AN EXPLORATORY STUDY OF US NAVY T-45C SIMULATION TRAINING

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ABSTRACT

Flight training is costly and workload intensive. According to a recent Government Accountability Office (GAO) report, the US Navy and US Air Force predict a 25% shortage of fighter pilots by 2023 (GAO, 2018). The military needs empirical research to determine the effectiveness of flight simulation training and whether simulation training can decrease the overall training time for student pilots. The purpose of this study was to compare intermediate and advanced military student pilots' scores on the T-45C OFT simulator training events and scores on the T-45C aircraft training events in four training domains; the intervention in this study included debriefs by flight instructors after simulator training. Significant differences between pre- and post-tests were observed in contact training of intermediate trainees ($p < .001$; $d = 0.54$); instrument training of intermediate and advanced trainees ($p < .001$; $d = 0.19$); tactical training of intermediate and advanced trainees ($p <.001$; $d = 0.45$); and formation training of advanced trainees ($p < .001$; $d = 0.22$). However, the effect sizes were small to moderate. The results of the study indicated that the training model of pre-test (simulator), debrief, and post-test (aircraft) was helpful in training T-45C intermediate and advanced pilots. Further research is needed to help military decision makers to determine optimal levels of simulation training and aircraft training of student pilots.

Keywords: military pilot training; military pilot simulation training; T-45C; T-45C OFT; military flight training

Introduction

Flight training is costly and workload intensive. However, due to pilot shortages and the demand to decrease the time to train pilots, innovative flight training methodologies and simulation technologies should be explored (Flight Safety Foundation, 2018). According to the Federal Aviation Administration (FAA), the number of pilots has decreased by 30% over the last three decades, and commercial airlines currently experience a pilot shortage (FAA, 2018). The four largest US airlines expect to lose approximately 18,000 pilots by 2022 due to mandatory retirement age requirements (Bachman, 2014). Similarly, according to a recent Government Accountability Office (GAO) report, the US Navy and US Air Force predict a 25% shortage of fighter pilots by 2023 (GAO, 2018). The costs to train military pilots can range from $3 million to $11 million per pilot and costs have also increased within the civilian sectors (Losey, 2018). As a result, evaluating the use of simulation technologies and finding innovative methods to reduce the time to train and certify pilots is an important research area to alleviate the expected pilot shortage tsunami.

Judy and Gollery (2019) conducted a research study of US Navy (USN) and US Marine Corps (USMC) T-45C intermediate and advanced flight students to compare actual aircraft training hours and flight simulation training hours and their relationships to the naval standard score (NSS). The researchers used archival data provided by the Chief of Naval Air Training (CNATRA) for the years 2015-2017. The current research study is a follow-up to the 2019 study and was designed to explore the differences between specific training event scores in the T-45C aircraft after flight students had prepared for the flight training events in a flight simulator and a debrief by an instructor.

Brief Review of Literature

A number of studies have been conducted over the past ten years to determine the potential cost and time savings of using simulations in pilot training and the effectiveness of simulations to prepare students for aircraft flight. A typical flight training model consists of classroom training, simulation, debriefs, and actual aircraft training. Flight schools and aviation academies have used flight simulations for decades to train pilots for aircraft flight. According to Fleming (2013), airline transport pilots (ATPs) can complete 25% of their needed flight hours in a flight simulator. The Federal Aviation Administration (FAA) rules allow a pilot to log 20% of the required hours for a commercial pilot's license in flight simulation and 20 hours toward instrument training certification.

