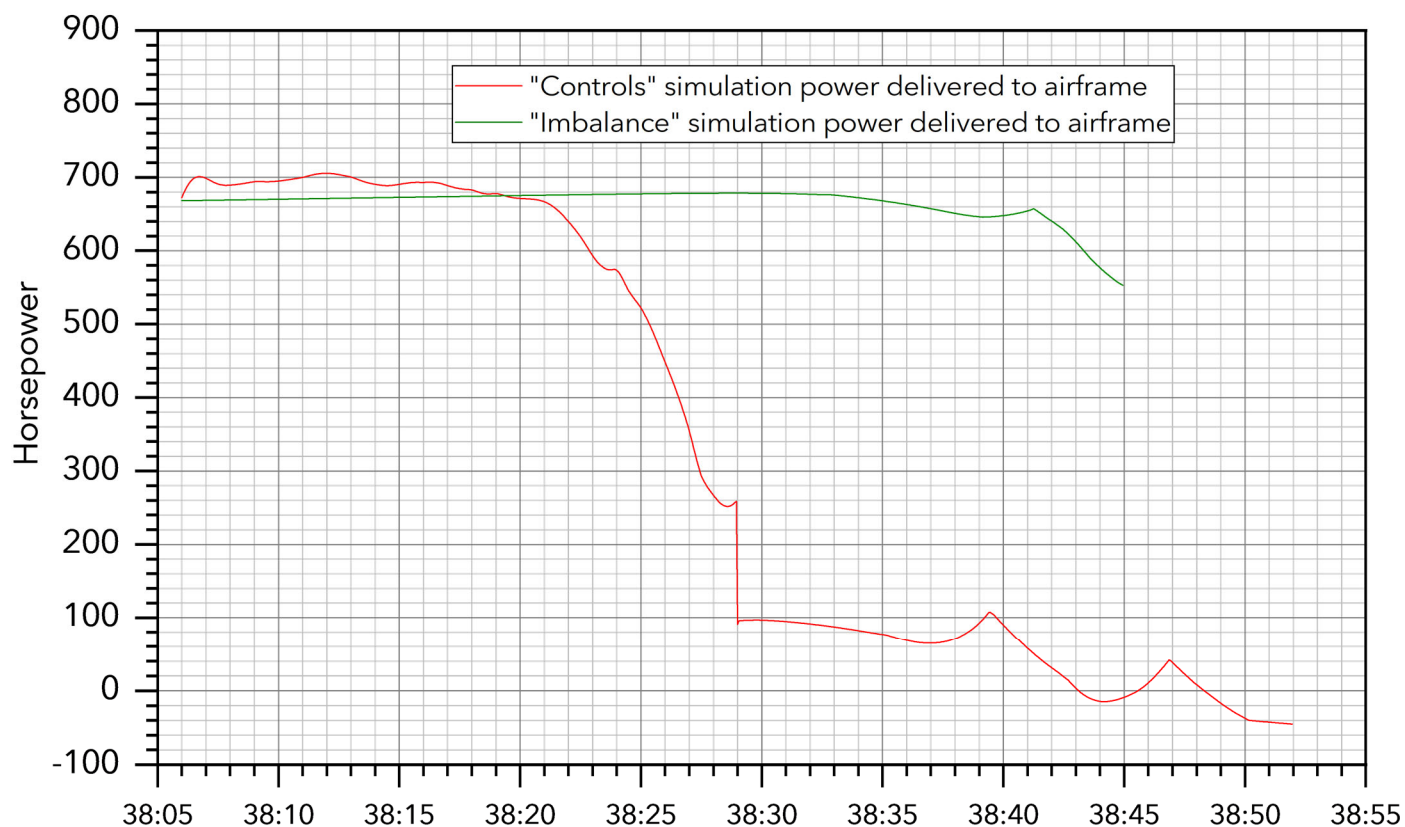
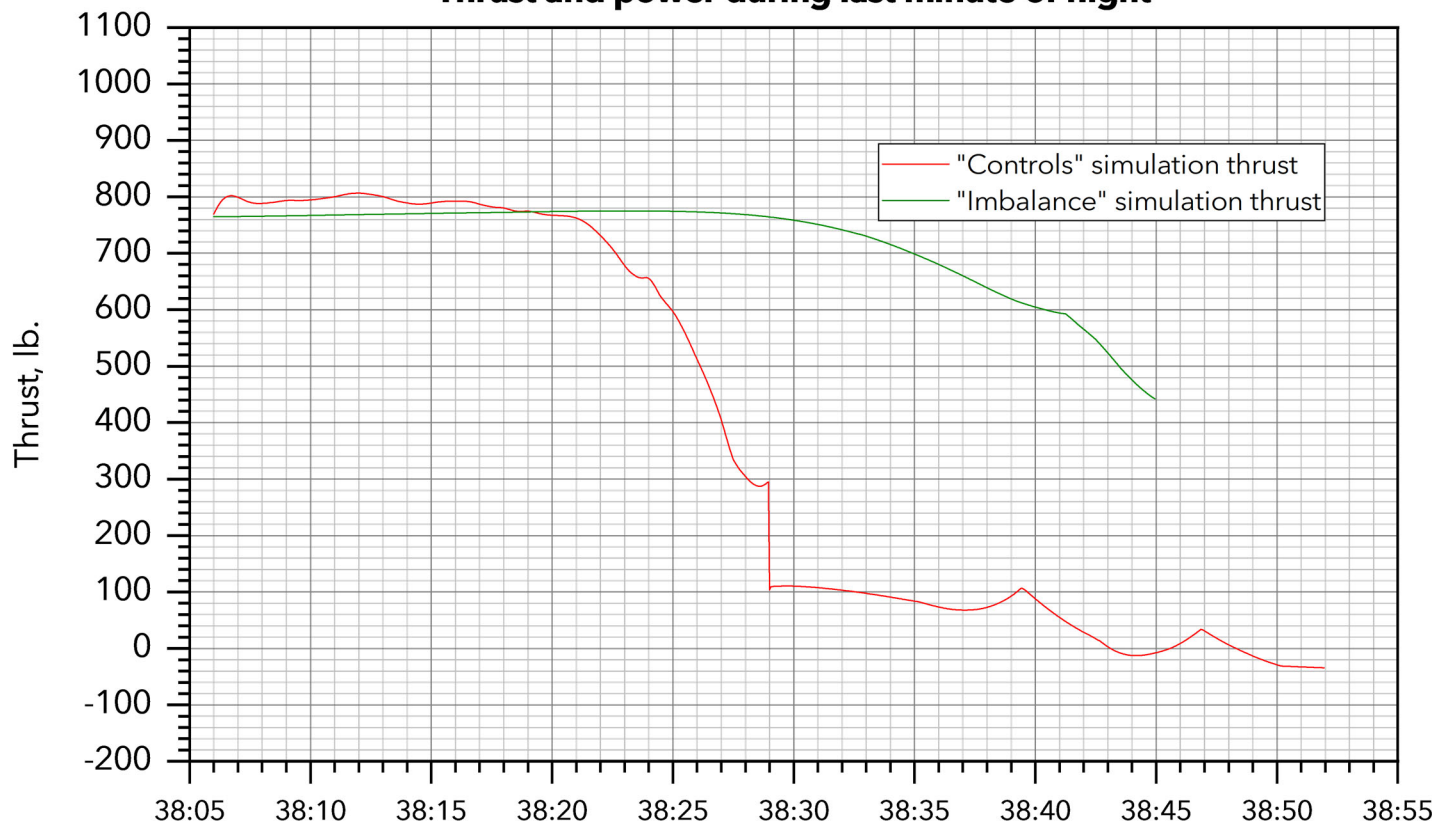


Figure 15.

CEN21FA376: Socata TBM-700, N700DT, Urbana, OH, 08/20/2021

Thrust and power during last minute of flight



ADS-B Time, MM:SS after 14:00:00 EDT

AIRCRAFT PERFORMANCE & SIMULATION STUDY

Figure 16.

