

National Transportation Safety Board

Office of Aviation Safety

Washington, DC 20594



CEN22FA081

HUMAN PERFORMANCE

Specialist's Factual Report

October 12, 2023

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A. ACCIDENT

Location: Fulshear, Texas
Date: December 21, 2021
Time: 0926 central standard time
Airplane: Cessna 208B
Dudek Paragliders Solo 21

B. HUMAN PERFORMANCE SPECIALIST

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C. FACTUAL INFORMATION

This report summarizes information relevant to human performance aspects of an accident involving a midair collision between a Cessna 208B and a Dudek powered paraglider.

1.0 Collision Geometry

The collision was documented by the aft-facing lens of a 360-degree video camera mounted on a selfie stick extended in front of the powered paraglider. The resulting video showed the Cessna approaching from the powered paraglider's right side, as described in the Onboard Image Recorder Specialist's Factual Report. When the Cessna first appeared in the video (about 6 second before the collision) its wings were slightly above the horizon. As the paraglider operator (PO) initiated a right turn and his body (and the camera) swung upward like a pendulum (about 2 seconds before the collision), the Cessna's wings were approximately level with the horizon.

The angle of collision was difficult to estimate due to distortion of the recorded images from the camera's wide-angle lens. For estimation purposes, a 90-degree collision angle will be assumed, as shown in figure 1. ADS-B data indicate that the Cessna was traveling at 162 knots (groundspeed). According to its manufacturer, the powered paraglider's trim speed range was 39-50 km/h, or 21-27 knots.¹ Therefore, the powered paraglider's speed can be estimated at 24 knots. The Pythagorean Theorem ($A^2 + B^2 = C^2$) was used to estimate a closing speed between the two aircraft of about 164 knots (figure 1).

¹ Information retrieved from [//dudek.eu/en/produkt/solo/](https://dudek.eu/en/produkt/solo/) on May 24, 2023.

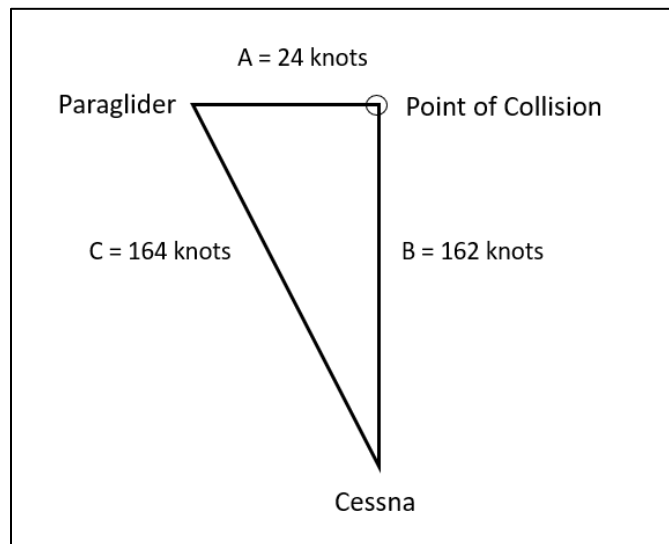


Figure 1. Collision geometry and closing speed (not to scale).

The Cessna was flying straight and level and was not maneuvered before hitting the powered paraglider. The powered paraglider was initially flying straight and level. About 8 seconds before the collision, the PO turned his head to the right, toward the approaching Cessna, and continued looking in that direction. About 6 seconds before the collision, he began maneuvering the powered paraglider (first left and then right), but he was struck by the Cessna's right wing.

The Pythagorean Theorem can again be used to determine the distance between the two aircraft. The powered parachute's airspeed of 24 knots can be converted to feet per second using the multiplier 1.68780986, which (rounded to the nearest tenth) yields 40.5 feet per second. The Cessna's airspeed can be similarly converted to 273.4 feet per second. At time eight seconds before collision, therefore, the two aircraft would have been 324 feet (side A) and 2,187 feet (side B) from the point of collision, respectively, and 2,211 feet apart (side C) (figure 2).

