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Recurring Event Sequences in Instructional Fixed-Wing General Aviation Accidents: A Sequence Analysis of National Transportation Safety Board Accident Reports, 2020-2025

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Accident classifications identify what happened during a flight, but they may reveal less about how an accident developed. This study examined 728 source-verified instructional fixed-wing general aviation accidents in the United States from 2020 through 2025. Each accident was classified by training context and accident category, then coded as an ordered sequence of events based on the available accident record. Landing and ground-control accidents were the most common, followed by power-loss or mechanical events and loss of control during takeoff or initial climb. Frequently observed sequences involved directional-control loss during landing, bounced or hard landings, landing-gear failures, and loss of control during attempted go-arounds. Accident distributions also differed between dual and solo instructional contexts. Some reports did not contain enough detail to support a specific sequence, so these cases were retained in a residual category rather than assigned a more precise classification. The findings show that examining the order in which events unfold can reveal recurring operational patterns that broad accident categories may conceal. These patterns may help guide further research and the review of flight-training practices, particularly in landing control, go-around decisions, and responses to mechanical or power-loss events.

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Introduction

General aviation flight instruction represents a distinct safety domain, as it merges routine aircraft operations with deliberate skill acquisition, supervision, evaluation, and repeated practice during high-workload flight stages. Unlike non-instructional flights, training flights are intentionally designed to immerse learners in scenarios requiring procedural execution, aircraft handling, decision-making, and error recovery, all under instructor supervision or within a supervised solo context. Therefore, accident analysis in instructional aviation should consider both the outcome and the sequence of events within the training environment.

Traditional general aviation accident surveillance relies on structured categories and official accident data. The National Transportation Safety Board (NTSB) offers CAROL, a public query tool containing aviation investigation data from 1962 onward (NTSB, n.d.). Although these resources are important for surveillance, they do not independently capture all training-relevant pathways described in accident narratives. The NTSB Aviation Coding Manual includes a sequence-of-events matrix and structured codes for occurrence, phase, cause, factor, and event (NTSB, 1998), showing a key methodological limitation: a single coded or defining event may summarize an accident but may obscure the preceding instructional sequence.

A further foundation for this study is the aviation safety community's adoption of standardized accident terminology. The CAST/ICAO Common Taxonomy Team developed occurrence categories to facilitate a shared focus on safety issues, while ICAO's ADREP taxonomy provides standardized attributes for accident and incident reporting. While these systems improve comparability, they also highlight the importance of taxonomy design. Effective accident prevention requires not only categorization but also retaining analytically meaningful distinctions among events that may share outcomes yet differ in operational development, training context, and intervention opportunities (CAST/ICAO Common Taxonomy Team, 2004; International Civil Aviation Organization [ICAO], n.d.).

This distinction is especially significant for instructional fixed-wing general aviation, as previous research demonstrates that training accidents and instructional loss-of-control events display identifiable patterns but require more in-depth analysis. Walach's review of NTSB safety events from 2013 to 2018 identified leading event types among pilots, such as loss of control in flight, powerplant system or component failure, abnormal runway contact, fuel-related issues, and loss of control on the ground, while also emphasizing differences in the training environment. Houston et al. similarly stressed the value of analyzing accident chains in instructional loss-of-control cases, as these chains can disclose patterns that broad first-occurrence or causal labels may not completely capture (Houston et al., 2012; Walach, 2023). The AOPA Air Safety Institute’s Fatal Flight Training Accident Report (2000–2019) identified loss of control in flight as the leading category of fatal instructional accidents, followed by midair collisions. The report additionally highlighted phase-specific concerns, including takeoff, climb, go-around, maneuvering, emergency procedures, and midair-collision exposure. These outcomes support the need for a training-specific analytic approach, as instructional accidents occur within distinct tasks, supervisory structures, and recurring practice environments that shape accident development (AOPA Air Safety Institute, 2024a, 2024b). Loss of control requires particular attention, as it continues to be a major issue in general aviation safety. NTSB safety materials identify inflight loss of control as a persistent source of fatal accidents, with approach to landing, maneuvering, and initial climb identified as especially consequential phases. FAA and FAASTeam materials similarly emphasize loss-of-control prevention, scenario-based proficiency, stabilized approaches, and early go-around decision-making as practical safeguards. These sources are relevant to the present study because the dataset contains not only final loss-of-control outcomes but also the preceding sequences involving takeoff, landing, go-around, power-loss, and approach events (Federal Aviation Administration [FAA], 2020; FAA Safety Team, 2017; NTSB, 2015, 2016).

The training implications of accident sequences are also evident in FAA instructional guidance. The Airplane Flying Handbook provides the baseline training framework for takeoffs, airport traffic patterns, approaches, landings, aircraft control, upset prevention, and emergency procedures. FAA Safety Team stabilized-approach guidance places additional emphasis on specified air speed, descent rate, configuration, checklist completion, and go-around when stabilized criteria are not met. In an instructional accident dataset, these concepts are not just background training doctrine; they provide the operational vocabulary needed to interpret whether an accident sequence involved approach instability, bounce recovery, delayed go-around, directional-control loss, power-loss response, or some other ordered pathway (FAA, 2021; FAA Safety Team, 2017).

