MULTI-METHOD APPROACH TO UNDERSTAND PILOT PERFORMANCE IN A SOCIOTECHNICAL AVIATION SYSTEM

by

Jason J. Saleem

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Advisory Committee

Dr. Brian M. Kleiner, Chairman

Dr. John G. Casali

Dr. Tonya L. Smith-Jackson

Dr. Kari L. Babski-Reeves

Dr. Antonio A. Trani

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Blacksburg, VA

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ABSTRACT

This research examined human-machine performance in a General Aviation (GA) environment under dynamic conditions using a combination of field study and laboratory experimentation. Using this combination of methods, the functional system of pilots performing a landing approach (both instrument and visual) with a Cessna 172 to the Roanoke Regional Airport (ROA) was described and analyzed. In the field study, data collection was guided by an integrative method based on macroergonomics (ME) and distributed cognition (DC), allowing the cognitive aspects of a sociotechnical system to be treated as equally important as the organizational components. Also of interest was how pilot performance was affected by the introduction of nighttime and deteriorating weather conditions to this GA environment. Few statistically significant differences were found between pilots who flew by visual flight rules (VFR) and those who flew by instrument flight rules (IFR) or within each of these pilot groups in terms of objective flight performance. However, there were several significant differences between VFR and IFR pilots and within each pilot group in terms of workload and especially situation awareness across conditions; situation awareness for VFR pilots was found to be significantly reduced compared to situation awareness for IFR pilots in nighttime and deteriorating weather conditions ($p < 0.05$).

In addition to these statistical findings and the methodological contribution of a joint systems/cognitive method, contributions of this dissertation include a greater understanding of the GA pilot/cockpit system and a systems-oriented cognitive model of this aviation environment as described by the ME/DC method for both VFR and IFR pilots. Further, procedural comparisons were performed between the flight simulator and the actual Cessna 172 used in the field study to increase our understanding of how to improve the validity associated with using simulators in research. Findings from both the laboratory and field studies in this research support new designs and technologies envisioned for future aviation systems that would assist the pilot during a landing

approach such as weather information systems, head-up displays, synthetic vision, three-dimensional auditory displays, increased automation, and communications filters. Potential future applications of this research are also explored.

ACKNOWLEDGEMENTS

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Several others made important contributions to this research and I am grateful for their assistance. Steve Edwards from the Department of Aerospace and Ocean Engineering provided his portable Global Positioning System unit during data collection in the field. Shane McLaughlin of the Virginia Tech Transportation Institute (VTTI) offered valuable input as a pilot during set up of the laboratory scenarios and also participated in a dry run flight in the field. He also provided a tour of facilities at the VTTI to facilitate ideas for data collection equipment for the field. Regina Young, dispatcher at the Virginia Tech Airport, assisted with scheduling the Cessna 172 for use during the field study. Randy Waldron of the Department of Industrial and Systems Engineering constructed a board to secure data collection equipment.

Howard Swingle's contributions to the field portion of this dissertation are numerous. Mr. Swingle attended Virginia Tech's Institutional Review Board (IRB) meeting regarding the safety of subjects for this dissertation at the request of Dr. Kleiner to give a pilot's perspective on the risks and hazards of this research. Mr. Swingle subsequently volunteered his time to serve as safety pilot for each flight conducted during the field study. In addition, Mr. Swingle resolved several logistical issues for the field study, some of which included renting and piloting an aircraft to test the data collection equipment, suggesting that data collection equipment be secured to a single board to increase safety, resolving issues relating to FAA regulations, and informing Roanoke air traffic control of our intentions prior to each flight. In short, the field study included in this dissertation would not have been possible without Mr. Swingle's logistical assistance and I am forever thankful for his generosity.

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HOW THIS DISSERTATION IS ORGANIZED

This dissertation employs three methods to examine the same aviation system, each of which are depicted in Figures 1 and 2 (research model, inputs/outputs) on pages 5 and 6. Two of the methods are laboratory experimentation and field study. The third is the method developed for this research which combines frameworks of macroergonomics (ME) and distributed cognition (DC). This ME/DC method is presented beginning on page 38 in the Methodology chapter. Since this method is executed in the field study, results and discussion of applying the ME/DC method are presented in the field study sections of the Results and Discussion chapters. The primary output from applying this method is a systems-oriented cognitive model for an IFR landing approach (pp. 101-111) and one for a VFR landing approach (pp. 111-118). Research objectives (p. 13) and research questions (p. 14) are presented at the end of the Introduction chapter. The contributions this dissertation makes are listed at the end of Chapter 2, Review of the Literature, beginning on page 35. The same graphic that was used in Figure 1 for the research model is adapted for the Conclusions chapter to illustrate these contributions (Figure 38 on page 168). Design implications resulting from this research are given beginning on page 158.

This document makes extensive use of Appendices, especially for raw data and data analyses from the laboratory experiment, for the complete transcriptions of the pilot/ATC communications from the field flight tests, and for complete transcriptions of pilot retrospective reports. A complete list of these appendices is given on page 191. Since the aviation domain uses numerous terms and acronyms specific to aviation, a glossary of terms and acronyms used in this document is given beginning on the next page. This glossary also provides clear, operational definitions of several terms used throughout this research (e.g., method, functional system, systems-oriented cognitive model).

GLOSSARY OF TERMS AND ACRONYMS

ADF – Automatic Direction Finder

AGATE – Advanced General Aviation Transport Experiments

AGL – Above Ground Level

ANOVA – Analysis of Variance

Artifact – resources in a system that can be used in a deliberate and conscious way by humans (e.g., computers, calculators, reference manuals).

ATC – Air Traffic Control

ATIS – Automatic Terminal Information Service

CDI – Course Deviation Indicator

CSCW – Computer Supported Cooperative Work

DC – Distributed Cognition

Distributed cognition (DC) – the concept that cognition is socially distributed amongst a group of people and the resources and materials (technological artifacts) in the work environment (i.e., a small sociotechnical system)

Dynamic conditions – in this dissertation, weather conditions that deteriorate from VMC to IMC

FAA – Federal Aviation Administration

Functional system – the functional system is the term used in distributed cognition literature as the unit of analysis; i.e., the small sociotechnical system being studied

FSS – Flight Service Station

GA – General Aviation

Glide slope – component of the ILS that provides vertical guidance in relation to the runway

GPS – Global Positioning System

GS – Glide Slope

HCI – Human-Computer Interaction

HITS – Highway in the Sky

ICAO – International Civil Aviation Organization

IFR – Instrument Flight Rules

iGATE – Integrated General Aviation Training Environment

ILS – Instrument Landing System

IMC – Instrument Meteorological Conditions

IRB – Institutional Review Board

Localizer – component of the ILS that provides lateral guidance in relation to the runway

Macroergonomics (ME) – organizational system design, work system design, top-down approach to system design

MANOVA – Multivariate Analysis of Variance

MCH – Modified Cooper-Harper Scale

ME – MacroErgonomics

MEAD – Macroergonomics Analysis and Design

Method – a plan for analysis employing an umbrella of tools and techniques

ME/DC method – work system analysis combining macroergonomics (ME) and distributed cognition (DC) and employing several data collection tools and techniques such as naturalistic observation with video and audio recording, field notes, retrospective reports, and interviewing.

MSL – Mean Sea Level

NASA – National Aeronautics and Space Administration

NDB – Non-directional beacon

NOTAM – Notice to Airmen

ODAM – Organizational Design and Management

ROA – Roanoke Regional Airport

SA – Situation Awareness

SAGAT – Situation Awareness Global Assessment Technique

SART – Situation Awareness Rating Technique

SATS – Small Aircraft Transportation System

Static conditions – in this dissertation, weather conditions that do not change during a given scenario

Sociotechnical system – a work system with social, technological, and environmental subsystems

Systems-oriented cognitive model

> *Systems-oriented* – the pilot/cockpit system as well as ground personnel (for example) the pilot is in contact with and the associated resources and communicative pathways.
>
> *Cognitive* – how the structures of this system are coordinated to produce the observed information propagation and representation as described by DC theory.
>
> *Model* – a descriptive model in written form with illustrations of the information flow and transformations.

Technological artifact – technological resources in a system (e.g., a computer)

UTM – Universal Transverse Mercator

VFR – Visual Flight Rules

VMC – Visual Meteorological Conditions

VOR – VHF Omni direction Range

VHF – Very High Frequency

Chapter 1. INTRODUCTION

Background

General Aviation (GA) is moving towards the concept of 'free flight'. Free flight is defined as "a safe and efficient flight operating capability under instrument flight rules (IFR) in which the operators have the freedom to select their paths and speed in real time" (e.g., Braune, Jahns, and Bittner, 1996, p. 102; Scallen, Smith, and Hancock, 1996, p. 69). In this operating system, a single-pilot/aircraft system is responsible for the air traffic control function and the aircraft itself will be able to 'self-separate' from other traffic in the vicinity. Changing the role of the pilot from a manual controller to a supervisory controller is a tremendous change to the current aviation system and requires rigorous human factors research. In order to ensure the safe transition to free flight and to integrate new aviation technologies necessary for this future GA environment, it is understood that human factors must be involved from the beginning and throughout the development of new technologies, policies and procedures (Braune, Jahns, and Bittner, 1996).

Changing role of the pilot. The need for human factors research in a future GA environment is great especially considering the changing role of the pilot envisioned for free flight. In the current GA system, a single-pilot is a 'manual controller' such that he/she controls the aircraft and makes the decisions (#2 in Table 1). A free flight environment, however, changes the role of the pilot by increasing the level of automation such that the pilot is performing a supervisory control function (#4 in Table 1).

TABLE 1

Changing Levels of Automation (from Kleiner and Shewchuk, 2001)

H	Hm	HM	Mh	M
HUMAN DOMINANT				TECHNOLOGY DOMINANT
1 human supplies power, decision making and control	2 mechanical support for power or control; human decision making	3 machine supplies power and information; human controls	4 machine supplies power, information, decisions and control; human monitors and/or supplies information	5 machine supplies power, information, decisions and control; no monitoring required
Direct Performer	**Manual Controller**	**Partner**	**Supervisory Controller**	**Executive Controller**

Note: H = Human; M= Machine

In the free flight environment, for example, ground based air traffic control is virtually eliminated. A single-pilot/aircraft system is responsible for the air traffic control function and the aircraft itself will be able to 'self-separate' from other traffic in the vicinity. Human factors research is needed to facilitate the pilot's changing role from a manual controller to a supervisory controller. This change in the pilot's role will occur with small iterations over many years. Research for this dissertation examined the current GA environment and may provide a baseline for future research involving the transition of the current GA environment to one of free flight.

Problem statement. Considering landing approaches as the focus and unit of analysis for this research is important as this is where most aviation accidents occur. Further, improving this portion of the flight will be necessary for future aviation systems that will employ free flight and new technology. Toward fully and properly understanding this system, a combination of methods should be employed. We should not rely on one strategy (e.g., simulation, field research). We should also consider new methods for system analysis that provide a more comprehensive understanding of the system. Indeed, a multidisciplinary approach can generate new and fresh ideas for research. Taking a multidisciplinary approach is a motivation behind one of the contributions of this dissertation. That is, developing a methodology for work system analysis that treats the system and cognitive components as equally important and applicable to GA. Previous approaches focus on engineering (organizational design/work system design) or the role of cognition (cognitive approaches; e.g., cognitive task analysis).

Within the system itself, we must consider different populations, as different populations may affect system design and imply different cognitive influences. For this dissertation, specifically, pilots who are trained to fly by VFR and those who are trained to fly IFR logically interact with the system in very different ways. These differences must also be considered and studied. Employing various research methods allows these differences to be analyzed both qualitatively, as in the field study, and statistically, as with controlled experimentation in the laboratory. How can the findings from a multi-method strategy be integrated toward better understanding the same system? Can the system analysis benefit from using a multidisciplinary approach, combining frameworks from different lines of research? This dissertation addresses these considerations.

Multi-method Approach

This dissertation employs different methods to examine the same aviation system, each giving a unique perspective to help provide a greater understanding of the system.

Research model. This research examines human-machine performance for a General Aviation (GA) using a combination of field research and laboratory experimentation, and using a novel method based on macroergonomics (ME) and distributed cognition (DC) (see Figures 1 and 2). Using these methods, the functional system of the pilot performing a landing approach (both instrument and visual) with a Cessna 172 to the Roanoke Regional Airport (ROA) was described and analyzed. This was the unit of analysis for all methods depicted in Figure 1. These methods used together were complementary, as the field study allowed for the examination of the aviation system as it exists in reality while the laboratory experiment allowed for the examination of conditions affecting the system that are too dangerous to study in the field (e.g., poor weather conditions). A visual flight rules (VFR) flight into instrument meteorological conditions (IMC), for example, accounts for a large portion of GA accidents (e.g., Goh and Wiegmann, 2001). IMC, measured in terms of cloud ceiling and visibility, are weather conditions inappropriate for pilots who are only trained to fly by VFR. This type of scenario would be too dangerous to study in the field but can easily be simulated in the laboratory using a flight simulator.

Data collection was in part guided by a method based on the macroergonomic analysis and design (MEAD) framework and DC theory. This ME/DC method (documented in the Methodology chapter) was developed in order to treat the cognitive aspects of a sociotechnical system as equally important as the organizational/structural components, and executed in the field study, as illustrated by Figure 1.

The field study itself examines this aviation system in reality. The field study was naturalistic and provided an opportunity to study the all characteristics of the system, much of which is lost in the laboratory. Using video and audio recordings in-flight, and retrospective pilot reports after landing, the information flow of the system was documented in detail as guided by the ME/DC method. Systems-oriented cognitive models for both VFR and IFR pilots were the primary output from executing the ME/DC method in the field.

The laboratory experiment simulated the same system studied in the field, and offered a means to study the effect of hazardous conditions (nighttime and deteriorating weather) that cannot be studied safely, ethically, and systematically in the field. Further, controlled experimentation in the laboratory allowed for statistical comparisons between VFR and IFR approaches in terms of flight performance, workload, and situation awareness. Procedural comparisons between the simulated and actual aviation systems are performed to increase our understanding of how to increase the fidelity and validity associated with using simulators in research. Figure 1 illustrates how the methods in this dissertation fit together and Figure 2 shows the inputs and outputs of each method. These inputs/outputs are described in detail in the Methodology chapter.

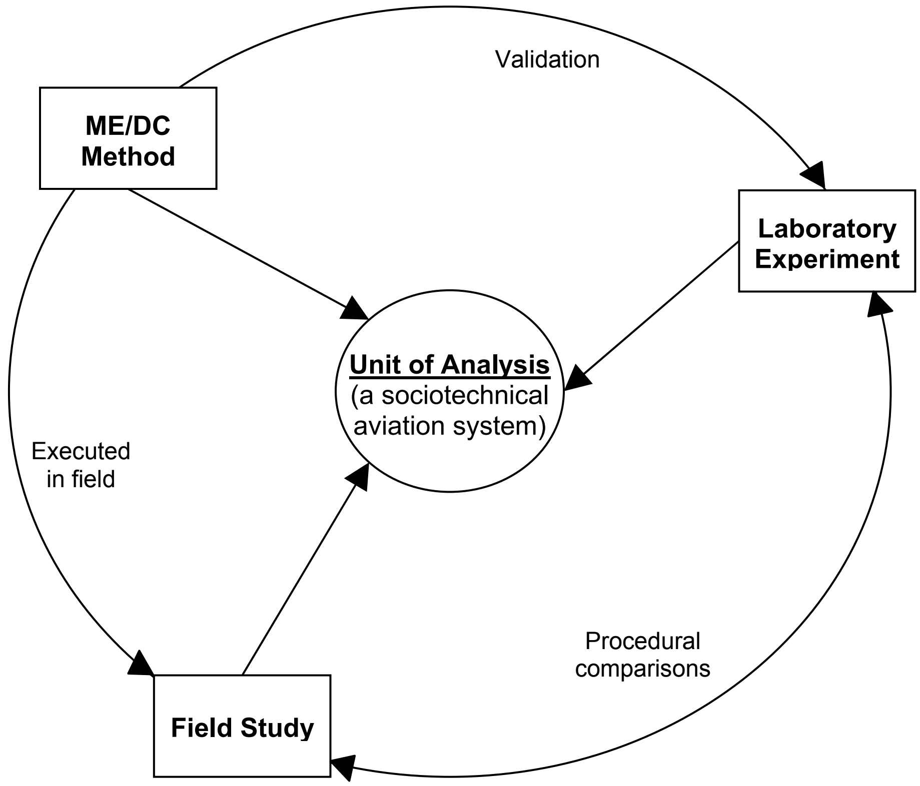

Figure 1. *Multi-method approach to understand pilot performance in a sociotechnical aviation system; research model.*

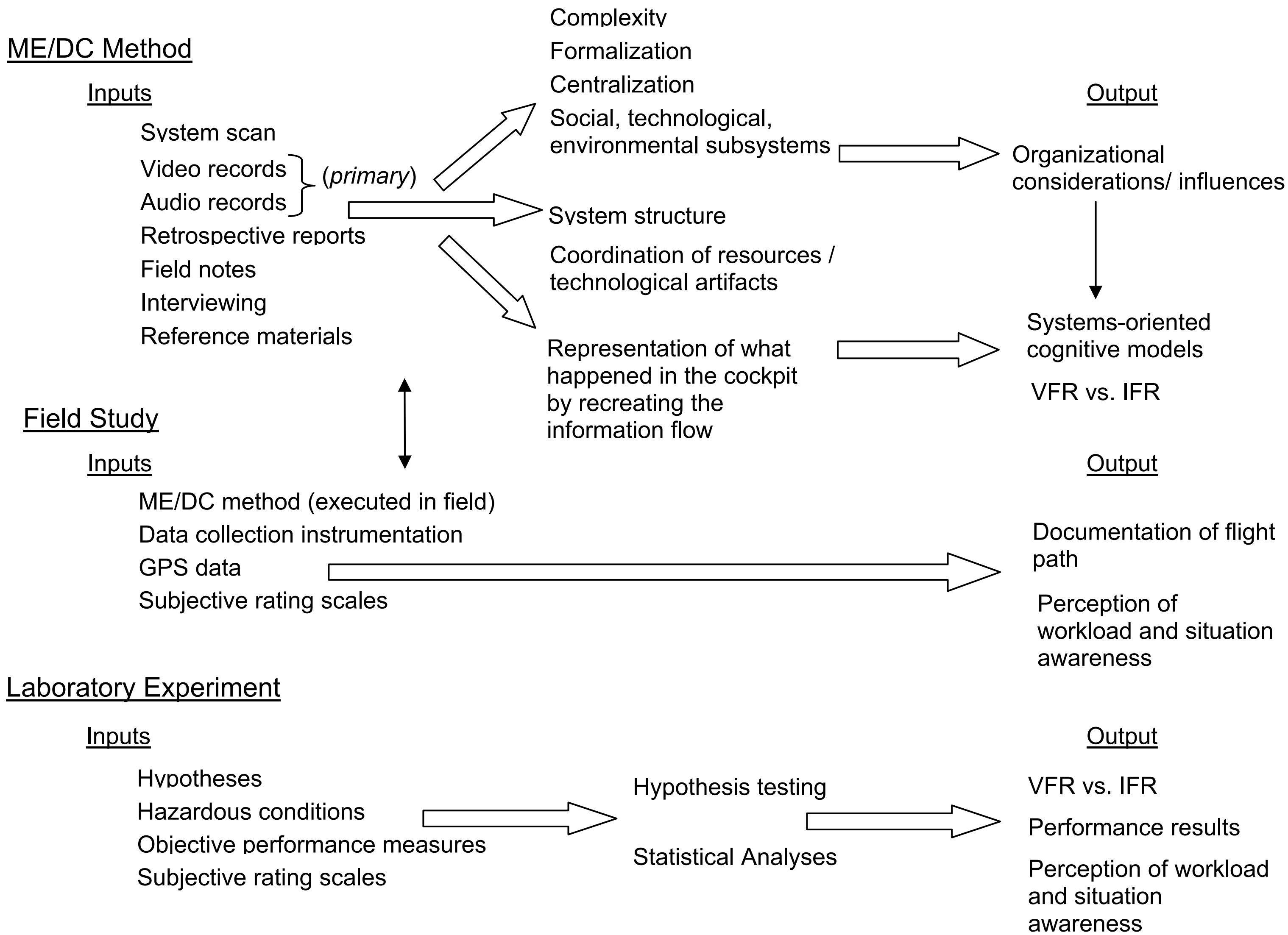

Figure 2. *Inputs / outputs of each method in research model.*

<u>The iGATE flight simulator</u>. A flight simulator, 'iGATE', was used for the laboratory portion of this dissertation. iGATE is an acronym for 'integrated General Aviation training environment". This simulator (Figure 3) is manufactured by FlyELITE and is FAA certified for IFR instruction. The iGATE is comprised of an instrument panel with a 'glass cockpit', which is a flat-screen monitor on which all items, except the radio stack and control elements, are depicted. The iGATE can portray the instrument panel and configuration of current General Aviation (GA) aircraft, including the Cessna 172, which was used for this dissertation. The left image shows the simulator console with pilot controls and the avionics panel. The right image is a close-up of the avionics panel for a Cessna 172 aircraft.

Figure 3. *The iGATE simulator (pictures taken in laboratory by the author).*

<u>Advantages of each method</u>. Certain strengths and weaknesses are associated with both field studies and laboratory experiments. Advantages with conducting a field study include observing a system as it behaves naturally, in "real-life". This is consistent with Hutchin's (1995a) belief that cognition should be studied as it exists "in the wild" and is the main reason why the developed method is being applied in the field since the method was adapted to include Hutchin's DC theory (described later in this chapter). Also, with a field study, realistic stresses and contingencies are automatically built into the observations and the results can be immediately applied to operations in the real world (Parker, Duffy, and Christensen, 1981). Although realism is an attractive quality

of a field study, a clear disadvantage of studies in the field is the difficulty in controlling extraneous variables.

Of course, the advantages and disadvantages of a laboratory experiment correspond to the weaknesses and strengths of a field study respectively. A laboratory experiment can conveniently control for extraneous variables but lacks the realism of a field study. A laboratory experiment also enables the researcher to repeat observations under the same conditions and vary the conditions systematically to observe changes in results (e.g., Hendrick and Kleiner, 2001, p. 40). The results obtained in the laboratory, however, may not always necessarily hold practical usefulness in the real-world.

For this dissertation, the field study was vital for applying the method that is based on the macroergonomics analysis and design framework and DC theory. Both of these concepts were developed for analyzing work systems as they exist in the 'real world'. Laboratory experimentation with a flight simulator, however, was also important as it allowed for further examination of the GA system with the introduction of conditions that would otherwise be hazardous in the real world (e.g., severe weather conditions).

Motivation for a Joint Investigative Method

Organizational and systems approaches to work system design have generally not focused on the role of cognition in their analyses, to the extent that they have tended to focus on developing models of user-centered design, implementation, and evaluation methods (Rogers and Ellis, 1994). Rogers and Ellis (1994) rationalize that since much of work activity is inherently cognitive (thinking, solving problems, predicting, making decisions, etc.), it is a mistake to phrase work only in terms of social and organizational concerns as the trend has been. The cognitive aspects must also be considered.

Traditional human-computer interaction (HCI) analyses that do emphasize cognition, on the other hand, have shortcomings for use with today's HCI problems. Traditional HCI models (hierarchical task analysis, cognitive task analysis, GOMS, etc.) treat work activities as straightforward 'individual' actions. These analyses break activities into separate tasks that in turn are broken down into smaller task components and so on. These analyses are designed to enable users to perform their tasks more efficiently where efficiency is measured by less time or fewer key strokes or mouse clicks (Rogers and Ellis, 1994). Many tasks, however, are situated within an intricate network of social interaction. Tasks are interleaved and shared and generally occur between people, machines/computers, and the artifacts in the environment (Rogers and Ellis, 1994).

A framework is needed to help understand interactions among people and technologies rather than an individual with a single interface. DC theory (Hollan, Hutchins, and Kirsh, D, 2000a) provides such a framework. This framework can be used to analyze the cognitive activities of people in their collaborative working environments rather than the working of the individual mind. By further incorporating DC into an organizational approach to the analysis of a work system, a gap in the current literature is addressed. A method that draws from macroergonomics (ME) and that uses DC theory was developed in order to treat the cognitive aspects of a sociotechnical system as equally important as the organizational/structural components. This joint method is hereafter referred to as the ME/DC method.

Developing the ME/DC Method

The following describes DC theory in detail and how it relates to macroergonomics. The modified macroergonomic analysis and design (MEAD) framework that incorporates DC theory is presented in the Methodology chapter.

Distributed cognition.

DC is the concept that cognition is socially distributed among a group of people and the resources and materials (technological artifacts) in the work environment (i.e., a small sociotechnical system). The fundamental assumption is that a cognitive process is not necessarily limited to the brain as traditional cognitive science presupposes. Hutchins (1995a) argues that cognitive science erected these boundaries primarily for analytic convenience but that these boundaries are not realistic as human cognition exists in its natural habitat. DC, therefore, assumes that a cognitive process involves the interactions among many brains and technological artifacts (Hollan et al., 2000a). Artifacts are the materials and resources in the system that can be used in a deliberate and conscious way by humans.

> The argument [for DC theory] is as follows. Cognitive processes involve trajectories of information (transmission and transformation), so the patterns of these information trajectories, if stable, reflect some underlying cognitive architecture. Since social organization - plus the structure added by the context of activity - largely determines the way information flows through a group, social organization may itself may be viewed as a form of cognitive architecture (Hollan et al., 2000a, p. 177).

This perspective helps us examine cognitive activities of people in their collaborative working environments rather than the working of the individual mind. "Distributed cognition is not some "new" kind of cognition, rather a recognition of the perspective that all of cognition can be fruitfully viewed as occurring in a distributed manner" (Halverson, 2002, p. 248).

DC does not simply refer to distributed information. Rather, it refers to the architecture through which information is propagated and represented. Furthermore, DC does not claim that artifacts are cognizing entities. The theory simply models both humans and their artifacts as representational systems. Therefore, DC is concerned with representations inside and outside the head - and the transformation these structures undergo (Nardi, 1996). The focus is on the representations both internal to the individual and those created and displayed by artifacts. With this viewpoint, DC can help answer the question, "What information is required to carry out some task and where should it be located, as an interface object [hardware or software] or as something that is mentally represented by the user?" (Wright, Fields, and Harrison, 2000, p. 12).

