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

Performance Study

Specialist Report
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A. ACCIDENT

Location:	Smyrna, Tennessee
Date:	May 29, 2021
Time:	1055 central daylight time (CDT)
Airplane:	Cessna 501, N66BK
NTSB Number:	ERA21FA234

B. SUMMARY

On May 29, 2021, about 1055 central daylight time, a Cessna 501 Citation, N66BK, was destroyed when it was involved in an accident shortly after takeoff from the Smyrna Airport (MQY), Smyrna, Tennessee. The pilot and six passengers were fatally injured. The airplane was operated as a Title 14 *Code of Federal Regulations* Part 91 personal flight.

C. PERFORMANCE STUDY

This performance study is based on Automatic Dependent Surveillance-Broadcast (ADS-B) data provided by the Federal Aviation Administration (FAA). ADS-B broadcasts an airplane's Global Positioning System (GPS) position, the time, the airplane's altitude, inertial speed, and other data to the ground where it is recorded. The GPS position has an accuracy of approximately 20 meters (65 ft) in both the horizontal and vertical dimensions. The ADS-B sampling was irregular, but position was sampled approximately once a second.

The airplane was in contact with air traffic control (ATC) during the flight [1]. The in-air portion of the communications are included in this report. The airplane was not equipped with a Cockpit Voice Recorder.

Weather Observation

Weather reported at MQY at the time of the accident was winds of 10 kts from 310°, temperature of 57°F (14°C), dewpoint 53°F (12°C). The skies were overcast with a ceiling 1,300 ft above ground level (agl). Barometric pressure was 30.04 inHg. Instrument meteorological conditions (IMC) prevailed.

Accident Flight

Figure 1 shows the ADS-B flight path taking off from runway 32 at MQY[1] just after 10:53. Figure 2 shows the recorded altitude relative to mean seal level (msl) and calculated speeds of the airplane. All altitudes shown are corrected from pressure altitude. The flight lasted approximately three minutes with the airplane initially climbing at a rate of 2,000 fpm. By 10:53:50 the airplane had entered the clouds and had begun a right turn towards its intended heading of 130°. At 10:54:18, the airplane reached an altitude of 2,900 ft msl while at an airspeed of 200 kts. It then descended while accelerating to nearly 290 kts of airspeed. The descent was arrested at 1,875 ft at 10:54:41 and the airplane again climbed, this time at more than 6,000 ft/min. The airplane reached its maximum altitude of 2,975 ft at 10:54:55 before beginning a steep descent while in a left roll. The final ADS-B point was recorded at 10:55:05 at an altitude of 1,025 ft over Percy Priest Reservoir, where the wreckage was recovered.