CEN21FA376
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CEN21FA376: Daher TBM-700, N700DT, Urbana, OH, 08/20/2021

"Recovery" scenario: plan view of final dive

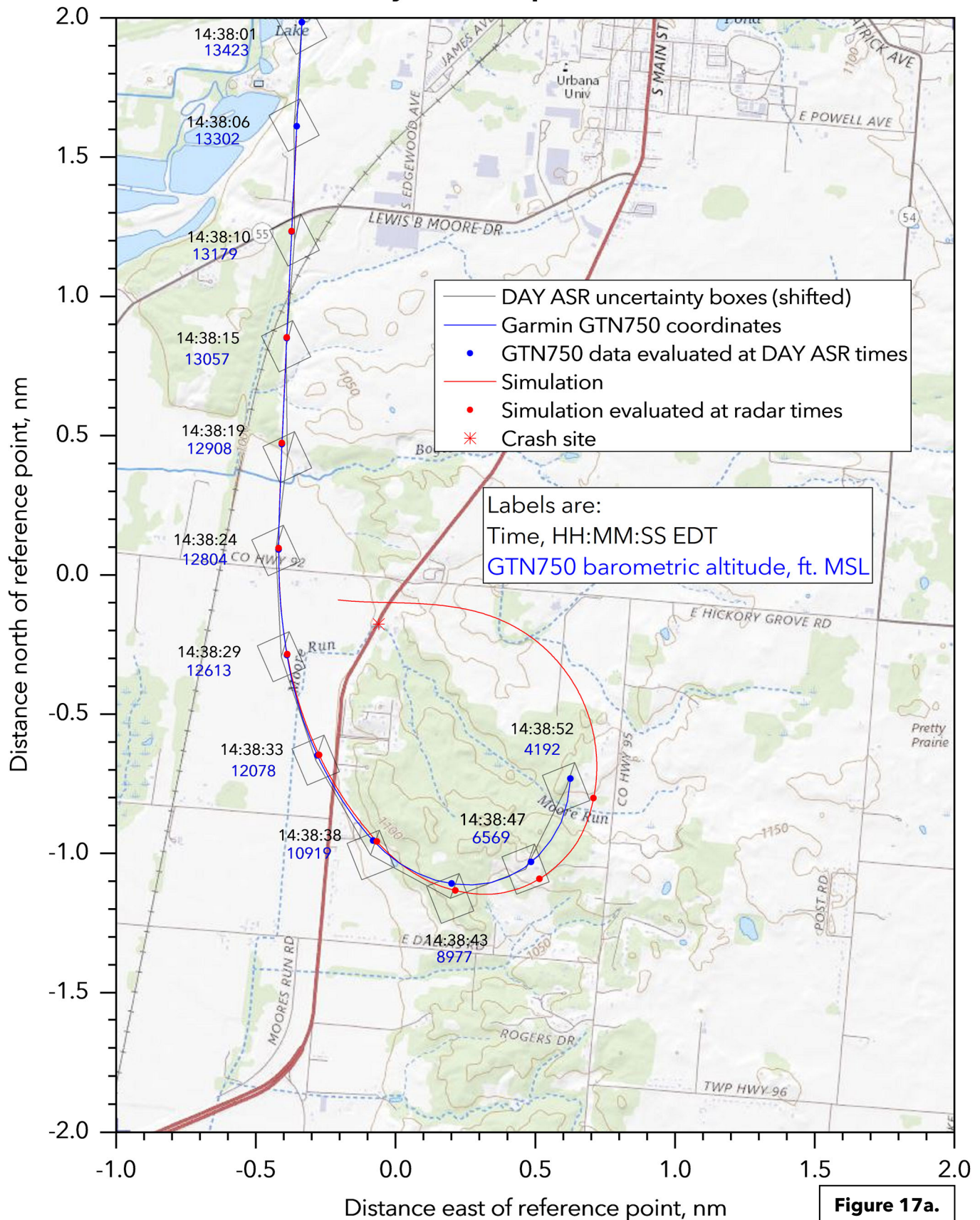


Figure 17a.

CEN21FA376: Daher TBM-700, N700DT, Urbana, OH, 08/20/2021

"Recovery" scenario: plan view of final dive

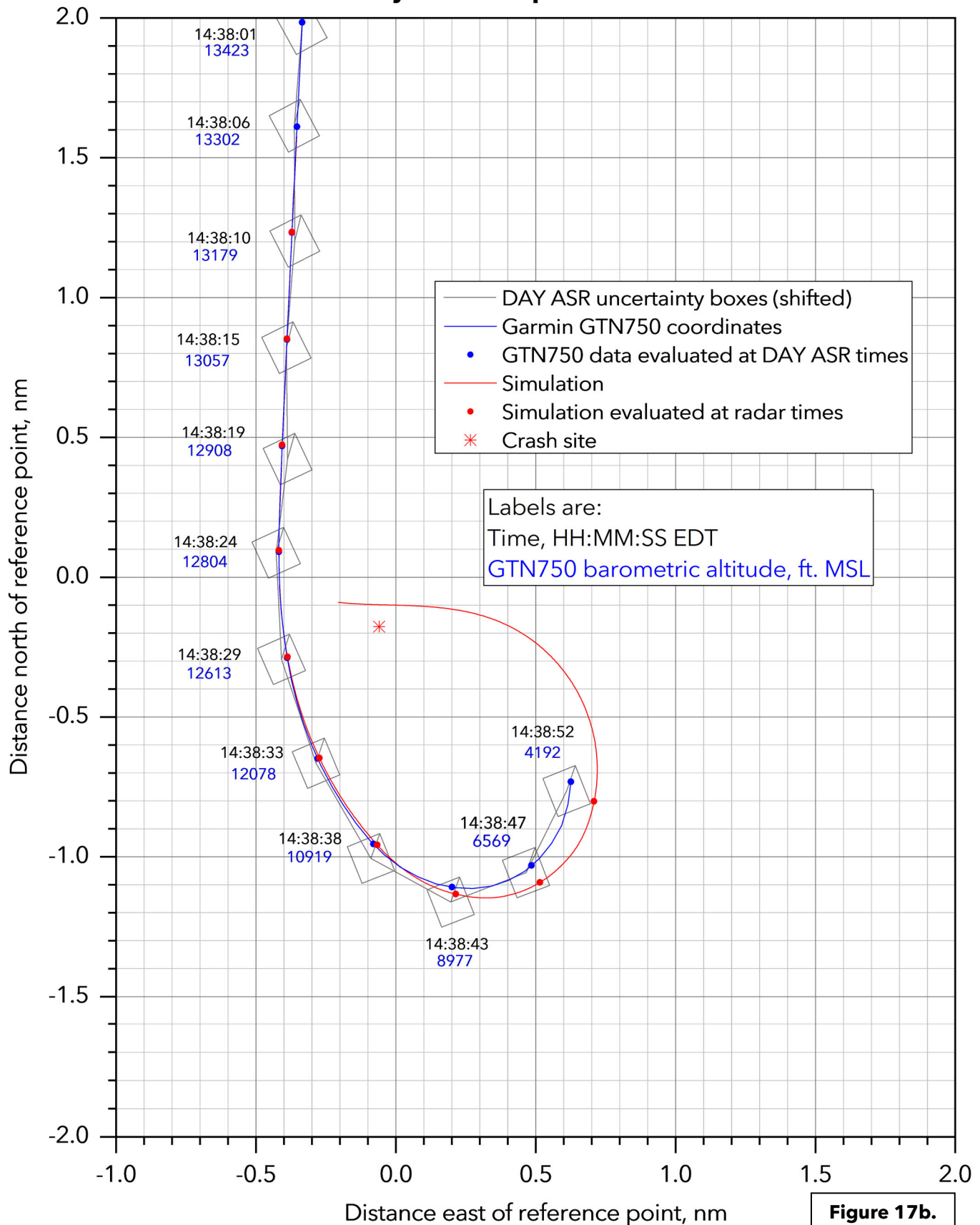


Figure 17b.