Caligan (2012) conducted a study to determine whether the flight time to solo was a predictor of future pilot performance. A survey was sent to 494,180 pilots who held private, commercial, or ATP certificates. Only 306 pilots responded to the survey and 33 responses were removed for errors, resulting in a sample size of 273. The research questions asked 1) whether the number of hours needed to solo were predictive of the number of hours needed to earn a private pilot license and 2) whether the number of hours needed to solo could predict whether the students passed the private pilot checkride on the first try. The results of the correlation and regression analyses revealed a significant relationship ($p < .05$) between the number of hours needed to solo as well as the number of hours needed to earn a private pilot's license (Caligan, 2012). However, there was no significant relationship between the number of hours needed to solo and the first-time pass rate on the private pilot checkride (Caligan, 2012). The researcher concluded that the flight instructor should continuously evaluate the student for any additional training time needed. Furthermore, Caligan (2012) recommended that further research should focus on determining whether simulation training methods could be used to reduce the amount of time students need to complete the private pilot's license.

An evaluation study by Koglbauer, Riesel, and Braunston (2016) was conducted to examine the outcomes of combining flight simulator training and actual aircraft training on student pilots' skill acquisition. The sample consisted of 61 general aviation flight students with zero flight hours and approximately 40 hours of classroom training. A pre-test/post-test, no control group design was used to compare flight simulator scores and scores on aircraft flight tests. The alpha level was set at 0.05; the *t* test of dependent samples and Pearson's coefficient of correlation were used to analyze the data. The results of the comparisons indicated that the students' aircraft flight performance scores were significantly higher on the post-test ($p < .01$) after using the simulator. In addition, a significant positive correlation was found between instructors' grades in the flight simulator and the aircraft flight post-test ($p < .01$). The researchers suggested that a combination of aircraft training and simulator training are positively related to aircraft flight scores of beginning pilots.

Military and civilian flight trainers frequently use flight simulations to help train pilots. However, the military wants to examine innovative simulation technologies such as virtual reality (VR) and augmented reality (AR) to help increase the effectiveness of simulations and to reduce actual fight training time. The US Navy estimates that 32% of all training will be synthetic in 2030, which will increase the demand for both simulators, pilot time and access to use simulators, and realistic flight simulations (Tublin, 2018).

Tublin (2018) conducted a survey of F/A-18 US Navy fleet squadrons to assess pilot training needs; an overwhelming number of students reported that computer-aided instruction (i.e., PowerPoint) was ineffective for pilot training. However, technical advances in simulators and simulations, especially VR and AR, could replace or at least enhance computer-aided flight instruction.

The Naval Post Graduate School (NPS) and Boeing recently created a F/A-18E/F virtual cockpit to develop pilot familiarization with the aircraft and to instruct cockpit checklist usage. The Navy conducted an experiment in which one group of student pilots used traditional training materials and the other group of student pilots used a VR headset training tool. The results revealed that the VR group completed the training more quickly and with greater accuracy (Tublin, 2018). The VR hardware solution used in the experiment was relatively inexpensive ($3,000), and the student pilots were enthusiastic about the future use of this technology in pilot training. As simulation usage and technology advance, simulation research may help policymakers find an effective ratio of simulation time to training hours in the aircraft.

Methods

The current study's design was a post-hoc, causal-comparative, within-subjects, repeated measures research design. The study used a pre-test/post-test, no control group methodology. The study's sample was purposive and was obtained from CNATRA's Training Information System (TIMS) database from years 2015 to 2017; this dataset was the latest available and served to control for hardware and software changes in the simulators. Training event scores for intermediate and advanced T-45C flight students were examined to explore whether flight simulation training combined with a follow-up debrief by an instructor would help prepare flight students for actual flight training events.

Intermediate pilot training consists of basic instruments, air navigation, cockpit familiarization, basic formation flying, and runway carrier take-off and landing practice (Naval Air Training Command, 2014). Advanced pilot training consists of operational navigation, tactical maneuvering, weapons delivery tactics, advanced flight formations, low-level flying, and aircraft carrier landing qualification (Naval Air Training Command, 2014). This study compared pre-test (simulator) training event scores and post-test (aircraft) training event scores. The independent variables were scores on specific simulator training events, and the dependent variables were scores on specific aircraft training events for each individual student pilot (i.e., matched data pairs). All the student pilots participated in an instructor debrief following the pre-test (simulator training event) prior to completing the post-test (aircraft training event). The study examined only USN and USMC flight simulation training event scores and actual aircraft training event scores for years 2015 through 2017. One aircraft, the T-45C, and one flight simulator, the T-45C OFT, were investigated in order to control key variables and to help ensure comparability of data.