Prior accident studies have used analytical approaches that answer different questions. Walach (2023) compared distributions in NTSB safety-event data using chi-square tests, Cramér's V, and odds ratios, an approach suited to identifying differences between training and non-training groups. Wiegmann et al. (2005) applied HFACS to classify human causal factors across unsafe acts, preconditions, supervision, and organizational influences. Houston et al. (2012) analyzed instructional loss-of-control reports across causal factors, flight phase and location, student and instructor experience, procedural errors, meteorological conditions, and recurring occurrences within accident chains, supplemented by selected chi-square tests. Distributional analyses identify which outcomes or factors recur, while accident-chain analysis retains how events are linked within individual cases. The present study extends this chain-oriented approach by explicitly coding source-supported event order across a broader instructional fixed-wing accident set and grouping recurrent ordered sequences into sequence families.

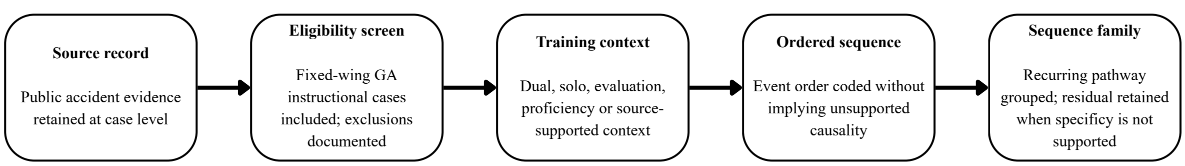
The present study addresses these methodological and practical requirements by developing and applying a source-verified sequence-analysis matrix for instructional fixed-wing general aviation accidents. Rather than assigning each case only a terminal category, the study records source-supported event order. Cases supported for inclusion but lacking sufficient detail for a specific sequence were retained in a source-defined residual pathway.

Accordingly, this study had three objectives. First, it classified source-verified instructional fixed-wing general aviation accidents by training context and adjudicated accident category. Second, it identified recurrent ordered sequence families across the manuscript-eligible analytic set. Third, it interpreted those sequence families in relation to instructional risk management, including supervision, intervention timing, scenario design, approach and landing control, go-around decision-making, power-loss response, and recurring ground-control pathways. The intended contribution is a transparent, auditable method for translating official accident narratives into training-relevant accident pathways.

The study addressed four research questions:

RQ1.
What instructional training contexts are represented in the source-verified fixed-wing general aviation accident set?
RQ2.
Which adjudicated accident categories and sequence families occur most frequently in the manuscript-eligible analytic set?
RQ3.
How do major accident categories differ across consolidated instructional contexts?
RQ4.
What does a conservative residual category reveal about the limits of public accident accounts and the need for source-transparent coding?

Figure 1
Source-Verified Accident Sequence Analysis Workflow



Note. The workflow emphasizes source verification, ordered-event coding, and conservative uncertainty management. Arrows indicate the progression of the analytic process, not causal relationships between accident events.

Method

Methodological Rationale and Design Logic

This study used a retrospective, source-verified accident-sequence design. The design was selected because the research question concerned how instructional accidents unfolded, not simply which categorical outcome was ultimately assigned. The NTSB

Aviation Coding Manual delivers a structured aviation accident coding architecture, and CICTT occurrence categories were developed to support safety analysis using common terminology across aviation reporting systems (National Transportation Safety Board [NTSB], 1998; CAST/ICAO Common Taxonomy Team, 2004).

The analytic approach was intentionally conservative. It treated source narratives as evidentiary records and avoided assigning sequence elements that were plausible but not explicitly supported. This approach is consistent with the wider logic of aviation accident taxonomy, where common terminology improves comparability but case-level interpretation still depends on documentary evidence and coding discipline (International Civil Aviation Organization [ICAO], n.d.; CAST/ICAO Common Taxonomy Team, 2004). It also parallels human-factors safety-analysis traditions such as HFACS, which emphasize structured classification to spot patterns and interventions without reducing an accident to blame attribution (Shappell & Wiegmann, 2000; Wiegmann et al., 2005).

Operational Definitions

Terms were operationalized before analysis to reduce ambiguity between training context, event order, and final accident category. The definitions below were used as manuscript-level decision rules rather than as assumptions about legal or probable cause.

Table 1
Core analytic definitions used in the source-verified sequence framework

Construct	Operational definition	Coding implication
Source-verified case	A record retained only when public accident evidence supported inclusion, context, and minimum sequence information.	Prevents unverified database fields from being treated as sufficient evidence.
Training context	The instructional role or purpose supported by the source record, such as dual instruction, solo flight, evaluation, proficiency, or other instructional activity.	Separates instructional exposure from aircraft ownership or operator labels.
Ordered sequence	A compact representation of temporally ordered events stated or strongly supported in the source narrative.	Preserves event order without converting sequence into causal certainty.
Sequence family	A grouping of recurrent ordered pathways that share practical training relevance.	Allows frequent scenarios to be discussed at the level of trainable risk controls.
Residual pathway	A deliberately conservative category for source-defined events that did not support finer classification.	Keeps uncertain cases visible and prevents overclassification.

Note. Definitions were applied to the manuscript-eligible analytic set and supported by the source-verification matrix.

Worked Coding Example

As a worked example, the source evidence for one manuscript-eligible case (C0874; NTSB investigation CEN20CA079) identified a familiarization flight with a flight instructor present in which an improper flare was followed by a bounced landing, loss of control on the ground, and tire and tailwheel failure. The case was translated through the coding architecture as follows: training context, Dual; accident category, Landing/LOC-G; ordered sequence, IMPROPER-FLARE → BOUNCE → LOC-G → GEAR/TIRE-FAILURE; and sequence family, Landing/ground-control pathway. This example demonstrates how source-supported role information established the training context, while the reported progression of events informed the accident category, ordered sequence, and sequence-family assignment. The arrows represent reported temporal order rather than causal certainty.

