

## U.S. NAVY PILOT COMPETENCE: AN EXPLORATORY STUDY OF FLIGHT SIMULATION TRAINING VERSUS ACTUAL AIRCRAFT TRAINING

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### ABSTRACT

*The purpose of this study was to investigate the relationships between US Navy T-45C flight simulation training time, actual aircraft training time, and intermediate and advanced jet pilot competence as measured by the Naval Standard Score (NSS). Examining the relationships between US Navy T-45C flight simulation time and actual aircraft flight time may provide further information on flight simulation training versus actual aircraft training to aviation authorities, flight instructors, the military aviation community, the commercial aviation community, and academia. The study was non-experimental, correlational, causal-comparative with an emphasis upon the establishment of mathematic and predictive relationships using archival data from the Chief of Naval Air Training (CNATRA) Training Information System's (TIMS) database. CNATRA aircraft hours, flight simulation hours, and NSS scores of intermediate and advanced flight students from 2015 to 2017 were analyzed and compared. Actual aircraft time was found to be a significant predictor of NSS scores for both intermediate and advanced pilot trainees. Implications of the study include recommendations for future research and strategies to improve flight simulation in pilot training.*

## **Introduction**

Military pilot training requires an enormous investment of time, energy, and resources. In fiscal year 2017, the United States Department of Defense spent approximately 1.6 billion dollars on flight training (Department of Defense, 2016). The Chief of Naval Operations (CNO) established a simulator training strategy in 2014 that stated, “To the maximum extent practicable, live training should be completed by simulators or fleet synthetic training where training effectiveness, safety, and operational readiness are not compromised” (Department of the Navy, 2014, p. 2). However, research suggests that flight simulation, though suitable for training a myriad of tasks required, may not be the best method for training certain critical aircraft tasks, such as those requiring significant mental problem-solving and high levels of performance (Beaubien, Stacy, Wiggins, & Lucia, 2016). Therefore, this study was conducted to investigate the relationships between flight simulation training, actual aircraft training, and intermediate and advanced jet pilot competence as measured by the Naval Standard Score (NSS).

The Department of the Navy is responsible for training both US Navy (USN) and US Marine (USMC) pilots at various Training Air Wings located across the United States. Military pilot training is extensive, costly, and in high demand. With the advent of computer-based technologies, pilot training via computer simulations became standard practice in military pilot training and has been, on the whole, very effective and efficient in developing the skills of naval pilots (Department of the Navy, 2010). Both the USN and the USMC are very interested in research designed to determine the optimal amount of training time necessary to achieve pilot expertise in various aircraft. A major question posed by the USN and the USMC focuses on the feasibility of reducing actual aircraft training time, which is labor and cost intensive, using

flight simulation training. In 2010, the Navy estimated that 61% of flight training should be actual aircraft training (Department of the Navy, 2010). This important question was the impetus for the study. Comparing actual aircraft training time and flight simulation training time to overall pilot competence would make an important contribution to policy and decision-making among the nation's military forces.

### **Naval Standard Score (NSS)**

The USN and USMC currently train fixed-wing pilots through Command Training Wings located across the U.S. Primary training, which is the introduction to jet training, is conducted in a Beechcraft T-6B Texan aircraft located at Training Wing FOUR in Corpus Christi, Texas, or at Training Wing FIVE located in Milton, Florida. Primary training takes approximately 28 weeks to complete. Upon completion of primary flight training, jet pilots move into intermediate training, followed by advanced training before earning their Wings of Gold. Intermediate and advanced flight training is conducted in a Boeing T-45C Goshawk aircraft at Training Wing ONE in Meridian, Mississippi or at Training Wing TWO in Kingsville, Texas. Intermediate training takes approximately 27 weeks to complete, and advanced training takes approximately 25 weeks to complete. Pilots who graduate from Training Wing ONE and TWO supply the operational needs of the USN and USMC as pilots for F/A-18 aircraft and next-generation F-35 jet aircraft.

Overall pilot effectiveness is measured by the NSS as determined by the flight instructor. The NSS is used to measure pilot competencies and skills for both the USN and USMC flight students. Chief of Naval Air Training (CNATRA) considers the NSS score to be a valid method of assessing pilot competency for the USN/USMC flight training program (Naval Air Training Command, 2014). The NSS is calculated separately for each flight