The training events were embedded within four CNATRA training domains: contact training, instrument training, formation training, and tactical training. *Contact training* included aircraft familiarization, out-of-control flight, night flight familiarization, and early field carrier landing stages; only intermediate level pilots participated in this training domain. *Instrument training* included emergency procedures, basic instruments, radio instruments, navigation, and instrument rating stages. *Formation training* included day and night formation flying. Both intermediate and advanced student pilots were included in instrument and formation training in this study. *Tactical training* included strike, tactical formation, fighter maneuvering, and carrier qualification landing stages; only advanced pilots participated in this training.

The pre-test simulation training events were performed in the T-45C operational flight trainers (OFT). The post-test aircraft training events were conducted in the T-45C Goshawk aircraft. Both pre-test (simulator) and post-test (aircraft) events occurred in the same four training domains.

The initial CNATRA sample size consisted of 462,190 aircraft and simulator training events from intermediate and advanced pilot training phases. The sample size was then narrowed to student pilots' matched simulator and aircraft scores for four primary US Navy training domains: contact training, instrument training, formation training, and tactical training; as mentioned earlier, the scores were matched for each individual pilot. The resulting sample size consisted of 42,825 matched simulator and aircraft events from contact training; 39,169 matched simulator and aircraft events from instrument training; 33,521 matched simulator and aircraft events from formation training, and 79,368 matched simulator and aircraft events from tactical training. Intermediate and advanced flight students were not disaggregated during analysis because both training events overlap in some of the training domain areas. Contact training included only intermediate students. Instrument and formation training included both intermediate and advanced students and tactical training included only advanced students. The purpose of the study was to compare scores on simulator training events and scores on aircraft training events in the four training domains.

Research Questions

In order to address the research problem, the following research questions were posed. Since this study was exploratory in nature, no hypotheses were presented.

Q1. Is there a difference between pre- and post-test scores on contact training tasks of intermediate level student pilots?

Q2. Is there a difference between pre- and post-test scores on instrument training tasks of intermediate and advanced level student pilots?

Q3. Is there a difference between pre- and post-test scores on formation training tasks of intermediate and advanced level student pilots?

Q4. Is there a difference between pre- and post-test scores on tactical training tasks of advanced level student pilots?

Intervention

The simulator (OFT) debrief was conducted by CNATRA flight instructors after each simulator training event and prior to each aircraft training event. The debriefs consisted of a discussion of the student pilot's overall score for each event, the rationale for the event score, and suggested areas for improvement.

Instrumentation

Flight simulation events (pre-tests) were completed in the T-45C Goshawk OFT, scored by the flight instructor, and added to the CNATRA database. The T-45C OFT (see Appendix A) is a high-fidelity instrument and visual flight simulator designed as a dome shell simulator with a digital cockpit, outside visual displays, and instructor station (Boeing, 2018). Actual aircraft events (post-tests) were conducted in the T-45C Goshawk aircraft (see Appendix A), scored by the instructor, and added to the CNATRA TIMS database. The T-45C Goshawk is a highly maneuverable turbofan jet military training aircraft built by the Boeing Company (Boeing, 2018).

Event Scoring

The pre- and post- training events' scores ranged from 1 to 5 and are considered interval level data; the events were scored by a flight instructor for both simulator and aircraft events. A score of 3 and above is considered passing. The scale was developed by CNATRA and used by the flight instructors as described below (Naval Air Training Command, 2014).

1: *Demonstrated*. The task was demonstrated by the instructor or performed solo by the student.

