NATIONAL TRANSPORTATION SAFETY BOARD

Office of Research and Engineering
Washington, D.C. 20594

May 30, 2013

Aircraft Performance GPS and Simulation Study

by John O'Callaghan

A. ACCIDENT

Location: Pellston, MI
Date: January 15, 2013
Time: 19:58 Eastern Standard Time (EST)
(00:58 Universal Coordinated Time (UTC) on January 16, 2013)[1]
Aircraft: Cessna 208B, registration N1120N
NTSB#: CEN13FA135

B. GROUP

Not Applicable

C. HISTORY OF FLIGHT

On January 15, 2013, about 19:58 EST (00:58 UTC on January 16), a Cessna 208B airplane, N1120N, was substantially damaged after colliding with trees shortly after takeoff from Pellston Regional Airport of Emmet County (KPLN), Pellston, Michigan. The certificated commercial pilot, the sole occupant, was fatally injured. The air cargo flight was operated by Martinaire Aviation, L.L.C. and was conducted under the provisions of 14 Code of Federal Regulations Part 135. Night visual meteorological conditions prevailed and a flight plan was filed. The flight originated from KPLN about 19:57 (00:58 UTC).

This Aircraft Performance GPS and Simulation Study presents the results of using data from a portable Garmin 696 Global Positioning System (GPS) unit carried aboard the airplane, evidence at the crash site, and simulation results to calculate the position and orientation of the airplane during the accident flight, and the consistency of this trajectory with the performance of the Cessna 208B.

A simulation of the flight that approximately matches the GPS data indicates that after lifting off at about 00:57:18 UTC, N1120N climbed at an average rate of about 600 ft./min. for about 24 seconds to about 960 ft. MSL, or about 240 ft. AGL. The rate of climb then decayed, and after reaching a peak altitude of about 980 ft. MSL (260 ft. AGL) at about 00:57:45, the airplane started to descend, and ultimately impacted terrain about 1 nmi west-southwest of the departure end of the runway. The exact time of the impact is not known, but using a constant throttle setting, the simulation flies from the last recorded GPS position at 00:57:58

[1] Local time at Pellston on the day of the accident was Eastern Standard Time (EST). EST = UTC - 5 hours. Times in this Study use the GPS time in UTC unless otherwise noted.

to the location and elevation of the impact site in about 15 seconds, putting the time of impact at about 00:58:13. The simulation rate of descent from 00:58:02 to the time of impact is between 650 and 680 ft./min.

The simulation indicates that the airplane was accelerating throughout the flight, from about 75 kts. groundspeed shortly after liftoff to about 145 kts. at impact. In addition, during the flight the airplane made a 42° right turn from the runway heading of 225° true to about 267° true. The peak simulation bank angle during this turn was 12.3°, at 00:57:51.3. At impact, the simulation indicates an airspeed of 156 KCAS, a pitch angle of -2°, and a bank angle of 4.5°.

Throughout the simulation, a constant throttle setting of 72% of full-throttle was maintained. This throttle setting resulted in the best match of the GPS and impact site data. The resulting shaft horsepower (SHP) developed by the engine was between 520 and 540 SHP, corresponding to an engine torque between 1518 ft.-lb. and 1570 ft.-lb..

The simulation was run for one of the four estimated loading scenarios provided by Martinaire. The resulting CG position was within limits, and the required elevator positions are well within the elevator travel limits. The other three loading scenarios provided by Martinaire are also within CG limits, and would not affect the required elevator positions significantly.

D. DETAILS OF THE INVESTIGATION

I. Airplane position based on GPS data

The Garmin GPSMAP 696 unit carried aboard N1120N, and the data extracted from that device, is described in detail in the *GPS Factual Report* (Ref. 1). According to Ref. 1,

> The Garmin GPSMAP 696 is a battery-powered portable multi-function display and GPS receiver with a 7-inch diagonal high resolution LCD display screen. The unit includes a built-in Jeppesen database and is capable of receiving XM satellite radio for flight information including NEXRAD Radar, lightning, METARs, TAFs, and TFRs. The unit can also perform and store weight and balance calculations. A built-in AOPA Airport Directory and SafeTaxi airport diagrams are included for selected airfields. The unit stores date, route-of-flight, and flight-time information for up to 50 flights. A flight record is triggered when groundspeed exceeds 30 knots and altitude exceeds 250 feet, and ends when groundspeed drops below 30 knots for 10 minutes or more. A detailed track log – including latitude, longitude, date, time, and GPS altitude information for an unspecified number of points – is stored within the unit whenever the receiver has a lock on the GPS navigation signal. Position is updated within the track log as a function of time or distance moved, depending on how the unit has been configured. Once the current track log memory becomes full, new information either overwrites the oldest information or recording stops, depending on how the unit is configured. The current track log can be saved to long-term memory and 15 saved track logs can be maintained in addition to the current track log. Track log storage may be activated or de-activated at user discretion. All recorded data is stored in non-volatile memory. The unit contains hardware and software permitting the download of recorded waypoint, route, and track log information to a PC via a built-in USB port. An internal button-battery is used to [provide] back-up power to the internal memory and real-time clock during those periods when main power is removed.

Ref. 1 indicates that data from the accident flight, consisting of 20 data points, was successfully extracted from the GPS device. The recorded GPS data is presented in Table 1, and is plotted in various Figures in this Study, as described below.

Presentation of the GPS data

To calculate performance parameters from the GPS data (such as ground speed, track angle, pitch and roll angles, etc.), it is convenient to express the position of the airplane in rectangular Cartesian coordinates. The Cartesian coordinate system used in this Study is centered at the KPLN runway 23 threshold and its axes extend east, north, and up from the center of the Earth. The GPS latitude and longitude data is converted into this coordinate system (using the WGS84 ellipsoid model of the Earth) for plotting and performance calculations. The latitude and longitude of the KPLN runway 23 threshold are:

45° 34' 40.5083" N latitude; 084° 47' 16.5731" W longitude; elevation 720.4 ft..

The north and east coordinates of the GPS points relative to the threshold are also listed in Table 1.

Time (UTC)	Latitude	Longitude	Altitude (ft. MSL)	Distance north of rwy 23 (nmi)	Distance east of rwy 23 (nmi)
00:54:28	45° 34' 11.964" N	084° 47' 14.316" W	716	-0.4759	0.0264
00:54:46	45° 34' 12.684" N	084° 47' 17.160" W	713	-0.4639	-0.0069
00:54:53	45° 34' 12.828" N	084° 47' 18.708" W	713	-0.4615	-0.0250
00:55:03	45° 34' 14.160" N	084° 47' 19.500" W	718	-0.4392	-0.0343
00:55:20	45° 34' 17.868" N	084° 47' 19.176" W	719	-0.3774	-0.0305
00:55:37	45° 34' 20.676" N	084° 47' 18.960" W	719	-0.3306	-0.0279
00:55:56	45° 34' 25.500" N	084° 47' 18.672" W	719	-0.2502	-0.0246
00:56:21	45° 34' 32.664" N	084° 47' 18.240" W	719	-0.1308	-0.0195
00:56:39	45° 34' 37.128" N	084° 47' 17.916" W	723	-0.0564	-0.0157
00:56:41	45° 34' 37.416" N	084° 47' 17.988" W	721	-0.0516	-0.0166
00:56:51	45° 34' 38.136" N	084° 47' 19.536" W	724	-0.0395	-0.0347
00:56:59	45° 34' 37.344" N	084° 47' 21.084" W	724	-0.0528	-0.0528
00:57:06	45° 34' 35.184" N	084° 47' 24.180" W	719	-0.0888	-0.0891
00:57:12	45° 34' 31.584" N	084° 47' 29.184" W	718	-0.1488	-0.1476
00:57:19	45° 34' 25.860" N	084° 47' 37.212" W	732	-0.2442	-0.2416
00:57:29	45° 34' 16.176" N	084° 47' 50.244" W	852	-0.4056	-0.3942
00:57:39	45° 34' 06.132" N	084° 48' 04.968" W	945	-0.5730	-0.5667
00:57:45	45° 34' 00.624" N	084° 48' 16.056" W	988	-0.6648	-0.6965
00:57:51	45° 33' 55.944" N	084° 48' 30.060" W	940	-0.7428	-0.8605
00:57:58	45° 33' 52.056" N	084° 48' 48.204" W	883	-0.8076	-1.0730

Table 1. Garmin GPSMAP 696 data points for the accident flight.

Figures 1 & 2 show the GPS data plotted in terms of nautical miles north and east of the runway 23 threshold. Figure 1 shows the data with a Cartesian grid background, and Figure 2 shows the data with a Google Earth satellite image background.

A three-dimensional Google Earth representation of the simulation solution that approximately matches the GPS and crash site data is shown in Figure 3. The labels in the Figure indicate the time, altitude, and calibrated airspeed corresponding to the position of the airplanes in the Figure. The orientation of the airplanes (drawn larger than their correct proportions for greater visibility) indicate the heading, pitch, and roll angles computed by the simulation at those points. The simulation is described in detail in Section D-IV.

The north and east positions of the GPS data are shown as a function of time in Figure 4, along with the simulation positions. The altitude of the airplane, as determined from the GPS data, is shown as a function of time in Figure 5, along with the simulation altitude.