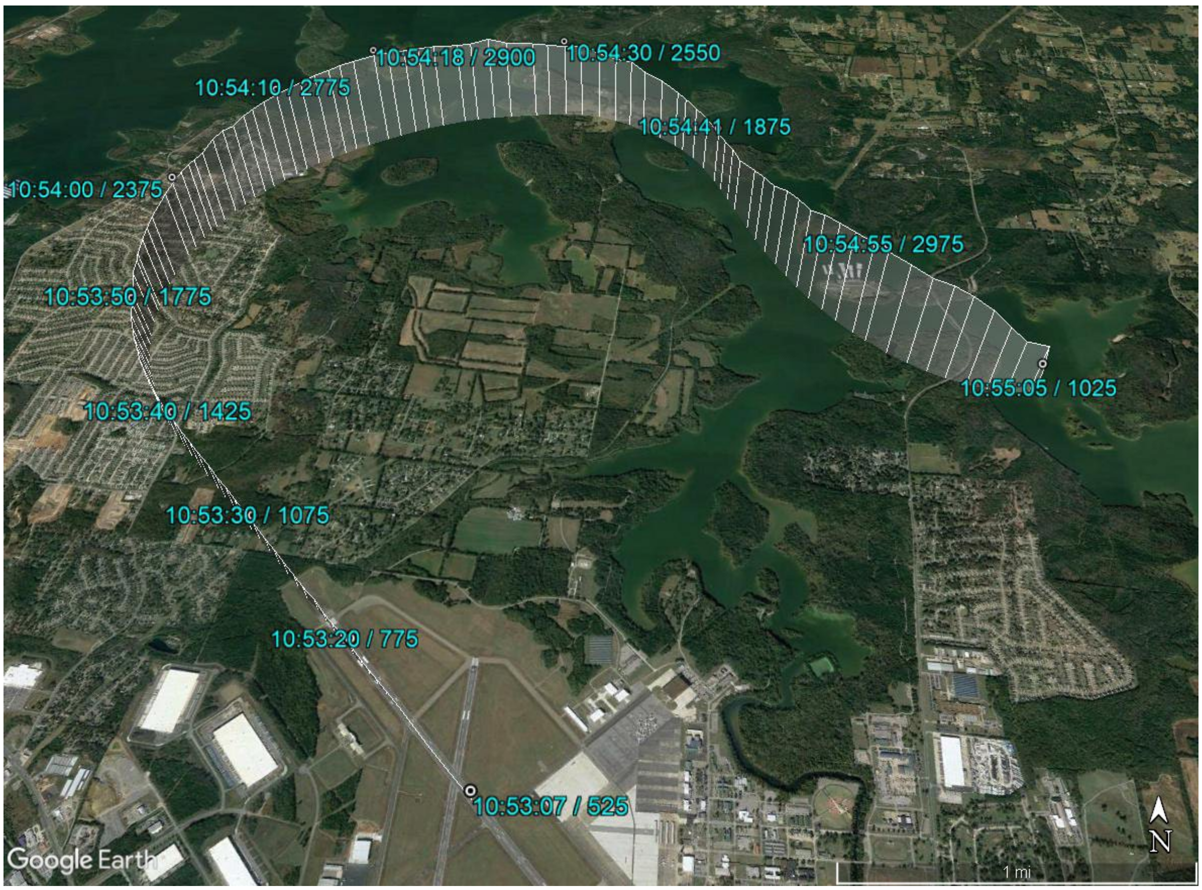

Figure 1. Flight path with time and altitude (msl) for selected points.

[1] The elevation of Runway 32 varies from 517 ft msl to 543 ft msl.