In a sample illustration of DC (Figure 4), an aviator is piloting a GA aircraft while in communication with air traffic control. The information flow of this system involves communications information between the pilot and air traffic control (ATC) (e.g., weather information), internal/external information representations of the pilot interacting with his/her instruments, and communications between an external navigational aid and the aircraft. The illustration depicts a small, distributed sociotechnical system formed for this particular aviation scenario. Cognition is distributed between the individuals and their technological artifacts and over time as the information changes.

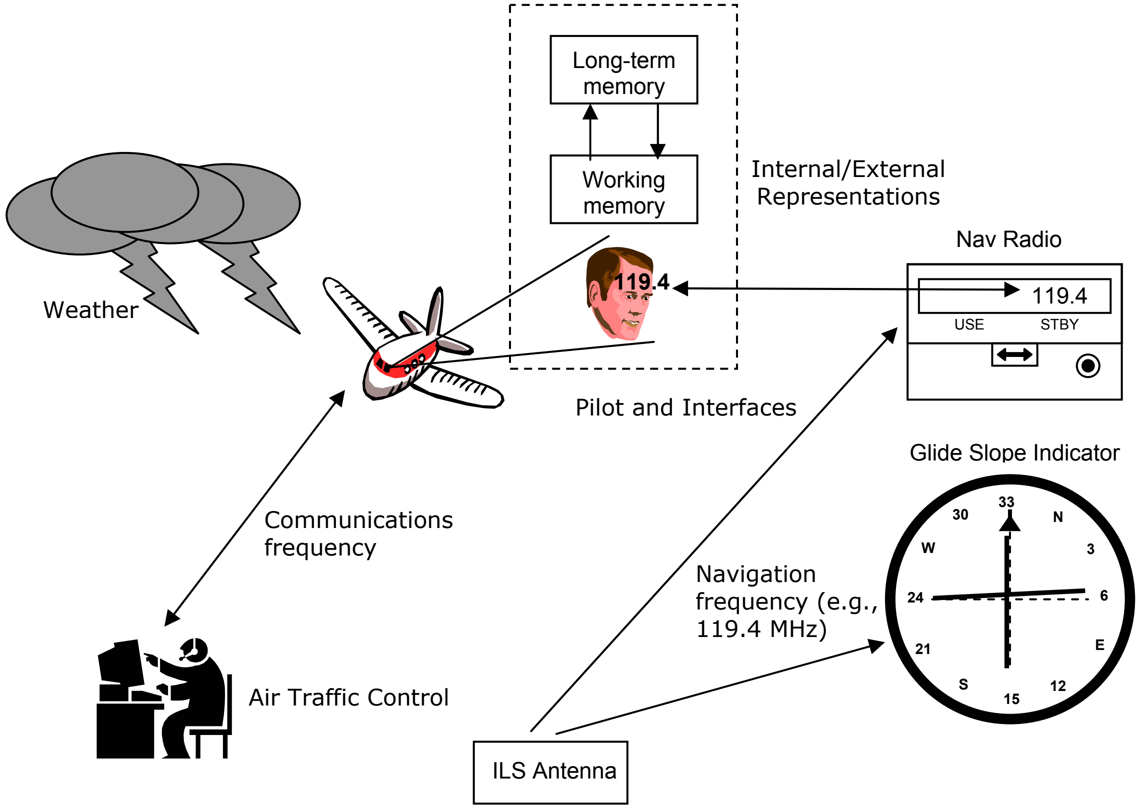

Figure 4. *Distributed cognition illustration.*

The goal in DC is to account for how the distributed structures, which comprise the sociotechnical system, are coordinated (i.e., how information is propagated through and across the artifacts and people). This is accomplished by analyzing various contributions of the environment in which the work activity takes place (usually ethnographically). These contributions come from the representational media (e.g., instruments, displays, manuals, navigation charts, etc), the interactions of individuals with each other, and their interactions with artifacts in the environment (Rogers and Ellis, 1994).

<u>Relationship between macroergonomics and distributed cognition</u>. DC theory is consistent with macroergonomics and its underlying sociotechnical systems framework. Hollan et al. (2000a) show how DC uses sociotechnical systems theory when considering a unit of analysis for DC applications. Macroergonomics is a top-down approach to work

system design whereas DC theory *expands* to include a small sociotechnical system as a unit of analysis (Figure 5). Both methodologies aid in system design. A merger of philosophies from both is a contribution of this dissertation. A methodology developed by the author (ME/DC method) treats the cognitive aspects and organizational components as equally important. The method based on the macroergonomics and distributed cognition frameworks, developed for use in this dissertation, and its expected output, is presented in the Methodology chapter.

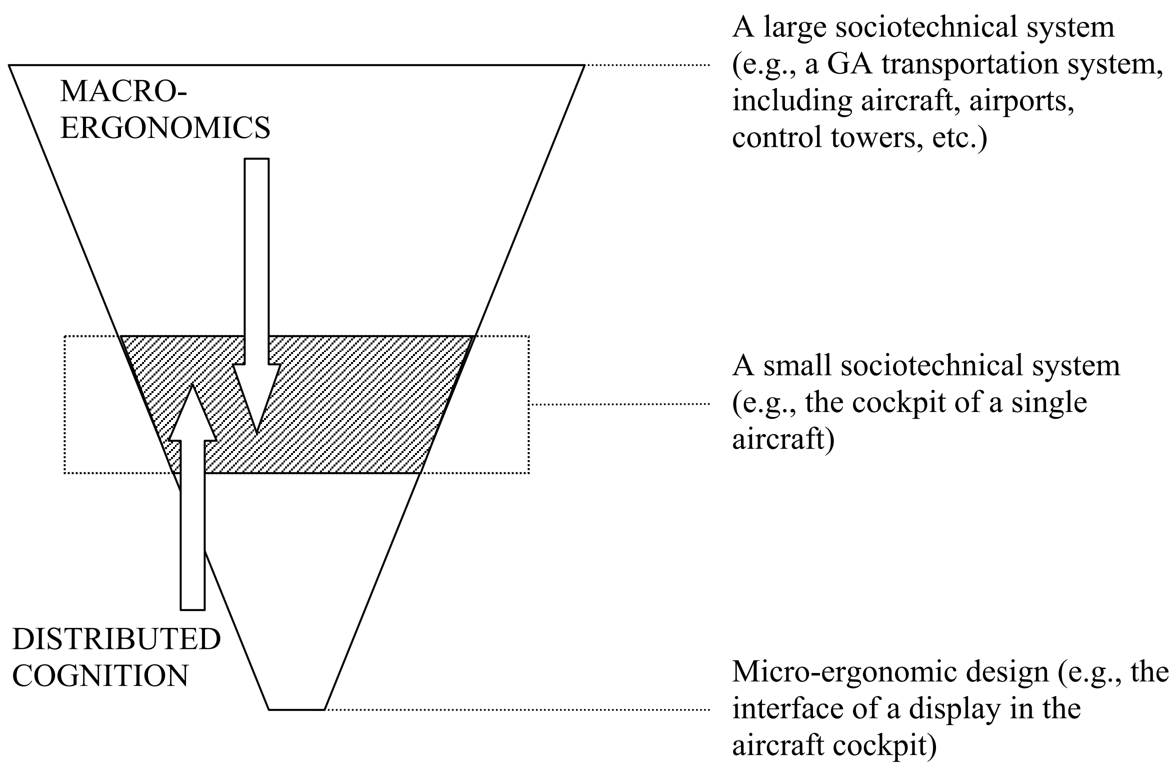

Figure 5. *Relationship between macroergonomics and distributed cognition. Both merge to share the same unit of analysis.*

Research Objectives and Research Questions

Several needs are addressed by this dissertation. This research is important toward examining the current GA environment and may provide a baseline for future research involving the transition of the current GA environment to one of free flight. Also, this research explored a novel method for examining this aviation system in the field, one that is designed to emphasize equal importance of organizational/structural components with the cognitive aspects. Further, this research employed both field and laboratory research methods in a complementary fashion, and integrated the findings from each study toward understanding the same system from different perspectives; human factors research that uses *both* laboratory and field methods to examine the same system are uncommon in aviation. Justification for this dissertation is developed further when considering previous literature in the next chapter. The research objectives for this dissertation were as follows:

1. Provide a greater understanding of the behavior of a GA pilot/cockpit system.

2. Develop a systems-oriented cognitive model of the human pilot in this aviation environment as described by the ME/DC method for both visual flight rules (VFR) and instrument flight rules (IFR) pilots.

3. Determine how pilot performance, workload, and situation awareness are affected during a landing approach and with the introduction of hazardous environmental conditions for both VFR and IFR pilots.

Table 2 shows the research questions associated with both the field study and the laboratory experiment using the flight simulator. The research questions in Table 2 are essentially an in-depth exploration of the research objectives stated above.

TABLE 2

Research Questions for the Field Study and the Flight Simulator Experiment

	FIELD STUDY	LABORATORY EXPERIMENT
RESEARCH QUESTIONS	1. What is the function/task allocation for this pilot/cockpit system? 2. What is the information flow in this pilot/cockpit system as the pilot performs an approach to an airport? 3. How are the structures of the system coordinated to produce the observed information propagation and representation? 4. How does the information flow of this system differ for VFR and IFR pilots?	5. How does the introduction of poor weather conditions and night time operations affect flight performance, workload, and situation awareness? 6. How do VFR and IFR pilots differ in terms of flight performance, workload, and/or situation awareness? 7. How does the introduction of these conditions affect the systems-oriented cognitive model derived from the application of the ME/DC method during the field study (for both pilot types)?

The information flow of the system for VFR and IFR was expected to differ, in certain respects, during approach procedures (Research Question #4). For example, the instrumentation and procedures used by each of the VFR and IFR pilots differ during a landing approach. Therefore, it was expected that the information flow (Research Question #2) and function allocation (Research Question #1) would differ between these pilot types. The ME/DC method was expected capture these differences during the field study and describe them in the form of a systems-oriented cognitive model (Research Question #3).

Differences in terms of flight performance, workload, and situation awareness between pilot types were explored in the laboratory experiment (Research Question #6). Specifically, differences in terms of performance, workload, and situation awareness were captured that result from the introduction of poor weather conditions and night time operations (Research Question #5).

The seventh research question explored how the introduction of these conditions in the laboratory affect the systems-level cognitive model derived from the application of the ME/DC method during the field study. By ‘systems-level’ cognitive model, the author means the pilot/cockpit system as well as ground personnel (for example) interacting with the pilot and the associated resources and communicative pathways. By ‘cognitive’ model, the author means how the structures of this system are coordinated to produce the observed information propagation and representation as described by DC theory. By ‘model’, the author means a descriptive model (in written form with illustrations of the information flow and transformations). The contributions this dissertation was expected to provide are explicitly listed at the end of the next chapter, Review of the Literature.

To summarize, this research examined an aviation system with a combination of methods including naturalistic field study and controlled laboratory experimentation. The aviation system was investigated from a unique perspective, considering both the organizational and cognitive influences, giving a greater understanding of the system, with practical design implications.

Chapter 2. REVIEW OF THE LITERATURE

Human Factors in General Aviation (GA)

Aviation was one of the original applications of human factors, as the human factors profession was born from post World War II analysis of military systems such as airplane systems (e.g., Wickens, 1992). However, in the past four decades, very little technology has changed in GA (e.g., Wise, Abbot, Beringer, Koonce, Kite, and Stokes, 1998). The NASA programs, Advanced General Aviation Transport Experiments (AGATE) and now the Small Aircraft Transportation System (SATS), are mechanisms for revitalizing the GA industry. Because little new technology has been introduced to GA in the past four decades, technologies envisioned for these new GA programs are not incremental advances, but revolutionary advances. Human factors involvement throughout the development of these new technologies is critical for the transition for today's GA environment to the one envisioned for 'free flight'.

The future GA environment involves the concept of free flight. Free flight is defined as "a safe and efficient flight operating capability under instrument flight rules (IFR) in which the operators have the freedom to select their paths and speed in real time" (e.g., Braune, Jahns, and Bittner, 1996, p. 102; Scallen, Smith, and Hancock, 1996, p. 69). In this operating system, the pilot/aircraft system is responsible for the air traffic control function and the aircraft itself will be able to 'self-separate' from other traffic in the vicinity. In the future GA environment, the role of the pilot will change from a manual controller to a supervisory controller. This gradual change requires thorough human factors research in order to ensure the safe transition to free flight and to integrate new technologies from AGATE and SATS (Braune, Jahns, and Bittner, 1996).

The goal of AGATE is to incorporate new and emerging technologies into the development of affordable, safer, and easier to fly GA aircraft (e.g., Gorder and Uhlarik, 1995) in an effort to revitalize the GA industry. With regards to AGATE's goal, Gorder and Uhlarik (1995) outline several human factors considerations: mental workload and situation awareness, multi-dimensional auditory displays, primary and secondary flight displays, heads-up display, and costs and flexibility of automation. A heads-up display, for example, is one of the new technologies envisioned for SATS aircraft. The heads-up display would feature a predictive "highway-in-the-sky" (HITS) image, which shows a marked pathway that the pilot uses to maintain the proper altitude and heading.

With regards to increasing the automation in the GA cockpit, human factors guidelines have been published (ICAO, as cited in Hoekstra, van Gent, and Ruigrok, 2002). To summarize, these guidelines state that the human must be in command of the system, informed so as to stay involved with the system's operations, and functions must be automated only if there is a good reason for doing so. Also, the human must be able to monitor the automated system and visa versa. Further, the automated system must be predictable, each element of the system must have knowledge of the other's intent, and automation must be designed to be simple to learn and operate.

Human Factors and Flight Simulators in GA

Human factors and flight simulation is an important part of a design or redesign process, particularly in the aviation domain. The human, after all, is the critical element in the pilot/aircraft system. Since human factors researchers specialize in determining pilot's physical and cognitive capabilities and limitations, they can identify changes that may improve overall system performance and implement and test these proposed changes in a flight simulator (Arbak, Derenski, and Walrath, 1993).

Investigating pilot decision making in free flight is one such example of how flight simulators are being used in this fashion (Scallen, Smith, and Hancock, 1996). 'Free flight' is the condition envisioned in the NASA SATS program where the pilots have the freedom to select their aircraft paths and speed in real time rather than a ground-based ATC performing this function. Scallen et al. (1996) developed a GA aircraft simulator specifically designed and outfitted to evaluate pilot decision making in the conditions proposed for the free flight structure. For example, the simulator was designed to handle real-time updating of airspace information which is necessary in free flight.

Mertens and Lewis (1982) performed two laboratory experiments using a fixed-based flight simulator to study the effect of different runway sizes on pilot performance during night VFR landing approaches. The authors found that as pilots practiced an approach to a wider runway, their approach angles increased in subsequent trials. As pilots practiced approaches to narrower runways, their approach angles decreased in subsequent trials. Visual illusions at night seem to be responsible for these results. For example, if a pilot flies a VFR approach to an unfamiliar airport at night where the runway is wider than he/she is used to, he/she is likely to pilot the aircraft too high and come in at too steep of an angle since he/she will use the same perspective cues for a more familiar (narrower runway). Further, there is a general tendency for pilots to fly shallower approaches at night when only the end lights of an unfamiliar runway are visible for vertical guidance (Mertens and Lewis, 1982). A clear danger in a night VFR approach is that many important visual cues are lost to the pilot.

Deteriorating weather conditions is another serious danger to VFR flights. Goh and Weigman (2001) is one example of a simulated study that investigated VFR flights into deteriorating weather conditions. This study used a PC-based simulator with X-Plane flight simulation software and yoke and rudder pedals as hardware peripherals. Pilots flew a Cessna 172 with the simulation software on a cross country scenario. Weather conditions deteriorated from marginal VFR conditions to IMC during the flight and pilots were forced to make a decision about continuing the fight into the deteriorating weather conditions or to discontinue the flight. The authors found that pilots were more likely to continue the flight rather than divert. Overconfidence in personal ability and inaccurate diagnosis of visibility conditions were found to be major factors in choosing to continue the flight into deteriorating weather conditions. The authors believed that if pilots had accurately assessed the visibility to be below VFR minimums (< 3 statute miles), they would have chosen to discontinue the flight.

Lintern and his colleagues have conducted several IFR flight simulator studies (e.g., Lintern, 1980; Lintern, Roscoe, Koonce, and Segal, 1990; Lintern, Roscoe, and Sivier, 1990; Lintern and Liu, 1991). All of these studies were ‘quasi-transfer’ landing experiments. Where a true transfer experimental design tests the effects of simulator training in an actual aircraft, a quasi-transfer design tests the simulator-to-simulator transfer of training. Lintern et al. (1990) found that simulator training with a computer-animated landing display can reduce the amount of actual flight time (specifically landings) during pilot training. Lintern and Liu (1991) findings support the flight simulator visual display design strategy of emphasizing abstract relationships such as compression and perspective gradients rather than high fidelity representations (e.g., rocks, roads, trees). That is, the only information that needs to be displayed is that which provides critical support for acquisition of target flight skills.

A study on the effects of approach angle and cloud ceiling on pilot performance was conducted using a medium-fidelity fixed-based flight simulator (Lancaster, Saleem, Robinson, Kleiner, and Casali, 2003). In this experiment, IFR pilots were subjected to one standard (3°) and two non-standard glide slopes (5° and 7°), each with two levels of cloud ceiling (200ft. and 400ft.), in an effort to determine the suitability of candidate future GA operations that are envisioned for NASA SATS. Results indicated little difference between standard and non-standard glide slope flight performance with respect to both vertical and lateral deviations, suggesting that performance was satisfactory up to and including the extreme condition. However, pilot workload was found to be unacceptable within the extreme conditions, suggesting that those approaches may be impractical for routine SATS approaches but may be survivable in an emergency. Actual or potential applications of this research include guidance in the development of flight performance objectives for future GA systems and as a basis for flight training requirements in these systems.

From the flight simulation human factors research literature reviewed, there are important findings relevant to this dissertation. One is how visual illusions at night seem to be responsible for night VFR accidents (Mertens and Lewis, 1982). Also, important visual cues are lost at night, making VFR at night more dangerous than day VFR. Another relevant finding is from Goh and Weigman (2001), who demonstrated that pilots were more likely to continue a VFR flight rather than divert in the face of deteriorating weather conditions. The major factors in pilots choosing to continue the flight were overconfidence in personal ability and inaccurate diagnosis of visibility conditions. Lintern and Liu (1991) found that a flight simulator's visual display should emphasize abstract relationships such as compression and perspective gradients rather than high fidelity representations (e.g., rocks, roads, trees). The author's study specifically related to the representing the horizon during simulated landing approaches. Only information should be used on the visual display that provides critical support for acquisition of target flight skills. In fact, it is this very design strategy that was used by the manufacturer of the iGATE flight simulator, which was used for the laboratory experiment portion of this dissertation. Finally, Lancaster et al. (2003) studied the effects of approach angle and weather ceiling on pilot performance and workload. However, this study used static weather conditions, only varied ceiling for weather, and only considered IFR pilots. The laboratory portion this dissertation used dynamic weather conditions, considered night time operations, consider both IFR and VFR pilots, and the differences exhibited between the two pilot types in terms of performance, workload, and situation awareness.

Human Factors on GA In-flight Approaches

Human factors studies in an actual aircraft are less common than studies performed in flight simulators. A specific example of a human factors study in an actual GA aircraft was conducted in-flight using a twin engine Aztec (Parker et al., 1981; Parker and Duffy, 1982). This field study of a single-pilot IFR flight was performed to evaluate a data-link communications system as an alternative to the current VHF voice link. Data-link communications were simulated with a Flight Data Console. The authors chose a field study over laboratory experimentation to ensure realistic conditions of cockpit workload and reasonable in-flight stress. The results of the study did not show that the Flight Data Console, using digital data-link communications, improved workload or flight proficiency over current VHF voice link communications. However, the authors believe that an improved human factors design of the Flight Data Console would yield improved results and would be accepted by GA pilots.

The above study of one example of flight testing performed for NASA. These flight tests are designed to test new aviation technologies like the Flight Data Console (Parker et al., 1981; Parker and Duffy, 1982) or a speech recognition system (Williamson, Barry, and Liggett, 1996), for example. However, there is little previous field research relevant to the field study proposed for this dissertation. One field study that is relevant is an experiment that measured and compared pilot workload for both VFR and IFR pilots (Wilson and Hankins, 1994) and is described in the next section.

VFR vs. IFR Performance Differences

The literature suggests that there is less risk during the approach and landing phase of IFR flights as compared to VFR flights (Bennett and Schwirzke, 1990; Bennett and Schwirzke, 1992). In fact, the data suggest that there is a 204% higher accident risk for VFR flights during these operations. This finding is based on the analysis of accident data as reported by the National Transportation Safety Board (from 1979-1988) and the Statistical Handbook of Aviation (U.S. Department of Transportation). Bennett and Schwirzke (1992) also found that single pilot IFR accident rate during night time is almost eight times the accident rate of day IFR approaches and 2.5 times the accident rate of day VFR approaches.

Wilson and Hankins (1994) measured pilot workload in an actual flight experiment using a Piper Arrow III general aviation aircraft. The authors compared several segments of both IFR and VFR flights (e.g., VFR takeoff, VFR climb out, VFR cruise, VFR landing, IFR cruise, IFR hold, IFR landing). Using brain wave measures (EEG) and subjective ratings (NASA-TLX), the authors found a higher level of pilot workload with both measures during IFR landings than VFR landings. However, the authors did not report these findings to be statistically significant.

Importance of Cognition in an Organizational Approach to Work System Design

Organizational approaches to work system design involving, for example, computer-supported cooperative work (CSCW), have minimized the role of cognition in their analyses, to the extent that they have tended to focus on developing models of user-centered design, implementation, and evaluation methods (Rogers and Ellis, 1994). Perhaps the only paper to treat the two as equal components previously is Orlikowski (1992), which describes the introduction of a new CSCW system. The author treated the organizational and cognitive elements as equally important in her analysis of changes in work practices and social interaction facilitated by the technology of the system. In other words, Orlikowski (1992) found that people's 'cognitions' about the technology and the structural properties of the organization equally influenced the effective utilization of the new system. The results of the analysis suggest that these two elements will together have a significant impact for the adoption, understanding, and early use of a new technology or system. Orlikowski's approach, however, is specific to the introduction of a new technology and only accounts for individual, 'shared cognitions' rather than taking a system's-level cognitive viewpoint.

This dissertation adopts the same philosophy of the importance of cognition in an organizational approach to design by adapting DC theory for use with a macroergonomics approach to work system design. DC theory was chosen because it is uses a system's-level cognitive viewpoint and is consistent with macroergonomics and its underlying sociotechnical systems framework as described in the Introduction.

Distributed Cognition

Evolution of DC theory. Hutchins (1991, 1995a, 1995b) is the chief architect of the DC framework, which is adapted for the ME/DC method. While studying complex ship navigation of U.S. Navy vessels, Hutchins (1995a) wondered how people go about knowing what they know and of the contribution of the environments in which knowing is accomplished. These questions became the foundation of the DC framework. In his paper, *"How a cockpit remembers its speed"* (1995b), he showed how the classical cognitive science approach could be applied to a unit of analysis that is larger than a person (i.e., a sociotechnical system). Hutchins used an airplane cockpit as an example. An advantage with this approach is that phenomena of interest can be directly observed by the representations that are inside in the cockpit system. In contrast, a classical cognitive science approach attempts to infer what was inside an individual's mind since these information processing phenomena can not be directly observed. Much of the 'memory' in the cockpit, however, is directly observable and encompasses internal processes, physical manipulation of objects, and creation/exchange of external representations.

Rogers and Ellis (1994) supported Hutchin's DC framework, arguing that it attempts to overcome the limitations of existing single-discipline frameworks for studying collaborative working. The main point in their position paper is that any adequate characterization of work activities requires crossing conventional disciplinary boundaries such that there can be analysis and synthesis of information from traditionally separate sources. Rogers and Ellis present Hutchin's DC framework as one that crosses the conventional disciplinary boundaries (e.g, cognitive, social, organizational).

Nardi (1996) criticized DC and argued that the DC framework uses an illogical notion that artifacts are cognizing entities (artifacts are the materials and resources in the system that can be used in a deliberate and conscious way by humans). Nardi points out that an artifact cannot know anything. Rather, an artifact serves as a medium of knowledge for a human. Therefore, the main criticism is that DC places people and machines/artifacts on equal cognitive footing. Wright et al. (2000) counters this criticism by clarifying the 'misunderstanding'. DC does views technological artifacts as *objects* of cognition. That is, Wright et al. (2000) argue that artifacts can be thought about and used in a deliberate and conscious way by humans and thus humans have a different epistemic status to technological artifacts, although both are modeled as representational systems in DC.

Wright et al., (2000) developed a 'distributed information resources model' (or 'resources model' for short) to model HCI based on DC concepts. Their model has two components: information structures and information strategies. Information structures allow for the description of the information form and content and how information is distributed between people and artifacts. Information strategies describe different ways in which resources can be used to make decisions about action. The strategy a user adopts is shaped in part by the resources available. The authors hoped that their model would help to relate HCI and CSCW issues more closely. The resources model by Wright et al. (2000) is one of the very few direct attempts to use the ideas of DC to account for HCI phenomena.

Currently, Hollan et al. (2000a) are presenting DC as a "new foundation for human-computer interaction research". They are working on an integrated framework for research that includes their DC framework while combining ethnographic observation with controlled experimentation. This research framework is applied to designing digital work materials for collaborative workplaces.

Artifacts. The term "artifact" is used very often in the HCI literature. Artifacts are the resources in a system that can be used in a deliberate and conscious way by humans. They include computers, calculators, reference manuals, and so on. Many of them have the potential to "make people smart" (Engestrom and Middleton, 1996). DC uses the concept that cognition is socially distributed amongst a group of people *and* the technological artifacts in the work environment. Moreover, DC explains the propagation of knowledge between individuals and artifacts. They are invented, used, worn out, and discarded and replaced by new ones (Engestrom and Middleton, 1996). In the case of an airplane cockpit as a small sociotechnical system, artifacts would include any of the displays and controls, for example.

