National Transportation Safety Board
Office of Research and Engineering
Washington, D.C. 20594

Airplane Performance Study

Specialist Report
Timothy Burtch

A. ACCIDENT

Location:	Gaithersburg, MD
Date:	December 8, 2014
Time:	1041 EST
Airplane:	Embraer EMB-500 Phenom 100, Registration N100EQ
NTSB Number:	DCA15MA029

B. GROUP

Chairman: Timothy Burtch
National Transportation Safety Board
Washington, DC

Member: Daniel Satoshi Marimoto
Embraer Air Safety Department
Ft. Lauderdale, FL

C. SUMMARY

On December 8, 2014, about 1041 Eastern Standard Time (EST), an Embraer EMB-500 Phenom 100, N100EQ[1], impacted terrain and houses about 0.75 miles short of runway 14 while on approach to Montgomery County Airpark (GAI), Gaithersburg, Maryland. The airline transport rated pilot and two passengers were fatally injured as were three persons on the ground. The airplane was destroyed during the impact and ensuing fire. Marginal visual meteorological conditions prevailed at the time, and the flight was operating on an instrument flight rules (IFR) flight plan. The airplane was registered to and operated by Sage Aviation LLC., of Chapel Hill, North Carolina, under the provisions of 14 Code of Federal Regulations Part 91 as a personal flight. The flight originated from Horace Williams Airport (IGX), Chapel Hill, North Carolina, with GAI as the intended destination.

[1]See Figures 1 and 2 for pictures of the accident airplane.

D. PERFORMANCE STUDY

The performance study describes the accident airplane ground track, altitude, speed, and attitude as well as the timing of select radio communication between ATC and N100EQ.

The ground track presented is from radar. The radar data are secondary returns (transponder code 4620) from the short-range Airport Surveillance Radar (ASR-9) located at Dulles International Airport (IAD). The radar data have approximately a 60 nautical mile (NM) range and an inherent uncertainty of ±2 Azimuth Change Pulses (ACP) = ± (2 ACP) x (360º/4096 ACP) = ±0.176° in azimuth, ±50 ft in altitude, and ±1/16 NM in range.

The airplane altitude, airspeed, attitude, angle-of-attack, and load factor data presented are from an L3 Solid-State Cockpit Voice and Data Recorder (CVDR) that was recovered from the wreckage. It should be noted that flap lever position 3 was not properly recorded on the CVDR. (See the Flight Data Recorder Specialist's Factual report for details.) However, flap position was recorded correctly, and the crew could visually confirm the flap lever position. As a result, the recorded lever position shown in the figures is as follows:

Flap Lever	Recorded Flap Lever	Flap Position (deg)
0	0	0
1	1	10
2	2	26
3	4	26
4	4	36

Times in the study are reported in EST as well as Greenwich Mean Time (GMT or "Z"): EST = GMT – 5 hr.

The National Transportation Safety Board's (NTSB) aircraft performance specialist was not on scene for the investigation.

Weather Observation

The Automated Weather Observation System (AWOS) report at GAI around the time of the accident is as follows:

METAR KGAI 081535Z 04006KT 10SM FEW021 OVC032 M01/M08 A3061 RMK AO1
GAI weather on the 8th at 1535 GMT/ 1035 EST, the wind is 040˚ at 6 knots (kt), visibility 10 statute miles, a few clouds at 2,100 feet (ft) above ground level (agl)[2], ceiling overcast at 3,200 ft agl, temperature -1° Celsius (C), dew point -8° C, altimeter setting 30.61 inches of mercury. Remarks: automated observation system without a precipitation discriminator.

Accident at 1541Z/1041 EST

[2] Accident pilot reported being in IMC at 15:38:27 at an altitude of 2,724 ft msl or approximately 2,185 ft agl.

Figures 3 and 4 show weather radar at the time of or shortly after the accident. The radar echoes in the figures combined with the flight track (shown in Figures 5 and 6) indicate that N100EQ was in instrument meteorological conditions (IMC) until approximately one mile from GAI and also in conditions that were favorable for structural icing for at least ten minutes during the approach. Multiple jet air carriers in the vicinity of the accident site reported icing conditions in the clouds with cloud tops ranging from 4,300 ft to 5,500 ft above mean sea level (msl). In addition, four minutes after the accident, there was another pilot report (PIREP) from a regional turboprop pilot who was encountering moderate mixed icing between 4,000 ft and 5,000 ft msl.

See the Meteorological Factual for more detailed weather.

Radar Ground Track with CVDR Altitude, Airspeed and Attitude

Figures 5 and 6 highlight the radar ground track for the final 27 minutes of flight. The radar "points" are actually boxes as shown in red in the figure. This is because of the uncertainty associated with the radar data mentioned earlier. The figures also show select radio communications between N100EQ and Potomac Consolidated Terminal Radar Approach CONtrol (TRACON) as the airplane flew vectors to the Global Positioning System (GPS) approach 14 at GAI. See Figure 7 for the instrument approach plate and Figure 8 for the approach plate superimposed on the radar ground track.

Figures 9 and 10 show the speed and altitude profiles for the accident flight captured on the CVDR. The de-ice discrete from the CVDR indicates that de-ice was selected for 2 min 23 sec upon reaching a cruising altitude of 23,000 ft but then remained off for the rest of the flight. Figure 9 also highlights (in red) the portion of the flight where the airplane likely entered the clouds and encountered structural icing during the approach (based on PIREPs of cloud tops and the presence of ice). The airplane entered the clouds around 15:23:41 at 5,500 ft msl and, at 15:38:27 while descending through 2,700 ft msl, the pilot reported being in IMC. That puts the airplane in visible moisture, an essential element for ice, for approximately 15 min.

Figure 11 indicates that the majority of the approach was uneventful with the autopilot on until the last 20 sec of the recording[3]. At 15:41:36, the autopilot disengaged when the aural stall warning system sounded with the airplane altitude at just over 800 ft msl. The airspeed had decayed from an initial airspeed of 166 kt at 15:35:00 to a speed of 88 kt, 6.6 min later[4]. Angle-of-attack (AOA) increased from 0.80 deg at 15:35:00 to 21 deg when the autopilot disengaged.

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[3] The Limitations section of the Phenom 100 FAA AFM states that the autopilot can mask tactile cues that indicate adverse changes in handling characteristics. The pilot should consider not using the autopilot when any ice is visible on the airplane. The autopilot should be periodically disconnected to check for unusually large control forces.

[4] The landing reference speed, V_{REF}, in the Phenom 100 Airplane Flight Manual (AFM) at a gross weight of 8,700 lb is 95 KIAS without ice protection and 117 KIAS with ice protection on. V_{REF} is the target airspeed at a point 50 feet above the runway threshold.

Figure 12 highlights the last minute of recorded data for the same altitude, airspeed, and AOA parameters shown in Figure 10. The first aural stall warning occurred at 15:41:36 and at a vane AOA of 21 deg, and the data indicate that it likely sounded seven more times before the recording ended. (The figure also shows that the stick pusher AOA of 28.4 deg was reached at least once and possibly as many as three times before the recording ended; however, stick pusher is not a recorded parameter, and a final determination as to whether the stick pusher activated could not be made.) Finally, the recorded engine fan speed, N1, increased from 45% at 15:41:20 to 67% at 15:41:36 when the aural stall warning system first triggered. The fan speed continued to climb to a peak of 86% at 15:41:39 where it remained until the end of the recording at 15:41:55. (See the "Phenom 100 Stall Warning System" section below for a more complete description of the stall warning and stick pusher thresholds.)

Figure 13 shows the bank angle for the last minute of the recording. Two seconds before the first aural stall warning, the airplane started to bank to the right. The airplane reached a bank angle of 21˚ before the aural stall warning sounded, and the airplane then quickly rolled left to 59˚. The airplane went through a series of (roll) oscillations over the next 14 sec before rolling to over 100˚ to the right when the recording ended. The CVDR did not record elevator position so the pilot's control response to the stall warning could not be determined. However, the airplane did pitch down following the first stall warning.

Figure 14 is a plot of the load factors during the last minute of recorded data. The normal load factor, n_z, shows a stall break at 15:41:35, less than one second before the aural stall warning and autopilot disconnect. Figure 15 shows the same stall break along with the pitch break that follows. (Figure 15 also highlights the difference between vane angle-of-attack, which is used by the stall warning system, and body angle-of-attack shown in blue[5].)

Figure 16 again shows the n_z stall break but with bank angle. Because of the different sample rates between load factor and bank, the exact bank angle at the break could not be determined. However, the airplane was rolling to the right with the autopilot still engaged at the stall break.

The Phenom 100 Stall Warning System

The Phenom 100 employs an aural warning as well as a stick pusher[6] to warn of and protect the pilot from an impending aerodynamic stall. Selection of the Phenom's pneumatic boots for de-ice protection of the wings and horizontal stabilizer lowers the angle-of-attack at which the aural warning and stick pusher systems will activate. As a result, the speed at which the systems will activate is higher[7].

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[5] Vane AOA is unique to an installation or airplane whereas body AOA is more general and is used by engineers to design the airplane. Body AOA is typically defined relative to a wing or fuselage reference plane.

[6] The electric stick pusher motor on the Phenom 100 applies approximately 150 lb of column force in the airplane-nose-down direction when the threshold pusher AOA is reached.

[7] The Limitations section of the Phenom 100 FAA AFM states that crew must activate the wing/stabilizer ice protection system at the first sign of ice formation or when the air temperature is below 5˚C with visible moisture. The AFM defines "in icing" as when "… there is ice accreted on airplane surfaces". These limitations require that

Table 1 summarizes the Phenom 100 stall warning, stick pusher, and roll angles-of-attacks with the ice protection system turned off[8].

Landing Gear/Flap Lever	α_{SW}, vane (deg)	α_{PSH}, vane (deg)	α_{ROLL}, vane (deg)
up/0	20.0	25.8	27.0
up/1	20.0	26.0	27.1
up/2	20.0	27.4	29.2
down/3	19.4	26.8	29.5
down/4	21.0	28.4	30.5

Table 1: Phenom 100 Stall Warning and Stick Pusher AOA, Ice Protection Off

Table 2 summarizes the stall warning, stick pusher, and roll angles-of-attacks with the ice protection system turned on.

Landing Gear/Flap Lever	α_{SWice}, vane (deg)	α_{PSHice}, vane (deg)	$\alpha_{ROLLice}$, vane (deg)
up/0	14.5	18.5	never obtained in flight test*
up/1	13.0	18.0	never obtained in flight test*
up/2	10.0	16.0	never obtained in flight test*
down/3	10.5	16.3	never obtained in flight test*
down/4	9.5	15.5	never obtained in flight test*

*Pusher activated well before the wing drop. As a result, α_{ROLL} was never obtained.

Table 2: Phenom 100 Stall Warning and Stick Pusher AOA, Ice Protection On

Limiting the discussion to the accident configuration, the gear down/landing flap 4, stall warning AOA is reduced by 11.5 deg and the stick pusher AOA is reduced by 12.9 deg when the ice protection system is selected. Subsequently, the aural stall warning system will sound at an AOA of 9.5 deg instead of 21 deg, and the stick pusher will activate at an AOA of 15.5 deg instead of 28.4 deg with the ice protection system turned on.

Figure 17 repeats Figure 16 but instead shows the stall warning and stick pusher AOA thresholds with the ice protection system turned on. This is only an estimate because the recorded data in Figure 17 are with the ice protection system turned off, and the thresholds shown in the figure are with the ice protection system turned on. Nevertheless, comparing Figures 16 and 17 shows that the aural stall warning would have sounded approximately 20 sec sooner, and the stick pusher would have activated about 10 sec sooner had the ice protection system been turned on during the approach into Gaithersburg.

the pilot see the ice. However, some Phenom pilots (including Embraer's) have reported that the silver wing color makes it difficult to see ice formation. An automatic ice detection system is offered as an option on the Phenom 300. See the Systems Group Chairman's Factual Report of Investigation for a more detailed description of the de-ice system.