2: *Unable*. The task was unsafe and the student could not perform the task within course training standards.

3: *Fair*. The task was safe, but the student lacked proficiency, and his or her deviations exceeded course training standards.

4: *Good*. The task was performed within course training standards.

5: *Excellent*. The task surpassed course training standards.

Limitations of the Study

The study analyzed post-hoc, archival data. The sample was purposive and drawn from two branches of military service, the USN and USMC, and may not be representative of all military or civilian pilots. CNATRA provided the archival dataset for years 2015 through 2017. Whether students repeated simulator events on their own time and prior to the graded aircraft events was unknown. By design, some simulator events present more difficult tasks than tasks in the aircraft. For example, a simulated instrument approach in a thunderstorm using instrument flight rules (IFR) is more difficult compared to an instrument approach in the actual aircraft during marginal visual flight rules (MVFR). However, conducting an inverted roll in the aircraft is typically more difficult than conducting the maneuver in the simulator. Additionally, based on the nature of high-risk military flying, flight students typically never perform certain maneuvers or training tasks in the aircraft prior to performing the tasks in the simulator. The study specifically investigated the training events conducted within the four training domain areas and did not compare intermediate students to advanced students. Finally, the study was exploratory in nature since no control group existed for comparison purposes.

Data Analyses

The data from matched pilot simulation event scores and actual aircraft event scores were analyzed using both descriptive and inferential statistical techniques. Mean scores (M), standard deviations (*SD*), and frequency counts (*n*) were the primary descriptive statistical techniques used to address the four research questions. The *t*-test of dependent means was used to compare pre-test scores (simulation training event scores) and post-test scores (actual aircraft training event scores). The alpha level of $p < .05$ was used as the threshold for statistical significance of findings. The magnitude of treatment effect (effect size) was assessed using the Cohen's *d* test statistic. Cohen's conventions of interpretation were used for the qualitative interpretation of effect size values in each of the study's four research questions.

Results

Descriptive Results

Descriptive statistics were calculated for each training domain area. The mean scores for each training domain increased from pre- to post- test in the instrument training domain. The results are depicted in Table 1.

Table 1

Event Score Means, Standard Deviations, and Frequencies for Total Sample

Training Domain	*N*	Mean		Standard Deviation	
Contact	42,825	Pre	3.08	pre	0.46
		Post	3.45	post	0.69
Instrument	39,169	Pre	3.61	pre	0.47
		Post	3.44	post	0.78
Formation	33,521	Pre	3.16	pre	0.54
		Post	3.54	post	0.84
Tactical	76,368	Pre	3.59	pre	0.53
		Post	3.77	post	0.63

Note. Event scores range from 1 to 5; 3 is considered passing.

Inferential Results

Research Question 1: Is there a difference between pre- and post-test scores on contact training tasks of intermediate level student pilots?

For the flight training domain of contact training, the *t*-test of dependent means was used to determine the mean score difference from pre-test (simulator) to post-test (aircraft); the result was significant (t = 112.12; p < .001). Cohen's *d* was used to determine the effect size (ES) of differences; the resulting ES was considered medium (d = 0.54). Table 2 reports a summary of findings for the Contact Training domain.

Table 2

Intermediate Pilots' Pre/Post Event Score Comparison of Contact Training Domain

Contact Training	*N*	Mean	Standard Deviation	*t*	*d*
Pre (Simulator)	42,825	3.08	0.46	112.12***	0.54
Post (Aircraft)	42.825	3.45	0.69		

***p < .001

Figure 1 displays the percentage of change of intermediate pilots' scores between simulator training and aircraft training for the contact training domain. Based on the sample size in the training domain (n = 42,825), the percentages were computed to show the percentage of simulator scores (pre) that were greater than aircraft scores (post).