The joint cognitive system. A very similar philosophy to DC is Hollnagel's concept of the "joint cognitive system" (also referred to as "joint system" or "joint cognition"). In the joint cognitive system, the human and machine are seen as two interacting cognitive systems (e.g., Hollnagel, 1999; Hollangel, 1998a; Hollnagel, 1998b, p. 71). This view is not restricted to just one human and one machine, it is also applied to systems where the components are a mixture of humans and machines (Hollnagel, 1999). An important assumption for the joint cognitive system is that *all work is cognitive*. That is, no distinction is made between cognitive work and non-cognitive work and artifacts (e.g., tools, materials) are all considered to be part of the joint cognitive system (Hollnagel, 1998a). This philosophy is strikingly similar to that of DC theory (e.g., Hollan et al., 2000a). "Joint cognitive systems" is also appropriately named because its aim is to describe how work affects the mind as well as how the mind affects the work (Hollnagel, 1997). Finally, cognition should be studied *within* a context (Hollnagel, 1998b, p. 98), or as Hutchins (1995a) would say, "in the wild". That is, the joint cognitive system exists in a social and organizational context and should therefore be studied within this context (Hollnagel, Cacciabbue, and Hoc, 1995). Considering this context, the boundaries of this joint system are defined by the nature of the investigation and the level of the analysis (Hollnagel et al., 1995).

DC case studies. There have been several case studies that have used a DC approach to analyze various work systems. Hutchins (1995a) actually began to develop his DC framework while studying navigation as it is performed by a team on the bridge of a naval vessel. Hutchins felt that a new framework was needed to understand the complex cultural nature of cognition, how cognition occurs in real life.

Soon after, DC was used to understand a memory task in the cockpit of a commercial airliner (Hutchins, 1995b). This is an example of how DC is used to analyze a small sociotechnical system as a unit of analysis rather than a single individual mind. In this case, Hutchins used DC to describe how the cockpit system remembers the speeds at which it is necessary to change the configuration of the wings in order to maintain a safe flight. Hutchin's DC framework assumes that these memories are retained in the cockpit system through various representations, not just inside a pilot's head. The representations in the cockpit system responsible for coordinating air speed with the wing flap and slat settings include, for example, a gross weight display, air speed indicators, and a speed select window of the flight guidance control panel. Other observable representations include the verbal exchanges among the crew members. In addition to observable representations, there are also assumed to be representations of the speeds that are not directly observable (i.e., the memories of the pilots themselves). The main point from this case study is that in much of the cockpit's remembering, functions are achieved by a person interpreting material symbols, rather than a person recalling those symbols from his or her memory (Hutchins, 1995b). This is why it is important to consider the cockpit itself as a cognitive system. Hutchins and Klausen (1996) later used DC to describe the communication between the airplane pilots and air traffic controllers for the purpose of changing the plane's cruising altitude. Since air traffic controllers are on the ground and not in the cockpit, this is an example of how the sociotechnical system being analyzed can sometimes be distributed (i.e., physically and socially).

Ackerman and Halverson (1998) used DC to study a telephone hotline group that specializes in answering human resource questions for company employees. Unlike the ship navigation and airplane cockpit case studies, this one has fewer pre-specified routines. Rather, the group uses a set of informal routines that can be combined flexibly to solve a large range of problems. The DC analysis for this case revealed a number of interesting aspects to the organization's memory. The term "organizational memory", however, is just a metaphor. It describes a supra-individual memory that uses several people and many artifacts (Ackerman and Halverson, 1998). Using the DC framework, the authors described how a simple phone call procedure involved several different memory states, and how a human agent translated among representational states or reconstructed memory states. The authors also showed that the memories involved in this example were often complexly distributed, interwoven, and occasionally overlaid. The necessary information to answer or solve a customer's question or problem is retrieved from the "organizational memories" of the telephone hotline group.

Wright et al. (2000) used DC as a foundation for developing their HCI analytical model called the "resources model". The authors used this model to compare interfaces, analyze interaction scenarios, and generate design alternatives. Wright et al. felt that Hutchin's DC framework was obviously relevant to HCI but stopped short of providing an explicit way of analyzing interaction. The DC based model in this case study was used to compare the chart making interfaces in a Microsoft spreadsheet application with similar interfaces in ClarisWorks spreadsheet software. The authors showed how the Microsoft Chart Wizard dialog boxes *externalizes* a plan for the user whereas the ClarisWorks interface forces the user to *internalize* a plan for making the chart. That is, a sequence of five dialog boxes in the Microsoft application represent a high-level plan for generating a chart. The relevant information is external to the user, represented on the interface itself. In contrast, the ClarisWorks interface has no plan-following resource externalized for the user. The order in which the actions must be carried out is unconstrained and must be remembered by the user (internally). The authors also analyze the interaction strategies associated with the different interfaces and show how design alternatives can be generated based on the application of their model.

In addition to the ones described previously, there have been several other case studies that have used DC. Rogers and Ellis (1994) used DC to describe the functional role of shared representations in the coordination of activities in a hospital department and computer-mediated work in an engineering company. Halverson (1995) used DC in an analysis of air traffic control. To demonstrate the approach of a DC based model, Hicks, Wright, and Pocock (1999) analyzed civil aircraft failure management systems.

And recently, Decortis, Noirfalise, and Saudelli (2000) compared and contrasted DC with activity theory and cognitive ergonomics as applied to a transport company.

The diversity of these case studies demonstrates how DC can be used to analyze work systems in a variety of domains. In each case, the unit of analysis was a small sociotechnical system. Further, a systems-level cognitive viewpoint was used to document the information flow of the system. That is, how the information was circulated, represented, and how these representations were transformed over time. For each case study, the authors explained how the structures of the system were coordinated to produce the system's behavior.

DC and Activity Theory. DC and activity theory are related as both frameworks are used to understand relationships among individuals, artifacts, and social groups (Nardi, 1996). Activity theory is a very complex concept and dates back to the 1920's. A key difference between the two is distributed cognition's emphasis is on representations of information and the transformations they undergo (Nardi, 1996). Further, activity theory views artifacts and people as distinctly different. In activity theory, artifacts mediate human activity. Distributed cognition theory, in contrast, views people and artifacts as conceptually equal representations in a system (Nardi, 1996). Another difference is that activity theory's unit of analysis is an activity itself whereas distributed cognition theory uses a small sociotechnical system as a unit of analysis. This is the main reason the distributed cognition framework is preferred over activity theory for this dissertation. Treating the cockpit of an airplane (a small sociotechnical system) as a unit of analysis is central to this dissertation. Despite the differences between the two frameworks, Nardi (1996) believes that the two are close in sprit and will perhaps merge over time.

Macroergonomics

Macroergonomics has its foundational beginnings with the formation of the organizational design and management (ODAM) technical group within the Human Factors Society in 1984. Later, the term ODAM was changed to *macroergonomics* as the ergonomics of work systems had been sufficiently developed into a separate, identifiable subdiscipline of human factors and ergonomics. Hendrick (1984, 1986) is the original architect of the macroergonomics framework.

Macroergonomics is often described as the 'third generation' of ergonomics, where human-machine technology characterizes the first generation of ergonomics and human-interface technology characterizes the second generation of ergonomics. Human-organization technology is the technology of macroergonomics (i.e, the 'third generation'). Macroergonomics focuses on the optimization of work system design through consideration of relevant personnel, technological, and environmental variables and their interactions. Conceptually, it is a *top-down* sociotechnical systems approach to the design of work systems and the application of the overall work system to the design of the human-job, human-machine, and human-software interfaces (Hendrick and Kleiner, 2001). Macroergonomics has been characterized as a sub-discipline of human factors engineering, an empirical science, a methodology, and a perspective (Hendrick and Kleiner, 2001). In this author's opinion, macroergonomics is best characterized as a *philosophy* - a way of thinking. The philosophy of macroergonomics practitioners is that good interface design at the micro-ergonomic level (e.g., human-computer interface design) cannot be properly achieved without first considering a large-system perspective of the entire organization or work system. The design characteristics of the overall work system are then carried through to the micro-ergonomic level (Hendrick and Kleiner, 2001).

A macroergonomics approach strives to fulfill the following three criteria for the effective design of a sociotechnical work system (Hendrick and Kleiner, 2001, p. 12):

1. Joint Design. The approach should be human-centered. Rather than designing the technological subsystem and requiring the personnel subsystem

to conform, the approach should require the design of the subsystems concurrently.

2. Humanized task approach. The function and task allocation process should first consider whether there is a need for a human to perform a given function or task before allocating functions to either humans or machines.
3. Consider organization's sociotechnical characteristics. The approach should systematically evaluate the organization's sociotechnical system characteristics, and then integrate them into the work system's design.

Function Allocation

The function/task allocation of the pilot/cockpit system was discussed within this dissertation. One way to classify the many function allocation methodologies is to arrange them into three approaches. The "left-over approach" is the first (e.g., Hendrick and Kleiner, 2001, p. 11; Bye et al., 1999). In this technology-driven approach, humans are viewed as unreliable and so anything that can be automated should be automated. Any tasks that cannot be automated (i.e., "left-over") are allocated to the human. The second approach is the "comparison" approach (e.g., Fitts, 1951 as cited in Clegg et al., 1989). The comparison approach attempts to estimate whether the human or machine is better equipped to perform each task in question. If the machine performs a task more efficiently, the task is allocated to the machine. The third approach is the "complementary" approach (e.g., Bye et al., 1999; Clegg et al., 1989). In this approach, the human-machine system is viewed as one entity, and the function allocation guidelines reflect how the human and machine can most efficiently perform the tasks together (Bye et al., 1999). For example, macroergonomics uses a complementary approach to function allocation by considering sociotechnical system characteristics and joint optimization (e.g., Hendrick and Kleiner, 2001; Kleiner, 1998).

Allocation of functions can also be viewed as static, dynamic, or adaptive (Sharit, 1997), where static function allocation is a predetermined allocation of functions, dynamic function allocation allows for the altering of the allocation of functions at any given point in time, and adaptive models allow the system to assume decision making and control when the human cannot.

Mental Workload

Since workload is measured and discussed in this dissertation, a review is provided in terms of various workload measures and their properties.

Measures of workload. Measures of mental workload are typically classified as performance measures (including primary and secondary task measures), physiological measures, and subjective measures (e.g., Wickens, 1992; Sanders and McCormick, 1993; Tsang and Wilson, 1997). For primary task techniques, actual performance of the operator and system is monitored and changes are recorded as the demands of the task vary (Tsang and Wilson, 1997). Secondary task measures estimate workload by imposing a secondary task as a measure of capacity not utilized in the primary task. Secondary task performance is assumed inversely proportional to the primary task resource demands (e.g., Wickens, 1992). As workload increases on the primary task, there will be a degradation of secondary task performance. Physiological (or "psychophysiological") measures assume that changes in the physiological system occur as the level of mental workload changes (Tsang and Wilson, 1997). Finally, subjective techniques use rating scales to collect operator opinion on workload level (e.g., Sanders and McCormick, 1993).

Based on the assumption that certain workload estimation techniques are better applied to certain types of pilot flight tasks, a comprehensive series of studies were performed at Virginia Tech that evaluated numerous workload measures emphasizing perceptual (Casali and Wierwille, 1984), mediational (Wierwille, Rahimi, and Casali, 1985), communications (Casali and Wierwille, 1983), and motor (Wierwille and Connor, 1983) activities. The conclusions from these studies are combined in Table 3. The Modified Cooper-Harper (MCH) scale (Appendix A) was used for this dissertation since it was found to be sensitive to changes in workload across all types of pilot activities (see Table 3). The MCH is a 10-point scale where participants follow a decision tree to arrive at an appropriate rating of workload.

TABLE 3
Measures found to be Sensitive to Changes in Workload considering Perceptual, Mediational, Communications, and Motor Activities

	Perceptual	Mediational	Communications	Motor
	From Casali and Wierwille (1984)	*From Wierwille et al. (1985)*	*From Casali and Wierwille (1983)*	*From Wierwille and Connor (1983)*
Opinion	Modified Cooper-Harper (MCH) scale	Modified Cooper-Harper (MCH) scale	Modified Cooper-Harper (MCH) scale	Cooper-Harper (CH) scale
	Workload-Compensation-Interference/Technical Effectiveness (WCI/TE) scale	Workload-Compensation-Interference/Technical Effectiveness (WCI/TE) scale	Multi-descriptor (MD) scale	Workload-Compensation-Interference/Technical Effectiveness (WCI/TE) scale
	Multi-descriptor (MD) scale			
Secondary Task	Time estimation standard deviation (TE)	Time estimation standard deviation (TE) [*but intrusive*!]	Time estimation standard deviation (TE)	Time estimation standard deviation (TE)
	Tapping regularity (TR)			
Physiological	Respiration rate (RR)	Eye blinks (EB)	Pupil diameter (PD)	Mean pulse rate
		Fixation fraction (FF)		
Primary Task	Danger-condition response time (DRT)	Mediational reaction time (MRT)	Errors of omission (ERRO)	Control movements per unit time (CM)
		Mediational error rate (MER)	Errors of commission (ERRC)	
			Communications response time (CRT)	

Properties of workload measures. Sources list several properties that should be considered when selecting workload measures (Table 4) (e.g., Wickens, 1992; Sanders and McCormick, 1993; Tsang and Wilson, 1997). Of the many workload measures proposed in the literature, few satisfy all of these criteria (Wickens, 1992). All of these properties are important. However, sensitivity, selectivity, and reliability are perhaps the most critical since without these properties, a workload measure is unlikely to yield useful data.

TABLE 4

Properties of Workload Measures

Property	*Description*
Sensitivity	How well a measure detects changes in mental workload
Intrusiveness	A workload estimation technique should not interfere with, contaminate, or disrupt the primary task whose workload is being assessed
Selectivity (validity)	How well the measure is sensitive only to differences in capacity demand and not to changes in other factors (e.g., physical load, emotional stress)
Diagnosticity	How precisely a measure can reveal the nature of workload (which aspect of the human information processing system is being overloaded?)
Reliability	Are the workload measures stable and consistent over a period of time?
Ease of Use	How easy is it to collect and analyze the data associated with the measure?
Acceptability	If the operators do not feel comfortable with the measure, they may refuse to cooperate with the data collection

Situation Awareness

Situation awareness (SA) is also measured and discussed in this dissertation. While SA is very much correlated with workload (e.g., Selcon, Taylor, and Koritsas, 1991), they are distinct constructs. Workload refers to the demand a task(s) imposes on a person's limited resources (Wickens, 1992, p. 390). SA, on the other hand, also considers non-attentional factors (e.g., domain knowledge) (Selcon et al., 1991). SA is perception and comprehension of elements in the environment and the projection of their status in the future (Endsley, 2002). SA is a person's internal representation of what is happening. It drives the decision making process and is a causal factor in human error, especially in the aviation domain. In aviation, there are several types of SA: geographical, spatial, temporal, system, and environmental.

The Situation Awareness Global Assessment Technique (SAGAT) and Situation Awareness Rating Technique (SART) and are the two most popular measures of SA. SAGAT is an objective measure of SA that employs randomly timed freezes in a simulation scenario (Endsley et al., 1998) whereas SART is a subjective measure of SA that uses 10 components related to the aviation domain that were determined to be relevant to SA (Taylor, 1990). SART was used as a measure of SA for the field study and laboratory experiment (Appendix B). SART was chosen for the field study and laboratory experiment because it has been found to be correlated with operator performance in the evaluation of different cockpit designs (Selcon and Taylor, 1990). Furthermore, SART can be used in real world tasks *and* simulations whereas SAGAT can only be used for simulations (e.g., Endsley et al., 1998).

There is a three-component version of SART (Selcon and Taylor, 1990) as an alternative to the 10-component version. This shorter version is meant to be less intrusive since it only requires the pilot to give ratings for three components, thus making it more appropriate for actual in-flight testing. The original 10-component version was used for this dissertation as the SART scale was used predominately for statistical analyses in the laboratory simulation portion of this research and has more specificity for components related to SA in aviation.

Summary

This dissertation addresses three items that are lacking from the current human factors literature and thus makes several important contributions.

1. A method for work system analysis that treats the organizational and cognitive components as equally important and applicable to General Aviation.

Approaches to work system design involving, for example, computer-supported cooperative work (CSCW), have generally not focused on the role of cognition in their analyses (Rogers and Ellis, 1994). One exception is Orlikowski (1992), who found that people's 'cognitions' about the technology and the structural properties of the organization each critically influenced the effective utilization of the new system. Orlikowski's approach, however, is specific to the introduction of a new technology and only accounts for individual, 'shared cognitions' rather than taking a system's level cognitive viewpoint.

This dissertation adopts the same philosophy of the importance of cognition in a systems approach to design, but uses Hutchin's (1995a) DC framework to view the entire sociotechnical system as a form of cognitive architecture. DC theory is adapted for use with a macroergonomics analytical approach as it is consistent with macroergonomics and its underlying sociotechnical systems framework.

2. A systems-oriented cognitive model of a pilot performing a landing approach in a GA aircraft as described by combination of the macroergonomics and DC frameworks (i.e., the ME/DC method).

How are the structures in the pilot/cockpit system coordinated during an IFR approach or VFR approach in a GA aircraft? That is, how is the information propagated and represented through and across the people and resources and across time? The DC framework has been used to describe aviation scenarios in previous studies (Halverson, 1995; Hutchins, 1995b; Hutchins and Klausen, 1996), but not an ILS or VFR landing approach in General Aviation as the present dissertation research proposes.

3. A description of differences between VFR and IFR pilots during a landing approach in terms of the information flow in the pilot/cockpit system and with the introduction of dynamic environmental conditions, and quantitatively in terms of flight performance, workload, and situation awareness.

How does this pilot/cockpit system described by #2 differ for VFR and IFR pilots? And how are these differences affected by the introduction of poor weather conditions and night time operations? Understanding these differences is of great interest as VFR and IFR follow different procedures and use different instrumentation during certain instances when performing a landing approach (e.g., an IFR pilot performing an instrument approach will use the glide slope indicator). How then do these differences affect how information is propagated and represented across the pilot, ATC controller, and technological artifacts in the system, for example?

Also, how do these pilot types differ in terms of flight performance, workload, and situation awareness under field and laboratory conditions? Understanding these differences between VFR and IFR pilots is not just of practical interest; to further understand the cognition (in terms of workload, situation awareness) of instrument-rated pilots, for example, we should consider and compare this pilot group to a pilots who are not instrument rated.

Expected Contributions

This dissertation addresses these literature gaps. Thus the expected contributions of this dissertation were:

1. Methodological: A method that draws from macroergonomics (ME) and that uses DC theory in order to treat the cognitive aspects of a sociotechnical system as equally important as the organizational components (ME/DC method).

2. <u>Content-based</u>: A 'systems-oriented cognitive model' (see below) of a pilot performing a landing approach in a GA aircraft as described the ME/DC method. This provided a greater understanding of the GA pilot/cockpit system.

   Systems-oriented - the pilot/cockpit system as well as ground personnel (for example) the pilot is in contact with and the associated resources and communicative pathways.

   Cognitive - how the structures of this system are coordinated to produce the observed information propagation and representation as described by DC theory.

   Model - a descriptive model in written form with illustrations of the information flow and transformations.

3. <u>Content-based</u>: A description of differences between VFR and IFR pilots during a landing approach in terms of the information flow in the pilot/cockpit system (through application of the ME/DC method) and in terms of flight performance, workload, and situation awareness under varying environmental conditions.

4. <u>Content-based</u>: Statistical comparisons between VFR and IFR pilots and within each pilot group during a landing approach for the laboratory experiment.

5. <u>Content-based</u>: Procedural comparisons between the flight simulator and the actual Cessna 172 used in the field study to increase our understanding of how to increase the validity associated with using the simulator in research.

6. <u>Redesign recommendations</u>: Redesign recommendations for the GA pilot/cockpit system may be warranted as a result of what is learned from the field study and laboratory experiment.

Taking a multidisciplinary approach (bringing together different lines of research) is a motivation behind the methodological contribution of this dissertation. That is, developing a method for work system analysis that treats the system and cognitive components as equally important and applicable to GA. The current literature does not provide such a methodology. Previous approaches focus on engineering (organizational design/work system design) or the role of cognition (cognitive approaches; e.g., cognitive task analysis). The ME/DC method used in this dissertation fills that gap. The unique perspective this method provides is fruitful as it allows for the examination of the HCI of a sociotechnical system rather than the interaction of just the pilot and a single control or display, while also considering the influence of the organizational/structural components of the system.

The content contributions this dissertation makes are also important. The systems-oriented cognitive models this dissertation produces for both VFR and IFR pilots as they conduct a landing approach give a greater understanding of the aviation system. The current literature does not examine this part of the aviation system using this unique viewpoint of distributed cognition, nor does the literature describe this aviation environment with a sociotechnical systems perspective as with the macroergonomics framework. The literature also lacks an in-depth analysis of the differences exhibited between VFR and IFR pilots. These differences are important to consider, as different populations may affect system design and imply different cognitive influences. Employing various research methods allows these differences to be analyzed both qualitatively, as in the field study, and statistically, as with controlled experimentation in the laboratory. Further, the multi-method strategy adopted by this dissertation integrates results from the field and laboratory toward better understanding the same aviation system. Human factors aviation research in the naturalistic environment (non-simulated) is not only infrequent, but using a combination of field and simulated methods in human factors aviation research is especially uncommon.

Chapter 3. METHODOLOGY

Methodologies for both the laboratory experiment, which involves a simulated Cessna 172, and the field study, which involves an actual Cessna 172, are described herein. Also presented is the method based on macroergonomics and distributed cognition which was developed specifically for and executed in the field study. This ME/CD method is presented first. See Figures 1 and 2 on pages 5 and 6 in the Introduction for a review of how the methods relate to each other and the inputs/outputs of each method.

THE ME/DC METHOD

<u>High-level Outline</u>.

1. Define the Boundaries of the Unit of Analysis
2. Overall System Scan
3. Bounded System Scan
4. Develop Scenario for Bounded System
5. Conduct Observations based on the Scenario
6. Determine the Bounded System's Function, Task, and Information Distribution

<u>Detailed Description</u>.

1. Define the Boundaries of the Unit of Analysis

   Previous applications of DC in the literature clearly define the boundaries of the unit of analysis (e.g., Ackerman and Halverson, 1998; Decortis, et al., 2000; Hutchins, 1995b) but do not give generalized criteria for doing so. The system is usually a small sociotechnical system (e.g., the cockpit of an airplane) and can in some cases be distributed. For example, in Figure 4, the sociotechnical system is more than just the airplane cockpit.

How then, are the boundaries of the subsystem (also referred to as a small sociotechnical system and the *functional* system) to be determined? The unit of analysis (the functional system) must be bounded based on the particular phenomena being analyzed. Before the boundaries of the functional system can be determined, the workings of the functional system must be documented. To do this, the observer must determine how the information is represented and how the representations are transformed, combined, and propagated through the system in order to produce the system's observable behavior (Ackerman and Halverson, 1998). The states of these representations refer to how the various information and knowledge resources are transformed during the work activities (Rogers and Ellis, 1994). The functional system's boundaries should reflect the system's behavior. Ackerman and Halverson (1998) advocate defining a system's boundaries with three separate limits: physical, resource, and temporal. Based on a review of the DC literature, the following are the criteria used to determine the boundaries of the functional system for this methodology:

1.1 What is the observed function (or purpose) of the sociotechnical system to be analyzed?
1.2 What physical features directly influence the system's behavior? How is the system's physical space described or geographically dispersed?
1.3 What resources (people, materials, technological artifacts) are available to affect the system's behavior?
1.4 How is the information in the system temporally distributed?
1.5 What are the communicative pathways of the system?
1.6 How are the structures identified in 1.2, 1.3, 1.4, and 1.5 coordinated (i.e., how is the information propagated and represented through and across the people and resources and across time)?

Number 1.6 should be accomplished by analyzing various contributions of the environment in which the work activity takes place. These contributions come from the representational media (e.g., instruments, displays, manuals, navigation charts, etc), the interactions of individuals with each other, and their interactions with artifacts in the environment (Rogers and Ellis, 1994).

A macroergonomics approach describes territorial, social, and time boundaries, (Hendrick and Kleiner, 2001, p. 71). These macroergonomics boundaries correspond to criteria 1.2, 1.3 and 1.4 respectively.

Considering these criteria, inputs from the "outside" would actually be included as part of the functional system if they have a directly observable and meaningful effect on the system's behavior. For example, in Figure 4, the main portion of the functional system is actually the cockpit of the aircraft. The figure also depicts an air traffic controller on the ground providing information to the pilot in the cockpit that could affect the pilot's behavior. In the terminology of DC, the air traffic controller (a resource), the controller’s radar scope (a technological artifact) and other materials, and the radio frequency (a communicative pathway) used to transmit the information to the aircraft, are all part of the functional system.

The above listed criteria can be defended by the studies from which they are based. Table 5 shows the recent distributed cognition literature that each criterion was derived from.

TABLE 5

Justification of the Criteria used for Determining the Boundaries of a Functional System

Criterion	Supporting Literature
1.1	Ackerman and Halverson, 1998; Hutchins, 1995b; Nardi, 1996
1.2	Ackerman and Halverson, 1998; Hutchins, 1995b
1.3	Ackerman and Halverson, 1998; Decortis et al., 2000; Hicks, et al., 1999; Hutchins, 1995b
1.4	Ackerman and Halverson, 1998; Hollan et al., 2000; Rogers and Ellis, 1994
1.5	Decortis et al, 2000; Rogers and Ellis, 1994
1.6	Ackerman and Halverson, 1998; Decortis et al., 2000; Hicks, et al., 1999; Hollan et al., 2000; Hutchins, 1995b; Nardi, 1996; Rogers and Ellis, 1994; Wright et al., 2000

Many of the DC case studies address all of these six criteria at least indirectly. However, the studies listed in Table 5 for each criterion are the ones that *directly* refer to each criterion beside which they are listed. So for example, a study may have explicitly discussed the importance of how the information is propagated and represented amongst the people and their resources (criterion 1.6) but not directly discuss the importance of considering the various communicative pathways of the system (criterion 1.5). Thus, that particular study would be listed in Table 5 for supporting criterion 1.6 but not criterion 1.5.

2. Overall System Scan

Consistent with a macroergonomics approach, a system scan needs to be performed on the overall work system (Hendrick and Kleiner, 2001). The overall large system structure needs to be defined, along with the technological, social, and environmental subsystems. Even though the unit of analysis is a small sociotechnical system (e.g., the cockpit of an airplane), the contextual system must be scanned (e.g., the NASA Small Aircraft Transportation System) to ensure ergonomic compatibility of the small sociotechnical system with the organization's overall structure. Of particular interest is how the overall work system structure influences the functional system (unit of analysis) as defined in Step 1.

2.1 Define the complexity, formalization, and centralization (Hendrick, 1986) of the overall work system.

2.1.1 Complexity refers to the degree of differentiation and integration that exists within the work system. Types of differentiation include horizontal differentiation (horizontal separation between units), vertical differentiation (depth of a system’s hierarchy), and spatial dispersion (degree to which the work system's facilities and personnel are geographically dispersed) (Hendrick, 1986). Integration refers to the number of mechanisms designed into a work system to ensure communication, coordination, and control among differentiated elements (Hendrick and Kleiner, 2001, p. 19).