II. Crash site information

The latitude and longitude coordinates of the crash site, and of significant elements of the debris field, were recorded on-scene by NTSB investigators. The first impact point is about 0.58 nmi (3520 ft.) west of the last GPS data point, and the main wreckage came to rest about .06 nmi (364 ft.) west of the first impact point. The latitude / longitude coordinates of the first impact point and main wreckage locations are:

First impact: 45° 33’ 50.4” N, 084° 49’ 37.2” W, elevation 714 ft. MSL
Main wreckage: 45° 33’ 50.7” N, 084° 49’ 42.3” W, elevation 714 ft. MSL

III. Weight and balance information

NTSB investigators were not able to discover an aircraft weight and balance form completed by the pilot for the accident flight. The Chief Pilot for Martinaire provided investigators with weight and balance forms for four possible loading scenarios of the accident airplane. The total ramp weight for each of these scenarios was 6770 lb., and the CG travel ranged from 190.9 inches aft of datum to 202.6 inches aft of datum. According to the weight and balance forms, the maximum ramp weight for N1120N was 8785 lb.. At 6770 lb., the allowable CG range extended from 186.6 to 204.35 inches aft of datum, so both the ramp weight and the CG positions for all four scenarios lie in the allowable ranges of weight and CG. For the simulation, the loading scenario depicted in Table 2 was selected, which corresponds to a ramp weight of 6770 lb. and a CG position of 191.1 inches aft of datum. A three-view drawing of the Cessna 208B, taken from the Pilot’s Operating Handbook (POH), is shown in Figure 6. POH depictions of the six cabin cargo zones, their moment arms, and the airplane center of gravity limits are presented in Figures 7 and 8.

Item	Weight, lb	Arm, in.	Moment/1000, in*lb
Airplane empty	4792	190.2	911.4
Pilot	200	135.5	27.1
Passenger	0	135.5	0
Fuel	1200	206.4	247.7
Zone 1	400	172.0	68.8
Zone 2	178	217.8	38.8
Zone 3	0	264.4	0
Zone 4	0	294.5	0
Zone 5	0	319.5	0
Zone 6	0	344.0	0
Total	**6770**	**191.1**	**1293.8**

Table 2. Simulation weight and balance scenario.

IV. Airplane performance calculations based on flight simulation

The GPS only recorded 6 points during which the airplane was clearly airborne, and the last data point was recorded 0.58 nmi east of the impact site; consequently, the GPS data does not provide a very detailed picture of the performance of the airplane during the whole flight. To obtain a more detailed estimate of performance throughout the flight, and to confirm the consistency of the recorded GPS data with the performance capabilities of the airplane, a six degree-of-freedom (6-DOF) simulation of the flight was performed. The objective of the simulation was to obtain a physics-based estimate of the trajectory and orientation of the airplane throughout the flight that is consistent with the performance capabilities of the Cessna 208B, and with the GPS and crash site information described above. These information sources constrain acceptable simulation solutions, as follows:

GPS data: The position of the airplane in the simulation solution should coincide with the GPS points at the times corresponding to those points, and the simulation altitude should coincide with the GPS altitude, within reasonable time and position uncertainty limits of the GPS data.

Crash site data: The simulation impact site should match the location of the first impact point, and the impact heading should have a large westerly component.

Performance data: The simulation should be representative of the Cessna 208B aerodynamics and engine thrust capabilities. Validated aerodynamics and engine simulation models provided by Kohlman Systems Research were used for this Study. The simulation engine power was set so as to provide a constant throttle setting throughout the flight (a throttle setting of 72% of maximum resulted in the best match of the GPS data).

A constant wind from 210° true at 15 knots, and a temperature of -3° C (26.6° F, or 29.9° F below standard temperature at the impact elevation of 714 ft.) is used in the simulation. These values are generally consistent with the METAR reports for KPLN surrounding the time of the accident; see Table 3. The constant wind at 15 kts. is used as a rough estimate of an “average” wind that corresponds to the METAR winds of 10-12 kts. with gusts to 16-17 kts..

Report time	Wind direction (true)	Wind speed (kts.)	Temperature (°C)	Sky condition (clouds)
23:54 UTC	210°	10 gusting 16	-3	Broken @ 3600 & 4800 ft. Overcast @ 5500 ft.
01:54 UTC	210°	12 gusting 17	-3	Overcast @ 5000 ft.

Table 3. METAR reports for KPLN. No report was recorded at 00:54 UTC (near the time of the accident).

The simulation uses a “math pilot” to generate control system inputs to produce pitch and roll angles that result in an approximate match of the GPS data, the impact point, and the general impact heading described above. Since the lift and drag characteristics in the simulation are representative of the airplane, the angle of attack, pitch, and roll angles computed by the simulation to match the target track are relevant and of interest, and are discussed below.

Per the NTSB Investigator In Charge (IIC’s) field notes (Ref. 2), the flap setting at impact was determined to be 0°. The Cessna (POH) procedure for takeoff flap management is as follows:

- Set flaps to 20° for takeoff
- Retract flaps to 10° at 85 kts. and positive climb rate
- Retract flaps to 0° at 95 kts. and positive climb rate

According to Ref. 2, the Martinaire procedure is as follows:

- Set flaps to 20° for takeoff
- At 500 ft. AGL, retract flaps to 10° with 85 kts. and positive climb rate
- At 1000 ft. AGL, retract flaps to 0° with 95 kts. and positive climb rate

The simulation starts at time 00:57:19, corresponding to the first GPS data point at which the airplane is clearly airborne. At this point, the airspeed is already 91 KCAS, and so the simulation starts with the flaps already at 10°, and transitions the flaps to 0° as the airplane accelerates through 95 KCAS. A retraction rate of 3.1°/sec. is assumed.

The simulation results are presented in Figures 1-5 and 9-13. The results meet the objectives outlined above very well; as shown in Figures 1 and 2, the position of the airplane differs from the GPS data by at most 0.013 nmi (80 ft.), and the impact is nearly coincident with the first impact point. At impact, the track of the airplane is about 271°, which is essentially due west. Figure 5 shows that the simulation altitude is within 16 ft. of the GPS points everywhere.

Figure 9 shows the speeds computed by the simulation. Note that the simulation ground speed matches the ground speed computed from the GPS data well, except at the last point (this because the speed at the last point is computed as the average speed between the second to last point and the last point, whereas the speeds at other points correspond to the average speed between the points immediately preceding and following the point in question). As mentioned, at the start of the simulation the airspeed is about 91 KCAS. During the climb to 980 ft MSL, the airplane accelerates to about 118 KCAS, and during the descent accelerates further to 156 KCAS at impact. The rate of climb during the ascent averages about 600 ft./min., and after 00:57:40 starts to drop rapidly, to about -680 ft./min. at impact.

Figure 10 shows the Euler angles computed by the simulation. During the climb, the pitch angle averages about 8° between 00:57:19 and 00:57:33, and the flight path angle averages about 4°. After 00:57:33, the pitch angle and flight path angle start to decrease; the pitch angle reaches -1° at 00:57:51, and remains between -1° and -2° until impact. Similarly, the flight path angle decreases to -2° at 00:57:50, and remains between -2° and -3° until impact. The right turn starts immediately at 00:57:19, with the airplane gradually rolling to a maximum roll angle of 12.3° (right) at about 00:57:51.3. During the descent, the airplane rolls back to the left slightly, reaching a roll angle of about 4.5° at impact.

Figure 10 also presents the “Apparent pitch angle” and “Apparent roll angle” that would result from the load factors computed by the simulation, which are presented in Figure 11. These are the pitch and roll angles that an airplane in unaccelerated flight (or equivalently, a pilot seated in a gimbaled chair on the ground) would require to produce load factors in each of the airplane body axes proportional to those plotted in Figure 11. In other words, these are the pitch and roll angles that make the load factor vector in the static case parallel (in airplane body axes) to the load factor vector in the actual accelerated flight case, and represent 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. The calculation of these angles is described in Section D-V.

Figure 12 shows the engine power parameters computed by the simulation. As described above, power in the simulation was set to the constant throttle position that resulted in the best match of the GPS data (72% of maximum throttle). Since the simulation flight path matches the GPS data well, it is likely that the power computed by the simulation is representative of the power present on the accident flight.

The top graph in Figure 12 indicates that the power delivered to the airframe (thrust times speed) is less than the shaft horsepower delivered by the engine. The reason for this is that the propeller efficiency is less than 1, as shown in the bottom graph of Figure 12. In fact, the plot shows that the propeller efficiency at low airspeeds is considerably lower than at higher airspeeds[2].

Figure 13 shows the flap and elevator positions computed by the simulation. The top graph shows the flaps starting at 10° and then transitioning to 0° as the airplane accelerates through 95 KCAS, per the POH schedule as described above.[3] The bottom graph shows the simulation elevator positions, which are well within the available elevator deflection range.

V. Calculation of the "apparent" pitch and roll angles

As described above, the "apparent" pitch and roll angles presented in Figure 10 represent 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 load factor 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 be a source of spatial disorientation.

Figure 14 shows the orientation of the resultant load factor vector $\vec{n}$ for two cases: in Figure 14a, the airplane is in accelerated flight, and $\vec{n}$ has a component along the x_b axis (n_x). In Figure 14b, the airplane is unaccelerated, and $\vec{n}$ is aligned with the gravity vector $\vec{g}$, along the earth's vertical axis (z_e). In both cases, the angle of the vector $\vec{n}$ relative to the airplane's vertical axis (z_b) is the same: θ_{APP}. In Figure 14b, θ_{APP} is also the actual pitch angle of the airplane axis system, but in Figure 14a, the actual pitch angle θ is less than θ_{APP}. However, in both cases the pilot's vestibular / kinesthetic system perceives the pitch angle as θ_{APP}. Hence, the perceived θ_{APP} matches the actual pitch angle θ only when $\vec{n}$ is aligned with $\vec{g}$ – i.e., when n_x and n_y are zero.

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[2] The "Power delivered to airframe" curve in Figure 12 is slightly higher than the product of the engine shaft horsepower and the propeller efficiency. The reason for this is that a small portion of the thrust of the engine comes from the "jet thrust" of the turboprop, and is not affected by the propeller efficiency.

[3] Figure 13 plots the actual, physical flap deflection angles used in the simulation, which differ slightly from the "nominal" flap positions used in the POH. Thus, a nominal flap setting of 10° corresponds to an actual flap deflection angle of 8.4°.