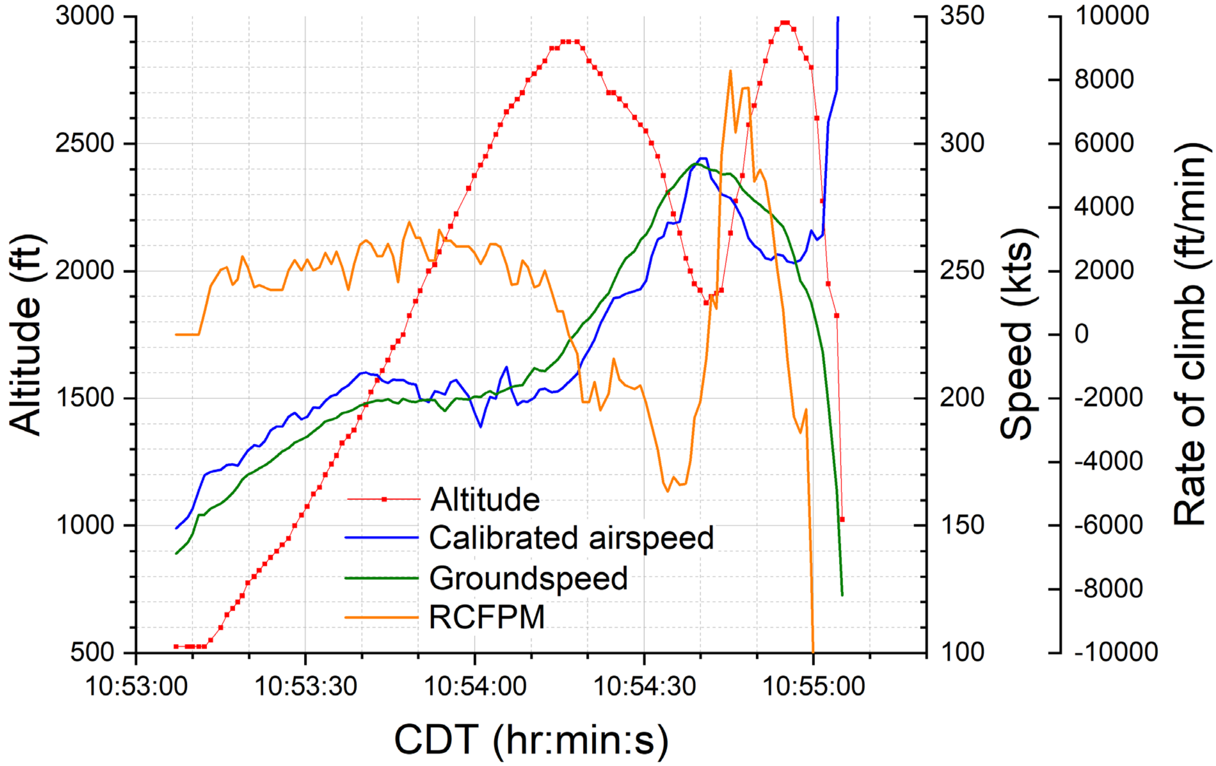

Figure 2. Altitude (msl), calculated air and groundspeeds, and rate of climb (RCFPM) versus time.

Airplane pitch and roll were calculated using a simplified aerodynamic model of the airplane and are shown in Figure 3. Pitch was between 5° and 10° nose up during the initial climb and the airplane banked about 30° right wing down as it turned. The nose started lowering after 10:54 and the rate of climb reduced. The pitch angle went nose down and the airplane began to descend at 10:54:18. As it descended, the right turn tightened and the airplane reached a maximum right bank angle of 60° by 10:54:35. The airplane began the second climb after 10:54:41 and pitched to near 13° nose up. By 10:54:43 the airplane was wings level and continued to roll left wing down and the flight path curved left. The airplane was -60° left wing down when the final descent began at 10:54:55.