2.1.2 Formalization is the degree to which tasks within the work system are standardized (Hendrick, 1986).

2.1.3 Centralization refers to the degree that formal decision-making is concentrated in an individual (Hendrick, 1986). A decentralized (i.e., more informal) decision making structure is sometimes preferable (e.g., in the case of an unpredictable environment).

2.2 Define the technological subsystem

The type of technology used can be defined according to Perrow's (1967) classification scheme. Perrow classifies technology by using two dichotomous variables shown in Table 6.

TABLE 6

Perrow's Technology Classification Scheme (from Hendrick and Kleiner, 2001, p. 49)

	Task Variability	
Problem Analyzability	*Routine with few exceptions*	*High variety with many exceptions*
Well defined and analyzable	Routine	Engineering
Ill-defined and unanalyzable	Craft	Non-routine

The type of technology affects the degree of centralization and formalization that should be used in the overall system's structure. Hendrick (1986) describes how the type of technology relates to centralization and formalization. Systems with routine technologies should use high formalization and centralization. Systems with non-routine technologies should use decentralization and low formalization. Engineering technologies are associated with moderate centralization but low formalization. Finally, craft technologies are associated with decentralization and low formalization.

2.3 Define the social subsystem

Hendrick and Kleiner (2001) define the social (or "personnel") subsystem by describing the degree of professionalism of the people, demographic characteristics, and psychosocial aspects (p. 51). Professionalism is viewed as a type of formalization internal to the individual and psychosocial aspects refers specifically to the cognitive complexity of the individuals (concrete versus abstract thinkers) (Hendrick and Kleiner, 2001). All three characteristics affect the functioning of the work system.

2.4 Define the environmental subsystem

There are five types of external environments that can have significant influence on the work system: socioeconomic, educational, political, cultural, and legal (Hendrick and Kleiner, 2001, p. 55). The relevance of each external environment type is dependent on the type of work system. Another environmental factor is the stakeholders (Hendrick and Kleiner, 2001, p. 56). All of the environmental factors vary along two environmental dimensions: change and complexity (Hendrick and Kleiner, 2001, p. 56). The degree of change and complexity determine the 'environmental uncertainty' of the system (Hendrick and Kleiner, 2001, p. 56).

3. Bounded System Scan

After the overall system is identified, the sub-unit (i.e., the unit of analysis) should also be scanned. Since the unit of analysis is a small subset of the overall organization that was scanned in Step 2, complexity, formalization, and centralization are unlikely to be applicable (e.g., the cockpit of an airplane would not be described by these characteristics). However, as the name implies, a small sociotechnical system would also have its own technological, social, and environmental subsystems. These subsystems should be described, but not necessarily in the same terms as in Step 2 for the overall work system. These subsystems should be described in a more micro-level of detail that corresponds to the bounded system. Specific technologies should be described, the person(s) tasks should be documented, and environmental influences should be considered first as they affect the overall work system and then how they in turn affect the bounded system (unit of analysis).

3.1 Define the technological components of the bounded system

What are the technological resources that are used to transform and propagate information in the functional system? Each technological artifact should be described. Furthermore, the means by which information is represented and transformed by these technological artifacts should be documented to the furthest extent possible. This documentation is completed and refined during Step 5.

3.2 Define the social components of the bounded system

How many persons operate in or directly influence the functional system? Describe each person's relevant tasks and how each person represents and transforms the information in conjunction with the technological artifacts. This documentation is completed and refined during Step 5.

3.3 Define the environmental components of the bounded system

How does the impact of the external environment types on the greater organization affect the bounded system? Also, how do the environmental characteristics of the greater organization itself affect the bounded system?

4. Develop Scenario for Bounded System

A scenario can be used to analyze the functional system. The information learned from the previous steps can be used to construct a scenario for the functional system. In addition, a pilot study can be conducted to gather baseline data to assist in constructing a scenario. This scenario can be real or simulated (*if* the simulation is of very high fidelity; e.g., Hutchins and Klausen, 1996). Almost all previous DC analyses have been ethnographic, as a main principle of DC theory is that cognition should be studied as it exists "in the wild" (Hutchins, 1995a).

5. Conduct Observations based on the Scenario

Only through direct observations of an actual scenario can the information flow be understood. Using the knowledge from Step 1, the goal in this step is to describe how structures in the functional system are coordinated. That is, how the information is propagated and represented through and across the people and resources and across time. Also, what are the communicative pathways for the information flow?

Throughout the scenario, observations can be recorded by using one or more of several ethnographic techniques. These observational techniques include, but are not limited to, participant observation, field notes, interviewing, surveys, video recording, and audio recording.

6. Determine the Bounded System's Function, Task, and Information Distribution

From the observations recorded in Step 5, the first task is to develop an understanding of the current function, task, and information allocation. Then reallocation/redesign can be considered. A macroergonomics perspective forces the question, 'Is the social subsystem designed concurrently with the technological subsystem (i.e., the technological subsystem should not dominate by requiring the social subsystem to conform)?' Also, does the functional system follow a human-centered task approach rather than a technology-driven approach (Hendrick and Kleiner, 2001)? A DC perspective can take allocation one step further by considering specific information distribution and representation. DC can help answer the question, "What information is required to carry out some task, and where should it be located, as an interface object, hardware or software, or as something that is mentally represented by the user?" (Wright, et al., 2000).

6.1 Function and task allocation

From a human factors engineering viewpoint, the best approach to function allocation is clearly the "complementary" approach (e.g., Bye, Hollnagel, Hoffman, and Miberg, 1999; Clegg, Ravden, Corbett, and Johnson, 1989). In this approach, the human-machine system is viewed as one entity (which is consistent with DC theory), and the function allocation guidelines reflect how the human and machine can most efficiently perform the tasks together (Bye et al., 1999). For example, macroergonomics uses a complementary approach to function allocation by considering sociotechnical system characteristics and joint optimization (e.g., Hendrick and Kleiner, 2001; Kleiner, 1998). This complementary approach to system design can help determine the appropriate level of automation in the functional system through analysis of various scenarios and information distributions.

6.2 Information distribution

The information structures in the functional system must be described. For example, there are three different means by which information can be represented in the functional system in terms of goals and the state of the world (e.g., Wright et al., 2000):

- the goal and state can be represented in the same external space,
- the state is represented externally and the goal is represented internally (in the person's memory), or
- the state and goal are represented in different external spaces.

A goal is a state of the world to be achieved and can be distributed across people and their artifacts (Wright et al., 2000). For example, an air traffic controller may command an aircraft currently at an altitude of 7000 feet to descend to an altitude of 5000 feet. The goal is 5000 feet and the current state is 7000 feet. The goal originates with the ATC controller and is transferred to the pilot. The pilot can represent the goal internally (with his/her memory) or transfer it to an artifact in the cockpit for future reference (e.g., a marking on the altimeter itself or a setting on a Global Positioning System [GPS] unit). The current state of the world, 7000 feet, is represented by the altimeter.

The results from Step 6 can lead to design changes of the functional system. These design changes could include physical changes to the structure of the functional system, hardware and/or software design changes, changes to the communicative pathways of the system, and changes to function, task, and/or information distribution and representation of the system.

Output of ME/DC Method

The preceding six step methodology is the 'ME/DC method', developed to treat the system characteristics and cognitive elements of a system as equally important. This method was applied to the system in the field study and the data from its application was used to produce a systems-level cognitive model of a pilot performing a landing approach (for both VFR and IFR pilots).

The output of the ME/DC method (see pp. 93-118 in Results chapter), and thus the systems level cognitive models (see p. 101 for IFR model and p. 111 for VFR model), is descriptive. Specifically, the output is a detailed documentation of the organizational/system components and information flow of the system. That is, how the structures of the system transform and transmit the information representations in the pilot/cockpit environment during a landing approach. Also, the characteristics of the transportation system itself, and how it influences the pilot/cockpit system, were identified and described. Documentation is provided, with supporting information flow representations, graphics, and tables. To complement the descriptive nature of the ME/DC method, continuous time markers were used throughout the field observations to add a quantitative component. With a continuous time measurement, specific periods of the landing approach can be associated with specific tasks (e.g., ATC communications, glide slope acquisition, flap settings, etc.). Also, specific time periods can be compared across other pilots performing different landing approaches.

Evaluation of the ME/DC Method

The ME/DC method is based on two well established frameworks, the macroergonomics analysis and design (MEAD) framework (e.g., Hendrick and Kleiner, 2001) and DC (e.g., Hollan, Hutchins, and Kirsh, 2000a). Therefore, the hybrid approach used for this dissertation was expected to have reliability and validity. The ME/DC method itself was evaluated in two ways. First, the consistency of observations across participants (Step 5 in the ME/DC method) was assessed (i.e., reliability). That is, the ME/DC method was expected to give a consistent description of how the structures in the functional system are coordinated across participants (e.g., similar information flow and representation, similar communicative pathways, etc.). Secondly, the systems-level cognitive model as described by the application of the ME/DC method in the field was expected to be replicated in the flight simulator experiment to support validity. For example, was the information propagation and representation as observed in the field similar to that observed in the laboratory?

LABORATORY EXPERIMENT

Purpose

The flight simulator enabled the experimenter to study how certain conditions, which would have otherwise been too dangerous or impossible to manipulate in the field, affected the GA pilot/cockpit system. These conditions included severe weather and night time operations. For example, a scenario involving the deterioration of visual meteorological conditions (VMC) to instrument meteorological conditions (IMC) was simulated. In this experiment, of interest was how the introduction of poor weather conditions and night time operations affected pilot performance, workload, and situation awareness of both VFR and IFR pilots. Results from this laboratory experiment was used to further build on the systems-level cognitive model of this aviation environment developed from the field study as described by the ME/DC method for VFR and IFR pilots. Also, procedural comparisons were made between the laboratory and field studies by conducting a task analysis of the flight simulator and the actual Cessna 172 in the field during both a visual and instrument approach to the Roanoke Regional Airport.

Hypotheses

The following hypotheses for the laboratory experiment relate to the research questions for the laboratory experiment on p. 14.

1. Significant differences in flight performance measures, workload, and situation awareness are expected when comparing day versus night operations for IFR pilots (poorer performance, greater workload, and reduced situation awareness for night operations).
2. No significant differences in performance, workload, or situation awareness are expected across weather conditions for IFR pilots.
3. Significant differences in flight performance measures, workload, and situation awareness are expected when comparing day versus night operations

and across weather conditions for VFR pilots (poorer performance, greater workload, and reduced situation awareness for night operations and poorer weather conditions).

4. Significant differences in flight performance measures, workload, and situation awareness are expected between VFR and IFR pilots for both independent variables (VFR pilots will have poorer performance, greater workload, and reduced situation awareness for night operations and poorer weather conditions compared to the IFR pilots).

Significant differences in performance, workload, and situation awareness were not expected to be observed for IFR pilots between weather conditions as IFR pilots rely on their instrumentation during an approach and not the external view for the 'above cloud ceiling' portion of the approach. However, significant differences were expected for flight performance, workload, and situation awareness when comparing day versus night operations for IFR pilots (poorer performance, greater workload, and reduced situation awareness for night operations). This hypothesis was based on previous accident statistics that suggest single pilot IFR accident rate during night time is almost eight times the accident rate of day IFR approaches, as previously mentioned (Bennett and Schwirzke, 1992). VFR pilots were expected to show poorer performance, greater workload, and reduced situation awareness in deteriorating weather conditions and in night time operations as these are major causes of GA VFR accidents (e.g., Goh and Wiegmann, 2001; Leland, 2001; O'Hare and Smitheram, 1995). VFR pilots were expected to have poorer flight performance compared to the IFR pilots since IFR pilots undergo greater training and can rely on their instruments during night time and poor weather conditions. Much of a pilot's ambient vision (peripheral visual information) is lost at night (e.g., Mertens and Lewis, 1982; Leland, 2001), suggesting that VFR is more dangerous than IFR during night time operations. The loss of perception of the horizon and motion cues during night VFR suggests lower situation awareness (Leland, 2001). In contrast, instrument training disciplines a pilot in attention management and disciplines a pilot to ignore false sensory perceptions and "believe" in the instruments (Leland, 2001). VFR pilots would also seem to be at a disadvantage when interpreting changing weather conditions compared to IFR pilots. The gradual transition from minimum VMC to IMC could make discrimination of weather conditions difficult for VFR pilots (Goh and Wiegmann, 2001).

Participants

A total of 16 pilots, eight VFR pilots and eight IFR-current pilots, were recruited for the laboratory study. "VFR" pilots in this study refer to pilots who have a private pilot's license, but do not hold an instrument rating and are allowed to fly by visual flight rules only. "IFR" pilots are those who have completed additional training to achieve an instrument rating and are legally qualified to fly in conditions of poor visibility and/or low cloud ceiling by solely using the instruments for navigation. Pilots, especially instrument-rated pilots, represent a selective pool of participants. Thus, compensation was relatively high; all participants were compensated $20 for each hour of their time. Subjects were recruited through the posting of flyers on campus and at Virginia airports, by word of mouth, and through email invitations. Participants were at least 18 years of age and participation was equally available to both males and females. Also, all participants possessed a pilot's license and pilots performing instrument approaches were IFR certified and current. Each participant's prior flight experience was recorded (VFR, cross-country, IFR, simulated, and total hours). No other exclusions were used in selecting participants.

Apparatus

The flight simulator used for this study was the 'iGATE', which is manufactured by FlyELITE and is FAA certified for IFR instruction. The iGATE is comprised of an instrument panel with a 'glass cockpit', which is a flat-screen monitor on which all items except the radio stack and control elements are depicted. The iGATE can be configured to simulate several different GA aircraft; for this experiment, it was configured to portray the instrument panel of a Cessna 172 (Figure 6).

Figure 6. *iGATE simulator, Cessna 172 (in lab)*.

The simulator is housed in the MacroErgonomics and Group Decision Systems Laboratory (MGDSL), room 563 Whittemore Hall, on the Virginia Tech campus. The system is equipped with an 'experimenter's station' in the form of a PC located outside the testing room which is connected to and controls aspects of the simulation (Figure 7). Live video of the simulator room was captured using a Sony DXC-327 camera (Figure 8) and was presented on a Sony Trinitron PVM-1341 monitor (located next to the experimenter's station in Figure 7).

Figure 7. *iGATE simulator, experimenter's station*.

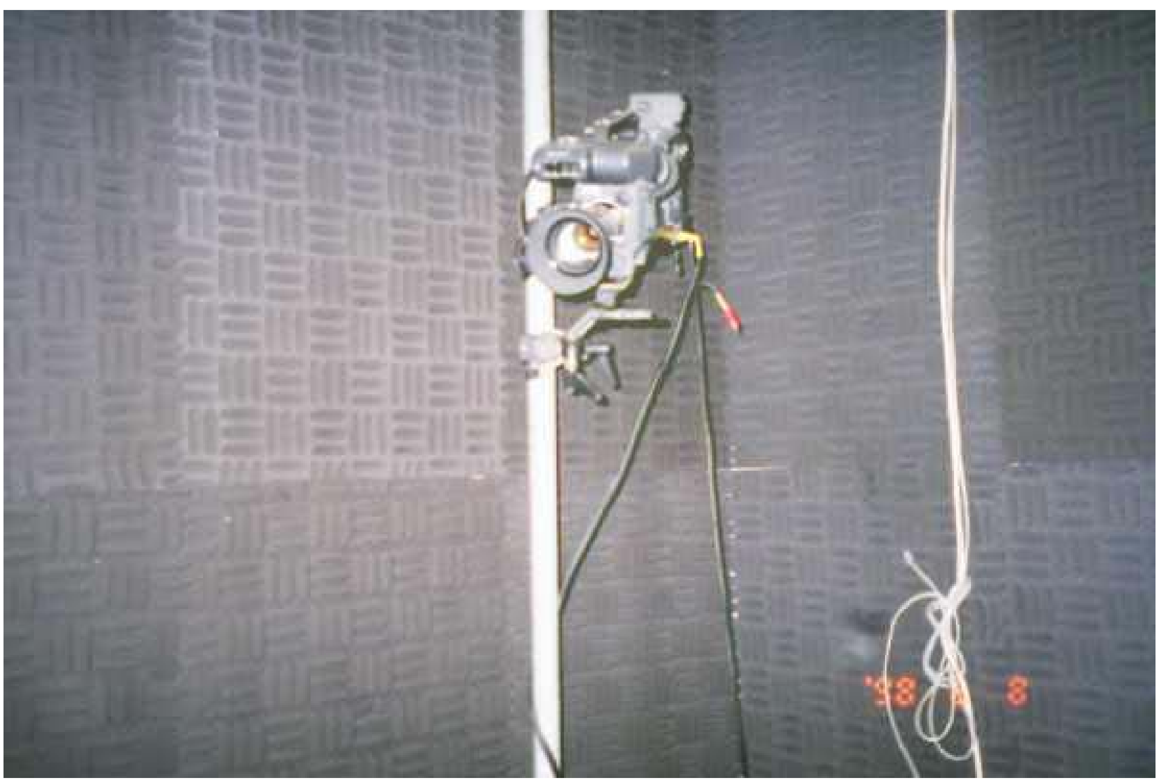

Figure 8. *Sony DXC-327 camera in simulator room*.

The walls of the simulator room were lined with Sonex SCOC2 acoustical foam. Realistic aircraft sounds, produced by the simulator, predominately engine noise, were channeled through a Parasound P/LD-100 line drive preamplifier and an OCM 200 Series amplifier and were presented through two Infinity SM-155 speakers (Figure 9) at a sound pressure level of 85dBA. This sound pressure level was based on previous studies at Virginia Tech using the same simulator to approximate the actual engine noise of a Cessna 172. Subjects wore a Bose Active Noise-reduction (ANR) Aviation headset during the experiment to minimize noise exposure and add realism to the simulation, as pilots wear aviation headsets in actual aircraft for communications.

Figure 9. *Infinity SM-155 speakers in simulator room*.

Procedure

Participants reported to the MacroErgonomics and Group Decision Systems Laboratory (MGDSL), room 567 Whittemore Hall, on the Virginia Tech campus. Before conducting any portion of the experiment, including pre-testing, all participants were required to read and sign an informed consent form (Appendix E), including permission to be video taped.

Experimental design and independent variables. The flight simulator experiment was a 2x2x2 mixed-factors design:

	VFR pilots		IFR pilots	
	Day	Night	Day	Night
Static, clear weather	s_1-s_8	s_1-s_8	s_9-s_{16}	s_9-s_{16}
Dynamic weather: VMC to IMC	s_1-s_8	s_1-s_8	s_9-s_{16}	s_9-s_{16}

*Control condition: static, clear weather, day flight

Figure 10. *Experimental design for laboratory experiment*.

The three independent variables were pilot type, daytime/nighttime, and weather. The pilot types, visual flight rules (VFR) certified and instrument flight rules (IFR) certified, is a between-subjects factor. Daytime/nighttime and weather conditions are within-subjects factors. The weather ceiling is the lowest layer of broken or overcast clouds present in feet above ground level. Visibility, during the day, represents the distance in miles at which predominant objects can be seen. During nighttime, visibility is the distance that unfocused lights of moderate intensity are visible. The simulated task for the IFR-current pilots was an instrument approach procedure with a Cessna 172 (depicted by the iGATE flight simulator) to Roanoke Regional Airport (Runway 33). VFR pilots performed a visual landing approach to the same airport and runway.

Beginning at a predetermined distance from the airport (i.e., 10 nautical miles), both pilot types performed landing approaches with each of four treatment combinations of weather and day/night as depicted in Figure 10. All landings used a 3° approach angle to the airport, as in the field study. Each treatment combination consisted of two consecutive runs/replications (two landing approaches). Thus each participant performed a total of eight landing approaches. Pilots were instructed to land only if they felt it was safe to do so. Otherwise, they were instructed to performed a 'go-around' or divert to another airport. Each landing run was completed and the simulation frozen upon a successful landing or if it became apparent that the participant intended to abort the landing. One of the weather levels used static, clear weather. This was ideal weather conditions with unlimited ceiling and visibility. During daytime, this weather level served as the control. The dynamic weather level starts with visual meteorological conditions (VMC) and deteriorates quickly to instrument meteorological conditions (IMC). Specifically, cloud ceiling above ground level and visibility began at 5000'/5 miles respectively and deteriorated to 4000'/2 miles during the simulation for this dynamic weather condition over the course of the approach. In order to reduce the effects of practice on the experimental outcome, the treatment conditions were randomly assigned for each participant. Each landing run was video taped, with the camera focused on the simulator instrument console.

<u>Participant familiarization</u>. Before the experimental session, for purposes of familiarization/training, participants flew simulated daylight approach procedures to the Roanoke Regional Airport with unlimited ceiling and visibility using a 3° approach angle. The training criterion was achieved after the pilot demonstrates two consecutive successful landings. However, the pilot was allowed to continue the familiarization session for up to one hour. If the pilot would have failed to meet the training criterion after one hour, he/she would have been dismissed from further participation. However, all participants met the criterion. After participants completed the familiarization procedure, they were given a ten-minute break before the experimental trials began.

Total time. The experimental session was expected to last approximately two hours and the familiarization session was expected to last up to one hour. Therefore, experimentation time was expected to be up to three hours per participant. In actuality, the average total participation time per pilot was two hours and 18 minutes. One extra IFR-rated participant (IFR09) was recruited to replace the data from participant IFR07, as it was learned that participant IFR07 did not complete his IFR check ride to be IFR-current. Thus a total of 17 subjects participated (eight VFR pilots, eight IFR pilots, and one pilot who was later dropped). Total experimentation time for the flight simulator experiment with 17 participants was over 39 hours.

Data collection / dependent measures. The flight performance data from each participant's flight scenario (such as deviation from flight path) was automatically collected by the simulation software and written to a local file on the experimenter's computer. Appendix C shows a complete list of variables automatically collected by the simulator software. From this list, the following variables were analyzed: total time, flight path angle, heading, pitch attitude, roll angle, altitude AGL, ground speed, indicated airspeed, vertical speed, ILS glideslope CDI, ILS localizer CDI, throttle input, flap deflection. Some of these variables relate to piloting activities (e.g., flap deflection) while others relate more directly to performance (e.g., ILS glideslope CDI, ILS localizer CDI). Some of the less "meaningful" variables are chosen out of convenience as the iGATE flight simulator automatically collects data for these measures and all measures chosen relate to piloting performance in varying degrees during a landing approach.

Subjective workload was assessed using the Modified Cooper-Harper (MCH) scale (Appendix A). The MCH was chosen since it was found to be sensitive to changes in workload across all types of pilot activities (see Table 3). The Situation Awareness Rating Technique (SART) was used as a measure of SA (Appendix B). SART is a popular measure that provides an assessment of SA based on operator opinion. The rating scale uses 10 independent dimensions that were elicited from knowledge of aircrew and therefore, the scale has high ecological validity (Taylor, 1990). The 10 dimensions are organized into three major groupings or 'domains': demand, supply, and understanding. User ratings from these domains are combined to provide an overall situation awareness score for the system (understanding total + supply total – demand total). SART was chosen for this laboratory experiment and subsequent field study because it has been found to be correlated with operator performance in the evaluation of different cockpit designs (Selcon and Taylor, 1990). The MCH and SART scales were administered after each treatment combination.

Statistical Methods

Analysis of Variance (ANOVA) was performed on the data from the experimental design for each flight performance measure to uncover significant main effects and interactions. MANOVA was not initially considered for the analysis as for MANOVA to be valid, the number of subjects in the smallest cell of the design must be larger than the number of dependent variables. This was not the case for this experiment (n per cell = 8; number of dependent variables = 13). However, MANOVA was performed after the initial statistical analysis (separate ANOVAs) by using a correlation matrix to partition the 13 performance variables into three smaller groups of variables based on areas of relatively high correlation, where the number of variables for each group was less than n per cell. A separate ANOVA was initially performed for each dependent variable. Post hoc comparisons were not necessary for this design since there are only two levels for each independent variable. Non-parametric comparisons were used for MCH and SART ratings. Specifically, since the design is a mixed-subjects design, the Wilcoxon Signed Ranks test was used for the within-subjects rating scale comparisons and the Kolmogorov-Smirnov test and the Mann-Whitney test were used for the between-subjects rating scale comparisons. An alpha level of α=0.05 was used for all of the statistical tests.

Application of the ME/DC Method

Although DC theory is meant for ethnographic field application, the applicable parts of the ME/DC method were also used to describe the simulated system in the laboratory (see Table 8, p. 71). Application of DC to a flight simulator is not unprecedented (Hutchins and Klausen, 1996). The ME/DC method was applied to the laboratory experiment to check for consistency between the field and simulated systems and also to study the validity of the method itself. That is, to check if the systems-level cognitive model described by the application of the ME/DC method in the field is also replicated in the laboratory through similar application of the method.

FIELD STUDY

Purpose

The functional system of the pilot performing an IFR and VFR landing approach to the Roanoke Regional Airport was described and analyzed. This task was the same task that was simulated in the laboratory experiment. The Roanoke Regional Airport was chosen for this study since it is the closest airport to Virginia Tech that has a complete instrument landing system (ILS) and a control tower. The ILS allows for IFR landing approaches and the control tower allows for the consideration of ATC communications during a landing approach. The ME/DC method was applied to this system. The ME/DC method is meant for field application as a main principle of DC theory is that cognition should be studied as it exists "in the wild" (Hutchins, 1995a). Also, the method draws from the macroergonomics analysis and design framework which was also designed for field application. Data was collected as the pilot performed the landing approach.

Hypothesis

It was hypothesized that the information flow observed in the pilot/cockpit system would differ between VFR and IFR pilots in certain respects during approach procedures. For example, the instrumentation and procedures used by each of the VFR and IFR pilots differ during a landing approach. Therefore, it was expected the information flow in the system would differ in certain respects between these pilot types. The ME/DC method was expected to be sensitive to these differences.

Participants

Three commercial pilots participated in the field study. One flew a visual approach (VFR) to Roanoke Runway 33 and the other two flew the instrument approach (ILS, Runway 33). More than three pilots could not be used in the field study due to FAA regulations that disallow compensation of non-commercial pilots, § 61.113 (a) and (c) of Title 14, Code of Federal Regulations (U.S. Government, 2003). Only commercial-rated pilots could legally be compensated to participate (as opposed to private pilots) and there were only three commercial pilots who were insured to fly Virginia Tech's Cessna 172. Participants were compensated $24/hr (the same rate for flight instruction at the Virginia Tech Airport). Each participant's prior flight experience was recorded (VFR, cross-country, IFR, simulated, and total hours).