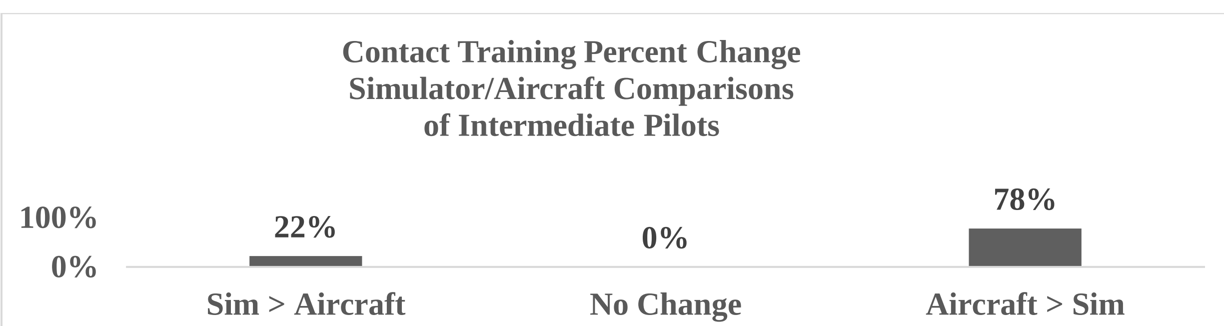

Figure 1. Contact Training Percent Change of Intermediate Pilots

Research Question 2: Is there a difference between pre- and post-test scores on Instrument Training tasks of intermediate and advanced level student pilots?

In the flight training domain of instrument training, the *t*-test of dependent means was used to determine the mean score difference from pre-test (simulator) to post-test (aircraft); the result was significant (t = 36.96; p < .001). Cohen's *d* was used to determine the effect size of differences between the pre-test and the post-test scores of both intermediate and advanced student pilots on instrument training tasks. The ES was considered small (d = 0.19). Table 3 contains a summary of findings for the instrument training domain.

Table 3

Intermediate/Advanced Pilots' Event Score Pre/Post Comparison of Instrument Training

Instrument Training	*N*	Mean	Standard Deviation	*t*	*d*
Pre (Simulator)	39.169	3.61	0.47	36.96***	0.19
Post (Aircraft)	39,169	3.44	0.78		

****p* < .001

Figure 2 depicts the percentage of change in scores between simulator training and aircraft training for Instrument Training among intermediate and advanced pilots.

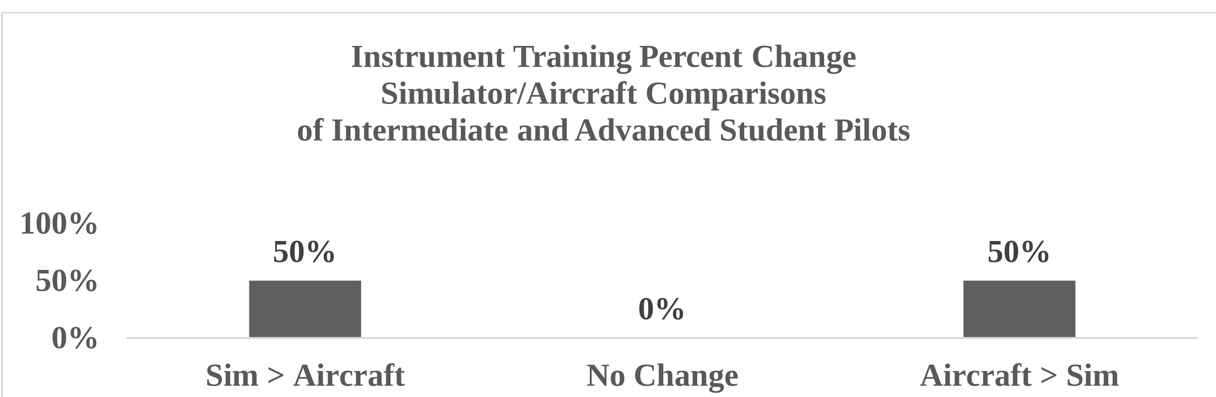

Figure 2. Instrument Training Percent Change of Intermediate and Advanced Student Pilots

Research Question 3: Is there a difference between pre- and post-test scores on Formation Training tasks of intermediate and advanced level student pilots?