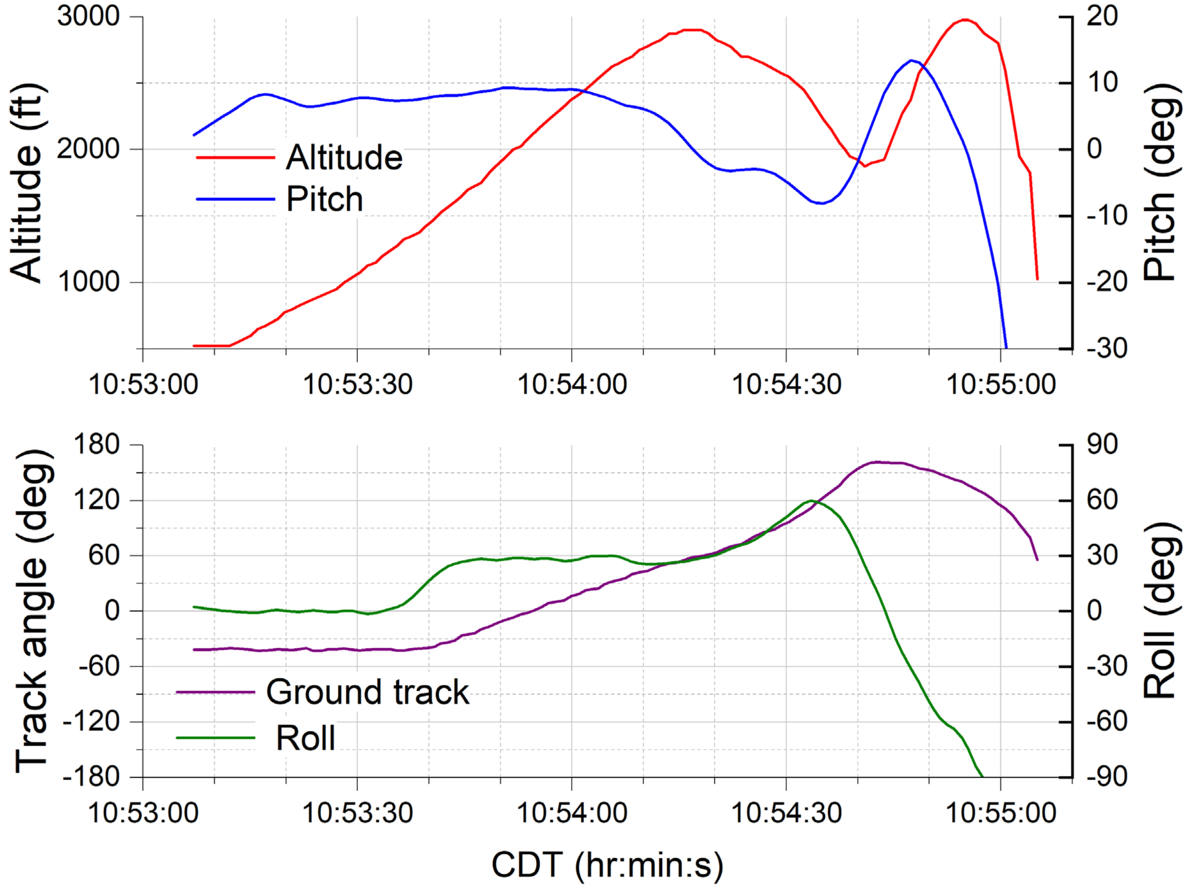

Figure 3. Airplane altitude (msl) and calculated pitch, track angle, and roll.

Air Traffic Control Communications

During flight, the pilot spoke with Nashville APC (approach control). Figure 4 shows ATC communications on a map of the flight. Figure 5 shows ATC communications on the altitude and track plot. At 10:54:30, while the airplane was in the first descent, ATC asked the pilot to "say altitude" and instructed a heading of 130°. The pilot did not respond and the airplane continued turning right, passing 130°. At 10:54:44, ATC asked if the pilot copied the 130° heading instruction. The airplane had begun to climb again and was on a track of 160°. The airplane then began to turn back left and the pilot responded to affirm 130°. The airplane passed through 130° during its final descent.