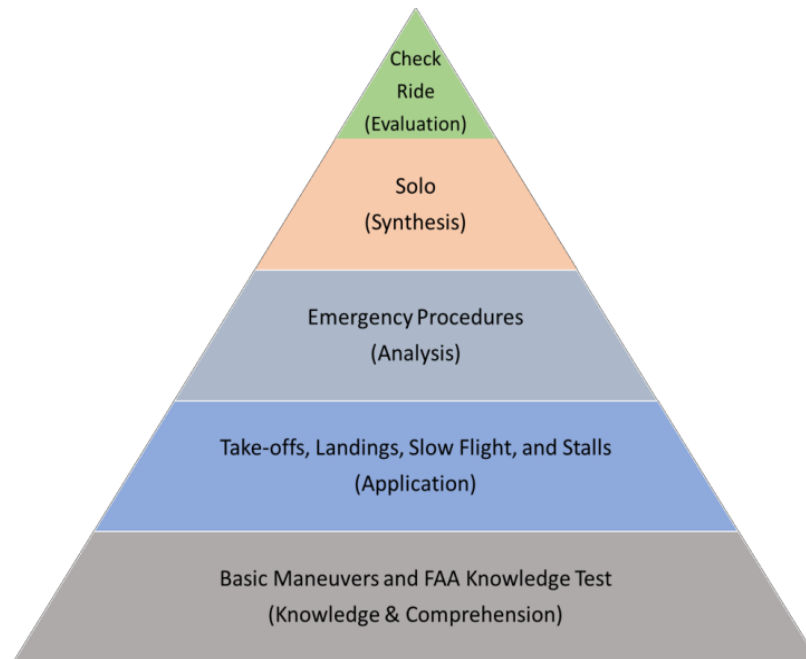
student who completes each phase of training (primary, intermediate, and advanced). This study focused only on training times of flight students in the intermediate and advanced phases of training.

### **Review of Literature**

Bloom's taxonomy of the cognitive domain is one of the most well-known models for describing thinking, learning, and instruction (Palmer, 2001). Bloom (1956) conducted extensive research leading to the identification of six levels of cognitive thought from lowest to highest complexity: knowledge, comprehension, application, analysis, synthesis, and evaluation (Bloom, 1956). Each of the levels of thinking includes and builds on the previous levels in the hierarchy. Over time, the taxonomy of the cognitive domain came to be known as Bloom's taxonomy.

#### **Bloom's Taxonomy and Flight Training**

Knowledge, perception, problem-solving, decision-making, awareness, and intellect are all critical elements of flight training. As flight students apply higher order thinking skills (HOTS) during flight training, they are continuously constructing knowledge and skills. The researcher proposed that flight training is similar to Bloom's taxonomy in that flight training builds upon each level of pilot training designated by the Federal Aviation Administration (FAA) and requires increased levels of complexity and performance as depicted in Figure 1.



*Figure 1.* Bloom's model and pilot training levels. Adapted from FAA, 2017, p. 6-3.

Each hierarchical level of the modified Bloom model for pilots depicted in Figure 1 builds on the previous levels, just as with Bloom's original model. In level one of the pilot model, the student pilot typically begins flight training by acquiring knowledge and comprehension of basic aircraft systems, rules, and regulations. This phase typically occurs during classroom instruction. Private pilots are required to take a written test and pass with a 70% or higher competence rating as one part of obtaining a pilot's license (FAA, 2018). Level two of the pilot model, application, requires considerable flight training time to learn and practice take-offs, in-flight maneuvers, and landings in both flight simulators and actual aircraft. In level three of the pilot model, analysis, emergency procedures require rapid analysis since the student must first recognize the emergency and then properly address the emergency (e.g., engine failure) to ensure safe recovery in the aircraft. Level four of the pilot model, synthesis, occurs as the student conducts his or her first solo flight without an instructor. Level five of the pilot model concludes the pilot hierarchy with an FAA-designated

examiner check-ride evaluation. As identified in Figure 1, the modified Bloom model for pilots developed by the researcher provides a conceptual framework for discussion of pilot training.

### **Flight Simulation Training**

A recent study of Navy F/A-18 pilots investigated methods to measure the ways learning occurs during simulated carrier landings (Beaubien et al., 2016). The authors studied fifteen Navy F/A-18 pilots who flew 24 landing passes in a high-fidelity simulator (Beaubien et al., 2016). Measures of performance (MOP) scores were analyzed for each landing and assessed during the last 18-23 seconds of the final approach. The MOP scores were then averaged, and each pilot was assigned a score. Based on the simulator analysis, the MOP scores demonstrated that performance had improved over time (Beaubien et al., 2016). However, the measures of learning (MOL) scores revealed that auditory and/or visual cues provided by the flight simulator actually resulted in reduced mean scores on final approach to landing. In other words, negative transfer of learning occurred from the simulator to actual pilot performance in the aircraft (Beaubien et al., 2016). Based on this study, both MOP and MOL scores should be assessed when conducting simulated flight training or to help improve flight simulation.