CEN21FA376: Socata TBM-700, N700DT, Urbana, OH, 08/20/2021

"Recovery" scenario: altitude vs. time during final descent

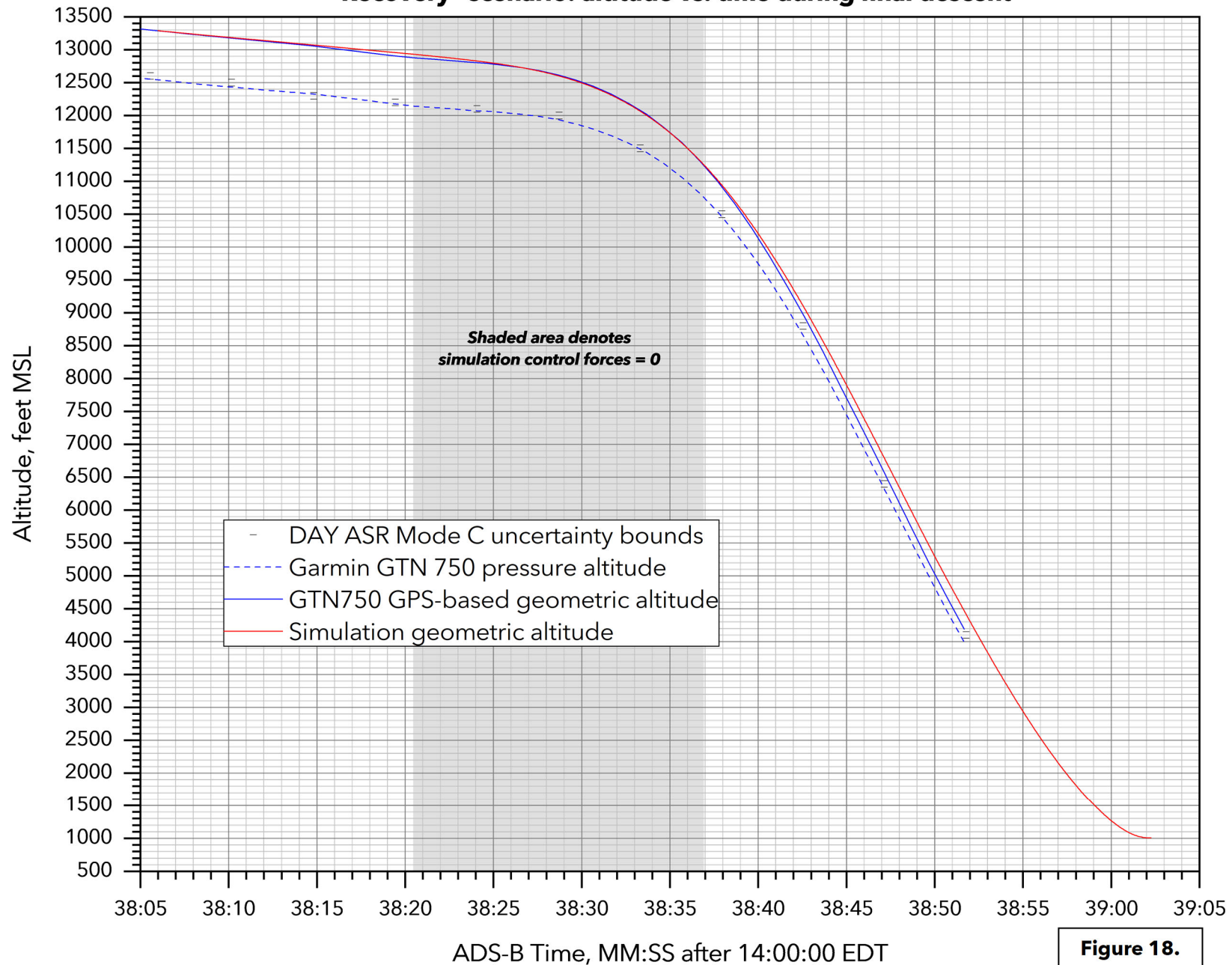


Figure 18.

CEN21FA376: Socata TBM-700, N700DT, Urbana, OH, 08/20/2021

"Recovery" scenario: north & east coordinates vs. time during final descent

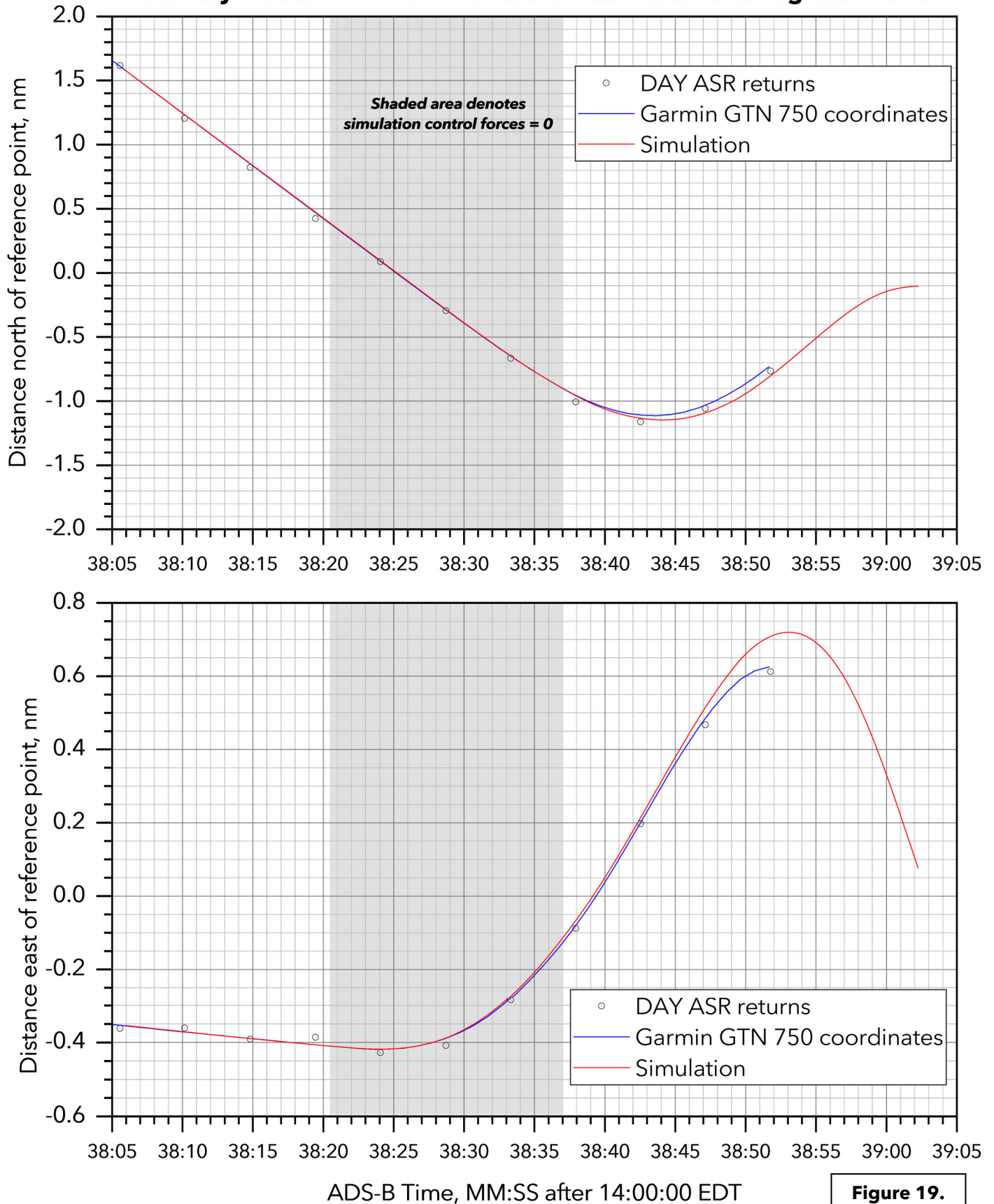


Figure 19.

