Fuel Planning Errors in General Aviation from 2015 to 2020

Hilary Kalagher

BACKGROUND: Planning, whether preflight or in-flight, is a cause of accident that is presumably almost entirely preventable. Planning skills on the part of the pilot should assist in avoiding dangerous situations with regards to light conditions, weather, fuel shortage, and/or improper weight and balance. Fuel planning is noted as especially unnecessary, as fuel planning is not considered a complex skill but part of proper flight preparation and in-flight planning.

METHODS: A total of 196 accident reports from 2015 until 2020 were extracted from the NTSB online database in which the probable cause included either preflight or in-flight planning as a cause attributed to the pilot. Of those accidents, the majority ($N = 131$, 67%) were attributed to fuel planning and were further analyzed.

RESULTS: Fuel-planning related accidents were significantly less often fatal compared to all planning-related accidents and all fuel-related accidents. The majority of fuel planning accidents resulted in fuel exhaustion. Additionally, the cause attributed to the accidents was frequently the skill-based error of "fuel planning (pilot)" and the crew resource management issue of "fuel-fluid level". Specific information regarding the pilot's fuel plan was only available in 52 (40%) of the accident reports.

CONCLUSIONS: The frequency of fuel-related planning accidents suggests that this aspect of pilotage is underestimated and requires more attention both in training and in standard operating procedures. In particular, more detailed information regarding the pilot's fuel plan is necessary in order to determine which step in the process most frequently results in an accident.

KEYWORDS: planning errors, general aviation, fuel management, accident causes.

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Planning, whether preflight or in-flight, is a cause of accident that is presumably almost entirely preventable. Yet it has been suggested that general aviation pilots receive insufficient direct instruction on how to carry out preflight planning.[3] Planning skills on the part of the pilot should assist in avoiding dangerous situations with regards to light conditions, weather, fuel shortage, and improper weight and balance.[4,7] Despite the avertable nature of planning-related accidents, the National Transportation Safety Board (NTSB)[8] Aviation Accident online database counts over 30 such accidents a year in the United States. Previous research on the planning of general aviation flights has focused almost exclusively on adverse weather planning,[11] with less attention to fuel-planning related accidents.

Fuel planning is not only a subset of all planning-related accidents but is also a subset of all fuel mismanagement accidents. In August 2017, the NTSB issued a safety alert in which they articulated that fuel mismanagement was the sixth leading cause of general aviation accidents in the United States.[9] Out of all fuel-mismanagement issues, fuel exhaustion (in which an aircraft runs out of fuel) and fuel starvation (in which fuel is in the aircraft's tanks but does not reach the engine) appear to be the most common. The NTSB estimates that 95% of all fuel mismanagement issues were associated with pilot error, with equipment-related issues accounting for the remaining 5%.

Effective fuel planning involves several steps and calculations and, although not considered a complex pilotage skill, is

From Drew University, Madison, NJ, USA.

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Address correspondence to: Hilary Kalagher, Ph.D., Psychology Department, Drew University, 36 Madison Ave., Madison, NJ 07922, USA; hkalagher@drew.edu.

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nevertheless important. The ability to plan effectively is a cognitive skill that is a component of executive function. In general, executive function skills such as planning, decision-making, and impulsivity are considered less developed in early adulthood,[10] which suggests an association of age and planning-related accidents. Experience and training are likely to mitigate any limitations imposed by age, suggesting an inverse relationship of experience of accidents attributed to planning errors. Experienced pilots appear to spend significant time in preflight planning and data gathering and engage in active contingency planning in flight.[1] In addition to age and experience, cognitive skills appear to play a role. For example, previous research has shown that pilots who decided to continue a risky simulated flight that involved low fuel levels only differed from their peers who elected not to continue on a measure of risk perception and not on other variables such as age or experience, as determined by total flight hours.[6] Lastly, it is important to highlight that simply having a plan is not sufficient. Decision errors (a conscious goal-directed behavior that proceeds as planned, but the plan proves inadequate or inappropriate for the situation) was previously found to contribute to 35% of general aviation accidents.[13]