[8] The stall warning and stick pusher angle-of-attacks listed are for $d\alpha/dt=0$ and can occur sooner based on AOA rate.

Low Speed Awareness Tape

Embraer incorporated yellow and red speed bands as well as a green "donut" on the Phenom 100 speed tape for low speed awareness. See Figure 18. The top of the red band marks where the pilot will hear the aural stall warning. The yellow band, just above, highlights the three knots prior to aural stall warning. Finally, the green circle on the speed tape denotes 1.3 times the stick pusher speed. (In this manner, the red and green symbols are displaying angle-of-attack information directly to the pilot on the speed tape, assuming the airplane is properly configured, e.g., ice protection selected when necessary.)

Figure 18 is a simulation of the Phenom 100's low speed awareness tape for three approaches into Gaithersburg: two at the accident flight conditions, with and without ice protection (the two tapes on the left), and one from a previous landing at GAI on 10/22/14 but at different points in the approach (the two tapes on the right). Note that "QNH ALT" in the figure is the same as "MSL ALT".

Comparing the first two tapes in the figure highlights what the low speed awareness system would have done had the ice protection system been selected during the accident approach. The first tape simulates the actual flight with the pilot slowing into the yellow (band) and close to the top of the red aural stall warning (at approximately 88 KIAS). The second tape, on the other hand, shows that the aural stall warning would have sounded earlier (at over 100 KIAS) if the ice protection system had been selected. This would have disconnected the autopilot and potentially given the pilot more time to recover.

Next in the figure, data from a 10/22/14 approach into Gaithersburg are used to simulate what might typically be seen by the accident pilot on the low speed awareness tape while landing Gaithersburg (but in the opposite direction on the 4,202 ft runway 32). The two tapes are from two different points on the approach with the ice protection system turned off. The first shows the airplane at 372 ft above the runway touchdown zone and 104 KIAS or about 23 kt above the aural stall warning. The second tape and the last one in the figure shows the airplane at an altitude of about 40 ft above the touchdown zone and approximately 7 kt above the aural stall warning.

While the runway at GAI is long enough to allow the Phenom 100 to land in nearly all conditions and configurations with the ice protection turned off, landing at GAI with the ice protection system turned on is not allowed under the Limitations section of the Phenom 100 AFM for many gross weight, pressure altitude, and wind combinations. The Phenom 100 AFM indicates that the unfactored landing distance[9] at the accident conditions is about 2,500 ft with the ice protection system turned off. The unfactored landing distance increases to about 4,000 ft with the ice protection system turned on. Factoring this distance and

[9] Unfactored landing distance is the actual distance to land the airplane from a point 50 ft above runway threshold at V_{REF} to a complete stop, using a normal landing technique. The required landing distance for dispatch is the unfactored landing distance increased by a factor according to the operating regulations.

considering climb gradients can make GAI an unsuitable airport for the Phenom 100 when environmental conditions dictate that the ice protection system be turned on[10].

Automatic Flight Control System

The Embraer Phenom 100 automatic flight control system (AFCS) is based on Garmin's G1000 avionics suite and is part of the "Prodigy" flight deck[11]. The AFCS utilizes the Garmin GFC 700, a dual channel, three-axis, fully digital, AHRS-based, autopilot that also provides flight director and yaw damper capabilities.

The Garmin GFC 700 has a number of both vertical and lateral modes that the pilot can select using the AFCS control unit (GMC 715) located on the glareshield and shown in Figure 19. According to CVDR data, N100EQ was configured to use the Flight Director (FD) during the approach (APR) with the "Glidepath" (GP) vertical mode[12] (FD/APR/GP) and the "Approach GPS" (GPS) lateral mode (FD/APR/GPS).

Figure 20 highlights the active Flight Director vertical modes during the approach. The Garmin GFC 700 was initially holding an altitude of 2,850 ft msl just outside of the Initial Approach Fix TIMBE (FD/APR/ALT). This is denoted by an Active Flight Director Vertical Mode of 5 in the figure. When the airplane intercepted the glidepath at 15:38:09, a descent rate of approximately 600 ft/min was commanded by the AFCS to track the glidepath (FD/APR/GP). This is denoted by an Active Flight Director Vertical Mode of 12 in the figure. Note: The AFCS commands elevator to control glidepath; the Phenom 100 does not have an autothrottle, and it is up to the pilot to command power as necessary to maintain the appropriate airspeed.

Figure 21 highlights the active Flight Director lateral mode during the approach. The autopilot was tracking the GPS waypoints contained on the approach plate shown in Figure 7 (BEGKA, TIMBE, JOXOX, 50 ft threshold crossing, touchdown) using the Wide Area Augmentation System (WAAS) GPS signal (FD/APR/GPS). This is denoted by an Active Flight Director Lateral Mode of 3 in the figure.

At 15:41:36, the autopilot disengaged when the aural stall warning system sounded, as per the design of the GFC 700. The indicated airspeed was 88 kt, 7 kt below V_{REF} (without ice protection). The airplane was at an altitude of about 803 ft msl and approaching the 789 ft msl decision altitude for the LPV approach to runway 14 at GAI.

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[10] The German Bureau of Aircraft Accident Investigation (BFU) is investigating a landing accident where a Phenom 100 struck a wing tip and fractured the landing gear while landing at Berlin-Schonefeld Airport on February 15, 2013. While the engine anti-ice had been activated, the wing/stabilizer de-ice protection had not been turned on. The BFU reported that the wing and horizontal tail leading edges had accreted up to 10 mm of ice. Information relating to the investigation is contained in the public interim report.

[11] The Prodigy flight deck was an integral part of the Phenom's single pilot certification.

[12] Glidepath is analogous to glideslope for GPS approaches supporting vertical guidance.

E. CONCLUSION

The weather data indicate that the accident flight encountered clouds and was exposed to structural icing conditions while descending into the Gaithersburg area. There were numerous reports of ice from pilots flying in the area, and the accident pilot indicated that he was still in the clouds almost 15 min after entering them.

The stall characteristics[13] exhibited by N100EQ during the Gaithersburg approach are consistent with an ice-contaminated airplane. The recorded normal load factor shows a stall break at about the same time the aural stall warning sounded, providing no advance warning of the impending stall to the pilot because the wing/stabilizer de-icing switch was not activated. The airplane was 283 ft above the runway threshold. Had the pilot turned on the airplane de-ice system, he likely would have received the aural stall warning about 20 sec sooner and well before the stall break.

Timothy Burtch
Specialist – Airplane Performance
National Transportation Safety Board

[13] The FAA Phenom Flight Standardization Board (FSB) report indicates that the need for a stick pusher on the Phenom resulted from 14 CFR Part 23 certification stall characteristic testing. The FSB report also calls the Phenom's stick pusher a "special flight characteristic" that all training providers and flight crews should be aware of. The FSB recommends that all Phenom pilots "understand that altitude loss in a stall can be significant if the stick pusher activates" and "be advised (that) an altitude loss of 400-500 feet can be expected at low altitude and a secondary stall is routine on the first attempt". The purpose of the FSB report is to specify FAA training, checking and currency requirements applicable to flight crews operating the Embraer Model 500, Phenom 100, and Model 505, Phenom 300, airplanes.

FIGURES

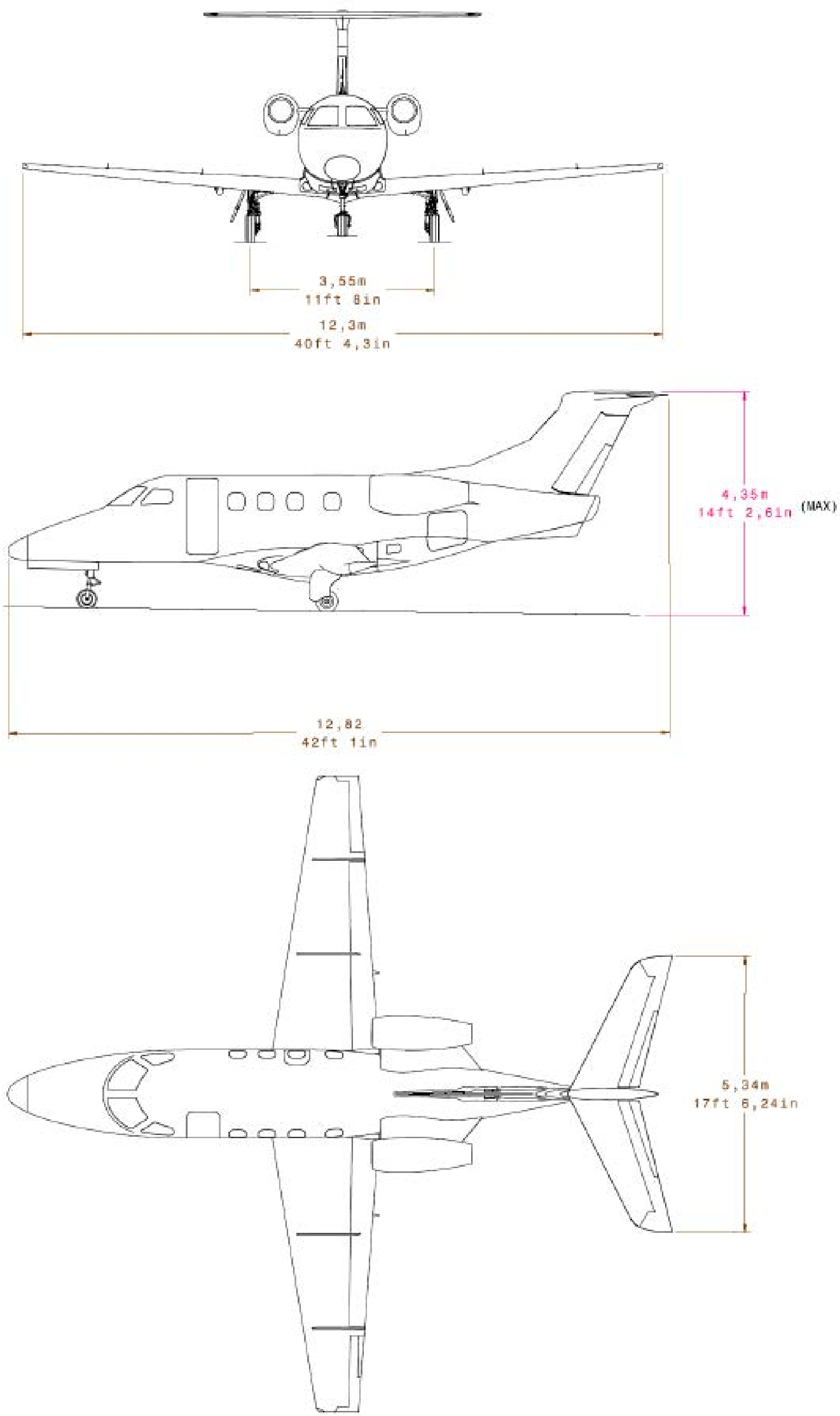


Figure 1: Embraer EMB-500 Phenom 100 Three-View

Figure 2: Accident Airplane, N100EQ, an Embraer EMB-500 Phenom 100, Manufactured in 2009