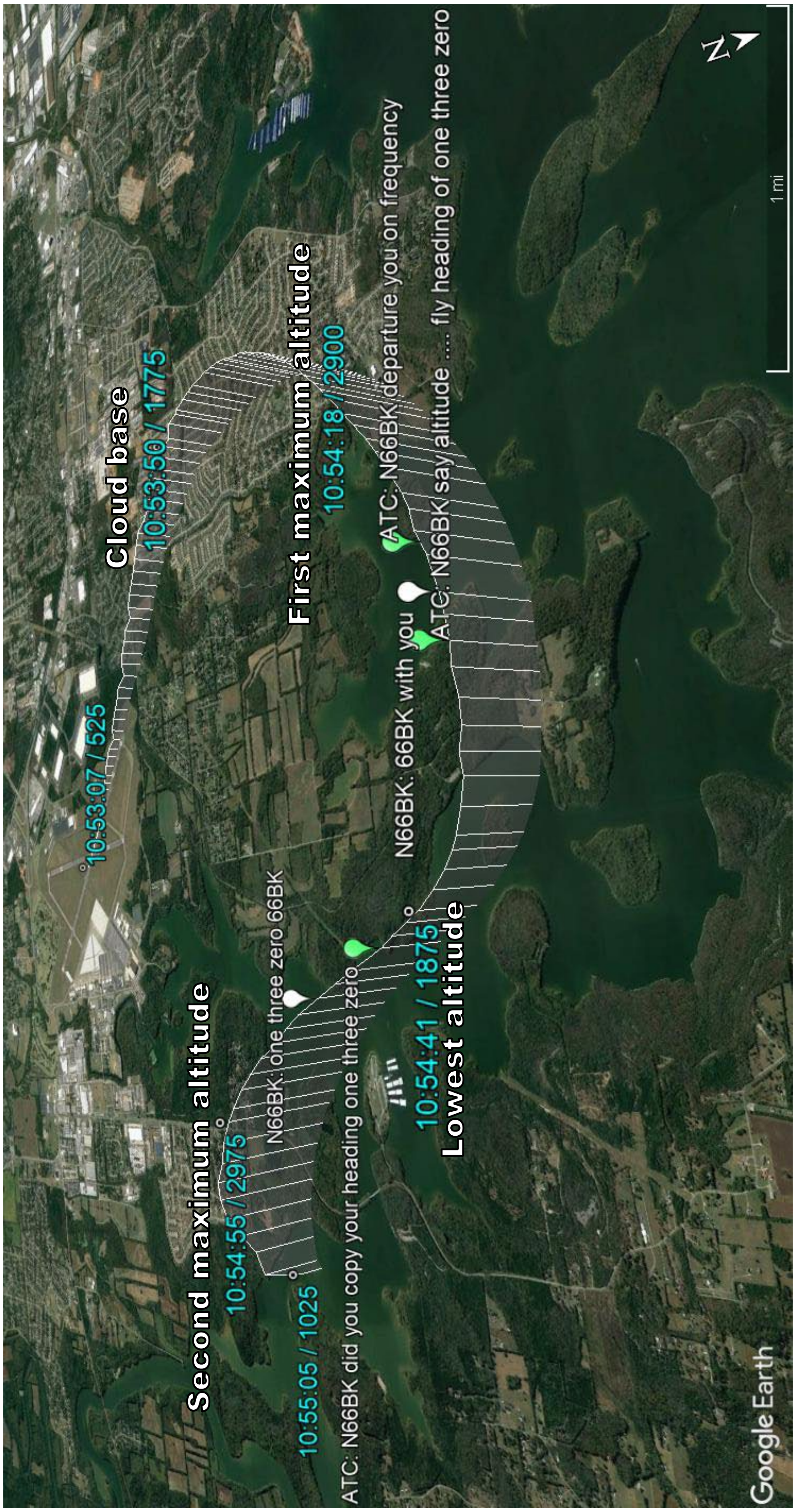

Figure 4. Airplane flight path with selected times and altitude in blue and ATC communications.