In this study, fuel-related planning accidents are examined. Factors such as age, experience, and having a detailed fuel-related plan are analyzed and the extent to which these factors are significantly associated with fatal accidents is also explored. To better understand their most common cause, the Human Factors Analysis and Classification System (HFACS) will be used.[12] The HFACS framework describes 17 causal categories within 4 levels of failure (organization influences, unsafe supervision, preconditions for unsafe acts, and the unsafe acts of operators). Previous research has shown that the causal factors typically populate only the bottom two levels of HFACS (i.e., preconditions for unsafe acts and unsafe acts of the operator).[12]

The first level (unsafe acts of operators) is broken down into two main categories: errors (activities that fail to achieve their intended outcome) and violations (behavior that represents the willful disregard for rules and regulations). To provide additional granularity, errors are further broken down into three subcategories: 1) decision errors (procedural errors, poor choices, or problem-solving errors); 2) skill-based errors (errors due to failures of attention, memory, and/or technique); and 3) perceptual errors (occur when sensory input is degraded). Violations can be further broken down into two subcategories: 1) routine infractions (the "bending" of the rules tolerated by authority); and 2) exceptional violations (deviations from the rules that are not tolerated by authority).

The second level of HFACS (preconditions for unsafe acts) can also be broken down into two main categories: 1) substandard conditions of operators, and 2) substandard practices of operators. Substandard of conditions of operators can be subcategorized in three ways: 1) adverse mental states (mental conditions that affect performance such as impairment or fatigue); 2) adverse physiological states (medical/physiological conditions that preclude safe operations); and 3) physical/mental limitations (occur when the situation exceeds the capabilities of the operator). Lastly, substandard practices of operators can be subcategorized into two categories: 1) crew resources management (poor communication/coordination among personnel such as inadequate preflight planning); and 2) personal readiness (failures to prepare mentally or physically such as self-medicating).

METHODS

Fatal and nonfatal accidents that occurred in the United States during the period between January 1, 2015, and December 31, 2020, in which the probable cause included either preflight or in-flight planning as a cause attributed to the pilot were selected from the NTSB Aviation Accident online database.[8] Only completed accident reports were included. All fuel-related planning accident reports ($N = 131$, 67%) were removed from the larger dataset of all planning-related accidents and further analyzed.

The reports were analyzed using the different categories provided by the NTSB that relate to the pilot, the aircraft, and the probable cause. Information regarding whether the report discussed the pilot's fuel plan was also documented. Significant relations were determined using Pearson's Chi-squared analysis with a 0.05 significance level. In instances in which the expected cell frequencies were not greater than or equal to 5, Fisher's exact test was used.

The causes attributed to the accidents by the NTSB investigators were additionally analyzed using HFACS.[12] The causal factors identified by the investigators were coded into the first two levels of the HFACS framework (i.e., preconditions for unsafe acts and unsafe acts of the operator). Of the 131 accident reports that were coded using the HFACs system, 65 (50%) were independently coded by both the author and a research assistant using previous research as a guide.[12] After the initial classifications of the human factors, the two independent ratings were compared. Where disagreements existed ($N = 11$, 17%), the two raters discussed, reconciled their differences, and consensus was reached. The remaining 66 reports were coded by the research assistant.

RESULTS

During the 6-yr period between 2015 and 2020, there were 131 accidents in which fuel planning was identified as a probable cause attributed to the pilot. These accidents represent a majority (67%) of all accidents during the same time period in which the probable cause was either preflight or in-flight planning. Fuel-related accidents were significantly less often fatal (10 out of 131) compared to other planning-related causes (21 out of 65) ($N = 196$, $\chi^2 = 19.86$, $P < 0.001$). Fuel planning accidents, however, accounted for a smaller proportion (21%) of all fuel-related accidents. Fuel planning accidents (10 out of 131) were less likely to result in a fatality compared to fuel-related accidents that were not attributed to planning (67 out of 481) ($N = 612$, $\chi^2 = 3.71$, $P = 0.05$). **Table I** shows the number of occurrences and percentages broken down by year. The

Table I. Fuel Planning Accidents from 2015 to 2020 Compared to All Planning-Related Accidents and All Fuel-Related Accidents.