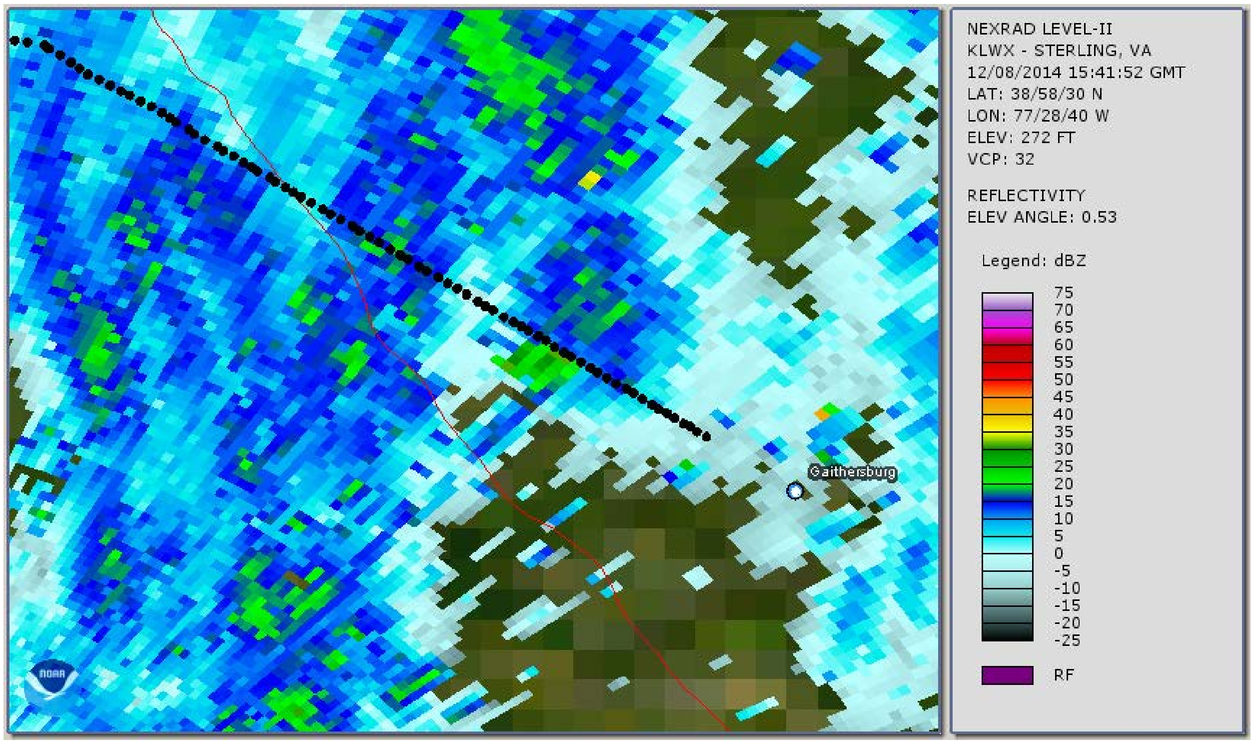


Figure 3: NEXRAD Radar Image at 1541 GMT/1041 EST

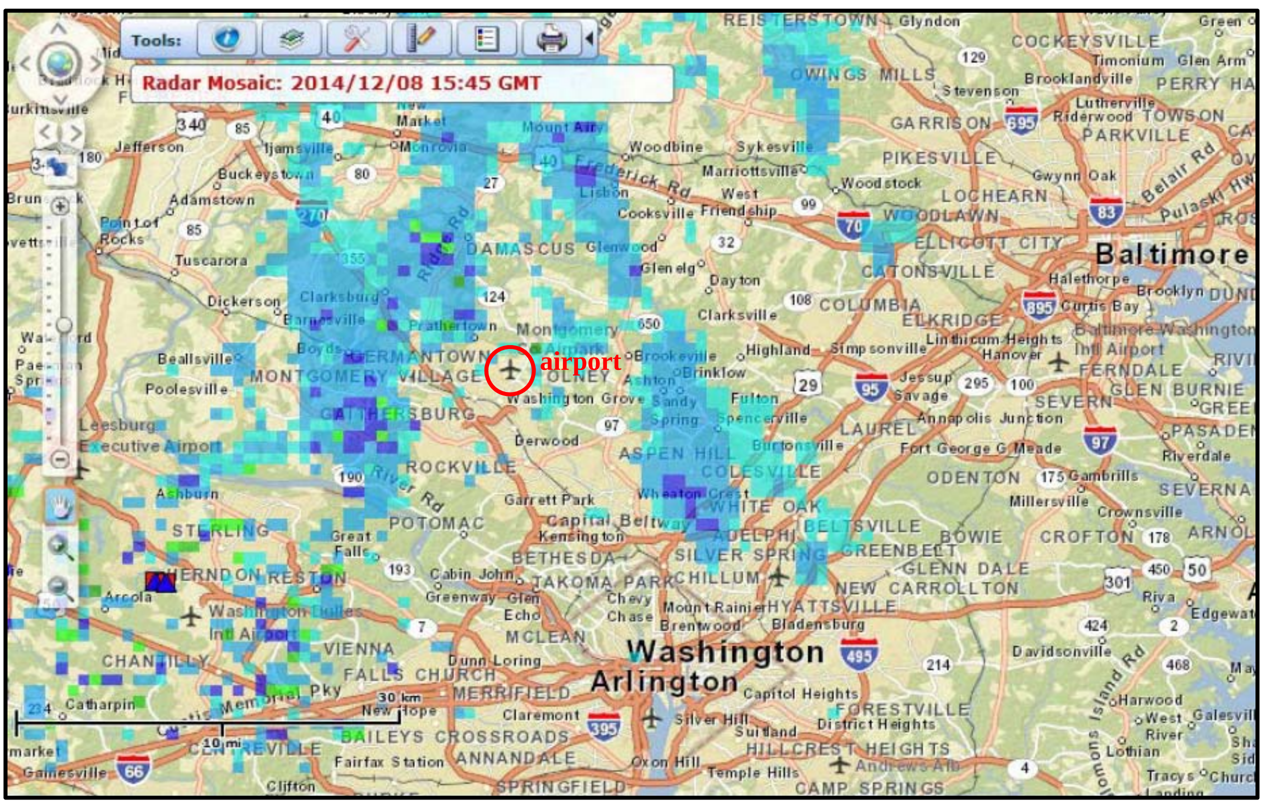


Figure 4: Radar Mosaic at 1545 GMT/1045 EST, Minutes After the Accident

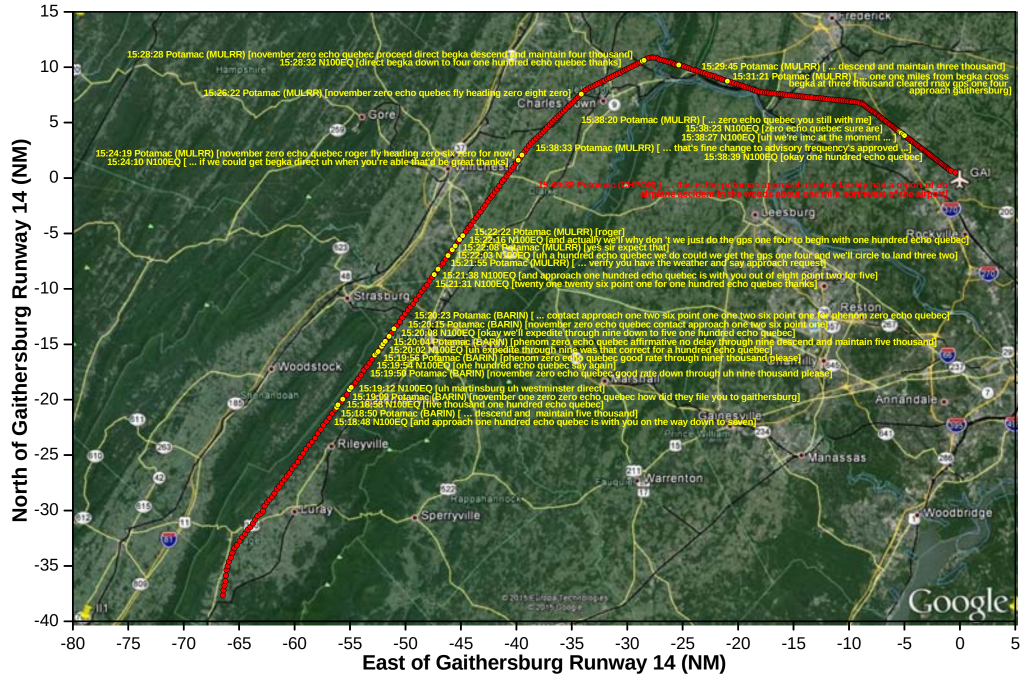


Figure 5: Radar Ground Track and Select Radio Communications[14]

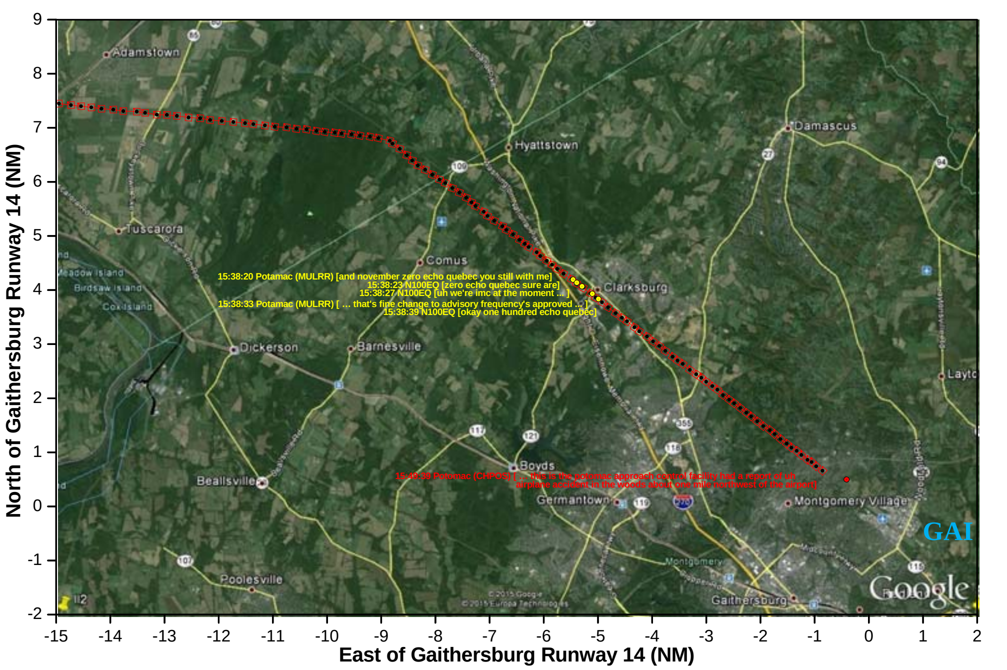


Figure 6: Radar Ground Track and Select Radio Communications in Final Minutes

[14] Sectors within the Potomac TRACON Shenandoah area are shown in parenthesis in the figure.