Apparatus

Each flight was conducted in Virginia Tech's Cessna 172 aircraft (Figure 11). The Cessna 172 is the most commonly used GA aircraft in the world and this plane is available for rental through the Virginia Tech Airport. Also, for the laboratory experiment, the iGATE flight simulator was used to simulate the Cessna 172. Thus, the same aircraft type was used for the field and simulated studies. General information on Virginia Tech's Cessna 172 is given in Table 7.

Figure 11. *Virginia Tech's Cessna 172 (picture taken in the field by the author).*

TABLE 7

General Information about Virginia Tech's Cessna 172 Aircraft

- Tail Number: N61891
- Model Year: 1975
- Hourly Rental Rate: $62.00
- Seats: 4 Passengers
- Horse Power: 150HP
- Cruise Speed: 105 Knots

Procedure

Before beginning with the field study, all participants were required to read and sign an informed consent including permission to be video taped (Appendix F) and a health screening and demographics form (Appendix G). Each participant was given a copy of the general instructions for the flight (Appendix H). After verifying that all data collection equipment was working properly, the pilot, safety pilot (required by the Virginia Tech IRB), and experimenter took off from the Virginia Tech airport towards Roanoke. The safety pilot was seated in the co-pilot's seat and the experimenter was seated in the back seat. The safety pilot was a licensed private pilot and certified for IFR piloting. His primary task during each flight was to watch for nearby traffic while the pilots flew by instruments. He was also present to pilot the aircraft in the event the participant became incapacitated during the flight. Two pilots performed an instrument approach procedure to Roanoke Regional Airport (Runway 33) and used a hood to simulated IMC. This airport is a controlled airport with an instrument landing system (ILS). Glide slope angle for this ILS is 3°, which is considered to be a standard approach angle. One pilot performed a visual landing approach to the same runway.

The flight from the Virginia Tech Airport to the Roanoke Regional Airport lasted approximately 18 minutes for the visual approach and over 30 minutes for each of the instrument approaches using the ILS 33. Each participant's landing at the Roanoke Regional Airport was "touch and go" (a landing with an immediate takeoff) and then direct back to the Virginia Tech airport for debriefing. Debriefing included retrospective verbal reports, informal interviewing, and workload and situation awareness rating scales (see below). Average total participation time per subject including the flight and debriefing session was two hours and 26 minutes.

Observations and Data Collection Instrumentation

Data collection consisted of video and audio recordings during the flight, retrospective reports, field notes, and interviewing, all of which relate directly to Step 5 (Conduct Observations based on Scenario, see p. 46 and p. 100) in the ME/DC method. GPS data and subjective rating scales were additional sources of data in the field.

All data collection in the aircraft was observational, passive, and non-intrusive. Any instrumentation hooked into the aircraft electrical system could have interfered with the operations of the normal aircraft instrumentation and would present a safety concern. Therefore, all 'foreign' instrumentation used during data collection in the aircraft was battery powered. This would include video/audio equipment, laptop computer, and GPS unit. Figure 12 depicts the data collection instrumentation set-up as a block diagram. Figures 13 and 14 are pictures of the actual set-up. Each component of the set-up is described in the subsequent sections. Except for the miniature video camera and GPS antenna, each component was secured to a board which sat on the experimenter's lap.

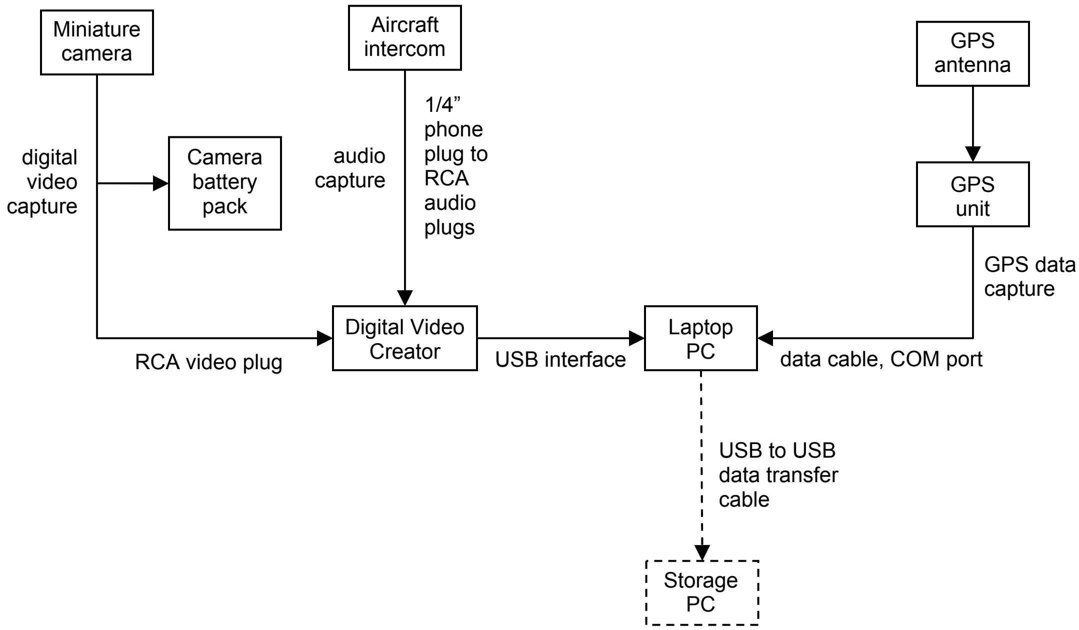

Figure 12. *Data collection configuration*.

Figure 13. *Data collection set-up, actual*.

Figure 14. *Data collection set-up, in aircraft.*

Video/audio recording. A SCS Inc. miniature pinhole video camera (model HRC-400P, dimensions 0.9" x 0.9"x 0.45") was securely mounted with a Velcro® brand fastener with Sticky Back® on the ceiling of the aircraft cockpit (Figure 15) to obtain a complete video record of each participant's approach and landing to the airport. The video from the miniature pinhole camera was converted from analog to digital in real time using a Dazzle Digital Video Creator (model DVC-80) and MGI VideoWave 4 software. The digital video was then transferred and captured by a laptop PC through the laptop's USB port with aforementioned software. The laptop possessed 3.5 GB of free space. To work with these space limitations, video frame rate was reduced to 10 frames per second. With this frame rate, the experimenter was able to record each approach to the Roanoke regional Airport in its entirety. For example, the video file size for the longest approach flight (approximately 32 minutes for participant IFR02) was 2.79 GB.

Audio communication had to be captured directly from the cockpit intercom radio because of the high intensity engine noise. This was done with a specialized audio cable that with a ¼” phone plug on one end that connected to the phone headphone jack and RCA plus on the other end which connected directly to the Dazzle Digital Video Creator. A special capture template was created with the MGI VideoWave software to capture the audio and video simultaneously; the audio communications were overlaid on the digital video and saved in the same file, time synchronized. After each field test, data was transferred from the laptop to the experimenter’s PC using a GWC Tech USB SmartNet Cable and corresponding software. This direct USB to USB port connection between computers allowed for the transfer of the large digital video files (between 2 and 3 GB per file). All audio records were transcribed (e.g., pilot/ATC communications). The printed transcriptions, as well as the video records, served as a rich source of data in understanding the information flow during the scenario, and together were the primary source of data for reconstructing the observed information flow during the field flights, as driven by the ME/DC method.

Figure 15. *Miniature camera attached to cockpit ceiling.*

Figure 16. *Camera view, still shot from actual video.*

GPS data acquisition. A Garmin GPSMAP 295 unit was used to capture positional information during each flight. The GPS data was continuously streamed in real time from the GPS unit to the laptop PC, using the NMEA interface protocol, with a connecting data cable through the communications port. A template was created with Hyperterminal software on the laptop PC to display and capture the GPS data for the entirety of each flight. The aircraft's latitude and longitude for each flight was extracted from the raw data (NMEA text strings) during the data reduction phase. Each aircraft's flight path was reconstructed and displayed (see Chapter 4) through conversion of latitude and longitude data to XY grid coordinates.

Field notes. Field notes from participant observation were recorded by the researcher (by hand) throughout the scenario as a secondary means of qualitative data collection and to augment the video/audio recordings.

Retrospective verbal reports. The video recordings were shown to participants promptly after returning to the Virginia Tech airport and they were asked to describe aloud what they were doing as they saw/heard what they did while reviewing the video. These retrospective verbal reports, which were also be recorded and transcribed, were a secondary source of data in understanding the information flow during the scenario (video and audio communications during the actual flight were the primary source). A limitation of a retrospective report is that there is a delay from when the participant provides the report from the actual event the participant is reporting on. In the field study, participants began their retrospective reports less than one hour from the beginning of their flight. However, in this case, pilots gave their retrospective reports as they reviewed a playback of the actual video and audio recordings of the flight. Further, there were no instances where pilots reported forgetting information during the retrospective report.

Interviewing. A post scenario interview after each flight was conducted as another means of collecting qualitative data. The questions were open-ended as the purpose was to enter missing information (e.g., help the researcher understand some of the activities and communication that took place during the scenario). The majority of the questions were asked during the video playback and thus were recorded and transcribed.

Subjective rating scales. The same workload and situation awareness rating scales that were used in the laboratory experiment were given to each participant at the beginning of the debriefing session (MCH and SART). However, since there were a total of three field participants, the subjective ranks were considered in a non-statistical capacity.

Procedural comparison. The procedures of the actual Cessna 172 from this field study were documented through task analysis and compared to the procedures of the iGATE simulator for the Cessna 172 (Tables 29 and 30, Results chapter). Comparison between the field and the laboratory involved determining if the tasks performed in the field by the pilot during a landing approach match the tasks performed with the flight simulator. This was done to consider the external validity of the iGATE simulator. The same approach to the Roanoke Regional Airport was used for both the field and simulated studies.

Application of ME/DC Method

The ME/DC method, as presented earlier in this chapter, was applied to this field study. This method describes the function/task allocation, pilot tasks for IFR and VFR approaches, the system's physical features and geographic distribution of the physical space, the people and technological artifacts that affect the system's behavior, the temporal distribution of the information, and the communicative pathways. An output of this method is an understanding of the information flow and representation as coordinated by these structures (i.e., a systems-level cognitive model). The method also provides a description of the overall organizational system in terms of complexity, formalization, and centralization as well as the sociotechnical subsystems of the overall organization and of the unit of analysis (the pilot/cockpit system). See Table 8 for each step involved in the ME/DC method, as applied to the studies in this dissertation.

Documentation is written, with supporting information flow representations, graphics, and tables. To complement the descriptive nature of the ME/DC method, a continuous time stamp was recorded throughout the field observations to add a quantitative component. With a continuous time measurement, specific periods of the landing approach were associated with specific tasks (e.g., ATC communications, glide slope acquisition, flap settings, etc.).

TABLE 8

Application of the ME/DC Method to the Field Study and Laboratory Experiment

	Output	
ME/DC Method	*Field Study*	*Laboratory Experiment*
Step 1	Boundaries of the functional system by defining the system's purpose, resources, communicative pathways, and how the structures of the system are coordinated.	This step was performed for the flight simulator experiment to check for consistency between the systems in the field study and laboratory experiment.
Step 2	Overall system scan by defining the complexity, formalization and centralization of the overall work system and by describing the technological, social, and environmental subsystems.	The output of this step from the field study is assumed to be the same for the laboratory experiment. The laboratory experiment is a simulated portion of the overall system from the field study.
Step 3	Bounded system scan by defining the technological, social, and environmental components of the functional system.	Repeated for flight simulator experiment to check for consistency between the systems in the field study and laboratory experiment.
Step 4	A scenario consisting of a landing approach to the Roanoke Regional Airport in a GA aircraft (both VFR and IFR).	Same scenario except simulated.
Step 5	Participant observation, video/audio recording, field notes, retrospective protocol, interviewing, flight performance measures, and workload and situation awareness rating scales.	The same workload and situation awareness rating scales were used. Also, the flight simulator software automatically collected data across several flight performance variables.
Step 6	Bounded system's function/task allocation and information distribution and representation.	Repeated for flight simulator experiment to check for consistency between the systems in the field study and laboratory experiment.

Analytical Methods

Qualitative data gathered from video/audio recording, field notes, and interviewing was used to help understand the system's organizational components and information distribution and representation as described by the ME/DC method. Organizational components of the Roanoke airspace system was described using a macroergonomics approach (Hendrick and Kleiner, 2001) by determining the complexity, formalization and centralization of the work system and by describing the technological, social, and environmental subsystems. The systems-level cognitive model, for both VFR and IFR approaches, was also derived from all of the qualitative data collected. This information flow of the instrument approach and visual approach to the Roanoke Regional Airport was described using Hutchin's (1991, 1995a, 1995b) framework of distributed cognition. The information flow of the system was described in terms of physical manipulation of objects, internal information representations, creation/exchange of external information representations through the various communicative pathways, and target and goal information states.

Chapter 4. RESULTS

Results from the laboratory, field, and ME/DC method are presented in this chapter. In the laboratory experiment, the nature of the data is primarily quantitative and includes statistical analysis of flight performance variables, workload ratings, and situation awareness ratings for the experimental design. Also presented are the landing statistics for both VFR and IFR pilots. The nature of the data presented from the field study, which was driven in part by the ME/DC method, is primarily qualitative, with complete transcriptions of the audio communications from each flight, and transcriptions of pilots' retrospective reports. Also included is a task analysis for both the instrument and visual approach to the Roanoke Regional Airport. The task analysis was used to conduct a procedural comparison between actual flights in the field and the flight simulator in the laboratory.

LABORATORY RESULTS

Since the statistical analyses are extensive, all statistically significant results and other important results are reported here and any results not given in this chapter are referenced and listed in Appendices. Raw data collected by the flight simulator for the flight performance variables includes eight spreadsheets (one spreadsheet for each run, two runs per condition) for each subject. Each spreadsheet is 13 variables by approximately *13,000* values (the simulator data collection module samples at 30 times per second). Thus, the raw data for the flight performance variables cannot be included in this document. However, the means for these variables for each subject and for each condition are included in Appendix I. Raw data from the subjective MCH and SART scales are included in Appendix J.

Flight Performance Variables

A correlation matrix was developed for 13 flight performance variables to assess the interdependencies of the measures (see Appendix R on p. 285). Based on areas of relatively high correlation from this matrix, the 13 measures were partitioned into three separate groups of variables (Appendix R). MANOVA was performed on each of the three groups of variables and indicated a main effect of Day/Night and an interaction of Pilot Type and Day/Night on the second grouping of variables (Appendix R). The MANOVA results are consistent with the individual ANOVAs. This second group of variables contained ILS localizer CDI and flight path angle, both of which were further explored with individual ANOVA, where main effects were discovered.

ANOVA for each of the flight performance variables was conducted for the 2x2x2 mixed factors design. The two significant p-values ($p \leq 0.05$) from ANOVA on the 13 dependent measures are summarized in Table 9.

TABLE 9

Summary of Significant ANOVA p-values

Dependent Measure	Factor	p-value
Flight Path Angle	B: Day/Night	0.025 (see Table 12)
ILS Localizer CDI	A: Pilot Type	0.014 (see Table 10)

Only the ANOVA tables with significant results are listed below. For a complete listing of all ANOVA results, refer to Appendix K. ANOVA for ILS Localizer CDI (Table 10) revealed a main effect of Pilot Type (p=0.014). There was a significant interaction of Pilot Type and Day/Night (Table 11) for Altitude (p=0.029). ANOVA for flight path angle (Table 12) revealed a main effect of Day/Night (p=0.025).

TABLE 10

Analysis of Variance for ILS Localizer CDI

A=Pilot Type; B=Day/Night; C=Weather

Source	**DF**	**SS**	**MS**	**F**	**P**
Between					
A	1	0.014702	0.014702	7.84	**0.014 ***
S(A)	14	0.026247	0.001875		
Within					
B	1	0.012939	0.012939	0.99	0.336
A*B	1	0.007439	0.007439	0.57	0.463
B*S(A)	14	0.182597	0.013043		
C	1	0.010252	0.010252	3.79	0.072
A*C	1	0.003452	0.003452	1.28	0.278
C*S(A)	14	0.037872	0.002705		
B*C	1	0.005077	0.005077	0.69	0.420
A*B*C	1	0.007877	0.007877	1.07	0.318
Error	14	0.102822	0.007344		
Total	63	0.411273			

* Indicates significant result ($p \leq 0.05$)

TABLE 11
Analysis of Variance for Altitude (above ground level, AGL)

A=Pilot Type; B=Day/Night; C=Weather

Source	**DF**	**SS**	**MS**	**F**	**P**
Between					
A	1	19435	19435	1.14	0.304
S(A)	14	239438	17103		
Within					
B	1	10343	10343	2.70	0.123
A*B	1	22699	22699	5.93	**0.029** *
B*S(A)	14	53611	3829		
C	1	4635	4635	3.13	0.099
A*C	1	5879	5879	3.97	0.066
C*S(A)	14	20713	1479		
B*C	1	3741	3741	0.96	0.345
A*B*C	1	3455	3455	0.88	0.363
Error	14	54767	3912		
Total	63	438715			

* Indicates significant result ($p \leq 0.05$)

TABLE 12
Analysis of Variance for Flight Path Angle

A=Pilot Type; B=Day/Night; C=Weather

Source	**DF**	**SS**	**MS**	**F**	**P**
Between					
A	1	0.0162562	0.0162562	3.02	0.104
S(A)	14	0.0753438	0.0053817		
Within					
B	1	0.0042250	0.0042250	6.28	**0.025** *
A*B	1	0.0010562	0.0010562	1.57	0.231
B*S(A)	14	0.0094187	0.0006728		
C	1	0.0056250	0.0056250	2.52	0.135
A*C	1	0.0045563	0.0045563	2.04	0.175
C*S(A)	14	0.0312187	0.0022299		
B*C	1	0.0004000	0.0004000	0.47	0.506
A*B*C	1	0.0014062	0.0014062	1.64	0.221
Error	14	0.0119938	0.0008567		
Total	63	0.1615000			

* Indicates significant result ($p \leq 0.05$)

To supplement the 2x2x2 mixed factors ANOVAs, the between-subjects factor, Pilot Type (A), was removed such that separate ANOVAs could be conducted for each pilot group. One significant result was found for the IFR group for flight path angle on day versus night operations (Table 13). A similar ANOVA for the VFR group did not yield the same significant result (p=0.509).

TABLE 13

Analysis of Variance for Flight Path Angle, IFR Pilots Only

A=Day/Night; B=Weather

Source	DF	SS	MS	F	P
Between					
S	7	0.0356219			
Within					
A	1	0.0047531	0.0047531	18.78	**0.003 ***
A*S	7	0.0017719	0.0002531		
B	1	0.0000281	0.0000281	0.02	0.895
B*S	7	0.0105969	0.0015138		
A*B	1	0.0001531	0.0001531	0.21	0.660
Error	7	0.0050719	0.0007246		
Total	31	0.0579969			

* Indicates significant result ($p \leq 0.01$)

Workload, Between-subjects Comparisons

The Kolmogorov-Smirnov Test was performed to test the hypothesis that VFR pilots would have greater workload than IFR pilots (Table 14). The Kolmogorov-Smirnov Test indicated that there was no significant difference in workload, as measured by the MCH rating scale, between VFR and IFR pilots.

TABLE 14

Kolmogorov-Smirnov Test for Workload Between VFR and IFR Pilots

H_0: $X_{0(VFR)} - X_{0(IFR)} = 0$
H_1: $X_{0(VFR)} - X_{0(IFR)} > 0$

Median Rating (MCH)	VFR Pilots	IFR Pilots
1	1	0
2	2	2
3	3	4
4	2	2
5	0	0
6	0	0
7	0	0
8	0	0
9	0	0
10	0	0
	m = 8	n = 8

Sample	1	2	3	4	5	6	7	8	9	10
$S_m(X)$	1/8	3/8	6/8	8/8	8/8	8/8	8/8	8/8	8/8	8/8
$S_n(X)$	0/8	2/8	6/8	8/8	8/8	8/8	8/8	8/8	8/8	8/8
$\|S_m\text{-}S_n\|$	.125	.125	0	0	0	0	0	0	0	0

Observed Value: $D_{m,n} = | S_m(X) - S_n(X) | = 0.125$

$C_{.05} = 40$ (tabled value)

Rejection Region: $mnD_{m,n} \geq C$;

$mnD_{m,n} = (8)(8)(0.125) = 8$

8 not $\geq$ 40, therefore, do not reject H_0;

VFR workload is not significantly higher than IFR workload.

Considering all conditions, the Kolmogorov-Smirnov Test did not indicate an *overall* increase in VFR workload compared to IFR workload. The Mann-Whitney Test was conducted to check for workload differences between VFR and IFR pilots for *each* specific condition and revealed that VFR workload was not significantly greater than IFR workload for any of the specific conditions and was actually significantly *less* than IFR workload for the control condition (static, clear weather during day time) (p=0.0229)

(Table 15). See Appendix L for a complete listing of all of the Mann-Whitney Tests for each condition.

TABLE 15

Mann-Whitney Test, Static Clear Weather during Day, VFR vs. IFR Workload

SCD-VFR N = 8 Median = 1.500
SCD-IFR N = 8 Median = 2.000
Point estimate for ETA1-ETA2 is -1.000
95.9 Percent CI for ETA1-ETA2 is (-0.999,0.000)
W = 50.0
Test of ETA1 = ETA2 vs ETA1 < ETA2 is significant at 0.0330
The test is significant at 0.0229 (adjusted for ties)

Workload, Within-subjects Comparisons

VFR. The Wilcoxon Signed Ranks Test was used for workload comparisons within the VFR pilot group. One statistically significant result was found. VFR workload was found to be greater with dynamic weather during day time when compared to static weather during day time (Table 16). See Appendix M for the complete listing of the Wilcoxon Signed Ranks Tests for all conditions within the VFR group.

TABLE 16

Wilcoxon Signed Ranks Test for VFR Workload, Static Clear Weather during Daytime (SCD) vs. Dynamic Weather during Daytime (DD)

Subjects	Static	Dynamic	d	Rank of d
1	1	3	2	(+) 6.5
2	1	2	1	(+) 3.5
3	2	4	2	(+) 6.5
4	1	1	0	1.5
5	2	4	2	(+) 6.5
6	3	3	0	1.5
7	2	3	1	(+) 3.5
8	1	3	2	(+) 6.5

H_0: $X_{0(VFR, DD)} = X_{0(VFR, SCD)}$

H_1: $X_{0(VFR, DD)} > X_{0(VFR, SCD)}$

$S_+ = (6.5+3.5+6.5+6.5+3.5+6.5) = 33$

$C_1 = 30$ [tabled value, $p(S+ \geq 30) = 0.055$]

Rejection Region: $S+ \geq C_1$

33 > 30, Reject H_0;

VFR workload with dynamic weather is greater than VFR workload with static weather, during day time (alpha level = 0.055).

IFR. The Wilcoxon Signed Ranks Test was used for workload comparisons within the IFR pilot group. No statistically significant differences in workload were found within the IFR group for any of the conditions. See Appendix M for the complete listing of the Wilcoxon Signed Ranks Tests for all conditions within the IFR group.

Situation Awareness, Between-subjects Comparisons

The Kolmogorov-Smirnov Test was performed to test the hypothesis that VFR pilots would have reduced situation awareness compared to IFR pilots (Table 17). The Kolmogorov-Smirnov Test indicated that VFR pilots did have significantly lower situation awareness than IFR pilots, as measured by the SART rating scale.

TABLE 17
Kolmogorov-Smirnov Test for Situation Awareness Between VFR and IFR Pilots

H_0: $X_{0(VFR)} - X_{0(IFR)} = 0$
H_1: $X_{0(VFR)} - X_{0(IFR)} < 0$

Median Rating (SART)	VFR Pilots	IFR Pilots
19	1	0
20	1	0
21	1	0
22	0	0
23	0	2
24	1	0
25	1	1
26	1	0
27	2	0
28	0	0
29	0	0
30	0	0
31	0	1
32	0	1
33	0	0
34	0	0
35	0	2
36	0	1
	m = 8	n = 8

Sample	19	20	21	22	23	24	25	26	27	28
$S_m(X)$	1/8	2/8	3/8	3/8	3/8	4/8	5/8	6/8	8/8	8/8
$S_n(X)$	0/8	0/8	0/8	0/8	2/8	2/8	3/8	3/8	3/8	3/8
$\|S_m\text{-}S_n\|$	.125	.250	.375	.375	.125	.250	.250	.375	.625	.625

Sample	29	30	31	32	33	34	35	36
$S_m(X)$	8/8	8/8	8/8	8/8	8/8	8/8	8/8	8/8
$S_n(X)$	3/8	3/8	4/8	5/8	5/8	5/8	7/8	8/8
$\|S_m\text{-}S_n\|$	.625	.625	.500	.375	.375	.375	.125	0

Observed Value: $D_{m,n} = | S_m(X) - S_n(X) | = 0.625$

$C_{.05} = 40$ (tabled value)

Rejection Region: $mnD_{m,n} \geq C$;

$mnD_{m,n} = (8)(8)(0.625) = 40$

40 = 40, therefore, reject H_0;

VFR situation awareness is significantly lower than IFR situation awareness.

Considering all conditions, the Kolmogorov-Smirnov Test indicated an *overall* decrease in VFR situation awareness compared to IFR situation awareness. The Mann-Whitney Test was conducted to check for situation awareness differences between VFR and IFR pilots for *each* specific condition and revealed that VFR situation awareness was significantly less than IFR situation awareness for each of the specific conditions (Tables 18-21) except static, clear weather at night time (p = 0.0571).

