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Retention of Aeronautical Knowledge

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Pilots' retention of aeronautical knowledge learned during private pilot training was studied in four experiments. In the first experiment, ten questions from the FAA private pilot airplane knowledge test were administered to sixty pilots, yielding an average score of 74.8%. Test scores were compared against seven characteristics of the pilots tested: certificates and ratings held, current role in aviation (pilot, CFI, or applicant for additional certificate/rating), total flight time, recent flight experience, reading habits, months passed since last evaluation, and months remaining until next evaluation. These factors explain some of the overall variability in test scores. Three follow-up experiments explored hypotheses about how retention might be affected by pilots' working environment: (1) pilots' knowledge becomes tuned to familiar aircraft charts; (2) difficult-to-remember regulations prompt pilots to substitute simpler rules that still allow them to operate legally; and (3) pilots' geographical region reinforces knowledge about local weather patterns, while knowledge of different weather patterns falls to disuse. The results well support two of these hypotheses but also further demonstrate that there are no simple-to-measure determinants of what aeronautical knowledge will be remembered and forgotten. The experience of everyday flying or teaching, together with recent flight experience and flight review requirements, does not appear to eliminate the need for ongoing study or rehearsal of aeronautical knowledge.

Introduction

Learning to operate an aircraft requires the pilot to master a formidable amount of aeronautical knowledge. Knowledge about weather, regulations, aerodynamics, airspace, navigation, and aircraft systems and performance serves as the basis of pilot decision-making and actions. Mastering this aeronautical knowledge is known to be a laborious task, one that requires many hours of study [Flouris, 2001; Casner et al, 2003]. And after the pilot has initially learned this compendium of aeronautical knowledge comes a second challenge: the challenge of remembering it.

We describe four experiments designed to measure the extent to which pilot remember the aeronautical knowledge they learn during training, and to discover some of the factors that influence which knowledge is remembered and which is forgotten.

Experiment 1

In our first experiment we administered ten questions drawn from the FAA private pilot knowledge exam to sixty pilots and asked them to provide us with details about seven aspects of their past and present aviation experience:

1) Certificates and ratings held;
2) Current role in aviation (active flight instructor, applicant for additional FAA certificate or rating, neither instructor nor applicant);
3) Total flight time;
4) Recent flight time (last 6 months, last 3 months);
5) Months since last flight review;
6) Months until next practical test (if applicant for additional certificate or rating);
7) Reading habits.

The data were analyzed to determine how much pilots remembered, and to look for correlations between retention and pilots' past and present experiences.

Apparatus

A paper and pencil, multiple-choice test was used for data collection. Each test contained the same ten questions randomly selected from the FAA private pilot item bank of questions. Questions that required extensive calculations (e.g., cross-country flight planning) were excluded, as were multiple questions drawn from the same topic area. The test was accompanied by a questionnaire that asked participants about the seven aspects of their past and recent aviation experience listed above.

Participants

Sixty pilots recruited from California Bay Area airports participated in the study. To ensure a more uniform distribution of pilots across our seven aspects of pilot experience variables, we recruited pilots in equal numbers from the three categories of the current role in aviation variable.

Procedure

The experimental tests were completed by participants at times of their choosing. There was no time limit for completing the test. All participants were informed that their responses would remain anonymous.

Results and Discussion

The results indicate a generally unimpressive overall performance. The average score for all sixty pilots was 74.8% with a standard deviation of 19.3%. Only 62% of all participants obtained a score higher than what is considered passing on the FAA private pilot knowledge test (70%). 15% of all participants obtained a score of 70%. 23% scored below 70%. Although a formal comparison is inappropriate due to the small sample size and limited variety of questions used here, it is interesting to note that only 38% scored higher than the national average score for the FAA private pilot airplane knowledge test (85%).

It is important to reiterate that every participant in the study held at least an FAA private pilot certificate. That is, every participant had, at some point in the past, achieved a passing score on the private pilot knowledge test from which the experimental test questions were drawn.

The data clearly show that significant forgetting of the material tested by the FAA questions had taken place.

Certificates and Ratings Held. The scores for all pilots were segregated in four groups based on the certificates and ratings held by each pilot. The four groups and their mean scores were as follows: Private Pilot = 70.5% (21.1%); Private Pilot w/Instrument Rating = 77.8% (17.9%); Commercial Pilot = 72.2% (20.5%); and Certified Flight Instructor = 79.1% (17.6%). No significant differences were found among any of the four groups. Although there is considerable overlap in the aeronautical knowledge required for each successive pilot certificate, requiring pilots to study similar material repeatedly as they progress, the data do not indicate an improvement in retention due to training experience.