CEN21FA376: Socata TBM-700, N700DT, Urbana, OH, 08/20/2021

"Recovery" scenario: speed & rate of climb during final descent

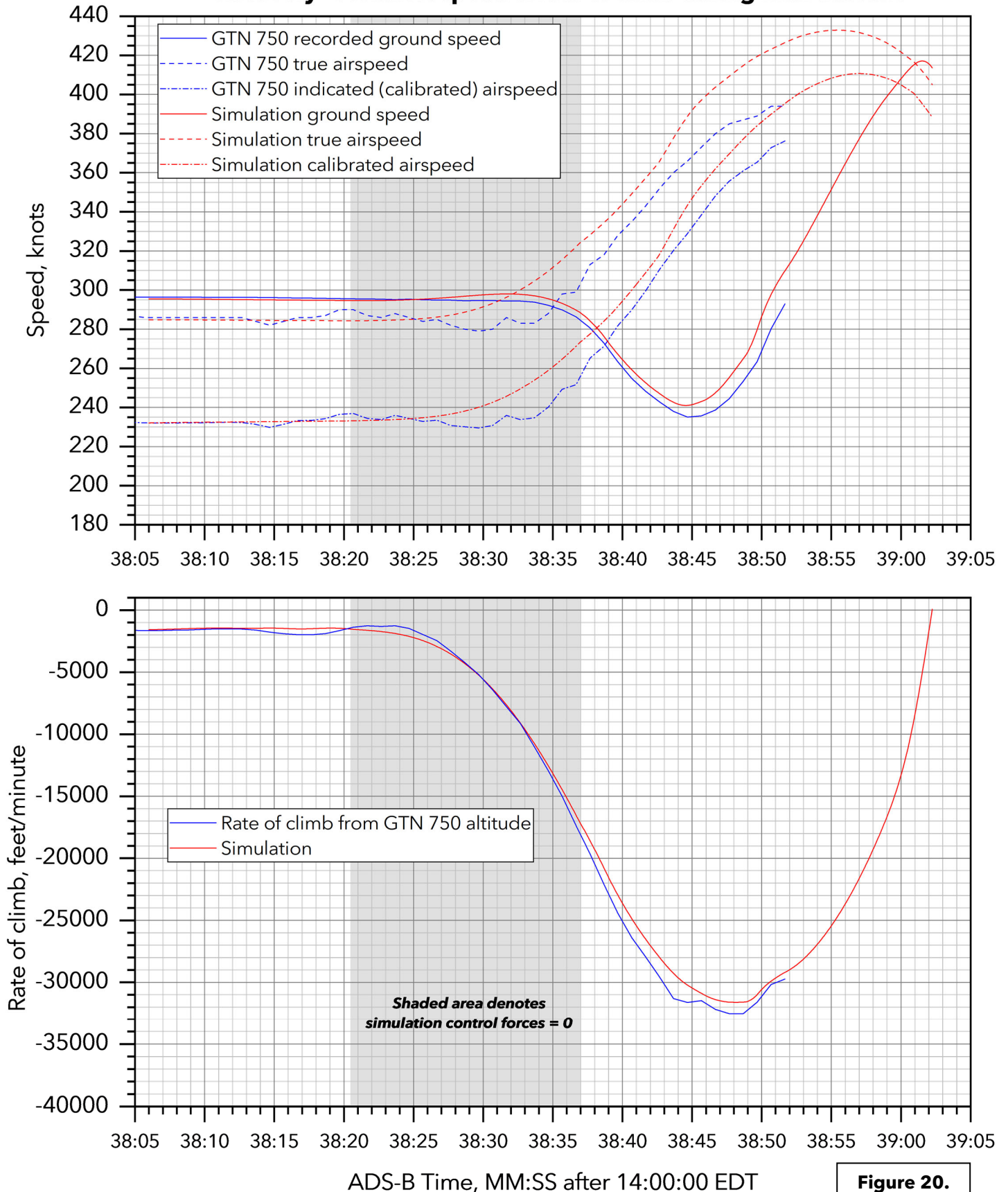


Figure 20.

CEN21FA376: Socata TBM-700, N700DT, Urbana, OH, 08/20/2021

"Recovery" scenario: Euler angles during final descent

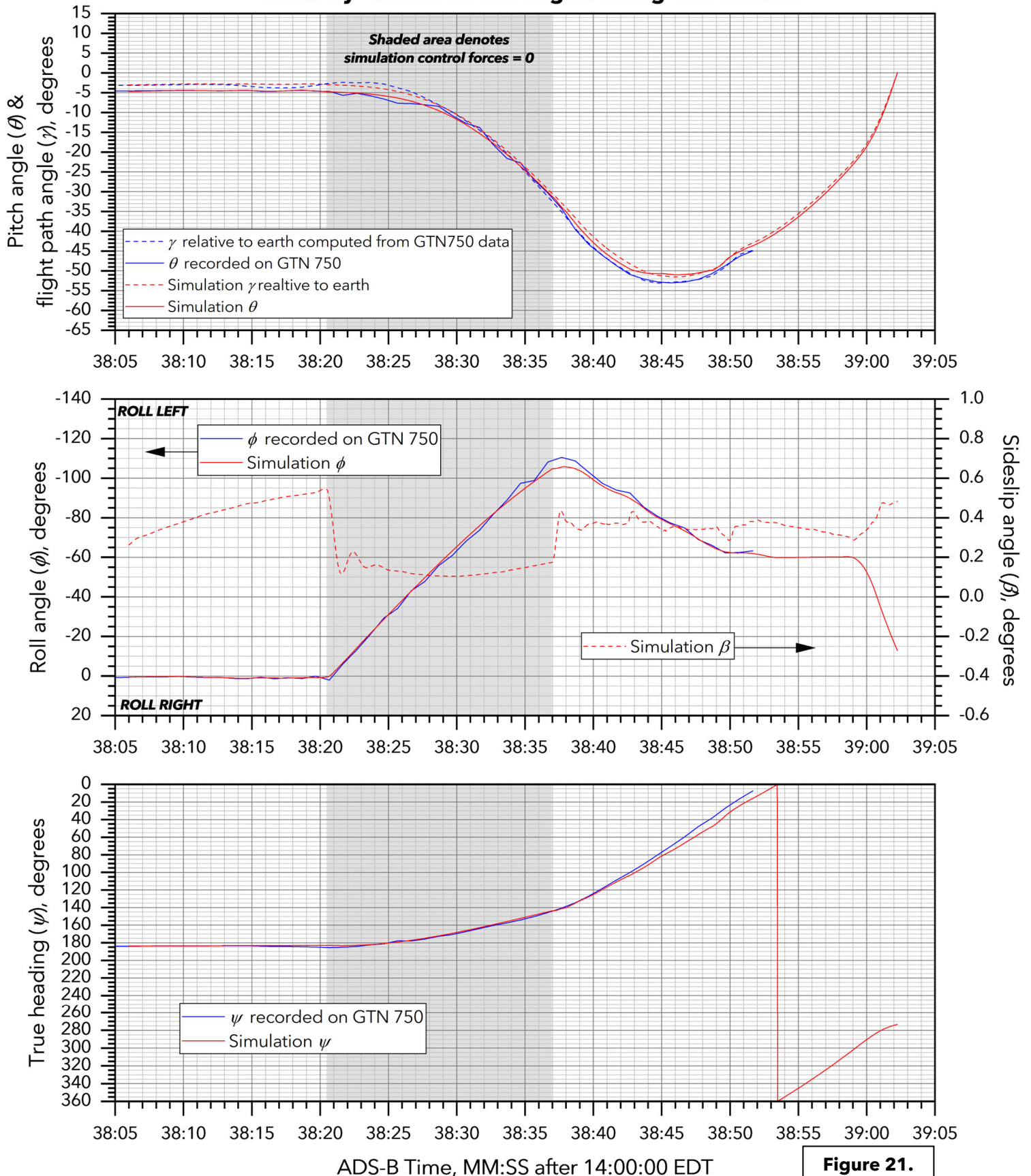


Figure 21.