The *t*-test of dependent means was used to determine the mean score difference from pre-test (simulator) to post-test (aircraft); the result was significant ($t = 82.82$; $p < .001$). Cohen's *d* was used to determine the effect size of differences between the pre-test and the post-test scores of intermediate and advanced student pilots on formation training tasks. The ES was considered medium ($d = 0.45$). Table 4 displays the results of the comparisons on the formation training domain.

Table 4

Intermediate/Advanced Pilots' Event Score Pre/Post Comparison of Formation Training

Formation Training	*N*	Mean	Standard Deviation	*t*	*d*
Pre (Simulator)	33,521	3.16	0.54	82.82***	0.45
Post (Aircraft)	33,521	3.54	0.84		

***$p < .001$

Figure 3 depicts the percentage of change in scores between simulator training and aircraft training for the training domain formation training among intermediate and advanced pilots.

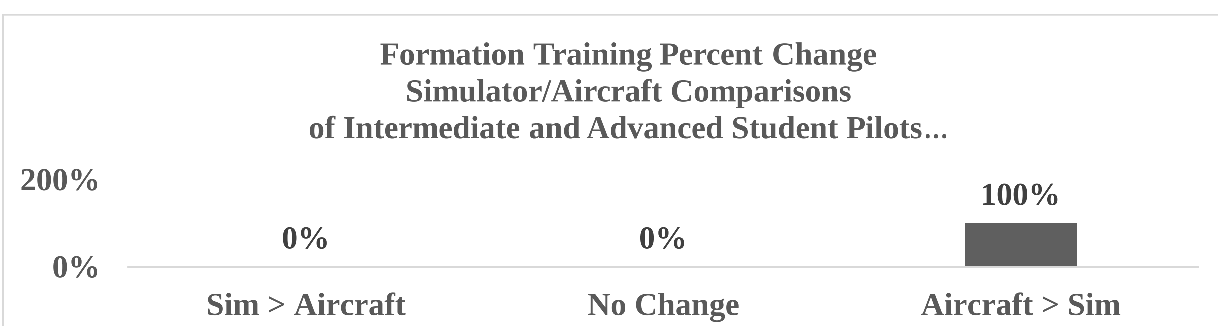

Figure 3. Formation Training Percent Change of Intermediate and Advanced Student Pilots

Research Question 4: Is there a difference between pre- and post-test scores on tactical training tasks of advanced level student pilots?

The *t*-test of dependent means was used to determine the mean score difference from pre-test (simulator) to post-test (aircraft); the result was significant (t = 60.41; p < .001). Cohen's *d* was used to determine the effect size of differences between the pre-test and the post-test scores of advanced student pilots; the ES was considered small, (d = 0.22). Table 5 contains a summary of findings for the tactical training domain.

Table 5

Advanced Pilots' Pre/Post Comparison of Tactical Training

Tactical Training	*N*	Mean	Standard Deviation	*t*	*d*
Pre (Sim)	76,368	3.59	0.53	60.41***	0.22
Post (Aircraft)	76,368	3.77	0.63		

***p < .001

Figure 4 displays the percentage of change in scores between simulator training and aircraft training for tactical training among advanced pilots.

