Comparing the Accuracy of Performing Digital and Paper Checklists Using a Feedback Package during Normal Workload Conditions in Simulated Flight

William Gene Rantz
Western Michigan University

Follow this and additional works at: http://scholarworks.wmich.edu/dissertations

Part of the Cognition and Perception Commons, Cognitive Psychology Commons, and the Industrial and Organizational Psychology Commons

Recommended Citation
http://scholarworks.wmich.edu/dissertations/676

This Dissertation—Open Access is brought to you for free and open access by the Graduate College at ScholarWorks at WMU. It has been accepted for inclusion in Dissertations by an authorized administrator of ScholarWorks at WMU. For more information, please contact maira.bundza@wmich.edu.
COMPARING THE ACCURACY OF PERFORMING DIGITAL AND PAPER CHECKLISTS USING A FEEDBACK PACKAGE DURING NORMAL WORKLOAD CONDITIONS IN SIMULATED FLIGHT

by

William Gene Rantz

A Dissertation
Submitted to the Faculty of The Graduate College in partial fulfillment of the requirements for the Degree of Doctor of Philosophy Department of Psychology Advisor: Dr. Ron Van Houten

Western Michigan University Kalamazoo, Michigan April 2009
INFORMATION TO USERS

The quality of this reproduction is dependent upon the quality of the copy submitted. Broken or indistinct print, colored or poor quality illustrations and photographs, print bleed-through, substandard margins, and improper alignment can adversely affect reproduction.

In the unlikely event that the author did not send a complete manuscript and there are missing pages, these will be noted. Also, if unauthorized copyright material had to be removed, a note will indicate the deletion.

UMI Microform 3354079
Copyright 2009 by ProQuest LLC.
All rights reserved. This microform edition is protected against unauthorized copying under Title 17, United States Code.
ACKNOWLEDGMENTS

I'd like to express my gratitude to the following individuals: To Dr. Ron Van Houten, my graduate committee chair, who spent countless hours guiding, inspiring, and reviewing my work. I would also like to thank my other graduate advisors, Dr. Brad Huitema, Dr. Al Poling, and Dr. Vladimir Risukhin, for keeping me balanced in the priorities of inferential statistics, experimental design, and developing ideas to formulate the scope and reach of this study. I will always remember and appreciate their sage advice. I must also express thanks to my former graduate advisor, Alyce Dickinson, for helping guide much of the foundation this study builds upon. Notable thanks to Gaurav Dave for his technical support in the experimentation laboratory and especially the observation station used for data collection. Great appreciation goes to Gil Sinclair for arranging simulator resources required to conduct the study. I need to especially thank my student research assistants, Bryan Hilton and Jared Neterer, for their hard work during simulator set up, validation, and data collection. Finally, I give thanks for the support from all my family members and especially my two sons, Garrett and Gavin, who have been patient with me through this long process.

William Gene Rantz
TABLE OF CONTENTS

ACKNOWLEDGMENTS ................................................................. ii
LIST OF TABLES ........................................................................ vi
LIST OF FIGURES ..................................................................... vii

CHAPTER

I. INTRODUCTION ..................................................................... 1
II. METHOD ............................................................................... 21
    Participants ........................................................................... 21
    Setting .................................................................................. 22
    Apparatus ............................................................................ 23
        Frasca 241, Cirrus SR20 FTD ............................................ 23
    Flight Patterns ...................................................................... 25
    The Flight Checklists .......................................................... 26
    Observation Equipment ....................................................... 26
    Dependent Variables .......................................................... 28
    Independent Variable .......................................................... 30
    Experimental Design ........................................................... 31
    Procedures ........................................................................... 32
    Recruitment ......................................................................... 32
    Informed Consent Process and Screening ............................ 32
Table of Contents—Continued

CHAPTER

Baseline ................................................................. 33
Post-Flight Checklist Feedback ................................. 34
Reversal ................................................................. 35
60–90 Day Post-Test Probe ...................................... 35
Debriefing ............................................................... 35
Data Analysis ......................................................... 35
Inter-Observer Agreement (IOA) .............................. 39
Independent Variable Integrity .............................. 39

III. RESULTS ................................................................ 41

IV. DISCUSSION ....................................................... 69

REFERENCES .......................................................... 81

APPENDICES

A. Participant Eligibility Questionnaire ...................... 90
B. Recruitment Flyer ................................................. 92
C. Recruitment Script ................................................ 94
D. Informed Consent Form ......................................... 96
E. Human Subjects Institutional Review Board Letter of Approval ........................................ 99
F. Technical Flight Pattern Parameters and Narration ........................................ 101
G. Flight Training Device Simulator Scenario Set Up ......................................... 114
H. Meteorological Terminal Aviation Weather Reports (METARS) and Automatic Terminal Information Service (ATIS) ......................................... 121
Table of Contents—Continued

APPENDICES

I. Flight Checklist ................................................................. 123
J. Observer's Checklist Behavior Protocol ................................. 126
K. Observer's Checklist Form .................................................. 130
L. Digital and Paper Checklist Pre-flight Instructional Script ........ 133
M. Technical Flight Pattern Diagram ....................................... 140
N. Post-flight Technical Briefing Script .................................... 142
O. Checklist Feedback Script and Graphs ................................. 144
P. 60–90 Day Post-Test Research Probe Checklist Survey ............ 147
Q. Debriefing Script ............................................................. 152
R. Statistical Analysis ........................................................... 154
S. Consolidated WMU Curriculum Checklist Procedures ............. 157
LIST OF TABLES

1. Percentage of Paper Checklist Baseline Trials Participants Performed Items in Error ................................................................. 52
2. Percentage of Digital Checklist Baseline Trials Participants Performed Items in Error .................................................................................. 56
3. Percentage of Items Omitted in Paper Checklist Baseline........................................................................................................ 60
4. Percentage of Items Omitted in Digital Checklist Baseline ........................................................................................................ 65
LIST OF FIGURES

1. Frasca 241, Cirrus SR20 Flight Training Device ........................................ 24
2. Graphic Instructor Station ............................................................................ 24
3. Avidyne Entegra EX5000C, Multi Functional Display with Digital Checklist ............................................. 27
4. Paper Checklist .......................................................................................... 27
5. Observation Equipment Station ................................................................. 28
6. Total Number of Paper and Digital Checklist Items Completed Correctly ...... 42
7. Percentage of Paper Checklist Errors for Each Condition Per Participant ...... 48
8. Percentage of Digital Checklist Errors for Each Condition Per Participant ...... 49
9. Percentage of Paper Checklist Items Omitted During Each Experimental Phase ........................................................................................................ 59
10. Percentage of Digital Checklist Items Omitted During Each Experimental Phase ................................................................................................. 63
11. Average Percent Paper Checklist Segment Timing Errors Per Phase .......... 68
12. Average Percent of Digital Segment Timing Errors Per Phase ................. 68
CHAPTER I

INTRODUCTION

The College of Aviation (COA) at Western Michigan University (WMU) has been granting baccalaureate degrees in aviation since 1939. During this long history, flight safety, especially in the form of risk management, has been an important teaching objective. Understanding the knowledge and behaviors required to effectively manage risk are an integral component of the professional pilot training curriculum (Western Michigan University: Professional Flight Training Program, 2004). The aviation industry demands that professional pilot graduates understand the inherent risks associated with flight operations and that individuals must continue to practice comprehensive preflight planning, attention to detail, procedural discipline, and run the checklists as printed (Wilson, 2008). Managing risks on the flight deck of any aircraft demands that pilots perform tasks in a timely, sequential, and correct manner. Consequences can be severe when seemingly simple tasks are interrupted, delayed, omitted, or completed incorrectly. Checklists are used by the flight crews to minimize errors in operational tasks. Although correct checklist use is an essential element of safety practice, it has a vague history and often nonstandard approaches to its use.

The origin of the first aviation checklist is difficult to pinpoint. Pope (1991) recalls, "As far back as the 1920's, U.S. Air Service airplanes had a checklist item that read 'Do not trust any altitude instrument'" (p. 1). Turner (2001) emphasized checklist
importance by recounting a 1935 fatal crash of Major Ployer Peter Hill at Wright Field in Dayton, Ohio. Major Hill was flying the prototype of the famous Boeing B-17 bomber of World War II and crashed shortly after take-off. The post-crash investigation revealed that the pilot had failed to perform a standard, yet critical, pre-flight task of removing wind gust locks to allow the control surfaces to function.

If a professional military-aircraft test pilot could forget such a critical step in their takeoff preparations, correctly reasoned Boeing and Army crash investigators, then any “line” aviator could too. The best solution was to make a list of all the things a pilot needed to do to prepare for takeoff and train the pilot to use the list to avoid missing anything. From there it was a quick leap to creating checklists for all phases of flight, not just for takeoff, and to require pilots to use the checklists. (Turner, 2001, p. 7)

As aircraft became more complicated, early checklists were developed to recall the process for modifying aircraft configuration. Checklist use was a foundation for verifying aircraft configuration, coordinating and enhancing crew performance, and providing the crew a quality control tool (Degani & Wiener, 1993).

The extent to which a checklist may be used during each flight can be dependent on many variables. The various “philosophies of use” or the “corporate culture” of the operator influence the method, design, and policies of using the checklist (Degani & Wiener, 1993; Federal Aviation Administration [FAA], 2000; Turner & Huntley, 1991). However, pilot behavior using checklists can be problematic.

With the increasing complexity of aircraft, the ability of the pilot(s) to accomplish all the necessary items for safety without some type of checklist was diminished, and the advent of larger and multiengine aircraft, a more formal checklist became necessary to assure completion of the multitude of items to be checked. However, as aircraft grew larger and more complex, as checklists grew in size, and as traffic increased, interference to checklist use also increased, with resultant increases in the probability that errors would be made in the use of checklists and checklist-driven procedures. Aviation Safety Reporting System (ASRS) reports, data in National Transportation Safety Board (NTSB) files, pilot reports and direct
cockpit observation indicate that checklists can be misused easily and are sometimes even ignored. (Turner & Huntley, 1991, p. 1)

Checklists organize tasks into sequences of actions that configure the aircraft and prepare the crew for evolving events. "The major function of the checklist is to ensure the crew will properly configure the plane for flight, and maintain this level of quality throughout the flight, and in every flight" (Degani & Wiener, 1990, p. 7). Emergency checklists are also used during nonstandard or emergency conditions. These checklists contain the essential steps for the particular emergency condition. Most emergency situations require timely action and many emergency checklists tasks are memorized (Gross, 1995). This rule-based behavior allows a practiced crew to perform the tasks in a deliberate and timely manner. However, all memorized emergency tasks should minimize the memory load on the pilots and, once the memorized tasks are complete, be confirmed against the appropriate checklist. (Burian, Barshi, & Dismukes, 1995; Civil Aviation Authority, 2002; Degani & Wiener, 1990; Pope, 1991; Turner et al., 1991).

Depending on the particular aircraft and how the manufacturer designed or the operator modified the procedures, some checklists can be very long with many items that cannot be reliably memorized by the pilot. Degani (2002) examined some of those human limitations, stating:

You see, there is a certain limit to how much a human, even the most conscientious one, can recall. We ask pilots to remember, flawlessly, many sets of procedure items, numbers, and sequences. At some point we hit a limitation of our memory abilities. And this is where an aid, like a checklist, comes in handy. (p. 6)

Aviation checklists commonly follow the sequential timeline of a normal flight and have (a) pre-flight segment which determines airworthiness of the aircraft, insuring approved weight and balance, navigation capacity, and systems operations; (b) takeoff
and climb segment to confirm proper secondary control surface settings on the aircraft, correct airspeed and climb angle; (c) cruise segment to establish proper engine performance, aircraft configuration, and altitude; (d) arrival segment which establishes the instrument approach the crew will use and prepares passengers for landing, descent configuration and airspeeds; and (e) landing and shut down segment to ensure appropriate aircraft systems transition to ground operations. While these are general descriptions, checklists can appear quite different between air carriers and aircraft (Degani & Wiener, 1994; Federal Aviation Administration, 1995).

Checklist devices or methods of presentations are described as paper, laminated paper/card, scroll paper, electromechanical, vocal, and computer-aided/electronic. The most common method of presentation for checklists is the laminated paper/card (Degani & Wiener, 1994; Turner & Huntley, 1991). While this statement may be true for all general aviation aircraft manufactured in the last one hundred years, the rise of lower cost computing hardware and software is rapidly changing how newer aircraft present checklists (Boorman, 2001a, 2001b). Within the last two decades, electronic or digital checklists have appeared on many regional and major airline flight decks, and some general aviation aircraft. These digital checklists are integrated into the new aircraft panel by the manufacturer with software designed to exclude many paper checklist errors observed in past studies (Arkell, 2006; Boorman, 2001a, 2001b). In Degani and Wiener (1990), they found

the current paper checklists have a number of design weaknesses. These problems included the lack of a pointer to the current checklist item, the inability to mark a skipped item, and difficulties in getting lost while switching between checklists. The field study on paper checklists identified a number of problems with paper checklists that may be alleviated with the use of an electronic checklist.
Boorman (2001a), working for the Boeing Commercial Airplane Division, conducted an investigation to validate the advantages of the Boeing B-777 electronic checklist (actually exists), electronic flight bags (postulated for study), and electronic checklist with alerting capability (postulated for study) compared to the traditional paper checklist. Boorman reviewed 81 accidents involving specific references to paper checklists as probable cause. The comparison used a list of commonly accepted error modes of the paper checklist and applied those modes when reviewing the accident data. Those modes were (a) items skipped, (b) losing place when distracted, (c) incorrect switch selected, (d) item incorrectly confirmed complete, (e) excessive psychomotor workload fumbling with paper, (f) unreadable text due to low illumination, (g) subsequent checklist accomplished before critical flight phase, and (h) all checklists omitted. While these errors are important to understand and are acknowledged in most of the literature, the assumption is a properly programmed electronic checklist should prevent these errors. During the study, each scenario was reviewed and, depending on the researcher’s interpretation of degree of checklist error involvement causing the accident, a probability of error number was assigned. The researchers posed a “what if” statement proposing, had the accident aircraft used one of three variant electronic checklists, what would the probability be of a “save” or “partial save” outcome. While all variants of the electronic checklist fared better that the paper checklist used in the accident, the summed probability value has extremely low external validity and comparing results with other studies has low or limited value. While the claim that using electronic checklists over traditional paper checklists will reduce or eliminate most paper checklist errors may be true, Boorman was concerned that without an automated alarm to alert pilots, even the
electronic checklist will not prevent omitted checklists (Boorman, 2001a, p. 5). Thus, certain errant behavior of the pilot is still a source of consternation to the human factors engineer which automation may not cure. Since Boorman’s study was a review of accident data and not an empirical study comparing the different performances resulting from different checklist presentations, its generality is limited. However Boorman states:

Significant changes in crew training, pilot demographics, airplane technology, and the air traffic environment have and will continue to take place. Will the context of checklist errors, and indeed checklists, be significantly altered in the future? An answer to this question is available: the fundamental role of checklists, to ensure that critical crew actions are accomplished at critical points in a flight, is likely to remain valid; and decreasing the chance of errors in the accomplishment of those actions will continue to benefit flight safety. (p. 6)

As avionics prices continue to decline, it is very likely more digital checklists will be installed on smaller general aviation aircraft, thereby expanding the demographics of the pilot users from airline professional to recreational novice. The future challenge is not that pilots understand that the checklist is a presentation method by which flight deck safety is enhanced. The challenge seems to be recognizing the absence of stimulus control in a varying environment may result in unpredictable checklist use.

Many aviation experts have addressed the significance and purpose of the checklist as well as the procedures and policies that surround checklist use (Adamski & Stahl, 1997; Degani, 1992, 2002; Degani & Wiener 1990, 1993; Federal Aviation Administration, 1995, 2000; Gross, 1995; Turner, 2001; Turner & Huntley, 1991). Even with the extensive ASRA reports, flight deck observations, and pilot questionnaires, the incorrect use of flight checklists is often cited as the probable cause or a contributing factor to a large number of crashes (Degani, 1992, 2002; Degani & Wiener, 1990, 1993; Diez, Boehm-Davis, & Holt, 2003; Turner, 2001; Turner & Huntley, 1991). Similarly,

More evidence that the flight crews improperly used checklist came from survey and observational studies by Lautmann and Gallimore (1987). In a survey study funded by the Boeing Aircraft Company, Lautmann and Gallimore analyzed twelve airlines accident and incident reports. They concluded that a significant number of those incidence where attributed to errors of the crew using the checklist.

In an early quantitative study, Diez, Boehm-Davis, and Holt (2003) observed the crew behavior of annunciating each (memorized-based) checklist item as required by the airlines standard operating procedures. During 43 revenue-generating flights, in medium range and regional jet aircraft, crews in the medium range jets were less likely to annunciate checklist items than those crews in regional jet operations (74% vs. 84% items annunciated). They also discovered that particular checklist segments were annunciated more than other segments. The cruise segment was the lowest with only 54% of the checklist items vocalized. The highest vocalizations rates were the In-range (near airport) segment with 85% vocalized and the Before-Landing segment with 87% annunciated. Results of this study may not generalize to other airlines that use paper or electronic checklists. The first limitation concerns observations being taken at only one airline where the standard operating procedures required checklist items to be memorized and confirmed by the other crewmember through annunciating each item. The second
limitation, while the observers counted any nonvocalization of a checklist item as an error, the item may have been completed correctly in silence and yet unconfirmed.

In an effort to identify whether crew coordination concepts, including checklist use taught during training transferred to line operations, Delta Airlines and The University of Texas Human Factors Research Project (UTHFRP) formed a collaborative research project. With funding from the National Aeronautics and Space Administration (NASA), the UTHFRP formed an observational audit method in an attempt to capture crew performance in its natural environment (Helmreich, Butler, Taggart, & Wilhelm, 1994; Klinect, 2005). Since its inception, the Line Operations Safety Audit (LOSA) has been used to collect thousands of domestic and international observations of flight crews (Helmreich, Klinect, Wilhelm, & Jones, 1999; Helmreich, Wilhelm, Klinect, & Merritt, 2001; Klinect, Murray, Merritt, & Helmreich, 2003).

In one study, LOSAAs were administered at three airlines with 184 flight crews on 314 flight segments (Helmreich et al., 2001; Klinect et al., 2003). LOSA errors were classified into five categories: (1) intentional noncompliance errors, (2) procedural errors, (3) communication errors, (4) proficiency errors, and (5) operational decision errors. Improper use of the checklist, such as doing the checklist from memory or incomplete or omitted items, was recorded as a rule compliance error. Seventy-three percent of the flight crews committed errors (Klinect et al., 2003). The number of errors ranged from 0 to 14 per flight, with an average of 2. Rule-compliance errors were the most frequently occurring errors, accounting for 53% of all errors (Helmreich, n.d.; Helmreich et al., 2001; Klinect et al., 2003). Checklist errors constituted the highest number of errors in this category. What they discovered was large and significant variability in crew
performance. Intentional noncompliance, of which checklist performance is included, between fleets of different aircraft within one particular airline was quite variable. Conventional technology (analog instrumented) aircraft with a 3-person crew had the lowest intentional noncompliance at 17% as compared with the highest intentional noncompliance of 53% observed in the conventional technology, 2-person crew. Of two fleets of advanced technology aircraft, fleet #1 had a 40% intentional noncompliance rate, while fleet #2 had a 30% intentional noncompliance rate. Helmreich (n.d.) and Klinect, Helmreich, and Wilhelm (1999) proceed to detail some major problem areas. While they did not provide data relating to the percentage of checklist errors within each intentional, noncompliance category, per fleet, they do summarize the most frequent classification of errors within the study. Management of automation systems accounted for the highest number of total errors at 31%. “The second highest classification (24%) was checklist errors such as nonstandard terminology, procedural errors, performance from memory, and failure to use required challenge and response methods” (Helmreich, n.d., p. 7). While the study was not specific regarding what type of checklist presentation was given to the crew, it can be assumed there was a mix of paper and electronic checklists.

During many accident investigations, a significant contributing cause was the crew having difficulty locating and retrieving time critical emergency information (Flight Safety Focus, 1985). Shamo, Dror, and Degani (1998, 1999) conducted a study in two phases examining the efficacy of a digitally formatted Integrated Crew Information System (ICIS). The ICIS digitally provides crew support in normal, non-normal checklist procedures, performance data, flight planning, and electronic charts. While this study did not focus on specific checklist use, it did demonstrate a task performance comparison
between paper checklist presentation and digital checklist presentation methods. Phase I compared the ICIS with traditional paper manuals using 72 captains and first officers in a Boeing 747-200 full motion simulator. Crews were asked to fly specific scenarios from take-off to landing, requiring performance calculations and multiple normal and non-normal checklist use. Participants were randomly assigned to two experimental conditions. The control group performed the scenarios using paper procedures (checklists) and manuals. The experimental group performed the same scenarios using the digital checklist and manuals (ICIS). An independent observer recorded crew behavior and error rate, including the severity of each error. Crew error was classified into three types. Type I error was deemed minor with a low probability of consequences. “Examples of Type I crew errors included the failure to declare a normal checklist complete, or starting a normal checklist without waiting for the captain’s command” (p. 5). Type II error was termed moderately severe and had a stronger potential for consequences. “Examples of Type II crew errors include declaring an emergency checklist complete without completing the clean-up items” (p. 5). Type III error was coined a major error and had significant and direct negative impact on the flight. “Examples of Type III errors include calculating an incorrect pitch attitude (for the Two Engine go-around maneuver), or skipping the landing check entirely” (p. 5). Phase one of the study found 144 type I errors, with 85 errors using the paper-based treatment and 59 errors using the digital-based treatment. Type II had 80 errors for crews using paper and 45 errors using the digital ICIS. Type III errors were much lower with 9 total crew errors, 8 errors with the traditional paper checklists and manual, and only one error using the digital presentation method. The researchers performed a t test analysis on the results and determined that
only type II crew errors between paper and digital presentations were statistically significant. Thus, the difference between the number of errors resulting from declaring emergency checklists complete and completing clean-up items, using a paper-based checklist and the digital checklist (ICIS) is not likely to be the result of sampling error. Phase I conclusion seems to suggest, in a simulated environment, errors will likely be lower if crews have access to digital formatted information retrieval systems as opposed to paper-based information systems. While accuracy of correctly completing specific items of the checklists was not an isolated dependent variable in this study, checklist use was included as a measured variable in the broad error types and in both treatment conditions. Pilot operating handbooks and manuals in this study would include performance graphs and reference material; these manuals would not be as efficient as presenting the same material in a searchable, digital format. Therefore, it is very likely the overall rapid searching to access specific information, other than checklist items, produced the main difference between traditional paper and digital formats and not due to the checklist itself.

Unlike the phase I study, phase II examined the efficacy of the ICIS, comparing an electronic integrated information media system with traditional paper manuals in a controlled, classroom setting. Shamo et al. (1998) selected 20 male airline crewmembers rated in the Boeing 747 to participate in the study. The dependent variable was the number of tasks completed correctly, incorrectly, and skipped, and the time to complete those tasks using both retrieval methods. Participants answered information retrieval and performance calculations from a computer-based questionnaire. Of the 350 questions, participants scored 120 correct using paper, 34 incorrect using paper, and skipped 21
questions using the paper retrieval method. Participants scored 157 correct using digital, 16 incorrect using digital, and did not skip any questions using the digital retrieval method. Interestingly, the average time to complete each task took nearly one minute longer using paper-based manuals that using digital retrieval methods. These results appear to show limited performance calculations and information retrieval tasks being performed quicker and with greater accuracy using a digital integrated information media that using a paper-based format. Once again, a $t$ test was performed resulting in a statistical significance of the percentage difference between the paper and the digital media. One problem with this study is its limited range and ability to generalize the results to paper or digital-based checklist performance on the actual flight deck or in simulation. The authors concluded that digital information retrieval method showed a fluency advantage over paper-based information retrieval method. Information retrieval is not the same behavior as checklist use. While retrieving information in a timely manner from large documents on the flight deck is an important task, it is not under the same control of environmental stimuli or rule statements as checklist performance.

A similar study conducted by Deaton, Glenn, Burke, Good, and Dorneich (2002) of CHI Systems compared an interactive electronic data retrieval system, which included digital checklist and performance chart presentations, with traditional paper checklists and manuals. This study had 10 Navy rotary-wing aircrews perform the data search in a H-60F helicopter simulator. This study measured the time required to access and retrieve information from both the paper and digital systems. The digital format had a faster means to access information over the paper manuals. As the search became more complex by using self-directed, sequential problem solving, certain scenarios benefited
either paper or digital and were cited as limitation to the study. Since this study focused on information retrieval and did not specifically measure checklist accuracy, little can be said regarding advantages or disadvantages of paper or digital checklist presentation.

Another study by Noyes and Starr (2007) examined a digital touch screen designed to present the checklist and confirm completing the items, compared to a speech channel which presents the checklist items while using speech-activated software to confirm completing each item while conducting a primary tracking task. This innovative study was conducted in a simulated environment using a generic, modern flight deck. The experimenter developed three checklists with 12 differing items for each checklist. Participants were randomly exposed to the three different checklists while alternating between each condition of speech response to “check” the item and “touch” screen response to check the item. Participants found that using the speech recognition to complete the checklist was less distractive while performing the tracking task than using the digital touch screen to complete the checklist. However, it took, on average, 10 seconds less to complete the digital checklist than using the speech recognition software.

Often time is a critical consideration when abnormal situations arise. Since no traditional paper checklist was used as a control treatment, no generalizations can be made to the degree of benefit using either digital touch or speech channel checklists on modern aircraft flight decks. An important question might be, to what extent is the traditional paper checklist presentation distracting from the tracking task, and would a paper checklist result in similar time savings?