### **Actual Aircraft Training**

Problem-solving, learning, and cognition are all key components of flight training and include a plethora of research studies in a wide variety of disciplines. Classifying the cognitive demands on pilots using a simulated device is an important method of describing and measuring learning during flight training to help ensure proficiency (Hoke, Reuter, Romeas, Montariol, Schnell, & Faubert, 2017). Hoke et al. (2017) conducted a study using a cognitive

assessment tool set (CATS) system, which was worn under a pilot's flight suit. The CATS system did not interfere with flying tasks and provided a real-time assessment of the cognitive workload during flight training. The study's sample included 10 low-time (100-300 flight hours) pilots ranging in age from 20 to 25 and holding a valid U.S. private pilot certificate with a Class III medical certification (Hoke et al., 2017). A Class III medical certification is granted by a designated FAA medical examiner for recreational and private pilots. The study used Neurotracker (NT) to evaluate the cognitive workload when piloting an L-29 jet trainer aircraft and a L-29 simulator. Neurotracker is a scientific instrument developed to help improve perceptual-cognitive abilities among athletes. The Neurotracker, also known as three-dimensional multiple object tracking (3D-MOT), isolates a number of mental skills used for reading and training and closely monitors the brain's processes during complex motion. Faubert and Sidebottom (2012) developed the 3D-MOT methodology to stimulate and measure brain networks that work together during motion processing, attention processing, and working memory. Using NT methodology, the Hoke et al. (2017) study revealed that flying, whether in an aircraft or a flight simulator, is a cognitively demanding task. However, the results of the study also showed that the pilots' maneuvers as measured by NT were more cognitively demanding when flying the L-29 jet aircraft than when flying in an L-29 simulator (Hoke et al., 2017). This study provides empirical evidence related to the questions the USN and USMC seek to answer.

### **Flight Simulator Effectiveness**

US Navy training has traditionally focused on live training events; however, ongoing budget constraints have served to promote the use of simulators to train pilots (Schank, Thie, Graff, Beel, & Sollinger, 2002). In 2002, the Department of the Navy asked the RAND

National Defense Research Institute to study the ways that a mix of classroom instruction, simulation training, and aircraft training events could increase pilot training effectiveness. The RAND study conducted by Schank et al. (2002) focused on two airborne training programs within the Navy's F/A-18 and the P-3C squadrons. Additionally, RAND also conducted a trade-off analysis between live and simulated training events while analyzing flying hours and simulator use for US Navy units. However, the data were based on best estimates and data that were readily available. The study found that F/A-18 simulators made only a modest contribution to flight training due to poor accessibility by pilots and low fidelity; however, P-3C simulators were more widely used and accepted by the P-3C pilot community. The P-3C simulators were used more often than the F/A-18 simulators by pilots, who judged that P-3C simulators replicated the flight environment better than the F/A-18 simulators.

The Navy employs four types of F/A-18 simulators, although some simulators are in the process of being replaced or are currently in the process of hardware and software upgrades. The RAND study found that the F/A-18 simulators were used by the fleet training schools 50% to 60% of the time; but fleet operational units (deployed units) used the simulators 20% of time, and they were unused 20% of the time. The RAND researchers also conducted interviews and determined that pilots frequently do not use the simulators due to a lack of realistic mission profiles, lack of fidelity between the simulation and actual flight time, and lack of availability. In 2002, pilots recognized the limitations and strengths of different types of simulators and made their opinions known, both verbally and in their non-use of the simulators.

An evaluation study by Koglbauer, Riesel, and Braunstingl (2016) was conducted on the effects of combining actual aircraft and simulator training on student pilots' skill



acquisition. The evaluation consisted of 61 general aviation flight students with zero flight hours and approximately 40 hours of classroom training. The evaluation employed a pre- and post-test design using the repeated measures *t*-test to compare simulator scores and scores on aircraft flight tests. The alpha level was set at 0.05, and the *t*-test of dependent samples and Pearson's correlation coefficient were used to analyze the data. The results indicated that the students' aircraft flight performance scores were significantly higher on the post-test ( $p < .01$ ) after using the simulator. Also, a significant positive correlation was found between instructor grades in the simulator and the aircraft flight post-test ( $p < .01$ ). The study indicated that a combination of actual aircraft training and simulator training have positive effects on beginning pilots during actual flight.

### **Methodology**

The current study was non-experimental, correlational, causal-comparative research using archival data from the CNATRA Training Information System (TIMS) database. Chief of Naval Air Training aircraft hours, flight simulation hours, and NSS scores of intermediate and advanced flight students from 2015 to 2017 were analyzed and compared.

### **Sample**

The study's sample was purposive and obtained from CNATRA's TIMS database from years 2015 to 2017. The dataset was purposive since the data were selected for only intermediate and advanced flight students who trained with the T-45C Goshawk and T-45C operational flight trainer (OFT). Additionally, the years 2015 to 2017 were chosen to ensure reliability and validity by limiting changes over time in simulation upgrades or aircraft technology. Participants included all USN and USMC intermediate and advanced T-45C Goshawk flight student completers from 2015 to 2017 from Training Wings ONE and TWO.