TABLE 18

Mann-Whitney Test, Static Clear Weather during Day, VFR vs. IFR Situation Awareness

SCD-VFR	N =	8	Median =	27.000
SCD-IFR	N =	8	Median =	31.500

Point estimate for ETA1-ETA2 is -5.000
95.9 Percent CI for ETA1-ETA2 is (-11.998,0.002)
W = 48.5
Test of ETA1 = ETA2 vs ETA1 < ETA2 is significant at 0.0230
The test is significant at 0.0227 (adjusted for ties)

TABLE 19

Mann-Whitney Test, Static Clear Weather during Night, VFR vs. IFR Situation Awareness

SCN-VFR	N =	8	Median =	24.500
SCN-IFR	N =	8	Median =	32.000

Point estimate for ETA1-ETA2 is -7.500
95.9 Percent CI for ETA1-ETA2 is (-12.000,1.999)
W = 52.5
Test of ETA1 = ETA2 vs ETA1 < ETA2 is significant at 0.0576
The test is significant at 0.0571 (adjusted for ties)

Cannot reject at alpha = 0.05

TABLE 20

Mann-Whitney Test, Dynamic Weather during Day, VFR vs. IFR Situation Awareness

```
DD-VFR      N =  8    Median =   21.000
DD-IFR      N =  8    Median =   30.500
Point estimate for ETA1-ETA2 is     -8.000
95.9 Percent CI for ETA1-ETA2 is (-12.999,-1.000)
W = 46.0
Test of ETA1 = ETA2  vs  ETA1 < ETA2 is significant at 0.0120
The test is significant at 0.0115 (adjusted for ties)
```

TABLE 21

Mann-Whitney Test, Dynamic Weather during Night, VFR vs. IFR Situation Awareness

```
DN-VFR      N =  8    Median =   23.00
DN-IFR      N =  8    Median =   30.50
Point estimate for ETA1-ETA2 is      -7.00
95.9 Percent CI for ETA1-ETA2 is (-13.00,1.00)
W = 49.5
Test of ETA1 = ETA2  vs  ETA1 < ETA2 is significant at 0.0294
The test is significant at 0.0291 (adjusted for ties)
```

Situation Awareness, Within-subjects Comparisons

VFR. The Wilcoxon Signed Ranks Test was used for situation awareness comparisons within the VFR pilot group. Two statistically significant results were found. VFR situation awareness at night was significantly reduced compared to VFR situation awareness during the day when weather was static and clear (Table 22). Also, VFR situation awareness with dynamic weather was significantly reduced compared to VFR situation awareness with static weather, during daytime (Table 23). See Appendix N for the complete listing of the Wilcoxon Signed Ranks Tests for all conditions within the VFR group.

TABLE 22

Wilcoxon Signed Ranks Test for VFR Situation Awareness, Static Clear Weather during Daytime (SCD) vs. Static Clear Weather during Nighttime (SCN)

Subjects	Day	Night	d	Rank of d
1	24	27	3	(+) 3.5
2	22	17	-5	(-) 6.5
3	28	23	-5	(-) 6.5
4	32	24	-8	(-) 8
5	19	20	1	(+) 2
6	28	25	-3	(-) 3.5
7	26	26	0	1
8	31	27	-4	(-) 5

H_0: $X_{0(VFR, SCN)} = X_{0(VFR, SCD)}$

H_1: $X_{0(VFR, SCN)} < X_{0(VFR, SCD)}$

$S_+ = (3.5+2) = 5.5$

$C_1 = 30$; $C_2 = 6$ [tabled value, $p(S+ \geq 30) = 0.055 = p(S+ \leq 6)$]

Rejection Region: $S+ \leq C_2$

$5.5 < 6$, Reject H_0;

VFR situation awareness at night is significantly reduced compared to VFR situation awareness during the day when weather is static (alpha level = 0.055).

TABLE 23

Wilcoxon Signed Ranks Test for VFR Situation Awareness, Static Clear Weather during Daytime (SCD) vs. Dynamic Weather during Daytime (DD)

Subjects	Static	Dynamic	d	Rank of d
1	24	19	-5	5.5
2	22	21	-1	1.5
3	28	17	-11	8
4	32	27	-5	5.5
5	19	20	1	(+) 1.5
6	28	26	-2	3.5
7	26	24	-2	3.5
8	31	21	-10	67

H_0: $X_{0(VFR, DD)} = X_{0(VFR, SCD)}$

H_1: $X_{0(VFR, DD)} < X_{0(VFR, SCD)}$

$S_+ = 1.5$

$C_1 = 30$; $C_2 = 6$ [tabled value, $p(S+ \geq 30) = 0.055 = p(S+ \leq 6)$]

Rejection Region: $S+ \leq C_2$

$1.5 < 6$, Reject H_0;

VFR situation awareness with dynamic weather is significantly reduced compared to VFR situation awareness with static weather, during day time (alpha level = 0.055).

<u>IFR</u>. The Wilcoxon Signed Ranks Test was used for situation awareness comparisons within the IFR pilot group. Two statistically significant differences were found. IFR situation awareness with dynamic weather was significantly different (reduced) compared to IFR situation awareness with static weather, during day time (Table 24) *and* during nighttime (Table 25). See Appendix N for the complete listing of the Wilcoxon Signed Ranks Tests for all conditions within the IFR group.

TABLE 24

Wilcoxon Signed Ranks Test for IFR Situation Awareness, Static Clear Weather during Daytime (SCD) vs. Dynamic Weather during Daytime (DD)

Subjects	Static	Dynamic	d	Rank of d
1	29	25	-4	5
2	26	21	-5	6
3	27	21	-6	7
4	31	31	0	2
5	34	37	3	(+) 4
6	36	36	0	2
7	32	32	0	2
8	41	30	-11	8

H_0: $X_{0(\mathrm{IFR,\ DD})} = X_{0(\mathrm{IFR,\ SCD})}$

H_1: $X_{0(\mathrm{IFR,\ DD})}$ not = $X_{0(\mathrm{IFR,\ SCD})}$

$S_+ = 4$

$C_1 = 32$; $C_2 = 4$ [tabled values, $p(S+ \geq 32) = 0.054 = p(S+ \leq 4)$]

Rejection Region: Either $S+ \geq C_1$ or $S+ \leq C_2$

4 = 4, Reject H_0;

IFR situation awareness with dynamic weather is significantly different (reduced) compared to IFR situation awareness with static weather, during day time (alpha level = 0.054).

TABLE 25

Wilcoxon Signed Ranks Test for IFR Situation Awareness, Static Clear Weather during Nighttime (SCN) vs. Dynamic Weather during Nighttime (DN)

Subjects	Static	Dynamic	d	Rank of d
1	22	22	0	1.5
2	22	23	+1	(+) 3.5
3	24	21	-3	6.5
4	32	29	-3	6.5
5	38	32	-6	8
6	36	35	-1	3.5
7	32	32	0	1.5
8	35	33	-2	5

H_0: $X_{0(IFR,\ DN)} = X_{0(IFR,\ SCN)}$

H_1: $X_{0(IFR,\ DN)}$ not = $X_{0(IFR,\ SCN)}$

$S_+ = 3.5$

$C_1 = 32$; $C_2 = 4$ [tabled values, $p(S+ \geq 32) = 0.054 = p(S+ \leq 4)$]

Rejection Region: Either $S+ \geq C_1$ or $S+ \leq C_2$

$3.5 < 4$; Reject H_0;

IFR situation awareness with dynamic weather is significantly different (reduced) compared to IFR situation awareness with static weather, during night time (alpha level = 0.054).

Landing Statistics

Table 26 shows the landing statistics for both the VFR and IFR pilots. There was one case from each pilot group of an aborted landing. One approach for the IFR group touched down slightly short of the runway. However, most approaches for each pilot group ended with a successful landing. These statistics support the lack of significant differences between the VFR and IFR pilots for the flight performance variables as tested with ANOVA.

TABLE 26

Landing Statistics

	VFR		
	Successful Landings	Aborted Landings	Short of Runway
Static Clear Weather during Daytime	16	0	0
Static Clear Weather during Nighttime	16	0	0
Dynamic Weather during Daytime	16	0	0
Dynamic Weather during Nighttime	15	1	0
	IFR		
	Successful Landings	Aborted Landings	Short of Runway
Static Clear Weather during Daytime	15	0	1
Static Clear Weather during Nighttime	16	0	0
Dynamic Weather during Daytime	16	0	0
Dynamic Weather during Nighttime	15	1	0

Note: Each participant performed two landing approaches per condition.
Note: There were no crashes.

FIELD RESULTS

The flight paths from each flight as recorded by the GPS receiver are presented. Due to length, the complete transcriptions of the audio communications from each flight and transcriptions of pilots' retrospective reports are presented in (Appendices O, P, and Q). This data was used, along with the video records, to help construct systems-oriented cognitive models for both VFR and IFR pilots as they conducted an approach to the Roanoke Regional Airport. These models are presented as part of the ME/DC method in this chapter, which was used to guide data collection in the field. A task analysis is also included for both approach types. This task analysis (pp. 119-125) does not relate to the systems-oriented cognitive models that document the information flow of the system (pp. 101-118). Rather, the task analysis was performed to compare the piloting procedures between the flight simulator in the laboratory with the procedures in the actual Cessna 172 from the field.

<u>GPS Data</u>

GPS data collected in the field was used to reconstruct the courses of each flight. Specifically, latitude and longitude coordinates of the aircraft, which were sampled once every two seconds by the GPS receiver, were later converted to Universal Transverse Mercator (UTM) coordinates. This is a conversion of geographical coordinates (latitude and longitude) from an ellipsoid to X, Y coordinates on a rectangular plane. The base latitude and base longitude references used for the conversion were 37° N and 81° W respectively. For Figures 17, 18, and 19, the reference was centered to the Virginia Tech Airport (X,Y = 0,0). These three figures show the flight paths for each pilot's flight from the Virginia Tech Airport (BCB) to the Roanoke Regional Airport (ROA).

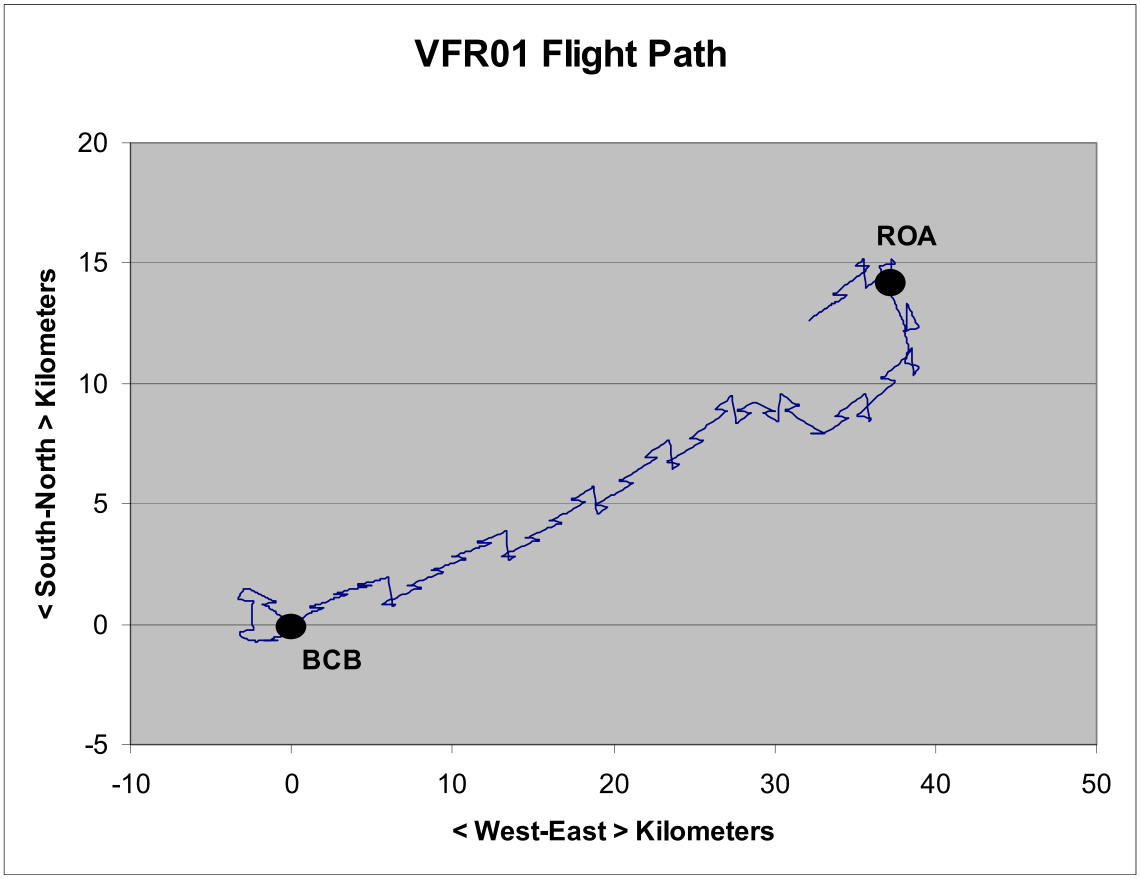

Figure 17. *Flight path for pilot VFR01.*

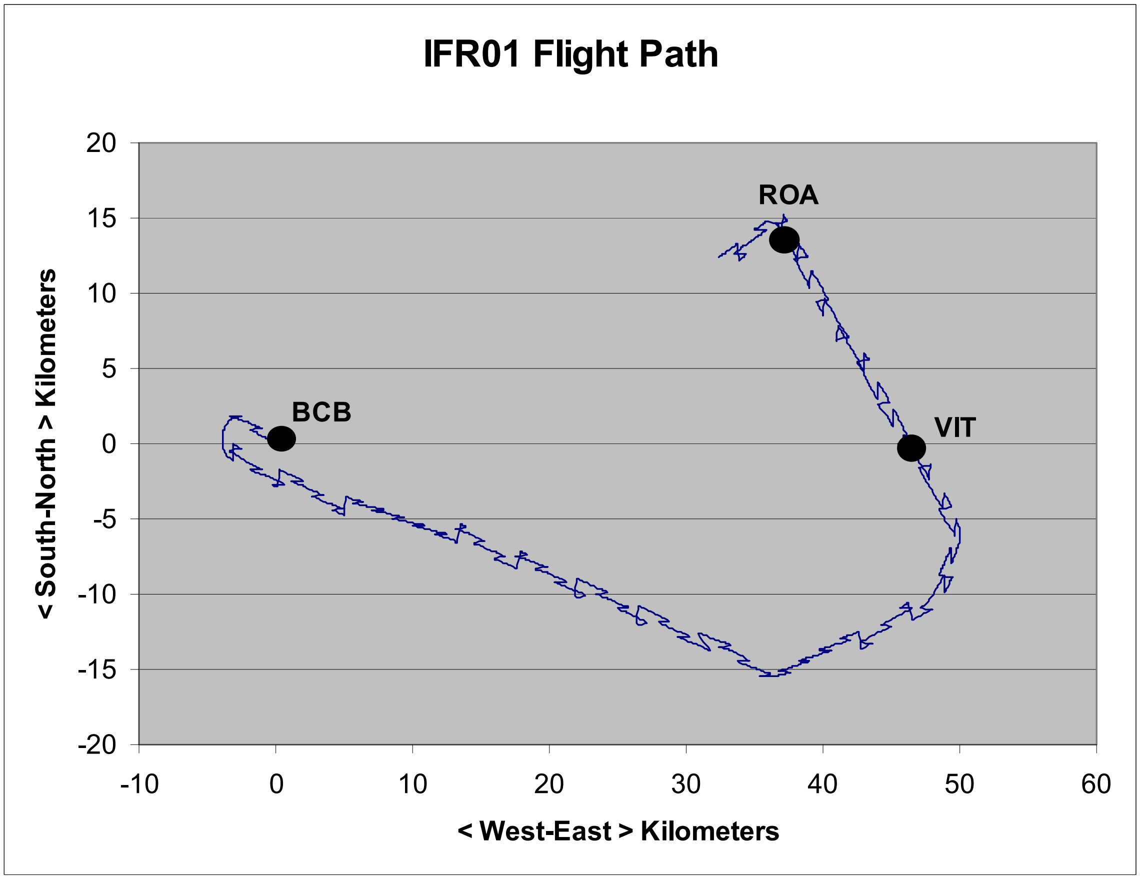

Figure 18. *Flight path for pilot IFR01.*

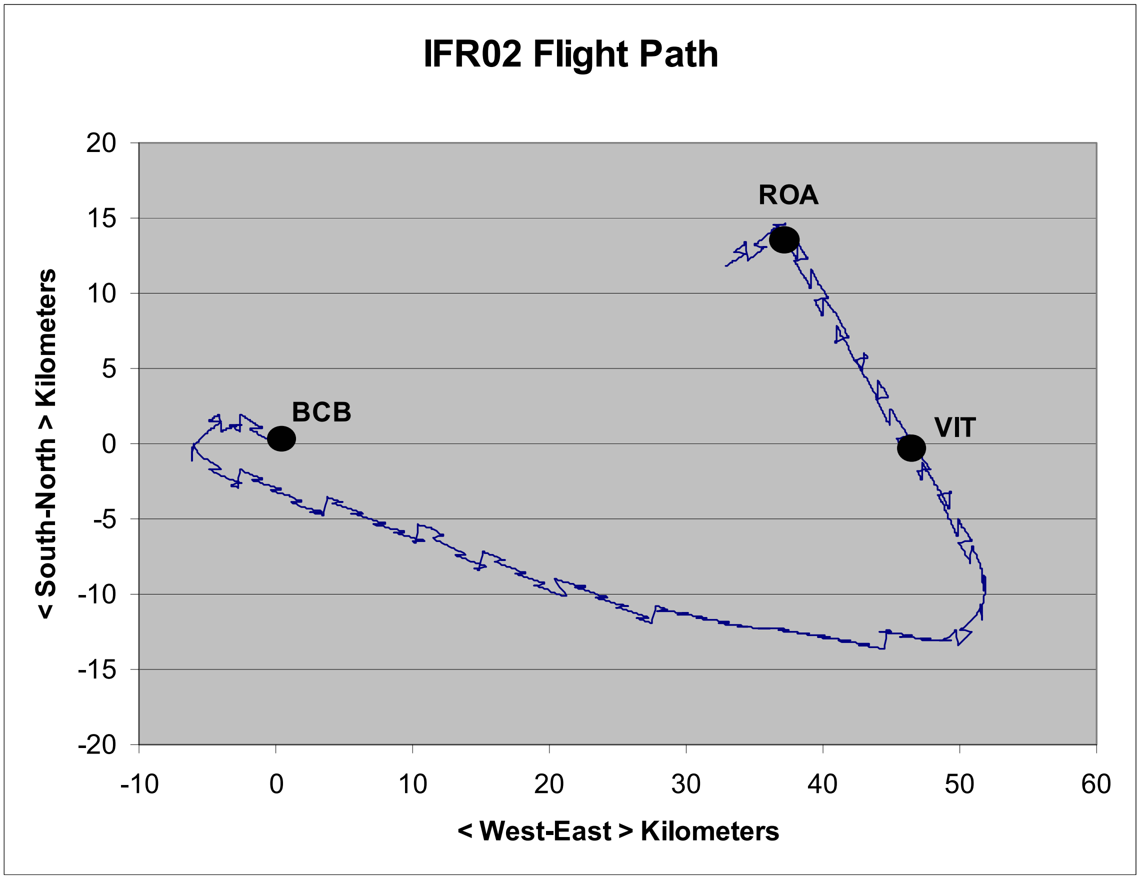

Figure 19. *Flight path for pilot IFR02.*

For each of the three flights, the estimated horizontal position error and estimated vertical position error was approximately 4 meters and 6 meters respectively. However, much of the "roughness" of each flight path depicted in Figures 17, 18, and 19 also likely resulted from the conversion of latitude and longitude coordinates (ellipsoidal) to X, Y coordinates (planar). Note that for the visual approach to ROA Runway 33 (Figure 17), the pilot's flies direct to Roanoke from BCB and enters the traffic pattern at ROA until oriented for the landing on Runway 33. In contrast, for the two instrument approaches (Figures 18 and 19), the pilots are vectored south east through Roanoke airspace by air traffic control to intercept the glide slope at approximately Vinton (VIT) for the ILS at Runway 33. For each flight path in Figures 17, 18, and 19, the very beginning of the approach back to BCB is shown after the touch-and-go at ROA.

Workload and Situation Awareness Ratings

Table 27 lists the workload and situation awareness rating scale scores from the MCH and SART scales respectively. However, these field ratings are based on two IFR observations/flights and one VFR flight and thus not statistically meaningful and are only used for descriptive purposes in the Discussion chapter.

TABLE 27

Subjective Workload and Situation Awareness Ratings from Field

	WORKLOAD	SITUATION AWARENESS			
	MCH	Demand Total	Supply Total	Understanding Total	OVERALL SART RATING
VFR 01	1	5	22	18	35
IFR 01	2	11	21	20	30
IFR 02	3	6	25	19	38

Note: Overall SART rating is determined by Understanding + Supply – Demand.

APPLICATION OF THE ME/DC METHOD

Since the ME/DC method was executed in the field, the output of this method, including the systems-oriented cognitive models for both VFR and IFR pilots is presented here. Data collected in the field used to construct these models included video records, pilot/ATC communications transcriptions, retrospective pilot reports, informal interview questions, field notes, and GPS flight path data. The system analyzed in the field was that of the pilot/cockpit system in a Cessna 172 and its related components within Roanoke airspace. The specific task within the airspace was both an instrument and visual approach to Runway 33.

Boundaries of the unit of analysis. Using the criteria on p. 39, the boundaries of the system are described as follows:

1.1 Observed function of the system

The function of the system is air transportation. Specifically, for the flights studied in this research, the function of the system is General Aviation transportation between the Virginia Tech Airport (BCB) and the Roanoke Regional Airport (ROA).

1.2 Physical features

The physical space of the system can be described as the interior cockpit of the Cessna 172 aircraft, the Class C airspace surrounding Roanoke, the Roanoke air traffic control tower, and Runway 33 at the Roanoke Regional Airport.

1.3 Resources

Personnel resources of this system include the pilot, safety pilot, air traffic controllers (including Roanoke Approach and Departure and Roanoke Tower), and pilots in other aircraft within the Roanoke airspace. The technological resources are numerous. These include the flight instruments on the cockpit instrument panel, the radio communication and navigation system, and several gauges (e.g., fuel and oil gauges) and switches (e.g., light switches, radio selector switches). The air traffic controllers also have several resources, including a radar display.

Figure 20 shows the many instruments and control mechanisms in the Cessna 172 used for the field study. The flight instrumentation can be divided into pitot-static, gyroscopic, and magnetic instruments. Pitot-static instruments are those that use air pressure and include the altimeter, vertical speed indicator, and airspeed indicator. The gyroscopic instruments include the heading indicator, attitude indicator, and turn coordinator. The aircraft also has a magnetic compass.

Figure 20. *Cockpit of Cessna 61891.*

In addition to the flight instrumentation listed above, the aircraft also has instrumentation used with external navigational aids. These include the ILS indicator, VOR indicator, and ADF bearing indicator. The radio stack on the cockpit console includes the communication and navigation radios, the ADF receiver, and transponder. Finally, of course, there are the flight control mechanisms (yoke, throttle, carburetor heat control knob, fuel mixture control knob, elevator trim wheel, wing flap control, rudder pedals).

1.4 Temporal distribution

As the pilot travels through the Roanoke airspace and makes the approach for Runway 33, the information representations in the cockpit change over time. For example, during the instrument approach, as the pilot acquires the ILS localizer and glide slope, the representation of this information changes on the glide slope indicator. Also, as time passes, the air traffic controller's external representation of all the traffic in the Roanoke airspace changes on the radar display. The pilot's corresponding internal representation of the surrounding traffic also changes. These representations are described in more detail in the systems-oriented cognitive models presented later in this chapter.

1.5 Communicative pathways

The communicative pathways in this system include the radio frequencies for Roanoke Approach and Departure (118.15 MHz), Roanoke Tower (118.3 MHz), Roanoke ATIS (118.65 MHz), and the aircraft's intercom and aviation headsets worn by the pilot and safety pilot. The navigation frequencies, which are also communicative pathways for the system's information flow, include the ILS for Runway 33 (109.7 MHz), the Vinton NDB (277 kHz), and the Woodrum VOR (114.9 MHz).

1.6 Coordination of structures

At a high level, the structures of the system include all aircraft within Roanoke airspace which are coordinated by commands given by Roanoke Approach and Departure and Roanoke Tower over specific communications frequencies. At a lower level, the system's structures include, for example, the navigational instruments, which receive information over the navigation radio through specified frequencies from navigational aids such the ILS at Runway 33, the NDB at Vinton, and the Woodrum VOR. The coordination of the system's structures is complex and described in detail in the in the systems-oriented cognitive models presented later in this chapter.

<u>Overall system scan</u>. The system analyzed for this study is part of the overall airspace system in the Class C airspace surrounding Roanoke as controlled by Roanoke air traffic control (Roanoke air traffic control includes Roanoke Approach and Departure and Roanoke Tower). Class C airspace surrounds many busy airports such as the Roanoke Regional Airport and provides mandatory radar service to both VFR and IFR aircraft. Any aircraft of any type (commercial or General Aviation) must establish contact with Roanoke Approach *before* entering Roanoke airspace. At any given time, Roanoke airspace contains several aircraft, all of which are controlled by Roanoke ATC.

The complexity of this system is described by its differentiation and spatial dispersion. Vertical differentiation in the system is small (just two levels). At the top of the hierarchy is the Roanoke Approach and Departure and Roanoke Tower. Below these two entities are all of the aircraft in Roanoke airspace at any given point in time.

Roanoke ATC commands all of these aircraft within Roanoke airspace. Roanoke airspace is the a cylindrical area around the Roanoke Regional Airport, approximately 20 nautical miles in diameter, and 5200 feet altitude MSL. The horizontal differentiation with regards to the control system is also small, as one entity controls the surrounding Roanoke airspace (Approach and Departure) and the other controls aircraft on *final* approach and departure (Tower). The aircraft in the system are not organized with horizontal differentiation with respect to an organizational hierarchy. The spatial dispersion of the system spans several geographic locations within Roanoke airspace and including the tower and Runway 33 at Roanoke Regional Airport, and the location of the aircraft with the airspace at any given point in time. The entire system is heavily integrated with a formal communications system that uses various radio frequencies, and a control system as described above that coordinates all of the aircraft in the Roanoke airspace and at the airport itself.

This aviation system is necessarily formalized. All communication and navigational procedures within the Roanoke airspace are standardized. The aircraft pilot has little flexibility within the Roanoke airspace as compared to the Class E and airspace outside of the Roanoke airspace which is uncontrolled (i.e., pilots maintain their own navigational control). Just before entering Roanoke airspace, the pilot must contact Roanoke ATC and state his/her intentions. ATC then gives the pilot a unique transponder code and gives the pilot navigational commands. Any aircraft maneuvers performed by the pilot are all routine (pilots learn step by step procedures for each aircraft maneuver during training).

The system is also very much centralized, where virtually all of the decision making inside the airspace is performed by Roanoke ATC. A notable exception is during final approach using the ILS. During this scenario, a pilot reaches the published "decision altitude" when descending down the glide slope (for Roanoke ILS Runway 33, the decision altitude is 500 feet AGL). At this altitude, the pilot can decide to abort the landing and execute a missed approach.