YEAR	FUEL PLANNING	ALL PLANNING	PERCENT OF ALL PLANNING ATTRIBUTED TO FUEL PLANNING	ALL FUEL-RELATED	PERCENT OF FUEL-RELATED ATTRIBUTED TO FUEL PLANNING
2015	38	52	73%	129	29%
2016	19	32	59%	131	15%
2017	18	30	60%	123	15%
2018	26	37	70%	127	20%
2019	20	24	83%	74	27%
2020	10	21	48%	28	36%
Total	131	196	67%	612	21%

accidents took place in 39 different states with the most occurring in Texas ($N = 19$), California ($N = 13$), and Florida ($N = 10$).

Most of the aircraft involved in the fuel planning accidents were airplanes ($N = 126$, 96%), while the remaining five (4%) were helicopters. These accidents were largely nonfatal ($N = 121$, 92%), while the remaining 10 fatal accidents resulted in a total of 10 fatalities. There was only one accident (nonfatal) operating under Part 133 (Rotorcraft External Load Operators) flight rules, and five (nonfatal) accidents under Part 137 (Dispensing Chemical and Agricultural Products), with the remaining operating under Part 91 (General Aviation). Only three (2%) of the aircraft in these accidents were destroyed, while the remaining 128 (98%) sustained substantial damage.

The age of the pilots ranged from 20 to 92 yr of age, with a mean of 51.2 yr. The pilots also varied considerably with regard to total experience, as measured by flight hours accrued; the hours ranged from 0 to 27,000 h with a mean of 2558.16 h. In 29 cases (22%) it was reported that an occupational pilot was flying the aircraft and in all these cases no fatalities were present.

Pilots who were 25 yr of age or younger were not more likely to have a fuel-related accident result in a fatality (1 out of 12) compared to pilots who were older than 25 yr of age (9 out of 118). However, pilots who were 65 yr of age or older were significantly more likely to have a fuel-related accident result in a fatality (6 out of 37) compared to pilots who were younger than 65 yr of age (4 out of 94) ($N = 131$, $\chi^2 = 5.39$, $P < 0.05$). Pilots who had logged more than 500 h (4 out of 51) were not more likely to have a fatal accident compared to pilots who had logged less than 500 flights hours (6 out of 80).

Several broad phases of flight were represented in the dataset for fuel-related planning accidents (see **Fig. 1**). As can be seen in the figure, the majority of the accidents occurred during the en route phase of flight. The accidents that occurred during this phase of flight were significantly less likely to result in fatalities (3 out of 82) compared to all other phases of flight combined (7 out of 49) ($P < 0.05$, as determined by Fisher's exact test). Most of the accidents required an off-field or emergency landing; however, these accidents were not found to be more fatal (4 out of 82) than the accidents that did not require an off-field or emergency landing (6 out of 49) ($P > 0.05$, Fisher's exact test). Additionally, the majority of the accidents were the result of fuel exhaustion (see **Fig. 2**).

The fuel-related planning accidents were further analyzed using the first two levels of the HFACS framework (see **Table II**). As can be seen in the table, the majority of the accidents were attributed by the NTSB investigators to be caused by either decision errors, skill-based errors, and/or crew resource management issues. These three categories were further broken down into the specific causal factors that were identified by the investigators in their reports (see **Table III**).

As can be seen in Table III, the majority of the fuel-related accident reports listed the skill-based error of "fuel planning (pilot)" and the crew resource management issue of "fuel-fluid level" as causal factors. These causes appeared together on 91 (69%) of the fuel-related planning accident reports. Additionally, when both of these causes were listed on the reports, it was significantly more likely that fuel exhaustion was determined to be involved in the accident (83 out of 110) compared to when both of these terms were not listed (8 out of 21) ($N = 131$, $\chi^2 = 11.60$, $P < 0.0001$).