Palmer and Degani (1991) did use a paper checklist as a control condition while comparing two versions of an electronic checklist. In their study at NASA Ames
Research Center, one version of the electronic checklist was manual-sensed, which required participants to touch the digital display to acknowledge completion of the checklist item. The second electronic checklist version automatically-sensed items completed without requiring a pilot's acknowledging touch. In this study, four 2-pilot flight crews were assigned to each of the checklist conditions. All of the crews regularly used digital presentations on the flight deck and were current flying Boeing 757, 767, 737-300/400, 747-400 aircraft. Palmer and Degani used the crew's observable behaviors to determine if covertly planted configuration problems could be identified and mitigated. These potential pitfalls were strategically placed so as to be obvious to any crew using the checklists in a proper way. The researchers also used some prompting "incentives for the crews to skip checklist items; several system malfunctions coupled with visual traffic which were timed to interrupt checklist usage; poor checklist sequence; pressures to rush checklist execution" (Palmer & Degani, 1991, p. 4). Three specific configuration probes were used to measure the effectiveness of each checklist condition: (a) anti-skid system from "On" to "Off," (b) spoilers changed from "Auto" to "Manual," and (c) stabilizer trim set to an incorrect setting. The study results demonstrated all four crews, during each checklist condition, detected the incorrect stabilizer trim. The anti-skid condition was identified by all four crews using the paper checklist; two crews using the manual-sense, digital checklist; and none of the crews using the auto-sense, digital checklist. The spoiler configuration problem was seen by three crews using the paper checklist; one of the crews using the manual-sense checklist; and none of the crews using the digital, auto-sense checklist. As Palmer and Degani suggest, "the crew responses to the three 'configuration probes' and our observations of crew behavior during the
experiment suggest that both electronic checklist designs encourage flight crews to not conduct their own checks” (p. 6). This study seems to illustrate that pilots fail to effectively monitor configuration states of the aircraft given increased automation in aircraft system reporting. Results seem to suggest that the paper checklist is superior to the two electronic checklist formats. The results might have been more valuable if they compared a normal digital checklist as another checklist condition. However, they did not compare a standard electronic checklist normally used in the airliners the crews normally flew. Since a standard digital checklist, such as providing digital checklist item presentations without the manual-sensed or automatically-sensed attributes, was not included in this study, it is difficult to generalize the study results to the effectiveness of paper compared to digital checklists on crew performance.

Although Degani and Wiener (1990) cited “social issues” as a core problem for checklist misuse, they failed to suggest any recommendations that might mitigate those behavioral factors. One interesting note they made concerned the importance of using a positive attitude regarding checklist use. Given the history and penchant of negative reporting in the aviation industry, positive reinforcement toward the use of the checklist has often been overlooked.

A recent novel study by Rantz, Dickinson, Sinclair, and Van Houten (in press) demonstrated a behavioral intervention designed to increase the appropriate use of flight checklists. Rantz et al. examined eight instrument-rated students from an accredited collegiate flight program by measuring paper checklists errors using a personal computer aviation training device (PC-ATD). Participants used a Cessna C-172 paper flight checklist while flying radar vectors from takeoff to an instrument landing system
approach and landing. During baseline, overall average checklist items were completed correctly 53% of the time. After a behavioral intervention of graphic feedback and praise for checklist improvement, performance improved to 98% items correct. Once feedback was withdrawn, performance remained high until the end of the study, with an average of 99% items correct. The importance of this study is the focus on changing the behavior of the pilots regarding checklist use.

In this study, post-flight graphic feedback and praise increased checklist compliance to near perfect levels. This is the first time this type of behavioral intervention has been used to alter checklist use. The intervention was a package and thus it is not possible to partial out the effects of the individual components. Nonetheless, the results of the current study are clear: Graphic feedback and praise can increase the accurate use of flight checklists. (Rantz et al., in press, p. 20)

From the accident reports and LOSA data, errors in using traditional paper or digital checklists have and continue to plague the industry. Given the number of aviation studies devoted to checklist use and how tasks are conducted on the flight deck, an extensive search of the aviation checklist literature revealed only one study that has examined (a) whether the traditional paper checklist could be used as a dependent variable, and (b) whether behavioral interventions could increase the appropriate use of flight checklists (Rantz et al., in press).

A comprehensive search of the Organizational Behavior Management (OBM) literature revealed paper checklists have been used as antecedents to textually present and prompt specific behavior chains (Rantz, 2005). Checklists can be constructed using a detailed task analysis of specific performances required.

Although a number of behavioral studies have employed checklists as part of or the sole independent variable in a treatment plan (Anderson, Crowell, Hantula, & Siroky, 1988; Austin, J., Weatherly, N. L., Gravina, N. E., 2005; Bacon, Fulton, &
Malott, 1982; Crowell, Anderson, Abel, & Sergio, 1988; Shier, Rae, & Austin, 2003) only a few studies have focused on checklist use as a dependent variable (Burgio, Whitman, & Reid, 1983). (Rantz et al., in press)

By clarifying tasks, which textual lists can provide, workers can reliably maximize and sequence their behavior, thereby improving performance (Anderson, Crowell, Hantula, & Siroky, 1988). If a task requires multiple responses and is presented in a complicated, unrelated sequence, checklists can reduce time and effort (Anderson, Crowell, Sponsel, Clarke, & Brence, 1982). Reliability and accuracy of performing sequential tasks can be improved by combining checklists during self-monitoring (Bacon, et al., 1982; Olson & Austin, 2001).

Textual checklists have been used in many settings (i.e., manufacturing, hotels, banks, offices, retail establishments, and restaurants) to improve a diverse array of performances, including cleaning and housekeeping tasks (Altus, Welsh, & Miller, 1991; Anderson, Crowell, Hantala, et al., 1988; Anderson, Crowell, Sponsel, et al., 1982), office tasks and bus operators (Bacon et al., 1982; Olson & Austin, 2001), banquet set-up times (LaFleur & Hyten, 1995), machine set-up time (Wittkopp, Rowan, & Poling, 1990), metal yield (Moses, Stahelski, & Knapp, 2000), end-of-shift closing tasks (Austin et al., 2005), staff-client contact time (Porterfield, Evans, & Blunden, 1985), customer service behaviors (Crowell et al., 1988), and surgical medicine (Haynes et al., 2009). “In most studies, paper checklists have been used as part of a treatment package, combined with verbal feedback, graphic feedback, goal setting and/or tangible rewards” (Rantz, 2007, p. 6). While checklist presentation has been exclusively paper in most of the pertinent literature, the effectiveness of the checklist, as part of an intervention package, presumably would be similar using a digital presentation. In one medical study, a
multifaceted intervention was used to reduce catheter-related bloodstream infections (CR-BSIs). Researchers used five intervention techniques, including the checklist, in the intensive care unit to reduce or eliminate CR-BSIs. During baseline, physicians followed infection control guidelines during 62% of the procedures. After the package intervention was given over a 4-year period, CR-BSI decreased from 11.3/1,000 catheter days to no CR-BSI infections. The researchers estimated they prevented 8 deaths, 43 catheter-related infections, and nearly $2 million in additional healthcare costs (Berenholtz et al., 2004). While this is good news for the treatment package of which the checklist is a part, it is difficult to extrapolate the extent the checklist contributed to the overall intervention effect.

Graphic feedback has been repeatedly demonstrated to be more effective than other types of feedback. In their review of feedback, Balcazar, Hopkins, and Suarez (1985-86) reported that graphic feedback produced more consistent improvements in performance than other types of feedback. Additionally, Austin et al. (2005) found that graphic feedback enhanced the effectiveness of verbal feedback, and Wilk and Redmon (1998) found that it enhanced the effectiveness of both verbal feedback and goal setting. In the current study, graphic feedback was combined with verbal praise because in another comprehensive review, Alvero, Bucklin, and Austin (2001) reported that the combination of graphic and verbal feedback was more effective than either alone, a finding that was experimentally verified by Crowell et al. (1988). (Rantz, 2007, p. 14)

Therefore, as a highly effective reinforcement method, graphic feedback was used in the current study, given the results of the previous study where graphic feedback significantly improved performance in paper checklist reading and accuracy in a simulated flight training environment (Rantz et al., in press).

In aviation, incorrect task checklist completion has been identified as the probable cause or a contributing factor to many aircraft crashes. Incorrect use of the checklist can lead to consequences that are literally fatal. In Boorman's (2001a) accident review study,
the digital checklist was cited as having specific advantages over the paper checklist. Currently, no empirical studies in either the aviation or OBM literature have compared the efficacy of the digital checklist compared with the traditional paper checklist. Due to constantly changing environmental demands, distractions, and schedule pressures, accurate completion of either paper or digital checklists during flight operations may be more demanding than many of the OBM settings previously examined. For example, in one fatal crash, the taxi checklist was not completed because of several interruptions (new weather information, checking aircraft and runway data) (Degani & Wiener, 1990). Many advanced airframe manufacturers such as Cirrus, Lancair, and Eclipse accepted recommendations from the Advanced General Aviation Transportation Experiments (AGATE) funded by NASA to make design innovations in crashworthiness, wing designs, and flight instrumentation (Fallows, 2001). Also using these recommendations Avidyne incorporated digital flight instrumentation and the digital flight checklist derivative, supplying the manufacturers with an appealing product for the emerging technologically advanced airplane market. Yet, to date, no study has examined checklist use or comparable accuracy between the paper or digital presentation methods and whether behavioral interventions can reduce errors of safety-related checklist behaviors. There are limited OBM studies examining how to increase checklist use and accuracy given graphic feedback and verbal praise. The current study filled that void by examining whether post-flight graphic feedback and verbal praise would increase the accuracy and quality of paper checklist use compared to digital checklist use by pilots during simulated flights.
This research provides a follow-up to the study by Rantz et al. (in press), which evaluated the effects of feedback and praise using a simple personal computer aviation training device and a paper checklist. The purpose of the present study is to compare and, if possible, improve the accuracy of both the traditional paper and standard digital checklists. While the aviation literature cites many studies where checklists are used, no study experimentally tests the hypothesis that using digital checklists are more accurate or complete than using paper checklists, given controlling other variables. While it has been shown in one aviation study and a few OBM studies that feedback improves paper checklist performance, no study has shown that feedback will improve digital checklist use.
CHAPTER II

METHOD

Participants

The College of Aviation at Western Michigan University offers three degree programs in aviation sciences. One program is the aviation flight science program specifically designed to educate and train future professional pilots. Upon graduation from the flight science program, students will have earned a Bachelor of Science degree, which includes a commercial pilot certificate with instrument and multiengine ratings. Six undergraduate students enrolled in the aviation flight science program at the college served as participants in this study. For inclusion in this study, participants needed a private pilot certificate and an instrument rating, and needed to have had experience using the Frasca Cirrus SR20 flight training device (FTD) or flying the actual Cirrus SR20. The experimental task in this study used the Frasca Cirrus SR20 FTD to simulate flying instrument approaches procedures. The instrument rating trains skills of using only flight instruments with no reference to outside visual aids to maintain the aircraft's proper attitude. An instrument rating also ensured each participant had a minimum of 125 flight hours as required by the FAA for this rating. A copy of the participant qualification questionnaire can be found in Appendix A.

Previous experience using the Frasca Cirrus SR20 FTD was another criterion for inclusion. Participants were required to have at least 5 hours of previous experience in the
FTD or have flown the actual aircraft in training. This minimum experience ensured the participants had previous exposure to the actual training aircraft or the training aircraft simulator. Participants reported this FTD experience and flight time on the participant qualification questionnaire in Appendix A.

Recruitment flyers were posted on the college campus and in-class announcements were used to notify potential participants of the opportunity to volunteer for the study. Participants were recruited during the first weeks of commercial pilot class. A copy of the recruitment flyer can be found in Appendix B. A copy of the in-class announcement script can be found in Appendix C. Twelve students initially offered to participate in the study. Only the final 6 had the time to commit to the study. Potential participants were asked to read a consent form (Appendix D). Only those who signed the consent document participated. The approval letter from Western Michigan University’s (WMU) Human Subjects Institutional Review Board (HSIRB) is in Appendix E.

Setting

The simulator and observation equipment was located in a hanger used exclusively by WMU to house simulators to train flight students at the Battle Creek Airport. Within the simulator area, enclosed structures restricted the vision of the participant to only the simulator. Neither the observation area nor equipment, excluding the video cameras, was visible to the participants. The experimental setting was in a Frasca 241 FTD, which simulated the flight deck of a Cirrus SR20 aircraft. The observational equipment station was set up adjacent to the Cirrus simulator unit.
Frasca 241, Cirrus SR20 FTD

The Frasca 241 FTD equipment is produced by Frasca International in Champaign, IL. The aircraft shell consists of the Cirrus aircraft forward cowling and flight deck with operating doors. The flight deck is open aft of the front seats to allow for observation during training near the instructor station (Figure 1). The graphic instructor station (GIST) software permitted the simulation of both the SR20 and the SR22 aircraft (Figure 2). The GIST displays the vertical and lateral position of the simulated aircraft, including the surrounding airports and navigation aids. All weather and location settings of the six flight plans were programmed using the GIST. The aircraft that was simulated in the current study was the Cirrus SR20. The SR20 is a technologically advanced aircraft with highly sophisticated avionics for navigation and automated flight including a Primary Flight Display (PFD) and a Multifunction Display (MFD). The Cirrus SR20 was chosen due to its increasing popularity in general aviation as well as the fact that it was the primary aircraft used in the WMU training fleet. Technical flight parameters, which depicted how well participants flew the designated flight patterns, vertically and horizontally, were recorded for each flight. The GIST simulation software automatically recorded these technical parameters and enabled them to be printed for technical feedback.
Figure 1. Frasca 241, Cirrus SR20 Flight Training Device

Figure 2. Graphic Instructor Station
There were six different flight patterns that were programmed to be flown during simulation sessions (see Appendix F). Each flight pattern was divided into eight segments: (a) before takeoff, (b) normal takeoff, (c) climb, (d) cruise, (e) descent, (f) before landing, (g) after landing, and (h) shutdown. Each segment corresponds to the eight checklist segments used for each radar vectored instrument approach flight. Each flight pattern took approximately 20-25 minutes to complete. To realistically simulate actual instrument approach and ensure that the each trial was conducted in a consistent way across participants, the experimenter provided scripted air traffic control radar vectors instruction throughout each flight trial. These instructions were transmitted using integrated headsets used by both the observer and the participant. Included along with the instructions are specific flight altitudes, headings and instructions for the flight patterns, and scripts for both the experimenter (i.e., the air traffic control instructions) and expected pilot responses. To ensure consistent environmental settings, the FTD was programmed with specific weather conditions corresponding to each of the six flight patterns. This programming provision controlled external flight variables such as visibility, cloud ceilings, temperature, fuel load, and airport visual effects (Appendix G). Each participant had access to the programmed weather conditions for each flight pattern as shown in Appendix H. This information was given to the individual prior to takeoff in the form of a normal local meteorological terminal aviation weather report (METAR) and the local airport terminal information service (ATIS).
The Flight Checklists

The digital and paper checklists each contained 70 identical checklist items divided into sections that corresponded to each of the eight flight segments (see Appendix I). The digital checklist was an integrated function of a multifunctional display (MFD) produced by Avidyne (Figure 3). The MFD model was the Entegra EX5000C used in Cirrus SRV, SR20, and SR22 aircraft. The paper checklist was a spiral-bound booklet (Figure 4) provided for use in the Cirrus Design SR20 (Pilot’s Checklist Cirrus SR20, 2002), both the digital and paper checklists are used in the college’s flight training curriculum. The digital checklist display, when used, was in a fixed position ahead and slightly to the right of the pilot’s central view. The paper checklist, when used, was positioned on the right leg or lap of the participant, and when not used, usually remained on the seat beside the participant.

Observation Equipment

Observations were taken remotely via video cameras, which displayed different view angles on computer monitors. The observation system is described in detail in the Dependent Variables section below. The observing equipment consisted of three Panasonic® color CCTV model WV-CP484 cameras with built-in microphones. The observer recording computer used a Panasonic® WJ-HD309A digital disk recorder with a 250 gigabyte hard drive, capable of storing up to 1,300 hours of video, a Panasonic® WJ-HD309A administrator console, Shure® SCM810 eight channel microphone mixer,
Preflight Walk-Around

1. Cabin
   a. Autopilot Disengage
   b. Avionics Power Switch
   c. Bat Master Switch
   d. Fuel Quantity
   e. Fuel Selector
   f. Flaps
   g. Vacuum and Oil Annunciators
   h. Lights
   i. Battery Switch
   j. Vacuums and Oil Annunciators
   k. Alternating State Source
   l. Circuit Breakers
   m. Fire Extinguisher

2. Emergency Egress Hammer

3. Left Fuselage
   a. Wing/Spars/Fuselage
   c. Wing/Spars/Fuselage
   e. Stab Blades
   f. Stab Blades

4. Emergency Data
   a. Elevator
   b. Horizontal and Vertical Stabilizers
   c. Rudder
   d. Elevator
   e. Rudder

*CHECKLIST CONTINUED BELOW*

Figure 3. Avidyne Entegra EX5000C, Multi Functional Display with Digital Checklist

Figure 4. Paper Checklist
and four Samsung® PO24FS 27-inch flat screen monitors with eight Samsung vertical mounted speakers (Figure 5).

*Figure 5. Observation Equipment Station*

**Dependent Variables**

The primary dependent variable consisted of the number of paper or digital checklist items completed correctly per flight. Four secondary dependent variables were (a) the percentage of total errors for each of the eight flight segments during each experimental phase (baseline, feedback, reversal, and probe) per participant; (b) the percentage of total baseline trials participants performed each of the checklist items in error; (c) the percentage of items omitted during each experimental phase (baseline,
feedback, reversal, and probe); and (d) the percentage of segment errors resulting from improper checklist segment timing.

All observed behaviors were compared to the criteria outlined in the checklist behavior protocol in Appendix J. Both observers participated in pilot testing, prior to the actual study, to eliminate any observer bias and to agree on scoring checklist items as “correct,” “incorrect,” or “omitted.” For a checklist item to be scored “correct,” participants had to (a) initiate the checklist segment at the appropriate time in the flight sequence, (b) initially vocalize the appropriate checklist item text, (c) engage in the behavior of looking in the direction of the appropriate operational item identified by the checklist item text; or (d) depending on the operational item identified by the checklist item text and behavior required, move a finger or hand to touch the specific operational item, or gesture by extending a directed finger at the operational item identified by the checklist item text; and (e) vocally identifying the appropriate condition or post-state of the operational item identified by the checklist item text. For example, (a) the climb checklist is required to be completed no sooner that attaining 1000 feet above the ground; (b) participant will vocalize the first checklist text item on the climb segment, “Power”; (c) participant will look at the manifold pressure display; (d) participant will touch the power lever and/or point to the manifold pressure display; and (e) participant will vocalize the appropriate condition or post-state of the power as “Set.” However, if the participant performed all climb checklist list items correctly, yet began the climb checklist below 1000 feet above the ground, all climb check items would be scored as “incorrect” and a climb segment timing error would be scored. If there was no vocalization of a checklist item, those items would be scored as “incorrect.” If checklist
items were performed out of sequence as listed in the checklist, those items completed out of order would be scored as “incorrect.” If any checklist item was vocalized and activated, yet not set to the required condition, such as flap movement or pitot heat turned ON or OFF, that item was scored as “incorrect.” Any checklist item skipped was scored as “omitted.” If a checklist item was completed after the item had been skipped, the score on that item was changed from “omitted” to “incorrect.”

The checklist behaviors were scored by trained observers using the checklist observation form included in Appendix K. The observers occupied an area adjacent to the Cirrus FTD and monitored four large computer monitors (Figure 5). All video cameras used by the observers had built-in microphones, which allowed the observers to see and hear both the nonverbal and verbal responses that were required to correctly complete the checklist. One camera was mounted midway on the glare shield of the instrument panel approximately 24 inches in front of the participant to capture facial position and eye movements. The second camera was positioned 35 inches behind and slightly above the participant to observe the participant’s arm positions and hand interactions with the flight panel. The third camera was positioned to record the instructor station, thereby ensuring situational awareness of the observer. All flights were recorded and stored digitally for the purposes of conducting inter-observer agreement checks.

Independent Variable

There were two independent conditions during this study, using paper or digital checklists. The independent variable was the presence or absence of post-flight (a) graphic feedback on the total number of checklist items completed correctly per flight;
(b) graphic feedback on the number of items completed correctly, incorrectly, and omitted for each of the eight flight segments per flight; and (c) praise for improvement in the number of checklist items completed correctly. Procedural details are described below in the Procedures section.

Experimental Design

An alternating treatments design was used to compare the efficacy of paper and digital checklists with and without feedback on checklist use. A multiple baseline design with reversal and an over 60 day probe across pairs of participants was used to evaluate the efficacy of feedback on checklist use. Sessions lasted approximately 2 hours and participants flew four different flight patterns per session. Each flight was considered a trial, and checklist performance was scored and graphed separately for each trial. Each flight lasted approximately 20-25 minutes. There were six different flight patterns. The order of exposure to the flight patterns was randomized in blocks of six for each participant. This procedure ensured no two patterns were repeated during one session.

A reversal phase was included to assess whether checklist performance would maintain after the post-flight feedback was withdrawn. An over 60 day probe past the end of the reversal phase was used to assess performance decrements over longer periods of nonexposure to the feedback condition.
Procedures

Recruitment

As indicated in the Participants section, potential participants were approached during commercial flight courses at the College of Aviation and recruited through the use of posted flyers on the college campus. When recruiting from classes, the experimenter asked individuals who were interested in learning more about the study to print their name, telephone number, or email address on a sheet of paper and give it to the experimenter. In addition, the experimenter handed out a sheet of paper with his name, telephone number, and email address, and told individuals that they could contact him by telephone or email if they preferred. The experimenter contacted individuals in the following 2 to 3 days to arrange a meeting to discuss the details of the study. If individuals contacted the experimenter based on the flyer, the experimenter repeated the information contained in the flyer and arranged a meeting to discuss the details of the study.

Informed Consent Process and Screening

The experimenter met individually with potential participants and obtained their consent using the consent document approved by the HSIRB. If consent was obtained, the experimenter asked them to complete the self-report inclusionary questionnaire. They were told that the experimenter would contact them within a few days to inform them if they had been selected to participate in the study. If selected, the experimenter scheduled the participants' first experimental session. The experimenter screened participants for
possession of a Private Pilot Certificate, instrument rating, and FTD experience by examining responses on the inclusionary questionnaire. The experimenter selected the first 6 participants who qualified.

Baseline

Participants were told that the Frasca 241 FTD simulator was programmed for normal flight and not to expect any aircraft system failures. Participants were briefed that each flight pattern was a radar-vectored instrument flight, with an instrument landing system (ILS) approach to a full stop landing. Participants were informed that their behavior during each flight trial would be observed and recorded using the pre-positioned video cameras. For each flight trial they were given automated terminal information concerning the weather and airport conditions, the Cirrus approved paper checklist, as well as the official ILS approach plate used to execute the instrument landing. Before the beginning of each session of four trials, a digital or paper checklist was randomly assigned for the first trial and the remaining trials alternated between paper and digital checklists. Additionally, they were told that the experimenter would provide them with some post-flight information after each flight and that it would take him about 5 minutes to prepare that material. Although this break was not necessary to provide the post-flight technical information during this phase, this break was necessary to permit the observer to summarize the participant’s checklist performance during the intervention phase. Thus, the same post-flight break was scheduled during this phase as well. See Appendix L for the instructional scripts that were read before the first flight and subsequent flights.
After the participant completed a flight, the experimenter printed out a technical diagram of the flight pattern flown by the participant. These diagrams were automatically created by the GIST simulator software, and displayed the lateral and vertical flight paths (Figure 2). A sample print out is contained in Appendix M. The experimenter gave the diagram to the participant and discussed the technical merits of the flight, praising adequate performance. The post-flight technical briefing is contained in Appendix N. This protocol was repeated for each flight during the baseline phase.

Post-Flight Checklist Feedback

In addition to giving participants the technical diagram feedback that depicted critical flight parameters after each flight, the experimenter provided feedback on the use of the flight checklist. After each flight, the experimenter immediately calculated the number of checklist items completed correctly, entered it into the computer, and printed a line graph that displayed the number of correctly completed items for each trial, including baseline. The experimenter also entered the number of items completed correctly, completed incorrectly, and omitted for each of the eight flight segments for that particular flight, and printed a bar graph that displayed those data. As in the baseline phase, the experimenter printed out a technical flight diagram as well. It took the experimenter approximately 5 minutes to complete these activities. The experimenter first showed the technical flight diagram to the participant and discussed the technical merits of the flight. He then showed the two checklist feedback graphs to the participants and praised any improvements. No detailed feedback was given to the participant, such as which
particular item(s) were performed as incorrect or omitted. This protocol was repeated for each flight. The feedback script and sample feedback graphs are provided in Appendix O.

Reversal

Feedback was no longer provided for use of the flight checklist after each flight. This phase was identical to the baseline phase.

60–90 Day Post-Test Probe

A probe was conducted to determine to what extent any performance improvement maintained. Four alternating trials were done using both paper checklists and digital checklists. Only technical feedback was given. This phase was identical to the baseline phase. A short self-report test was given to determine the participant’s accuracy of memorized checklist items. Questions also checked if any new rules may have been formed after participating in the study (see Appendix P).

Debriefing

Immediately after participants completed their last session they were debriefed. The experimenter read the debriefing script (see Appendix Q), answered any questions they had, and thanked them for participating in the experiment.

Data Analysis

The statistical analysis used in this study was based on the general time-series intervention regression modeling approach described in Huijema and McKean (1998,
This approach accommodates both independent and autocorrelated error structures encountered in time-series intervention designs of the type used in behavioral research. Variations of this approach have been developed for the analysis of both simple and complex versions of single-case time-series designs (Huitema, 2009b, 2009c).

New variants of these statistical models were developed specifically for the present study (Huitema, 2009a). Characteristics of data patterns found in previous work on pilot checklist behavior (Rantz, 2007; Rantz et al., in press) were acknowledged in building a model of hypothesized pilot behavior. A result of this is a model that provides answers to the specific questions of interest in the current investigation. For example, because the previous research has shown that there is usually an immediate intervention effect during the first intervention session, another increment during the second session, and the full effect during the third and subsequent intervention sessions, parameters are included in the model to measure these three increments. Consequently, the dynamic nature of the intervention effect (i.e., the pattern of change during the intervention phase) is captured using these three parameters. Other parameters are provided in the model to describe change from one phase to another.