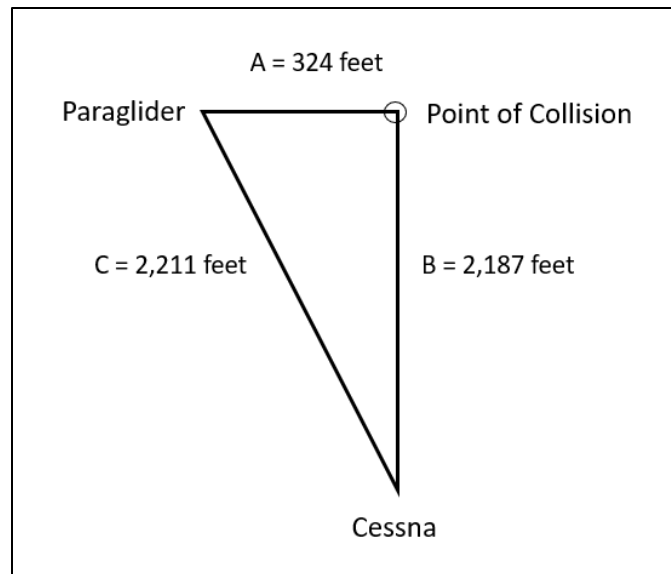


Figure 2. Distances between aircraft and the point of collision at time 8 seconds before collision.

The subtended visual angle² of a distant object can be calculated using the formula $\theta = 2 \cdot \tan^{-1} \left\{ \frac{\text{Size}/2}{\text{Distance}} \right\}$. The Cessna's wingspan was 52 feet. At a distance of 2,211 feet, the subtended angle of the Cessna wing on the PO's retina was 1.35 degrees. (For comparison, a thumbnail held at arm's length subtends a visual angle of about 1.5 degrees.)³ Visual acuity drops dramatically just 2 degrees away from the center of fixation (an area known as the fovea), and it is very poor in the peripheral field.⁴ Therefore, the PO likely needed to fixate on the Cessna to recognize it as an approaching object. Although the periphery is sensitive to motion, the Cessna would have had little apparent motion because the aircraft were on a collision course.

Video recovered from the powered paraglider indicates that the Cessna pilot's view of the powered paraglider was not blocked by aircraft structure, and that the powered paraglider would have appeared somewhere near the center of the Cessna pilot's field of view. Given that the two aircraft were operating at the same altitude, the paraglider would have been vertically centered in the Cessna pilot's field of view. Given the speeds of the two aircraft and assuming a collision angle of 90 degrees, the angular displacement from the horizontal center of the Cessna pilot's field of view can be calculated using the formula $\alpha = \tan^{-1} (A/B)$ (see labeled triangle in figure 3). Using time 8 seconds before the collision, $\tan^{-1} (324/2187) = 8.43^\circ$. This would be

² Subtended visual angle is the acute angle of a triangle defined by points located at the eye of a viewer and the outside edges of a distant object being viewed. The angle is a function of the size of the viewed object and its distance from the viewer. The angle is directly related to the size of the retinal image, with larger angles corresponding to larger retinal images.

³ Gibb, R., Gray, R., and Scharff, L. (2010). *Aviation visual perception: Research, misperception and mishaps*. London: Routledge.

⁴ Galluscio, E.H. (1990). *Biological psychology*. New York, Macmillan.

true for at any point in time while the aircraft were approaching each other on a 90-degree collision course. Thus, the powered paraglider appeared about 8.43° left of center in the Cessna pilot's field of view. Despite the powered paraglider's position near the center of the Cessna pilot's field of view, the Cessna pilot did not maneuver the Cessna away from the powered paraglider.