Because "fuel planning (pilot)" was so frequently listed as cause, the NTSB reports were further analyzed to determine the extent to which the investigators documented the pilot's

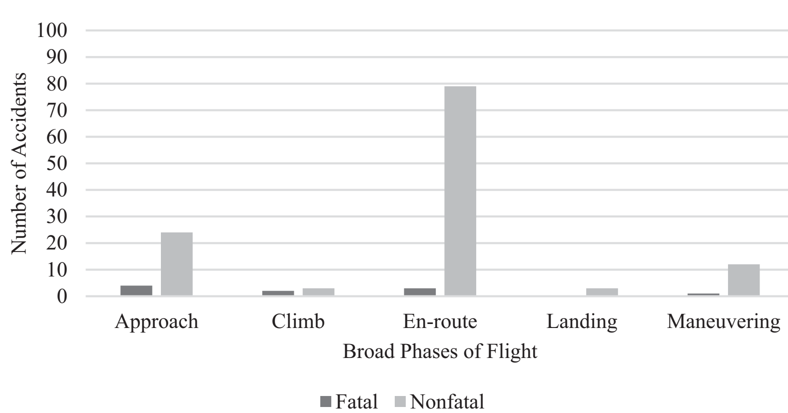

Fig. 1. Number of fatal and nonfatal accidents across the broad phases of flight for fuel-related planning accidents.

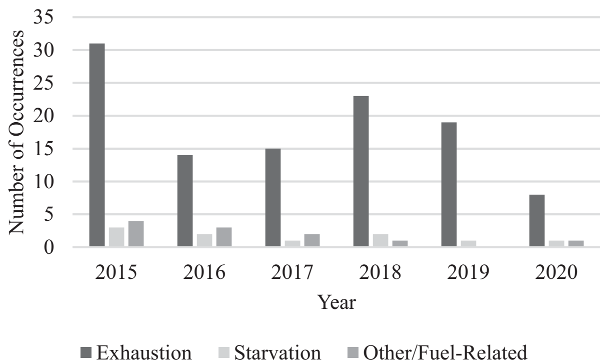

Fig. 2. The number of occurrences of fuel exhaustion and fuel starvation from 2015 to 2020.

fuel plan and whether the reports analyzed fuel consumption. The pilot's fuel plan was only documented in 52 (40%) of the reports. The reports of accidents that involved an occupational pilot were not more likely to contain information regarding the pilot's fuel plan (13 out of 29) compared to non-occupational pilots (39 out of 100) ($N = 129$, $\chi^2 = 0.34$, n.s.). Moreover, a discussion of the aircraft's fuel consumption and how the conditions at the time of the accident affected the consumption rate was present in 65 (50%) of the accident reports. The reports of accidents that involved an occupational pilot were not more likely to contain information regarding fuel consumption (18 out of 64) compared to non-occupational pilots (11 out of 65) ($N = 129$, $\chi^2 = 2.32$, n.s.).

DISCUSSION

Planning-related accidents are a frequent but avoidable cause of accident, which continue to occur with all types of aircraft and across the United States. These factors prove especially instructive as they point to the main types of planning problems that are the most dangerous as well as the kind of aircraft and pilot characteristics most likely associated with fatalities.

Table II. Number of Incidents Associated with HFACs Causal Categories Found in the Fuel-Related Planning Accidents Category.

HFACS LEVEL	CATEGORIES	SUBCATEGORIES	NUMBER OF INCIDENTS
1	Errors	Decision errors	40 (14%)
		Skill-based errors	124 (43%)
		Perceptual errors	0
	Violations	Routine infractions	0
		Exceptional	0
2	Substandard conditions of operators	Adverse mental state	0
		Adverse physiological state	0
		Physical/mental limitation	0
	Substandard practices of operators	Crew resource management	126 (43%)
		Personal readiness	0

Percentages of overall instances of HFAC codes attributed in the dataset are presented in parentheses.
Because accidents are generally associated with more than one causal factor, the numbers in the table exceed the total number of accidents examined.

Table III. Causal Factors as Identified by the NTSB Investigators Organized by HFACS Subcategories.