CEN21FA376: Socata TBM-700, N700DT, Urbana, OH, 08/20/2021

"Recovery" scenario: angular rates during final descent

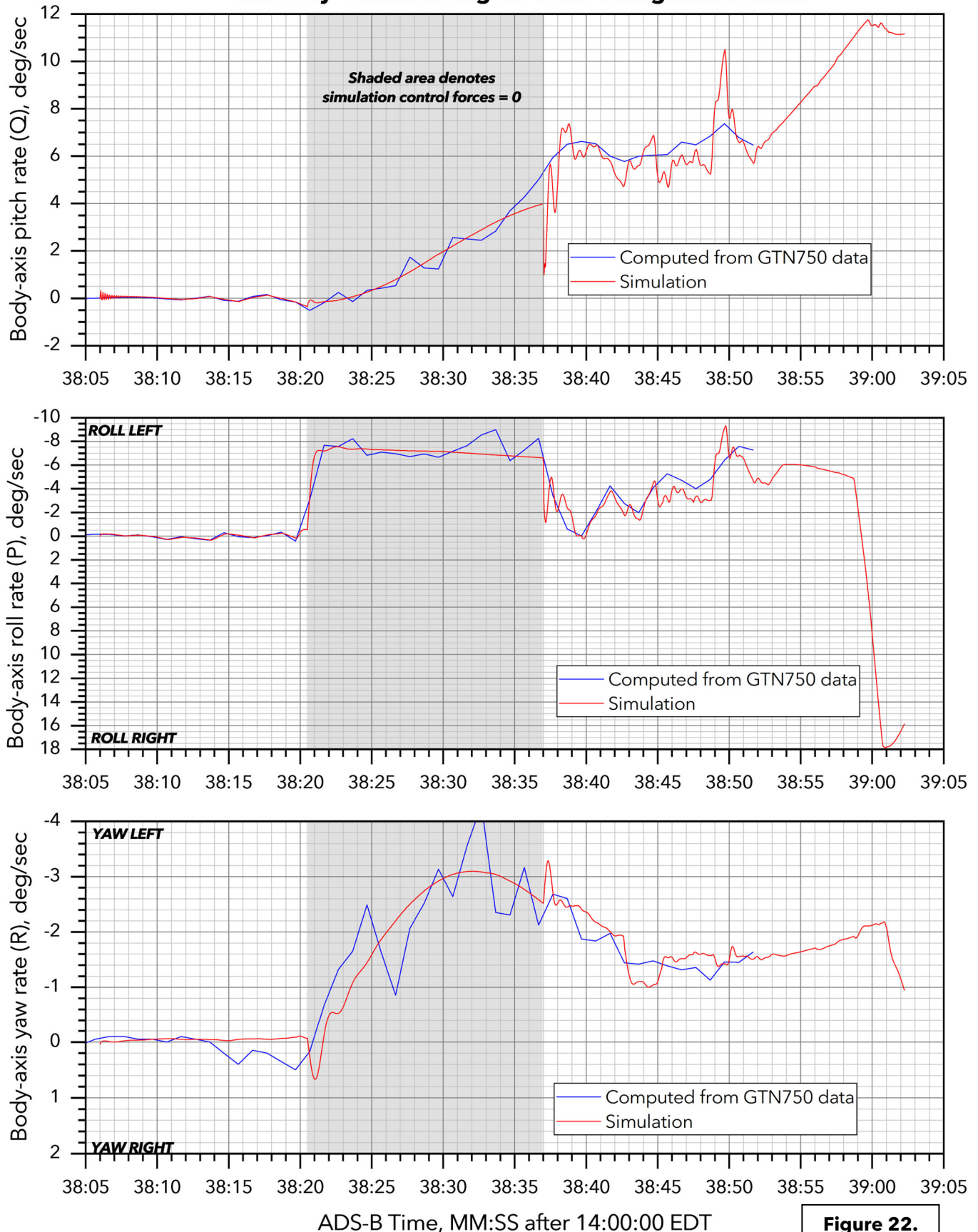


Figure 22.

CEN21FA376: Socata TBM-700, N700DT, Urbana, OH, 08/20/2021

"Recovery" scenario: Euler angle rates during final descent

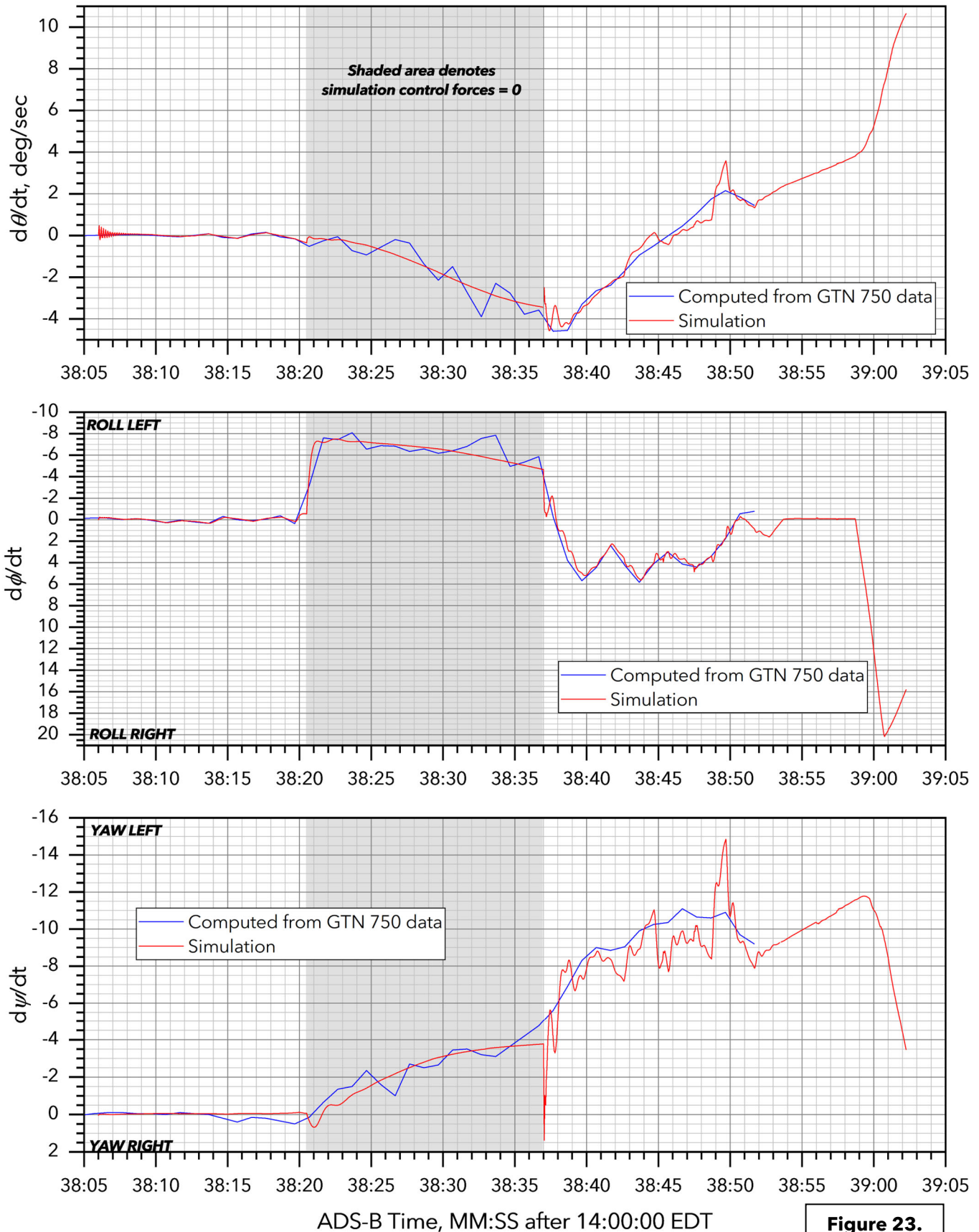


Figure 23.