While Boorman, (2001a, 2001b) has made observations using digital checklists on the flight deck and in simulation as well as post-accident analysis, postulating different outcomes if digital checklist had been used, no empirical study has attempted to test the actual difference between paper and digital checklist presentations. It would seem important for the industry to determine, descriptively and inferentially, if such a
difference exists and to what extent any difference would impact the accuracy of checklist performance.

The general analytic approach is comprised of three aspects. First, the parameters of a time-series regression model of the behavior of each individual participant are estimated using the model mentioned above. Second, the parameter estimates from the individual participant model are used as dependent variables for a group level analysis. The individual and group level analyses are carried out separately on data obtained under both digital and paper feedback conditions. The purpose of these analyses is to characterize the effects of condition changes on checklist behavior for both individual participants and for the group as a whole. The third aspect of the analysis is to compare the effectiveness of digital feedback relative to paper feedback.

The individual level time-series statistical model, which is estimated separately for each participant, is written as follows (Huitema, 2009a):

\[ Y_t = \beta_0 + \beta_1 d_1 + \beta_2 d_2 + \beta_3 d_3 + \beta_4 d_4 + \beta_5 d_5 + \beta_6 d_6 + \beta_7 y + \epsilon_t \]

where

- \( Y_t \) is the dependent variable score at time \( t \),
- \( \beta_0 \) is a parameter measuring the mean of the baseline phase,
- \( \beta_1 \) is a parameter measuring the change in level from the baseline mean to the first time period in the intervention phase (phase two),
- \( d_1 \) is a dummy variable with zeros associated with \( t = 1 \) through \( n_1 \) and ones associated with \( t = n_1 + 1 \) through \( N \),
- \( \beta_2 \) is a parameter measuring the change in level from the first time period
to the second time period in the intervention phase (phase two),

d$_2$ is a dummy variable with zeros associated with $t = 1$ through $n_1 + 1$ and
ones associated with $t = n_1 + 2$ through $N$.

$\beta_3$ is a parameter measuring the difference between the level at
time period $t = n_1 + 2$ and the average level for time periods $n_1 + 3$
through $n_2$,

d$_3$ is a dummy variable with zeros associated with $t = 1$ through
$n_1 + 2$ and ones associated with $t = n_1 + 3$ through $N$.

$\beta_4$ is a parameter measuring the difference between the average
for time periods $n_1 + 3$ through $n_2$ and the average for the
third phase (i.e., for time periods $n_2 + 1$ through $n_3$),

d$_4$ is a dummy variable with zeros associated with $t = 1$ through
$n_1 + n_2$ and ones associated with $t = n_1 + n_2 + 1$ through $N$,

$\beta_5$ is a parameter measuring the difference between the average
for the third phase and the average for the fourth (probe)
phase,

d$_5$ is a dummy variable with zeros associated with $t = 1$ through
$n_1 + n_2 + n_3$ and ones associated with $t = n_1 + n_2 + n_3 + 1$
through $N$,

$\phi_1$ is the lag-1 autoregressive coefficient,

$\gamma_t = [Y_t - \beta_0 + \beta_1 d_1 + \beta_2 d_2 + \beta_3 d_3 + \beta_4 d_4 + \beta_5 d_5 + \beta_6 d_6]$ and,

$\epsilon_t$ is the error at time $t$, which is assumed to be independent and
identically distributed with mean zero and a common variance for all time points.

Inter-Observer Agreement (IOA)

A second observer watched randomly selected recordings of the flights and scored performance using the checklist observation form (Appendix I). After a participant completed the study, numbers corresponding to each trial were placed in a container and four trials for the baseline phase, four trials for the intervention phase, and two trials for the reversal phase were randomly drawn. This process was repeated for each participant. This ensured that (a) at least 25% of the sessions were rescored for each participant, and (b) the trials that were rescored were randomly selected. Inter-observer agreement was determined for the total number of checklist items completed correctly. Inter-observer agreement was calculated as follows: number of agreements divided by the number of agreements plus disagreements, multiplied by 100. Inter-observer agreement for correct and incorrect item errors was an average of 95% with a range of 79% to 100%. Inter-observer agreement for omitted items was an average of 97% with a range of 63% to 100%.

Independent Variable Integrity

To be sure that the technical flight and checklist feedback was administered correctly, the experimenter read from prepared scripts (Appendices L, N, and O). In addition, participants were asked to initial the technical flight diagrams and the checklist feedback graphs that were used during post-flight briefing sessions and give them back to
the experimenter. One hundred percent of all flight diagrams and feedback graphs were initialed by the participants.
CHAPTER III

RESULTS

Figure 6 displays the total number of paper checklist items completed correctly (open circles) together with the total number of digital checklist items completed correctly (closed circles) for each participant per trial. All participants increased paper and digital checklist performance accuracy over baseline when post-flight graphic feedback was provided and those improvements remained during the withdrawal phase and during a delayed probe.

Baseline paper and digital checklist performance varied considerably across participants with participant 1 showing the lowest level of performance in both paper (average 87% error) and digital (average 89% error). Participant 1 had a mean average of 3.37 correct for digital checklist items and 6.11 correct for paper. Both participant 2 and 4 showed the highest level in paper checklist (average 43% error) and both participants scored a mean average of 39.67 correct. However, participant 2 averaged 33% error for the highest performance in digital checklist use with a mean average of 44.28 correct. Baseline trends were fairly stable over time for 4 participants (P1, P3, P4, and P5), with the exception of participant 2, who, despite overall high mean average scores, performed one high peak in digital and one high peak in paper performance and showed a steady, overall decline in both paper and digital accuracy from the first trial; and participant 6, who showed wide variability between paper (38.92 mean average correct) and digital (37.89 mean average correct) performance. Overall paper checklist baseline
Figure 6. Total Number of Paper and Digital Checklist Items Completed Correctly
performance averaged 62% errors (27.42 mean average) for all participants, while digital baseline performance averaged 61% errors (26.57 mean average).

During baseline, accuracy between paper and digital checklists for each participant varied by reversing accuracy trends between checklists. Given the visual data, neither paper nor digital checklists appeared to demonstrate the superiority of one checklist as more accurate over the other. Participant 1, though low performing in both checklists, maintained higher accuracy using the paper checklist and never reversed to higher accuracy using the digital checklist while ending baseline with equally low performance for both checklists. Participant 3 began with higher accuracy using the paper checklist then reversed accuracy twice to end baseline with equal performance with both paper and digital. Participant 2 began as a high performer using the paper checklist then reversed accuracy three times ending baseline with higher performance using digital. Participant 6 began with higher performance using the paper checklist then reversed accuracy four times ending baseline with higher accuracy using digital. Both participant 4 and participant 5 began with increased accuracy using the paper checklist then reversed accuracy five times before ending baseline. Participant 5 ended baseline performing more accurate using digital while the only exception, participant 4, ended baseline with higher performance using the paper checklist.

Overall performance in both paper and digital checklist accuracy increased for all participants after the intervention was introduced. There was a dramatic intervention effect using both paper and digital checklists for both individual participants and cumulative across all participants. Two participants (P1 and P3) showed an abrupt level change of over 50% improvement in the first trial, following the introduction of the
treatment and then continued an increasing trend. Participant 1 initially increased paper checklist accuracy 71% after the intervention, improving total correct checklist items from 1 item correct out of 70 items to 51 items correct. Participant 3 had the highest initial performance increase across both the digital and paper checklists, increasing level change by 61% for digital checklist items done correctly and 44% for paper checklist items. Participant 5 experienced an initial increase in level change of 36% improvement for digital and 40% improvement for paper checklist items performed correctly. Two participants showed an increasing level change, for both digital and paper, followed by an increasing trend (P2, P4). Only participant 6, while initially increasing 13% in paper checklist performance, demonstrated an initial single trial decrease of 1% in digital accuracy followed by an increasing digital trend.

Performance criteria for the reversal phase was established as three consecutive trials in either paper or digital where participant’s checklist performance met or exceeded 95% correct on checklist items. All participants reached reversal criteria during paper checklist trials.

Overall across all participants, the average percentage of paper checklist items completed correctly increased from 38% items correct during the baseline phase to 90% items correct during the intervention phase. The average percentage of digital checklist items increased from 39% items completed correctly to 89% items correct during intervention. Improvement continued to near perfect levels for participants during the reversal phase with 100% paper checklist items correct and 99% digital items correct. The average percentage of paper checklist performance declined 3% between a 60 and 90
day delay. The average percentage of digital checklist performance declined 4% during that same time period.

Data contained in Figure 6 were used in the inferential analysis given the model, \( Y_t = \beta_0 + \beta_1 d_1 + \beta_2 d_2 + \beta_3 d_3 + \beta_4 d_4 + \beta_5 d_5 + \beta_6 d_6 + \phi_1 \gamma + \varepsilon_t \). The parameters of this model were estimated for each participant using the bootstrap based time-series regression method described in McKnight, McKean, and Huitema (2000). This method has been implemented in software (Timeseries) running on a server accessible through the Department of Statistics, Western Michigan University. Results were statistically significant for each individual’s intervention effect in both paper and digital checklist use. Performance was generally not significant once optimum performance levels were reached during each following phase (Appendix R).

After parameter estimates for each participant were computed, they were used as dependent variable scores in the group level analysis. The purpose of this analysis was to provide an overall evaluation of the effects of the interventions for the group of six pilots. The next stage of the group analysis consisted of conventional one-sample \( t \) tests to evaluate the hypothesis that each intervention and phase-change parameter value is equal to zero. Once again, results were statistically significant for the overall intervention effect in both paper and digital checklist use. As for each individual’s results above, performance was generally not significant once optimum performance levels were reached during each following phase (Appendix R).

The third aspect of the analysis involved computing the difference in performance under the digital and paper conditions at each observation point and testing the difference between the digital and paper means. Once again, the double bootstrap method of
McKnight et al. (2000) was used to estimate the parameters of a time-series model
developed to evaluate the hypothesis of zero difference between digital and paper
feedback; this is a model that contains only an intercept and an autoregressive parameter.
The difference between paper and digital checklist performance was found not to be
statistically significant ($t = 1.78, p = .08$).

Figure 7 shows the percentage of total paper checklist errors for each participant
during each of the eight segments for each phase of the experiment. During all trials using
paper checklists, 2,448 total errors were counted. Generally, the percentage of errors by
flight segment varied across participants and phases. For all participants, paper checklist
ersions decreased during the intervention phase. With the exception of near perfect
performance of the before takeoff and normal takeoff checklist segment, perfect paper
checklist performance was observed during reversal.

During the paper checklist baseline, the average percent errors for the after
landing checklist errors was lowest (50%, range = 0–100%) and highest errors for the
normal takeoff segment (75%, range = 56.67–84.44%). All participants performed poorly
during the normal takeoff segment. The paper checklist segment with the second highest
errors was the climb (72.0%, range = 11.11–100%). Participants 3 and 4 had higher
performance during the climb segment. The third highest errors was the descent segment
(66%, range = 50.0–93.33%). Descent error rates across all participants seem to be
consistent, with participant 3 performing slightly better. Errors in the before landing
segment (64%, range = 6.67–100%) were highly variable, with four participants showing
higher levels of error (P3, P4, P5, and P6) and participants 1 and 2 demonstrated lower
error rates. Shutdown errors (61%, range = 16.67–100%) were quite variable, with three
participants (P1, P3, and P5) performing with high error rates and three participants (P2, P4, and P6) performing with lower error rates. The two remaining baseline phase checklist segments were before takeoff segment (58%, range = 36.29–95.48%), and the cruise segment (52%, range = 13.33–100%). Each segment demonstrated quite variable performance across all participants.

Errors decreased considerably for all participants during paper checklist intervention. As with baseline, the normal takeoff segment had the highest number of errors during intervention (20%, range = 8.0–26.76%) The cruise and the after landing segments had the lowest number of errors (0%).

As indicated earlier, paper checklist errors were very low during reversal. All segments had perfect performance with the exception of the before takeoff and the normal takeoff segments with 1% error each.

Figure 8 shows the percentage of total digital checklist errors for each participant, during each of the eight segments, for each phase of the experiment. During all trials using digital checklists, 2,566 total errors were counted. Similar to paper checklist errors, the percentage of errors by flight segment varied across participants and phases. For all participants, digital checklist errors decreased during the intervention phase. Comparable to the paper checklist performance, near perfect digital checklist performance was observed during reversal.

Corresponding to observations using paper checklists, the lowest errors in digital checklist baseline was the after landing checklist (50%, range = 1.85–100%). As with paper, the highest errors occurred during the normal takeoff segment (71%, range =
Figure 7. Percentage of Paper Checklist Errors for Each Condition Per Participant
Figure 8. Percentage of Digital Checklist Errors for Each Condition Per Participant
56.67–88.89%). All participants performed poorly during the normal takeoff segment. The second highest digital checklist errors occurred in the shutdown segment (69%, range = 28.57–100%). Participants 2 and 4 had lower error rates while the remaining participants had much higher errors during the digital shutdown segment. Errors in the climb segment (63%, range = 6.67–100%) varied across participants, with only participant 4 performing below 10% error. Before takeoff errors (62%, range = 39.25–100%) showed variability across all participants. The before landing (60%, range = 3.33–95.56%) showed variable error rates, with three participants (P3, P4, and P5) having high error rates, participant 2 had a very low error rate, and the remaining participants (P1 and P6) having moderate error rates. The descent segment (57%, range = 18.06–100%) varied across all participants. The cruise segment (56%, range = 26.65–100%) had high errors for participant 1 and 5, while the remaining participants (P2, P3, P4, and P6) were moderately similar. The digital baseline checklist segment errors corresponded to three paper checklist segment errors. Highest errors in the normal takeoff segment occurred for both paper and digital checklists. Lowest errors in the after landing segment and the cruise segment occurred for both paper and digital checklists.

Errors decreased for all participants during digital checklist intervention. Again, as with the paper and digital baseline, the normal takeoff segment had the highest number of errors during digital intervention (20%, range = 0–35.00%). Similar to the paper checklist intervention, the cruise and the after landing segments had the lowest number of errors (4%).
As mentioned prior, digital checklist errors were very low during reversal. All segments had perfect performance with the exception of a 1% error rate for the before takeoff segment and a 3% error rate for the descent segment.

Table 1 shows the percentage of trials that participants completed each item incorrectly during paper checklist baseline. Shading was used to highlight percentage errors of 50% or greater for each participant. Also, the paper checklist item text is shaded if the percentage of error was 50% or greater for 4 or more participants. Thus, horizontally shaded patterns indicate problematic checklist items, while vertically shaded patterns indicate particular participants who made a high percentage of errors on more than 35 out of 70 items. This process was repeated for the digital checklist baseline in Table 2.

As identified in Figure 7, several paper checklist segments emerge as having problematic status. As indicated earlier, a total of 2,448 total errors occurred during the paper checklist trials. The normal takeoff segment is highlighted as having the highest frequency of errors, with 5 out of 6 items being consistently performed in error by all of the participants. Only retracting the flaps after takeoff was performed with little or no errors. A majority of participants (P1, P2, P5, and P6) scored errors in the climb check, which had the second highest frequency of high percentage item errors. The descent segment was the third highest in percentage item errors, with most participants scoring a lower percentage of errors than the previous two segments. Only participant 4 scored less than a 50% error rate in the descent segment. The before landing checklist segment is the last, in which a majority of participants (P3, P4, P5, and P6) had high percentage.
Table 1

Percentage of Paper Checklist Baseline Trials Participants Performed Items in Error

<table>
<thead>
<tr>
<th>Segment / Item</th>
<th>P1</th>
<th>P2</th>
<th>P3</th>
<th>P4</th>
<th>P5</th>
<th>P6</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Before Takeoff</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Doors</td>
<td>100</td>
<td>0</td>
<td>22</td>
<td>11</td>
<td>100</td>
<td>17</td>
</tr>
<tr>
<td>CAPS Handle</td>
<td>100</td>
<td>0</td>
<td>11</td>
<td>44</td>
<td>100</td>
<td>8</td>
</tr>
<tr>
<td>Belts &amp; Harnesses</td>
<td>100</td>
<td>17</td>
<td>0</td>
<td>33</td>
<td>100</td>
<td>8</td>
</tr>
<tr>
<td>Fuel Quantity</td>
<td>100</td>
<td>33</td>
<td>56</td>
<td>89</td>
<td>67</td>
<td>17</td>
</tr>
<tr>
<td>Fuel Selector</td>
<td>100</td>
<td>17</td>
<td>67</td>
<td>33</td>
<td>67</td>
<td>8</td>
</tr>
<tr>
<td>Fuel Pump</td>
<td>80</td>
<td>17</td>
<td>44</td>
<td>33</td>
<td>58</td>
<td>8</td>
</tr>
<tr>
<td>Flaps</td>
<td>80</td>
<td>0</td>
<td>11</td>
<td>11</td>
<td>50</td>
<td>25</td>
</tr>
<tr>
<td>Transponder</td>
<td>80</td>
<td>17</td>
<td>100</td>
<td>33</td>
<td>67</td>
<td>8</td>
</tr>
<tr>
<td>Autopilot</td>
<td>80</td>
<td>0</td>
<td>100</td>
<td>56</td>
<td>58</td>
<td>17</td>
</tr>
<tr>
<td>Nav Radio/GPS</td>
<td>100</td>
<td>0</td>
<td>22</td>
<td>11</td>
<td>58</td>
<td>0</td>
</tr>
<tr>
<td>Cabin Heat/Defrost</td>
<td>100</td>
<td>50</td>
<td>100</td>
<td>33</td>
<td>100</td>
<td>17</td>
</tr>
<tr>
<td>Brakes</td>
<td>80</td>
<td>67</td>
<td>78</td>
<td>100</td>
<td>83</td>
<td>0</td>
</tr>
<tr>
<td>Power Lever</td>
<td>80</td>
<td>33</td>
<td>78</td>
<td>11</td>
<td>33</td>
<td>0</td>
</tr>
<tr>
<td>Alternator</td>
<td>100</td>
<td>83</td>
<td>100</td>
<td>44</td>
<td>75</td>
<td>75</td>
</tr>
<tr>
<td>Pitot Heat</td>
<td>100</td>
<td>50</td>
<td>100</td>
<td>100</td>
<td>83</td>
<td>67</td>
</tr>
<tr>
<td>Nav Light</td>
<td>100</td>
<td>50</td>
<td>100</td>
<td>100</td>
<td>83</td>
<td>75</td>
</tr>
<tr>
<td>Landing Light</td>
<td>100</td>
<td>50</td>
<td>100</td>
<td>100</td>
<td>83</td>
<td>83</td>
</tr>
<tr>
<td>Annunciator Light</td>
<td>100</td>
<td>50</td>
<td>100</td>
<td>89</td>
<td>75</td>
<td>100</td>
</tr>
<tr>
<td>Voltage</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>56</td>
<td>58</td>
<td>92</td>
</tr>
<tr>
<td>Pitot Heat</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>92</td>
<td>100</td>
</tr>
<tr>
<td>Nav Light</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Landing Light</td>
<td>80</td>
<td>83</td>
<td>89</td>
<td>100</td>
<td>75</td>
<td>92</td>
</tr>
<tr>
<td>Magneto</td>
<td>100</td>
<td>17</td>
<td>44</td>
<td>0</td>
<td>25</td>
<td>25</td>
</tr>
<tr>
<td>Ignition Switch-Right</td>
<td>100</td>
<td>17</td>
<td>56</td>
<td>0</td>
<td>17</td>
<td>25</td>
</tr>
<tr>
<td>Ignition Switch-Left</td>
<td>100</td>
<td>17</td>
<td>56</td>
<td>0</td>
<td>17</td>
<td>25</td>
</tr>
</tbody>
</table>
Table 1—Continued

<table>
<thead>
<tr>
<th>Segment / Item</th>
<th>P1</th>
<th>P2</th>
<th>P3</th>
<th>P4</th>
<th>P5</th>
<th>P6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engine Parameters</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>78</td>
<td>50</td>
<td>33</td>
</tr>
<tr>
<td>Power Lever</td>
<td>100</td>
<td>17</td>
<td>89</td>
<td>22</td>
<td>83</td>
<td>25</td>
</tr>
<tr>
<td>Flight Instruments</td>
<td>100</td>
<td>67</td>
<td>11</td>
<td>11</td>
<td>75</td>
<td>42</td>
</tr>
<tr>
<td>Flight Controls</td>
<td>100</td>
<td>0</td>
<td>0</td>
<td>11</td>
<td>67</td>
<td>17</td>
</tr>
<tr>
<td>Trim</td>
<td>100</td>
<td>0</td>
<td>11</td>
<td>22</td>
<td>42</td>
<td>8</td>
</tr>
<tr>
<td>Autopilot</td>
<td>100</td>
<td>100</td>
<td>11</td>
<td>11</td>
<td>25</td>
<td>8</td>
</tr>
</tbody>
</table>

Normal Takeoff

<table>
<thead>
<tr>
<th>Segment / Item</th>
<th>P1</th>
<th>P2</th>
<th>P3</th>
<th>P4</th>
<th>P5</th>
<th>P6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power Lever</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>39</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Engine Parameters</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>39</td>
<td>17</td>
<td>100</td>
</tr>
<tr>
<td>Brakes</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>39</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Elevator Control</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>39</td>
<td>88</td>
<td>88</td>
</tr>
<tr>
<td>Flaps</td>
<td>0</td>
<td>0</td>
<td>22</td>
<td>0</td>
<td>8</td>
<td>0</td>
</tr>
</tbody>
</table>

Climb

<table>
<thead>
<tr>
<th>Segment / Item</th>
<th>P1</th>
<th>P2</th>
<th>P3</th>
<th>P4</th>
<th>P5</th>
<th>P6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Climb Power</td>
<td>100</td>
<td>100</td>
<td>44</td>
<td>0</td>
<td>92</td>
<td>92</td>
</tr>
<tr>
<td>Flaps</td>
<td>60</td>
<td>100</td>
<td>44</td>
<td>0</td>
<td>92</td>
<td>92</td>
</tr>
<tr>
<td>Mixture</td>
<td>100</td>
<td>100</td>
<td>44</td>
<td>11</td>
<td>92</td>
<td>100</td>
</tr>
<tr>
<td>Engine Parameters</td>
<td>100</td>
<td>100</td>
<td>44</td>
<td>33</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Fuel Pump</td>
<td>60</td>
<td>100</td>
<td>44</td>
<td>11</td>
<td>100</td>
<td>92</td>
</tr>
</tbody>
</table>

Cruise

<table>
<thead>
<tr>
<th>Segment / Item</th>
<th>P1</th>
<th>P2</th>
<th>P3</th>
<th>P4</th>
<th>P5</th>
<th>P6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel Pump</td>
<td>80</td>
<td>33</td>
<td>22</td>
<td>22</td>
<td>100</td>
<td>50</td>
</tr>
<tr>
<td>Cruise Power</td>
<td>100</td>
<td>33</td>
<td>11</td>
<td>22</td>
<td>100</td>
<td>42</td>
</tr>
<tr>
<td>Mixture</td>
<td>100</td>
<td>33</td>
<td>11</td>
<td>33</td>
<td>100</td>
<td>42</td>
</tr>
<tr>
<td>Engine Parameters</td>
<td>100</td>
<td>33</td>
<td>11</td>
<td>22</td>
<td>100</td>
<td>52</td>
</tr>
<tr>
<td>Fuel Flow</td>
<td>100</td>
<td>33</td>
<td>11</td>
<td>22</td>
<td>100</td>
<td>42</td>
</tr>
</tbody>
</table>
Table 1—Continued

<table>
<thead>
<tr>
<th>Segment / Item</th>
<th>P1</th>
<th>P2</th>
<th>P3</th>
<th>P4</th>
<th>P5</th>
<th>P6</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Descent</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Altimeter</td>
<td>100</td>
<td>67</td>
<td>44</td>
<td>67</td>
<td>58</td>
<td>50</td>
</tr>
<tr>
<td>Cabin Heat/Defrost</td>
<td>100</td>
<td>67</td>
<td>78</td>
<td>67</td>
<td>58</td>
<td>50</td>
</tr>
<tr>
<td>Landing Light</td>
<td>80</td>
<td>67</td>
<td>44</td>
<td>67</td>
<td>58</td>
<td>50</td>
</tr>
<tr>
<td>Fuel System</td>
<td>100</td>
<td>67</td>
<td>44</td>
<td>67</td>
<td>58</td>
<td>50</td>
</tr>
<tr>
<td>Mixture</td>
<td>80</td>
<td>67</td>
<td>44</td>
<td>67</td>
<td>58</td>
<td>50</td>
</tr>
<tr>
<td>Brake Pressure</td>
<td>100</td>
<td>67</td>
<td>44</td>
<td>67</td>
<td>58</td>
<td>50</td>
</tr>
<tr>
<td><strong>Before Landing</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Seat-Belt/Harness</td>
<td>40</td>
<td>0</td>
<td>67</td>
<td>100</td>
<td>100</td>
<td>58</td>
</tr>
<tr>
<td>Fuel Pump</td>
<td>40</td>
<td>0</td>
<td>67</td>
<td>100</td>
<td>100</td>
<td>58</td>
</tr>
<tr>
<td>Mixture</td>
<td>40</td>
<td>0</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>58</td>
</tr>
<tr>
<td>Flaps</td>
<td>40</td>
<td>33</td>
<td>89</td>
<td>80</td>
<td>83</td>
<td>58</td>
</tr>
<tr>
<td>Antenna</td>
<td>60</td>
<td>0</td>
<td>98</td>
<td>100</td>
<td>83</td>
<td>67</td>
</tr>
<tr>
<td><strong>After Landing</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Power Lever</td>
<td>100</td>
<td>0</td>
<td>100</td>
<td>0</td>
<td>92</td>
<td>50</td>
</tr>
<tr>
<td>Fuel Pump</td>
<td>100</td>
<td>0</td>
<td>89</td>
<td>0</td>
<td>58</td>
<td>25</td>
</tr>
<tr>
<td>Flaps</td>
<td>100</td>
<td>0</td>
<td>78</td>
<td>0</td>
<td>58</td>
<td>25</td>
</tr>
<tr>
<td>Transponder</td>
<td>100</td>
<td>0</td>
<td>100</td>
<td>0</td>
<td>83</td>
<td>25</td>
</tr>
<tr>
<td>Lights</td>
<td>100</td>
<td>0</td>
<td>100</td>
<td>0</td>
<td>75</td>
<td>25</td>
</tr>
<tr>
<td>Pitot Heat</td>
<td>100</td>
<td>0</td>
<td>100</td>
<td>11</td>
<td>75</td>
<td>25</td>
</tr>
<tr>
<td><strong>Shutdown</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fuel Pump</td>
<td>100</td>
<td>0</td>
<td>78</td>
<td>11</td>
<td>92</td>
<td>25</td>
</tr>
<tr>
<td>Throttle</td>
<td>100</td>
<td>0</td>
<td>78</td>
<td>0</td>
<td>92</td>
<td>0</td>
</tr>
<tr>
<td>Ignition Switch</td>
<td>100</td>
<td>0</td>
<td>100</td>
<td>44</td>
<td>100</td>
<td>17</td>
</tr>
<tr>
<td>Mixture</td>
<td>100</td>
<td>0</td>
<td>78</td>
<td>0</td>
<td>92</td>
<td>25</td>
</tr>
<tr>
<td>All Switches</td>
<td>100</td>
<td>0</td>
<td>89</td>
<td>0</td>
<td>92</td>
<td>42</td>
</tr>
<tr>
<td>Magnetos</td>
<td>100</td>
<td>17</td>
<td>100</td>
<td>11</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>ELT</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
</tbody>
</table>

| Average Percent Total Error | 88 | 43 | 65 | 43 | 81 | 55 |
Table 2 shows the percentage of trials that participants completed each item incorrectly during digital checklist baseline. Shading was used once again to highlight percentage errors of 50% or greater are for each participant. Also, the digital checklist item text is shaded if the percentage of error was 50% or greater for 4 or more participants.