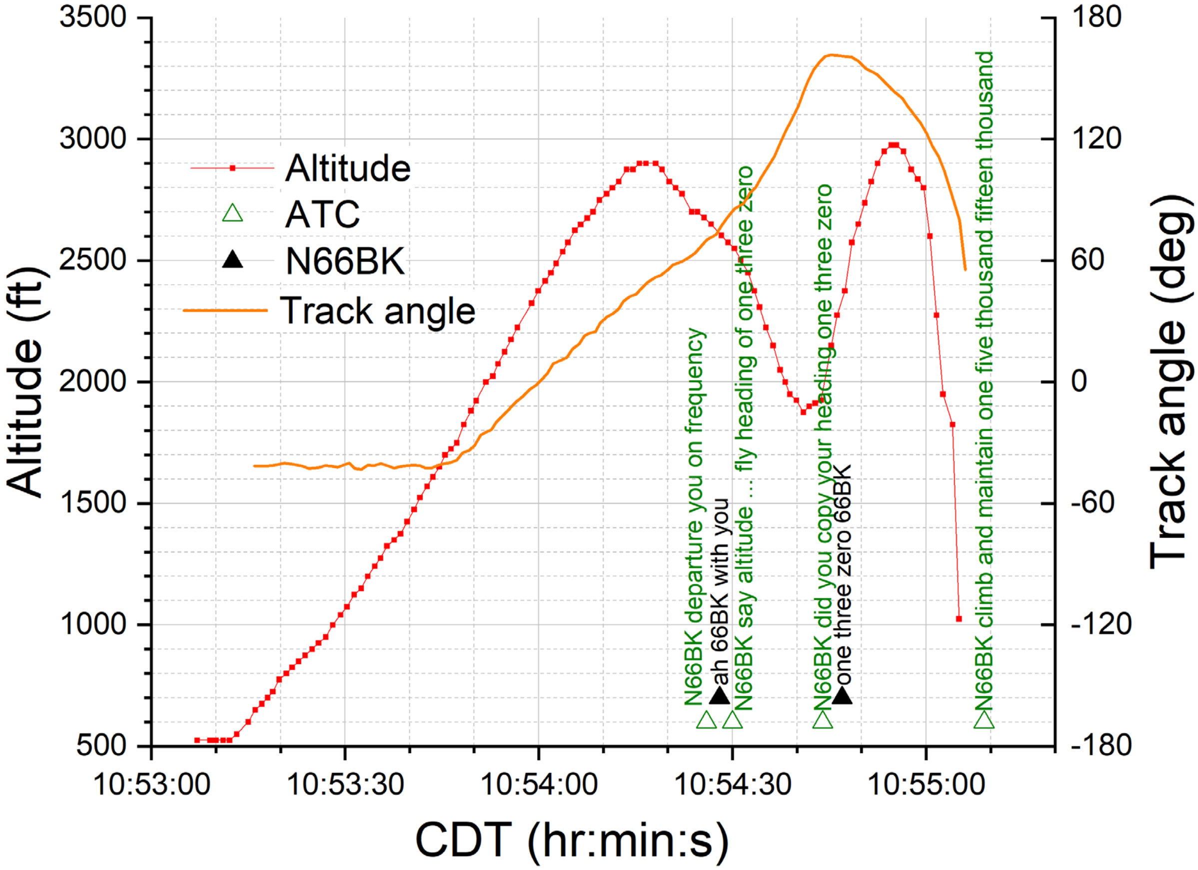

Figure 5. Airplane altitude (msl) and track angle with ATC communications.

Apparent Angles

To obtain a more detailed estimate of performance throughout the flight and to confirm the consistency of the recorded ADS-B 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 was consistent with the performance capabilities of the Cessna 501 and the ADS-B data. The simulation used a "math pilot" to generate control system inputs to produce pitch and roll angles that result in an approximate match of a target trajectory defined by a smoothed track through the recorded data. However, the pitch and roll angles that produced the accident trajectory may not have resulted entirely from control inputs but could have resulted entirely or in part from another source such as control failures or damage and consequently the simulation results, by themselves, do not provide information from which to determine the source of the rolling and pitching moments acting on the airplane. However, for this accident, no evidence of a control failure or damage prior to impact with the reservoir were found.

The simulation also calculated airplane load factors for the flight which were used to determine the "apparent" pitch and roll angles. The vestibular system of the inner ear allows a person to have a sense of balance and spatial orientation. However, like all accelerometers, the vestibular system cannot distinguish between load factors due to motion versus load factors due to gravity. On its own, the inner ear cannot differentiate between accelerations and tilt. Additional sensory inputs, such as visual cues, are needed to correctly perceive attitude and acceleration. When a pilot misperceives attitude and acceleration it is known as the "somatogravic illusion" and can cause spatial disorientation. Further information is available in the FAA's Pilot's Handbook of Aeronautical Knowledge [2].

Figure 6 shows the orientation of the resultant load factor vector $\vec{n}$ for two cases. In the left image, the airplane is unaccelerated and $\vec{n}$ is aligned with the gravity vector g, along the earth's vertical axis (z_e). In the right image, the airplane is in accelerated flight and $\vec{n}$ has a component along the x_b axis (n_x). In both cases, the angle of the vector $\vec{n}$ relative to the airplane's vertical axis (z_b) is the same: θ_{APP}, or the "apparent" pitch angle. While in the left image, θ_{APP} is the actual pitch angle of the airplane ($\theta_{APP} = \theta$), in the right image the actual pitch angle is less than θ_{APP}. However, in both cases the pilot's vestibular/kinematic system alone would perceive the pitch angle as θ_{APP}.