Current Role. The purpose of our three experimental groups was to measure the effect of the role that each pilot currently assumes on retention of aeronautical knowledge. It is important to note that this variable represents a notion different from that of certificates and ratings held by each pilot participant. The current role variable describes what each pilot is currently doing with the certificates and ratings that they hold. A participant in the Pilot group may have been a member of the Applicant group earlier that week before passing an Airline Transport Pilot practical test. Similarly, a member of the Applicant group may have been a member of the Pilot group a week earlier simply by deciding to pursue a Flight Instructor certificate. Thus, the three groups describe the status of pilot participants on the day and time that the test was administered.

The mean scores and standard deviations for the CFI, Applicant, and Pilot groups are shown in Table 1.

A comparison of the means between the three groups revealed a marginally significant difference between the CFI and Pilot groups ($df=18$, $t=1.49$, $p < 0.09$). The large variability in scores among all three groups blurred the distinction between the means for all three groups. This result generally supports the idea that flight instructors rehearse their knowledge more often than other pilots, and that this leads to better retention. This result puts an interesting twist on the earlier finding about certificates and ratings held. Knowledge retention seems to be affected not by the holding of certificates and ratings, but to some extent what pilots are currently doing with those certificates and ratings.

Total and Recent Flight and Teaching Experience. The total and recent flight experience for all pilots tested is shown in Table 2, along with correlation coefficients comparing flight experience and scores on the experimental test.

There was little observed correlation between test scores and total flight experience. The three groups combined showed significant correlations between test scores and flight experience during the past six months ($df=58$, $t=2.75$, $p < .01$) and the past three months ($df=58$, $t=2.48$, $p < .01$). Most of this correlation is accounted for by the CFI group: past six months ($df=18$, $t=2.26$, $p < .05$), and past three months ($df=18$, $t=2.58$, $p < .01$).

Upcoming and Past Evaluations. There are generally two types of formal evaluations for the population of U.S. pilots: practical tests and flight reviews. The pilots in the Applicant group, by definition, were preparing for upcoming practical tests. All sixty of our pilot participants are subject to a flight review every 24 calendar months.

A significant negative correlation found was between test scores for the Applicant group and number of months remaining until the applicant's upcoming practical test ($r=-0.68$, $df=18$, $t=3.93$, $p < .005$). The closer each applicant was to their future practical test, the higher were their scores.

A similar correlation was found between test scores for the Pilot group and number of months since each pilot's last flight review ($r=-.44$, $df=18$, $t=1.96$, $p < .05$). Recently completed flight reviews were associated with higher scores. This result suggests that the flight review only modestly serves to maintain pilot mastery of aeronautical knowledge.

Reading Habits. All pilots were asked to provide a Likert-type response to the question: "How often do you read magazines or books about flight training topics?" Interestingly, there were no differences in the reported reading frequency between the Pilot, Applicant, and CFI groups. Correlation coefficients for reading frequency and experimental test scores are shown in Table 3.

Summary

Overall, the seven aspects of pilot experience account for only modest portions of the variability in scores we observed. The data clearly show that there is much more to the story about knowledge retention than certificates and ratings, flight time, and upcoming flight reviews and check rides. Pursuing these goals alone does not ensure that pilots will remember what they have learned.

A significant correlation was observed for the Applicant group ($df=18$, $t=2.65$, $p < .01$). The more time that these pilots reported that they spent reading, the better they did on the experimental test.

Experiment 2

The second experiment explored a hypothesis about why pilots performed modestly on test questions that required the use of aircraft performance and weight and balance charts. It may be that pilots' knowledge and methods tend to become finely tuned to the particular procedures and materials they use, while more general knowledge and skill becomes less available [Greeno, 1974; Logan, 1988]. Pilots' ability to work problems such as weight and balance and density altitude may be highest when using familiar charts, but less when using different charts.

To test this hypothesis, we recruited a sample of pilots who flew regularly in one make and model single-engine airplane and who had never flown in a second make and model single-engine airplane. These pilots were asked to solve weight and balance problems in both airplanes. It is important to note that all pilot participants held at least a private pilot certificate with an airplane category and single-engine class rating.

If our hypothesis about knowledge specialization is correct, pilots will be more successful at solving the weight and balance problems in the familiar airplane.

Apparatus

A paper and pencil test was used for data collection. Each test contained three weight and balance problems drawn from a test bank of four possible problems as follows. Two problems used weight and balance charts for a single-engine domestic airplane for which all pilots had significant experience and had flown within the preceding days. The remaining two problems used weight and balance charts for a different single engine domestic airplane that none of the pilots had ever flown. One problem for each manufacturer's charts resulted in a within-limits solution, while the other problem resulted in an out-of-limits or "no go" solution. Each problem required pilots to do three things: (1) calculate gross weight; (2) calculate total moments; and (3) determine whether or not the airplane was safe to fly as loaded. The test was accompanied by a questionnaire that asked participants about the certificates and ratings they hold and their total and recent flight time.