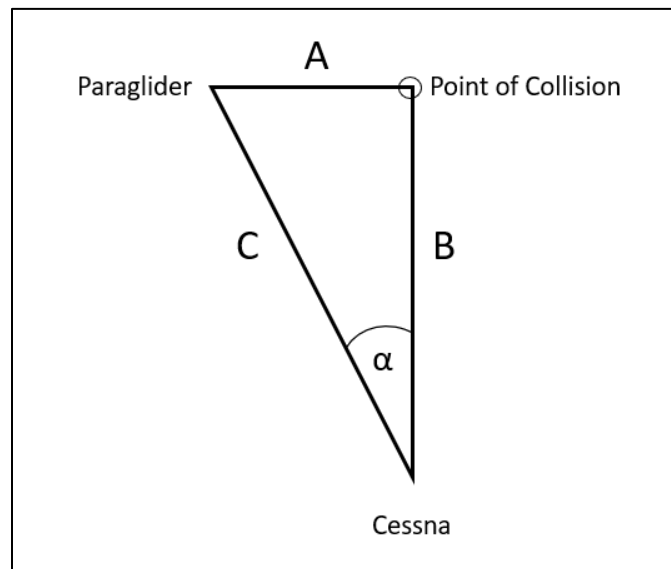


Figure 3. Horizontal displacement (α) of the powered paraglider in the Cessna pilot's field of view (not to scale).

2.0 Recognition Time and Subtended Visual Angle

Federal Aviation Administration (FAA) Advisory Circular 90-48E, Pilot's Role in Collision Avoidance identifies the perceptual, cognitive, and psychomotor steps required for collision avoidance and provides the following approximation of the of time required for each step (Table 1). This breakdown indicates that 12.5 seconds can be expected to elapse between the time that a pilot sees a conflicting aircraft and the time an avoidance maneuver begins.

Table 1. Aircraft Identification and Reaction Time Chart⁵

Process/Task	Response (Seconds)	Cumulative (Seconds)
See an object ahead	0.1	0.1
Recognize that object is an aircraft	1.0	1.1
Become aware that a collision course exists	5.0	6.1
Make a decision to turn left or right	4.0	10.1
Muscular reaction	0.4	10.5
Aircraft lag in response to flight control input	2.0	12.5
Total time before aircraft begins to move	12.5	

At time 12.5 seconds to collision, the Cessna and the powered paraglider were 3,455 feet apart. The wing of the powered paraglider was the largest component of that aircraft.⁶ The Cessna pilot's view of the powered paraglider was from the side; therefore, the chord of powered paraglider wing was the widest visible dimension of the powered paraglider. The powered paraglider's wingspan was 28 feet, and its aspect ratio was 4.02. $\text{Chord} = \text{span} / \text{aspect ratio} = 28/4.02$, therefore the powered paraglider's wing chord was about 7 feet. Using the previously described formula $[\theta = 2 \cdot \tan^{-1} \{(\text{Size}/2) / \text{Distance}\}]$, the subtended angle of the chord 12.5 seconds before collision (from the Cessna pilot's point of view) can be estimated at 0.116 degrees. Values for other distances are listed in table 2.

Table 2. Subtended Angle of the Paraglider Wing Chord from the Cessna Pilot's Perspective

Time to Collision (Seconds)	Distance Between Aircraft (Feet)	Distance Between Aircraft (Nautical Miles)	Subtended Angle of Powered paraglider Wing (Degrees)
1	276	0.05	1.451
2	553	0.09	0.725
3	829	0.14	0.484
4	1106	0.18	0.363
5	1382	0.23	0.290
6	1658	0.27	0.242
7	1935	0.32	0.207
8	2211	0.36	0.181
9	2488	0.41	0.161
10	2764	0.45	0.145
11	3040	0.50	0.132
12	3317	0.55	0.121
13	3593	0.59	0.112
14	3870	0.64	0.104
15	4146	0.68	0.097
16	4423	0.73	0.091
17	4699	0.77	0.085
18	4975	0.82	0.081
19	5252	0.86	0.076
20	5528	0.91	0.073

⁵ FAA. (2022). *Advisory Circular 90-48E*. Pilot's Role in Collision Avoidance. Washington, DC.

⁶ The motor fan cage on the PO's back was 4.5 feet tall, the PO was less than 6 feet tall and folded into a seated position, and the lines between the wing and the cage were too thin to see at a distance.

Visual acuity is the ability to see high levels of detail in an image. Distant acuity is commonly measured using a Snellen eye chart containing static, high contrast letters positioned 20 feet from an observer.⁷ The ability to resolve a detail (a line or a space) as small as 1 minute of arc is considered normal acuity. This permits a person to recognize a simple shape (such as a test letter such as "E") that subtends 5 minutes of arc (0.083 degrees). As can be interpolated from table 2, the subtended angle of the wing chord reached this angle about 17.5 seconds before the collision.