The technological subsystem of this overall system can be defined by the type of technology used. According to Table 6 on p. 43, aviation technologies can be classified as "routine", where problems are well-defined and analyzable and task variability is routine with few exceptions. Indeed, all aviation technologies follow strict FAA guidelines, and General Aviation piloting tasks are routine as previously mentioned. Systems with routine technologies, according to Hendrick and Kleiner (2001), are suited for standardized coordination and control procedures and thus are associated with high formalization and centralization (p. 50). As previously described, the aviation system within Roanoke airspace is indeed highly formalized and centralized.

The social subsystem of the system is extremely varied. The professionalism of the ATC controllers and the pilots is very high, as both controllers and pilots are by nature, very skilled positions. Commercial pilots, like the ones who participated in this field study, are generally even more skilled than private pilots, as commercial pilots undergo a greater degree of training. Demographic characteristics and psychophysical aspects of GA pilots are highly variable. Pilots come from all walks of life and age. The only common bond seems to be a passion for flying.

Of the five external environments given by Hendrick and Kleiner (2001), the environmental subsystem for this aviation system is primarily influenced by the legal environment and also the educational environment to a lesser degree. Strict FAA rules and regulations on every aspect of aviation dominate the environment. In fact, the FAA has a code of regulations to drive every aspect of aviation (U.S. Government, 2003). The educational environment is also a factor. The training required to receive a private pilot's license is extensive and expensive. The average student pilot at the Virginia Tech Airport, for example, will undergo between 60 and 70 hours of training at a cost of approximately $4000 to attain a private pilot's license. Further training hours and expenses are required to obtain an instrument rating, commercial rating, etc. Thus the availability of the training facilities and programs are limited to those individuals who can afford the expenses and spare the time required. Availability of training aircraft and flight instructors is also limited.

Bounded system scan. The unit of analysis, the pilot/cockpit system and related distributed components, is also scanned as it is a small sociotechnical system. That is, it also has its own technological, social, and environmental subsystems. These subsystems are described in the same terms as for the overall work system but on a more micro-level of detail that corresponds to the bounded system. Specific technologies are described, the pilot's tasks are documented (see task analyses, Tables 29 and 30), and environmental influences are considered as they affect the bounded system (unit of analysis).

Technological components of the bounded system include the flight instruments on the cockpit instrument panel, the radio communication and navigation system, and several gauges (e.g., fuel and oil gauges) and switches (e.g., light switches, radio selector switches). The air traffic controllers also have several resources, including a radar display. As previously noted, the flight instruments are the altimeter, vertical speed indicator, airspeed indicator, heading indicator, attitude indicator, turn coordinator, and magnetic compass. In addition to these flight instruments, the aircraft also has instrumentation used with external navigational aids. These include the ILS indicator, VOR bearing indicator, and ADF bearing indicator. The radio stack on the cockpit console includes the communication and navigation radios and the transponder. The flight control mechanisms include the yoke, throttle, carburetor heat control knob, fuel mixture control knob, elevator trim wheel, wing flap control, and rudder pedals. The social components of the unit of analysis include the pilot and safety pilot in the aircraft, the controllers at the Roanoke Regional Airport, and the pilots of other aircraft in the airspace. The information flow and coordination of the technological components is described in detail in the systems-oriented cognitive models presented later in this chapter, as is the interaction of the pilots and air traffic controllers.

The strong external legal environment that dominates the overall aviation system in turn drives the procedures that are conducted within the unit of analysis. For example, the pilot *must* contact Roanoke Approach before entering Roanoke airspace. The pilot *must* fly at the vector and altitude specified by Roanoke Approach during an instrument approach. FAA regulations are the legal underpinnings for these procedures. Further, each class of airspace has its own rules associated with it. For Class C airspace (Roanoke airspace), a pilot can fly VFR only if visibility is greater than 3 statute miles and must maintain clearance from any clouds (at least 500 feet below, 1000 feet above, and 2000 feet horizontal). The educational environment also affects the system. For example, most private pilots are not trained and certified to fly an instrument landing. If a flight begins under VMC and the weather deteriorates to IMC by the time the pilot reaches the

Roanoke airport, he/she may not be trained to perform an instrument landing in poor weather conditions. Attempting to pilot an aircraft by VFR in poor weather conditions is a leading cause of aviation accidents.

Scenario for bounded system. A scenario was used to analyze this aviation system. The scenario for the two IFR-rated pilots was to perform an ILS approach to the Roanoke Regional Airport, Runway 33. The VFR pilot performed a visual landing approach to the same Runway. The scenarios were completely naturalistic, with no interference from the researcher. A safety pilot sat in the co-pilot's seat during the scenarios as required by Virginia Tech's Institutional Review Board (IRB). The FAA also requires a safety pilot for practice ILS approaches. The safety pilot's function is to scan the sky for traffic and other potential hazards as the pilot flies solely by instruments.

Observations based on the scenario. Observations during each flight included video and audio recordings, field notes, retrospective verbal reports, and informal interviewing. Flight performance variables were also recorded with a GPS for reference information for each flight. Transcriptions of the pilot/ATC communications from each flight and transcriptions of each retrospective verbal report appear in Appendices O, P, and Q.

Bounded system's function, task, and information distribution. The function and task allocation of the pilot/cockpit system has not changed much since the beginning of aviation. Although the degree of automation has somewhat increased, the pilot has always been a 'manual controller' such that he/she controls the aircraft and makes the decisions (#2 in Table 1), while the aircraft supplies information and power to the pilot. Of course, air traffic controllers play a critical role in this system, as much of the navigational decision making for the aircraft originates from them when the aircraft is in controlled airspace, especially in IMC. Further, a certain amount of the information is supplied to the pilot from air traffic control, through the aircraft. Based on the observations from the field study, the information flow of this system is described in detail in the following sections with supporting illustrations, and constitute descriptive, systems-oriented cognitive models of the IFR and VFR pilots as they perform an approach to the Roanoke Regional Airport. The next sections present the information flow for the instrument approach based on the data collected from the two participants (IFR01 and IFR02) who flew instrument approaches and the information flow for the visual approach based on the data collected from the participant (VFR01) who flew the visual approach. This small sociotechnical system, as depicted in the following sections, is in fact a system of distributed cognition. Hutchin's (1991, 1995a, 1995b) distributed cognition framework considers the entire sociotechnical system as a form of cognitive architecture. This cognitive perspective allows the information flow to be described by directly observable representations inside the cockpit.

Systems-Oriented Cognitive Models

The following systems-oriented cognitive models are presented from an information flow perspective, as the information is transformed and propagated through the various resources in the system (both people and technology), as opposed to a mere task analysis, which simply documents the step-by-step procedures of the pilot. Data used to generate these models were collected with video, audio, retrospective reports, interviewing, and field notes. All of these data collection techniques are driven by Step 5 of the ME/DC method (see p. 46 and p. 100). The printed audio transcriptions, as well as the video records, served as a rich source of data in understanding the information flow during the scenario, and together were the primary source of data for reconstructing the observed information flow during the field flights. Pilot retrospective reports, interviewing, and field notes were all secondary sources for constructing these models. The separate sources of data are complementary, as they provide for a means of corroborating components of the models. That is, observations from one source of data (e.g, pilot retrospective report) are often independently verifiable through other sources of data (e.g., pilot/ATC communications and video records).

Systems-oriented cognitive model for pilot performing an ILS approach. This system of the pilot performing an approach to Roanoke through the Roanoke airspace is a small sociotechnical system involving the pilot, nearby traffic, air traffic controls, and their associated technology and communicative pathways. Before entering Roanoke airspace, the pilot tunes the radio to the frequency for Roanoke's ATIS to receive important information relating to Roanoke Airspace. This is a mandatory procedure for all traffic entering the airspace before contacting Roanoke Approach. The frequency for Roanoke ATIS is either an internal representation, remembered by the pilot, or an external representation, printed on the approach plate for ILS RWY 33 (Appendix D) or on the sectional aeronautical chart, both of which are resources carried by the pilot. Since the pilots who participated in this field study fly often through Roanoke airspace, the frequency originates as an internal representation that is retrieved from long-term memory to working memory. The ATIS frequency then becomes represented externally on the radio display as the pilot turns the radio knobs to enter the frequency. At this point, the pilot does not need to retain the frequency in working memory. This internal to external representation is depicted in Figure 21.

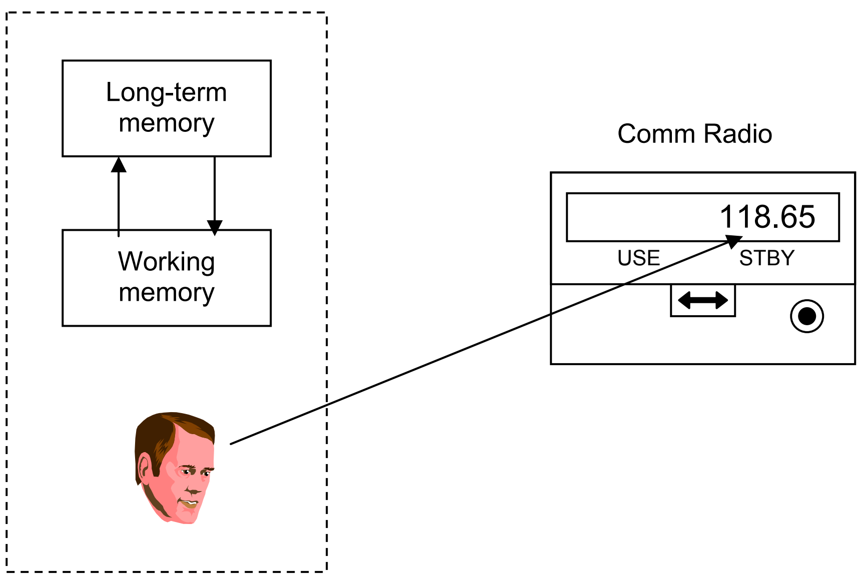

Figure 21. *Internal to external representation of the frequency for Roanoke ATIS.*

After entering the frequency on the radio, the pilot presses the flip/flop button to transfer the frequency from 'standby' to 'use'. The automated terminal information, a pre-recorded voice recording, is received by the pilot through the headset over this frequency (118.65 MHz). The pilot allows this broadcast to repeat until he/she has retained all relevant information (e.g., wind direction and speed, visibility, ceiling level, temperature and dew point, altimeter setting, and NOTAMs). Upon hearing the altimeter setting, which for example was 30.30 in. Hg (inches of mercury) for the first instrument approach in this study, the pilot resets the altimeter. Resetting the altimeter is critical, especially when flying by instruments, as changes in air pressure directly affect the accuracy of the altimeter. The information flow of the altimeter setting in this case originates at the Roanoke airport and is received by the aircraft over the communications frequency of 118.65 MHz represented by a prerecorded voice. After the pilot hears the altimeter setting it becomes an internal working memory until the pilot transfers the setting to the altimeter. After entering the correct setting, it is now an external representation on the altimeter itself.

Next, the pilot must contact Roanoke Approach just before entering Roanoke airspace. The pilot relays his/her aircraft identification, location, intentions, and ATIS code. The following is an excerpt from the communications transcription of the first instrument approach flight (IFR01) from the field study (Appendix P: C14-C19, C23).

P= Pilot; RAD = Roanoke Approach and Departure (ATC)

Code	**Time**	**Source**	**Communication**
C14	2:29	P	Roanoke Approach, Cessna six-one-eight-niner-one.
C15	2:38	RAD	Cessna six-one-eight-niner-one, Roanoke Approach.
C16	2:42	P	On approach, Cessna six-one-eight-niner-one, Cessna 172, approximately twenty miles to the west, four-thousand-five-hundred. Like to practice ILS three-three, and land or do a touch-and-go on three-three, and direct Virginia Tech VFR.
C17	2:58	P	With quebec.
C18	3:08	RAD	Cessna six-one-eight-niner-one, squawk zero-three-two-two.
C19	3:12	P	Zero-three-two-two.
C23	3:44	RAD	Cessna six-one-eight-niner-one, your radar contact, five miles southeast of Blacksburg airport showing four-thousand-four-hundred now.

The pilot establishes communications with Roanoke Approach by entering the appropriate frequency (118.15 MHz) into the radio, just like he/she did to receive ATIS. As before, the frequency originates as an internal representation that retrieved from the pilot's long-term memory to working memory (or from the approach plate if not remembered). The Roanoke Approach frequency then becomes represented externally on the radio display as the pilot turns the radio knobs to enter the frequency. From the transcription excerpt, the pilot stated his aircraft identification (Cessna 61891), location (approximately twenty miles to the west, four-thousand-five-hundred [altitude]), intentions (practice ILS 33, and land or do a touch-and-go on [Runway] 33, and direct Virginia Tech VFR), and ATIS code (quebec).

In response, the air traffic controller gave the pilot a unique identification code, "squawk 0322." The pilot must enter this code into his transponder and press the Ident button on command, which causes the transponder to return a positive identification on the air traffic controller's radar screen. Note that the pilot is required to repeat any commands and numbers given by the air traffic controller as a means of error checking. Figure 22 shows the information flow between the air traffic controller and pilot and their respective technological artifacts when establishing radar contact.

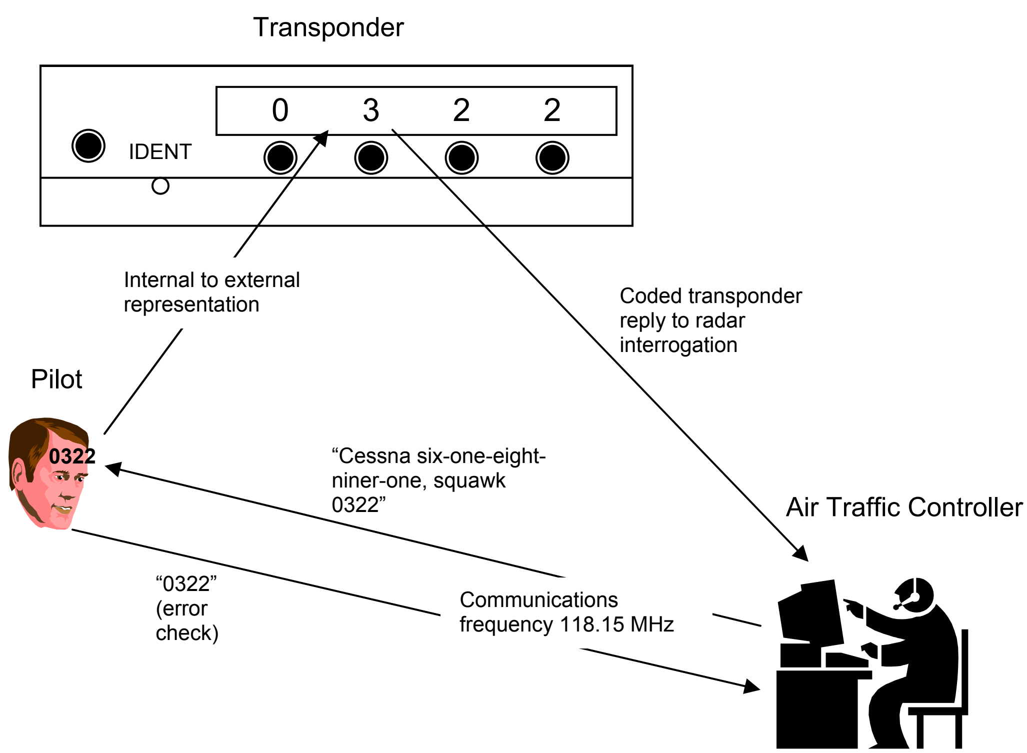

Figure 22. *Information flow during initial contact with air traffic control.*

Pilot attention is divided between visual and auditory channels while piloting the aircraft through Roanoke airspace. In addition to using visual channels to monitor the aircraft's instruments, the pilot is also constantly attending to the ATC communications. The pilot is listening for his aircraft identification, 'Cessna 61891'. That's how the pilot knows the air traffic controller is talking to him out of the several aircraft in his airspace. From the above communications excerpt, when the air traffic controller said, "Cessna six-one-eight-niner-one, squawk 0322", the pilot first attended to his aircraft identification, and then retained the given transponder code in working memory. After repeating the code back to the air traffic controller, he then enters the code into the transponder. The code originated as an internal representation with the air traffic controller, was transferred to the pilot over a radio frequency, became represented internally with the pilot, and was transformed as an external representation on the transponder. An interrogation signal from air traffic control causes the transponder to send the coded transponder signal back to the air traffic controller, this time as an external representation on his radar screen. The transponder signal on the radar screen gives the air traffic controller a positive identification of the pilot's aircraft.

In a similar fashion to the pilot tuning the communication radio to the frequency for Roanoke's ATIS as described earlier and shown in Figure 21, the pilot at this point must tune the navigation radio to the frequency for ILS 33 (109.7 MHz) and tune the ADF to the frequency for Vinton NDB (277 kHz). If these frequencies are not remembered by the pilot, he/she reads them from his/her approach plate. Both pilots who flew ILS instrument approach for this study had these frequencies stored in long-term memory. For the navigation radio receiver, after the pilot enters the ILS frequency, he/she presses the 'ident' button on the receiver to receive the Morse code unique to this navigational aid. The pilot hears the Morse code and compares the signal to the printed Morse code on the approach plate for ILS RWY 33. This is how the pilot ensures the navigational aid is working properly. This same procedure is followed for the Vinton NDB with the ADF receiver.

To intercept the ILS localizer, the air traffic controller gives the pilot a series of heading commands to slowly vector the pilot to the localizer's intercept until the pilot has established the localizer. The following is a list of all of the heading commands that were given to participant IFR01 by the air traffic controller, taken from the communications transcription of his flight (Appendix P: C25-C26, C71-C72, C86-C87, C104-C105, C108-C109, C113-C114).

P= Pilot; RAD = Roanoke Approach and Departure (ATC)

Code	**Time**	**Source**	**Communication**
C25	3:55	RAD	Alright, heading one-one-zero for now. Vectored for ILS three-three…
C26	4:09	P	Affirm, one-one-zero VFR, eight-niner-one.
C71	13:39	RAD	Cessna six-one-eight-niner-one turn left, left-turn heading zero-seven-zero.
C72	13:44	P	Left zero-seven-zero, eight-niner-one.
C86	15:38	RAD	Cessna eight-niner-one, turn left heading zero-six-zero. Suggested altitude for the ILS approach will be three-thousand-eight-hundred.
C87	15:46	P	Zero-six-zero, we'll descent to three-thousand-eight-hundred, eight-niner-one.
C104	17:39	RAD	Cessna eight-niner-one, turn left heading zero-three-zero.
C105	17:43	P	Left zero-three-zero, eight-niner-one.
C108	18:25	RAD	Cessna six-one-eight-niner-one, turn left heading zero-two-zero.
C109	18:30	P	Left zero-two-zero, eight-niner-one.
C113	19:11	RAD	And Cessna six-one-eight-niner-one, you're four miles from Vinton, turn left heading three-six-zero, maintain three-thousand-eight-hundred until established on localizer you're cleared ILS Runway three-three approach.
C114	19:20	P	Left three-six-zero, three-thousand-eight-hundred until established, cleared ILS three-three approach, eight-niner-one.

Each turn requires the pilot to coordinate the same activities. Using one example, at time index 13:39, the air traffic controller commands the pilot to make a left turn, heading 070 degrees. When the command was given, the aircraft's heading was 110 degrees. Achieving the target heading of 70 degrees can be described in terms of a target state and current state (Wright et al, 2000). Figure 23 illustrates the heading representations from current to target states.

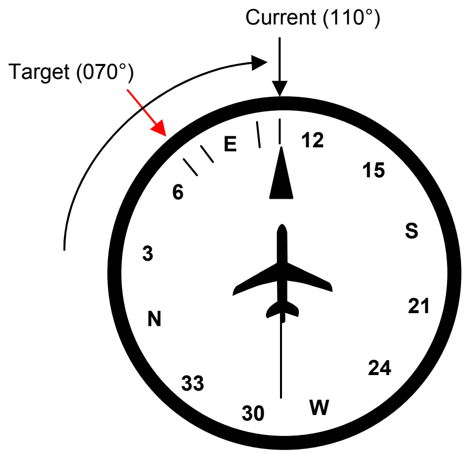

Figure 23. *Information representations of current and target aircraft heading*.

The target heading, 70 degrees, originated from the air traffic controller and was transferred to the pilot in the aircraft though the communications frequency. The pilot heard the target heading, and confirmed it by repeating to the air traffic controller. Rather than retaining the target heading as an internal, remembered representation, the pilot finds the target heading on the heading indicator. Thus both the current and target headings are external representations on the heading indicator. The pilot turns the aircraft left and tracks the heading indicator until the current state matches the target state. The heading indicator turns to the right as the current heading approaches the target heading, indicating a left turn. The pilot performs this type of tracking with the heading indicator for each course correction given by the air traffic controller.

After the pilot intercepts the ILS localizer, he/she then intercepts the ILS glide slope by flying straight and level, maintaining the localizer at all times. The localizer indicates lateral deviation from desired flight path and the glide slope indicates vertical deviation from desired flight path. Both of these lateral and vertical components are represented on the glide slope indicator. Earlier in the flight, the pilot tuned the navigation radio to the frequency for ILS 33 (109.7 MHz). The localizer and glide slope signals that are continuously transmitted from the ILS antenna by Runway 33 are then received by the aircraft's on-board antenna system. The signal is processed by the ILS computer and then sent to and displayed on the glide slope indicator (Figure 24).

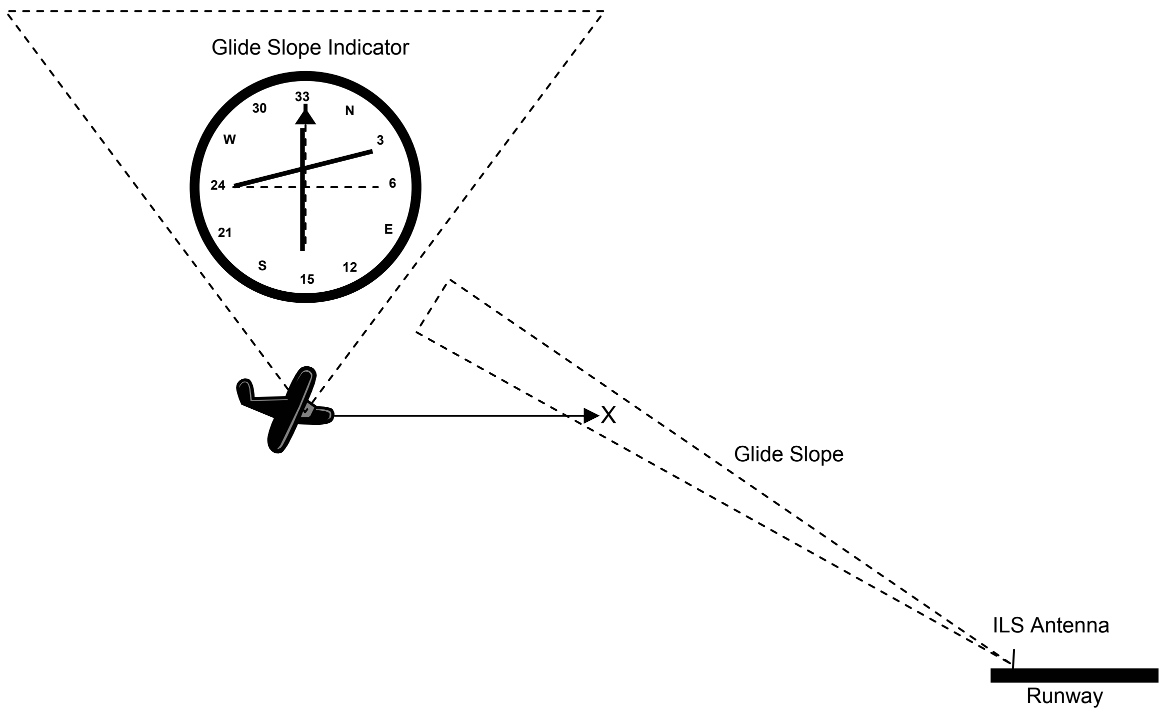

Figure 24. *Flow of ILS localizer and glide slope information.*

The ILS information that is received by the aircraft from the ILS antenna over the navigation frequency is not understood by the pilot until it is transformed by the on-board ILS computer and displayed in the glide slope indicator. The vertical needle represents the localizer. When the vertical needle is directly lined up in the middle on the vertical dotted line as in Figure 24, the aircraft is perfectly lined up with Runway 33. Next, the pilots acquires the glide slope when the horizontal needle drops and becomes lined up on the horizontal dotted line. In Figure 24, the pilot has acquired the localizer but the glide slope is above the aircraft. As the pilot flies straight and level, he will intercept the glide slope.

After the pilot intercepts the glide slope, he/she reduces power to achieve a speed of approximately 70 mph as he/she travels down the glide path. During the flight down the glide path, the pilot must keep the localizer and glide slope needles aligned, while performing additional tasks. For example, at approximately the same time the pilot intercepts the glide slope, which is very close to the Vinton NBD (3.8 nautical miles from the airport), Roanoke Approach will have the pilot contact the tower. The following is an excerpt from the flight communications transcript from participant IFR02 (Appendix Q: E89-E93).

P= Pilot; RAD = Roanoke Approach and Departure; Tower = Roanoke Tower

Code	**Time**	**Source**	**Communication**
E89	18:31	RAD	Cessna eight-niner-one, tower one-one-eight-point-three, see ya.
E90	18:34	P	Eight-niner-one, over to tower, one-one-eight-point-three, see ya.
E91	18:42	P	Roanoke tower, Skyhawk six-one-eight-niner-one, I'm outside of Vinton, ILS three-three.
E92	18:47	Tower	Skyhawk six-one-eight-niner-one, Roanoke tower, continue route for three-three, there's a vehicle on the runway.
E93	18:52	P	Eight-niner-one.

In this particular example, the pilot had to make these communications with air traffic control just before she intercepted the ILS localizer at time index 19:22. In the other instrument flight, with participant IFR01, the pilot was told to contact tower after he established the localizer and at virtually the same time he was about the intercept the glide slope. During this time, the pilot is performing motor tasks as he/she pilots the aircraft, visual-spatial tasks by aligning the localizer and glide slope needles, and auditory tasks when listening for air traffic control commands and then repeating the commands back for error-checking. At this time, the aircraft is close to or over the Vinton NDB, so the pilot also is watching for the ADF bearing indicator to swing as the aircraft passing over the NDB station at Vinton. Indeed, both instrument pilots indicated in their retrospective reports that this was the busiest, most demanding portion of the flight (see Appendix P: D89, D93, D102-D104; and Appendix Q: F85). In terms of the information flow of this sociotechnical system, the information is concentrated on the pilot and his/her instruments at this point in time (Figure 25).