The sample size consisted of 358 intermediate flight students and 334 advanced flight students from Training Wings ONE and TWO. Flight students are required to complete a minimum number of aircraft training hours and flight simulation hours, but students can request more unproctored time in the simulator; as a result, simulator times are different for each student.

The study was designed to compare actual aircraft training hours and flight simulation training hours and their relationships to the naval standard score (NSS) of intermediate and advanced USN and USMC flight students. The independent variables were actual aircraft hours and flight simulation hours. The independent variables were continuous, interval-level data. The dependent variable was the NSS score, which was normalized by the Navy as interval-level data with a NSS range of 20 to 80, mean of 50, and a standard deviation of 10.

The researcher did not analyze any demographic data such as gender, military rank, or age. The study examined only USN and USMC actual aircraft hours, flight simulation hours, and the NSS for years 2015 to 2017. The study investigated the relationships between the T-45C aircraft and associated T-45C OFT flight simulator in order to control key variables and to help ensure comparability of data.

### **Instrumentation**

The independent variables were actual aircraft hours and flight simulation hours. Actual aircraft hours were flight hours completed in the T-45C Goshawk aircraft as recorded in the CNATRA TIMS database. Actual aircraft hours were flown in the T-45C Goshawk, a highly maneuverable, Boeing turbofan jet military training aircraft, as depicted in Figure 2 (Boeing, 2018).



*Figure 2.* T-45C Goshawk. Reprinted with permission, U.S. Navy.

The T-45C consists of a digital cockpit with integrated navigational displays, weapon delivery systems, and communication systems. Flight simulation hours were gathered from the T-45C Goshawk OFT as recorded in the CNATRA TIMS database. The T-45C OFT is a high-fidelity, dome shell visual flight simulator with a digital cockpit, outside visual displays, and instructor station as depicted in Figure 3 (Boeing, 2018).



*Figure 3.* T-45 OFT. Reprinted with permission, U.S. Navy.

The dependent variable in this study, the NSS, was used to measure pilot competencies and skills for both the USN and USMC flight students. Chief of Naval Air Training considers the NSS score to be a valid method of assessing pilot competency for the Department of the Navy's flight training program (Naval Air Training Command, 2014). The NSS is calculated

separately for each flight student who completes each phase of training (primary, intermediate, and advanced). The NSS is a normalized, cumulative score ranging from 20 to 80 and is based on training events' scores. The mean NSS is 50 with a standard deviation of 10. During all three levels of training, a NSS score greater than 50 is considered by the Navy to be above average, and a score of 60 would imply one standard deviation above average. Navy flight students completing primary training with an NSS score less than 50 are not eligible to fly pilot strike aircraft (e.g., F/A 18); Marine Corps flight students with an NSS less than 52 are not eligible to pilot Strike aircraft (Naval Air Training Command, 2014). This study focused on training times of flight students in the intermediate and advanced phases of training.

Data were collected from the CNATRA TIMS database and exported into a Microsoft Office Excel file. Flight student data were then imported into *Statistical Package for the Social Sciences Version 24 (SPSS)* for analysis purposes.

### **Data Analyses**

Descriptive statistical techniques were used to analyze the archival dataset. Specifically, missing data, essential demographic variables, and data array normality tests was conducted for reporting purposes. The mean was calculated for flight simulation hours, actual aircraft hours, and the NSS scores for both intermediate and advanced flight training students. Additionally, Cohen's *d* and Cohen's *q* were used to evaluate the magnitude of effect sizes. The alpha level of .05 was utilized as the threshold value for determining statistical significance.

In advance of comparative analyses requiring the assumption of normality, the study's data arrays were assessed for normality using the *Shapiro-Wilk* test. To address the first and

second research questions, multiple linear regression was used to determine the significant predictor(s) of the NSS scores. The independent variables were flight simulation time and actual aircraft time; the dependent variables were the NSS scores of intermediate pilot trainees and of advanced pilot trainees. Using the Fisher  $r$  to  $z$  transformation test statistic, the difference in correlations between simulation time and aircraft time and NSS was evaluated for statistical significance. Cohen's  $q$  test statistic was used to evaluate the effect size of correlations between simulation time and aircraft time. The alpha level of .05 was utilized as the threshold value for determining statistical significance.

In light of the non-normal distribution of the data related to the comparison in research question three, the *Mann-Whitney U* test was used to evaluate the statistical significance of the difference between mean ranks for training type (flight simulation time versus actual aircraft time) and training phase (intermediate and advanced). Cohen's  $d$  statistic was used to evaluate the magnitude of difference of mean ranking (effect size) in the respective comparisons. The alpha level of .05 was utilized as the threshold value for determining statistical significance.