To compute θ_{APP} and ϕ_{APP}, we seek the pitch and roll angles in an unaccelerated axis system that will produce a vector $\vec{n}$ parallel (in airplane body axes) to the vector $\vec{n}$ in the accelerated system. In the unaccelerated system, $\vec{n}$ has Earth-axis components $\{0, 0, -g\}$, or equivalently

$$\vec{n} = \begin{pmatrix} 0 \\ 0 \\ -|\vec{n}| \end{pmatrix}_{EARTH} \qquad [1]$$

where

$$|\vec{n}| = \sqrt{(n_x)^2 + (n_y)^2 + (n_z)^2} = g \qquad [2]$$

Transforming these components into airplane body axis gives

$$\vec{n} = -|\vec{n}| \begin{pmatrix} -\sin\theta \\ \sin\phi\cos\theta \\ \cos\phi\sin\theta \end{pmatrix}_{BODY} \qquad [3]$$

Considering now the accelerated case, the magnitude of the load factor vector $\vec{n}$ will not, in general, equal the acceleration due to gravity (g). However, we seek θ_{APP} and ϕ_{APP} such that when the airplane body axis is oriented with these angles in an unaccelerated system (while preserving the magnitude of the load factor vector $\vec{n}$), the resulting body-axis components of $\vec{n}$ will match the load factors n_x, n_y, and n_z from the accelerated case. From equation [3],

$$|\vec{n}| \begin{pmatrix} \sin\theta_{APP} \\ -\sin\phi_{APP}\cos\theta_{APP} \\ -\cos\phi_{APP}\sin\theta_{APP} \end{pmatrix}_{BODY} = \begin{pmatrix} n_x \\ n_y \\ n_z \end{pmatrix} \qquad [4]$$

θ_{APP} and ϕ_{APP} can now be calculated as:

$$\theta_{APP} = \sin^{-1}\left(\frac{n_x}{|\vec{n}|}\right) \qquad [5]$$

$$\phi_{APP} = \sin^{-1}\left(\frac{-n_y}{|\vec{n}|\cos\theta_{APP}}\right) \qquad [6]$$

The results of these calculations are shown in Figure 10. Note that throughout the flight, the apparent roll angle ϕ_{APP} is close to zero (about 1°), and that the apparent pitch angle θ_{APP} is always greater than zero – even when the real pitch angle is less than zero. This suggests that conditions that could have produced a somatogravic illusion of a climb, even when the airplane was in a descent, may have been present during the accident flight.

E. CONCLUSIONS

This Aircraft Performance GPS and Simulation Study presents the results of using data from a portable GPS unit, crash site information, and a simulator model of the Cessna 208B as the basis for a simulation that provides a physics-based estimate of the position and orientation of the airplane throughout the accident flight. The performance observations noted here are based on the results of this simulation.

The first GPS point showing N1120N clearly airborne was recorded at 00:57:29 as the airplane was climbing at about 700 ft./min. through about 730 ft. MSL (14 ft. AGL), on a track of about 223° true, and accelerating through 91 KCAS. N1120N continued accelerating while climbing at about 500-700 ft/min to an altitude of about 960 ft. MSL (240 ft AGL). The rate of climb then decayed, and after reaching a peak altitude of about 980 ft. MSL (260 ft. AGL) at about 00:57:45, the airplane started to descend, and ultimately impacted terrain about 1 nmi west-southwest of the departure end of the runway. The exact time of the impact is not known, but the simulation flies from the last recorded GPS position to the location and elevation of the impact site in about 15 seconds, putting the time of impact at about 00:58:13. The simulation rate of descent from 00:57:52 to the time of impact is about 650 to 680 ft./min. The elapsed time from the start of the simulation at 00:57:19 to impact is 54 seconds.

The simulation indicates that the airplane was accelerating throughout the flight, from about 75 kts. groundspeed shortly after liftoff to about 145 kts. at impact. In addition, the airplane entered a right bank almost immediately after liftoff, and during the flight made a 42° right turn from the runway heading of 225° true to about 267° true. The peak simulation bank angle during this turn was 12.3°. At impact, the simulation indicates an airspeed of 156 KCAS, a pitch angle of -2°, and a bank angle of 4.5°.

Throughout the simulation, a constant throttle setting of 72% of full-throttle was maintained. This throttle setting resulted in the best match of the GPS and impact site data. Since the simulation flight path matches the GPS data well, it is likely that the power computed by the simulation is representative of the power present on the accident flight.

The load factors output by the simulation were used compute “apparent” pitch and roll angles, defined as the angles that make the load factor vector in an unaccelerated reference system parallel (in airplane body axes) to the load factor vector in the actual accelerated reference system. These angles represent 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. Throughout the flight, the apparent roll angle is close to zero, and the apparent pitch angle is always greater than zero – even when the real pitch angle is less than zero. This suggests that conditions that could have produced a somatogravic illusion of a climb, even when the airplane was in a descent, may have been present during the accident flight.

John O’Callaghan
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F. REFERENCES

1. National Transportation Safety Board, Office of Research and Engineering, *GPS Factual Report, Cessna 208 N1120N*, *Pellston, MI, January 15, 2013*, NTSB Accident Number CEN13FA135, Docket Item 2 (Washington, DC: NTSB, May 15, 2013). (Contact NTSB at pubinq@ntsb.gov).

2. National Transportation Safety Board, Office of Aviation Safety, *Field Notes, Cessna 208 N1120N*, *Pellston, MI, January 15, 2013*, NTSB Accident Number CEN13FA135.

FIGURES

CEN13FA135: Cessna 208B, N1120N, Pellston, MI, 01/15/2013
Flight path relative to KPLN runway 23

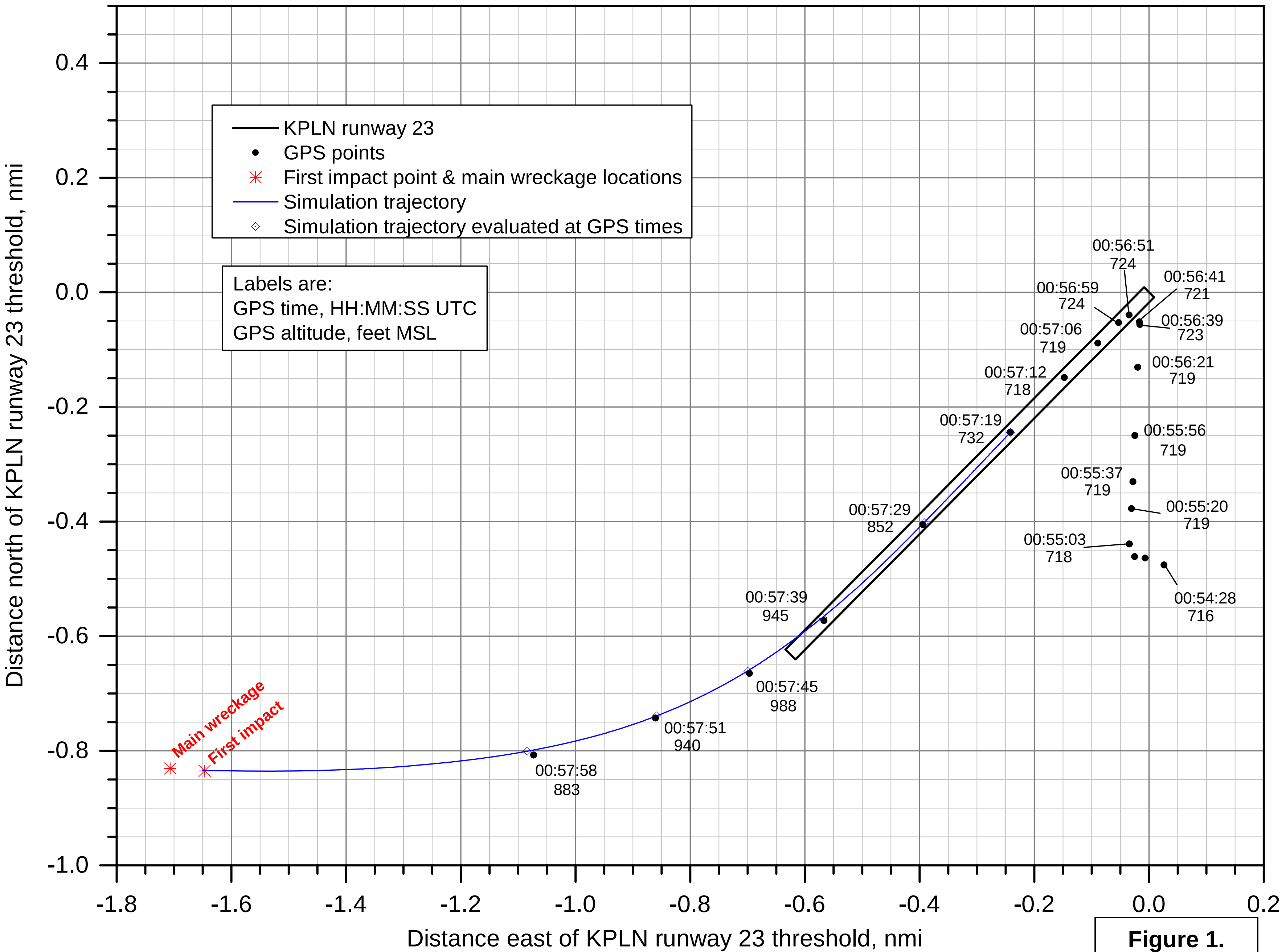


Figure 1.