Several digital checklist segments have a high frequency of errors. As indicated earlier, a total of 2,566 total errors occurred during the digital checklist trials. Similar to the paper checklist segments, the digital normal takeoff segment had the highest frequency of errors. As with the corresponding paper checklist segment, 5 out of 6 items were consistently performed in error by all of the participants. Flap retraction was the only item in this segment that had a low percentage error rate. The second highest percentage error rate for digital was the shutdown segment. This differed from the order of paper segments. The shutdown segment had a majority of participants (P1, P3, P5, and P6) score higher percentages of errors in the shutdown check. The climb segment was the third highest in percentage item errors with most participants (P1, P2, P5, and P6) scoring more than 50% errors. Again, most participants (P1, P3, P4, and P5) exceeded 50% of item errors in the before takeoff checklist segment. It appeared that a block of before takeoff checklist items (14-22), beginning with the alternator and ending with the landing light, was extremely problematic for all participants in both paper and digital formats.

Figure 9 displays the percentage of items omitted during the paper checklist segments for each experimental phase. As explained in the methods section, all incorrect and omitted observations were scored as errors. While an item may have been done in
Table 2

*Percentage of Digital Checklist Baseline Trials Participants Performed Items in Error*

<table>
<thead>
<tr>
<th>Segment / Item</th>
<th>P1</th>
<th>P2</th>
<th>P3</th>
<th>P4</th>
<th>P5</th>
<th>P6</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Before Takeoff</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Doors</td>
<td>100</td>
<td>17</td>
<td>11</td>
<td>22</td>
<td>92</td>
<td>17</td>
</tr>
<tr>
<td>CAPS Handle</td>
<td>100</td>
<td>33</td>
<td>0</td>
<td>33</td>
<td>100</td>
<td>8</td>
</tr>
<tr>
<td>Belts &amp; Harnesses</td>
<td>100</td>
<td>33</td>
<td>0</td>
<td>44</td>
<td>100</td>
<td>8</td>
</tr>
<tr>
<td>Fuel Quantity</td>
<td>100</td>
<td>33</td>
<td>78</td>
<td>100</td>
<td>58</td>
<td>8</td>
</tr>
<tr>
<td>Fuel Selector</td>
<td>100</td>
<td>33</td>
<td>67</td>
<td>56</td>
<td>50</td>
<td>25</td>
</tr>
<tr>
<td>Fuel Pump</td>
<td>100</td>
<td>33</td>
<td>56</td>
<td>11</td>
<td>67</td>
<td>8</td>
</tr>
<tr>
<td>Flaps</td>
<td>100</td>
<td>0</td>
<td>0</td>
<td>33</td>
<td>33</td>
<td>17</td>
</tr>
<tr>
<td>Transponder</td>
<td>100</td>
<td>0</td>
<td>78</td>
<td>22</td>
<td>58</td>
<td>8</td>
</tr>
<tr>
<td>Autopilot</td>
<td>100</td>
<td>0</td>
<td>100</td>
<td>56</td>
<td>58</td>
<td>8</td>
</tr>
<tr>
<td>Nav Radio/GPS</td>
<td>100</td>
<td>17</td>
<td>11</td>
<td>22</td>
<td>50</td>
<td>8</td>
</tr>
<tr>
<td>Cabin Heat/Defrost</td>
<td>100</td>
<td>83</td>
<td>89</td>
<td>44</td>
<td>100</td>
<td>17</td>
</tr>
<tr>
<td>Brakes</td>
<td>100</td>
<td>83</td>
<td>78</td>
<td>100</td>
<td>100</td>
<td>17</td>
</tr>
<tr>
<td>Power Lever</td>
<td>100</td>
<td>33</td>
<td>78</td>
<td>11</td>
<td>33</td>
<td>25</td>
</tr>
<tr>
<td>Alternator</td>
<td>100</td>
<td>33</td>
<td>89</td>
<td>44</td>
<td>92</td>
<td>100</td>
</tr>
<tr>
<td>Pitot Heat</td>
<td>100</td>
<td>67</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Nav Light</td>
<td>100</td>
<td>67</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Landing Light</td>
<td>100</td>
<td>50</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Annunciator Light</td>
<td>100</td>
<td>50</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Voltage</td>
<td>100</td>
<td>67</td>
<td>100</td>
<td>56</td>
<td>42</td>
<td>100</td>
</tr>
<tr>
<td>Pitot Heat</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Nav Light</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>83</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Landing Light</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>92</td>
<td>100</td>
</tr>
<tr>
<td>Magnetsos</td>
<td>100</td>
<td>0</td>
<td>56</td>
<td>44</td>
<td>50</td>
<td>42</td>
</tr>
<tr>
<td>Ignition Switch-Right</td>
<td>100</td>
<td>0</td>
<td>44</td>
<td>22</td>
<td>42</td>
<td>42</td>
</tr>
<tr>
<td>Ignition Switch-Left</td>
<td>100</td>
<td>0</td>
<td>44</td>
<td>22</td>
<td>42</td>
<td>42</td>
</tr>
<tr>
<td>Engine Parameters</td>
<td>100</td>
<td>83</td>
<td>89</td>
<td>89</td>
<td>67</td>
<td>83</td>
</tr>
</tbody>
</table>
Table 2—Continued

<table>
<thead>
<tr>
<th>Segment / Item</th>
<th>P1</th>
<th>P2</th>
<th>P3</th>
<th>P4</th>
<th>P5</th>
<th>P6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power Lever</td>
<td>100</td>
<td>0</td>
<td>89</td>
<td>11</td>
<td>92</td>
<td>56</td>
</tr>
<tr>
<td>Flight Instruments</td>
<td>100</td>
<td>67</td>
<td>0</td>
<td>22</td>
<td>75</td>
<td>42</td>
</tr>
<tr>
<td>Flight Controls</td>
<td>100</td>
<td>0</td>
<td>22</td>
<td>22</td>
<td>67</td>
<td>8</td>
</tr>
<tr>
<td>Trim</td>
<td>100</td>
<td>0</td>
<td>56</td>
<td>44</td>
<td>42</td>
<td>25</td>
</tr>
<tr>
<td>Autopilot</td>
<td>100</td>
<td>33</td>
<td>56</td>
<td>11</td>
<td>42</td>
<td>8</td>
</tr>
</tbody>
</table>

Normal Takeoff

<table>
<thead>
<tr>
<th>Segment / Item</th>
<th>P1</th>
<th>P2</th>
<th>P3</th>
<th>P4</th>
<th>P5</th>
<th>P6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power Lever</td>
<td>100</td>
<td>33</td>
<td>100</td>
<td>89</td>
<td>92</td>
<td>67</td>
</tr>
<tr>
<td>Engine Parameters</td>
<td>100</td>
<td>33</td>
<td>100</td>
<td>89</td>
<td>33</td>
<td>92</td>
</tr>
<tr>
<td>Brakes</td>
<td>100</td>
<td>33</td>
<td>100</td>
<td>89</td>
<td>92</td>
<td>67</td>
</tr>
<tr>
<td>Elevator Control</td>
<td>100</td>
<td>33</td>
<td>100</td>
<td>89</td>
<td>58</td>
<td>67</td>
</tr>
<tr>
<td>Flaps</td>
<td>0</td>
<td>17</td>
<td>0</td>
<td>22</td>
<td>8</td>
<td>17</td>
</tr>
</tbody>
</table>

Climb

<table>
<thead>
<tr>
<th>Segment / Item</th>
<th>P1</th>
<th>P2</th>
<th>P3</th>
<th>P4</th>
<th>P5</th>
<th>P6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Climb Power</td>
<td>100</td>
<td>67</td>
<td>33</td>
<td>0</td>
<td>58</td>
<td>55</td>
</tr>
<tr>
<td>Flaps</td>
<td>100</td>
<td>67</td>
<td>33</td>
<td>0</td>
<td>75</td>
<td>25</td>
</tr>
<tr>
<td>Mixture</td>
<td>100</td>
<td>33</td>
<td>33</td>
<td>11</td>
<td>92</td>
<td>75</td>
</tr>
<tr>
<td>Engine Parameters</td>
<td>100</td>
<td>67</td>
<td>44</td>
<td>22</td>
<td>92</td>
<td>100</td>
</tr>
<tr>
<td>Fuel Pump</td>
<td>100</td>
<td>67</td>
<td>44</td>
<td>0</td>
<td>92</td>
<td>50</td>
</tr>
</tbody>
</table>

Cruise

<table>
<thead>
<tr>
<th>Segment / Item</th>
<th>P1</th>
<th>P2</th>
<th>P3</th>
<th>P4</th>
<th>P5</th>
<th>P6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel Pump</td>
<td>100</td>
<td>50</td>
<td>22</td>
<td>22</td>
<td>100</td>
<td>50</td>
</tr>
<tr>
<td>Cruise Power</td>
<td>100</td>
<td>33</td>
<td>33</td>
<td>22</td>
<td>100</td>
<td>42</td>
</tr>
<tr>
<td>Mixture</td>
<td>100</td>
<td>33</td>
<td>22</td>
<td>22</td>
<td>92</td>
<td>42</td>
</tr>
<tr>
<td>Engine Parameters</td>
<td>100</td>
<td>33</td>
<td>33</td>
<td>44</td>
<td>100</td>
<td>50</td>
</tr>
<tr>
<td>Fuel Flow</td>
<td>100</td>
<td>33</td>
<td>22</td>
<td>22</td>
<td>100</td>
<td>50</td>
</tr>
</tbody>
</table>

Descent

<table>
<thead>
<tr>
<th>Segment / Item</th>
<th>P1</th>
<th>P2</th>
<th>P3</th>
<th>P4</th>
<th>P5</th>
<th>P6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Altimeter</td>
<td>100</td>
<td>17</td>
<td>67</td>
<td>44</td>
<td>92</td>
<td>17</td>
</tr>
<tr>
<td>Cabin Heat/Defrost</td>
<td>100</td>
<td>17</td>
<td>67</td>
<td>44</td>
<td>100</td>
<td>17</td>
</tr>
<tr>
<td>Landing Light</td>
<td>100</td>
<td>17</td>
<td>67</td>
<td>44</td>
<td>92</td>
<td>17</td>
</tr>
</tbody>
</table>
Table 2—Continued

<table>
<thead>
<tr>
<th>Segment / Item</th>
<th>P1</th>
<th>P2</th>
<th>P3</th>
<th>P4</th>
<th>P5</th>
<th>P6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel System</td>
<td>100</td>
<td>17</td>
<td>67</td>
<td>44</td>
<td>100</td>
<td>17</td>
</tr>
<tr>
<td>Mixture</td>
<td>100</td>
<td>17</td>
<td>67</td>
<td>44</td>
<td>100</td>
<td>17</td>
</tr>
<tr>
<td>Brake Pressure</td>
<td>100</td>
<td>33</td>
<td>67</td>
<td>44</td>
<td>83</td>
<td>25</td>
</tr>
</tbody>
</table>

Before Landing

<table>
<thead>
<tr>
<th>Item</th>
<th>P1</th>
<th>P2</th>
<th>P3</th>
<th>P4</th>
<th>P5</th>
<th>P6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seat Belt/Harness</td>
<td>60</td>
<td>0</td>
<td>67</td>
<td>100</td>
<td>92</td>
<td>51</td>
</tr>
<tr>
<td>Fuel Pump</td>
<td>40</td>
<td>0</td>
<td>67</td>
<td>89</td>
<td>92</td>
<td>50</td>
</tr>
<tr>
<td>Mixture</td>
<td>40</td>
<td>0</td>
<td>67</td>
<td>100</td>
<td>92</td>
<td>50</td>
</tr>
<tr>
<td>Flaps</td>
<td>40</td>
<td>17</td>
<td>67</td>
<td>100</td>
<td>92</td>
<td>50</td>
</tr>
<tr>
<td>Autopilot</td>
<td>60</td>
<td>0</td>
<td>67</td>
<td>89</td>
<td>92</td>
<td>50</td>
</tr>
</tbody>
</table>

After Landing

<table>
<thead>
<tr>
<th>Item</th>
<th>P1</th>
<th>P2</th>
<th>P3</th>
<th>P4</th>
<th>P5</th>
<th>P6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power Lever</td>
<td>100</td>
<td>0</td>
<td>89</td>
<td>0</td>
<td>92</td>
<td>33</td>
</tr>
<tr>
<td>Fuel Pump</td>
<td>100</td>
<td>0</td>
<td>89</td>
<td>11</td>
<td>67</td>
<td>25</td>
</tr>
<tr>
<td>Flaps</td>
<td>100</td>
<td>0</td>
<td>89</td>
<td>0</td>
<td>67</td>
<td>25</td>
</tr>
<tr>
<td>Transponder</td>
<td>100</td>
<td>0</td>
<td>89</td>
<td>0</td>
<td>75</td>
<td>17</td>
</tr>
<tr>
<td>Lights</td>
<td>100</td>
<td>0</td>
<td>89</td>
<td>0</td>
<td>83</td>
<td>25</td>
</tr>
<tr>
<td>Pitot Heat</td>
<td>100</td>
<td>17</td>
<td>89</td>
<td>0</td>
<td>83</td>
<td>33</td>
</tr>
</tbody>
</table>

Shutdown

<table>
<thead>
<tr>
<th>Item</th>
<th>P1</th>
<th>P2</th>
<th>P3</th>
<th>P4</th>
<th>P5</th>
<th>P6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel Pump</td>
<td>100</td>
<td>0</td>
<td>89</td>
<td>33</td>
<td>83</td>
<td>50</td>
</tr>
<tr>
<td>Throttle</td>
<td>200</td>
<td>0</td>
<td>89</td>
<td>22</td>
<td>83</td>
<td>25</td>
</tr>
<tr>
<td>Ignition Switch</td>
<td>100</td>
<td>33</td>
<td>89</td>
<td>33</td>
<td>100</td>
<td>33</td>
</tr>
<tr>
<td>Mixture</td>
<td>100</td>
<td>0</td>
<td>89</td>
<td>11</td>
<td>73</td>
<td>50</td>
</tr>
<tr>
<td>All Switches</td>
<td>100</td>
<td>17</td>
<td>100</td>
<td>33</td>
<td>100</td>
<td>67</td>
</tr>
<tr>
<td>Magneto</td>
<td>100</td>
<td>50</td>
<td>100</td>
<td>44</td>
<td>100</td>
<td>50</td>
</tr>
<tr>
<td>Ignition</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>50</td>
<td>100</td>
<td>50</td>
</tr>
</tbody>
</table>

Average Percent Total Error | 89  | 33  | 66  | 43  | 83  | 51  |
error or incorrectly, it is important to try to identify any items omitted in the checklist process. Those particular missed items are very likely to be problematic to the future outcome of the flight. Participant 1 and 4 had higher percentages (19, 18%) of omits as opposed to participant 5 and 6 (5%, 2%).

![Percent of Paper Checklist Items Omitted](image)

*Figure 9. Percentage of Paper Checklist Items Omitted During Each Experimental Phase*

Table 3 illustrates the percent items were observed as omitted in the paper checklist during baseline. Once again, each item was shaded if that item had 50% or more omits. No particular item had 4 or more participants scoring over 50% omits to require shading that item. No particular participant scored 50% or more items omitted to require shading that participant.
### Table 3

**Percentage of Items Omitted in Paper Checklist Baseline**

<table>
<thead>
<tr>
<th>Segment / Item</th>
<th>P1</th>
<th>P2</th>
<th>P3</th>
<th>P4</th>
<th>P5</th>
<th>P6</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Before Takeoff</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Doors</td>
<td>0</td>
<td>0</td>
<td>11</td>
<td>0</td>
<td>33</td>
<td>0</td>
</tr>
<tr>
<td>CAPS Handle</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>33</td>
<td>17</td>
<td>0</td>
</tr>
<tr>
<td>Belts &amp; Harnesses</td>
<td>0</td>
<td>17</td>
<td>0</td>
<td>11</td>
<td>17</td>
<td>0</td>
</tr>
<tr>
<td>Fuel Quantity</td>
<td>0</td>
<td>17</td>
<td>11</td>
<td>56</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Fuel Selector</td>
<td>0</td>
<td>0</td>
<td>22</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Fuel Pump</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Flaps</td>
<td>0</td>
<td>0</td>
<td>11</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Transponder</td>
<td>0</td>
<td>0</td>
<td>22</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Autopilot</td>
<td>0</td>
<td>0</td>
<td>22</td>
<td>33</td>
<td>8</td>
<td>0</td>
</tr>
<tr>
<td>Nav Radio/GPS</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>8</td>
<td>0</td>
</tr>
<tr>
<td>Cabin Heat/Defrost</td>
<td>0</td>
<td>50</td>
<td>33</td>
<td>11</td>
<td>17</td>
<td>0</td>
</tr>
<tr>
<td>Brakes</td>
<td>0</td>
<td>67</td>
<td>0</td>
<td>78</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Power Lever</td>
<td>0</td>
<td>17</td>
<td>11</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Alternator</td>
<td>0</td>
<td>50</td>
<td>22</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Pitot Heat</td>
<td>0</td>
<td>17</td>
<td>22</td>
<td>33</td>
<td>8</td>
<td>0</td>
</tr>
<tr>
<td>Nav Light</td>
<td>0</td>
<td>17</td>
<td>22</td>
<td>33</td>
<td>8</td>
<td>0</td>
</tr>
<tr>
<td>Landing Light</td>
<td>0</td>
<td>17</td>
<td>22</td>
<td>33</td>
<td>8</td>
<td>0</td>
</tr>
<tr>
<td>Annunciator Light</td>
<td>0</td>
<td>33</td>
<td>22</td>
<td>33</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Voltage</td>
<td>0</td>
<td>67</td>
<td>22</td>
<td>11</td>
<td>8</td>
<td>0</td>
</tr>
<tr>
<td>Pitot Heat</td>
<td>0</td>
<td>83</td>
<td>33</td>
<td>78</td>
<td>8</td>
<td>0</td>
</tr>
<tr>
<td>Nav Light</td>
<td>0</td>
<td>83</td>
<td>33</td>
<td>78</td>
<td>8</td>
<td>0</td>
</tr>
<tr>
<td>Landing Light</td>
<td>0</td>
<td>83</td>
<td>33</td>
<td>78</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Magneto</td>
<td>0</td>
<td>0</td>
<td>11</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Ignition Switch-Right</td>
<td>0</td>
<td>0</td>
<td>11</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Ignition Switch-Left</td>
<td>0</td>
<td>0</td>
<td>11</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Engine Parameters</td>
<td>0</td>
<td>83</td>
<td>33</td>
<td>56</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Segment / Item</td>
<td>P1</td>
<td>P2</td>
<td>P3</td>
<td>P4</td>
<td>P5</td>
<td>P6</td>
</tr>
<tr>
<td>----------------</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>----</td>
</tr>
<tr>
<td>Power Lever</td>
<td>0</td>
<td>17</td>
<td>22</td>
<td>11</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Flight Instruments</td>
<td>0</td>
<td>67</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Flight Controls</td>
<td>20</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Trim</td>
<td>20</td>
<td>0</td>
<td>0</td>
<td>22</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Autopilot</td>
<td>20</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Normal Takeoff</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Power Lever</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Engine Parameters</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>17</td>
<td>0</td>
</tr>
<tr>
<td>Brakes</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>17</td>
<td>0</td>
</tr>
<tr>
<td>Elevator Control</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Flaps</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Climb</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Climb Power</td>
<td>60</td>
<td>0</td>
<td>22</td>
<td>0</td>
<td>8</td>
<td>0</td>
</tr>
<tr>
<td>Flaps</td>
<td>20</td>
<td>0</td>
<td>22</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Mixture</td>
<td>80</td>
<td>0</td>
<td>22</td>
<td>11</td>
<td>17</td>
<td>0</td>
</tr>
<tr>
<td>Engine Parameters</td>
<td>80</td>
<td>0</td>
<td>22</td>
<td>11</td>
<td>17</td>
<td>0</td>
</tr>
<tr>
<td>Fuel Pump</td>
<td>0</td>
<td>0</td>
<td>22</td>
<td>11</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Cruise</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fuel Pump</td>
<td>60</td>
<td>0</td>
<td>11</td>
<td>22</td>
<td>17</td>
<td>0</td>
</tr>
<tr>
<td>Cruise Power</td>
<td>80</td>
<td>0</td>
<td>0</td>
<td>22</td>
<td>17</td>
<td>0</td>
</tr>
<tr>
<td>Mixture</td>
<td>80</td>
<td>0</td>
<td>0</td>
<td>22</td>
<td>17</td>
<td>0</td>
</tr>
<tr>
<td>Engine Parameters</td>
<td>80</td>
<td>0</td>
<td>0</td>
<td>22</td>
<td>17</td>
<td>0</td>
</tr>
<tr>
<td>Fuel Flow</td>
<td>80</td>
<td>0</td>
<td>0</td>
<td>22</td>
<td>17</td>
<td>0</td>
</tr>
<tr>
<td>Descent</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Altimeter</td>
<td>80</td>
<td>0</td>
<td>11</td>
<td>0</td>
<td>0</td>
<td>8</td>
</tr>
<tr>
<td>Cabin Heat/Defrost</td>
<td>80</td>
<td>17</td>
<td>44</td>
<td>0</td>
<td>0</td>
<td>8</td>
</tr>
</tbody>
</table>
Table 3—Continued

<table>
<thead>
<tr>
<th>Segment / Item</th>
<th>P1</th>
<th>P2</th>
<th>P3</th>
<th>P4</th>
<th>P5</th>
<th>P6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Landing Light</td>
<td>40</td>
<td>0</td>
<td>11</td>
<td>0</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>Fuel System</td>
<td>80</td>
<td>0</td>
<td>11</td>
<td>0</td>
<td>8</td>
<td>0</td>
</tr>
<tr>
<td>Mixture</td>
<td>60</td>
<td>17</td>
<td>11</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Brake Pressure</td>
<td>80</td>
<td>17</td>
<td>11</td>
<td>0</td>
<td>0</td>
<td>8</td>
</tr>
<tr>
<td><strong>Before Landing</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Seat Belt/Harness</td>
<td>20</td>
<td>0</td>
<td>0</td>
<td>78</td>
<td>8</td>
<td>17</td>
</tr>
<tr>
<td>Fuel Pump</td>
<td>20</td>
<td>0</td>
<td>0</td>
<td>22</td>
<td>0</td>
<td>8</td>
</tr>
<tr>
<td>Mixture</td>
<td>20</td>
<td>0</td>
<td>11</td>
<td>78</td>
<td>0</td>
<td>8</td>
</tr>
<tr>
<td>Flaps</td>
<td>20</td>
<td>0</td>
<td>0</td>
<td>56</td>
<td>0</td>
<td>8</td>
</tr>
<tr>
<td>Autopilot</td>
<td>40</td>
<td>0</td>
<td>0</td>
<td>78</td>
<td>0</td>
<td>8</td>
</tr>
<tr>
<td><strong>After Landing</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Power Lever</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>8</td>
</tr>
<tr>
<td>Fuel Pump</td>
<td>0</td>
<td>0</td>
<td>33</td>
<td>0</td>
<td>0</td>
<td>8</td>
</tr>
<tr>
<td>Flaps</td>
<td>0</td>
<td>0</td>
<td>33</td>
<td>0</td>
<td>0</td>
<td>8</td>
</tr>
<tr>
<td>Transponder</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>8</td>
</tr>
<tr>
<td>Lights</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>8</td>
</tr>
<tr>
<td>Pitot Heat</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>8</td>
</tr>
<tr>
<td><strong>Shutdown</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fuel Pump</td>
<td>0</td>
<td>0</td>
<td>11</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Throttle</td>
<td>0</td>
<td>0</td>
<td>11</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Ignition Switch</td>
<td>60</td>
<td>0</td>
<td>33</td>
<td>33</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Mixture</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>All Switches</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Magnetos</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>ELT</td>
<td>40</td>
<td>83</td>
<td>33</td>
<td>100</td>
<td>0</td>
<td>8</td>
</tr>
<tr>
<td><strong>Average Percent Omitted</strong></td>
<td>19</td>
<td>13</td>
<td>12</td>
<td>18</td>
<td>5</td>
<td>2</td>
</tr>
</tbody>
</table>
Figure 10 shows the percentage of items omitted during the digital checklist segments for each experimental phase. As explained in the methods section, all incorrect and omitted observations were scored as errors. While an item may have been done in error or incorrectly, it is important to try to identify any items omitted in the checklist process. Those particular missed items are very likely to be problematic to the future outcome of the flight. Similar to the paper checklist performance Participant 1 and 4 had higher percentages (24% each) of omits as opposed to participant 5 and 6 (6%, 1%). Several participants (P1, P2, P4, and P5) omitted a higher percentage of items while using the digital checklist. Participant 3 and 6 omitted 1% fewer items using the paper checklist.