Ancillary analyses were also conducted using *Chi-Square* to compare the intermediate and advanced training groups' mean scores on the NSS to determine whether significant differences existed. Scores on the NSS were disaggregated into three different NSS sets ( $SS \leq 50$ ,  $NSS + 1$  Standard Deviation ( $SD$ ), and  $NSS + 2 SD$ ) and then compared based on trainee group. The alpha level of .05 was utilized as the threshold value for determining statistical significance of differences.

### Results

Prior to formally addressing the research questions, preliminary analyses of the study’s data were conducted. Specifically, missing data analysis, data array normality analyses, and descriptive analyses of study variables were conducted.

Frequencies and percentages of missing data were analyzed using descriptive statistical techniques. With regard to the three essential data arrays (simulation hours, flight hours, and NSS scores), a total of nine data points of a possible 2,073 (0.43%) were identified as missing. In light of the minimal degree of missing data (< 1.0%), the researcher determined that imputation of missing data points within the essential arrays was not necessary based on Schafer’s (1999) assertion that a missing data rate of 5% or less is inconsequential.

In advance of comparative analyses requiring the assumption of normality, the study’s data arrays were assessed for normality/relative normality using the Shapiro-Wilk test.

Results of the *Shapiro-Wilk* test are depicted in Table 1.

Table 1

*Shapiro-Wilk Test Results by Training Type, Training Group, and NSS score*

Group	SIM Hours			Flight Hours			NSS		
	S-W	df	p	S-W	df	p	S-W	df	P
Intermediate <i>n</i> = 334	0.86	328	.000*	0.93	328	.000*	0.99	328	.003*
Advanced <i>n</i> = 358	0.86	357	.000*	0.83	357	.000*	0.99	357	.68 <sup>a</sup>

<sup>a</sup> *p* > .05 \**p* < .05

As seen in Table 1, only one of the six essential data arrays evaluated, Advanced Group NSS Score, was found to be normally distributed ( $p > .05$ ). As a result, analyses of non-normal data were required and are discussed in upcoming analyses.

Descriptive statistics were used to describe the study's participants and their scores on the independent and dependent variables. The results are depicted in Table 2.

Table 2

*Mean and Standard Deviations on Intermediate and Advanced Flight Students*

Group	SIM Hours			Flight Hours			NSS		
	<i>n</i>	Mean	<i>SD</i>	<i>n</i>	Mean	<i>SD</i>	<i>n</i>	Mean	<i>SD</i>
Intermediate	334	84.72	5.98	336	81.34	8.45	330	48.86	11.15
Advanced	358	24.92	3.24	358	85.64	8.94	357	50.00	10.66

Table 2 reveals that mean simulation hours for the intermediate group were considerably higher than simulation hours for the advanced group. However, mean flight hours for both training groups were similar, and the standard deviations were smaller than for simulation hours.

### Research Questions

*Q1: Which is the best predictor of the NSS scores of intermediate pilot trainees: flight simulation time or actual aircraft time?*

Research question 1 was predictive in nature, involving two independent covariates. Multiple linear regression was conducted to evaluate the predictive abilities of flight simulation

training time and actual aircraft training time. Table 3 depicts the results of the statistical test for the intermediate group of pilot trainees.

Table 3

*Prediction of NSS by Training Type of Intermediate Group (n=334)*

Model	<i>B</i>	Standard Error	Standardized $\beta$
Intercept	100.26	9.39	
Simulation Training	-0.02	0.12	-.01
Aircraft Training	-0.61	0.12	-.32***

\*\*\* $p < .001$

The results indicated that actual aircraft training time was a strong, significant ( $p < .001$ ) predictor of NSS scores of intermediate pilot trainees. Flight simulation training time was not a significant predictor of NSS scores of intermediate pilot trainees. The regression weight ( $\beta = -0.61$ ) indicates that for every one unit increase in aircraft training time there is a -0.61 decrease in the NSS score. In other words, for every 1 hour increase in aircraft training time, there is a -0.61 decrease in the NSS score. The -0.61 decrease in the NSS score could possibly point to negative transfer from simulation training or the increased complexity of training in the actual aircraft. Additionally, the -0.61 could simply be related to the student pilot's learning curve transition from simulated flight to real-flight in the actual T-45 aircraft.

The significant, predictive effect for actual aircraft training method in this sample is considered medium ( $ES = .12$ ) (Field, 2013). Using the Fisher  $r$  to  $z$  transformation test statistic, the difference in correlations between flight simulation time, actual aircraft time, and NSS scores was statistically significant ( $z = -4.10$ ;  $p < .001$ ). Using Cohen  $q$  to evaluate the comparative relational effect between the two training methods, the magnitude of effect (favoring actual aircraft training) was considered medium (Cohen's  $q = 0.32$ ; Cohen, 1988).



*Q2: Which is the best predictor of the NSS scores of advanced pilot trainees: flight simulation time or actual aircraft time?*

Research question 2 was predictive in nature, involving two independent covariates. Multiple linear regression was used to evaluate the predictive abilities of both flight simulation training time and actual aircraft training time. Table 4 depicts the results of the analysis.