Data Source and Source Verification

The source universe was a working screening matrix of potentially relevant instructional fixed-wing general aviation accidents assembled for this study and then verified against official accident source material. Verification relied primarily on NTSB accident records and related source documentation. The retrieval boundary and the information preserved for reconstruction of the initial candidate set are described below.

The retained screening file contained 884 records associated with accident events dated January 1, 2020, through December 31, 2025. Of these, 883 were coded as U.S. events, and one foreign record was excluded before manuscript analysis. The final manuscript analytic set was therefore limited to source-verified U.S. records. After all eligibility and source-verification steps, the manuscript analytic set comprised 728 includable cases.

Each candidate case was reviewed at the case level before inclusion in the analytic dataset. A record was coded as source verified only when the available source material supported the case identifier, instructional relevance, aircraft/operation fit, and sufficient accident narrative or probable-cause information to support the coding fields used in the matrix. This procedure separated source availability from analytic interpretation: the presence of a case in an accident database was not, by itself, treated as sufficient for detailed sequence coding. During source verification, 153 of the 883 U.S. records were excluded because the available documentation was insufficient to support source-verified classification, the accident narrative was ambiguous, or the case could not be confidently reconciled with the study coding taxonomy. The final cleaned matrix retained 730 source-verified records, of which 728 were retained as manuscript-eligible cases, and two were excluded during final eligibility screening.

Initial CAROL Retrieval and Screening Boundary

To assess whether the initial CAROL screening procedure could be recovered, I conducted a best-effort reconstruction using the NTSB CAROL Aviation Investigation

Search on September 4, 2026 (National Transportation Safety Board [NTSB], n.d.). The reconstructed search used an event-date range of January 1, 2020, through December 31, 2025; event type Accident; aircraft category Airplane; FAR Part 91: General aviation; and purpose of flight Instructional. No keyword sentence search was used, and all remaining search fields, including country and report status, were left blank. The reconstructed search returned 937 unique investigations. Matching NTSB investigation numbers against the retained 884-record candidate file identified 881 overlapping cases, representing 99.7% of the original candidate file and 94.0% of the reconstructed export. Three cases in the original file were not returned by the reconstructed search (CEN24LA270, GAA21WA044, and WPR24FA103), while 56 cases appeared only in the reconstructed export. All 56 additional cases had event dates in 2024 or 2025, a pattern consistent with subsequent database updates or changes in record indexing. Although the original query log, interface state, and export timestamp remain unavailable, the near-complete overlap provides empirical support for the reconstructed screening boundary while preserving appropriate uncertainty about the exact original search.

Because the original CAROL query log and export metadata were not retained, the reconstructed search cannot establish the exact original retrieval. Reproducibility therefore begins with the retained 884-record screening file and the documented screening, source-verification, coding, and exclusion procedures.

The analyses reported here were based on the retained 884-record candidate file. The 56 investigations identified only in the reconstructed search were outside that candidate file and were not included in the reported analytic set. Their identification demonstrates that near-complete recovery of the original candidate file does not establish complete coverage of all potentially eligible accidents during the study period.

These 56 investigations were not assessed for eligibility in the present analysis.

Eligibility Criteria and Exclusions

The manuscript analytic set included source-verified accident records involving U.S. instructional fixed-wing general aviation operations from 2020-2025 when the source material supported inclusion, and the accident sequence was codable as either Yes or Partial. The analytic definition emphasized instructional context rather than operator identity alone, because instructional exposure can occur across dual instruction, solo instructional flight, proficiency-related flight, evaluation, and other training-associated settings. General aviation was treated operationally as civil fixed-wing activity outside scheduled air carrier operations and focused primarily on noncommercial instructional activity.

Exclusions were applied conservatively and documented in the matrix. Records were excluded when the source evidence indicated that the event was outside the analytic scope or when the available narrative and probable-cause information were insufficient to support sequence coding. Two additional source-verified records were excluded during final manuscript eligibility screening, reducing the source-verified set from 730 records to the 728-case manuscript analytic set. The excluded records were retained in the workbook for auditability rather than deleted, preserving the distinction between source verification and manuscript eligibility.

Coding Architecture

Coding used a layered architecture intended to preserve both comparability and case specificity. The first layer identified training context; the second layer assigned an adjudicated accident category. The third layer encoded the ordered accident sequence using succinct event tokens connected by arrows. The fourth layer grouped similar ordered sequences into sequence families for manuscript-level interpretation. This architecture was chosen because categorical accident summaries support aggregation but often obscure whether an event emerged from a preexisting aircraft condition, instructional scenario, environmental condition, pilot-response pathway, or terminal control-loss mechanism.

The adjudicated accident categories were not intended to replace established taxonomies such as ADREP or CICTT occurrence categories. Rather, they served as study-specific analytic categories aligned with the same methodological premise: common terminology improves comparison and safety communication (ICAO, n.d.; CAST/ICAO Common Taxonomy Team, 2004). Where appropriate, categories reflected familiar aviation safety groupings such as loss of control in flight, loss of control on ground, fuel-related events, power-loss/mechanical events, collision pathways, and weather or terrain events. However, the study preserved additional specificity when instructional interpretation required it, such as distinguishing landing/LOC-G from approach/landing LOC-I or takeoff/initial-climb LOC.