Figure 10. Percentage of Digital Checklist Items Omitted During Each Experimental Phase
Table 4 illustrates the percent items were observed as omitted in the paper checklist during baseline. As with the paper checklist, each item was shaded if that item had 50% or more omits. No particular item had 4 or more participants scoring over 50% omits to require shading that item. No particular participant scored 50% or more items omitted to require shading that participant.

Figure 11 illustrates the average percent of paper checklist segments timing errors in each experimental phase. This graph represents errors in timing the use of a particular segment of the checklist. Segments done at the incorrect time during the trial were scored as incorrect or, if skipped, omitted. The paper checklist descent segment was the highest timing error for any phase at 43% of all segment timing errors. The before landing segment was second (39%) and the climb segment was third (38%). All timing errors were reduced during intervention. Timing errors were eliminated during reversal.

Figure 12 shows the average percent of digital checklist segments timing errors in each experimental phase. The digital checklist before landing segment was the highest timing error for any phase at 42% of all segment timing errors. The descent segment was second (39%) and the climb segment was third (22%). Timing errors for the segments were reduced during intervention and were eliminated in all segments during reversal excluding the digital descent segment.
Table 4

*Percentage of Items Omitted in Digital Checklist Baseline*

<table>
<thead>
<tr>
<th>Segment / Item</th>
<th>P1</th>
<th>P2</th>
<th>P3</th>
<th>P4</th>
<th>P5</th>
<th>P6</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Before Takeoff</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Doors</td>
<td>0</td>
<td>0</td>
<td>11</td>
<td>11</td>
<td>25</td>
<td>0</td>
</tr>
<tr>
<td>CAPS Handle</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>22</td>
<td>8</td>
<td>0</td>
</tr>
<tr>
<td>Belts &amp; Harnesses</td>
<td>0</td>
<td>17</td>
<td>0</td>
<td>0</td>
<td>25</td>
<td>0</td>
</tr>
<tr>
<td>Fuel Quantity</td>
<td>0</td>
<td>17</td>
<td>44</td>
<td>89</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Fuel Selector</td>
<td>0</td>
<td>0</td>
<td>22</td>
<td>22</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Fuel Pump</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>11</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Flaps</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>11</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Transponder</td>
<td>0</td>
<td>0</td>
<td>33</td>
<td>11</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Autopilot</td>
<td>0</td>
<td>0</td>
<td>33</td>
<td>44</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Nav Radio/GPS</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>11</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Cabin Heat/Defrost</td>
<td>0</td>
<td>83</td>
<td>22</td>
<td>33</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Brakes</td>
<td>0</td>
<td>67</td>
<td>0</td>
<td>100</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Power Lever</td>
<td>0</td>
<td>17</td>
<td>11</td>
<td>11</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Alternator</td>
<td>0</td>
<td>33</td>
<td>11</td>
<td>11</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Pitot Heat</td>
<td>0</td>
<td>67</td>
<td>22</td>
<td>22</td>
<td>8</td>
<td>0</td>
</tr>
<tr>
<td>Nav Light</td>
<td>0</td>
<td>67</td>
<td>22</td>
<td>22</td>
<td>8</td>
<td>0</td>
</tr>
<tr>
<td>Landing Light</td>
<td>0</td>
<td>50</td>
<td>22</td>
<td>22</td>
<td>8</td>
<td>0</td>
</tr>
<tr>
<td>Annunciator Light</td>
<td>0</td>
<td>50</td>
<td>22</td>
<td>22</td>
<td>8</td>
<td>0</td>
</tr>
<tr>
<td>Voltage</td>
<td>0</td>
<td>67</td>
<td>22</td>
<td>11</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Pitot Heat</td>
<td>0</td>
<td>100</td>
<td>33</td>
<td>100</td>
<td>17</td>
<td>0</td>
</tr>
<tr>
<td>Nav Light</td>
<td>0</td>
<td>100</td>
<td>33</td>
<td>100</td>
<td>17</td>
<td>0</td>
</tr>
<tr>
<td>Landing Light</td>
<td>0</td>
<td>100</td>
<td>33</td>
<td>100</td>
<td>17</td>
<td>0</td>
</tr>
<tr>
<td>Magnetos</td>
<td>0</td>
<td>0</td>
<td>11</td>
<td>22</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Ignition Switch-Right</td>
<td>0</td>
<td>0</td>
<td>11</td>
<td>11</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Ignition Switch-Left</td>
<td>0</td>
<td>0</td>
<td>11</td>
<td>11</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Engine Parameters</td>
<td>0</td>
<td>67</td>
<td>22</td>
<td>67</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Segment / Item</td>
<td>P1</td>
<td>P2</td>
<td>P3</td>
<td>P4</td>
<td>P5</td>
<td>P6</td>
</tr>
<tr>
<td>---------------------</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>----</td>
</tr>
<tr>
<td>Power Lever</td>
<td>0</td>
<td>0</td>
<td>11</td>
<td>11</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Flight Instruments</td>
<td>0</td>
<td>50</td>
<td>0</td>
<td>11</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Flight Controls</td>
<td>0</td>
<td>0</td>
<td>11</td>
<td>11</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Trim</td>
<td>0</td>
<td>0</td>
<td>11</td>
<td>33</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Autopilot</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>11</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

**Normal Takeoff**

<table>
<thead>
<tr>
<th>Segment / Item</th>
<th>P1</th>
<th>P2</th>
<th>P3</th>
<th>P4</th>
<th>P5</th>
<th>P6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power Lever</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Engine Parameters</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Brakes</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Elevator Control</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Flaps</td>
<td>0</td>
<td>17</td>
<td>0</td>
<td>11</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

**Climb**

<table>
<thead>
<tr>
<th>Segment / Item</th>
<th>P1</th>
<th>P2</th>
<th>P3</th>
<th>P4</th>
<th>P5</th>
<th>P6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Climb Power</td>
<td>60</td>
<td>0</td>
<td>11</td>
<td>0</td>
<td>8</td>
<td>0</td>
</tr>
<tr>
<td>Flaps</td>
<td>40</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Mixture</td>
<td>60</td>
<td>0</td>
<td>0</td>
<td>11</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Engine Parameters</td>
<td>60</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>Fuel Pump</td>
<td>20</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>8</td>
</tr>
</tbody>
</table>

**Cruise**

<table>
<thead>
<tr>
<th>Segment / Item</th>
<th>P1</th>
<th>P2</th>
<th>P3</th>
<th>P4</th>
<th>P5</th>
<th>P6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel Pump</td>
<td>80</td>
<td>0</td>
<td>11</td>
<td>11</td>
<td>33</td>
<td>0</td>
</tr>
<tr>
<td>Cruise Power</td>
<td>80</td>
<td>0</td>
<td>11</td>
<td>11</td>
<td>33</td>
<td>0</td>
</tr>
<tr>
<td>Mixture</td>
<td>80</td>
<td>0</td>
<td>11</td>
<td>11</td>
<td>33</td>
<td>0</td>
</tr>
<tr>
<td>Engine Parameters</td>
<td>80</td>
<td>0</td>
<td>11</td>
<td>22</td>
<td>33</td>
<td>0</td>
</tr>
<tr>
<td>Fuel Flow</td>
<td>80</td>
<td>0</td>
<td>11</td>
<td>11</td>
<td>33</td>
<td>0</td>
</tr>
</tbody>
</table>

**Descent**

<table>
<thead>
<tr>
<th>Segment / Item</th>
<th>P1</th>
<th>P2</th>
<th>P3</th>
<th>P4</th>
<th>P5</th>
<th>P6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Altimeter</td>
<td>60</td>
<td>0</td>
<td>0</td>
<td>11</td>
<td>8</td>
<td>0</td>
</tr>
<tr>
<td>Cabin Heat/Defrost</td>
<td>60</td>
<td>0</td>
<td>0</td>
<td>11</td>
<td>17</td>
<td>0</td>
</tr>
<tr>
<td>Landing Light</td>
<td>40</td>
<td>0</td>
<td>0</td>
<td>11</td>
<td>8</td>
<td>0</td>
</tr>
<tr>
<td>Segment / Item</td>
<td>P1</td>
<td>P2</td>
<td>P3</td>
<td>P4</td>
<td>P5</td>
<td>P6</td>
</tr>
<tr>
<td>----------------------</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>----</td>
</tr>
<tr>
<td>Fuel System</td>
<td>60</td>
<td>0</td>
<td>0</td>
<td>11</td>
<td>8</td>
<td>0</td>
</tr>
<tr>
<td>Mixture</td>
<td>60</td>
<td>0</td>
<td>0</td>
<td>11</td>
<td>8</td>
<td>0</td>
</tr>
<tr>
<td>Brake Pressure</td>
<td>60</td>
<td>0</td>
<td>0</td>
<td>11</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Before Landing

| Seat Belt/Harness   | 60 | 0  | 0  | 100| 17 | 8  |
| Fuel Pump           | 20 | 0  | 0  | 44 | 0  | 0  |
| Mixture             | 20 | 0  | 0  | 100| 0  | 0  |
| Flaps               | 20 | 0  | 0  | 67 | 0  | 0  |
| Autopilot           | 40 | 0  | 0  | 89 | 0  | 0  |

After Landing

| Power Lever         | 80 | 0  | 22 | 0  | 0  | 0  |
| Fuel Pump           | 80 | 0  | 11 | 11 | 0  | 0  |
| Flaps               | 80 | 0  | 11 | 0  | 0  | 0  |
| Transponder         | 80 | 0  | 22 | 0  | 0  | 0  |
| Lights              | 80 | 0  | 22 | 0  | 0  | 0  |
| Pitot Heat          | 80 | 0  | 22 | 0  | 0  | 0  |

Shutdown

| Fuel Pump           | 0  | 0  | 0  | 22 | 0  | 0  |
| Throttle            | 0  | 0  | 0  | 0  | 0  | 0  |
| Ignition Switch     | 0  | 0  | 0  | 11 | 0  | 0  |
| Mixture             | 0  | 0  | 0  | 0  | 0  | 0  |
| All Switches        | 0  | 0  | 33 | 0  | 0  | 0  |
| Magnetos            | 0  | 0  | 0  | 0  | 0  | 0  |
| ELT                 | 80 | 83 | 44 | 89 | 0  | 8  |

Average Percent Omitted

| 24 | 15 | 11 | 24 | 6  | 0.5 |
Figure 11: Average Percent Paper Checklist Segment Timing Errors Per Phase

Figure 12: Average Percent of Digital Segment Timing Errors Per Phase
CHAPTER IV

DISCUSSION

As numerous studies and accidents have shown (Adamski & Stahl, 1997; Degani, 1992, 2002; Degani & Wiener, 1990, 1993; Federal Aviation Administration [FAA], 1995, 2000; Gross, 1995; Helmreich, Wilhelm, Klinect, & Merritt, 2001; Klinect, Murray, Merritt, & Helmreich, 2003; Lautmann & Gallimore, 1987; NTSB, 1969, 1975, 1982, 1988a, 1988b, 1989, 1990, 1997, 1998, 2001, 2002, 2003a, 2003b, 2004a, 2004b, 2006, 2007a, 2007b, 2008a, 2008b, 2008c, 2008d; Turner, 2001; Turner & Huntley, 1991), managing tasks and reducing error in a high risk environment such as flight can be enhanced by using flight checklists. This research is a follow-up to the study by Rantz, Dickinson, Sinclair, and Van Houten (in press), which evaluated the effects of feedback and praise on the use of a simple personal computer aviation training device and a paper checklist. The present study confirmed the findings of the former study, while using a much higher level of simulation. The current study additionally included comparing pilot’s performance using both paper and electronic checklists during all phases of the experiment. The results of the present study also suggest using graphic feedback and praise can simultaneously improve checklist reading performance in both traditional paper and modern digital presentation modes. The results also indicated, contrary to common opinion, that the use of a digital checklist did not lead to a reduction in errors compared to the traditional paper checklist in a normal workload environment. This study also suggests a pilot’s checklist performance, regardless of presentation method, may be
influenced by common underlying rule-based behaviors (learning history) or certain environmental variables.

Similar to data collected by the LOSA teams (Helmreich et al., 1999; Helmreich et al., 2001; Klinect et al., 2003), and observed by (Rantz et al., in press), this study uncovered a wide variety of checklist error during baseline, regardless whether the checklist was presented using a traditional paper or Avidyne digital format. Performance between paper and digital checklist presentations was very consistent within individuals and between experimental phase changes. Checklist performance using both paper and digital checklist formats increased to high levels of accuracy after participants were given post-flight feedback and praise for accurate checklist use, and remained at high levels after feedback and praise was removed. While this study suggests the form of checklist presentation has little influence on the accuracy of checklist performance, pilot behavior, while using both forms of checklist presentation, is influenced by graphic feedback and praise.

Overall across all participants, the average percentage of paper checklist items completed correctly per trial increased from 38% items correct during the baseline phase to 90% items correct during the intervention phase. Digital checklist items increased from 39% items completed correctly to 89% items correct during intervention and averaged 99% during the last 3 session of the treatment phase for the paper checklist and 95% of the last 3 sessions with the digital checklist. Improvement maintained at near perfect levels for participants during the reversal phase with 100% paper checklist items correct and 99% digital items checklist items correct. Increases in performance have been observed in other studies after treating with graphic feedback and praise (Austin et al.,
71

2005; Crowell et al., 1988; Wilk & Redmon, 1998). The feedback package used in this study proved effective in both checklist presentation methods. The value of any intervention used to improve performance can be measured by decrements in future performance. Therefore maintenance probes data were collected from each participant after a 60-80 day delay following completion of the reversal phase. The probe data suggests the potential of the feedback intervention packet to maintain appropriate checklist behavior at nearly full strength, for both presentation methods, over at least a period an 80 days.

Given the scripted pretrial statement that participants should use the checklists as they would during any normal flight, baseline checklist performance, using both paper and digital, varied significantly across participants. While half of the participant’s performance reached a poor performance plateau of stability during baseline, the performance of the remaining half continued to decline to extremely poor levels. Environmental variables that could account for this level of performance may include (a) inadequate curricular planning resulting in lack of rule-based antecedents (knowledge) regarding the importance of checklists, (b) lack of actual or simulated flight training to identify salient environmental stimuli to prompt checklist behavior, (c) absent or infrequent feedback directed at checklist use during instructional flight, (d) absent or infrequent feedback directed at checklist use during non-instructional flight, (e) Lack of clear contingencies regarding aversive consequences for performing checklists poorly while in a simulated environment, or (f) any combination of these variables.

A review of the Private Pilot training curriculum (Western Michigan University, 2004) revealed that training in checklist use specifically occurred during lessons 1-6 with
level 1 for specific performance criteria standards of checklist use and level 2 for preflight procedures for lesson 18-19. However the manual contained no evidence articulating formal follow up assessment or feedback specifically for checklist use. A further review of the Instrument Pilot training curriculum (Western Michigan University, 2004) showed checklist use was required during most of the lessons (Appendix S). It appears that greater emphasis is being placed on using and holding a higher criteria standard for checklist use; however as with the Private Pilot curriculum, there is no requirement for formal follow up assessment or feedback specifically for checklist use during either instructional or non-instructional flight.

Depending on the location of the aircraft during a particular flight, salient stimuli should be obvious to the flight crews that should occasion the start of particular checklist segments. The training curriculum operations manual did not contain lesson plans describing specific environmental stimuli that should prompt pilots to begin using segments of the checklist. However the *Pilot Operating Handbook* (2003) for the Cirrus SR20 does contain descriptors identifying specific environmental stimuli for checklist prompts. Those checklist segments include, a) before starting engine, paired stimuli-prior to engine start, b) engine start, paired stimuli-start engine, c) before taxi, paired stimuli-prior to taxi, d) taxing, paired stimuli-during taxi/after taxi, e) before takeoff, paired stimuli-at end of runway/in run up area and prior to takeoff, f) takeoff, paired stimuli-prior to takeoff, g) climb, paired stimuli-1000 feet above the ground, h) cruise, paired stimuli-reaching desired or assigned cruise altitude, i) descent, paired stimuli-top of the descent into the destination, j) before landing, paired stimuli-for visual flight rules, downwind leg, for instrument flight rules, 2 nautical miles prior to final approach fix, k)
after landing, paired stimuli-after clearing active runway, 1) shutdown, paired stimuli-
ready to shutdown. Perhaps while reading the POH, pilots memorize these prompts, again
no evidence of assessing the understanding of these prompts could be found in the
curricular documents. Similar studies in behavior-based safety research have observed
that using antecedents alone, or rules designed to improve safe behavior are not as
effective as one would expect (Austin, Alvero, & Olson, 1998; Engerman, Austin, &
Bailey, 1997; Ludwig & Geller, 1997; Olson & Austin, 2001; Streff, Kalsher, & Geller,
1993). Thus, rule statements regarding the importance of consistent checklist use may be,
at best, problematic. Given this condition, combined with the difficulty finding rule
statements within the training lessons, impart unclear rule-based objectives for proper
behavior regarding checklist use.

In a preemptive effort not to bias the present study by specifically inquiring about
past checklist use or its importance, no pre-test of stimuli prompts or rules for checklist
use was given to the participants before the experiment. Figures 6 and 7 show the average
percentage of timing errors using the checklists, these timing errors very likely indicate
missed prompts by the participants. These segment timing errors appear to be nearly
identical between both checklist presentation methods. Paper and digital checklist
segment timing errors in baseline occurred during the climb, cruise, descent, and before
landing segments of flight. Given the overall improvement to nearly perfect performance
after the feedback intervention, participants may have forgotten or ignored the prompts
during baseline or they may have believed nothing aversive or bad would happen to them
while operating in a simulated flight environment.
Four participants showed a sudden level change in correct items completed after the first intervention trial (P1, P2, P3, and P5) during both methods of checklist presentation. Additionally, all four maintained high performance levels by correctly completing checklist items during maintenance condition and the probe measure. With a rapid level change in performance after the start of the intervention and the maintenance of that performance through reversal and the probe phase, it is likely that checklist use was controlled by rule-governed behavior. Both Michael (1993) and Skinner (1974) suggest that when a sudden change in behavior is observed following an intervention it is likely a result of rule governed as opposed to direct acting contingencies. “Rules can usually be learned more quickly than the behavior shaped by the contingencies they describe. Most people can learn the instruction ‘Push down on the gearshift lever before moving it into the reverse position’ more readily that the actual shifting movement, especially if the lever does not move easily or if, in other cars with which the driver is familiar, it does not need to be pushed down. Rules make it easier to profit from similarities between contingencies. Rules are particularly valuable when contingencies are complex or unclear or for any other reason not very effective.” (Skinner 1974 p. 138). Since immediate improvements in both checklist segment timing and correctly completing checklist items occurred after feedback, participants likely recalled pre-existing rule statements or developed new rule statements regarding external environmental prompts to begin specific items segments. While the process involved in changing rules is not clear, it is likely new rules formed after receiving the feedback intervention. Thus, the new rules may have paired appropriate checklist reading behavior with both the checklist items and specific prompting stimuli in the flight environment.
The appropriate checklist behavior remained strong even after the feedback was withdrawn during reversal and during the probe period (Galizio, 1979; Shimoff, Catania, & Matthews, 1981). Since this process was observed while participant’s used the paper and the digital checklist, the new rules seem to be equally effective in improving behavior while using both presentation methods.

The remaining two participants (P4 and P6) initially did not show an immediate level change following the introduction of the feedback and praise condition. In fact participant 6 actually decreased slightly in the first digital checklist trial after the intervention. This reduction was only temporary as the following trials demonstrated, participant 6 rapidly improved for the remaining trails. This small initial effect size may have been a result of participants contacting direct acting contingencies. The graphically illustrated feedback given to all participants included a specific number of checklist items that were incorrect or omitted and not the specific items (Appendix O). Without identifying specific correct or incorrect items, it becomes difficult for the participant to compare old rule statements or develop new rule statements to immediately improve performance to perfect levels. This course grained feedback may have resulted in participants re-stating old rules to achieve rapid initial improvement in checklist performance. Given the gradual improvement in performance from the graphic feedback intervention, participants may have been exposed to direct acting contingencies of the feedback as evident by increasing performance using a trial and error method of behavior. More likely checklist behavior came under the control of both rule statements and direct acting contingencies. However to what extent each controlled behavior is unknown. On the other hand, rule-governed behavior can appear to be contingency-governed behavior
(Shimoff et al., 1986). No participant demonstrated perfect initial performance after the first intervention trial. While all participants’ initial effect size varied, all demonstrated some type of trial and error learning curve. Since all of these participants maintained their high level of checklist performance, using both paper and digital presentation methods, after removal of feedback and during the probe period, it is likely new rule statements were devised.

Observations of baseline checklist behavior using paper and digital checklists revealed many unique and nonstandard forms of checking items. These behaviors varied across participants and segments yet each nonstandard behavior, unique to a particular individual, was strong and consistent for that individual. Examples include nonstandard call outs for checked items such as, “Ps and Ts in the green” referring to oil pressure and engine temperatures checks prior to take off, making the statement “load” referring to checking voltage, alternator, and annunciator lights during the before takeoff checks, and “everything looks good” referring to all before takeoff items. There was also evidence of hand waving behavior that simulated the proper behavior of touching or pointing to the checklist item and confirming the status of each item.

One can only speculate how checklist behavior could drift into uniquely novel performances within each participant. Perhaps nonstandard call outs for items were used by flight instructors and those rule statements were adopted by the participant. Participants may not be consistently exposed to reinforcing feedback in the instructional and non instructional environment regarding appropriate checklist behavior. Participants who once performed the checklist behaviors correctly may have discovered the new behavior to be more expeditious, thus taking less time; the new behavior has reinforcing
consequences and is less aversive to overall checklist completion. Safety consultant, Aubrey Daniels says of consequences in the work environment, "Every behavior has a consequence. In fact behavior can be viewed as a function of its consequence. That is, consequences do not simply influence what someone does; they control it. In order to understand why people do what they do, instead of asking, 'Why did they do that?' ask, 'What happens to them when they do that?' When you understand the consequences, you are able to understand the behavior" (Daniels, 1989, p. 23).

The power of graphic feedback, to positively change paper and digital checklist behavior, was observed in a particular behavior shift from checking items using a memorized ‘flow’ technique for certain segments to a ‘check and do’ technique for the same segments after intervention within certain individuals. The flow technique is used to check each item in a memorized pattern sequence followed by reviewing the checklist segment to verify that each item has been completed. The check and do technique is to read an item from the checklist and check that item before returning to the checklist to check the next item. Since this study had not anticipated such a shift in checklist use, not all observations can confirm this behavior shift for all participants after intervention. Perhaps this shift in checklist use occurred as a result of weak memorized item sequenced rule statements when the participant may have discovered, after feedback, that they could not remember all the items. This change in behavior after the feedback intervention, illustrates the likely strength of graphic feedback and the potential control it exerted over both checklist presentations. To what extent participants developed stronger memorized item sequenced rule statements and returned to the memorized flow as a result of the feedback consequences, is unknown and should be the focus of a future study.
It is likely that all participants developed some form of new rules, the types and strength of those new rules may have been different. The rules may have been related to avoiding an unsafe condition. For example, participants may have developed a rule such as “I am not using my checklist correctly. If I do not improve using my checklist when I actually fly, I might make a mistake and have an incident or accident”. If this type of rule was developed, accurate checklist use might well generalize to actual flight. Another type of rule may have developed given the flight simulated condition for the participant while being observed. A rule statement such as, “I don’t want to look bad and perform below what I can usually do, especially when a more experienced pilot is observing me”. This rule could relate to the non threat environment of the simulator or one contingency for behavior change was the condition of being observed and evaluated. However after the study, no statements relating to the non-threat environment of the simulator or being evaluated was heard from the participants. During the post study briefing, some participants related new rule statement such as, “I always double check to make sure I covered everything”, and “I emphases the checklist more to myself now and try to complete all checklists 100% accurate instead of breezing through them as I did before”. Two participants made new rule statements to properly state each checklist item aloud and to say the correct response to each checklist item. Another participant stated, “Try to focus more on accuracy of checklist completion. ‘Announce’ the end or beginning of checklists”. Perhaps new rules such as these, pairing the sight of the checklist item and hearing the call out auditory of the checklist item with correctly completing the checklist item, will partially reinforce the continued use of the checklist. Bacon et al. (1982) proposed continued use of the checklist can not be maintained by instructions alone,
"Another likely reason for continued use was the pairing of checklist usage with task completion. Use of the checklist increased the likelihood of subsequent checklist usage because workers were more successful in completing their tasks during intervention. Whether task completion directly affects checklist usage, or if it is related to some form of self-instructions concerning checklists is a question for the future" (p. 23).

There are several possibilities for future research. The possibilities most directly related to the current study would include: (a) replicating the current study and ascertaining whether checklist compliance transfers to actual flight; (b) replicating the current study using control and experimental groups during simulated training flights thereby comparing a current and modified checklist curriculum and; (c) replicating the current study and ascertaining how a voice prompting checklist compares with traditional paper and digital checklist compliance in a simulated environment.