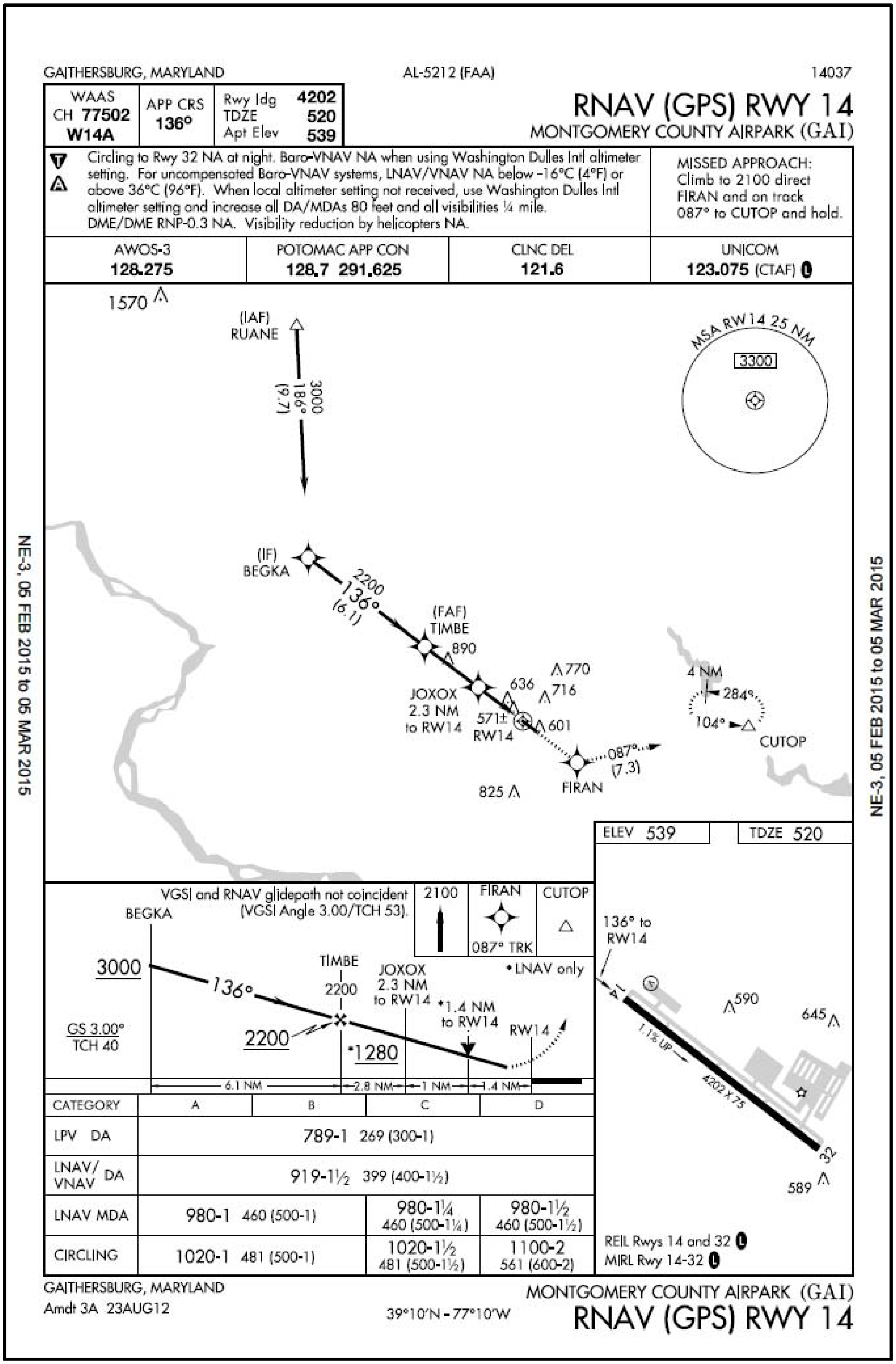


Figure 7: GPS Instrument Approach Plate for GAI Runway 14

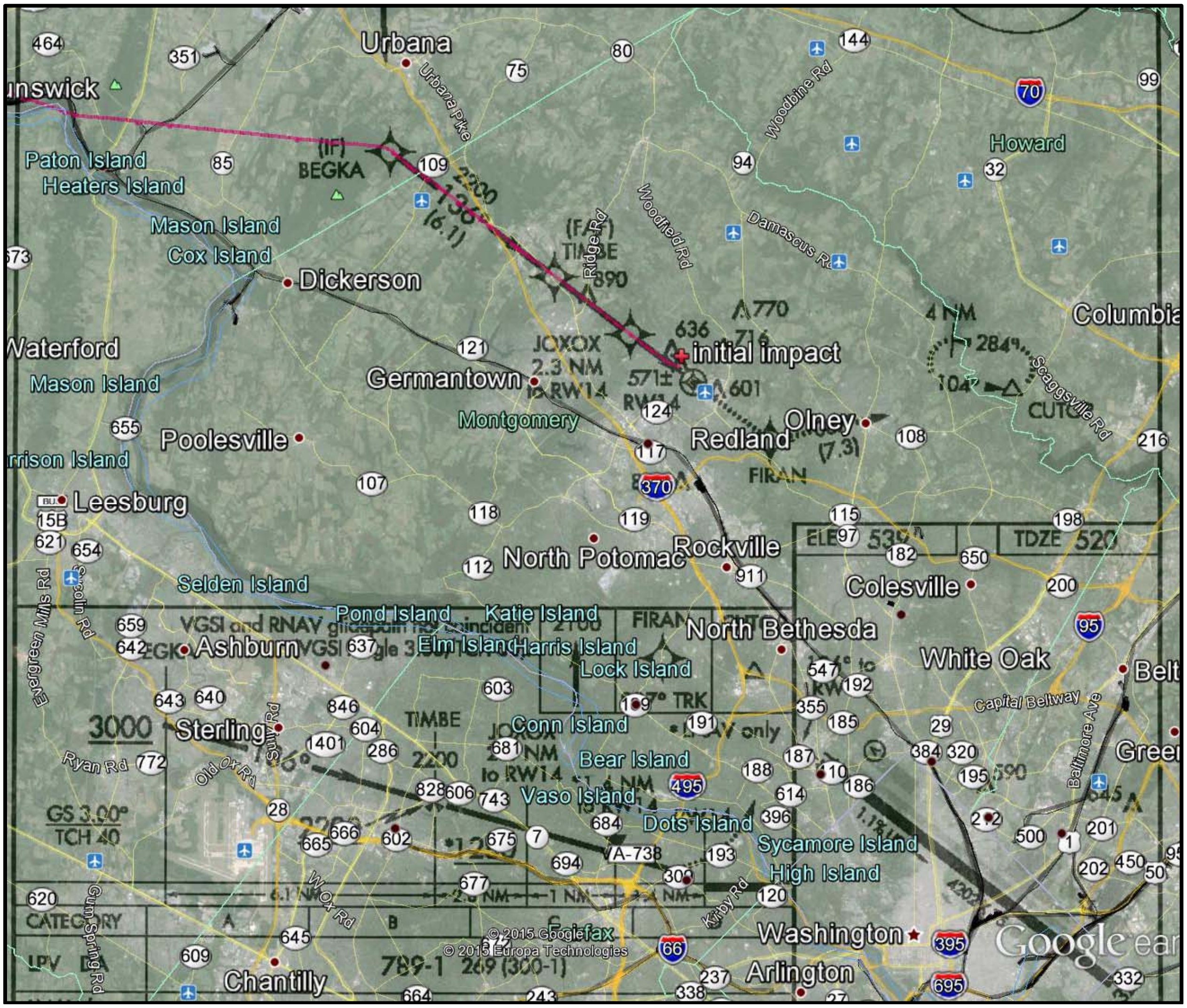


Figure 8: Radar Ground Track and Approach Plate for GAI Runway 14

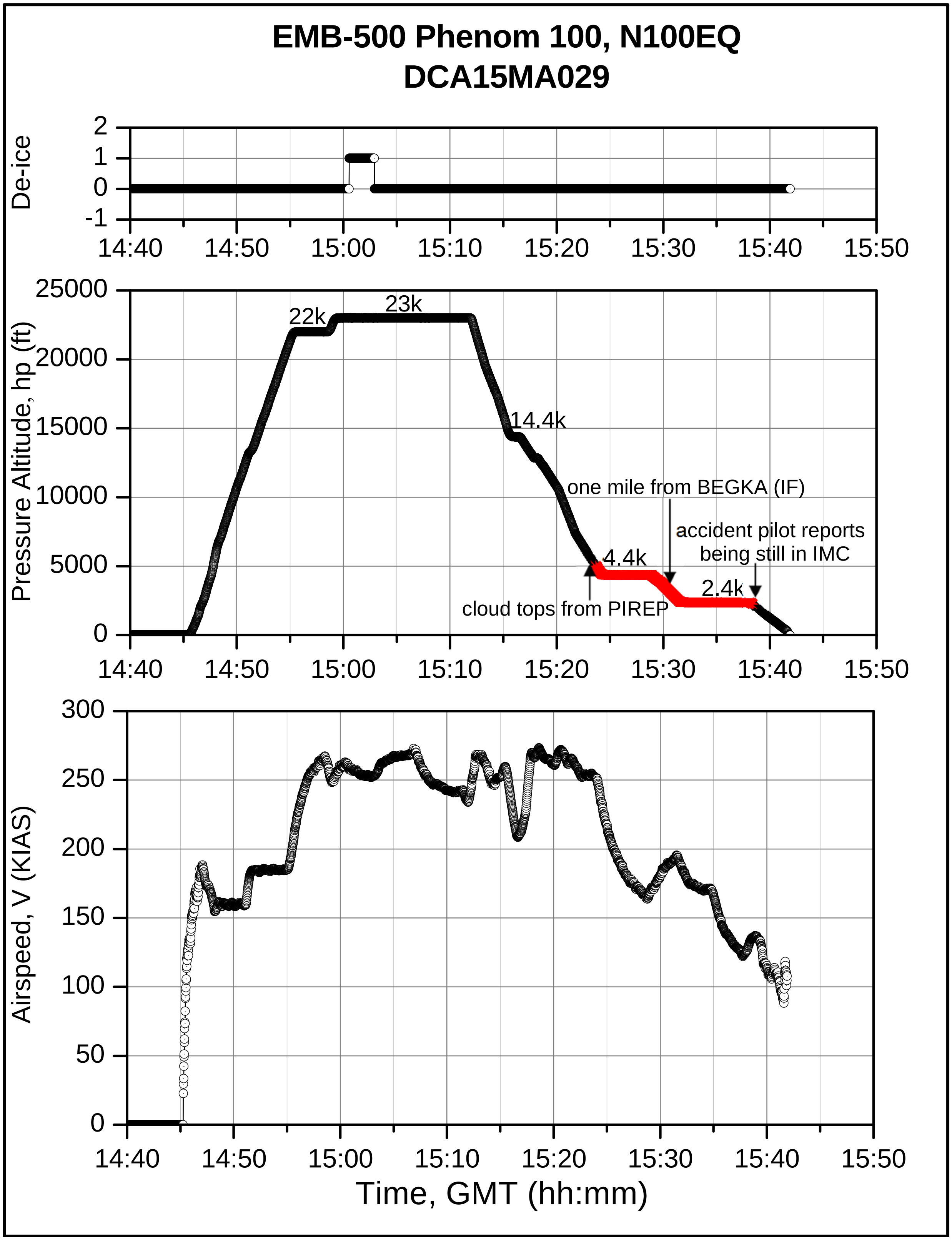


Figure 9: N100EQ Speed and Altitude Profile with Likely Ice Encounter in Red

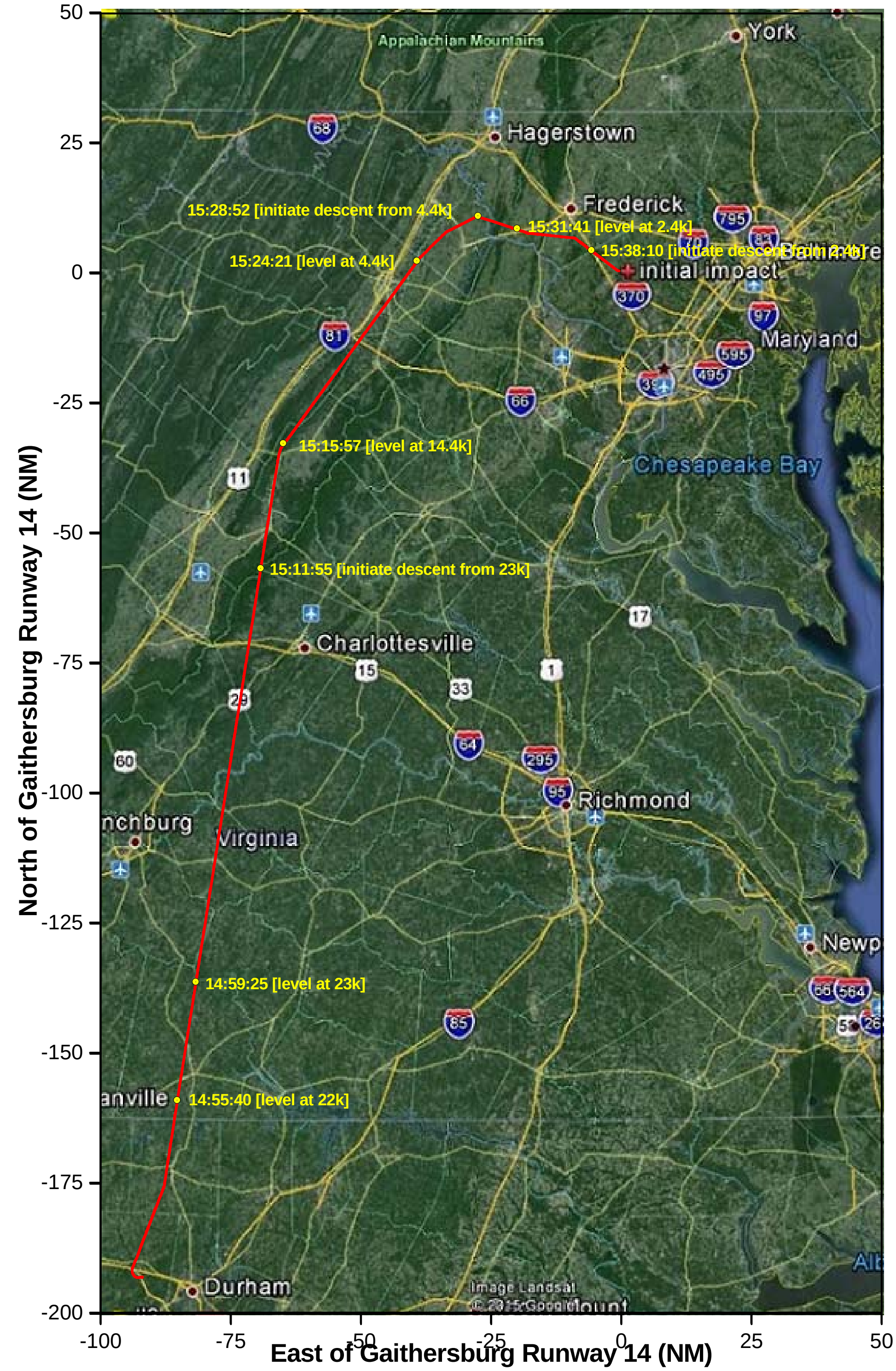


Figure 10: CVDR Ground Track with Altitude Changes
(note: Altitudes are pressure altitudes as shown in Figure 9.)