Training-Context Adjudication

Training context was adjudicated from the source record rather than inferred solely from aircraft ownership, operator type, or flight phase. Cases were assigned to contexts such as dual, solo, dual/other-instructional, solo/other-instructional, evaluation, proficiency, introductory, familiarization, time-building, outreach, or instructor-checkout when the source narrative supported that classification. This distinction was central to the study design because instructional risk is not uniform across training arrangements. Dual instruction, supervised solo flight, and evaluation or proficiency events provide different opportunities for supervision, intervention, error recovery, and training-task exposure.

Ordered Sequence Coding

Ordered sequence coding was the study's core methodological contribution. Each case was translated into a compact event string representing the progression from initiating condition to accident outcome. Tokens were written in operationally interpretable terms, such as POWER-LOSS, GO-AROUND, DIRECTIONAL-CONTROL-LOSS, RUNWAY-EXCURSION, OBSTACLE-COLLISION, HARD-

LANDING, or DAMAGE. Arrows represent ordered progression, not statistical causality. For example, a coded sequence could represent an initiating aircraft or environmental condition, a pilot or instructor response, a loss-of-control state, a collision or terrain-contact mechanism, and the damage outcome.

Sequence coding separated reported event order from causal certainty. Events were included only when supported by the source narrative, and ambiguous ordering was coded conservatively. When the narrative did not support a more specific pathway, the case was assigned to the source-defined miscellaneous pathway.

Sequence-Family Construction

Sequence families were constructed after case-level sequence coding. The purpose of the family layer was to find recurring pathways that were meaningful for instructional safety but without requiring every case to have identical language. Families therefore grouped substantively similar sequences, such as landing directional-control-loss excursion/obstacle pathways, flare/bounce/hard-landing pathways, landing-gear mechanical-failure collapse pathways, attempted go-around control-loss terrain-impact pathways, taxi clearance ground-obstacle collision pathways, and carburetor-icing partial-power-loss pathways. Family assignment was based on source-supported sequence similarity, not on post hoc outcome preference.

The residual source-defined miscellaneous pathway was retained as a conservative category for cases that supported inclusion but lacked sufficient detail for a more granular sequence-family assignment. This prevented unsupported precision while retaining eligible cases in the analytic set.

Quality Control and Auditability

Quality control occurred at three levels. First, source verification was used to confirm that included records had sufficient documentary support. Second, internal consistency tests were applied to ensure that manuscript eligibility, sequence codability, training context, accident category, ordered sequence, sequence family, and source URL fields were coherent. Third, a final quality-control cleanup made eligibility labels explicit, corrected high-priority taxonomy-coherence issues, canonicalized durable CAROL source URLs, and regenerated manuscript-ready distributions. All final cleanup actions were recorded in the workbook audit log.

The final analytic file retained the coding fields and audit documentation described in Appendix A, allowing manuscript results to be traced to individual source records. The file was then treated as the locked analytic dataset for manuscript drafting. Apart from the prespecified chi-square analysis of consolidated training context and accident category, the analyses were descriptive and taxonomy-driven.

Independent Reliability Assessment of Accident-Category and Training-Context Coding

I coded the primary 728-case analytic matrix. An independent reliability assessment was then conducted on a stratified random sample of 79 cases (10.9%); it was not a complete second coding of the dataset. Sampling was proportional to the accident-category distribution and used a fixed random seed of 42. The independent coder assigned codes using only the source evidence notes and source URLs and was blinded to the first set of adjudicated accident category and adjudicated training context labels. The remaining 649 cases were source verified and internally audited but were not independently recoded. Accordingly, the reliability estimates evaluate sampled coding reproducibility rather than independent case-level verification of the complete analytic matrix.

Blinding was imperfect for one sampled case. During earlier exploration of the workbook structure, the independent coder had briefly viewed 10 example rows from the worksheet containing the manuscript-ready, verified data. One of those cases, C0005, was subsequently included in the random sample. This prior exposure created the possibility that familiarity with the record influenced the coder’s later assessment, although the extent of any influence could not be determined. The case represented 1 of 79 sampled records (1.3%) and is disclosed as a potential source of bias when interpreting the reliability estimates.

The independent coder performed the sampled coding separately from my original classifications and without access to those labels, subject to the one-case blinding disclosure above. The materials available for this manuscript do not document the coder’s professional qualifications or institutional, supervisory, authorship, or financial relationship to me, nor do they specify the independent coder's background in aviation safety or human factors. As such, readers cannot assess the degree of subject-matter expertise brought to the reliability assessment. The manuscript therefore claims procedural independence for the coding exercise, not verified institutional independence or subject-matter credentialing. These details, including coder qualifications and relevant domain experience, should be documented prospectively in any continued validation study.

Agreement was calculated by comparing my original classifications with the independent coder’s classifications. Exact percentage agreement and unweighted Cohen’s κ were calculated for the 17-category accident classification. Percentage agreement described how often the two coders assigned the same category, while Cohen’s κ accounted for agreement expected by chance. Training context was evaluated after collapsing the first set of labels to Dual versus Solo and restricting the calculation to cases for which the independent coder could make a determinate classification from the available evidence. Cases judged ambiguous by the independent coder were retained as indeterminate for that field rather than forced into a Dual or Solo category. Accordingly, the training-context agreement estimates apply only to cases with sufficient evidence for a determinate independent classification.