Given the results of the current study, more research is required to determine to what extent new rules form under a feedback and praise intervention and specifically how those new rules influence checklist behavior. Possible future research should examine the proportion of new rules and contingency shaped behavior within the environment influence and maintain checklist behaviors.

Because this study was conducted in a normal workload environment, further study should increase the workload demands of the pilots to determine if increased distractions cause higher errors using either paper or digital checklists. Even while operating in a normal workload condition, many errors occurred during elevated workload segments of the checklist. Generally these segments included the climb, descent and before landing portions. Providing increased workload may reveal greater differences
in checklist performance given how the checklist is presented. Increased workload may
also evaluate the effectiveness of the feedback intervention package regarding initial
effect sizes and duration of effect.

This study demonstrated in a flight training device, using traditional paper or
digital checklists, in a training environment, resulted in no performance differences
between the two checklist presentations. This statistically non significant conclusion may
run counter to industry opinions claiming the digital format is superior over paper. This
claim may be true in some specific operational environments; however that can not be
concluded while operating under the conditions of this study. While both checklists have
their strengths, the inherent weakness of each are comprised of, a) the lack of pre-existing
effective rule statements regarding the consistent and proper use of the checklist, b) the
lack of salient stimuli recognition to prompt the beginning of each checklist and, c) the
lack of effective reinforcers to increase and maintain checklist use. The results of the
study are certain: There are no differences between using traditional paper and modern
Avidyne digital checklists in a simulated training environment and graphic feedback and
praise can improve checklist reading performance for both paper and digital checklists.
REFERENCES


Civil Aviation Authority. (2002). *CAP 676 Guidelines for the design and presentation of emergency and abnormal checklists*. Safety Regulation Group, Civil Aviation Authority. West Sussex, UK: Author.


Appendix A

Participant Eligibility Questionnaire
Participant Eligibility Questionnaire

Please complete the following questions. All information you provide will remain confidential.

Participant Name ________________________  Participant Number _________________

1. Are you instrument rated? Yes _____ No _____

2. How many total actual or simulated instrument hours have you logged?
   _____ hrs

3. What is your total flight time?
   _____ hrs

4. How many total ILS approaches have you done?
   _____ hrs

5. Have you used a Cirrus SR20 Flight Training Device (FTD) for flight practice?
   Yes_____ No _____

6. If you answered yes to Question 5; how many hours would you estimate you have used the FTD for flight practice?
   _____ hrs

7. Approximately how many hours have you flown in the past 3 months? _____ hrs

8. How many hours have you flown solo or as PIC after your Private Certificate? _____ hrs

9. Approximately how many total landings have you made since learning to fly? _____

10. Approximately how many hours do you have in a Cirrus SR20 or SR22? _____ hrs

11. Approximately how long can you devote to this study? _________________ end date.

12. Is it possible for you to return after the study is complete for one session?
    Yes_____ No _____

13. What other aircraft types have you flown? ______________________________________

14. How long has it been since you have flown another aircraft other that the SR20 or SR22? _____

15. How many hours did it take you to solo? _____ How many hours did it take you to get your Private Pilot Certificate? _____
Appendix B

Recruitment Flyer
Participants Sought for an Instrument Flight Research Study

I am looking for Instrument rated pilots to participate in a study designed to determine how pilots perform flying instrument approach procedures using the Cirrus SR20 Flight Training Device (FTD).

Participants will receive extra FTD simulation instrument flight time to practice local approach procedures in this study. To be eligible to participate you must have a valid instrument rating.

Sessions will be conducted in the simulation building in Battle Creek. The study will last 5-6 weeks (9-11 sessions total). Sessions will be about 2 hours and you will be asked to attend two sessions per week. You will be asked to fly 4 instrument approaches during each session.

If you are interested in learning more about the study, please contact Professor Rantz. Be sure to provide your name, e-mail address or telephone number, and the times you can be reached.

All information is confidential.

For more information contact Professor Rantz:

E-mail: william.rantz@wmich.edu
or
Phone: (269) 492-2881
Appendix C

Recruitment Script
Recruitment Script

Hi. I'm Professor Rantz I am a faculty member in the College of Aviation and a doctoral student in the Psychology Department at Western Michigan University. I am conducting a research study as part of my doctoral training. I am looking for instrument rated pilots to participate in this study which is designed to determine how pilots perform flying instrument approach procedures using a Cirrus Flight Training Device.

Participants will receive extra CIRRUS SR20 FTD simulation instrument flight time to practice local approach procedures in this study. To be eligible to participate, you must possess a valid instrument rating.

Sessions will be conducted in the simulation building in Battle Creek. The study will last 5-6 weeks (9-11 sessions total). Sessions will be about 2 hours and you will be asked to attend two sessions per week. You will be asked to fly 4 instrument approaches during each session.

You may withdraw from this research study at any time. Your participation is completely voluntary. Your willingness to participate in the study or your withdrawal from the study at a later time will not affect your grade in this or any other class.

Thank you for your time!
Appendix D

Informed Consent Form
Western Michigan University
Department of Psychology

Instrument Landing Approaches Using a Cirrus SR20 Flight Training Device

Principal Investigator: Ron Van Houten, Ph.D.
Student Investigator: William Rantz

You are being invited to participate in a research study designed to determine how well pilots can fly an instrument landing approach using a Cirrus SR20 Flight Training Device (FTD). The study is being conducted by Professor William Rantz who is both a faculty member in the College of Aviation at Western Michigan University and a graduate student in the Department of Psychology at Western Michigan University. Professor Rantz is conducting this study as part of his doctoral training in the Department of Psychology. Dr. Ron Van Houten is his graduate advisor.

Eligibility requirements. To be eligible to participate, you must have a private pilot certificate and a valid instrument rating. You also must be able to attend at least two two-hour sessions each week for 4-5 weeks.

Study procedures and length of participation. During each session, you will fly three standard instrument landing system approaches to an airport using a FTD. Each session will last approximately two hours and you will be asked to attend from 9 to 11 experimental sessions over a 4 to 5-week period. The total number of sessions you will attend will depend upon your performance. Your performance on the FTD will be assessed during the first session, however, and there is a possibility that your participation will be terminated after the first session based on that assessment.

Digital Video and Audio Recording. All sessions will be digitally recorded to enable us to accurately assess your flight performance. The recordings will be held in strictest confidence. The digital computer file will be identified only by a number that is assigned to you. The recordings will not be used for public presentations. At the end of the study, these recordings will be destroyed.

Risks. You may experience some physical minor fatigue, or stress when you are performing the instrument landing approaches. To offset this, you will not begin the next flight in the session until you are ready. You may also stop the session at any time by telling the experimenter you do not want to continue.

Benefits. You may improve your flight and instrument landing approach skills by repeatedly flying the simulated flight patterns. You may also learn about research regarding how post-flight feedback may improve performance. The information obtained from the study may suggest ways to improve the flight training of student pilots.
Confidentiality. All information obtained in this study will remain strictly confidential. When results of the study are presented publicly, you will not be identified. You will be assigned a number and that number will be used to identify your data.

Voluntary participation. Your participation in this study is completely voluntary. You may withdraw at any time without penalty. Your participation in the study, or your withdrawal from the study, will not affect your grades in any of your courses. If you are currently enrolled in a class taught by Professor Rantz, your willingness to participate or your later withdrawal from the study will not affect your grade in the current class or any future class you may take with him. At the end of the study, the experimenter will answer any questions you have and explain how your data will help to learn more about how post-flight feedback may improve performance.

Who to contact if I have questions. If you have any questions about this study you can call Professor Rantz at 269-492-2881. You may also call Professor Rantz’s faculty advisor, Dr. Van Houten, at 387-4471. In addition, you may also contact the Chair, Human Subjects Institutional Review Board (387-8293), or the Vice President for Research (387-8298), if questions or problems arise during the course of the study.

This consent document has been approved for use for one year by the Human Subjects Institutional Review Board as indicated by the stamped date and signature of the board chair in the upper right corner. Do not participate in this study if the stamped date is older than one year.

Your signature below indicates that you have read the above information and agree to participate in the study.

Participant Signature: ________________________ Date: ________

Please keep the attached copy of this form for your records.
Appendix E

Human Subjects Institutional Review Board
Letter of Approval
Date: March 3, 2008

To: Ron Van Houten, Principal Investigator
   William Rantz, Student Investigator for dissertation
   Bryan Hilton, Student Investigator

From: Amy Naugle, Ph.D., Chair

Re: HSIRB Project Number: 08-02-42

This letter will serve as confirmation that your research project entitled “Comparing the Accuracy of Performing Digital and Paper Checklists Using a Feedback Intervention Package during Normal and High Workload Conditions in Simulated Flight” has been approved under the expedited category of review by the Human Subjects Institutional Review Board. The conditions and duration of this approval are specified in the Policies of Western Michigan University. You may now begin to implement the research as described in the application.

Please note that you may only conduct this research exactly in the form it was approved. You must seek specific board approval for any changes in this project. You must also seek reapproval if the project extends beyond the termination date noted below. In addition, if there are any unanticipated adverse reactions or unanticipated events associated with the conduct of this research, you should immediately suspend the project and contact the Chair of the HSIRB for consultation.

The Board wishes you success in the pursuit of your research goals.

Approval Termination: March 3, 2009
Appendix F

Technical Flight Pattern Parameters and Narration
NORMAL WORKLOAD-Technical Flight Pattern Parameters and Narration
Flight Pattern 1 KBTL

(EXPERIMENTER): Session start, please begin. Contact tower when ready for takeoff.

Using flow pattern-Before Takeoff checks completed (31 checklist items)

(PARTICIPANT): Battle Creek Tower Western 45 ready for departure runway 23.

(EXPERIMENTER): Western 45 you are cleared for departure. Fly runway heading climb and maintain 3,000'.

(PARTICIPANT): Fly runway heading climb and maintain 3,000' Western 45

Using do-list-Normal Takeoff checks completed (5 checklist items)

After reaching 1000' AGL

Using flow pattern-Climb checks completed above 1000' (5 checklist items)

(EXPERIMENTER): Western 45 contact Kalamazoo Approach on 119.2.

(PARTICIPANT): Contacting Kalamazoo Approach on 119.2 Western 45.

(PARTICIPANT): Kalamazoo Approach Western 45 is with you heading 230 climbing to 3,000'.

(EXPERIMENTER): Western 45 roger.

(EXPERIMENTER): Western 45 turn left heading of 120.

(PARTICIPANT): Turning left to a heading of 120 Western 45.

Using flow pattern-Cruise checks complete after level at 3,000' (5 checklist items)

(EXPERIMENTER): Western 45 turn left heading of 050 descend and maintain 2,500'.

(PARTICIPANT): Turning left to a heading of 050 descending to 2,500' Western 45.

Using flow pattern-Descent checks complete prior to IAF and 2,500' (6 checklist items)

(EXPERIMENTER): Western 45 turn left to a heading of 320.
(PARTICIPANT): Turning left to a heading of 320 Western 45.

(EXPERIMENTER): Western 45 turn left to a heading of 270 cleared for the ILS 23 contact Battle Creek Tower 118.1.

(PARTICIPANT): Contacting Battle Creek Tower on 118.1 Western 45.

(PARTICIPANT): Battle Creek Tower this is Western 45 on the ILS 23.

(EXPERIMENTER): Western 45 you are cleared to land runway 23.

(PARTICIPANT): Cleared to land runway 23 Western 45.

Using flow pattern—Before Landing checks complete prior to FAF (5 checklist items)

2 miles outside FAF—Power 50% 22” MP, flaps 50%, airspeed 100 knots, maintain 2,500’ until established on the glide slope.

FAF inbound and established on glide slope—Power 25% 12” MP, flaps 50%, airspeed 100 knots, descent rate of 500 feet per minute is established.

Short final—Power as required, flaps 100%, airspeed 75 knots over threshold of runway.

(EXPERIMENTER): Western 45 turn left to exit the active runway and park.

Using flow pattern—After Landing checks (6 items)

Using do-list—Shutdown checks (7 items)

(EXPERIMENTER): This session is over. Please relax and I will join you in a few minutes.
NORMAL WORKLOAD-Technical Flight Pattern Parameters and Narration
Flight Pattern 2 KAZO

(EXPERIMENTER): Session start, please begin. Contact tower when ready for takeoff.

Using flow pattern-Before Takeoff checks completed (31 checklist items)

(PARTICIPANT): Kalamazoo Tower Western 45 ready for departure runway 35.

(EXPERIMENTER): Western 45 you are cleared for departure. Fly runway heading climb and maintain 3,500’.

(PARTICIPANT): Fly runway heading climb and maintain 3,500’ Western 45

Using do-list-Normal Takeoff checks completed (5 checklist items)

After reaching 1000’ AGL

Using flow pattern-Climb checks completed above 1000’ (5 checklist items)

(EXPERIMENTER): Western 45 contact Kalamazoo Approach on 121.2.

(PARTICIPANT): Contacting Kalamazoo Approach on 121.2 Western 45.

(PARTICIPANT): Kalamazoo Approach Western 45 is with you heading 350 climbing to 3,500’.

(EXPERIMENTER): Western 45 roger.

(EXPERIMENTER): Western 45 turn left heading of 260.

(PARTICIPANT): Turning left to a heading of 260 Western 45.

Using flow pattern-Cruise checks complete after level at 3,500’ (5 checklist items)

(EXPERIMENTER): Western 45 turn left heading of 170 and descend to 3,000’.

(PARTICIPANT): Turning left to a heading of 170 and descending to 3,000’ Western 45.

Using flow pattern-Descent checks complete prior to IAP and 3,000’ (6 checklist items)

(EXPERIMENTER): Western 45 turn left to a heading of 080.
(PARTICIPANT): Turning left to a heading of 080 Western 45.

(EXPERIMENTER): Western 45 turn left to a heading of 030 cleared for the ILS 35 contact Kalamazoo Tower 118.3.

(PARTICIPANT): Contacting Kalamazoo Tower on 118.3 Western 45.

(PARTICIPANT): Kalamazoo Tower this is Western 45 on the ILS 35.

(OBSERVER): Western 45 you are cleared to land runway 35.

(PARTICIPANT): Cleared to land runway 35 Western 45.

Using flow pattern—Before Landing checks complete prior to FAF (5 checklist items)

2 miles outside FAF—Power 50% 22” MP, flaps 50%, airspeed 100 knots, maintain 2,500’ until established on the glide slope.

FAF inbound and established on glide slope—Power 25% 12” MP, flaps 50%, airspeed 100 knots, descent rate of 500 feet per minute is established.

Short final—Power as required, flaps 100%, airspeed 75 knots over threshold of runway.

(EXPERIMENTER): Western 45 turn left to exit the active runway and park.

Using flow pattern—After Landing checks (6 items)

Using do-list—Shutdown checks (7 items)

(EXPERIMENTER): This session is over. Please relax and I will join you in a few minutes.
NORMAL WORKLOAD-Technical Flight Pattern Parameters and Narration
Flight Pattern 3 KLAN

(EXPERIMENTER): Session start, please begin. Contact tower when ready for takeoff.

Using flow pattern-Before Takeoff checks completed (31 checklist items)

(PARTICIPANT): Lansing Tower Western 45 ready for departure runway 10R.

(EXPERIMENTER): Western 45 you are cleared for departure. Fly runway heading climb and maintain 3,000'.

(PARTICIPANT): Fly runway heading climb and maintain 3,000' Western 45

Using do-list-Normal Takeoff checks completed (5 checklist items)

After reaching 1000’ AGL

Using flow pattern-Climb checks completed above 1000’ (5 checklist items)

(EXPERIMENTER): Western 45 contact Lansing Approach on 133.475.

(PARTICIPANT): Contacting Lansing Approach on 133.475 Western 45.

(PARTICIPANT): Lansing Approach Western 45 is with you heading 100 climbing to 3,000.

(EXPERIMENTER): Western 45 roger.

(EXPERIMENTER): Western 45 turn right heading of 190.

(PARTICIPANT): Turning right to a heading of 190 Western 45.

Using flow pattern-Cruise checks complete after level at 3,000’ (5 checklist items)

(EXPERIMENTER): Western 45 turn right heading of 280 and descend to 2,500’.

(PARTICIPANT): Turning right to a heading of 280 and descending to 2,500’ Western 45.

Using flow pattern-Descent checks complete prior to IAP and 2,500’ (6 checklist items)
(EXPERIMENTER): *Western 45 turn right to a heading of 010.*

(PARTICIPANT): *Turning right to a heading of 010 Western 45.*

(EXPERIMENTER): *Western 45 turn right to a heading of 060 cleared for the ILS 10R contact Lansing Tower 119.9.*

(PARTICIPANT): *Contacting Lansing Tower on 119.9 Western 45.*

(PARTICIPANT): *Lansing Tower this is Western 45 on the ILS 10R.*

(OBSERVER): *Western 45 you are cleared to land runway 10R.*

(PARTICIPANT): *Cleared to land runway 10R Western 45.*

**Using flow pattern—Before Landing checks complete prior to FAF (5 checklist items)**

2 miles outside FAF—Power 50% 22” MP, flaps 50%, airspeed 100 knots, maintain 2,500’ until established on the glide slope.

FAF inbound and established on glide slope—Power 25% 12” MP, flaps 50%, airspeed 100 knots, descent rate of 500 feet per minute is established.

Short final—Power as required, flaps 100%, airspeed 75 knots over threshold of runway.

(EXPERIMENTER): *Western 45 turn left to exit the active runway and park.*

**Using flow pattern—After Landing checks (6 items)**

**Using do-list—Shutdown checks (7 items)**

(EXPERIMENTER): *This session is over. Please relax and I will join you in a few minutes.*
NORMAL WORKLOAD-Technical Flight Pattern Parameters and Narration
Flight Pattern 4 KJXN

(EXPERIMENTER): Session start, please begin. Contact tower when ready for takeoff.

Using flow pattern-Before Takeoff checks completed (31 checklist items)

(PARTICIPANT): Jackson Tower Western 45 ready for departure runway 24.

(EXPERIMENTER): Western 45 you are cleared for departure. Fly runway heading climb and maintain 3,500'.

(PARTICIPANT): Fly runway heading climb and maintain 3,500' Western 45

Using do-list-Normal Takeoff checks completed (5 checklist items)

After reaching 1000’ AGL

Using flow pattern-Climb checks completed above 1000’ (5 checklist items)

(EXPERIMENTER): Western 45 contact Lansing Approach on 127.3.

(PARTICIPANT): Contacting Lansing Approach on 127.3 Western 45.

(PARTICIPANT): Lansing Approach Western 45 is with you heading 240 climbing to 3,500.

(EXPERIMENTER): Western 45 roger.

(EXPERIMENTER): Western 45 turn left heading of 150.

(PARTICIPANT): Turning left to a heading of 150 Western 45.

Using flow pattern-Cruise checks complete after level at 3,500’ (5 checklist items)

(EXPERIMENTER): Western 45 turn left heading of 060 and descend to 3,000’.

(PARTICIPANT): Turning left to a heading of 060 and descending to 3,000’ Western 45.

Using flow pattern-Descent checks complete prior to IAP and 3,000’ (6 checklist items)

(EXPERIMENTER): Western 45 turn left to a heading of 330.
(PARTICIPANT): Turning left to a heading of 330 Western 45.

(EXPERIMENTER): Western 45 turn left to a heading of 280 cleared for the ILS 24 contact Jackson Tower 120.7.

(PARTICIPANT): Contacting Jackson Tower on 120.7 Western 45.

(PARTICIPANT): Jackson Tower this is Western 45 on the ILS 24.

(OBSERVER: Western 45 you are cleared to land runway 24.

(PARTICIPANT): Cleared to land runway 24 Western 45.

Using flow pattern-Before Landing checks complete prior to FAF (5 checklist items)

2 miles outside FAF—Power 50% 22” MP, flaps 50%, airspeed 100 knots, maintain 2,500’ until established on the glide slope.

FAF inbound and established on glide slope—Power 25% 12” MP, flaps 50%, airspeed 100 knots, descent rate of 500 feet per minute is established.

Short final—Power as required, flaps 100%, airspeed 75 knots over threshold of runway.

(EXPERIMENTER): Western 45 turn left to exit the active runway and park.

Using flow pattern-After Landing checks (6 items)

Using do-list-Shutdown checks (7 items)

(EXPERIMENTER): This session is over. Please relax and I will join you in a few minutes.
NORMAL WORKLOAD—Technical Flight Pattern Parameters and Narration
Flight Pattern 5 KGRR

(EXPERIMENTER): Session start, please begin. Contact tower when ready for takeoff.

Using flow pattern—Before Takeoff checks completed (31 checklist items)

(PARTICIPANT): Grand Rapids Tower Western 45 ready for departure runway 8R.

(EXPERIMENTER): Western 45 you are cleared for departure. Fly runway heading climb and maintain 3,200'.

(PARTICIPANT): Fly runway heading climb and maintain 3,200' Western 45

Using do-list—Normal Takeoff checks completed (5 checklist items)

After reaching 1000' AGL

Using flow pattern—Climb checks completed above 1000' (5 checklist items)

(EXPERIMENTER): Western 45 contact Grand Rapids Approach on 128.4.

(PARTICIPANT): Contacting Grand Rapids Approach on 128.4 Western 45.

(PARTICIPANT): Grand Rapids Approach Western 45 is with you heading 080 climbing to 3,200'.

(EXPERIMENTER): Western 45 roger.

(EXPERIMENTER): Western 45 turn right heading of 170.

(PARTICIPANT): Turning right to a heading of 170 Western 45.

Using flow pattern—Cruise checks complete after level at 3,200 (5 checklist items)

(EXPERIMENTER): Western 45 turn right heading of 260 and descend to 2,700'.

(PARTICIPANT): Turning right to a heading of 260 descending to 2,700' Western 45.

Using flow pattern—Descent checks complete prior to IAP and 2,700’ (6 checklist items)

(EXPERIMENTER): Western 45 turn right to a heading of 350 and descend to 2,700'.
(PARTICIPANT): Turning right to a heading of 350 and descending to 2,700' Western 45.

(EXPERIMENTER): Western 45 turn right to a heading of 040 cleared for the ILS 8R contact Grand Rapids Tower 128.4.

(PARTICIPANT): Contacting Grand Rapids Tower on 128.4 Western 45.

(PARTICIPANT): Grand Rapids Tower this is Western 45 on the ILS 8R.

(OBSERVER): Western 45 you are cleared to land runway 8R.

(PARTICIPANT): Cleared to land runway 8R Western 45.

Using flow pattern-Before Landing checks complete prior to FAF (5 checklist items)

2 miles outside FAF-Power 50% 22” MP, flaps 50%, airspeed 100 knots, maintain 2,500’ until established on the glide slope.

FAF inbound and established on glide slope-Power 25% 12” MP, flaps 50%, airspeed 100 knots, descent rate of 500 feet per minute is established.

Short final-Power as required, flaps 100%, airspeed 75 knots over threshold of runway.

(EXPERIMENTER): Western 45 turn left to exit the active runway and park.

Using flow pattern-After Landing checks (6 items)

Using do-list-Shutdown checks (7 items)

(EXPERIMENTER): This session is over. Please relax and I will join you in a few minutes.
(EXPERIMENTER): Session start, please begin. Contact clearance delivery when ready for takeoff.

Using flow pattern-Before Takeoff checks completed (31 checklist items)

(PARTICIPANT): South Bend Clearance Delivery Western 45 ready for departure runway 27.

(EXPERIMENTER): Western 45 you are cleared for departure. Fly runway heading climb and maintain 3,000'.

(PARTICIPANT): Fly runway heading climb and maintain 3,000' Western 45

Using do-list-Normal Takeoff checks completed (5 checklist items)

After reaching 1000 AGL

Using flow pattern-Climb checks completed above 1000' (5 checklist items)

(EXPERIMENTER): Western 45 contact South Bend Approach on 118.55.

(PARTICIPANT): Contacting South Bend Approach on 118.55 Western 45.

(PARTICIPANT): South Bend Approach Western 45 is with you heading 270 climbing to 3,000.

(EXPERIMENTER): Western 45 roger.

(EXPERIMENTER): Western 45 turn left heading of 180.

(PARTICIPANT): Turning left to a heading of 180 Western 45.

Using flow pattern-Cruise checks complete after level at 3,000 (5 checklist items)

(EXPERIMENTER): Western 45 turn left heading of 090 and descend to 2,500.

(PARTICIPANT): Turning left to a heading of 090 and descending to 2,500 Western 45.
Using flow pattern-Descent checks complete prior to IAP and 2,500 (6 checklist items)

(EXPERIMENTER): *Western 45 turn left to a heading of 360.*

(PARTICIPANT): *Turning left to a heading of 360 Western 45.*

(EXPERIMENTER): *Western 45 turn left to a heading of 310 cleared for the ILS 27 contact Benton Harbor CTA F 123.0.*

(PARTICIPANT): *Contacting Benton Harbor CTA F on 123.0 Western 45.*

(PARTICIPANT): *Benton Harbor traffic Western 45 on the ILS 27.*

Using flow pattern-Before Landing checks complete prior to FAF (5 checklist items)

2 miles outside FAF-Power 50% 22” MP, flaps 50%, airspeed 100 knots, maintain 2,500’ until established on the glide slope.

FAF inbound and established on glide slope-Power 25% 12” MP, flaps 50%, airspeed 100 knots, descent rate of 500 feet per minute is established.

Short final-Power as required, flaps 100%, airspeed 75 knots over threshold of runway.