HFAC SUBCATEGORY	CAUSAL FACTOR IDENTIFIED BY NTSB INVESTIGATOR	NUMBER OF OCCURRENCES
Decision errors	Fuel inadequate inspection	8 (2%)
	Lack of action	2 (0.6%)
	Weather evaluation inadequate	2 (0.6%)
	Flight planning/navigation	2 (0.6%)
	Decision making/ judgment	25 (8%)
	Other (e.g., aborted takeoff/landing)	3 (0.9%)
Skill-based errors	Fuel planning (pilot)	122 (37%)
	Other (e.g., aircraft control)	12 (4%)
Crew resource management	Fuel - fluid level	117 (36%)
	Fuel - fluid management	29 (9%)
	Fuel quantity indicator - incorrect service/management	2 (0.6%)
	Fuel indication system - incorrect service management	1 (0.3%)
	Fuel quantity indicator - damaged/ degraded	1 (0.3%)
	Preflight planning preparation inadequate	2 (0.6%)

Percentages of overall instances of HFAC codes attributed in the dataset are presented in parentheses.
Because accidents are generally associated with more than one causal factor, the numbers in the table exceed the total number of accidents examined.

The frequency of fuel-related planning accidents suggests that this aspect of pilotage is underestimated and requires more attention both in training and in standard operating procedures. It is noted that, for instance, highly experienced pilots found in aerial applications also report fuel management as a common cause of accident.[5,14] Even though fuel-related accidents are not often associated with fatalities, it is a detail of aviation practice that needs constant attention and, as a consequence, may prevent dozens of accidents in the United States each year. Importantly, despite the NTSB's safety alert,[9] fuel planning-related accidents have not appeared to decrease since 2017 when the alert was issued.

In the present dataset, fuel exhaustion (when the aircraft runs out of fuel) was the primary issue. Additionally, the skill-based error of "fuel planning (pilot)" and the crew resource management issue of "fuel-fluid level" are the critical causal factors. It was, however, encouraging to see in the dataset that pilots operating under Federal Aviation Regulations (FAR) Part 133 (Rotorcraft External Load Operators) and 137 (Dispensing Chemicals and Agricultural Products) were not part of any fatal accident and that all pilots identified as occupational pilots were also absent among the fatalities in our dataset. It suggests that professionalism among pilots does not prevent all planning-related accidents from occurring, but that at least fatal accidents are significantly less likely.

Fuel planning-related accidents did not appear more frequently among younger pilots; on the contrary, a significant relationship was found with pilots over 65 yr of age, which partly confirms previous research that suggested male pilots, those older than 60 yr of age, and with more experience are more likely to be involved in a fatal accident.[2] In the present dataset, however, a significant relation was not found when experience, as determined by flight hours accrued, was compared with fatal accidents.

Importantly, detailed information regarding the pilot's fuel plan was only present in 40% of the accident reports. Without such information it is not possible to know if the pilot took into consideration all the variables that affect consumption rate (e.g., air temperature conditions, wind direction, altitude pressure, fuel mixture ratio, and average throttle percentage) and contingency planning for longer than expected flights such as would occur if the pilot needed to perform a go-around.

Based on the above outcomes, there are two recommendations for flight training and for general mitigation strategies. First, there is a need for more detailed information on the NTSB reports. It is interesting that "fuel planning (pilot)" is so frequently attributed as a cause, but the accident reports do not consistently discuss what, if any, plan the pilots had. By conducting standardized interviews, NTSB investigators will be able to document the complete fuel planning process that took place so that it will be possible to determine which aspect of the plan led to the failure. Second, because we cannot assume that all instances of poor fuel planning result in an accident, it is necessary to ascertain information from pilots regarding their normal fuel planning procedures. Although it is important to know what pilots should do for proper fuel planning, it is vitally important to know what pilots are doing so that we can know which step in the fuel planning process needs to be highlighted in training. Future research could address this by interviewing both experienced and inexperienced pilots.

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Author and Affiliation: Hilary Kalagher, Ph.D., Drew University, Madison, NJ, USA.

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