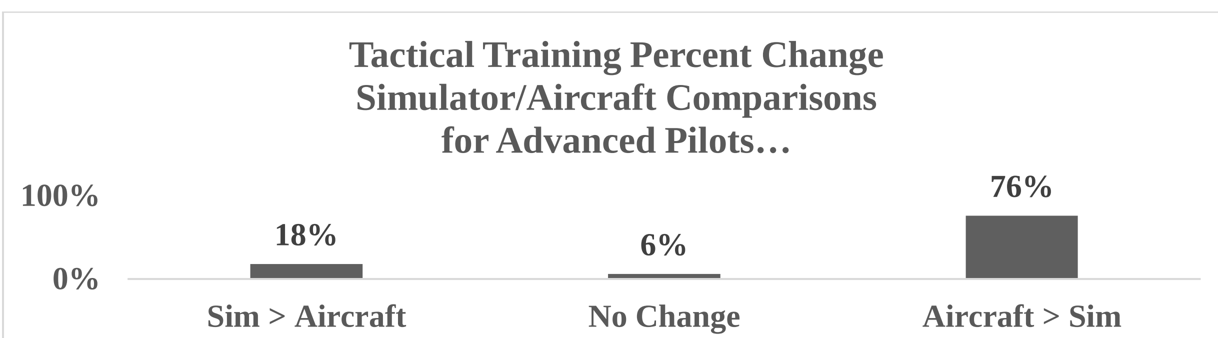

Figure 4. Tactical Training Percent Change of Advanced Pilots

Discussion

The four research questions in this study focused on four pilot training domains among intermediate and advanced student pilots: contact training (Q1), instrument training (Q2), formation training (Q3), and tactical training (Q4).

The results of the study revealed that all four pre/post comparisons were statistically significant ($p < .001$). All the domain post-test (aircraft) mean scores were significantly higher than the pre-test (simulator) scores except for the Instrument Training domain, which included both intermediate and advanced pilots. In the instrument training domain, the mean (aircraft) post-test score was significantly lower than the mean (simulator) pre-test scores. Logically, one might anticipate higher post-test scores after practice of events in a simulator. Due to the large sample size, however, the statistically significant findings should be viewed cautiously. Since no control group was available for this study, the results revealed only differences between simulator events and aircraft events, not causal relationships. Further experimental research is needed to evaluate the differences simulation training might make in actual aircraft performance.

For Research Question 1, contact training results of intermediate pilots revealed that 78% of the aircraft event scores were greater than simulator event scores, and 22% of simulator scores were greater than aircraft event scores. In cases in which the aircraft score is greater than the simulator score, the contact training model of pre-test (simulation), instructor debrief, and post-test (aircraft) would appear to be effective ($p < .05$; $d = 0.54$). However, when the simulator score is greater than the aircraft score, two conclusions may be drawn; either 1) the simulator may not effectively prepare the students for the aircraft event or 2) the actual aircraft tasks were more difficult in that domain. More research is needed to reach definitive conclusions.

Research Question 2 investigated the differences between scores of both intermediate and advanced student pilots in the instrument training domain. The results revealed statistically significant differences between pre- and post-test scores ($p < .001$). However, the mean post-test (aircraft) score was lower than the pre-test (simulation) score. In addition, fifty percent of aircraft scores were greater than the simulator scores. These results may imply that the simulator's instrument training events are harder than the aircraft training events. As mentioned earlier, simulator training events often include extreme and challenging weather scenarios and flight emergencies. In the actual aircraft training scenario, the instructor will not endanger the aircraft or personnel to fly in weather that is considered too risky for student pilots. Another possible explanation might be that the mean simulation scores may be higher due to their being too easy compared to actual aircraft execution of the tasks. The effect size in this comparison was small ($d = 0.19$), indicating that the change in score from simulator to aircraft training was negligible. This finding is notable since the instrument training domain emphasizes emergency procedures and is the training phase in which students earn their instrument rating. Not all emergency procedures can be executed in the aircraft, a common constraint in aviation training. Actual aircraft training events are not flown in bad weather or executed during authentic in-flight emergencies. Even in actual aircraft training, emergency procedures are "simulated" (e.g., engine out).