(EXPERIMENTER): *Western 45 turn left to exit the active runway and park.*

Using flow pattern-After Landing checks (6 items)

Using do-list-Shutdown checks (7 items)

(EXPERIMENTER): *This session is over. Please relax and I will join you in a few minutes.*
Appendix G

Flight Training Device Simulator Scenario Set Up
**SCENARIO 1 SIMULATOR SETUP - KBTL**

**Environment Page**

**Conditions:**
- ISA Deviation: -20°C
- Altimeter: 30.08”
- Turbulence: 0
- Runway Condition: Dry
- Wind Shear: None

**Clouds:**
- 1st Layer
  - Overcast
  - Top: 9,000’ AGL
  - Bottom: 250’ AGL
  - Rugged Bottom: Off

- 2nd Layer: Off

**Winds:**
- Ground Level
  - Direction: 230°
  - Speed: 10 kts
  - Gust: None

- 2nd & 3rd Layer: Off

**Visual:**
- Time of Day: Day
- Precipitation: None
- Visibility: ½ SM
- Ground Scud: 0

**Loading Page**

- Gallons Fuel R: 30.3
- Gallons Fuel L: 30.3
- Payload: 200 lbs
- CG%: _______

**Circuit Breakers Page**

- Autopilot: INOP

**Airport Settings**

- Beacon: Commercial Lighted Land
- Light Gun: Off
- Taxiway: On
- Approach Lights: MALSR
- VASI/PAPI: PAPI (L)
SCENARIO 2 SIMULATOR SETUP - KAZO

Environment Page
Conditions:
- ISA Deviation: -22°C
- Altimeter: 29.85"
- Turbulence: 0
- Runway Condition: Dry
- Wind Shear: None

Clouds:
- 1st Layer
  - Overcast
  - Top: 9,000’ AGL
  - Bottom: 250’ AGL
  - Rugged Bottom: Off

- 2nd Layer: Off

Winds:
- Ground Level
  - Direction: 350°
  - Speed: 10 kts
  - Gust: None

- 2nd & 3rd Layer: Off

Visual:
- Time of Day: Day
- Precipitation: None
- Visibility: ½ SM
- Ground Scud: 0

Loading Page
- Gallons Fuel R: 30.3
- Gallons Fuel L: 30.3
- Payload: 200 lbs
- CG%: ________

Circuit Breakers Page
- Autopilot: INOP

Airport Settings
- Beacon: Commercial Lighted Land
- Light Gun: Off
- Taxiway: On
- Approach Lights: MALSR
- VASI/PAPI: PAPI (L)
SCENARIO 3 SIMULATOR SETUP - KLAN

Environment Page
Conditions: ISA Deviation: -18°C
           Altimeter: 30.28”
           Turbulence: 0
           Runway Condition: Dry
           Wind Shear: None

Clouds: 1st Layer
        Overcast
        Top: 9,000’ AGL
        Bottom: 250’ AGL
        Rugged Bottom: Off

2nd Layer: Off

Winds: Ground Level
       Direction: 100°
       Speed: 10 kts
       Gust: None

2nd & 3rd Layer: Off

Visual: Time of Day: Day
        Precipitation: None
        Visibility: ½ SM
        Ground Scud: 0

Loading Page
Gallons Fuel R: 30.3
Gallons Fuel L: 30.3
Payload: 200 lbs
CG%: _______

Circuit Breakers Page
Autopilot: INOP

Airport Settings
Beacon: Commercial Lighted Land
Light Gun: Off
Taxiway: On
Approach Lights: MALSR
VASI/PAPI: NONE
SCENARIO 4 SIMULATOR SETUP – KJXN

Environment Page
Conditions:
- ISA Deviation: -24°C
- Altimeter: 29.73"
- Turbulence: 0
- Runway Condition: Dry
- Wind Shear: None

Clouds:
- 1st Layer
  - Overcast
  - Top: 9,000’ AGL
  - Bottom: 250’ AGL
  - Rugged Bottom: Off

- 2nd Layer: Off

Winds:
- Ground Level
  - Direction: 240°
  - Speed: 10 kts
  - Gust: None

- 2nd & 3rd Layer: Off

Visual:
- Time of Day: Day
- Precipitation: None
- Visibility: ½ SM
- Ground Scud: 0

Loading Page
- Gallons Fuel R: 30.3
- Gallons Fuel L: 30.3
- Payload: 200 lbs
- CG%: ________

Circuit Breakers Page
- Autopilot: INOP

Airport Settings
- Beacon: Commercial Lighted Land
- Light Gun: Off
- Taxiway: On
- Approach Lights: MALSR
- VASI/PAPI: NONE
SCENARIO 5 SIMULATOR SETUP – KGRR

Environment Page
Conditions:
- ISA Deviation: -16°C
- Altimeter: 29.58"
- Turbulence: 0
- Runway Condition: Dry
- Wind Shear: None

Clouds:
- 1st Layer
  - Overcast
  - Top: 9,000' AGL
  - Bottom: 250' AGL
  - Rugged Bottom: Off

- 2nd Layer: Off

Winds:
- Ground Level
  - Direction: 080°
  - Speed: 10 kts
  - Gust: None

- 2nd & 3rd Layer: Off

Visual:
- Time of Day: Day
- Precipitation: None
- Visibility: ½ SM
- Ground Scud: 0

Loading Page
- Gallons Fuel R: 30.3
- Gallons Fuel L: 30.3
- Payload: 200 lbs
- CG%: ________

Circuit Breakers Page
- Autopilot: INOP

Airport Settings
- Beacon: Commercial Lighted Land
- Light Gun: Off
- Taxiway: On
- Approach Lights: MALSR
- VASI/PAPI: NONE
SCENARIO 6 SIMULATOR SETUP – KBIV

Environment Page

Conditions:
- ISA Deviation: -30°C
- Altimeter: 30.11”
- Turbulence: 0
- Runway Condition: Dry
- Wind Shear: None

Clouds:
- 1st Layer
  - Overcast
  - Top: 9,000’ AGL
  - Bottom: 250’ AGL
  - Rugged Bottom: Off

- 2nd Layer: Off

Winds:
- Ground Level
  - Direction: 260°
  - Speed: 10 kts
  - Gust: None

- 2nd & 3rd Layer: Off

Visual:
- Time of Day: Day
- Precipitation: None
- Visibility: ½ SM
- Ground Scud: 0

Loading Page

- Gallons Fuel R: 30.3
- Gallons Fuel L: 30.3
- Payload: 200 lbs
- CG%: ________

Circuit Breakers Page

- Autopilot: INOP

Airport Settings

- Beacon: Commercial Lighted Land
- Light Gun: Off
- Taxiway: On
- Approach Lights: MALSR
- VASI/PAPI: VASI
Appendix H

Meteorological Terminal Aviation Weather Reports (METARS) and Automatic Terminal Information Service (ATIS)
ATIS Information

Battle Creek information ALPHA, 1151 Zulu weather. Wind 230/10. Visibility ½ mile. OVC002. Temperature -7, Dew-point -7. Altimeter 30.08. ILS approach 23. Departures, runway 23. All aircraft read back all hold short instructions. Inform ATC that you have information ALPHA.

Kalamazoo information BRAVO, 1355 Zulu weather. Wind 350/10. Visibility ½ mile. OVC002. Temperature -9, Dew-point -9. Altimeter 29.85. ILS approach 35. Departures, runway 35. All aircraft read back all hold short instructions. Inform ATC that you have information BRAVO.

Lansing information CHARLIE, 2153 Zulu weather. Wind 010/10. Visibility ½ mile. OVC002. Temperature -5, Dew-point -5. Altimeter 30.28. ILS approach 10R. Departures, runway 10R & 10L. All aircraft read back all hold short instructions. Inform ATC that you have information CHARLIE.


Grand Rapids information ECHO, 0300 Zulu weather. Wind 080/10. Visibility ½ mile. OVC002. Temperature -3, Dew-point -3. Altimeter 29.58. ILS approach 8R. Departures, runway 8R & 8L. All aircraft read back all hold short instructions. Inform ATC that you have information ECHO.


METARS

KBTL 23010KT 1/2SM OVC002 M07/M07 A3008 RMK A02
KAZO 35010KT 1/2SM OVC002 M09/M09 A2985 RMK A02
KLAN AUTO 10010KT 1/2SM OVC002 M05/M05 A3028 RMK A02
KJXN AUTO 24010KT 1/2SM OVC002 M11/M11 A2973 RMK A02
KGRR AUTO 08010KT 1/2SM OVC002 M03/M03 A2958 RMK A02
KBIV AUTO 26010KT 1/2SM OVC002 M16/M16 A3011 RMK A02
Appendix I

Flight Checklist
### Before Takeoff

- Doors ........................................... LATCHED
- CAPS Handle ................................ Verify Pin Removed
- Seat Belts and Shoulder Harness ........... SECURE
- Fuel Quantity ................................ CONFIRMED
- Fuel Selector ................................. FULLEST TANK
- Fuel Pump ...................................... ON
- Flaps ........................................... SET 50% & CHECK
- Transponder ................................... SET
- Autopilot ...................................... CHECK
- Navigation Radios/GPS ...................... SET for Takeoff
- Cabin Heat/Defrost .......................... AS REQUIRED
- Brakes ......................................... HOLD
- Power Lever .................................. 1700 RPM
- Alternator .................................... CHECK
- Pitot Heat ..................................... ON
- Navigation Lights ............................. ON
- Landing Light .................................. ON
- Annunciator Lights ......................... CHECK
- Voltage ......................................... CHECK
- Pitot Heat ..................................... AS REQUIRED
- Navigation Lights ............................. AS REQUIRED
- Landing Light .................................. AS REQUIRED
- Magnetos ....................................... CHECK Left then Right
- Ignition Switch ....................... R, note RPM, then BOTH
- Ignition Switch ......................... L, note RPM, then BOTH
- Engine Parameters ............................ CHECK
- Power Lever .................................. 1000 RPM
- Flight Instruments, HSI, and Altimeter .... CHECK & SET
- Flight Controls ............................. FREE & CORRECT
- Trim ............................................ SET Takeoff
- Autopilot ...................................... DISCONNECT

### Normal Takeoff

- Brakes ......................................... RELEASE
- Power Levers ................................ FULL FORWARD
- Engine Parameters ............................ CHECK
- Elevator Control ......................... ROTATE Smoothly at 65-70 KIAS
- AT 85 KIAS, Flaps .......................... UP

### Climb

- Climb ........................................... SET
- Flaps ............................................. Verify UP
- Mixture .......................................... FULL RICH
- Engine Parameters ............................ CHECK
- Fuel Pump ...................................... OFF
<table>
<thead>
<tr>
<th>Cruise</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel Pump</td>
</tr>
<tr>
<td>Cruise Power</td>
</tr>
<tr>
<td>Mixture</td>
</tr>
<tr>
<td>Engine Parameters</td>
</tr>
<tr>
<td>Fuel Flow and Balance</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Descent</td>
</tr>
<tr>
<td>Altimeter</td>
</tr>
<tr>
<td>Cabin Heat/Defrost</td>
</tr>
<tr>
<td>Landing Light</td>
</tr>
<tr>
<td>Fuel System</td>
</tr>
<tr>
<td>Mixture</td>
</tr>
<tr>
<td>Brake Pressure</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Before Landing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seat Belt and Shoulder Harness</td>
</tr>
<tr>
<td>Fuel Pump</td>
</tr>
<tr>
<td>Mixture</td>
</tr>
<tr>
<td>Flaps</td>
</tr>
<tr>
<td>Autopilot</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>After Landing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power Lever</td>
</tr>
<tr>
<td>Fuel Pump</td>
</tr>
<tr>
<td>Flaps</td>
</tr>
<tr>
<td>Transponder</td>
</tr>
<tr>
<td>Lights</td>
</tr>
<tr>
<td>Pitot Heat</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Shutdown</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel Pump (if used)</td>
</tr>
<tr>
<td>Throttle</td>
</tr>
<tr>
<td>Ignition Switch</td>
</tr>
<tr>
<td>Mixture</td>
</tr>
<tr>
<td>All Switches</td>
</tr>
<tr>
<td>Magnetos</td>
</tr>
<tr>
<td>ELT</td>
</tr>
</tbody>
</table>
Appendix J

Observer's Checklist Behavior Protocol
Observer's Checklist Behavior Protocol

BEFORE TAKEOFF

1. Doors: Tactual contact or (pushing door) Verbal "Latched"
2. CAPS Handle: Tactual contact to Verify Pin Removed
3. Seat Belts & Shoulder Harnesses: Tactual contact & Secure
4. Fuel Quantity: Tactual contact or (pointing gesture) Quarter Tank Minimum- Verbal "Confirm"
5. Fuel Selector: Tactual contact to lever Verbal “Fullest Tank”
6. Fuel Pump: Tactual contact to switch Verbal “On”
7. Flaps: Tactual contact Flap Handle- Verbal "Set 50% & Check"
8. Transponder: Tactual contact Code Set To-1200- Verbal "Set"
9. Autopilot: Tactual contact Verbal “Check”
10. Navigation Radios: Eye contact Tactual contact Set Comm Freq. ______ Tower / Set Nav Freq. ______ ILS OBS inbound course aligned-Verbal “Set for Takeoff”
11. Cabin Heat/Defrost Tactual contact Verbal “As Required”
12. Brakes: Tactual contact with feet- Verbal "Hold"
13. Power Lever Tactual contact Verbal “1700 RPM”
14. Alternator Tactual contact Verbal “Check”
15. Pitot Heat: If Required Tactual contact Verbal "On" if Not Required No Eye Contact- Verbal "Not Required"
17. Landing Light: Tactual contact Light switch- Verbal "On"
18. Annunciator Lights: Tactual contact Verbal “Check”
19. Voltage: Tactual contact Verbal “Check”
20. Pitot Heat: If Required Tactual contact Verbal "On" if Not Required No Eye Contact- Verbal "Not Required"
21. Navigation Lights: Tactual contact Light switch- Verbal "On or Off"
22. Landing Light: Tactual contact Light switch- Verbal "On or Off"
23. Magneto: Tactual contact Key switch
24. Ignition Switch: Tactual contact Key switch turn to Right, Check RPM, turn to Both Verbal “Check”
25. Ignition Switch: Tactual contact Key switch turn to Left, Check RPM, turn to Both Verbal “Check”
26. Engine Parameters: Tactual contact or (pointing gesture) RPM-1700, Oil Press-50-90, Oil Temp-100-245, Suction-4.5-5.4- Verbal "Check"
27. Power Lever: Tactual contact RPM-1000
28. Flight Instruments: Airspeed-Zero, Attitude-Erect & level, Altitude-Field elevation MSL, Heading-Heading Ind & Compass agree, Tactual contact
29. Flight Controls: Rotates yoke from left stop to right stop in forward position, repeated in aft position Verbal "Free & Correct"
30. Trim: Tactual contact Rotate Trim Wheel- Verbal "Set"
31. Autopilot: Tactual contact Verbal “Disconnect”
NORMAL TAKEOFF

32. **Power Lever:** Tactual contact  Push Full forward
33. **Engine Instruments:** Tactual contact or (pointing gesture) RPM-1700, Oil Press-30-60, Oil Temp-100-240, CHT-240-420, Volts-24-30, Suction-4.5-5.4- Verbal "Check"
34. **Brakes:** Release with feet
35. **Elevator Controls:** Tactual contact Rotate 65-70- KIAS
36. **Flaps:** Tactual contact Up at 85 KIAS Verbal “Flaps up”

CLIMB

37. **Power Lever:** Tactual contact Set climb power Verbal "Set"
38. **Flaps:** Tactual contact Head turn to look and verify retracted Verbal "Up"
39. **Mixture:** Tactual contact Mixture Control Full Forward- Verbal "Full Rich"
40. **Engine Parameters:** Tactual contact or (pointing gesture) RPM-1700, Oil Press-50-90, Oil Temp-100-245, Suction-4.5-5.4- Verbal "Check"
41. **Fuel Pump:** Tactual contact to switch Verbal “Off”

CRUISE

42. **Fuel Pump:** Tactual contact to switch Verbal “Off”
43. **Power Lever:** Tactual contact Set cruise power Verbal "Set"
44. **Mixture:** Tactual contact Mixture Control pull aft- Verbal "Lean"
45. **Engine Parameters:** Tactual contact or (pointing gesture) RPM-1700, Oil Press-50-90, Oil Temp-100-245, Suction-4.5-5.4- Verbal "Check"
46. **Fuel Flow & Balance:** Tactual contact or (pointing gesture)

DESCENT

47. **Altimeter:** Tactual contact or Selector Knob & Pressure in Kohlsman Window (pointing gesture) Verbal "Set"
48. **Cabin Heat/Defrost** Tactual contact Verbal “As Required”
49. **Landing Light:** Tactual contact Light switch- Verbal "On"
50. **Fuel System:** Tactual contact or (pointing gesture) Verbal “Check”
51. **Mixture:** Tactual contact Mixture Control push forward or leave alone- Verbal "As Required"
52. **Brake Pressure:** Tactual pressing with feet

BEFORE LANDING

53. **Seat Belts & Shoulder Harnesses:** Tactual contact & Secure
54. **Fuel Pump:** Tactual contact to switch Verbal “Boost”
55. **Mixture:** Tactual contact Mixture Control Full Forward- Verbal "Full Rich"
56. **Flaps:** Tactual contact Head turn to look and verify deployed Verbal "Flaps 50%"
57. **Autopilot:** Tactual contact Verbal “Off”
AFTER LANDING

58. **Power Lever**: Tactual contact RPM-1000
59. **Fuel Pump**: Tactual contact to switch Verbal "Off"
60. **Flaps**: Tactual contact Flap Handle- Verbal "Up"
61. **Transponder**: Tactual contact Set To-Standby- Verbal "Standby"
62. **Lights**: Tactual contact Landing Light switch- Verbal "Off"
63. **Pitot Heat**: Tactual contact Verbal "Off"

SHUTDOWN

64. **Fuel Pump**: Tactual contact to switch Verbal "Off"
65. **Power Lever**: Tactual contact RPM-Verbal "Idle"
66. **Ignition Switch**: Tactual contact Key switch turn quickly to left to Off and quickly return to both Verbal "Check"
67. **Mixture**: Tactual contact Mixture Control pull aft- Verbal "Cutoff"
68. **All Switched**: Tactual contact Verbal "Off"
69. **Magneto**: Tactual contact Key switch turn to left to Off Verbal "Off"
70. **ELT**: Tactual contact Verbal "Check"

Eye Contact-Refers to the participant's behavior of looking in the direction of a discriminative stimulus such as a instrument, lever, or object
Tactual Contact-Refers to the participant's behavior of moving a finger or hand to touch a discriminative stimulus
Pointing Gesture-Refers to the participant's behavior to extend a directed finger at a discriminative stimulus
Verbal-Refers to the participant's vocal behavior directed at tacting the condition or state of the discriminative stimulus

CORRECT response: A response which uses the behavior of looking at the correct checklist item; moving an arm, hand or finger to touch or point to the correct item; vocal behavior identifying the correct item and tacting the correct condition or state of the item.

INCORRECT response: A response which uses the behavior of looking at the incorrect checklist item; moving an arm, hand or finger to touch or point to the incorrect item; vocal behavior identifying an incorrect item and tacting the incorrect condition or state of the item; or any correct response not accompanied by correct vocal behavior.

OMITTED response: An absence of responding.
Appendix K

Observer's Checklist Form
Observer's Checklist

<table>
<thead>
<tr>
<th>Task Description</th>
<th>Correct</th>
<th>Incorrect</th>
<th>Omitted</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before Takeoff</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Doors...LATCHED</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CAPS Handle...Verify Pin Removed</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Belts &amp; Harness...SECURE</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fuel Quantity...CONFIRMED</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fuel Selector...FULLEST TANK</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fuel Pump...ON</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flaps...SET 50% &amp; CHECK</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Xponder...SET</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Autopilot...CHECK</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nav Radio/GPS...SET for Takeoff</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cabin Heat/Defrost...AS REQUIRED</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brakes...HOLD</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Power Lever...1700 RPM</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alternator...CHECK</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pitot Heat...ON</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nav Lights...ON</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Landing Light...ON</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Annunciator Lights...CHECK</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Voltage...CHECK</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pitot Heat...AS REQUIRED</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Navigation Lights...AS REQUIRED</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Landing Light...AS REQUIRED</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Magnetos...CHECK Left then Right</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ignition Switch R, note RPM, then BOTH</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ignition Switch L, note RPM, then BOTH</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Engine Parameters...CHECK</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Power Lever...1000 RPM</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flight Inst, HSI, &amp; Alt...CHECK &amp; SET</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flight Controls...FREE &amp; CORRECT</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trim...SET Takeoff</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Autopilot...DISCONNECT</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Normal Takeoff Seg. Time Error</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Power Levers...FULL FORWARD</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Engine Parameters...CHECK</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brakes...RELEASE</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elevator Control...ROTATE at 65-70 KIAS</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>At 85 KIAS, Flaps...UP</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Climb Seg. Time Error

Climb Power...SET

Flaps...Verify UP

Mixture...FULL RICH

Engine Parameters...CHECK

Fuel Pump...OFF
**Cruise Seg. Time Error**
- Fuel Pump...OFF
- Cruise Power...SET
- Mixture...LEAN as required
- Engine Parameters...MONITOR
- Fuel Flow and Balance...MONITOR

**Descent Seg. Time Error**
- Altimeter...SET
- Cabin Heat/Defrost...AS REQUIRED
- Landing Light...ON
- Fuel System...CHECK
- Mixture...AS REQUIRED
- Brake Pressure...CHECK

**Before Landing Seg. Time Error**
- Seat Belt and Shoulder Harness...SECURE
- Fuel Pump...BOOST
- Mixture...FULL RICH
- Flaps...AS REQUIRED
- Autopilot...AS REQUIRED

**After Landing Seg. Time Error**
- Power Lever...1000 RPM
- Fuel Pump...OFF
- Flaps...UP
- Transponder...STBY
- Lights...AS REQUIRED
- Pitot Heat...OFF

**Shutdown Seg. Time Error**
- Fuel Pump...OFF
- Throttle...IDLE
- Ignition Switch...CYCLE
- Mixture...CUTOFF
- All Switches...OFF
- Magnetos...OFF
- ELT...TRANSMIT LIGHT OUT

**Response / No Response Totals**

**Segment Time Error Totals**

---

***RECORDER OFF***

Observer: ____________________

Additional Comments:

_____________________________________________________________________

_____________________________________________________________________

_____________________________________________________________________

_____________________________________________________________________

_____________________________________________________________________
Appendix L

Digital and Paper Checklist Pre-flight Instructional Script
Paper Checklist Pre-flight Instructional Script

We will be conducting four instrument flights per session. One session should last about two hours. Please consider each flight as a complete flight and not just pattern work. Please hand fly the simulator as the auto pilot will be disabled. Each of the four flights today will conclude with a different instrument landing system approach to a full stop landing and engine shutdown. You will be given assigned headings and altitudes to maintain until you are cleared for the instrument approach. As you can see, we have the instrument approach plate for the ILS runway [runway number] at [name of airport]. To save time on the sessions, we will be starting the flights with the engine already running. We are assessing the utilization of different modes of the MFD for each flight. During this flight, please leave the MFD in the engine parameter mode for the entire session. You may need to refer to your paper checklist. Please use the checklist as you would during any normal flight. You should talk aloud and touch each check item while doing your flow checks to confirm it is complete. Please take a moment to familiarize yourself with the ILS approach plate. Here is a copy of the latest Automatic Terminal Information Service (ATIS) information. Please be certain you understand how the FTD works and that you are comfortable at the FTD station. So as not to interfere in your flight, I will not be able to help you in any way. We will be observing and recording your flight using the video cameras, computer monitor, and flight simulation software to permit us to conduct a post-flight briefing. I will play the role of Air Traffic Control and provide you with appropriate vectors and altitudes. You will need to talk with [name of airport] Tower and [name of airport Approach Control]. After each landing and before you are re-positioned...
at the end of another runway for another take off, we will provide you with some post-flight information. So there will be a short break of 3-5 minutes before we can give you that information. [(Initial session) Also, as indicated in the informed consent document, we will be assessing your performance today, and there is a chance that you may be eliminated from the study after today’s session]. We are starting the flight at the hold line of runway [runway number] in [airport]. The before starting engine, engine start, before taxi, and taxiing checklists have been completed but not the before takeoff segment. Do you have any questions before we begin? If for any reason you feel you need to discontinue the flight, just tell me that by saying it out loud and I will terminate the flight immediately. Are you ready? Please wait for my call to announce the beginning of the flight.
Subsequent Paper Checklist Pre-flight Instructional Script

You have been re-positioned at [airport] near the end of runway [number] for another flight. As you can see, we have the instrument approach plate for the ILS runway [runway number] at [name of airport]. As before, please keep the MFD in the engine parameter mode and use the paper checklist as you would during any normal flight. You should talk aloud and touch each check item while doing your flow checks to confirm it is complete. Please take a moment to familiarize yourself with the ILS approach plate. Once again, I will play the role of Air Traffic Control and provide you with appropriate vectors and altitudes. You will need to talk with [name of airport] Tower and [name of airport Approach Control]. Here is a copy of the latest Automatic Terminal Information Service (ATIS) information. We are starting the flight at the hold line of runway [runway number] at [airport name]. Once again the engine will be running and the before starting engine, engine start, before taxi, and taxiing checklists have been completed but not the before takeoff segment. Do you have any questions before we begin? If for any reason you feel you need to discontinue the flight, just tell me that by saying it out loud and I will terminate the flight immediately. Are you ready? Please wait for my call to announce the beginning of the flight.
We will be conducting four instrument flights per session. One session should last about two hours. Please consider each flight as a complete flight and not just pattern work.

Please hand fly the simulator as the auto pilot will be disabled. Each of the four flights today will conclude with a different instrument landing system approach to a full stop landing and engine shutdown. You will be given assigned headings and altitudes to maintain until you are cleared for the instrument approach. As you can see, we have the instrument approach plate for the ILS runway [runway number] at [name of airport]. To save time on the sessions, we will be starting the flights with the engine already running.

Please fly the aircraft and use the checklist as you would during any normal flight. You should talk aloud and touch each check item while doing your flow checks to confirm it is complete. Please take a moment to familiarize yourself with the ILS approach plate. Here is a copy of the latest Automatic Terminal Information Service (ATIS) information.

Please be certain you understand how the FTD works and that you are comfortable at the FTD station. So as not to interfere in your flight, I will not be able to help you in any way.