CEN21FA376: Socata TBM-700, N700DT, Urbana, OH, 08/20/2021

"Recovery" scenario: load factors during final descent

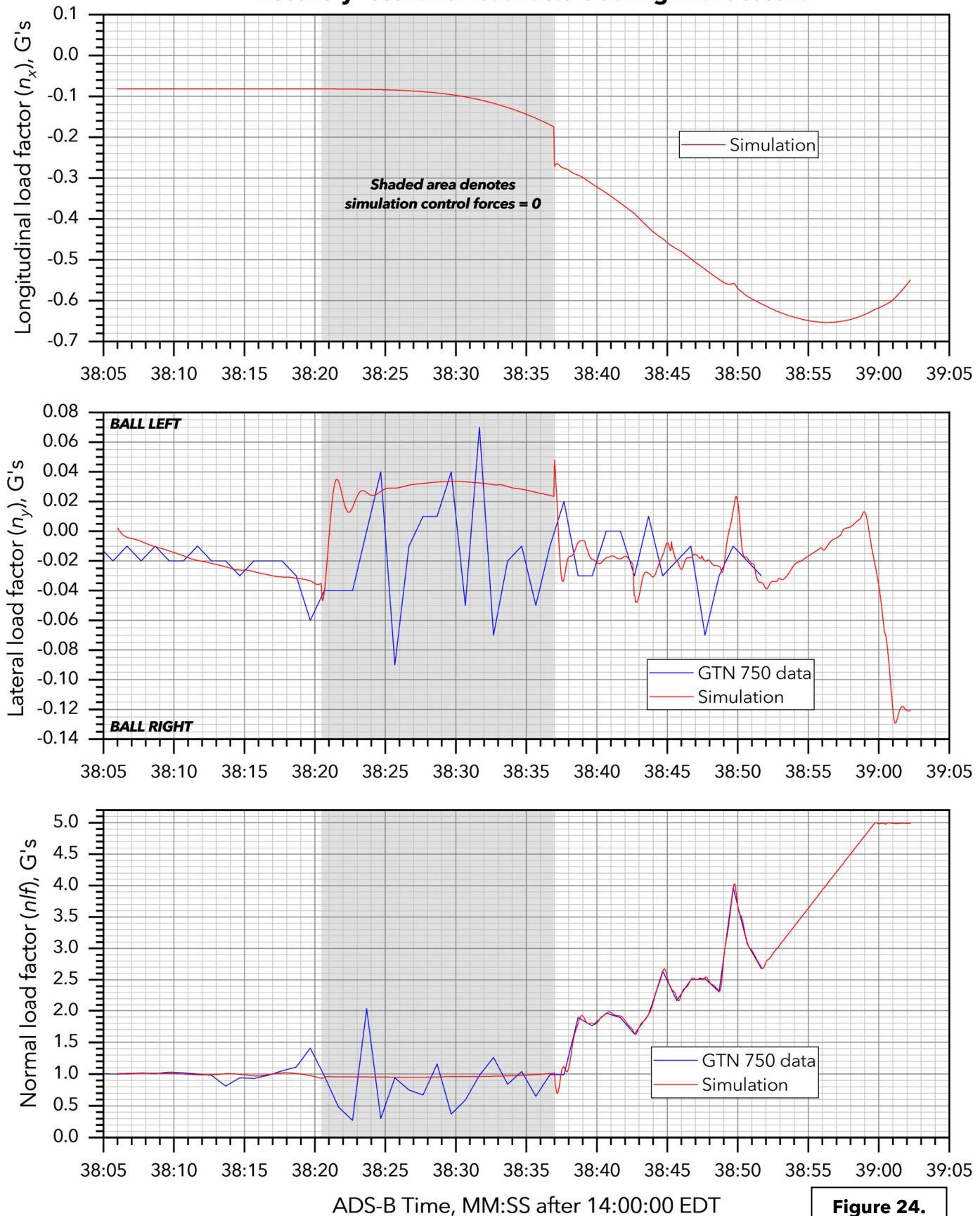


Figure 24.

CEN21FA376: Socata TBM-700, N700DT, Urbana, OH, 08/20/2021

"Recovery" scenario: flight controls during final descent

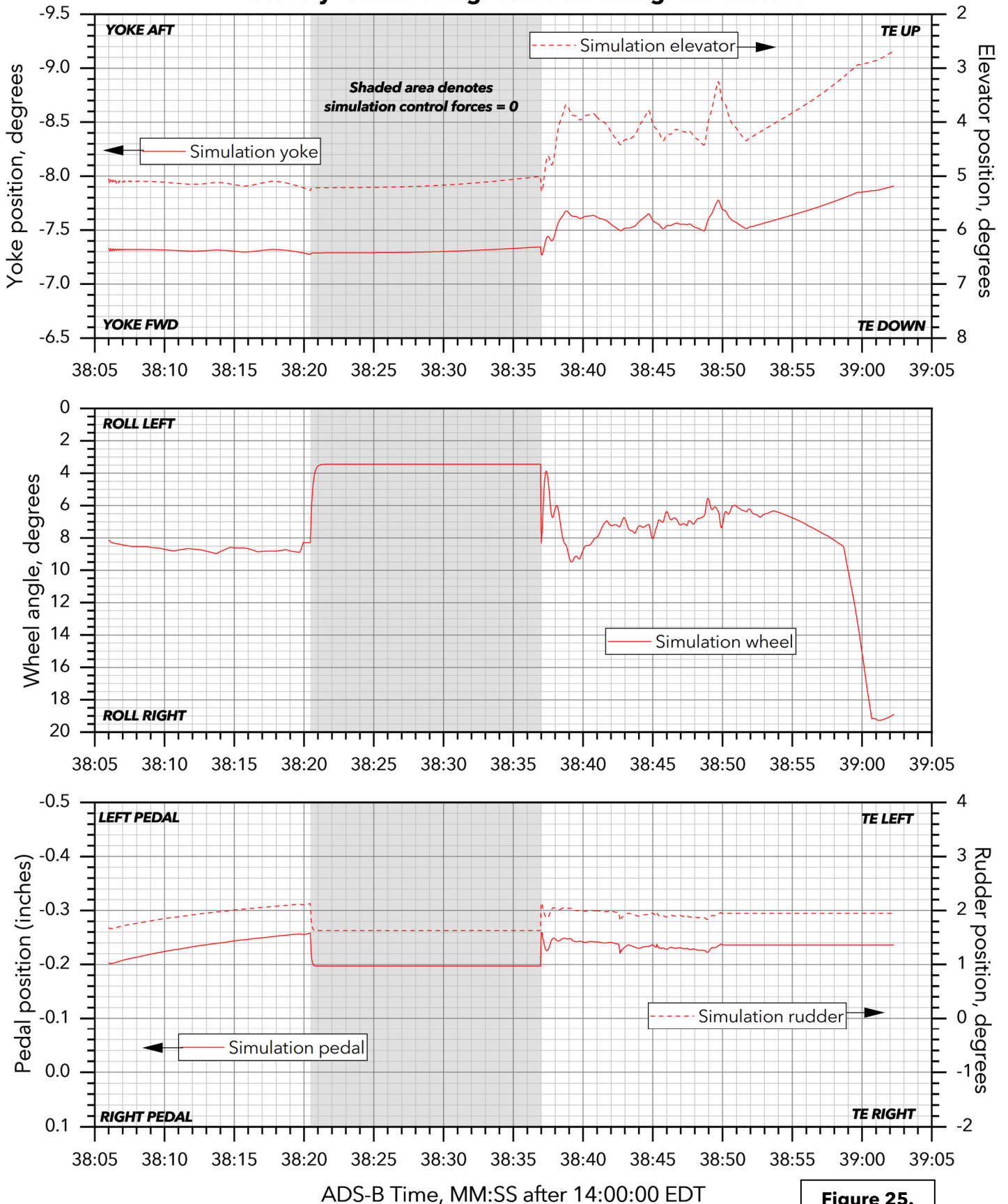


Figure 25.