Analysis Plan

The analysis was descriptive and taxonomy-driven. Frequencies, percentages, and cross-tabulations summarized training context, sequence codability, accident category, and sequence family. The primary objective was to identify recurrent, source-supported pathways relevant to instructional risk management and future research. Because validated flight-activity denominators were unavailable, the analyses describe distributions of accident records rather than accident rates or comparative operational risk.

Table 2

Case-flow summary for source verification, final eligibility, and sequence codability

Stage	Records retained	Records excluded	Exclusion rationale or coding status
Initial records identified	884	N/A	Compiled accident records before geographic and source-verification screening
U.S. records retained	883	1	One non-U.S. record excluded before manuscript analysis
Source-verified records retained	730	153	Excluded when documentation was insufficient, the narrative was ambiguous, or the case could not be confidently reconciled with the coding taxonomy.
Manuscript-eligible analytic set	728	2	Two source-verified records excluded during final manuscript eligibility screening
Fully sequence-codable cases	727	N/A	99.9% of the manuscript-eligible analytic set
Partially sequence-codable cases	1	N/A	0.1% of the manuscript-eligible analytic set

Note. Case-flow rows report retained and excluded records at each screening stage. Sequence-codability percentages are calculated using the manuscript-eligible source-verified analytic set (N = 728).

Results

Training Context

The manuscript-eligible analytic set contained 728 source-verified instructional fixed-wing general aviation accidents. The matrix recorded 727 cases (99.9%) as fully sequence-codable and 1 case (0.1%) as partially sequence-codable. These coding-status counts should be distinguished from the specificity of sequence-family assignments. As reported below, 109 cases were assigned to the source-defined miscellaneous pathway because the available narratives did not support a more specific assignment.

Training context was not evenly distributed across the analytic set. The largest group was Dual/Other-Instructional (345 cases, 47.4%), followed by Solo (210 cases, 28.8%), Dual (158 cases, 21.7%), and Solo/Other-Instructional (6 cases, 0.8%).

Table 3 also reports the less frequent evaluation, proficiency, introductory, instructor-checkout, time-building, outreach, and familiarization contexts.

Table 3
Training-Context Distribution in the Manuscript Analytic Set

Training context	n	%
Dual/Other-Instructional	345	47.4
Solo	210	28.8
Dual	158	21.7
Solo/Other-Instructional	6	0.8
Dual/Evaluation	3	0.4
Dual/Proficiency	1	0.1
Dual/Introductory	1	0.1
Dual/Instructor-checkout	1	0.1
Dual/Time-building	1	0.1
Dual/Outreach	1	0.1
Dual/Familiarization	1	0.1

Note. Percentages are calculated using the manuscript-eligible source-verified analytic set unless otherwise indicated.

Accident Categories

Landing/LOC-G was the largest adjudicated accident category, with 262 cases (36.0%). This was followed by Other (148 cases, 20.3%), Power-loss/Mechanical (131 cases, 18.0%), Takeoff/Initial climb LOC (61 cases, 8.4%), Fuel management (31 cases, 4.3%), Collision/bird-wildlife (27 cases, 3.7%), and Approach/landing LOC-I (21 cases, 2.9%).

This pattern is substantively coherent with external instructional and general aviation safety literature, which consistently identifies loss of control, abnormal runway contact or landing events, powerplant or mechanical failures, and fuel-related issues as recurrent general aviation safety problems (Walach, 2023).

Table 4
Adjudicated Accident Categories

Accident category	n	%
Landing/LOC-G	262	36.0
Other	148	20.3
Power-loss/Mechanical	131	18.0
Takeoff/Initial climb LOC	61	8.4
Fuel management	31	4.3
Collision/bird-wildlife	27	3.7
Approach/landing LOC-I	21	2.9
Collision/wildlife	16	2.2
Stall-spin/LOC-I	8	1.1
Midair/Traffic	7	1.0
Approach/landing obstacle impact	5	0.7
Weather/CFIT	3	0.4
Structural overload	2	0.3
Unclassified	2	0.3
Landing/LOC-I	2	0.3
Collision/Obstacle/Terrain	1	0.1
Climb LOC-I	1	0.1

Note. Percentages are calculated using the manuscript-eligible source-verified analytic set (N = 728). Percentages may not sum to exactly 100.0% because of rounding.

Sequence Families

The sequence-family analysis added insight beyond the adjudicated accident categories. The largest family was source-defined miscellaneous (109 cases, 15.0%), followed by Landing directional-control-loss excursion/obstacle pathway (36 cases, 4.9%), Flare/bounce/hard-landing pathway (30 cases, 4.1%), and Landing-gear mechanical failure collapse pathway (27 cases, 3.7%).

To clarify the relationship between the broader Other accident category reported in Table 4 and the sequence-family results, the 148 cases classified as Other (20.3% of the analytic set) comprised two distinct groups. Of these, 109 cases (15.0%) were assigned to the source-defined miscellaneous pathway because the available accident narrative did not support a more specific ordered-sequence assignment. The remaining 39 cases (5.4%) represented heterogeneous low-frequency pathways, including ground-clearance, vehicle, propeller-contact, obstacle, and unusual operational events (see Appendix B, Table B1). In answer to RQ4, this decomposition shows that the broader Other category does not represent a single homogeneous accident mechanism. Instead, it distinguishes cases limited by narrative specificity from uncommon but source-supported pathways. This treatment makes the evidentiary limits of public accident accounts explicit, avoids forcing unsupported classification, and is consistent with prevention-oriented taxonomy principles (CAST/ICAO Common Taxonomy Team, 2004; ICAO, n.d.).