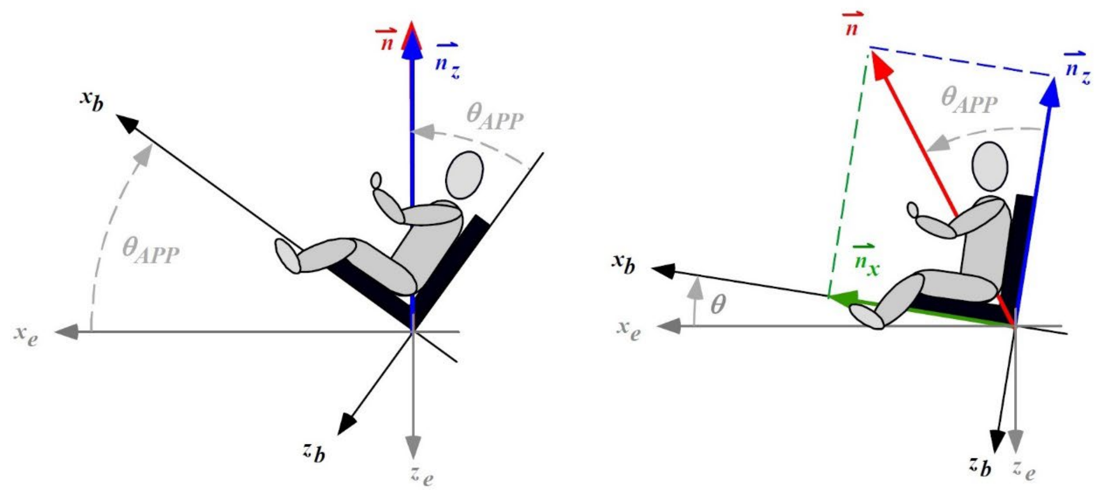

Figure 6. Apparent angles in an unaccelerated (left) and accelerated (right) reference frame.

The following equations represent the apparent pitch and roll angles for a worst-case scenario where acceleration is wholly mis-equated for gravity, but the actual pilot perception could range anywhere between an accurate attitude to one where the airplane attitude is wholly mis-equated. 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 are needed to compute θ_{APP} and ϕ_{APP}. In the unaccelerated system, $\vec{n}$ has Earth-axis components {0, 0, -g}, or equivalently

$$\vec{n} = \begin{pmatrix} 0 \\ 0 \\ -|\vec{n}| \end{pmatrix}_{EARTH}$$

Where

$$|\vec{n}| = \sqrt{(n_x)^2 + \left(n_y\right)^2 + (n_z)^2} = g$$

Transforming these components into airplane body axis for the unaccelerated system gives

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

For the accelerated system, θ_{APP} and ϕ_{APP} are such that when the airplane body axis is aligned with these angles in an unaccelerated system, the resulting body-axis components of $\vec{n}$ will match the load factors n_x, n_y, and n_z from the accelerated case. So, the last equation is set as

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

And θ_{APP} and ϕ_{APP} can be calculated as

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

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

Figure 7, below, shows the actual and calculated apparent pitch and roll angles along with the flight altitude. During the descents, it was possible that the pilot perceived that the aircraft was nose-up rather than nose-down due to the airplane's accelerations. Throughout the whole of the flight, it was possible that the roll angle could have felt much less extreme than it actually was. Data for the calculated angles are terminated before the end of the flight because the simulation could not accurately match the flight path once the airplane was in a steep descent and large roll to the left.