CEN21FA376: Socata TBM-700, N700DT, Urbana, OH, 08/20/2021

"Recovery" scenario: control forces during final descent

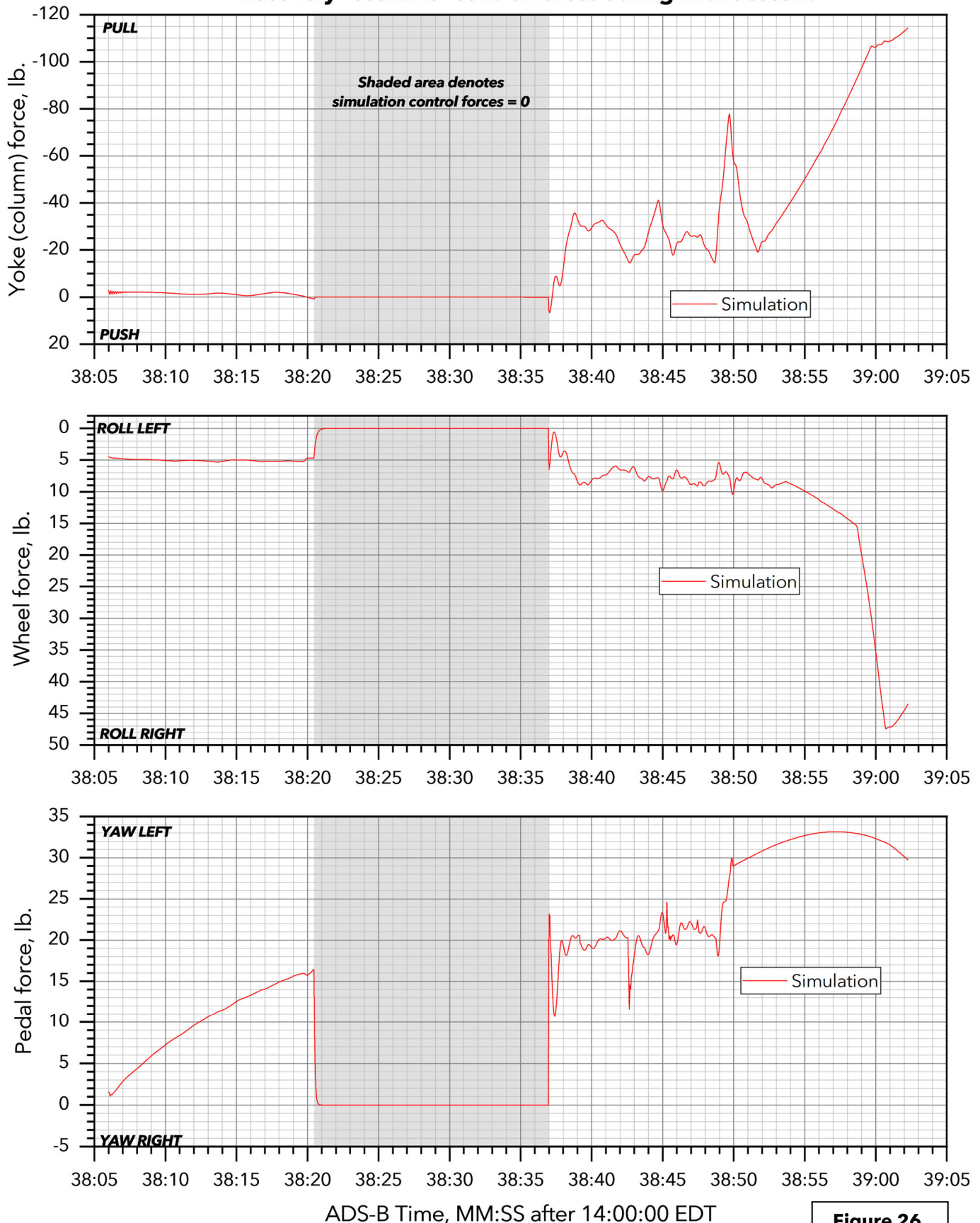
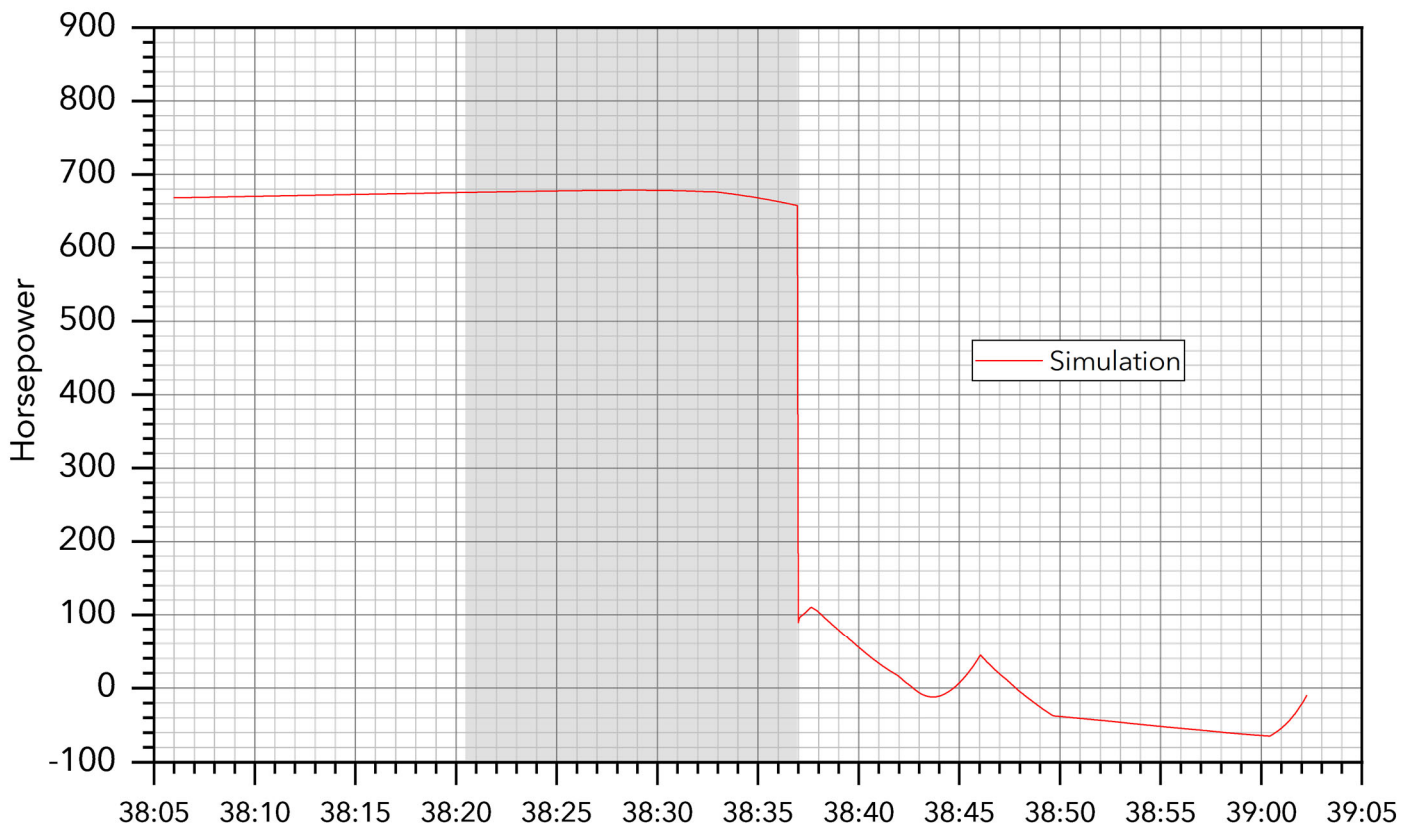
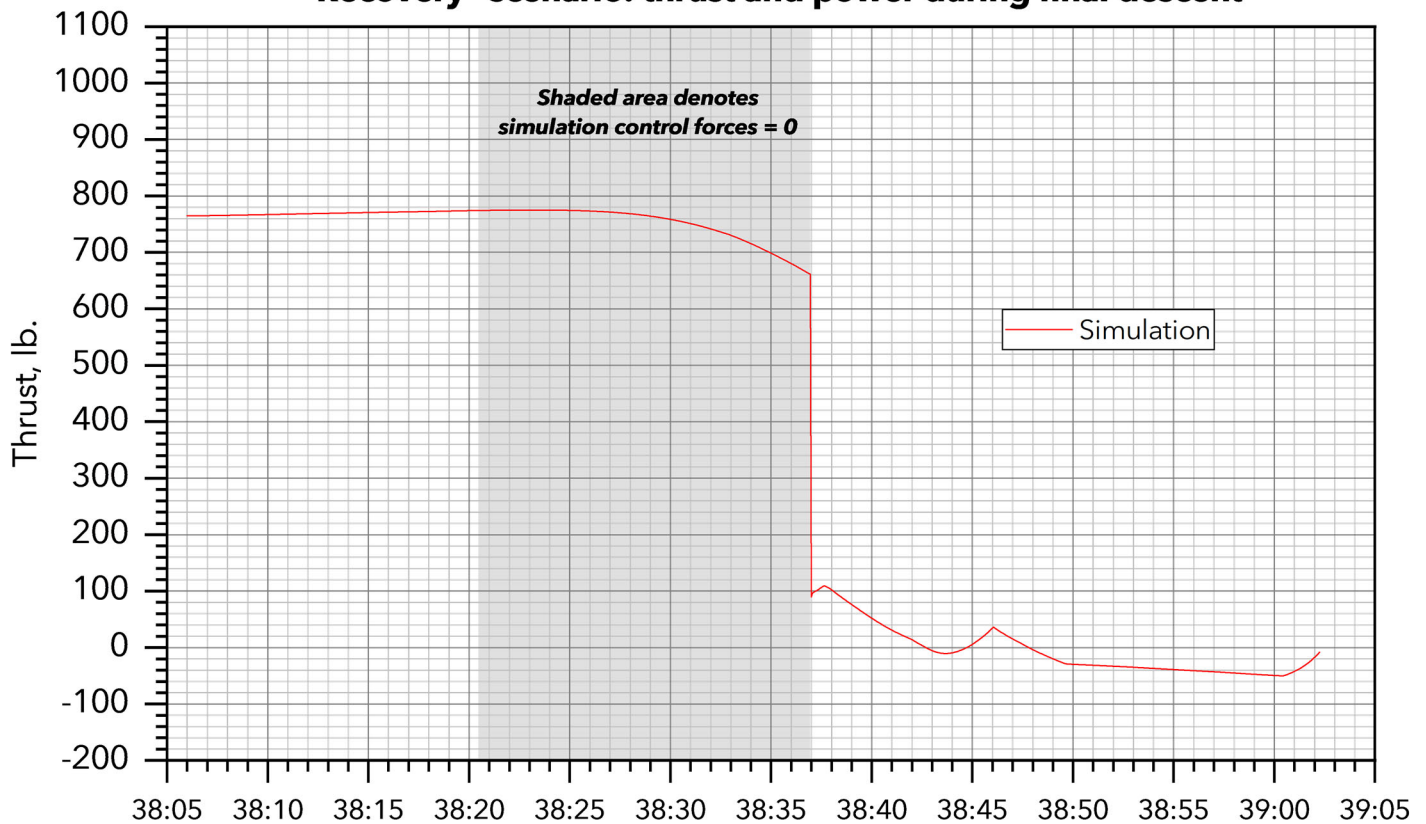