CEN13FA135: Cessna 208B, N1120N, Pellston, MI, 01/15/2013
Flight path relative to KPLN runway 23

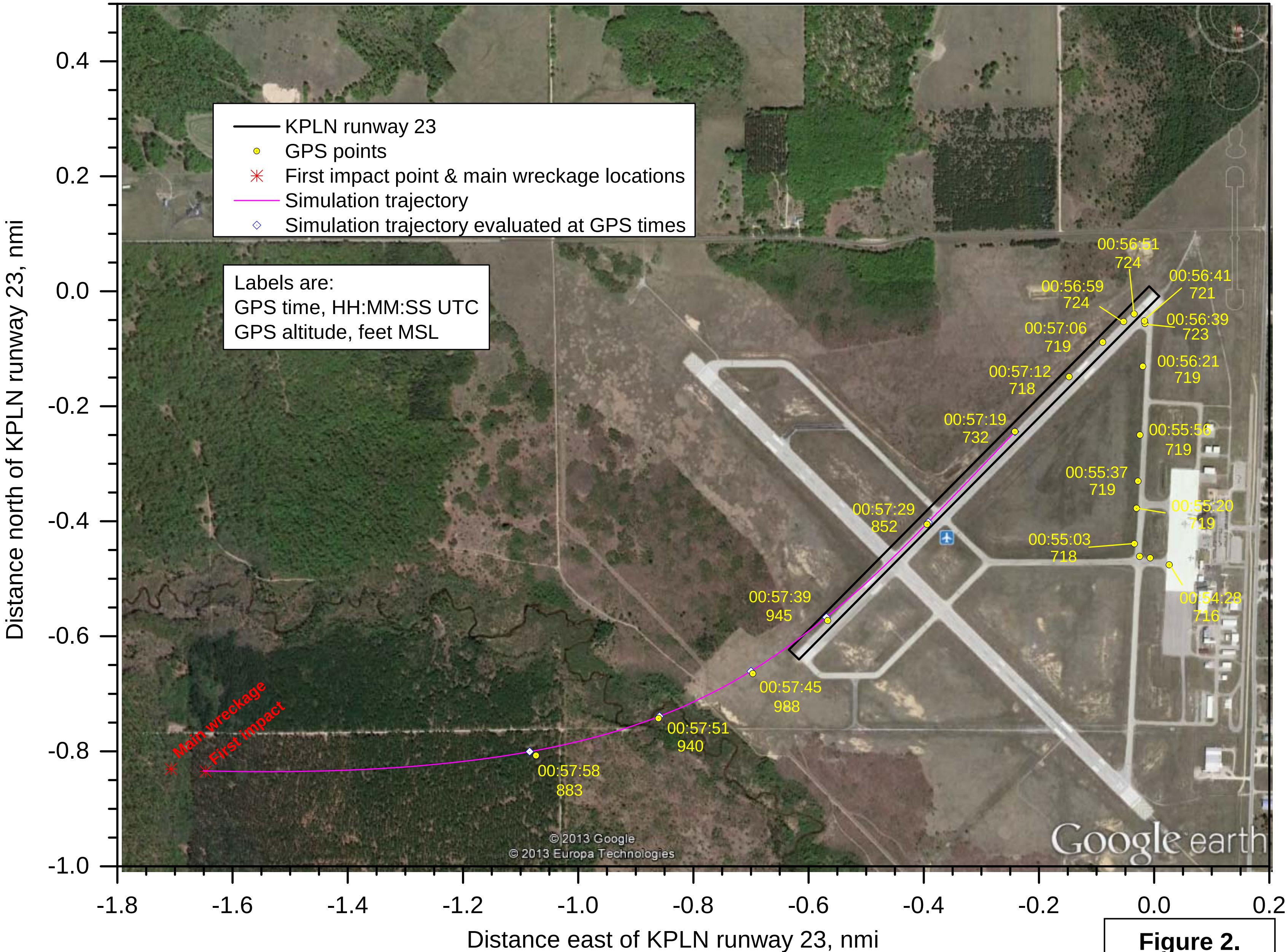
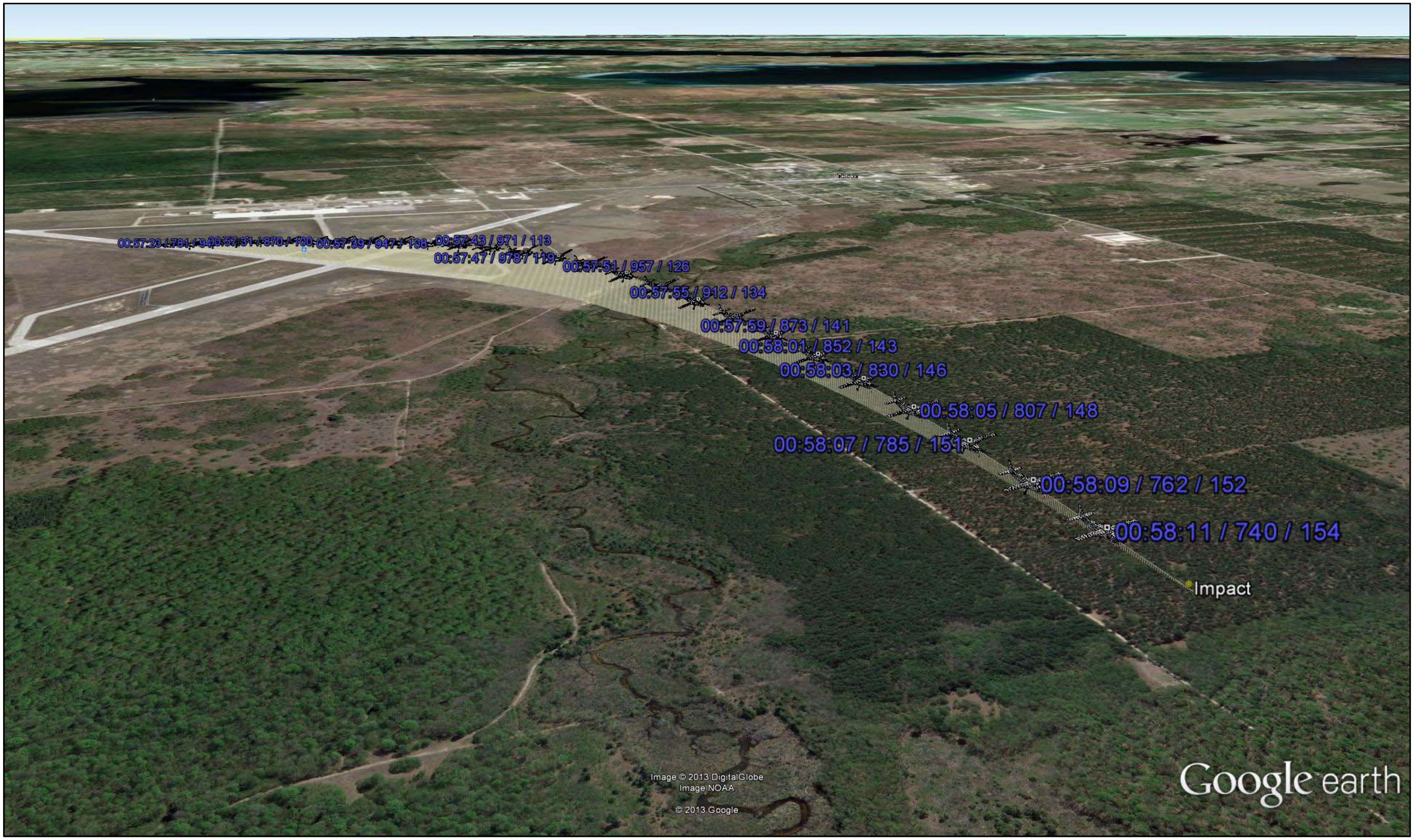


Figure 2.



NOTE: Airplane figures are drawn larger than their correct proportions for greater visibility.

Figure 3.