We will be observing and recording your flight using the video cameras, computer monitor, and flight simulation software to permit me to conduct a post-flight briefing. I will play the role of Air Traffic Control and provide you with appropriate vectors and altitudes. You will need to talk with [name of airport] Tower and [name of airport Approach Control]. After each landing and before you are re-positioned at the end of another runway for another take off, we will provide you with some post-flight information. So there will be a short break of 3-5 minutes before we give you that
information. [(Initial session) Also, as indicated in the informed consent document, we will be assessing your performance today, and there is a chance that you may be eliminated from the study after today’s session]. We are starting the flight at the hold line of runway [runway number] in [airport]. The before starting engine, engine start, before taxi, and taxiing checklists have been completed but not the before takeoff segment. Do you have any questions before we begin? If for any reason you feel you need to discontinue the flight, just tell me that by saying it out loud and I will terminate the flight immediately. Are you ready? Please wait for my call to announce the beginning of the flight. Are you ready?
Subsequent Digital Checklist Pre-flight Instructional Script

You have been re-positioned at [airport] near the end of runway [number] for another flight. As you can see, we have the instrument approach plate for the ILS runway [runway number] at [name of airport]. As before, please use the checklist as you would during any normal flight. You should talk aloud and touch each check item while doing your flow checks to confirm it is complete. Please take a moment to familiarize yourself with the ILS approach plate. Once again, I will play the role of Air Traffic Control and provide you with appropriate vectors and altitudes. You will need to talk with [name of airport] Tower and [name of airport Approach Control]. Here is a copy of the latest Automatic Terminal Information Service (ATIS) information. We are starting the flight at the hold line of runway [runway number] at [airport name]. Once again the engine will be running and the before starting engine, engine start, before taxi, and taxiing checklists have been completed but not the before takeoff segment. Do you have any questions before we begin? If for any reason you feel you need to discontinue the flight, just tell me that by saying it out loud and I will terminate the flight immediately. Are you ready? Please wait for my call to announce the beginning of the flight.
Appendix M

Technical Flight Pattern Diagram
Appendix N

Post-flight Technical Briefing Script
The Post-flight Technical Briefing Script

Based on the flight just conducted, I want to show you the technical pattern of your flight. Here is a printout of the altitude and course information for the last approach. Please look at this diagram [point out good features of performance and praise those]. Please initial this diagram and return it to me now before you begin your next flight. Please do not discuss this study with anyone else because we have not yet completed the study and to do so may influence our future observations of other participants.

Thank you.
Appendix O

Checklist Feedback Script and Graphs
Checklist Feedback Script and Graphs

I also want to show you the total number of checklist items that you completed correctly from your last flight and all your previous flights. As you can see, you completed ____ out of 70 items correctly. (If that is an improvement, the experimenter will praise the participant.)

This next graph shows you more specific information. It shows the number of items you completed correctly, incorrectly, and omitted for each of the flight segments. Please look at this graph. Do you have any questions? OK, please initial each graph and return them to me and then we will begin the next flight. Please do not discuss this study with anyone else because we have not yet completed the study and to do so may influence our future observations of other participants.

Thank you.
Checklist Feedback Graphs

**Participant __ - Items Completed Correctly**

Black Dots = Digital Checklist/Blue Triangles = Paper Checklist

Number of Items

Trials

**Participant__ Session__ Trial__ Paper__ Digital__**

- Total Items
- Correct
- Incorrect
- Omitted

Before Takeoff
Normal Takeoff
Climb
Cruise
Descent
Before Landing
After Landing
Shut Down
Total
Appendix P

60–90 Day Post-Test Research Probe Checklist Survey
**60+ Days Post-Test Research Probe Checklist Survey**

Participant Number ___________ Date ______________

Please fill out this post-flight questionnaire from *your memory*. Please do not ask anyone or look at the POH for any advice. We would like to understand the extent of your memory concerning checklist function and performance in your flying. If you cannot remember an item or segment, please leave the space blank.

1) Please indicate which of the following checklists are do-lists and which are flow checks.

<table>
<thead>
<tr>
<th>Checklist</th>
<th>DO-LIST or FLOW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before Takeoff</td>
<td>Do</td>
</tr>
<tr>
<td>Normal Takeoff</td>
<td>Do</td>
</tr>
<tr>
<td>Climb</td>
<td>Do</td>
</tr>
<tr>
<td>Cruise</td>
<td>Do</td>
</tr>
<tr>
<td>Descent</td>
<td>Do</td>
</tr>
<tr>
<td>Before Landing</td>
<td>Do</td>
</tr>
<tr>
<td>After Landing</td>
<td>Do</td>
</tr>
<tr>
<td>Shutdown</td>
<td>Do</td>
</tr>
</tbody>
</table>

2) When is a checklist segment considered complete *(please choose one)*?
   A) When I say (aloud or to myself) the last checklist item in that segment
   B) When I turn the checklist page (paper) or scroll (digital) to the next page
   C) When I say (aloud or to myself) that particular segment is complete
   D) When I say (aloud or to myself) the first item on the next checklist segment

3) During a closed pattern and while receiving radar vectors for an ILS approach, please indicate the appropriate time during the flight to conduct each checklist.

<table>
<thead>
<tr>
<th>Checklist</th>
<th>Time During Flight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before Takeoff</td>
<td></td>
</tr>
<tr>
<td>Normal Takeoff</td>
<td></td>
</tr>
<tr>
<td>Climb</td>
<td></td>
</tr>
<tr>
<td>Cruise</td>
<td></td>
</tr>
<tr>
<td>Descent</td>
<td></td>
</tr>
<tr>
<td>Before Landing</td>
<td></td>
</tr>
<tr>
<td>After Landing</td>
<td></td>
</tr>
<tr>
<td>Shutdown</td>
<td></td>
</tr>
</tbody>
</table>
4) Please list, in the appropriate order, the items and responses of each checklist. (i.e. for the item "Seat Belts & Shoulder Harness," the response may be "Secure")

<table>
<thead>
<tr>
<th>Before Takeoff Checklist ITEMS</th>
<th>Before Takeoff Checklist RESPONSES</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td></td>
</tr>
<tr>
<td>18</td>
<td></td>
</tr>
<tr>
<td>19</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td></td>
</tr>
<tr>
<td>21</td>
<td></td>
</tr>
<tr>
<td>22</td>
<td></td>
</tr>
<tr>
<td>23</td>
<td></td>
</tr>
<tr>
<td>24</td>
<td></td>
</tr>
<tr>
<td>25</td>
<td></td>
</tr>
<tr>
<td>26</td>
<td></td>
</tr>
<tr>
<td>27</td>
<td></td>
</tr>
<tr>
<td>28</td>
<td></td>
</tr>
<tr>
<td>29</td>
<td></td>
</tr>
<tr>
<td>30</td>
<td></td>
</tr>
<tr>
<td>31</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Normal Takeoff Checklist ITEMS</th>
<th>Normal Takeoff Checklist RESPONSES</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Climb Checklist</td>
<td>Climb Checklist</td>
</tr>
<tr>
<td>----------------</td>
<td>----------------</td>
</tr>
<tr>
<td>ITEMS</td>
<td>RESPONSES</td>
</tr>
<tr>
<td>1</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Cruise Checklist</th>
<th>Cruise Checklist</th>
</tr>
</thead>
<tbody>
<tr>
<td>ITEMS</td>
<td>RESPONSES</td>
</tr>
<tr>
<td>1</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Descent Checklist</th>
<th>Descent Checklist</th>
</tr>
</thead>
<tbody>
<tr>
<td>ITEMS</td>
<td>RESPONSES</td>
</tr>
<tr>
<td>1</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Before Landing Checklist</th>
<th>Before Landing Checklist</th>
</tr>
</thead>
<tbody>
<tr>
<td>ITEMS</td>
<td>RESPONSES</td>
</tr>
<tr>
<td>1</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>After Landing Checklist</th>
<th>After Landing Checklist</th>
</tr>
</thead>
<tbody>
<tr>
<td>ITEMS</td>
<td>RESPONSES</td>
</tr>
<tr>
<td>1</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td></td>
</tr>
</tbody>
</table>
5) On a scale from 1 to 10, with 1 being the lowest and 10 being the highest, how much emphasis would you say your flight instructor(s) (past and present) placed on proper checklist usage? Please explain.

6) Approximately how many total hours have you flown since participating in this study? _______

7) Approximately how many of those total hours after this study did you fly in the Cirrus SR20? _______

8) Have you changed the way you perform checklists as a result of your experience in this study? _______

9) If you have changed your checklist reading behavior, please explain what you do different now than before the study.
Appendix Q

Debriefing Script
Debriefing Script

Thank you for participating in this study. The purpose of this study is to determine the accuracy differences between digital and paper checklist performance and if either or both can be improved by using graphic feedback after a flight. Results of this study will be used as part of the requirements to complete my doctoral training in the Psychology Department at Western Michigan University. I would like to take you through the summary data of your performance during the experiment. We assigned you to fly using both the digital and paper checklist. During the first part of the study, we did not give you any feedback about how well you completed the checklist. Then we added the graphic feedback during session # [fill in the session number]. We then stopped giving you the graphic feedback on checklist performance to see if any increases during the preceding sessions would continue once we no longer gave you that feedback. We also increased your workload from normal to high periodically to see if any improvements would continue under those conditions. Do you have any questions about your data, the study or your participation? Please do not discuss this study with anyone else because we have not yet completed the study and to do so may influence our future observations of other participants. Would you mind returning to the simulator after two months from today to fly several more instrument approaches?

Thank you again for participating in this study.
Appendix R

Statistical Analysis
## Individual Data Analysis

### Participant 1

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Paper Estimate</th>
<th>p-value</th>
<th>Digital Parameter</th>
<th>Estimate</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\beta_0$</td>
<td>6.10</td>
<td>5.40</td>
<td>$\beta_0$</td>
<td>3.37</td>
<td>3.75</td>
</tr>
<tr>
<td>$\beta_1$</td>
<td>44.04</td>
<td>2.43</td>
<td>$\beta_1$</td>
<td>12.83</td>
<td>9.60</td>
</tr>
<tr>
<td>$\beta_2$</td>
<td>1.08</td>
<td>0.73</td>
<td>$\beta_2$</td>
<td>48.03</td>
<td>1.31</td>
</tr>
<tr>
<td>$\beta_3$</td>
<td>17.68</td>
<td>1.21</td>
<td>$\beta_3$</td>
<td>3.89</td>
<td>0.03</td>
</tr>
<tr>
<td>$\beta_4$</td>
<td>1.05</td>
<td>0.46</td>
<td>$\beta_4$</td>
<td>1.62</td>
<td>0.05</td>
</tr>
<tr>
<td>$\beta_5$</td>
<td>-1.76</td>
<td>0.35</td>
<td>$\beta_5$</td>
<td>-0.34</td>
<td>0.70</td>
</tr>
</tbody>
</table>

### Participant 2

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Paper Estimate</th>
<th>p-value</th>
<th>Digital Parameter</th>
<th>Estimate</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\beta_0$</td>
<td>39.67</td>
<td>1.15</td>
<td>$\beta_0$</td>
<td>44.27</td>
<td>2.96</td>
</tr>
<tr>
<td>$\beta_1$</td>
<td>14.68</td>
<td>0.06</td>
<td>$\beta_1$</td>
<td>14.22</td>
<td>0.07</td>
</tr>
<tr>
<td>$\beta_2$</td>
<td>8.05</td>
<td>0.32</td>
<td>$\beta_2$</td>
<td>8.78</td>
<td>0.29</td>
</tr>
<tr>
<td>$\beta_3$</td>
<td>6.67</td>
<td>0.38</td>
<td>$\beta_3$</td>
<td>-3.44</td>
<td>0.63</td>
</tr>
<tr>
<td>$\beta_4$</td>
<td>0.51</td>
<td>0.92</td>
<td>$\beta_4$</td>
<td>3.79</td>
<td>0.37</td>
</tr>
<tr>
<td>$\beta_5$</td>
<td>-2.04</td>
<td>0.74</td>
<td>$\beta_5$</td>
<td>0.26</td>
<td>0.96</td>
</tr>
</tbody>
</table>

### Participant 3

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Paper Estimate</th>
<th>p-value</th>
<th>Digital Parameter</th>
<th>Estimate</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\beta_0$</td>
<td>24.16</td>
<td>1.10</td>
<td>$\beta_0$</td>
<td>21.39</td>
<td>0.67</td>
</tr>
<tr>
<td>$\beta_1$</td>
<td>26.82</td>
<td>5.61</td>
<td>$\beta_1$</td>
<td>43.04</td>
<td>6.18</td>
</tr>
<tr>
<td>$\beta_2$</td>
<td>5.65</td>
<td>0.20</td>
<td>$\beta_2$</td>
<td>4.05</td>
<td>0.39</td>
</tr>
<tr>
<td>$\beta_3$</td>
<td>12.64</td>
<td>.006</td>
<td>$\beta_3$</td>
<td>0.05</td>
<td>0.98</td>
</tr>
<tr>
<td>$\beta_4$</td>
<td>0.34</td>
<td>0.91</td>
<td>$\beta_4$</td>
<td>0.05</td>
<td>0.98</td>
</tr>
<tr>
<td>$\beta_5$</td>
<td>-2.46</td>
<td>0.48</td>
<td>$\beta_5$</td>
<td>0.05</td>
<td>0.99</td>
</tr>
</tbody>
</table>

### Participant 4

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Paper Estimate</th>
<th>p-value</th>
<th>Digital Parameter</th>
<th>Estimate</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\beta_0$</td>
<td>39.66</td>
<td>4.58</td>
<td>$\beta_0$</td>
<td>38.54</td>
<td>2.81</td>
</tr>
<tr>
<td>$\beta_1$</td>
<td>10.22</td>
<td>0.02</td>
<td>$\beta_1$</td>
<td>6.61</td>
<td>0.28</td>
</tr>
<tr>
<td>$\beta_2$</td>
<td>8.86</td>
<td>0.16</td>
<td>$\beta_2$</td>
<td>12.76</td>
<td>0.10</td>
</tr>
<tr>
<td>$\beta_3$</td>
<td>6.34</td>
<td>0.16</td>
<td>$\beta_3$</td>
<td>6.85</td>
<td>0.24</td>
</tr>
<tr>
<td>$\beta_4$</td>
<td>4.39</td>
<td>0.06</td>
<td>$\beta_4$</td>
<td>3.60</td>
<td>0.29</td>
</tr>
<tr>
<td>$\beta_5$</td>
<td>-7.82</td>
<td>0.01</td>
<td>$\beta_5$</td>
<td>-1.38</td>
<td>0.77</td>
</tr>
<tr>
<td>Parameter</td>
<td>Estimate</td>
<td>p-value</td>
<td>Parameter</td>
<td>Estimate</td>
<td>p-value</td>
</tr>
<tr>
<td>-----------</td>
<td>----------</td>
<td>---------</td>
<td>-----------</td>
<td>----------</td>
<td>---------</td>
</tr>
<tr>
<td>$\beta_0$</td>
<td>16.03</td>
<td>6.26</td>
<td>$\beta_0$</td>
<td>13.95</td>
<td>1.13</td>
</tr>
<tr>
<td>$\beta_1$</td>
<td>30.96</td>
<td>0.00</td>
<td>$\beta_1$</td>
<td>30.59</td>
<td>4.32</td>
</tr>
<tr>
<td>$\beta_2$</td>
<td>14.51</td>
<td>0.08</td>
<td>$\beta_2$</td>
<td>12.84</td>
<td>0.09</td>
</tr>
<tr>
<td>$\beta_3$</td>
<td>5.82</td>
<td>0.39</td>
<td>$\beta_3$</td>
<td>5.52</td>
<td>0.35</td>
</tr>
<tr>
<td>$\beta_4$</td>
<td>2.70</td>
<td>0.66</td>
<td>$\beta_4$</td>
<td>6.78</td>
<td>0.23</td>
</tr>
<tr>
<td>$\beta_5$</td>
<td>-0.77</td>
<td>0.91</td>
<td>$\beta_5$</td>
<td>-4.90</td>
<td>0.41</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Estimate</th>
<th>p-value</th>
<th>Parameter</th>
<th>Estimate</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\beta_0$</td>
<td>38.92</td>
<td>3.17</td>
<td>$\beta_0$</td>
<td>37.89</td>
<td>2.09</td>
</tr>
<tr>
<td>$\beta_1$</td>
<td>8.49</td>
<td>0.24</td>
<td>$\beta_1$</td>
<td>1.78</td>
<td>0.73</td>
</tr>
<tr>
<td>$\beta_2$</td>
<td>18.77</td>
<td>0.01</td>
<td>$\beta_2$</td>
<td>19.72</td>
<td>0.00</td>
</tr>
<tr>
<td>$\beta_3$</td>
<td>1.94</td>
<td>0.80</td>
<td>$\beta_3$</td>
<td>6.22</td>
<td>0.23</td>
</tr>
<tr>
<td>$\beta_4$</td>
<td>0.24</td>
<td>0.97</td>
<td>$\beta_4$</td>
<td>2.47</td>
<td>0.54</td>
</tr>
<tr>
<td>$\beta_5$</td>
<td>-2.69</td>
<td>0.65</td>
<td>$\beta_5$</td>
<td>-2.39</td>
<td>0.56</td>
</tr>
</tbody>
</table>

### Participant 5

### Participant 6

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Mean AVG</th>
<th>p-value</th>
<th>Parameter</th>
<th>Mean AVG</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\beta_0$</td>
<td>27.42</td>
<td>.005</td>
<td>$\beta_0$</td>
<td>26.57</td>
<td>.01</td>
</tr>
<tr>
<td>$\beta_1$</td>
<td>22.54</td>
<td>.010</td>
<td>$\beta_1$</td>
<td>18.18</td>
<td>.04</td>
</tr>
<tr>
<td>$\beta_2$</td>
<td>9.49</td>
<td>.014</td>
<td>$\beta_2$</td>
<td>17.70</td>
<td>.04</td>
</tr>
<tr>
<td>$\beta_3$</td>
<td>8.52</td>
<td>.014</td>
<td>$\beta_3$</td>
<td>3.185</td>
<td>.11</td>
</tr>
<tr>
<td>$\beta_4$</td>
<td>1.54</td>
<td>.073</td>
<td>$\beta_4$</td>
<td>3.05</td>
<td>.02</td>
</tr>
<tr>
<td>$\beta_5$</td>
<td>-2.92</td>
<td>.035</td>
<td>$\beta_5$</td>
<td>-1.45</td>
<td>.13</td>
</tr>
</tbody>
</table>

### Group Data Analysis
Appendix S

Consolidated WMU Curriculum Checklist Procedures
WMU Curriculum Checklist Procedures

Frasca Cirrus SR20 FTD Use Policy (Version 1: 12/12/06)

Use of Checklist
3. Use of all other checklist per phase of flight is required, starting with BEFORE STARTING ENGINE.

Flight Operations Manual (01/03/2008)

WMU91.171 Checklists
A. When operating WMU aircraft, pilots shall use appropriate checklist for all normal operations. For emergency operations, memory drills should be accomplished as required and followed up with a physical checklist when time permits.
B. If at any time the flow of a checklist is interrupted and the pilot can not be certain as to where he/she left off, the pilot should return to the beginning of that section and complete the entire checklist.

Training Course Outline (Revision 9 – July 2007)

COMPLETION STANDARDS FOR WMU PROFESSIONAL FLIGHT PROGRAM
Each flight lesson should include a post flight debrief that critiques the students performance. The critique should be in relationship to specified tasks and minimum completion standards stated for each task. Western (non-141 requirement) requires the student to receive an overall grade for each flight. This letter grade should be a Western grade relative to the student’s preparation and performance as compared to the required completion standards of the lesson and attempts required. Solo flights should be graded as either Satisfactory / Unsatisfactory. Additionally, each critique sheet indicates tasks and the associated levels of completion standards. When evaluating each task and completing the critique sheet in the student record folder, the following criteria (on the next page) shall be used for evaluating task standards:

Level D – Instructor Demonstration Only
Knowledge – Instructor teaches the element of the lesson.
Performance – Student watches instructor.

Level 0 – Unsatisfactory Performance
Knowledge – Student lacks an understanding or is experiencing difficulty with the concepts, skills, or procedures for accomplishing the basic elements or maneuvers. The student achieves less than 60% on written or oral tests.
Performance – Instructor intervention is required. Student is unable to accomplish the elements of the maneuver or is unsafe while performing them even after re-teaching. Such minimal performance is a bar to further progress.
Level 1 – Instructor Demonstration – Student Performance
Knowledge – Student begins to understand concepts, skills, or procedures for accomplishing the basic elements or maneuvers. The student can achieve at least 60% on written or oral tests.
Performance – Student accomplishes elements or maneuvers by way of instructor direction, teaching, or re-teaching, and with occasional instructor intervention.

Level 2 – Understanding with Occasional Instructor Assistance
Knowledge – Student demonstrates a 70% mastery of referenced material on written or oral tests, usually applies concepts, skills, or procedures for accomplishing the basic elements or maneuvers.
Performance – The student understands and safely demonstrates elements and maneuvers consistently to within double the standards found in the appropriate PTS with occasional instructor assistance. The student only needs additional practice to meet PTS standards.

Level 3 – PTS Standard
Knowledge – Student consistently demonstrates a minimum 80% mastery of referenced material on written or oral tests; explanation of the elements and objectives of maneuvers; voluntarily evaluates and critiques his/her personal performance.
Performance – Student consistently applies concepts and skills to accomplish lesson elements and maneuvers to standards as referenced by the current PTS with minimal assistance and no instructor intervention. The student critiques and evaluates personal performance.

Level 4 – Associating Knowledge to new Situations – Mastery of the Lesson
Knowledge – Student consistently demonstrates exceptional performance in both written and oral testing above and beyond PTS. Student consistently demonstrates a minimum 90% mastery of referenced material on written or oral tests, explanation of the elements and the objectives of maneuvers.
Performance – Student consistently correlates concepts and skills, and demonstrates exceptional performance above and beyond PTS. The student demonstrates attitude, ethics, and communication skills essential for professional flight crew interaction.

Level S - Satisfactory Completion of Element

*Parenthetical numbers indicate completion standard level.*
**Private Pilot**

Lesson 1: Preflight Procedures, Cockpit Inspection Including Certificates and Documents (1)
Checks Before Starting (1)
Checks After Starting (D)
Power Checks (Run-Up) (1)

Lesson 2: Preflight Procedures (1)
Checks Before Starting (1)
Taxi Checks (D)

Lesson 3: Taxi Checks (1)

Lesson 4: Taxi Checks (1)
Airfield Approach (Arrival), Checks (1)

Lesson 5: Taxi and Checks (2)
Climb Checks (1)
Arrival Checks (1)
Pre-Landing Checks (1)

Lesson 6: Traffic Pattern and Landing Checks Demo (D)

Lesson 7-11: NONE

Lesson 11A: As assigned by Flight Instructor

Lesson 12: NONE

Lesson 12A: As assigned by Flight Instructor

Lesson 13A: As assigned by Flight Instructor

Lesson 13S: NONE

Lesson 14-16: NONE

Lesson 16A: As assigned by Flight Instructor

Lesson 17: NONE

Lesson 17A: As assigned by Flight Instructor
Lesson 18-19: Preflight Procedures (2)

Lesson 20-32: NONE

Lesson 32A: As assigned by Flight Instructor

Lesson 33: As assigned by Flight Instructor

Lesson 34: NONE

Lesson 35A: As assigned by Flight Instructor

Lesson 36: PTS Tasks

*Instrument Rating*

Lesson 51: Taxi Checks (D)

Lesson 52: Checklist Use (1)

Lesson 53: Cockpit Preparation and External Checks (1)
  Checklist Use (2)
  Instrument and Taxi Checks (1)

Lesson 54: Checklist Use (2)
  Instrument and Taxi Checks (1)

Lesson 55: Checklist Use (3)
  Instrument and Taxi Checks (2)

Lesson 56: Checklist Use and Instrument Checks (2)

Lesson 57: Checklist Use and Taxi Checks (2)

Lesson 58: Checklist Use and Instrument Checks (S)

Lesson 59: Checklist Use and Taxi Checks (3)

Lesson 60: NONE

Lesson 61: Checklist Use (Including Taxi Checks) (3)

Lesson 62-64: Checklist Use and Instrument Checks (3)
Lesson 65: Checklist Use and Instrument Checks (3)
Memorization of Checks and Flows At Segments On The Approach (1)

Lesson 66: Checklist Use, Navigation Checks, and Instrument Checks (3)
Memorization of Checks and Flows At Segments On The Approach (1)

Lesson 67-68: Checklist Use, Navigation Checks, and Instrument Checks (3)
Memorization of Checks and Flows At Segments On The Approach (2)

Lesson 69: Checklist Use and Instrument Checks (3)
Memorization of Checks and Flows At Segments On The Approach (2)

Lesson 70: Checklist Use, Navigation Checks, and Instrument Checks (3)
Memorization of Checks and Flows At Segments On The Approach (2)

Lesson 71: Checklist Use, Navigation Checks, and Instrument Checks (3)
Memorization of Checks and Flows At Segments On The Approach (2)
Memorization of Checks and Flows At Segments On The Approach (1)

Lesson 72-73: Checklist Use, Navigation Checks, and Instrument Checks (3)
Memorization of Checks and Flows At Segments On The Approach (2)

Lesson 74: Checklist Use, Navigation Checks, and Instrument Checks (3)

Lesson 75: Checklist Use, Navigation Checks, and Instrument Checks (3)
Memorization of Checks and Flows At Segments On The Approach (2)

Lesson 76: Checklist Use, Navigation Checks, and Instrument Checks (S)

Lesson 77-78: Checklist Use, Navigation Checks, and Instrument Checks (3)

Lesson 79: Checklist Use, Navigation Checks, and Instrument Checks (2)

Lesson 80: Checklist Use, Navigation Checks, and Instrument Checks (3)

Lesson 81: Cockpit Checks (2)

Lesson 82: Checklist Use and Instrument Checks (S)

Lesson 83: Cockpit Checks (2)

Lesson 84-86: Cockpit Checks (3)