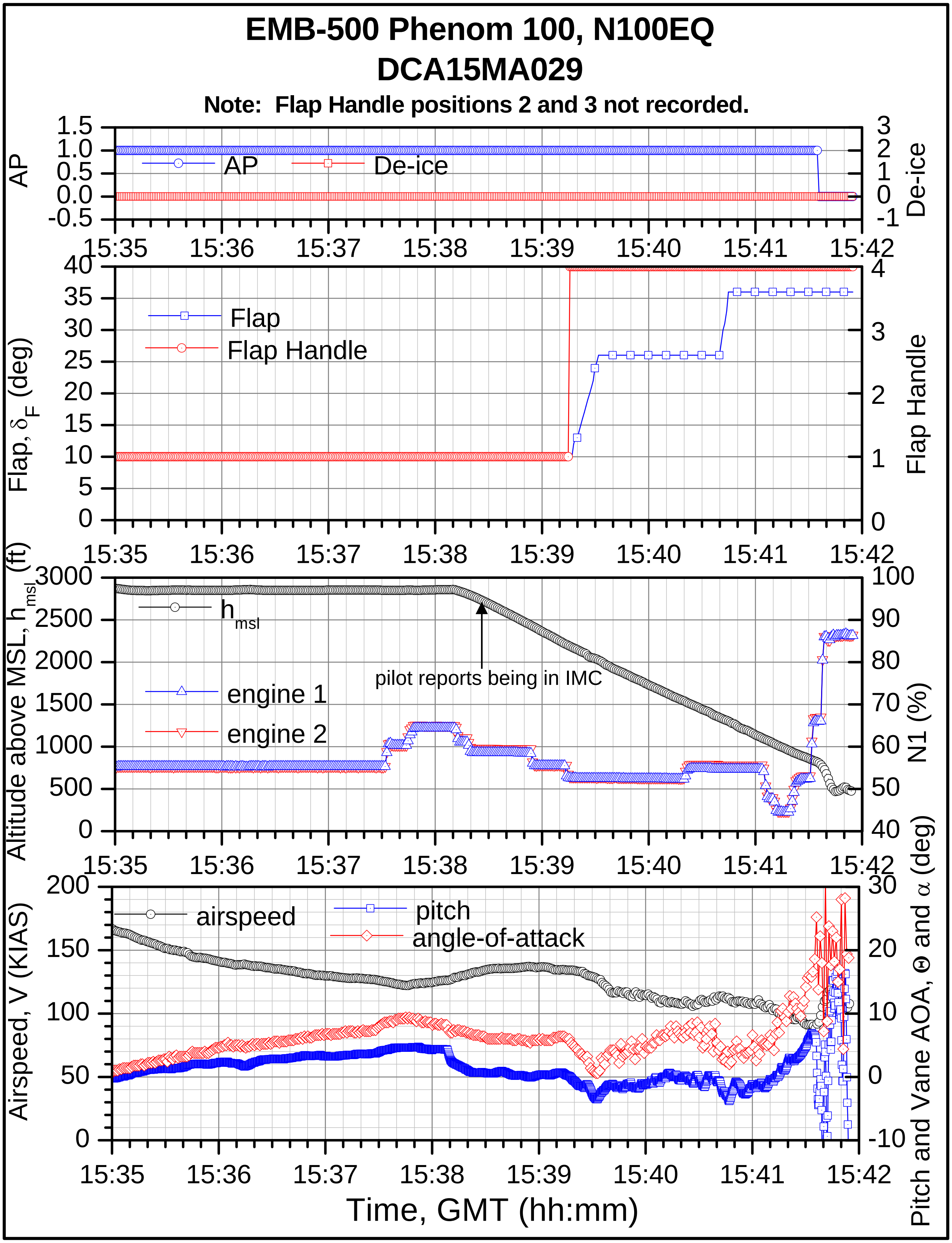


Figure 11: Altitude and Speed for Last Seven Minutes of Flight

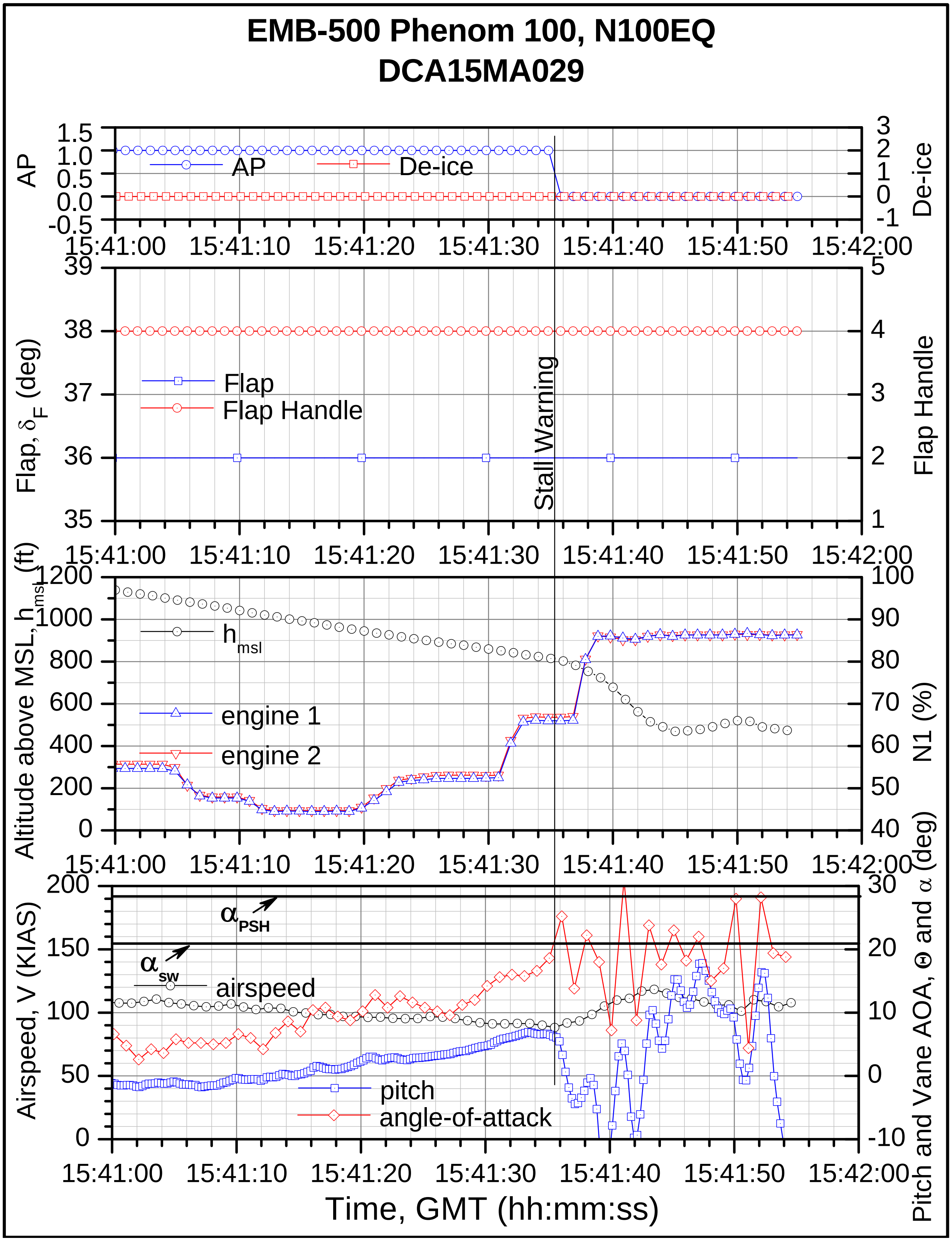


Figure 12: Altitude and Speed for Last Minute of Flight

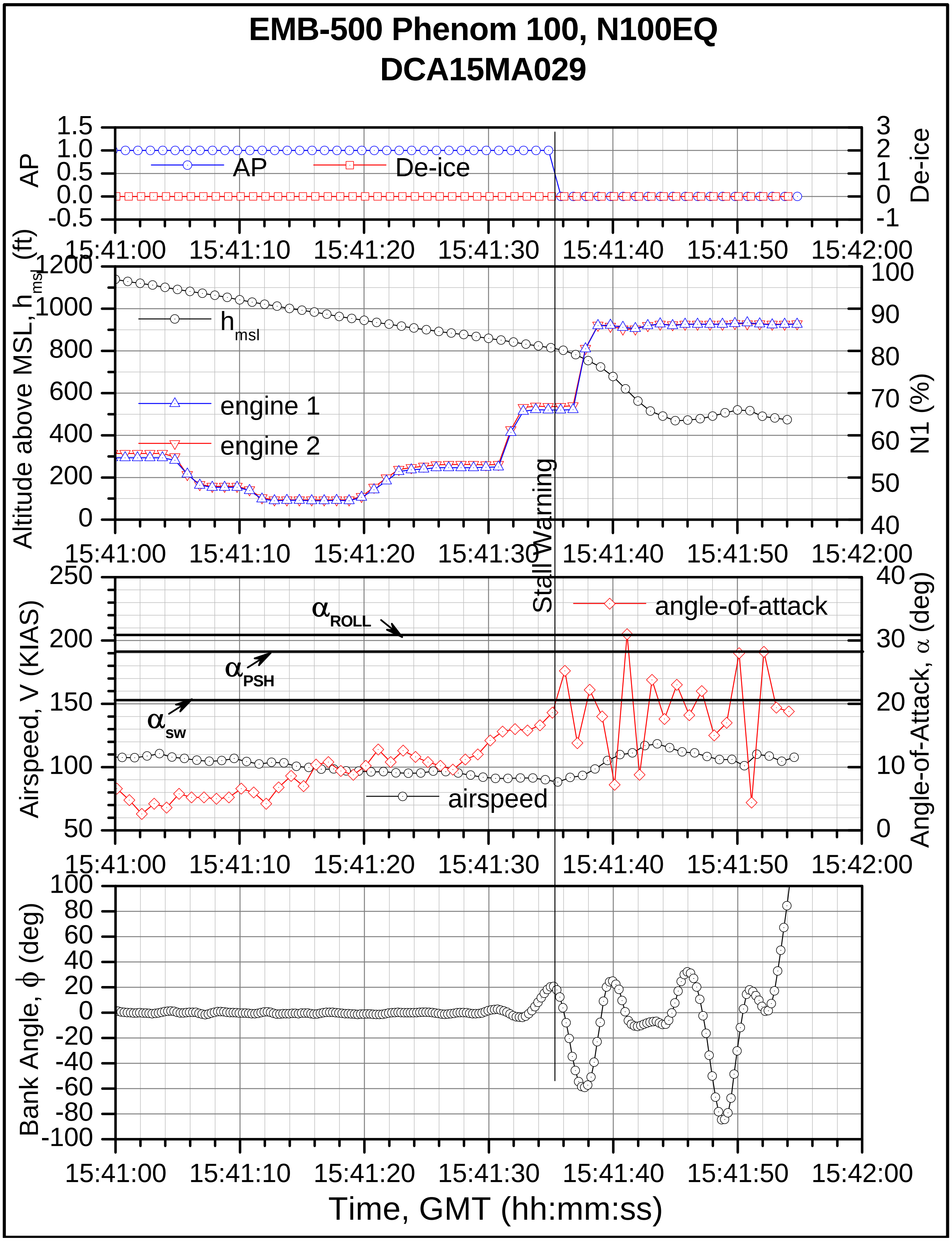