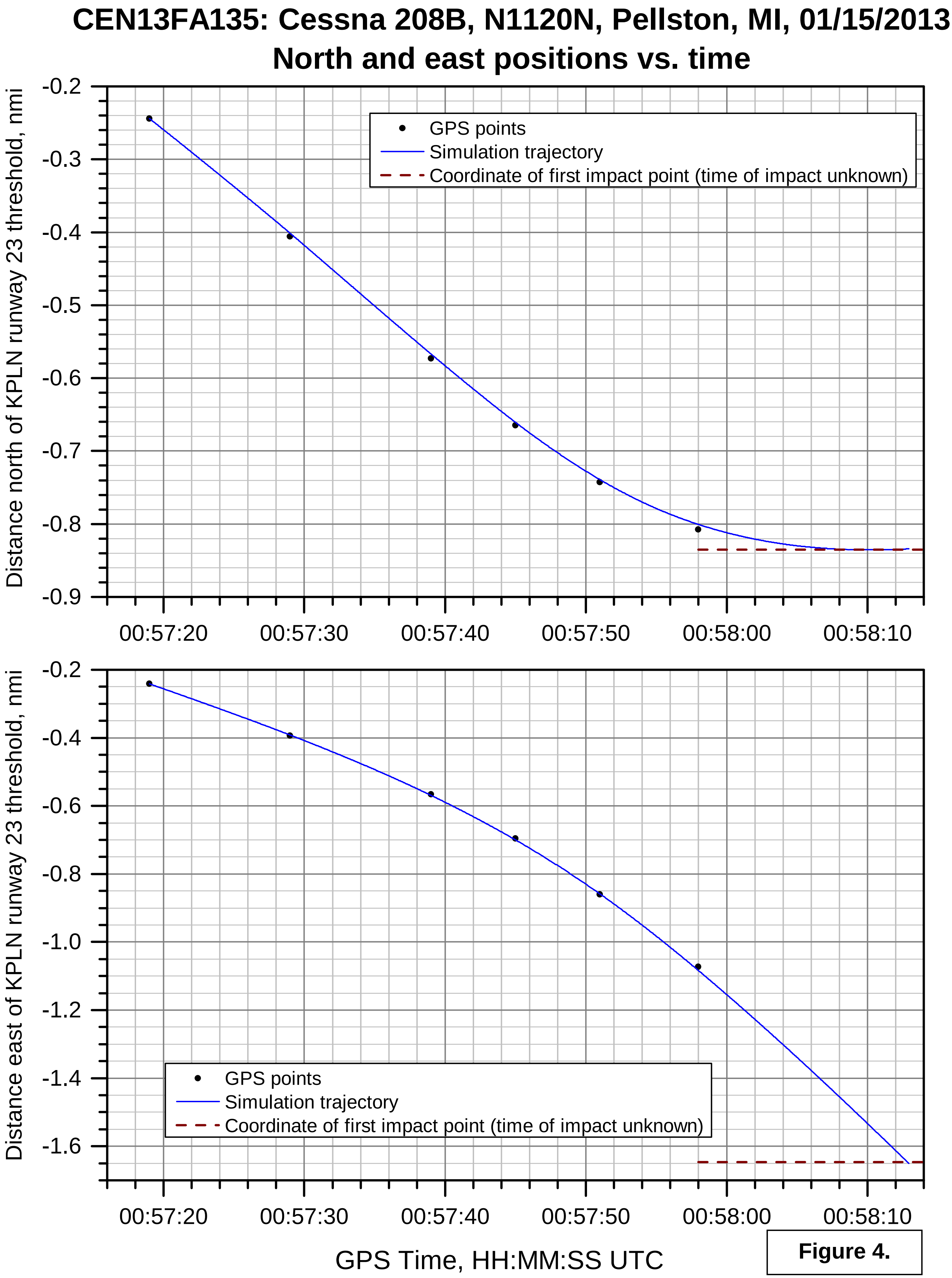

CEN13FA135: Cessna 208B, N1120N, Pellston, MI, 01/15/2013
North and east positions vs. time
Distance north of KPLN runway 23 threshold, nmi
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7
-0.8
-0.9
GPS points
Simulation trajectory
Coordinate of first impact point (time of impact unknown)
00:57:20
00:57:30
00:57:40
00:57:50
00:58:00
00:58:10
Distance east of KPLN runway 23 threshold, nmi
-0.2
-0.4
-0.6
-0.8
-1.0
-1.2
-1.4
-1.6
GPS points
Simulation trajectory
Coordinate of first impact point (time of impact unknown)
00:57:20
00:57:30
00:57:40
00:57:50
00:58:00
00:58:10
GPS Time, HH:MM:SS UTC

Figure 4.

CEN13FA135: Cessna 208B, N1120N, Pellston, MI, 01/15/2013
Altitude based on GPS data and simulation

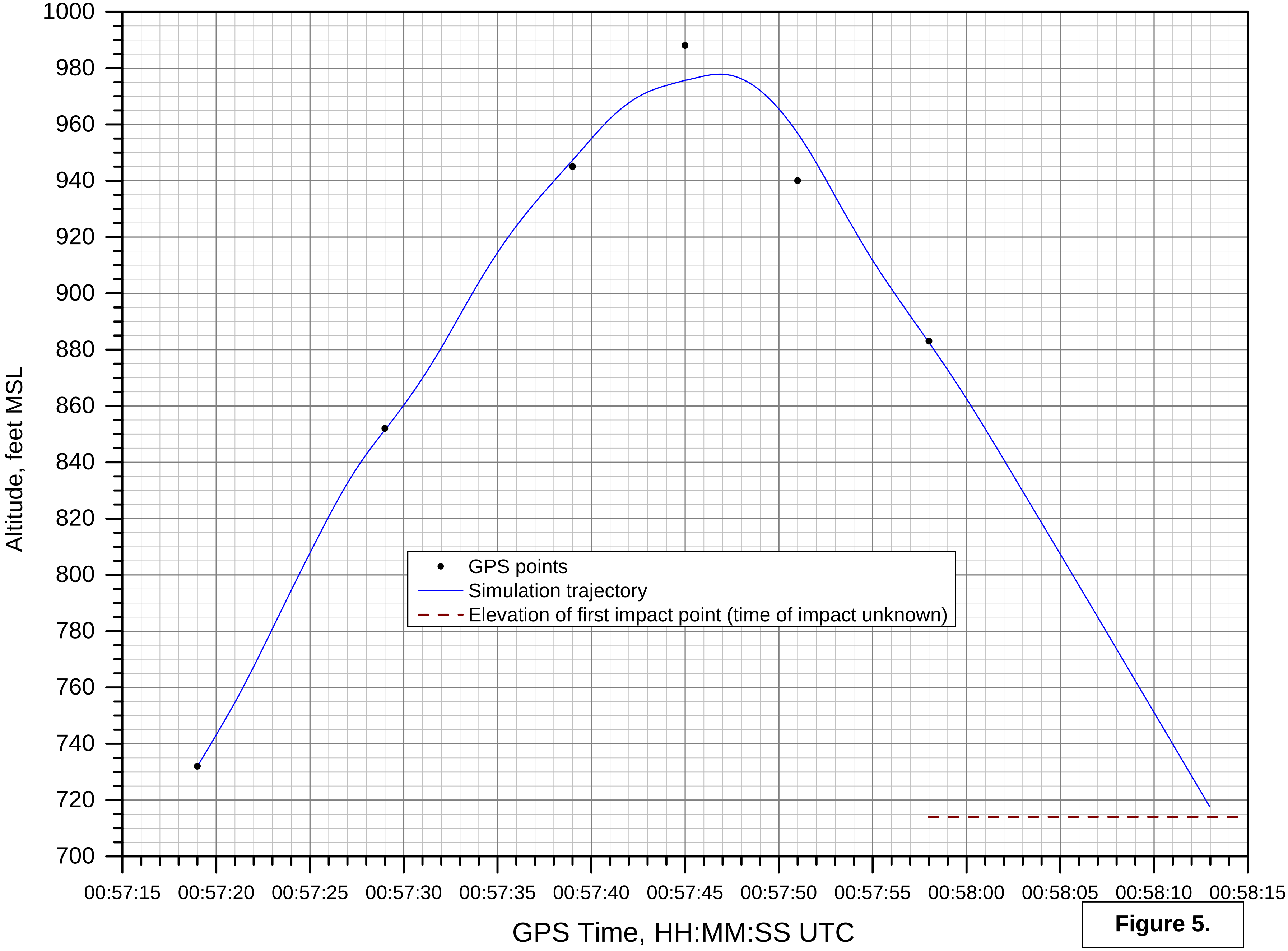
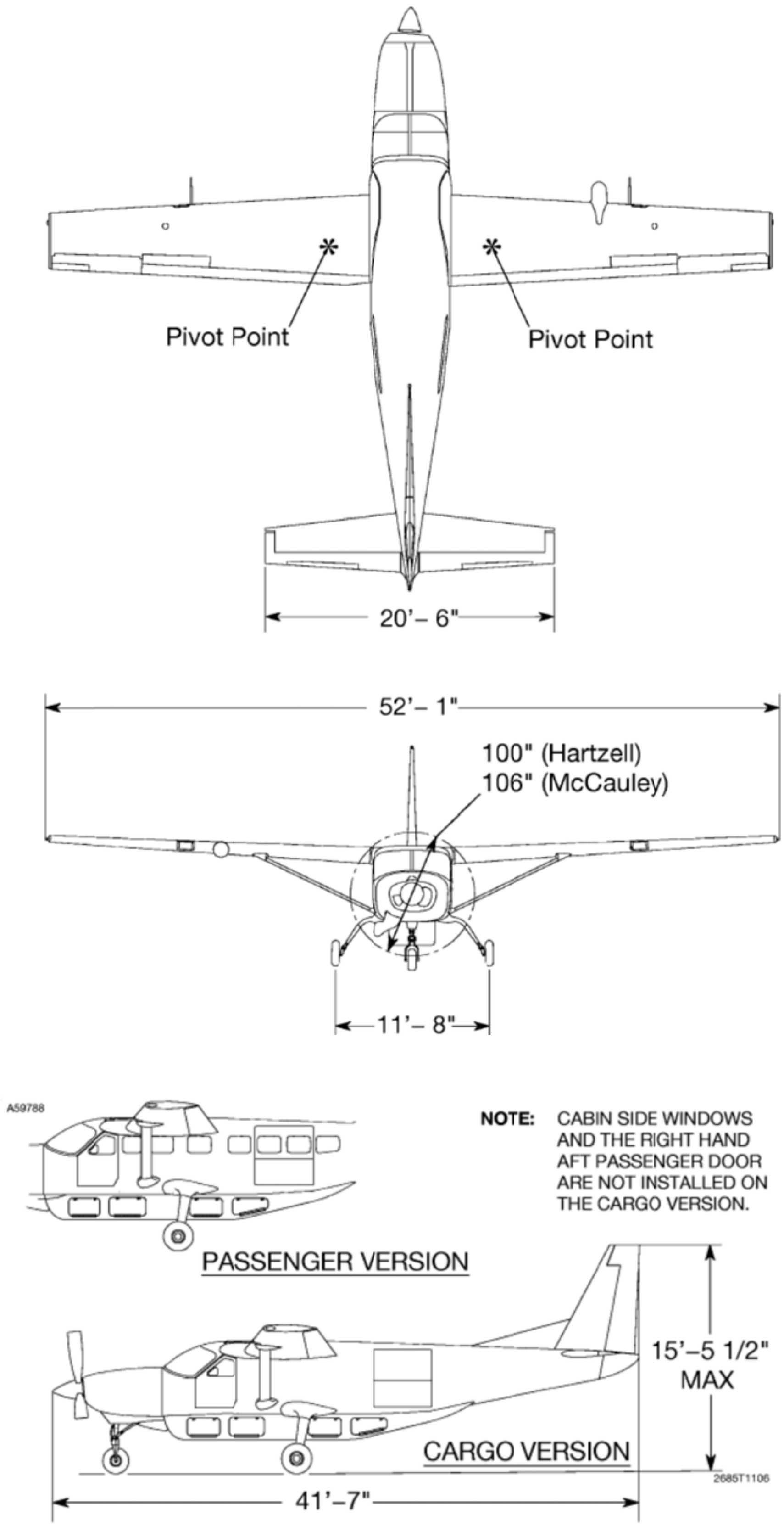


Figure 5.