Figure 26.

CEN21FA376: Socata TBM-700, N700DT, Urbana, OH, 08/20/2021

"Recovery" scenario: thrust and power during final descent



ADS-B Time, MM:SS after 14:00:00 EDT

Figure 27.

CEN21FA376: Socata TBM-700, N700DT, Urbana, OH, 08/20/2021

Winds aloft from 19:00 UTC (15:00 EDT) HRRR model sounding & Garmin data

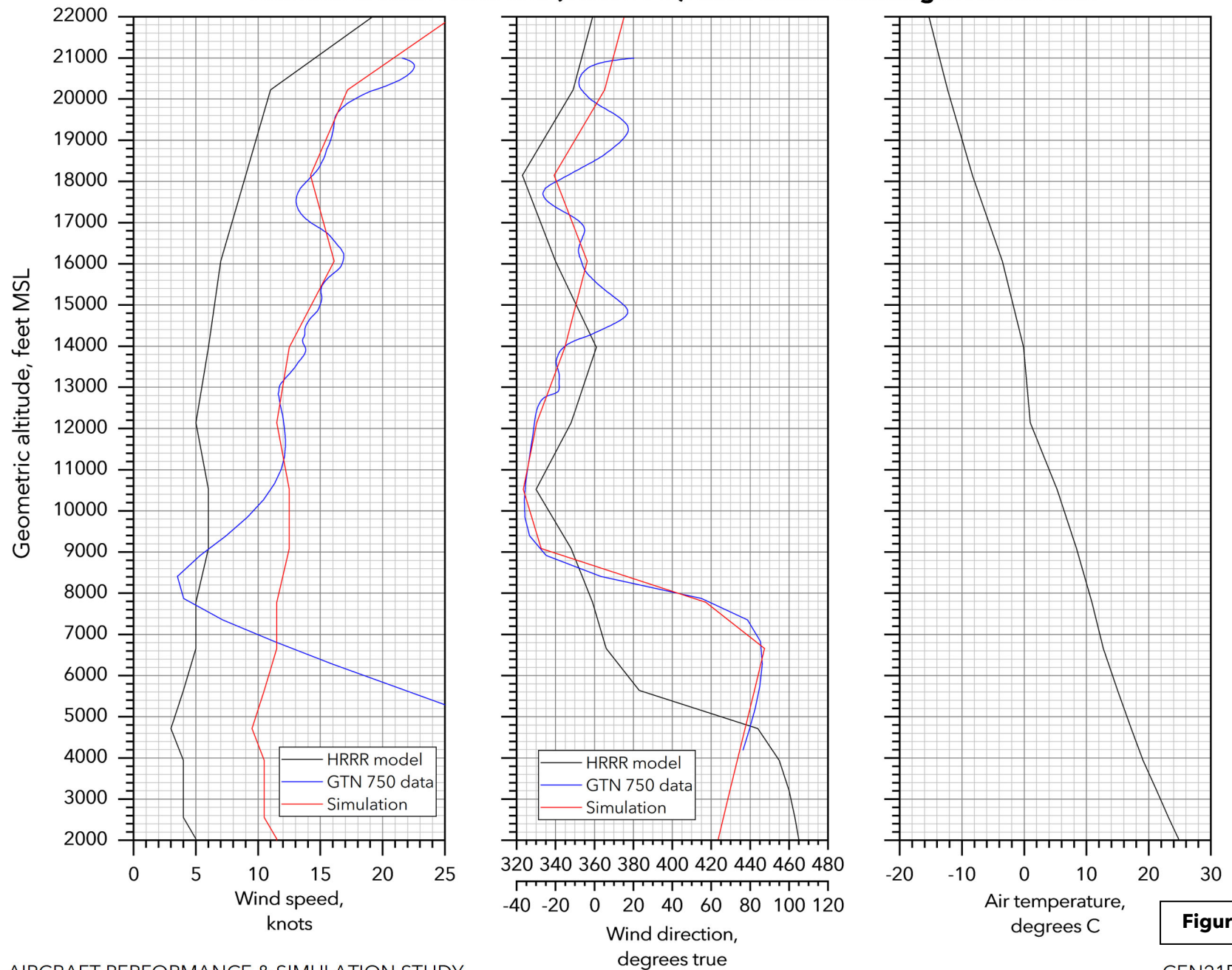


Figure 28.

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