Table 4

*Prediction of NSS by Training Type of Advanced Group (n=358)*

<b>Model</b>	<b>B</b>	<b>Standard Error</b>	<b>Standardized <math>\beta</math></b>
Intercept	63.32	6.15	
Simulation Training	0.13	0.23	.04
Aircraft Training	0.19	0.08	.15*

\* $p < .05$

Aircraft training time was a statistically significant predictor ( $p < .05$ ) of NSS scores of advanced pilot trainees. The predictive effect for the aircraft training method was considered small ( $ES = .02$ ) (Field, 2013). Using the Fisher  $r$  to  $z$  transformation test statistic, the difference in correlations between flight simulation time, actual aircraft time, and advanced pilots' NSS scores was not statistically significant ( $z = 1.48$ ;  $p = .07$ ). Using the Cohen  $q$  statistic to evaluate the comparative relational effect between the two training methods, the magnitude of effect (favoring aircraft training) was considered small (Cohen's  $q = 0.11$ ) (Cohen, 1988). The regression weight ( $\beta = 0.19$ ) means that for every one unit increase in aircraft training time there was a 0.19 increase in the NSS score. In other words, for every 1-hour increase in aircraft training time, there was a 0.19 increase in the NSS score. The results indicated that actual flight time of advanced pilots was a statistically significant predictor of

NSS scores in this sample.

*Q3: Are there any significant differences between the intermediate and advanced pilot trainees' flight simulation time and actual aircraft time?*

In light of the non-normal distribution of the data arrays related to the comparison inherent in Research question 3, a non-parametric test statistic alternative to the *t*-test of independent means was utilized for analytical purposes. The Mann-Whitney U test was used to determine whether significant differences existed between mean ranks of training type (flight simulation time and actual aircraft time) and training groups (intermediate and advanced). Cohen's *d* statistic was used to evaluate the relative magnitude of difference of mean ranks (effect size) in the respective comparisons. The results of the analyses are depicted in Table 5.

Table 5

*Mann-Whitney U Test and Cohen's d of Training Type and Training Group*

<b>Comparison</b>	<b><i>n</i></b>	<b>Mean Rank</b>	<b><i>Z</i></b>	<b><i>p</i></b>	<b><i>d</i></b>
Intermediate SIM Hours	334	525.50	22.75	.000***	3.45 <sup>a</sup>
Advanced SIM Hours	358	179.50			
Intermediate Aircraft Hours	336	278.65	8.77	.000***	0.71
Advanced Aircraft Hours	358	412.12			

\*\*\**p* < .001    <sup>a</sup> Cohen's *d* = very large effect size (*d* ≥ 1.30)

The mean rankings of flight simulation training hours of intermediate and advanced pilot trainees were significantly different. The intermediate pilot trainees utilized simulation

training significantly more often ( $p < .001$ ) than advanced pilot trainees, and the magnitude of effect as measured by *Cohen's d* was considered very large ( $d > 1.30$ ).

With regard to actual aircraft training time, the mean rankings between intermediate and advanced trainees were also significantly different ( $p < .01$ ). Advanced pilot trainees utilized actual aircraft time significantly more often than intermediate pilot trainees, and the magnitude of effect (effect size) in this comparison approached large ( $d = .80$ ). These results point to the greater use of simulation time at the intermediate level of pilot training than at the advanced level. The differences in simulation and flight training mean rankings of intermediate and advanced pilot trainees were significantly different.

### **Ancillary Results**

Based on the significant findings of the intermediate and advanced groups favoring actual aircraft training time in Research Questions 1 and 2, additional analyses were conducted to compare the intermediate and advanced training groups' scores on the NSS to determine whether significant differences existed. Scores on the NSS were disaggregated into 3 different NSS sets: ( $NSS \leq 50$  (the mean score for completers),  $NSS + 1$  Standard Deviation (*SD*), and  $NSS + 2$  *SD*). The sets were then compared based on trainee group. Table 6 depicts the results of the comparisons of the two training groups using the Chi-Square test for the NSS category of  $NSS \leq 50$ .

Table 6

*Chi-Square Comparison of NSS Score  $\leq 50$  by Pilot Training Group*

<b>Group</b>	<b>NSS <math>\leq 50</math> (n)</b>	<b>NSS <math>\leq 50</math> (%)</b>
Intermediate	140	42.4
Advanced*	182	51.0

$$*x^2 (1) = 5.94 \quad p = .03$$

The results revealed that the two training groups in this comparison were significantly different ( $p < .05$ ) in favor of the advanced group. In other words, advanced pilot trainees were significantly more likely than intermediate pilot trainees to score at the NSS mean score of 50 or below.

Tables 7 and 8 depict the results of comparisons of NSS scores of the intermediate and advanced training groups.