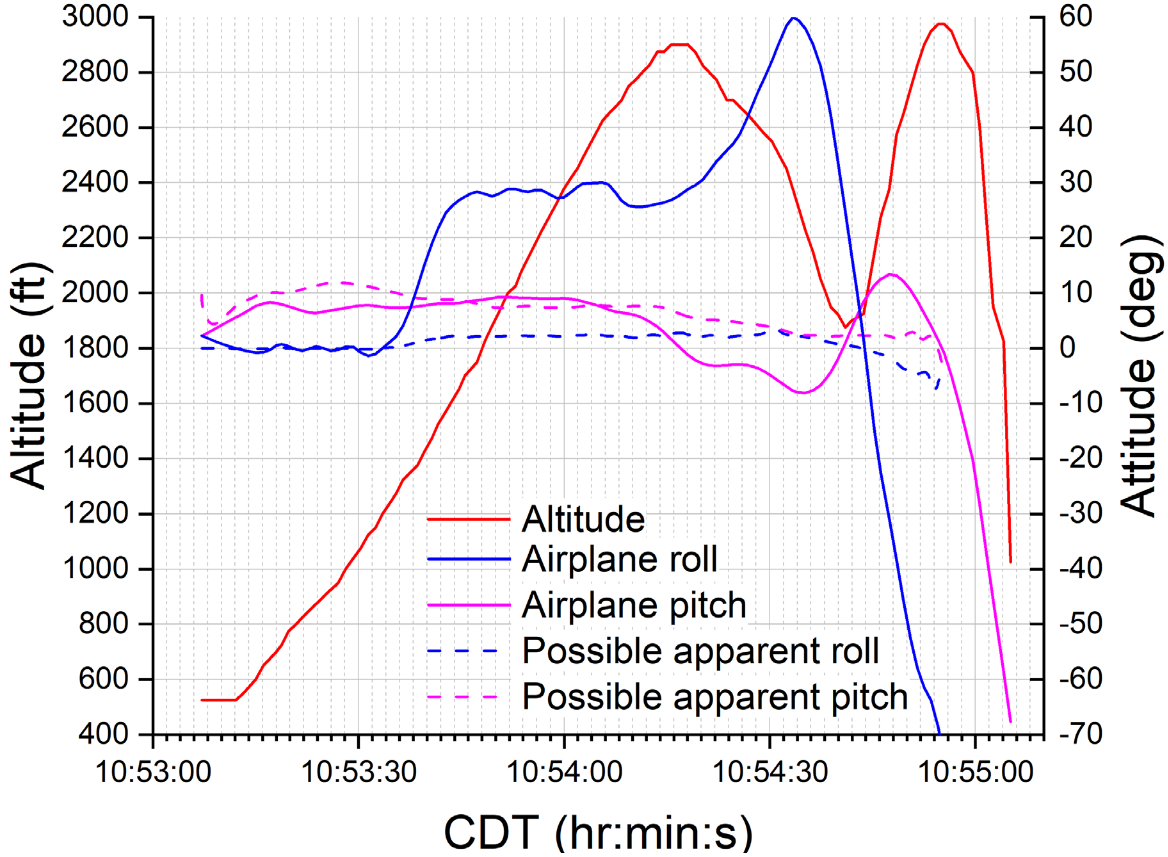

Figure 7. Actual and apparent pitch and roll angles.

D. CONCLUSIONS

The airplane took off from Smyrna Airport in instrument meteorological conditions and entered the clouds while performing a climbing right turn. The airplane stopped climbing about 75 seconds into the flight and began to descend. During the descent, ATC instructed a heading of 130°. The pilot did not respond initially. The airplane transitioned to a rapid climb and had continued to turn right through the instructed heading when ATC again contacted. The pilot responded and the airplane began a left turn. Twelve seconds later the airplane began a rapid descent while in a left turn. The airplane impacted the surface of a lake. Airplane accelerations were such that the pilot had the opportunity to misinterpret the descents or the steepness of the turns.

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E. REFERENCES

1. Air Traffic Control Communications, ERA21FA234, National Transportation Safety Board, 2021.

2. Chapter 17: Aeromedical Factors, *Pilot's Handbook of Aeronautical Knowledge*, FAA-H-8083-258, Federal Aviation Administration 2016.