Research Question 3 compared the pre- and post-test scores of intermediate and advanced pilots in the formation training domain; the result was significant ($p < .001$). The effect size was considered medium ($d = 0.45$); one-hundred percent of aircraft scores were greater than simulator scores. The results suggest that the simulator/debrief/aircraft training model is helpful in the formation training domain. However, another conclusion might be that the simulator events are too simple compared to actual aircraft flight events. Since formation training requires critical flight maneuvering within tight tolerances, the more likely scenario is that the simulator can only perform a small set of the training events. More research is needed to determine the relationships between simulator and aircraft training in this domain.

Research Question 4 investigated the differences between pre- and post-test scores of advanced pilots for the tactical training domain, and the result was significant ($p < .001$). The mean (aircraft) post-test score was significantly different from, or higher, than the mean (simulation) score. The analyses also revealed that 76% of aircraft scores were greater than simulator scores, 18% of aircraft scores were lower than simulator scores, and 6% saw no change in scores. The effect size in this comparison was small ($d = 0.22$). Tactical training involves carrier landing qualification; in this sample, 18% of the simulator scores were greater than aircraft scores. The probable explanation relates to the fact that real-world carrier landing events include more variables than can be authentically reproduced in the simulator. However, aircraft carrier landings are easier today than in the past due to advanced onboard automation technologies.

Overall, the results of the study indicated that the training model of pre-test (simulator), debrief, and post-test (aircraft) was helpful in training T-45C intermediate and advanced pilots. However, without a control group for comparison purposes and information on the numbers of practice sessions in simulator training prior to aircraft training, definite conclusions are difficult to ascertain. All training comparison were statistically significant: however, the effect sizes were small to moderate. The results of this study indicated that the use of simulators is somewhat helpful for intermediate student pilots in the contact training domain, somewhat helpful for intermediate and advanced pilots in the instrument training and formation training domains, and somewhat helpful for advanced student pilots in the tactical training domain. To accurately determine the impact or effect of simulation practice on actual aircraft performance would require rigorously controlled experimental studies, which are not often feasible. Future research studies are needed to measure and assess the effects of simulation training events with instructor debriefs and the inclusion of additional simulation technologies such as augmented reality (AR), virtual reality (VR), or mixed reality (XR). Additionally, if simulations were introduced earlier in pilot training curricula, training event scores might increase and potentially reduce the time to train student pilots. For example, many flight schools, including those of the US Military, are experimenting with computer tablet-based and competency-based training in lieu of classroom training. A survey of F/A-18 training squadrons found that Navy fleet pilots preferred simulator technologies, including AR/VR, over computer-assisted instructional slides (Tublin, 2018). As simulation technologies improve and more simulations are introduced into pilot training curricula, future experimental research may assist the military to determine the optimal mix of simulation and aircraft flight training.

Recommendations for Future Research

The results of this exploratory study indicated that flight training in a simulator is helpful, but the study also pointed to potential shortfalls and recognized the need for more experimental research on flight training. Flight training with simulators has increased over the years; as new technologies such as VR and competency-based training become more common, even further research is required. Additional studies might focus on the introduction of VR and other simulation technologies earlier in the ground-based instructional phases to determine whether aircraft training scores increase and whether the overall time to train pilots decreases. Even a strategy as simple as providing a flight student with a tablet-based VR simulator to use while studying might improve training scores.

The US Navy and commercial airline industries are very interested in ways to improve the effectiveness of pilot training and to reduce costs and pilot training time. The potential benefits of reduced time and effort to bring military and commercial pilots to the high levels of proficiency required certainly warrant deep explorations of simulation usage and instructional methodologies. An experimental study using experimental and control groups could explore the effects of specific amounts of simulation time and methodologies earlier in pilot training phases as well as the traditional training model utilized in this study. As the need for more pilots rises, rigorous research is indispensable to answer the critical questions regarding ways flight schools can improve flight training in order to produce the next generation of pilots.

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Appendix A

T-45C OFT (Reprinted with permission, U.S. Navy)

T-45C Goshawk (Reprinted with permission, U.S. Navy).

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