Figure 13: Bank Angle for Last Minute of Flight

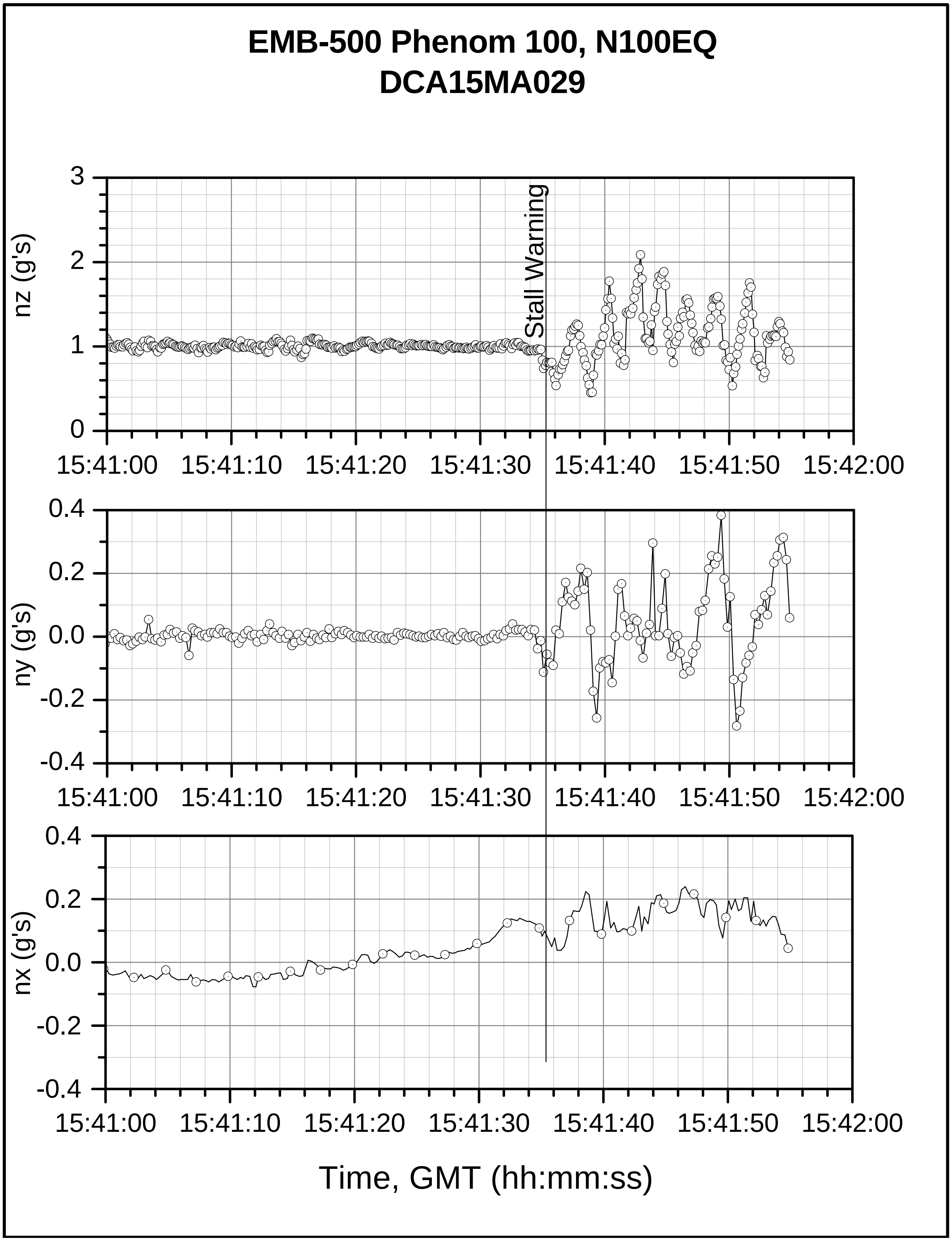


Figure 14: Load Factor for Last Minute of Flight

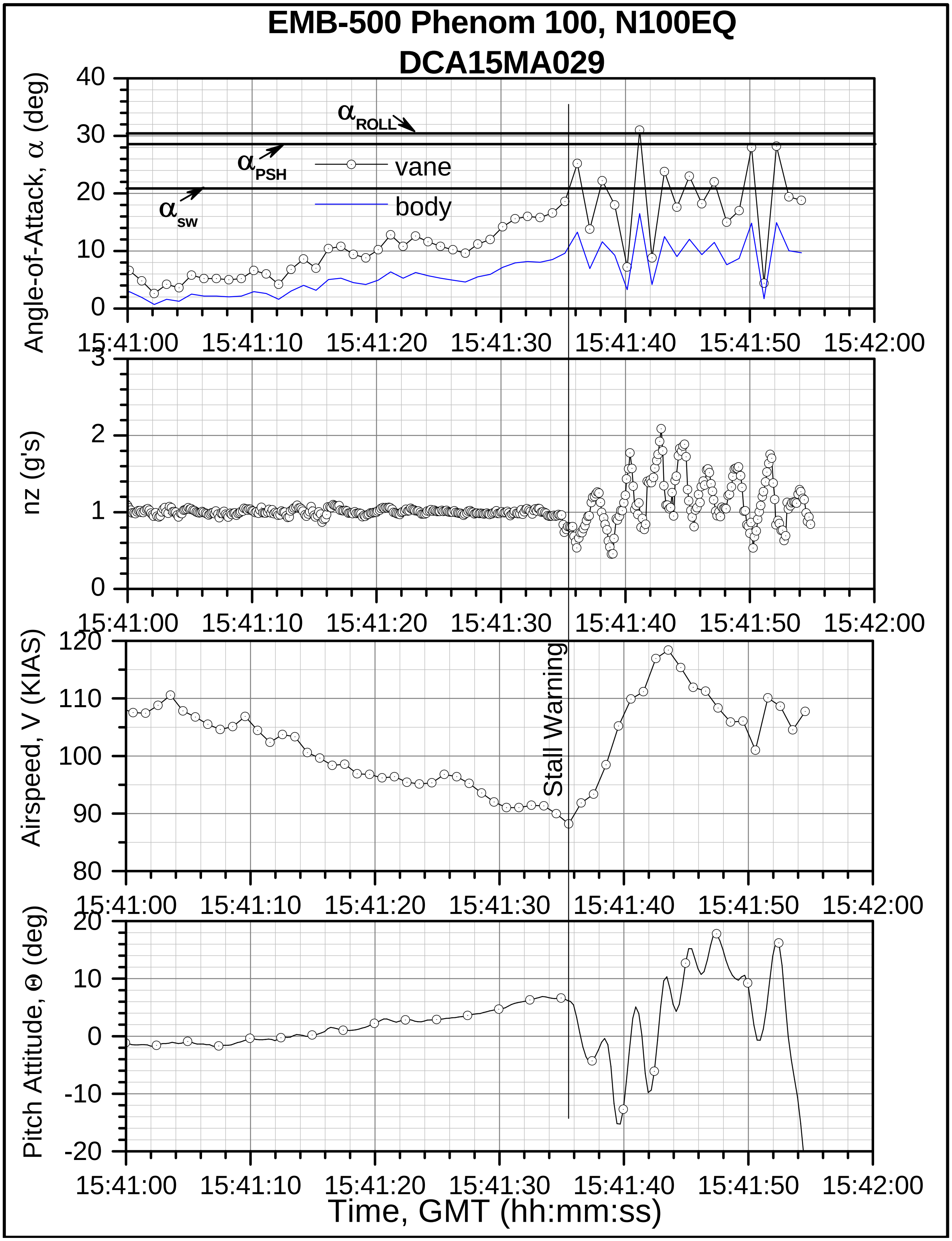


Figure 15: Pitch with n_z Stall Break

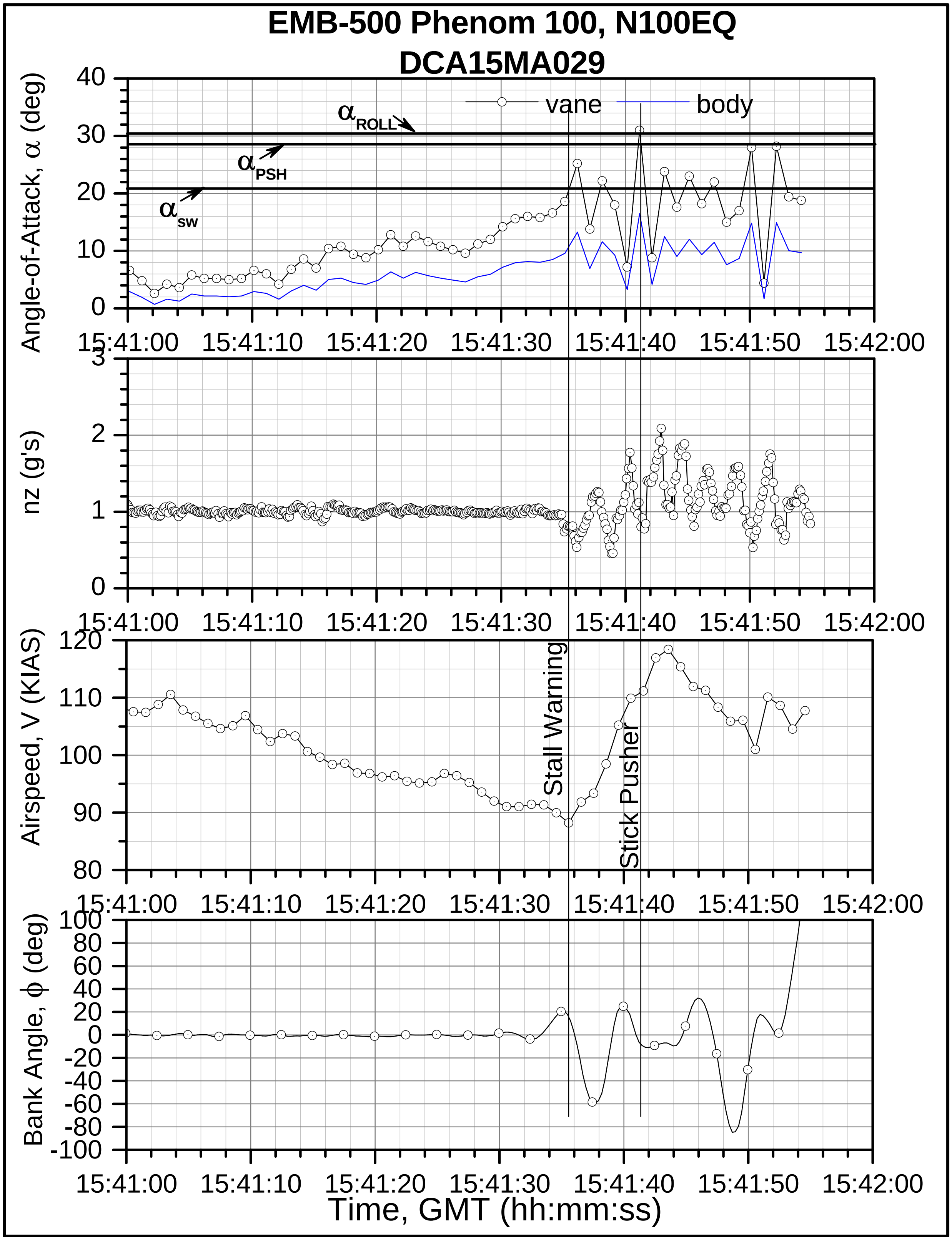