Pivot Point
Pivot Point
20'– 6"
52'– 1"
100" (Hartzell)
106" (McCauley)
11'– 8"
A59788
NOTE: CABIN SIDE WINDOWS AND THE RIGHT HAND AFT PASSENGER DOOR ARE NOT INSTALLED ON THE CARGO VERSION.
PASSENGER VERSION
15'–5 1/2" MAX
CARGO VERSION
2685T1106
41'–7"

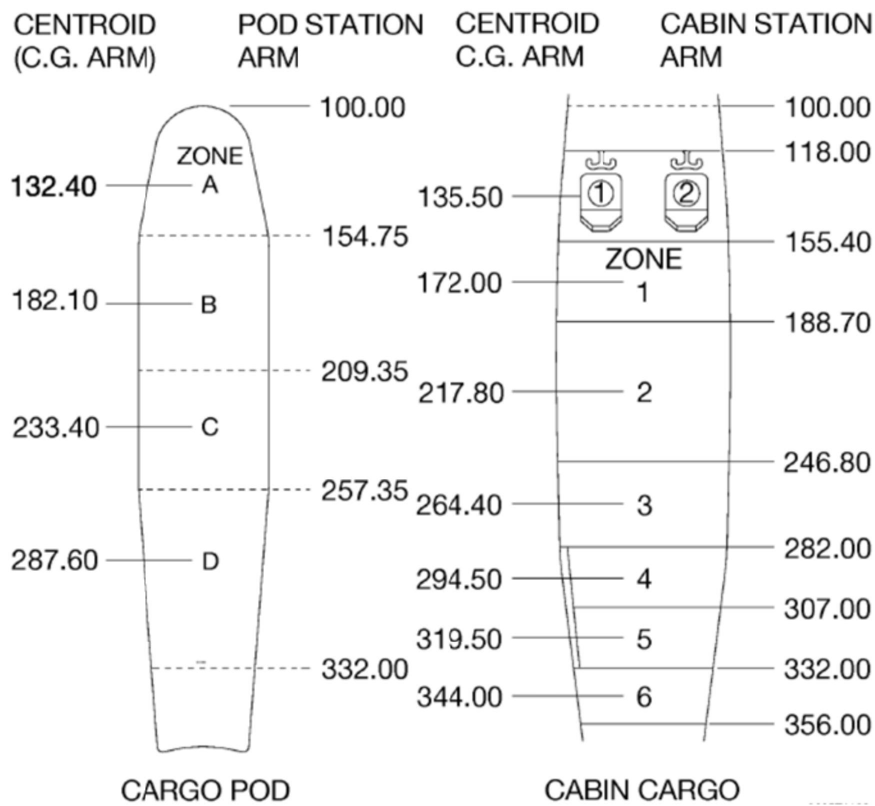


Figure 7. Cessna 208B cargo zones and moment arms, per the Pilot Operating Handbook.

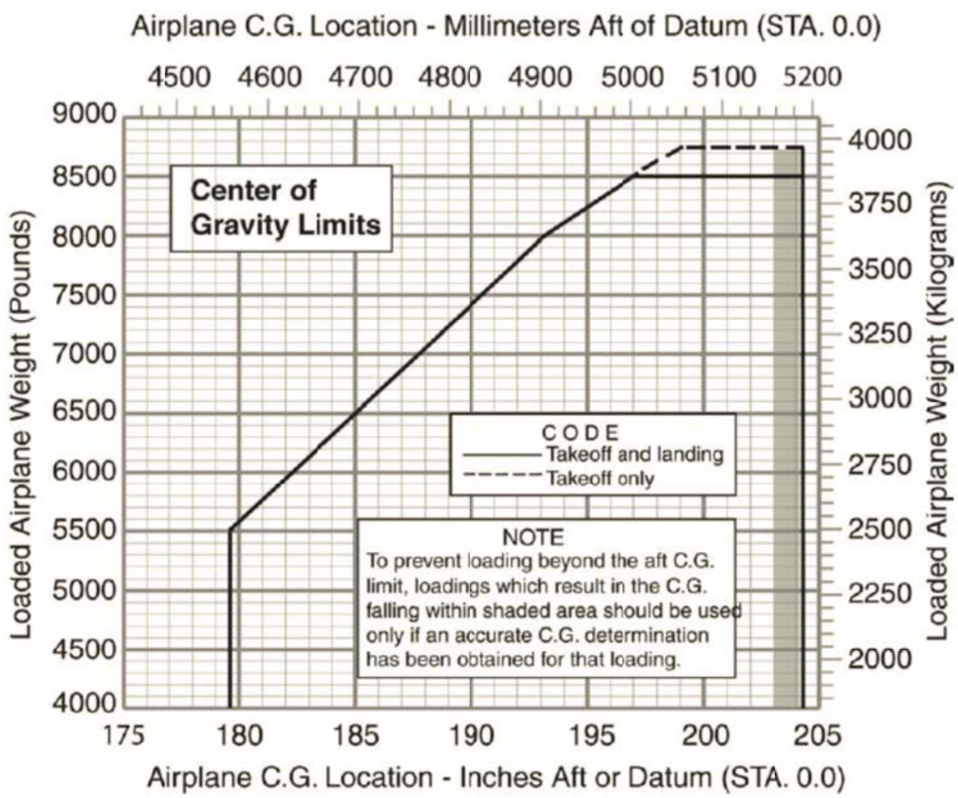


Figure 8. Cessna 208B center of gravity envelope, per the Pilot Operating Handbook.

CEN13FA135: Cessna 208B, N1120N, Pellston, MI, 01/15/2013
Speed and rate of climb based on GPS and simulation data

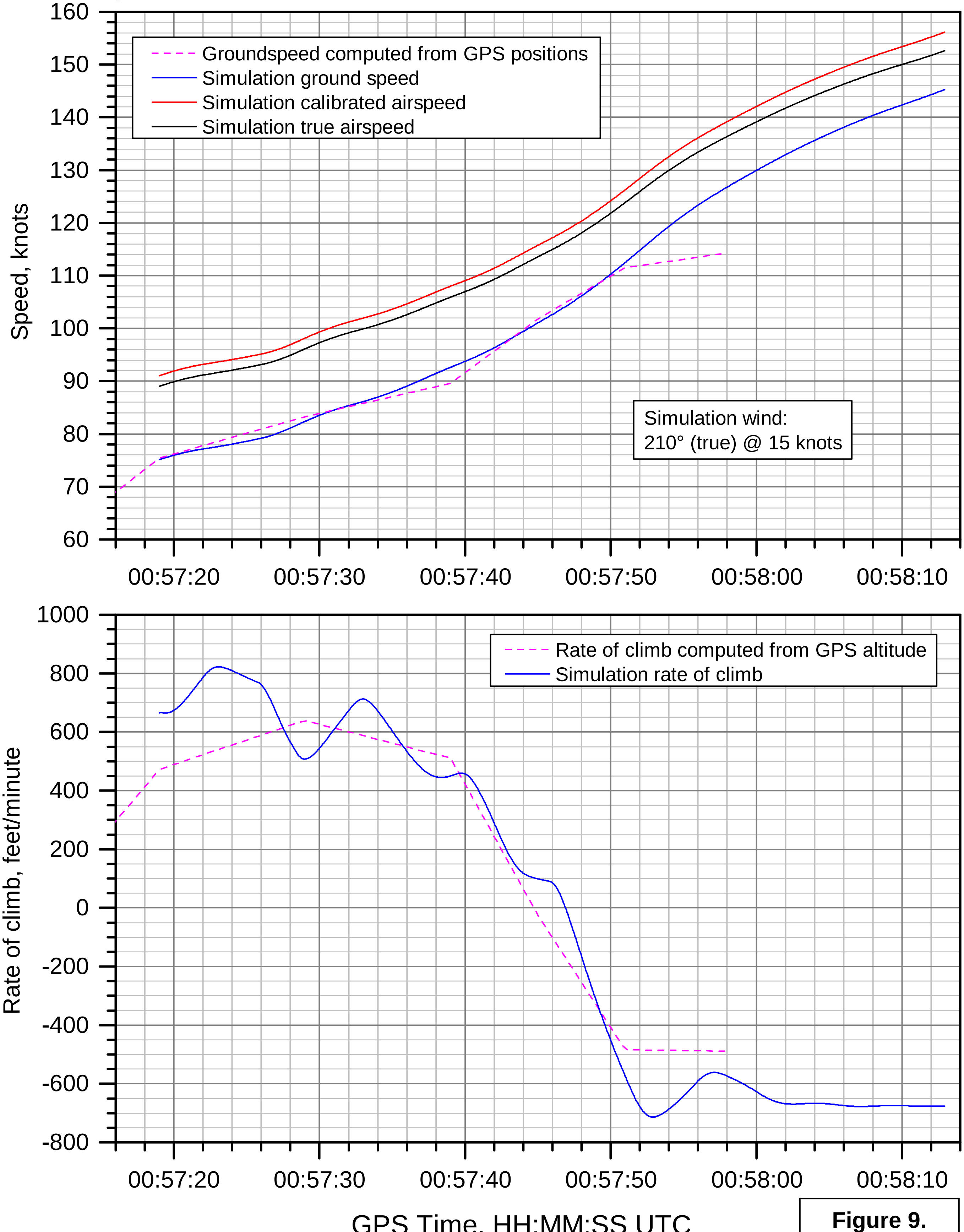


Figure 9.