Table 5
Most Frequent Ordered Sequence Families

Sequence family	n	%
Source-defined miscellaneous pathway	109	15.0
Landing directional-control-loss excursion/obstacle pathway	36	4.9
Flare/bounce/hard-landing pathway	30	4.1
Landing-gear mechanical failure collapse pathway	27	3.7
Attempted go-around control-loss terrain-impact pathway	19	2.6
Taxi clearance ground-obstacle collision pathway	13	1.8
Carburetor-icing partial-power-loss pathway	11	1.5
Takeoff wind/directional-control-loss obstacle-impact pathway	11	1.5
Landing/ground-control pathway	11	1.5
In-flight bird-collision pathway	7	1.0
Inadequate visual lookout collision pathway	5	0.7
Takeoff deer-collision pathway	5	0.7
Approach bird-collision pathway	4	0.5
Undetermined total engine-power-loss pathway	4	0.5

Mechanical/power-loss pathway	4	0.5

Note. Percentages are calculated using the manuscript-eligible source-verified analytic set unless otherwise indicated.

Training Context by Accident Category

The consolidated context-by-category analysis showed that accident pathways differed by instructional context. To avoid unstable inference from sparse cells, the inferential test was conducted on a collapsed dual-versus-solo table using five major accident-category groups. Rare instructional contexts were retained descriptively but excluded from the primary chi-square test. Low-frequency accident categories remained in the test after being combined into the Other/residual group.

A Pearson chi-square test of independence was conducted on the collapsed dual-versus-solo table. The association between instructional context and major accident-category group was statistically significant, $\chi^2(4, N = 719) = 78.12$, $p < .001$. Cramér’s V was .33, denoting a moderate association. All expected cell counts in the collapsed table exceeded 5. The test compares observed accident distributions, not exposure-adjusted risk.

Table 6
Collapsed Dual-Versus-Solo Accident-Category Distribution Used for Inferential Testing

Accident category group	**Dual instructional, n**	**Solo instructional, n**	**Total**
Landing/LOC-G	142	118	260
Power-loss/Mechanical	122	6	128
Takeoff/Initial climb LOC	33	26	59
Fuel management	22	7	29
Other/residual categories	184	59	243
Total	503	216	719

Note. Dual instructional combines Dual and Dual/Other-Instructional cases. Solo instructional combines Solo and Solo/Other-Instructional cases. Rare evaluation, proficiency, introductory, familiarization, instructor-checkout, outreach, and time-building contexts were excluded from this inferential table because of sparse counts and are reported descriptively in Table 7.

Table 7
Sparse Instructional/Evaluation Contexts Retained for Descriptive Transparency

Accident category group	Other instructional contexts, n
Landing/LOC-G	2
Power-loss/Mechanical	3
Takeoff/Initial climb LOC	2
Fuel management	2
Other/residual categories	0
Total	9

Note. These cases were retained in the analytic dataset but excluded from the primary chi-square test because sparse counts would make asymptotic inference unstable.

Independent Reliability Results

For the 17-category accident classification, the first and independent codes agreed in 55 of 79 cases (69.6%), with Cohen's κ = .634. The coefficient is reported without giving a qualitative strength label. Disagreements commonly involved adjacent or nested classifications. In several instances, the independent coder assigned a more specific category to a case originally classified as Other when the short evidence note did not make the first residual assignment apparent without fuller narrative context.

For collapsed training context, the independent coder made a determinate Dual or Solo classification for 47 of 79 cases (59.5%); 32 cases (40.5%) received indeterminate independent classifications. Among the 47 determinate pairs, agreement occurred in 40 cases (85.1%), with Cohen's κ = .707. All seven disagreements had the same direction: the independent coder assigned Dual whereas the first adjudicated label collapsed to Solo. These cases contained evidence-note language referring to a flight instructor's delayed remedial action, failure to monitor, or similar instructor involvement.

Training-context agreement applies only to the 47 determinate pairs and must not be generalized to all 79 sampled cases or the complete dataset. The 32 indeterminate ratings limit its interpretation.

The independent exercise did not include separate recoding of the ordered-sequence or sequence-family fields. Accordingly, no agreement statistic is available for either the construction of ordered sequences or their assignment to sequence families.

Discussion

This study developed and applied a source-verified sequence-analysis approach to instructional fixed-wing general aviation accidents. The resulting matrix suggests that a sequence-based view can add practical interpretation beyond broad accident categories. The findings do not imply that one causal factor dominates instructional aviation risk. Instead, they show that instructional accidents recur through multiple recognizable pathways, including landing directional-control loss, power-loss or mechanical sequences, takeoff and initial-climb control-loss sequences, fuel-management events, wildlife or bird collisions, and approach-related loss of control or obstacle-impact events. Building on the results, the subsequent section briefly previews practical effects for flight training, such as targeted evaluations of go-around decision-making, ground-control management, and training in response to mechanical irregularities.

Landing and ground-control pathways were prominent in the observed accident distribution. Sequence coding distinguished directional-control excursions, flare and bounce sequences, hard landings, and attempted go-around control-loss pathways. These descriptive patterns may be used to generate hypotheses for curriculum review and future intervention studies, but they do not establish that any particular training emphasis would reduce accident risk.