Table 7

*Chi-Square Comparison of NSS Score  $\leq 60$  (+1 SD) by Pilot Training Group*

<b>Group</b>	<b>NSS <math>\leq 60</math> (+1 SD) (n)</b>	<b>NSS <math>\leq 60</math> (+1 SD) (%)</b>
Intermediate	49	14.8
Advanced	55	15.4

$$x^2 (1) = 0.04 \quad p = .84$$

Table 8

*Chi-Square Comparison of NSS Score  $\leq 70$  (+2 SD) by Pilot Training Group*

<b>Group</b>	<b>NSS <math>\leq 70</math> (+2 SD) (n)</b>	<b>NSS <math>\leq 70</math> (+2 SD) (%)</b>
Intermediate	17	5.2
Advanced	10	2.8

$$x^2 (1) = 2.51 \quad p = .11$$

Tables 7 and 8 reveal that there were no significant differences between intermediate and advanced pilot trainees on the  $NSS + 1 SD$  or on the  $NSS + 2 SD$  scores. No statistical differences were observed between intermediate and advanced flight students who scored above the mean score of 50 on the NSS.

### **Summary of Results**

Actual aircraft training time was a significant predictor of NSS scores for both intermediate and advanced pilot trainees. In addition, there were significant differences between mean flight simulation training times and mean actual aircraft times of intermediate and advanced pilot trainees in favor of actual aircraft training time. Significant differences between intermediate and advanced pilot trainees were observed for  $NSS \leq 50$ , but no significant differences were observed for  $NSS + 1 SD$  and  $NSS + 2 SD$ .

### **Discussion**

The results for research questions one, two, and three were consistent with literature based on Bloom's (1956) comprehensive model for higher-order thinking and the pilot training tasks involved in the US Navy's T-45C intermediate and advanced training phases. Intermediate military 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). These tasks involve the knowledge, comprehension, application, and analysis levels of Bloom's adapted model for pilots theorized by the researcher. Advanced military pilot training consists of operational navigation, tactical maneuvering, weapons delivery, advanced flight formations, low level flying, and aircraft carrier qualification (Naval Air Training Command, 2014). Realistic scenario-based training is demanded in the advanced training phase compared to the intermediate training phase. The

advanced phase of US Navy flight training heavily involves the analysis, synthesis, and evaluation levels of the Bloom model.

Actual aircraft training time was a significant predictor of NSS scores for both intermediate and advanced training phases. However, the magnitude of effect favoring actual aircraft training for the intermediate training phase was considered medium (Cohen's  $q = 0.32$ ) and the magnitude of effect favoring actual aircraft training in the advanced training phase was considered small (Cohen's  $q = 0.11$ ).

The results of research question three revealed that advanced pilot trainees spent significantly more training time in actual aircraft than intermediate pilots. The magnitude of effect of the comparison was large ( $d = .80$ ), which was not surprising since the advanced training phase includes more difficult tasks than the intermediate training phase. These results align with those of Betts et al. (2010) who found that pilots ranked Close Air Support (CAS) or strike as the most critical mission training tasks for deployed military pilots. Close air support and strike tasks used in combat and other mission-critical scenarios involve a great deal of rehearsal to achieve optimal functioning, and the margin for error is quite small.

Ancillary analyses of the current study disaggregated NSS scores into three different sets (NSS  $\leq 50$ , NSS +1 Standard Deviation ( $SD$ ), and NSS + 2  $SD$ ) and then compared the NSS scores based on intermediate or advanced trainee group. A NSS of 50 or below is considered below average and not passing. The results of the ancillary analyses indicated that the difference between intermediate and advanced pilots at the NSS cutoff of 50 or less was significant ( $p = .03$ ). Advanced pilot trainees were significantly more likely than intermediate pilot trainees to score at the NSS mean of 50 or below. Again, the results favoring advanced pilot trainees is not surprising since the advanced phase of pilot training is more difficult than

intermediate training.

As a result, more flight students in the advanced phase earned a NSS of 50 or below; a score below 50 is the Navy's cutoff score for not passing each level of flight training. When the NSS scores were one or two standard deviations above the mean, there were no significant differences between intermediate and advanced pilot trainees on the NSS. However, the numbers and percentages of pilot trainees who scored one or two standard deviations above the mean on the NSS were small, reflecting the inherent difficulty of the tasks and pilot execution required to earn a score above the mean.

Whatever the optimal ratios of flight simulation time to actual aircraft time, the review of literature points to the critical need for simulators that are designed for maximum fidelity in order to contribute to pilot competence (Povenmire & Roscoe, 1972). The RAND study conducted by Schank et al. (2002) found that F/A-18 simulators were not used or widely accepted by pilots due to low fidelity; however, P-3C simulators were used more often because the P-3C flight simulators more closely replicated the actual P-3C flight environment.