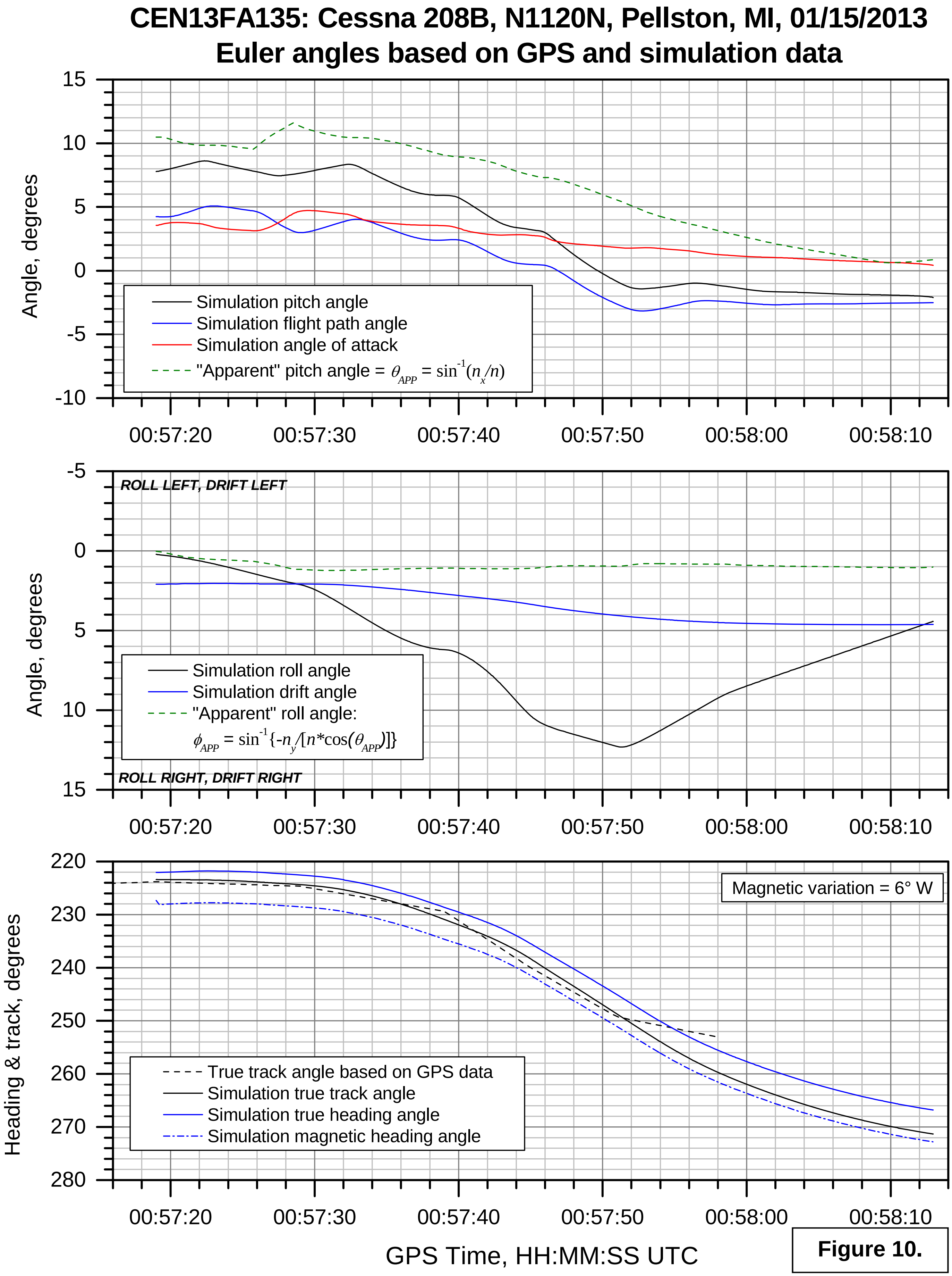

CEN13FA135: Cessna 208B, N1120N, Pellston, MI, 01/15/2013
Euler angles based on GPS and simulation data
Angle, degrees
Simulation pitch angle
Simulation flight path angle
Simulation angle of attack
"Apparent" pitch angle = $\theta_{APP} = \sin^{-1}(n_x/n)$
ROLL LEFT, DRIFT LEFT
ROLL RIGHT, DRIFT RIGHT
Simulation roll angle
Simulation drift angle
"Apparent" roll angle:
$\phi_{APP} = \sin^{-1}\{-n_y/[n*\cos(\theta_{APP})]\}$
Heading & track, degrees
Magnetic variation = 6° W
True track angle based on GPS data
Simulation true track angle
Simulation true heading angle
Simulation magnetic heading angle
00:57:20
00:57:30
00:57:40
00:57:50
00:58:00
00:58:10
GPS Time, HH:MM:SS UTC

Figure 10.

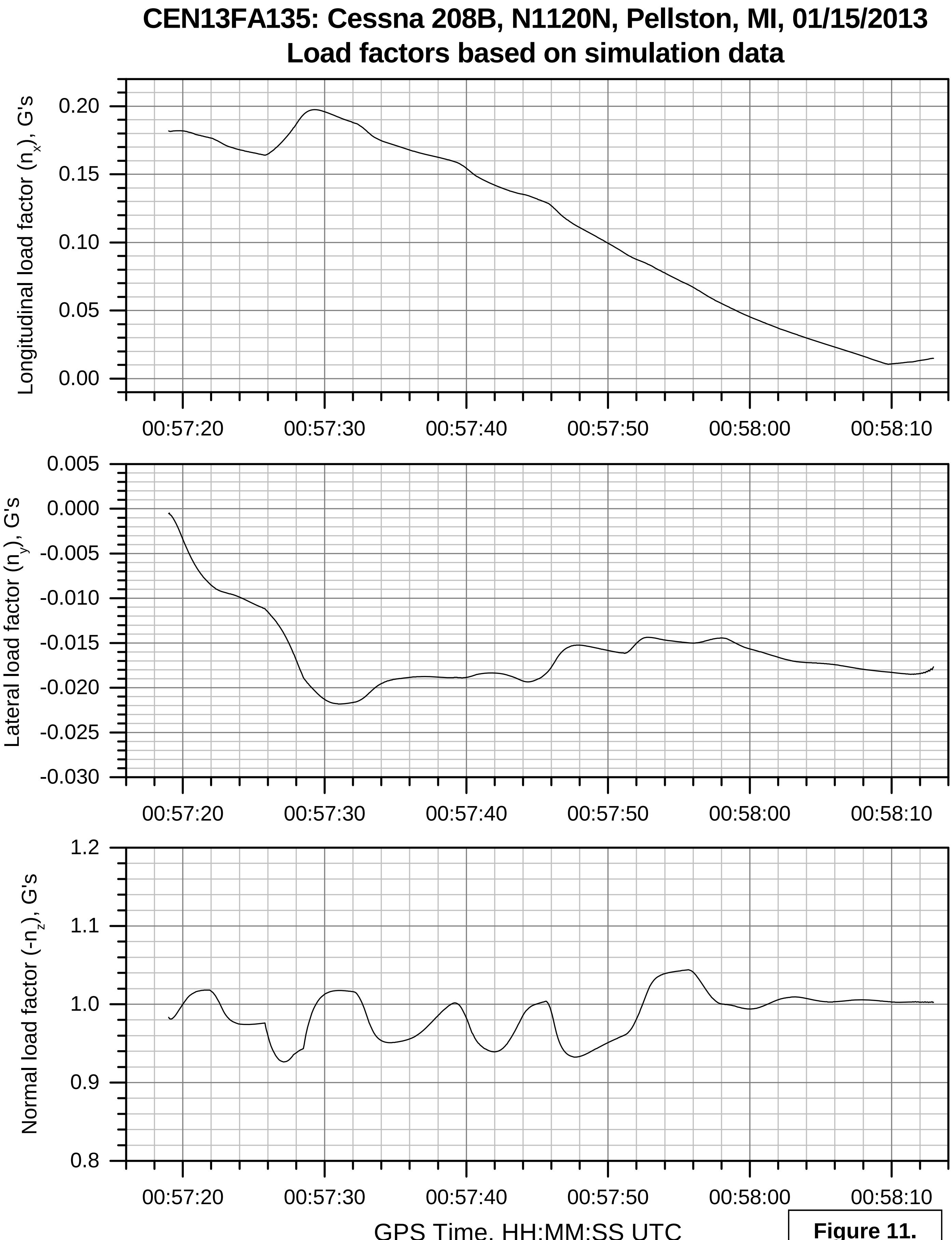

CEN13FA135: Cessna 208B, N1120N, Pellston, MI, 01/15/2013
Load factors based on simulation data
Longitudinal load factor (n_x), G's
0.20
0.15
0.10
0.05
0.00
Lateral load factor (n_y), G's
0.005
0.000
-0.005
-0.010
-0.015
-0.020
-0.025
-0.030
Normal load factor (-n_z), G's
1.2
1.1
1.0
0.9
0.8
00:57:20
00:57:30
00:57:40
00:57:50
00:58:00
00:58:10
GPS Time, HH:MM:SS UTC

Figure 11.