Power-loss and mechanical categories were also prominent, particularly in dual contexts. Sequence analysis separated initiating conditions from documented response pathways, including recognition, troubleshooting, forced-landing planning, and instructor takeover. These observations may inform the design of future training research; they do not establish causal mechanisms or demonstrate the effectiveness of specific instructional interventions.

Because neither set of ratings can be treated as a gold standard, the seven disagreements do not establish that the original Solo classifications were incorrect. Nevertheless, their uniform direction indicates that the context comparison may be sensitive to systematic classification at the Dual/Solo boundary. If the independent judgments more accurately represented the underlying instructional context, Table 6 would overcount Solo cases and undercount Dual cases. The category-specific effect on the chi-square statistic and Cramér's V cannot be estimated from the 47 determinate pairs, particularly because 32 of the 79 sampled cases received indeterminate independent ratings. Therefore, the large Power-loss/Mechanical difference (122 Dual cases versus 6 Solo cases) should be interpreted as a descriptive pattern based on the adjudicated classifications, not as a classification-invariant result.

Practical Implications for Flight Training

The following implications are intended to generate hypotheses and should not be interpreted as evidence that the proposed training changes would diminish accident rates. Nevertheless, the functional applications derived from the identified accident sequences suggest several directions for research and training development.

Documented landing and ground-control sequences warrant detailed evaluations of go-around decision thresholds, directional-control management, crosswind technique, bounced-landing recovery, and runway-excursion prevention. These topics could be incorporated into scenario-based training modules, permitting flight instructors to simulate and debrief specific accident pathways with students. For instance, if sequence analysis shows a recurrent pattern of directional-control loss during crosswind landings, a training organization could revise its lesson plan to include a dedicated module on crosswind technique, simulated crosswind landings in both flight and simulator environments, and updated instructor briefings emphasizing decision triggers for go-around and best practices for early intervention. Similarly, takeoff and initial-climb patterns point out the importance of reviewing and possibly refining training on reject criteria, configuration checks, airspeed discipline, and responses to degraded climb performance. Incorporating these findings into practical simulator exercises may enhance pilot readiness for abnormal takeoff scenarios.

Power-loss and mechanical pathways indicate a need for prospective study on the effectiveness of training in real-time diagnosis, forced-landing planning, cockpit task prioritization, and clear instructor-student role delineation during abnormal events. Curricula could be adjusted based on the results by ensuring forced-landing scenarios are explicitly addressed in ground instruction, flight training, and instructor checkouts, with recommended briefing language for responding to engine failure during climb-out.

The recurrent sequence families align with specific competencies in the current FAA Airman Certification Standards. Landing directional control, flare/bounce/hard-landing, and attempted go-around pathways correspond to the Private Pilot for Airplane Category ACS (FAA-S-ACS-6C), Area of Operation IV, particularly Normal Approach and Landing and Go-Around/Rejected Landing, which address stabilized approaches, wind correction, directional control, control use during roundout and touchdown, and timely go-around decisions. The taxi-clearance ground-obstacle pathway corresponds to Area of Operation II, Taxiing, including clearance compliance, situational awareness, and positive aircraft control. Carburetor icing, partial-power loss, and other mechanical pathways correspond to Area of Operation IX, Emergency Operations, particularly Emergency Approach and Landing and Systems and Equipment Malfunctions. The Flight Instructor for Airplane Category ACS (FAA-S-ACS-25) incorporates parallel instructional competencies, including correction of common errors and positive exchange of flight controls. These correspondences identify existing standards through which the sequence findings may inform scenario design and debriefing; they do not establish that failure to meet an ACS element caused any accident (FAA, 2024a, 2024b).

The source-verified sequence framework may also help generate priorities for instructor-standardization research. Training organizations could use recurrent sequence families to identify candidate topics for lesson-plan review, stage checks, solo-endorsement preparation, or recurrent instructor discussion.

Limitations

This study has several major limitations. First, without exposure denominators such as flight hours, operation counts, landing cycles, solo endorsements, or maneuver exposures, the descriptive results cannot estimate accident rates. Second, although the reconstructed CAROL search recovered 881 of the original 884 cases, the unavailable original query log and export metadata prevent exact regeneration of the candidate set. Third, the analytic set is limited to source-verified U.S. instructional fixed-wing general aviation accidents from January 1, 2020, through December 31, 2025. These constraints limit risk inference, exact retrieval reproducibility, and transferability.

Fourth, the dataset contains recent accident years. NTSB investigations can remain preliminary or incomplete for a period after the accident, and some 2024–2025 records may contain less complete narrative information than older finalized reports. This may affect sequence specificity and source-verification confidence for recent cases. Fifth, the sequence-family architecture depends on the content and clarity of formal accounts; incomplete or ambiguous documentation can constrain sequence specificity.

Sixth, only 79 of 728 cases were independently recoded, and training-context agreement was conditional on the 47 determinate ratings; one sampled case was subject to imperfect blinding. Seventh, ordered-sequence construction and sequence-family assignment were not independently evaluated, so the reported agreement statistics do not establish the reliability of sequence-family frequencies or pathway interpretations. Eighth, the available materials do not document the independent coder's qualifications or institutional relationships. Ninth, sequence arrows represent reported temporal order rather than causal effects, and the proposed instructional implications remain hypotheses for future evaluation. Tenth, all 56 investigations identified only in the reconstructed search involved events in 2024 or 2025. Their absence from the retained candidate file may affect the representation of recent accident years; the extent of that effect cannot be determined without assessing their eligibility and classifications.