Participants and Procedure

Twenty-four current and active pilots recruited from local California Bay Area airports participated in the study. The same procedure from Experiment 1 was used to administer the tests.

Results and Discussion

The results for the four problems are shown in Table 4. Each problem was graded using three criteria: (1) correct weight calculation; (2) correct balance calculation; and (3) correct decision about whether the airplane was loaded within limits.

There was a significant difference between the Unfamiliar Airplane Out-Of-Limits problem and all other problems. No other significant differences between the other problems were found.

There is reasonable evidence to support the hypothesis that pilots well retain the particulars of the aircraft weight and balance charts they use everyday, and are less skilled at using charts for difference airplanes. Pilot who had never flown our control airplane were able to recognize a "no go" situation only 50 percent of the time. It can be argued that this result is natural: problem solving will be better for anyone using familiar materials.

Experiment 3

This experiment explored a hypothesis about why pilots performed modestly on questions about aviation regulations that contained intricate and sometimes similar details. It may be that pilots develop and use simplifications for aeronautical knowledge that requires tedious rote memorization. In the case of regulations, a simplification might discard difficult-to-remember details in favor of a simpler rule that, while not correct according to the regulations, allows pilots to operate legally. For example, suppose a pilot states that, for all Class G airspace situations, the minimum visibility is 5 statute miles, while the minimum distance from clouds is 1,000 ft. above and below, and 1 statute mile horizontal. This simplification results in knowledge that is incorrect according to the regulations, yet allows him to operate legally in all Class G airspace situations.

To answer these questions, we asked a group of pilots to answer six questions about regulations, and scored their answers as correct, legal, or altogether wrong. For each question, pilots were also asked to indicate (yes or no) if they were certain that their answer was correct according to the regulations, or if they were uncertain and would use their answer to operate legally.

Apparatus

A paper and pencil, multiple-choice was used for data collection. Each test contained the same six questions, in shuffled order.

Three questions asked pilots to supply VFR weather minimums for Class G airspace in three different situations (14 CFR 91.155):

- Day, 1,200 ft. or less;
- Day, more than 1,200 ft. but less than 10,000 ft;
- Night 1,200 ft. or less.

The three remaining questions asked pilots about rules for operating at night:

- What time can a pilot begin logging night flight (14 CFR 1.1)?
- At what time must an airplane have operational position lights (14 CFR 91.209)?
- What time must passengers be dropped off if the pilot has not met the recent flight experience requirements for night flight (14 CFR 61.57(b))?

Participants and Procedure

Eighteen current and active pilots recruited from local California Bay Area airports participated in the study. Pilots received a NASA Aviation t-shirt as compensation for participating in the study. The same procedure from Experiments 1 and 2 was used to administer the tests.

Results and Discussion

The results for the six questions are shown in Table 5.

The results directly support the hypothesis about knowledge simplification: pilots characteristically gave incorrect yet legal responses.

Perhaps the most interesting results pertain to the certainty measures. Despite being given the option to say they were unsure, pilots frequently stated that they had provided the correct answer when in fact they had provided a merely legal answer, or an answer that was neither correct nor legal. On only one question did pilots' certainty significantly correlate with the correctness of their response. This suggests that pilots had not only forgotten the regulations but were also unaware they had forgotten them. The certainty data also rule out the theory that pilots offload the burden of remembering weather minimums and simply look them up prior to flight, or rely on notes during flight. If pilots followed such a strategy, it seems unlikely that their certainty estimates would be so high and so far amiss.

Experiment 4

This last experiment tested the hypothesis that pilots in different geographical areas would exhibit greater retention of aeronautical knowledge that was more applicable to their own environment. We selected eight questions about density altitude and airplane performance from the FAA Private Pilot knowledge test bank and administered them to pilots in two geographical areas: (1) the California coast during the winter; and (2) Denver, Colorado during the summer. Four questions were "conceptual questions" that probed pilots' understanding of the concepts that underlie density altitude. The remaining four questions asked pilots to use charts, perform calculations, and solve density altitude and airplane performance problems. The average elevation of the California airports at which pilots were recruited was 28 ft. The average elevation of the Colorado airports was 5770 ft. The average daily peak temperature in California during data collection was approximately 50 degrees Fahrenheit. The average daily peak temperature in Colorado during data collection was approximately 95 degrees Fahrenheit.

Apparatus

A paper and pencil, multiple-choice test was used for data collection. Each test contained the eight density altitude questions described above. The test was accompanied by a questionnaire that asked participants about the certificates and rating they held and their total and recent flight time.