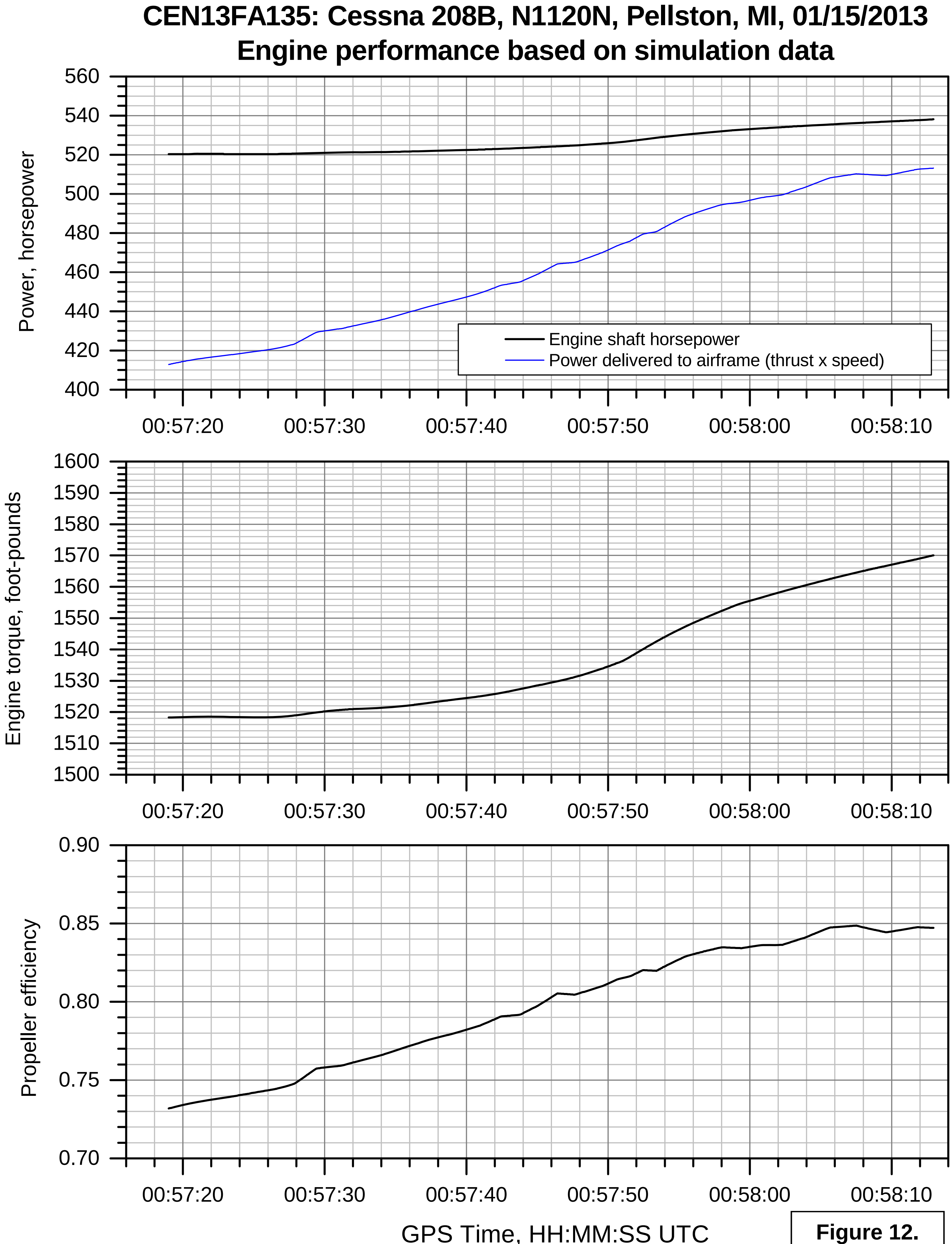

CEN13FA135: Cessna 208B, N1120N, Pellston, MI, 01/15/2013
Engine performance based on simulation data
Power, horsepower
560
540
520
500
480
460
440
420
400
Engine shaft horsepower
Power delivered to airframe (thrust x speed)
00:57:20
00:57:30
00:57:40
00:57:50
00:58:00
00:58:10
Engine torque, foot-pounds
1600
1590
1580
1570
1560
1550
1540
1530
1520
1510
1500
Propeller efficiency
0.90
0.85
0.80
0.75
0.70
GPS Time, HH:MM:SS UTC

Figure 12.

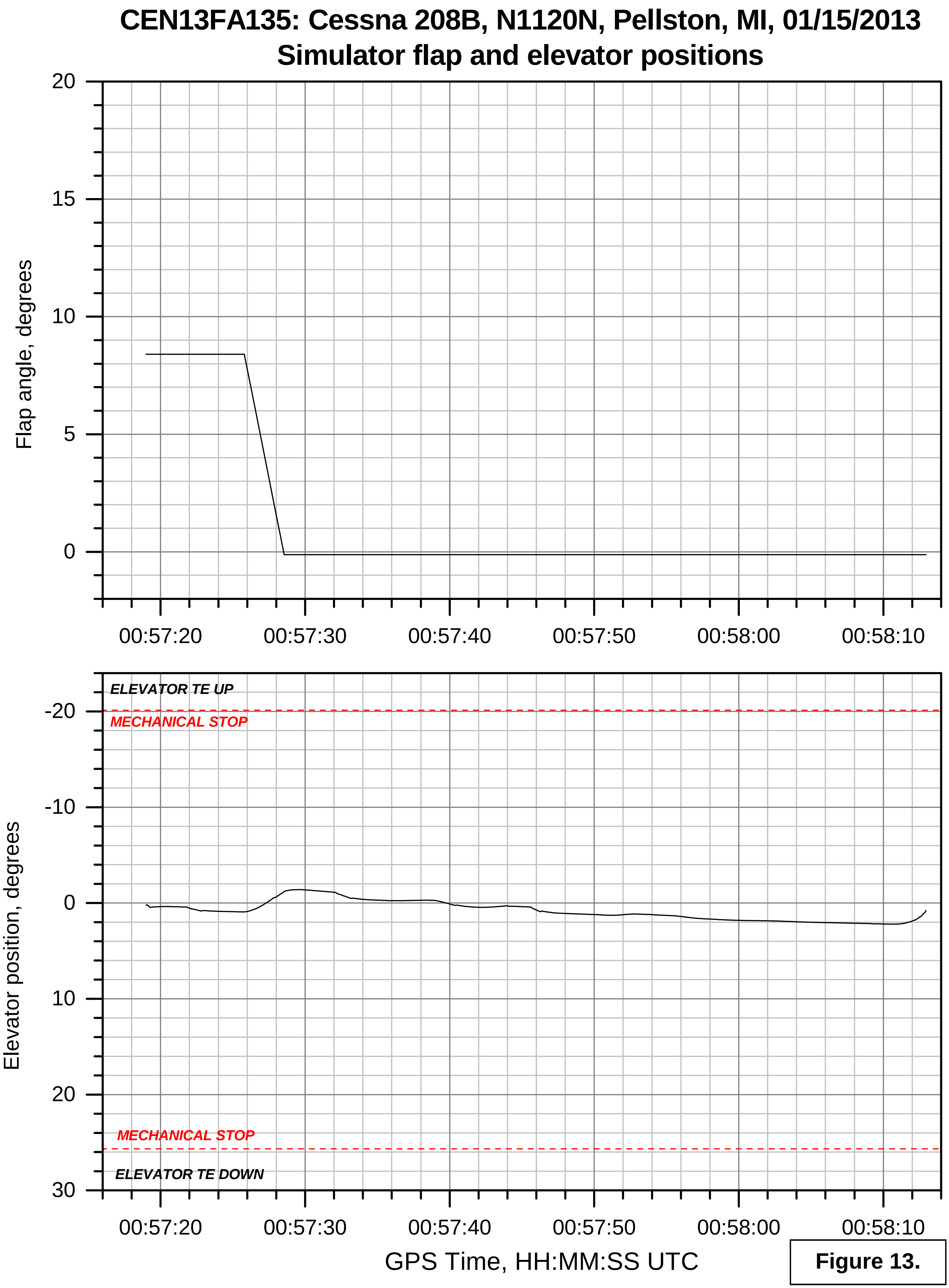

CEN13FA135: Cessna 208B, N1120N, Pellston, MI, 01/15/2013
Simulator flap and elevator positions
Flap angle, degrees
20
15
10
5
0
00:57:20
00:57:30
00:57:40
00:57:50
00:58:00
00:58:10
Elevator position, degrees
ELEVATOR TE UP
MECHANICAL STOP
-20
-10
0
10
20
30
MECHANICAL STOP
ELEVATOR TE DOWN
00:57:20
00:57:30
00:57:40
00:57:50
00:58:00
00:58:10
GPS Time, HH:MM:SS UTC

Figure 13.

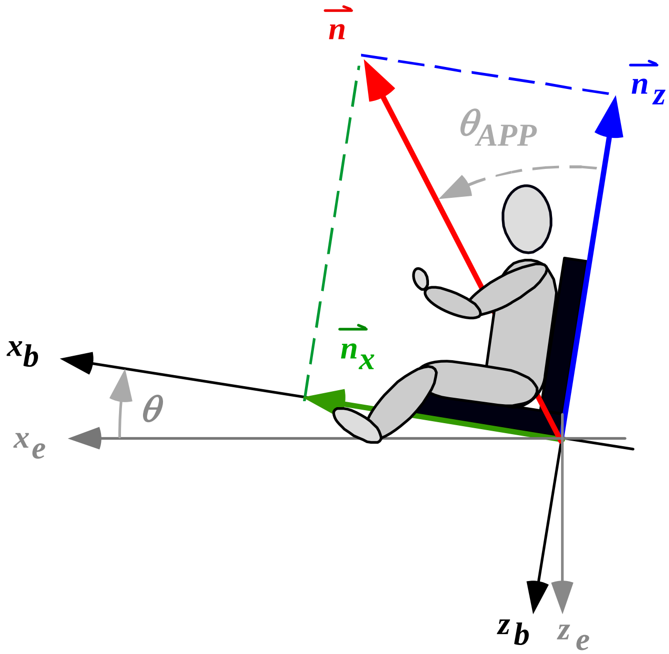


Figure 14a. Load factor vector $\vec{n}$ in an accelerated reference frame. Note that for $n_x > 0$, $\theta_{APP} > \theta$.

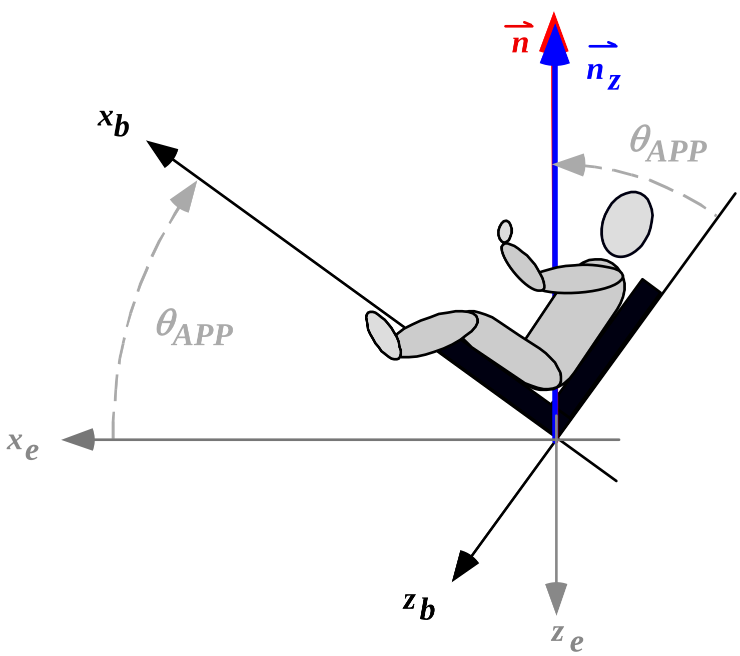


Figure 14b. Equivalent load factor vector $\vec{n}$ in an unaccelerated reference frame.