Future Research

Building on the methodological results and limitations identified in this study, subsequent research should pursue several priorities to deepen comprehension and enhance the pragmatic utility of sequence-based instructional accident analysis. First, independent coding reliability should be strictly evaluated by enlisting multiple qualified coders to recode a substantially larger proportion of the analytic matrix. Such efforts should employ full formal narratives, comprehensive blinding protocols, documented coder independence, and prespecified criteria for indeterminate ratings. Quantitative reproducibility metrics must be reported for both the full validation sample and relevant conditional subsets to facilitate critical assessment of coding reproducibility.

Second, future research should incorporate activity denominators, such as flight hours, operation counts, maneuver exposures, and training stages, to calculate accident rates and compare instructional contexts.

Third, comparative studies should extend the source-verified sequence framework to noninstructional and international general aviation datasets, enabling investigation of which sequence patterns are unique to U.S. instructional operations and which reveal broader structural issues. However, expected challenges in applying the framework to international datasets should be noted. For example, differences in accident taxonomy, reporting standards, and the quality or detail of narrative records may limit direct comparability or demand adaptation of coding procedures. Addressing taxonomy compatibility, language differences, and variability in accident documentation will be important for guaranteeing that future international analyses preserve analytic exactness and allow meaningful interpretation. This approach would enhance the generalizability and the applicability of sequence-based methodologies.

Furthermore, subsequent research should empirically link identified sequence families to targeted safety interventions, prospectively evaluating whether curriculum modifications or scenario-based training reduce the recurrence of the most frequent accident pathways. Such intervention studies are essential to move beyond descriptive analysis toward evidence-based recommendations for training effectiveness.

Given the substantial manual effort required to code 728 accident narratives, future research should evaluate natural language processing-assisted or other semi-automated approaches to sequence extraction. Such systems could identify candidate event terms and temporal relationships for coder review, but qualified human coders should verify every proposed sequence and residual assignment against the source narrative. Validation should compare automated suggestions with an independently adjudicated reference set before these tools are used for substantive analysis.

Conclusion

This study developed and applied a source-verified sequence approach to 728 instructional fixed-wing general aviation accident records occurring in the United States between January 1, 2020, and December 31, 2025. Landing and ground-control events, power-loss or mechanical events, takeoff and initial-climb loss-of-control events, fuel-management events, and collision or wildlife pathways were prominent in the analytic set.

Ordered-sequence coding provided greater operational resolution than broad accident-category reporting alone. In particular, it distinguished recurrent pathways involving directional-control loss, flare and bounce recovery, go-around decisions, mechanical or power-loss developments, and instructor-response opportunities. The residual source-defined pathway preserved cases for which the public evidence supported inclusion but did not support more granular classification without speculation.

The findings are descriptive and should not be interpreted as exposure-adjusted estimates of accident risk or as evidence that particular instructional interventions will reduce accidents. Nevertheless, the recurrent sequences identify candidate priorities for curriculum review, instructor standardization, scenario-based training, and prospective safety research.

Because ordered sequences and sequence-family assignments were not independently recoded, their reliability remains to be tested directly in future research.

Ethics Statement

This study used publicly available accident records and did not involve interaction with human participants or access to private, identifiable human-subject data. Institutional review board approval was therefore not required.

Data Availability Statement

The underlying source records are publicly available from the cited accident-reporting databases. The cleaned coding matrix and coding documentation are available from the author upon reasonable request, subject to applicable source-use and documentation limitations.

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Conflict of Interest Statement

The author declares no conflicts of interest.

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Appendix A

Audit Trail and Reproducibility Statement

The analytic matrix retained case-level identifiers, source URLs or reference IDs, source evidence notes, adjudicated training context, manuscript eligibility, ordered sequence, sequence codability, adjudicated accident category, and sequence family. This structure enables the manuscript results to be traced back to source evidence and supports future independent review. The final workflow also retained quality-control logs and pass-level source-review summaries so that inclusion decisions, exclusions, and conservative residual classifications remain auditable.

Appendix B

Residual Category Transparency

The source-defined miscellaneous pathway contained 109 cases (15.0% of the analytic set); Table B1 distinguishes these cases from the 39 heterogeneous low-frequency Other pathways.

Table B1
Interpretive treatment of residual and other miscellaneous pathways

Pathway group	Cases	Percent of analytic set	Interpretive treatment
Source-defined miscellaneous pathway	109	15.0%	Retained as a conservative uncertainty category; not interpreted as a unified causal mechanism.
Other category excluding source-defined miscellaneous	39	5.4%	Reviewed as heterogeneous low-frequency pathways, including ground-clearance, vehicle, propeller-contact, obstacle, and unusual operational events.
All other adjudicated categories	580	79.7%	Interpreted through their respective major accident categories and sequence families.

Note. Percentages are calculated from the manuscript-eligible source-verified analytic set (N = 728). Values may not sum to 100.0% because of rounding.

Appendix C

Independent Reliability Assessment Summary

Using seed 42, a stratified random sample of 79 cases (10.9%) was independently assessed from the source evidence notes and source URLs; one sampled case was subject to imperfect blinding.

Accident-category agreement was 69.6% ($\kappa = .634$). For training context, agreement was 85.1% ($\kappa = .707$) among 47 determinate cases; 32 cases were indeterminate, and all seven disagreements involved an independent Dual classification and an original Solo classification. Because ordered sequences and sequence-family assignments were not independently recoded, these statistics do not establish their reliability.