Figure 16: Bank Angle with n_z Stall Break

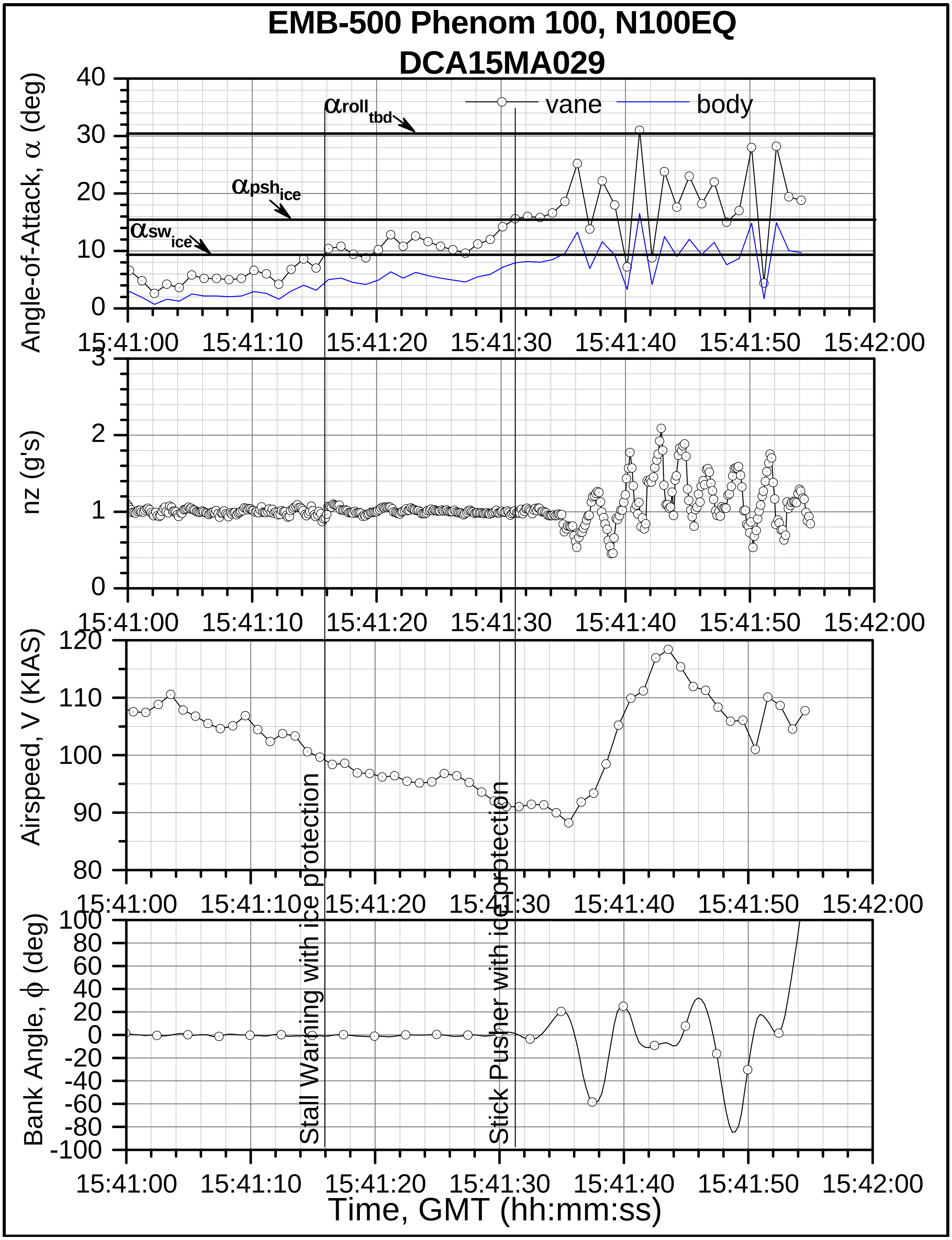


Figure 17: Bank Angle with n_z Stall Break, Wing/Stabilizer De-ice On Stall Thresholds

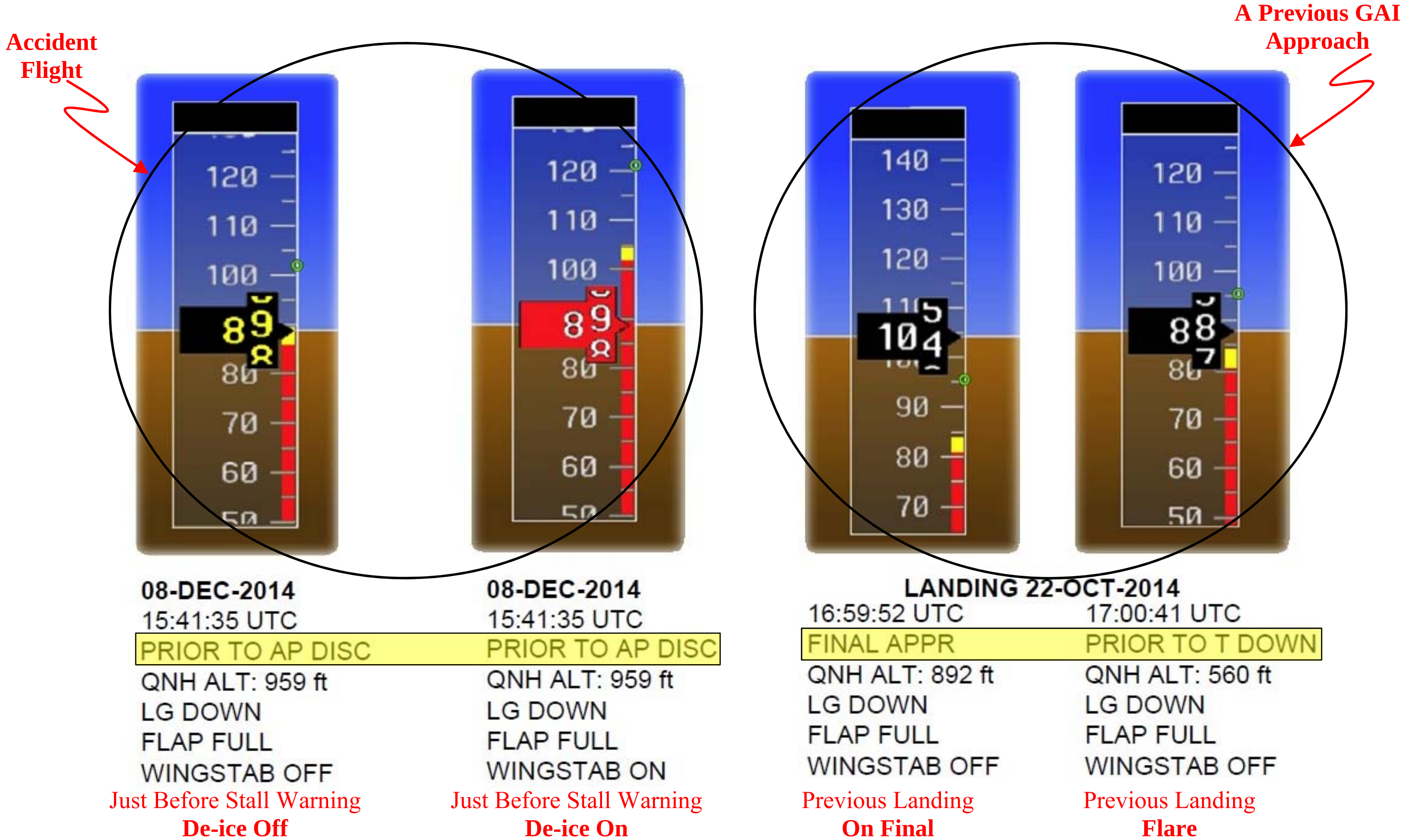
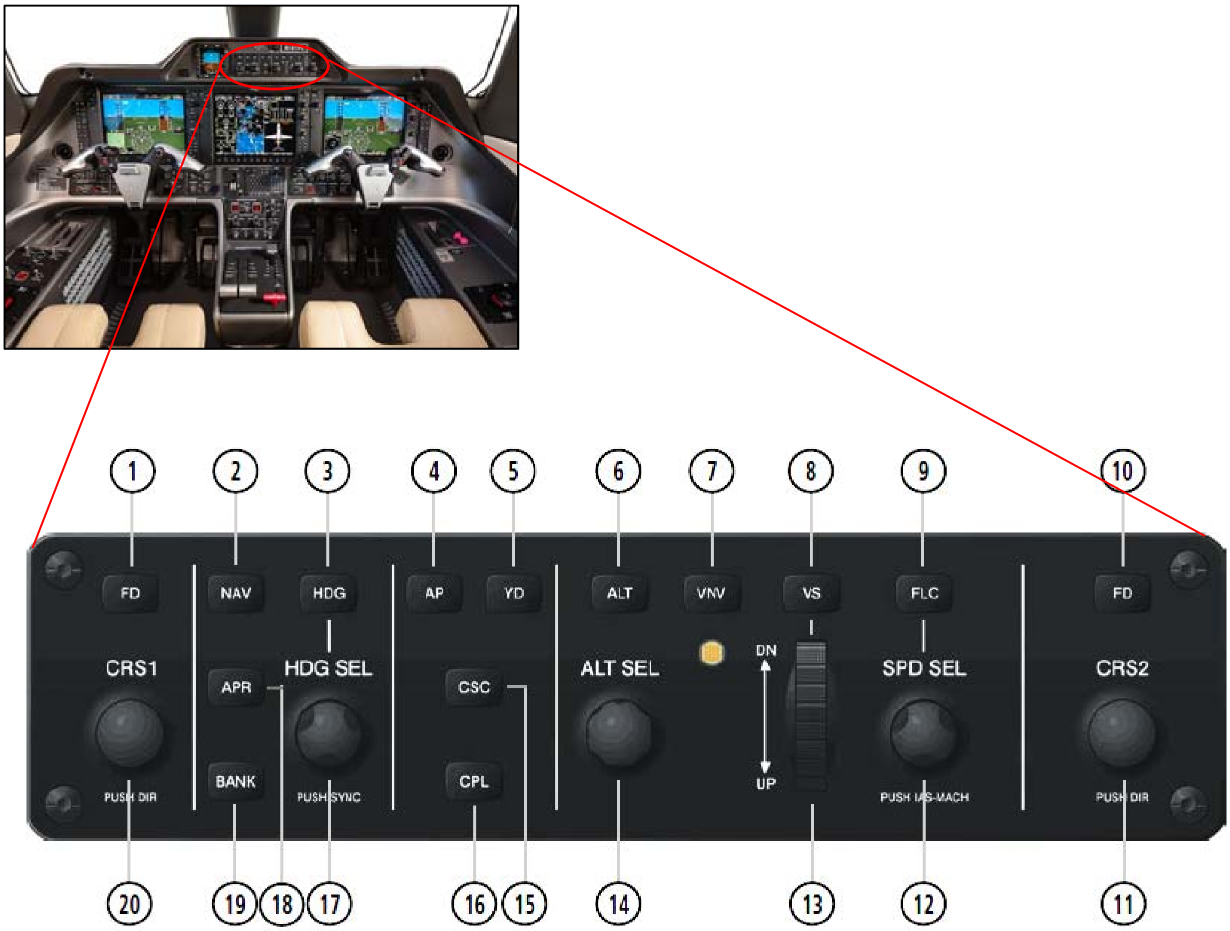