Participants and Procedure

Thirty-six current and active pilots participated in the experiment: 18 pilots from California, 18 from Colorado. The same procedure used in the previous experiments was used to administer the tests.

Results and Discussion

The mean scores and standard deviations for the two groups are shown in Table 6.

The scores for the two groups were nearly identical, offering no support for our hypothesis that pilots who operate everyday in high density altitude conditions know more than pilots who operate at sea level in a cool climate. This result is both surprising and counterintuitive. There are a number of possible explanations for this outcome, and for why the hypothesis may warrant further investigation.

First, most pilot participants in both groups were students and flight instructors who worked in a training environment at local flight schools. It may be that these two environments are more similar than we suspected. The airplanes used at each flight school were able to take off, climb, and land at any time of the day at either location. Furthermore, there is no significant terrain within close proximity of either airport to make climb rates an immediate safety issue.

Second, Experiment 3 established that pilots devise and use simplifications of aeronautical knowledge they have learned. There are a number of "rules of thumb" that can be used in lieu of performing more tedious density altitude and takeoff performance calculations. For example, at an average field elevation of 5,770 feet, density altitude can be approximated by simply adding two zeros to the temperature in Fahrenheit. Depending on atmospheric pressure, density altitude is roughly 7,000 feet at 70 degrees, 8,000 feet at 80 degrees, 9,000 feet at 90 degrees, etc. Pilots may also rely on practical rules for takeoff performance such as the "70-50" rule: if the airplane has not developed 70% of the target rotation speed after using 50% of the available runway, the takeoff should be aborted.

Lastly, it may be that our decision to use FAA test questions to test what pilots know about density altitude and airplane performance was entirely insensitive to what knowledge pilots retained, and what new knowledge they have acquired. Perhaps a future study that undertook a more detailed review of pilot knowledge, beyond standardized multiple-choice questions, could reveal differences in what pilots know.

SUMMARY AND CONCLUSIONS

The results of four experiments cast considerable doubt on the assumption that everyday flying experience and recent flight review requirements provide pilots with the opportunity to rehearse and retain the aeronautical knowledge they learned during primary flight training. The results indicate a need for regular study, not only in areas of suspected disuse, such as regulations, emergencies, and unfamiliar weather patterns, but also in what may seem to be familiar areas. The results for weight and balance problems using familiar aircraft charts demonstrate that pilots may not get as much practice in some areas as our intuitions may suggest. The certainty measures associated with incorrect responses to questions about regulations further demonstrate that pilots do not always know what they do not know.

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Table 1: Mean test scores and standard deviations for the three groups.

	CFI Group	Applicant Group	Pilot Group
Mean	79.0	76.0	69.5
Standard Deviation	18.0	17.0	22.1

Table 2: Correlations between test scores and total and recent flight experience.

	Total Flight Time		Past 6 Months		Past 3 Months	
	Hours	r	Hours	r	Hours	r
Pilot Group	382	.05	35	.21	13	.31
Applicant Group	272	.37	57	.14	32	-.21
CFI Group	1294	.04	178	**.47**	94	**.52**
All Three Groups	649	.11	90	**.34**	46	**.31**

Table 3: Correlations between test scores and reported reading frequency

Pilot Group	-.02
Applicant Group	.53 **
CFI Group	.05
All Three Groups	.14

Table 4: Mean scores for weight and balance problems

Familiar Airplane						Unfamiliar Airplane					
Within Limits			Out-Of-Limits			Within Limits			Out-Of-Limits		
Wt.	Bal.	Go?	Wt.	Bal.	Go/	Wt.	Bal.	Go?	Wt.	Bal.	Go?
.83	.89	.78	1.0	.94	.83	.94	.83	.78	.94	.5	.5

Table 5: Scores and certainty measures for regulations questions.

Class G 1			**Class G 2**			**Class G 3**		
Correct	Legal	Wrong	Correct	Legal	Wrong	Correct	Legal	Wrong
.67	1.0	0	.5	1.0	0	.89	1.0	0
Certainty								
.72			.67			.78		
Correlation: Certainty / Correctness								
r=.35			**r=.47**			r=-.19		

Night 1			**Night 2**			**Night 3**		
Correct	Legal	Wrong	Correct	Legal	Wrong	Correct	Legal	Wrong
.61	.72	.28	.56	.89	.11	.44	.89	.11
Certainty								
.78			.83			.72		
Correlation: Certainty / Correctness								
r=.12			r=.06			r=.31		
Correlation: Legal / Correctness								
r=-.03			r=-.16			r=-.22		

Table 6: Mean scores for density altitude test for California and Colorado groups.

	Overall Score	Concept Questions	Problems
California Coast	.85 (.13)	.97 (.24)	.74 (.08)
Denver, Colorado	.86 (.14)	.97 (.23)	.75 (.08)