Flight simulation has definite value in flight training. According to a study conducted by Koglbauer et al. (2016), flight students' aircraft performance scores were significantly higher on a post-test ( $p < .01$ ) after using a flight simulator. The authors concluded that a combination of actual flight training and flight simulator training would have positive effects on pilots' competence.

Conducting simulator flights prior to actual flights reinforces positive transfer of skills. Roof (1996) found that significant cost savings, a critical concern for military budgets, could be realized when military training events were flown in a flight simulator more than 20 times. These findings were also uncovered at a time when flight simulations were designed

for a personal computer and were not especially sophisticated compared to today's flight simulators. Roof also concluded in his 1996 study that certain flight tasks could be effectively moved to simulators without compromising pilot training; however, he was quick to point out that critical "must-fly" tasks he identified, mapped, and carried out in actual aircraft training.

Schank et al. (2002) also suggested that independent of simulation accuracy or fidelity, some training events such as tasks requiring essential physiological cues are best flown in an actual aircraft. The Training and Readiness (T&R) matrices developed by the military, combined with the "must-fly" criteria developed by Roof (1996), provide important design information to guide the development of high-fidelity flight simulations.

### **Recommendations for Future Research**

This study could be replicated using other military aircraft types and simulators, as well as for commercial aviation platforms. Additionally, the study did not assess individual training event scores, but evaluated only overall pilot NSS scores of intermediate and advanced military pilot trainees. Additional studies could focus on comparing pilot trainees' scores on individual training tasks to determine whether a specific training task score could be predicted based on flight simulation time or actual aircraft training time. This type of study might advance the research evidence needed to determine the optimal ratios of simulation time versus aircraft time for military pilots without compromising pilot readiness and competence.

The researcher's observations of pilot training and interviews with flight instructors at U.S. Navy Training Wing TWO uncovered other recommendations for future research regarding the use of simulators in pilot training. The instructors and pilots recommended



improvement of flight simulation fidelity, particularly in the intermediate training phase; the T-45C flight simulator plays an important role in familiarizing the intermediate pilot with the cockpit hardware and aircraft systems' functionality, and designers need to continue to improve and assess the quality of the simulations. The interviewees also suggested improvement of T-45C flight simulator visuals to prepare the advanced pilot trainees' effectiveness during formation flying, tactics, and weapons delivery—all critical tasks in combat situations. Also suggested was the inclusion of Virtual Reality (VR) and Augmented Reality (AR) in the advanced phases of flight simulator training to make visuals outside the cockpit more realistic. The interviewees also suggested the need for more research on new methods to improve de-briefs after simulator or flight training events; the pilots specifically recommended more research on the possibility of 3-dimensional capabilities to help de-brief specific training scenarios. Research related to these specific areas of need will advance military pilot training in valuable ways.

Based on the review of literature, flight training programs should encourage greater simulator participation by pilots at all stages of their training and development and make better use of simulators as a complement to actual aircraft training, but not as a substitute for actual aircraft training. Roof (1996) concluded that substantial cost savings could be realized by moving certain tasks, excluding “must-fly” tasks, from live aircraft training to a simulator with no degradation in training or safety. These conclusions require further study and analysis.

Future research should examine methodologies and evaluation tools that could be used to conduct flight simulation versus actual aircraft military flight training experiments. For example, a thorough analysis of the Navy's T&R Matrices for aircraft types should be

carefully reviewed. Using the analyses and experimental results, tasks from the actual aircraft could be mapped and built into the design of a flight simulator. Mapping essential aircraft training tasks to simulator devices is an important step in ensuring that operational readiness is not compromised.

Simulation fidelity remains a concern; based on Bloom's cognitive model, higher-order thinking is critical when simulating flight as well as when flying an aircraft. Even with advances in electronic technologies such as high-definition and faster computer processing, simulation models should incorporate higher fidelity to support more training tasks. Virtual reality and augmented reality are advanced technologies that have the potential to be highly effective in flight simulation training. For example, AR may add value both in cost savings and fidelity to current simulators without the extensive need for physical or software flight simulator changes. This type of research will undoubtedly prove highly useful to both military and commercial pilot training programs.

More research should be conducted on pilots' views on flight simulation and the concern that many pilots do not take simulation practice as seriously as actual aircraft flight (Schank et al., 2002). Flight instructors should be well trained in the use of simulations and could incorporate a method that holds pilots accountable for simulation training. Perhaps the simulations can be timed to more realistically emulate rapid and error-free decision-making required of every pilot. Flight instructors could require pilots to repeat tasks in the simulator until the task is executed perfectly. The Department of the Navy may wish to consider increasing the required number of hours spent in simulators as their design elements improve. As the need arises to move more aircraft training tasks into the simulator, the accountability of both pilots and instructors is vitally important not only for learning, but also for flight safety.

Research designed to address these important recommendations will provide more evidence regarding the critical design and pilot usage elements that make simulations effective.

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