Figure 18: Embraer EMB-500 Phenom 100 Low Speed Awareness Tape Simulations



1, 10 FD Key – Activates/deactivates the selected flight director (pilot- or copilot-side) in default vertical and lateral modes.
2 **NAV Key** – Selects/deselects Navigation Mode.
3 **HDG Key** – Selects/deselects Heading Select Mode.
4 **AP Key** – Engages/disengages the autopilot
5 **YD Key** – Engages/disengages the yaw damper.
6 **ALT Key** – Selects/deselects Altitude Hold Mode.
7 **VNV Key** – Selects/deselects Vertical Path Tracking Mode for Vertical Navigation flight control.
8 **VS Key** – Selects/deselects Vertical Speed Mode.
9 **FLC Key** – Selects/deselects Flight Level Change Mode.
11, 20 CRS Knobs – Adjusts the Selected Course in 1° increments on the Horizontal Situation Indicator (HSI) of the corresponding PFD.
12 **SPD SEL Knob** – Adjusts the Airspeed Reference and bug in 1-kt (0.01 M) increments.
13 **UP/DN Wheel** – Adjusts theVertical Speed Reference and bug in 100-fpm increments.
14 **ALT SEL Knob** – Adjusts the Selected Altitude and bug in 100-ft increments.
15 **CSC Key** – Selects/deselects Current Speed Control (when Altitude Hold Mode is active)(if available).
16 **CPL Key** – Transfers selection between the active flight director and standby flight director.
17 **HDG SEL Knob** – Adjusts the Selected Heading and bug in 1° increments on the HSI (both PFDs).
18 **APR Key** – Selects/deselects Approach Mode.
19 **BANK Key** – Manually selects/deselects Low Bank Mode.

Figure 19: AFCS Control Unit (GMC 715)

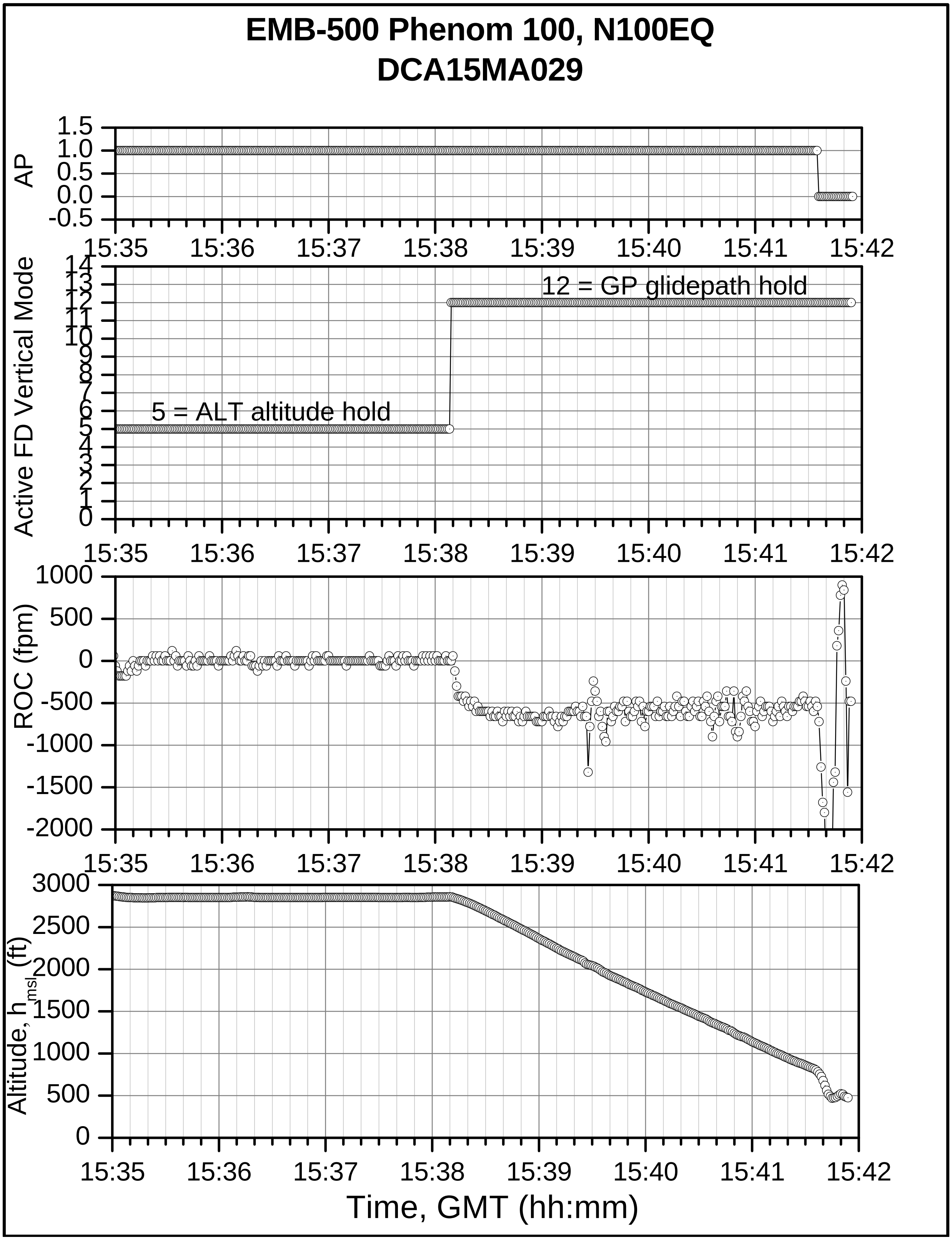


Figure 20: Active Flight Director Vertical Modes During the Approach

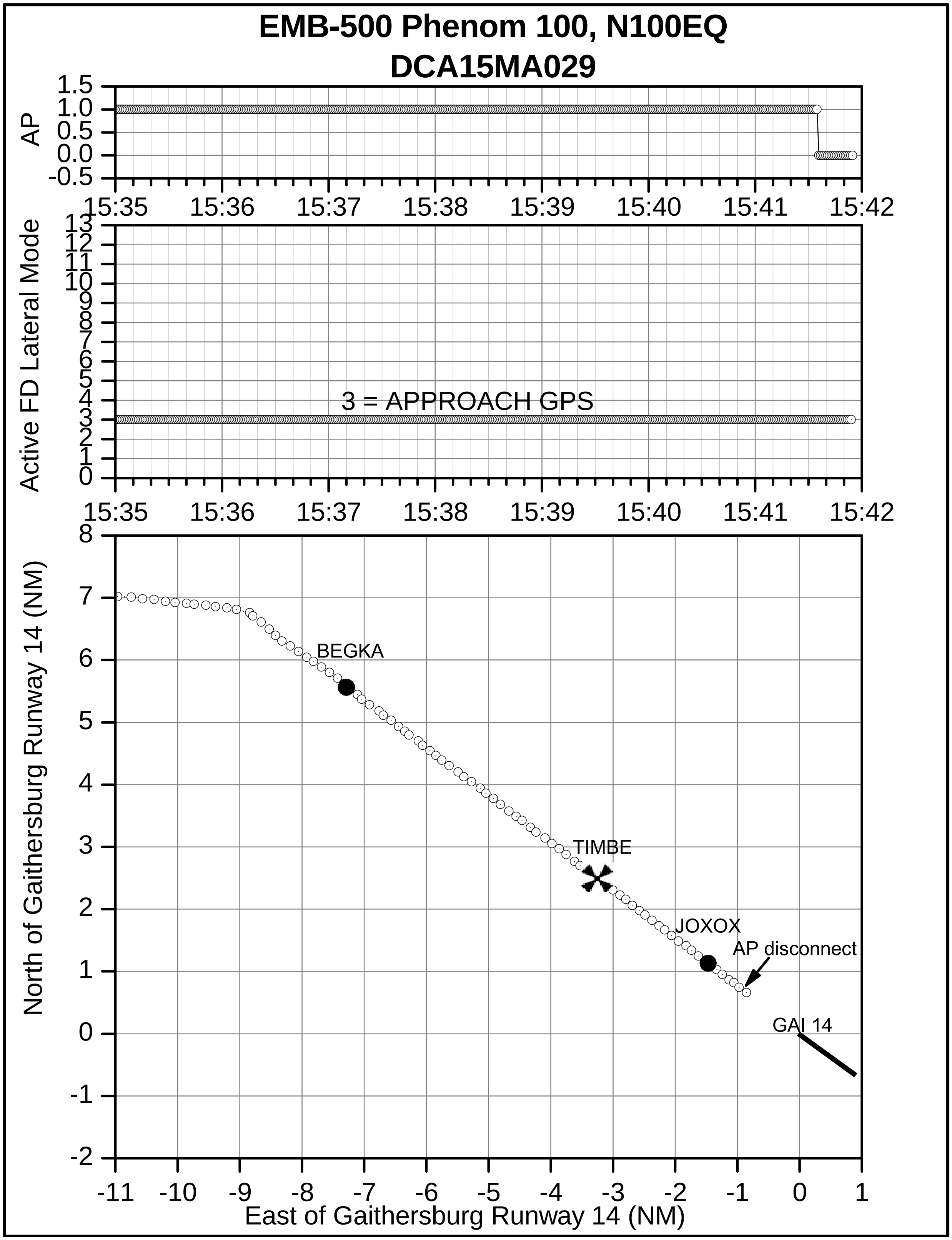


Figure 21: Active Flight Director Lateral Mode During the Approach
(note: Ground track from radar. Waypoint locations are approximate.)