The powered paraglider was probably not as familiar to the Cessna pilot as a letter of the alphabet. The paraglider was superimposed on a horizon containing terrain features creating a complex background. Research indicates that the minimum subtended angle required for recognizing an uncommon shape in a field of distractor items is 0.20 degrees.⁸ Using this criterion, the powered paraglider wing would have been recognizable 7.4 seconds before collision.

Visual contrast is another consideration for estimating recognition time. The powered paraglider wing was white and pale blue, with pale orange tips. It was likely superimposed on or adjacent to (just below) a bright blue sky. The PO, who was suspended below the powered paraglider wing, was wearing a dark brown or olive-colored flight suit and was likely superimposed on or adjacent to the terrain which was a patchwork of brown and green colors. The minimum subtended angle for recognizing complex, low contrast targets is about 0.40 to 0.60 degrees.⁹ Using this criterion, the powered paraglider wing would have been recognizable 2 or 3 seconds before the collision.

3.0 Limitations of Visual Scanning

As previously stated, visual acuity is dramatically lower more than 2 degrees away from the center of fixation. To compensate for the small foveal area, the FAA recommends pilots make separate fixations on different portions of the visual field, no less than 10 degrees apart, and devote at least one second to each fixation.¹⁰ As highlighted by an Australian Transport Safety Board (ATSB) study, a pilot using this strategy would need 54 seconds to systematically scan an area 180 degrees wide and 30 degrees tall. By the time they completed such a scan, the scene could have changed, and they would need to start over, causing the ATSB to conclude that the

⁷ Gibb, Gray & Scharff (2010) Ibid.

⁸ Steedman, W.C., Baker, C.A. (1960). Target size and recognition. *Human Factors*, 2(3), 120-127.

⁹ Van Cott, H.P, Kinkade, R.G. (1972). *Human Engineering Guide to Equipment Design (Revised Edition)*. U.S. Government Printing Office, Washington, DC.

¹⁰ Federal Aviation Administration (2022). Pilots' role in collision Avoidance. *FAA Advisory Circular 90-48E*. October 20, 2022.

systematic use of this strategy is impractical.¹¹ A mathematical modeling study determined that the likelihood of detecting a 40-foot-wide aircraft using optimum scanning techniques was just 30 percent, for a closing speed of 200 knots.¹²

Research indicates that pilots do not systematically scan the visual field. Their scans are biased.¹³ Moreover, research indicates that general aviation pilots may only spend 30 to 50 percent of their time scanning outside the cockpit.¹⁴ The authors of a study that examined data from actual flights and actual intruder aircraft determined that there was an 85% probability detection would occur 12 or fewer seconds before a collision, given a closing speed of 120 knots.¹⁵

The Cessna was operating under 14 CFR Part 135 on an instrument flight plan in visual meteorological conditions. The Cessna was equipped with a transponder and was broadcasting ADS-B OUT, so it was visible to the air traffic control system. The powered paraglider was operating under 14 CFR Part 103. It was not equipped with a transponder or broadcasting ADS-B OUT, so it could not be detected by air traffic control. Neither aircraft was equipped with ADS-B IN technology, cockpit display of traffic information, or a traffic alerting system.

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¹¹ Australian Transport Safety Board. (1991). *Limitations of the see-and-avoid principle*. Australian Transport Safety Report. Canberra, Australia.

¹² Morris, C. (2005). Midair collisions: Limitations of the see-and-avoid concept in civil aviation. *Aviation, Space, and Environmental Medicine*, 76, 357-65.

¹³ Colvin, K. Dodhia, R., and Dismukes, R.K. (2005). "Is pilots' visual scanning adequate to avoid mid-air collisions?" *Proceedings of the 2005 International Symposium on Aviation Psychology*, 141-146.

¹⁴ Colvin, Dodhia, & Dismukes (2005). Ibid; Suzler, See also R.L. & Skelton, G.E. (1976) Visual attention of private pilots, the proportion of time devoted to outside the cockpit. *FAA report RD-76-80*, May.

¹⁵ Andrews, J.W. 1991. Unalerted Air-to-Air Visual Acquisition. *Report No. DOT/FAA/PM-87/34*. Massachusetts Institute of Technology, Lincoln Laboratory, Lexington, MA.