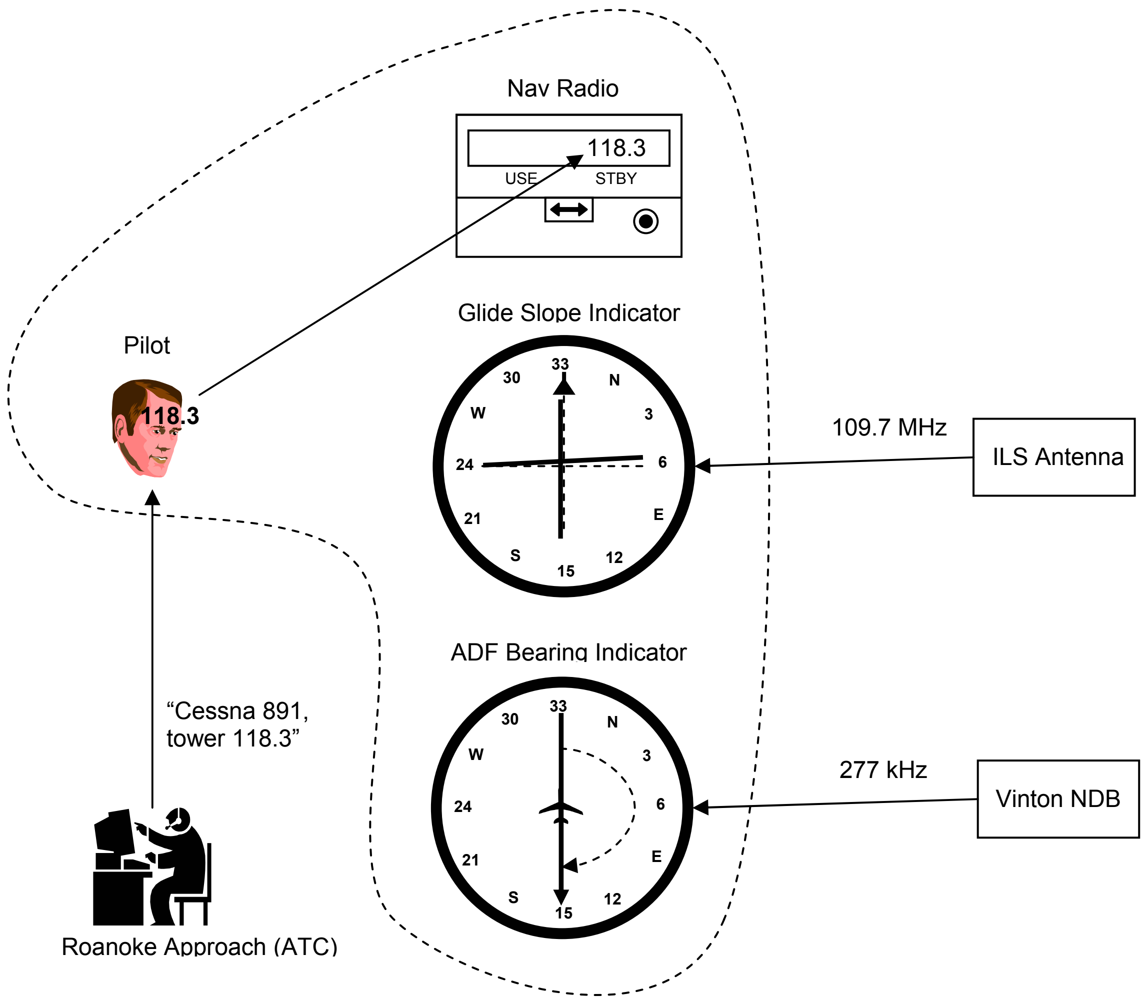

Figure 25. *Information flow of system as aircraft enters final approach.*

Positional information for the Vinton NBD navigational aid is transmitted over frequency 277 kHz and transformed to be represented on the ADF bearing indicator. The needle on the ADF bearing indicator always points toward the Vinton NDB. As the aircraft travels over the Vinton NDB, the needle swings from 330 degrees, the current heading of the aircraft, to 150 degrees, when the aircraft has passed and the station and is now behind the aircraft. Lateral and vertical information for the glide slope is transmitted over frequency 109.7 MHz and transformed to be represented on the glide slope indicator. A command originates from Roanoke Approach for the pilot to contact Roanoke Tower at

118.3 MHz. The information is received by the pilot as an internal representation and transformed as an external representation on the communication radio receiver.

As the pilot receives clearance to land from the tower and proceeds down the glide slope, he/she passes the outer marker beacon 2.7 nautical miles from the airport and the middle marker beacon 1.4 nautical miles from the airport. The pilot is alerted when the aircraft is passing over both beacons by a tone over the headset and a flashing signal on the radio stack. Just before the middle marker, the pilot reaches the decision height for the ILS 33 approach, which is 500 feet above ground level (AGL). At this point, the pilot switches to visual. If the pilot has the runway in site, he/she continues down and lands on the runway. If the runway is not is site, the pilot is required to execute a missed approach and abort the landing.

<u>Systems-oriented cognitive model for pilot performing a visual approach</u>. One pilot from this field study, participant VFR01, flew a visual approach to Roanoke Runway 33. Just as with the instrument approach, a pilot performing the visual approach must tune the radio to the frequency for Roanoke's ATIS to receive important information relating to Roanoke Airspace before entering Roanoke airspace (see Figure 21); a distributed cognition perspective of the information flow of this procedure is not repeated here. The pilot must also contact Roanoke Approach before entering Roanoke airspace. Below is an excerpt of the communications transcription from the initial contact between pilot VFR01 and air traffic control (Appendix O: A05-A09).

P= Pilot; RAD = Roanoke Approach and Departure

Code	**Time**	**Source**	**Communication**
A05	2:39	P	Roanoke approach, Cessna six-one-eight-niner-one.
A06	2:42	RAD	Cessna six-one-eight-niner-one, Roanoke Approach.
A07	2:45	P	Uh, yeah, Cessna six-one-eight-niner-one, we're two miles east of Blacksburg, requesting touch-and-go to Runway 33 at 4000 feet with yankee.
A08	2:55	RAD	Cessna six-one-eight-niner-one, squawk zero-three-three-one.
A09	2:58	P	Zero-three-three-one.

The pilot established communications with Roanoke Approach and stated his aircraft identification, location, intentions, and ATIS code (quebec). In response, the air traffic controller gave the pilot a unique identification code, "squawk 0331." Again, the information flow is the same as described in the instrument procedure (see Figure 22). Key differences between the visual approach and instrument approach begin after this point. Since the pilot is not flying the ILS approach, rather than programming the navigation radio for the ILS at Runway 33, the pilot chose to set the navigation radio to the Woodrum VOR. VOR is an acronym for 'very high frequency (VHF) omni direction range' and is a course navigational aid, similar to the NDB. Since this is a VFR flight, using these navigational aids is not mandatory. However, pilot VFR01 indicated that he was using this navigational aid as a back-up in his retrospective report (APPENDIX O: B26). It is not uncommon for pilots who are flying visual to use VORs as navigational back-ups. The Woodrum VOR is located at the Roanoke Regional Airport itself. Since the pilot is flying a visual approach, he is not vectored around the airspace by air traffic control to intercept the ILS over Vinton. Rather he can use the Woodrum VOR to help navigate directly to the Roanoke until he has the airport in site. Figure 26 illustrates the information flow of the system as the pilot establishes contact with the Woodrum VOR.

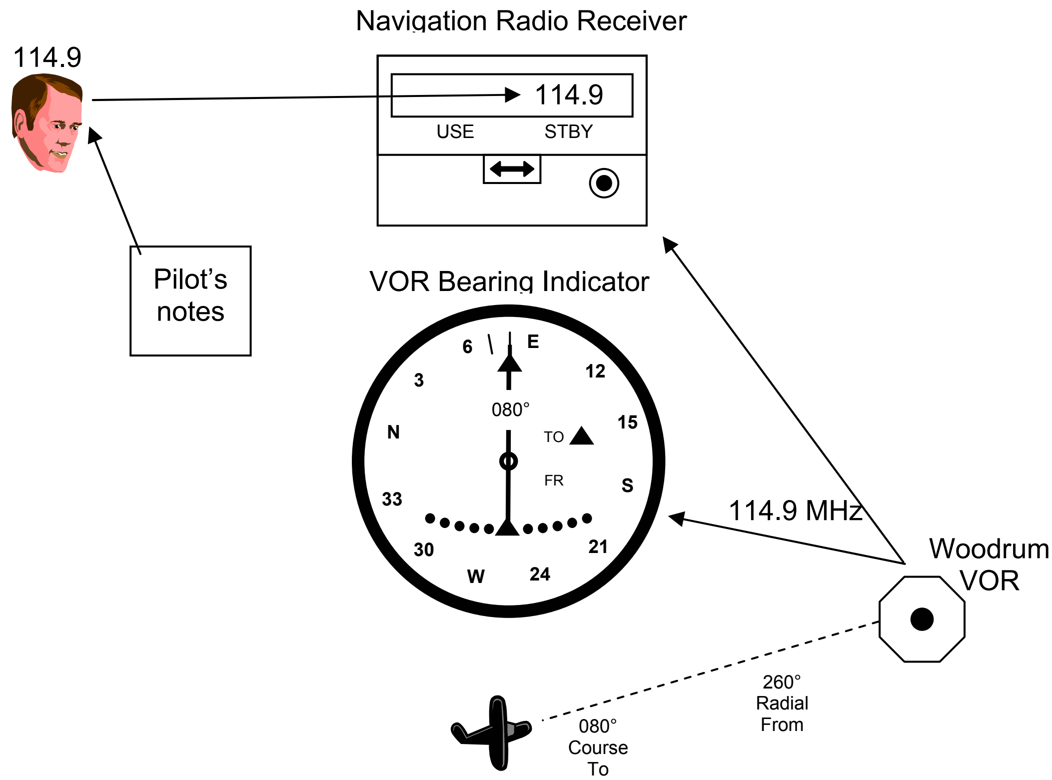

Figure 26. *Information transformations and representations when navigating with Woodrum VOR.*

Before the flight, the pilot recorded notes to take with him in the aircraft. These pre-flight notes, which are considered a resource in this system, included the frequency for the Woodrum VOR, 114.9 Mz. The pilot found the frequency for the Woodrum VOR from his sectional aeronautical chart. During the flight, when he was ready to establish contact with the Woodrum VOR, he checked his notes for the frequency and then programmed it into this navigation radio. The frequency was transformed from an external representation on the notes, to an internal representation in the pilot's working memory, and then back to an external representation on the navigation radio. After the pilot presses the flip/flop button to activate the frequency on the radio, the radio receives the signal transmission from the Woodrum VOR over the 114.9 MHz frequency. The navigational information from the Woodrum VOR received over this frequency is translated onto the VOR bearing indicator into an external representation understood by the pilot. By holding the needle in the center of the VOR bearing indicator, he is on course to the Roanoke airport heading 80 degrees along the VOR's 260 degree radial.

During an instrument approach to the airport, air traffic control assigns the pilot headings and altitudes and ensures separation from other traffic in the airspace. During a visual approach to the airport, it is the pilot's responsibility to watch out for other traffic in the airspace at all times. The air traffic controller does assist by providing positional information for nearby traffic and will sometimes give course adjustment commands to the VFR flights. The following is a list of relevant traffic communications involving two other aircraft during the visual approach for participant VFR01 (Appendix O: A13-A15, A18-A21, A35-A38).

P = Pilot (Subject VFR01); RAD = Roanoke Approach and Departure; Tower = Roanoke Tower; OA1 = Other Aircraft 1; OA2 = Other Aircraft 2

Code	**Time**	**Source**	**Communication**
A13	4:29	OA1	Departure, Blueridge four-zero-four, checking in, passing four thousand for five thousand.
A14	4:33	RAD	Blueridge four-zero-four, Roanoke Approach, radar contact, turn right heading three-one-zero vector free to climb, climb and maintain one-zero-thousand.
A15	4:43	OA1	Ahh, one-zero-thousand, right turn to three-one-zero vector, free to climb, Blueridge four-zero-four.
A18	6:13	RAD	Blueridge four-zero-four, turn right heading zero-five-zero, direct Montebello.
A19	6:18	OA1	Zero-five-zero, direct Montebello, Blueridge four-zero-four.
A20	6:30	RAD	Blueridge four-zero-four, climb and maintain one-two thousand.
A21	6:33	OA1	Up to one-two thousand, Blueridge four-zero-four.
A35	10:28	Tower	Cessna six-one-eight-niner-one! Roanoke Tower, make a hard right turn for me heading about one-two-zero for right now please, vector away from departure traffic.
A36	10:35	P	One-two-zero, eight-niner-one.
A37	10:38	Tower	Piedmont three-three twenty-six, wind two-four-zero at seven, Runway two-four, cleared for take-off.
A38	10:43	OA2	Cleared for take-off, and what was heading for Piedmont thirty-three twenty-six?

During the approach, there were two other aircraft in the Roanoke airspace at the same time. This is a relatively small number of aircraft; in comparison, there were about a dozen aircraft in the airspace during the flight for participant IFR01. However, the small number during the visual approach is enough to illustrate the information flow of the system concerning traffic. The air traffic controller has an external representation of all the traffic in the Roanoke airspace on the radar display before him/her. Each mark on the radar screen includes the aircraft identification, altitude, and ground speed. This additional information on the radar screen is being received by each aircraft's transponder. In stark contrast, the pilot must carry an internal representation of the surrounding aircraft in the airspace. The pilot listens to the communications from the air traffic controller and other pilots and develops a four dimensional representation of surrounding traffic. The representation involves four dimensions because the pilot projects relevant parts of this traffic pattern into the future for potential effects on his/her flight path and scans for traffic that is close to his/her aircraft until he/she has visual contact with that traffic. Indeed, this task relates to situation awareness. Figure 27 illustrates the external and internal representations of traffic information.

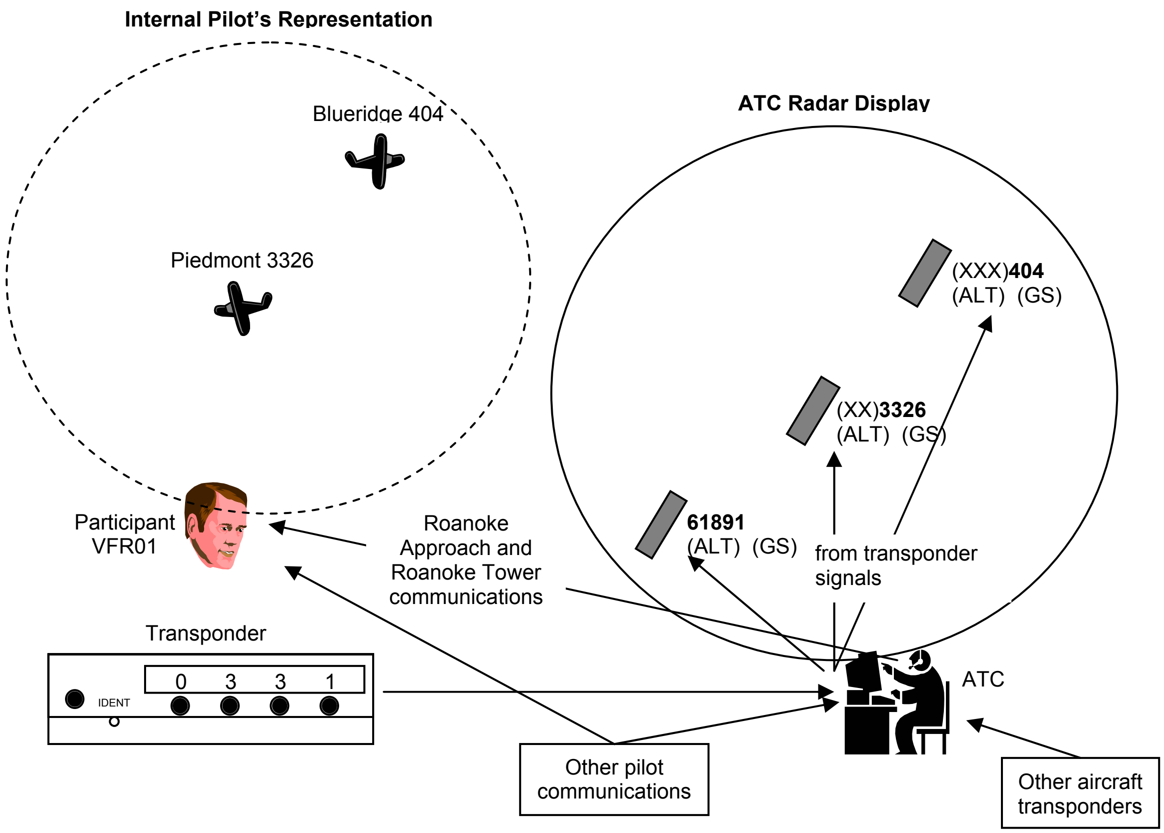

Figure 27. *The distributed cognition of traffic information.*

The air traffic controllers' representation of the traffic in the airspace is constructed from the primary radar returns and the transponder signals from all the aircraft. This information is displayed externally on the radar screen. The pilot, however, receives the positional information for other traffic through the communications. For example, when Roanoke Approach says, "*Blueridge 404, turn right heading 050, direct Montebello*" (A18), participant VFR01 knows the aircraft is on the other side of the airport from his aircraft, heading away from the airport and thus does not have to be concerned with the position of that particular aircraft. However, when Roanoke Tower contacts him and says, "*Cessna 61891! Roanoke Tower, make a hard right turn for me heading about 120 for right now please, vector away from departure traffic*" (A35), not only did he have to make a course adjustment to avoid the aircraft (Piedmont 3326), but he needs to look out for the aircraft until he has visual contact with it. As the pilot receives relevant traffic positional information from the communications, this information is transformed and represented internally in the pilot's working memory. The pilot can use the heading of a nearby aircraft, and if it is climbing or descending, and project this information into future to understand if there may be a potential conflict with his own aircraft.

After the pilot has the airport in site, he informs Roanoke Approach. In response, Roanoke Approach tells the pilot to enter the traffic pattern around the airport for Runway 33 and to contact the tower at 118.3 MHz. The command originates from Roanoke Approach and the information is received by the pilot as an internal representation and then transformed as an external representation on the communication radio receiver. Roanoke tower gives final clearance for landing on Runway 33. During final approach, the pilot does not use instruments to fly down the glide slope as in the instrument approach discussed previously. Rather, the pilot has the runway in site for the entire decent and closely monitors both airspeed and vertical speed with the airspeed and vertical speed indicators. Vertical speed on the descent is usually about -500 feet per minute (same as with the instrument approach). The pilot monitors the airspeed indicator until airspeed has slowed to at least 85 knots (V_{FE}, maximum flap extended speed) before applying flaps. Flaps allow the pilot to steepen the angle of descent on the approach without increasing airspeed. Figure 28 shows how the pilot monitors the airspeeds in terms of current and goal states.

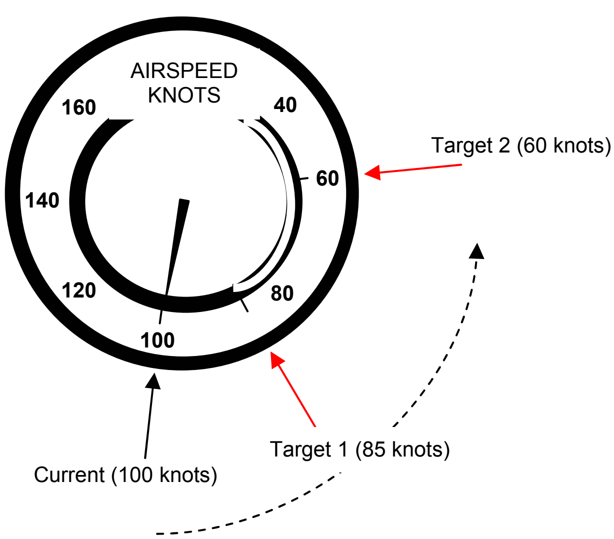

Figure 28. *Information representations of current and target aircraft speeds.*

The pilot is concerned with three speeds during the final approach as depicted in Figure 28. Each of these three speeds was represented externally on the airspeed indicator. The needle on the airspeed indicator points the current speed of the aircraft. The pilot adjusts the pitch of the aircraft to control for airspeed and brings the airspeed to the first target speed, 85 knots. This is known as the maximum flap extended speed (V_{FE}) and is represented by the beginning of the white arc. The white arc on an aircraft's airspeed indicator represents the flap operating range. When the current speed matches the target 1 speed, the pilot can safely apply flaps. The second target speed, 60 knots, is the approximate speed the pilot uses just before landing the aircraft.

To summarize, the information flow of the instrument approach and visual approach to the Roanoke Regional Airport was described using Hutchin's (1991, 1995a, 1995b) framework of distributed cognition. The information flow of the system was described in terms of physical manipulation of objects, internal information representations, creation/exchange of external information representations through the various communicative pathways, and target and goal information states. Theses systems-oriented cognitive models (pp. 101-118) were presented from an information flow perspective, as the information is transformed and propagated through the various resources in the system (both people and technology), as opposed to a mere task analysis, which simply documents the step-by-step procedures of the pilot.

Pilot Errors Observed in the Field

For each field flight there occurred significant errors committed by each pilot, listed in Table 28, which were captured by video and audio. The ME/DC method, which employs video and audio recordings during observation, was designed to understand the system as it works in its natural environment, but it is also sensitive to rare events. The errors observed during the field observation are examples of these rare events.

TABLE 28

Pilot Errors

PARTICIPANT	TIME INDEX	TRANSCRIPT CODE	ERROR
VFR01	6:55	Appendix O: A23-A24, A32-A36	Participant VFR01 initially failed to contact Roanoke Tower when instructed to do so by Roanoke Approach
IFR01	22:34	Appendix P: C127-C133	Participant IFR01 contacted Roanoke Tower and requested a landing for Runway 6 when intending to land on Runway 33
IFR02	16:11	Appendix Q: E76, E78-E79	Participant IFR02 failed to attend to a course correction given by Roanoke Approach

These errors are explored in detail in the Discussion chapter on pages 144-148.

Procedural Comparison

The procedures of the actual Cessna 172 from the field study are documented through task analysis and compared to the procedures of the iGATE simulator for the Cessna 172. These task analyses do not relate to the systems-oriented cognitive models presented previously that document the information flow of the system (pp. 101-118). Rather, they relate directly to the procedural comparison which was conducted to assess the fidelity of the flight simulator used in the laboratory. The same visual and instrument approaches to the Roanoke airport were used for both the field and simulated studies. Table 29 compares the task analyses from the actual field flights and the simulator experiment for the instrument approach and Table 30 does the same for the visual approach. The task analyses were compiled by using the field video/audio, laboratory video, retrospective pilot reports, and reference materials (Cessna Aircraft Company, 1975; Jeppesen Sanderson, Inc., 2002; Martini and Norris, 1993). Comparison involves determining if the tasks performed in the field by the pilot during a landing approach match the tasks performed with the flight simulator. This procedural comparison is performed to examine the external validity of the iGATE simulator.

TABLE 29

Task Analysis and Procedural Comparison of Instrument Approach from Field Flight and Simulator

ACTUAL (FIELD) Cessna 172M 1975	SIMULATOR (LAB) Cessna 172R 1997-2001
Listen to Roanoke ATIS Turn radio knobs to set communication frequency to 118.65 Press flip/flop button to transfer frequency from 'standby' to 'use'. Acquire relevant information (e.g, weather, NOTAMs, ATIS code).	Read Roanoke ATIS (ATIS is text only on simulator display) Turn radio knobs to set frequency to 118.65 Press flip/flop button to transfer frequency from 'standby' to 'use'. Acquire relevant information (weather only for simulator).
Contact to Roanoke Approach Turn radio knobs to set communication frequency to 118.15 Give Roanoke Approach your aircraft identification, your current position, your intentions, and your ATIS code.	(*no ATC communications with simulator*)
Set transponder to code provided by Roanoke Approach Turn transponder knobs to, for example, 0331	
Reference approach plate for ROA ILS 33 Check for relevant information (e.g., communications/navigations frequencies, time to missed approach point, decision height, etc.)	Reference approach plate for ROA ILS 33 Check for relevant information (e.g., navigations frequencies, time to missed approach point, decision height, etc.)
Tune radio to ILS frequency Turn radio knobs to set navigation frequency to 109.7 Press flip/flop button on radio to enter frequency as current. Press ident button on radio to receive navigational aid's Morse code to confirm navigational aid is working properly.	Tune radio to ILS frequency Turn radio knobs to set navigation frequency to 109.7 Press flip/flop button on radio to enter frequency as current. Press ident button on radio to receive navigational aid's Morse code to confirm navigational aid is working properly.

continued...

Set ADF for Vinton NDB Turn ADF knobs to set navigation frequency for 277 Press ident button on radio to receive navigational aid's Morse code to confirm navigational aid is working properly.	Set ADF for Vinton NDB Turn ADF knobs to set frequency for 277 Press ident button on radio to receive navigational aid's Morse code to confirm navigational aid is working properly.
Establish localizer	(*already established on localizer*)
Establish glide slope	Establish glide slope
Set timer for missed approach	Set timer for missed approach
Contact Roanoke Tower at Roanoke Approaches's command Turn radio knobs to set communication frequency to 118.3 Inform tower of status	(*no ATC communications with simulator*)
Adjust pitch to control vertical speed to establish an appropriate descent rate (approximately -500 feet per minute). Increase back-pressure on yoke to pitch up.	Adjust pitch to control vertical speed to establish an appropriate descent rate (approximately -500 feet per minute). Increase back-pressure on yoke to pitch up.
Adjust power to control airspeed to establish a speed of approximately 70 mph/60 knots Move throttle toward closing position to achieve desired power	Adjust power to control airspeed to establish a speed of approximately 70 mph/60 knots Move throttle toward closing position to achieve desired power
Maintain localizer and glide slope with GSI	Maintain localizer and glide slope with GSI
Ensure fuel selector valve is set to 'Both' If it is not, turn fuel selector valve handle to 'Both'	Ensure fuel selector valve is set to 'Both' (*location of fuel selector valve on simulator is not accurate*) If it is not, turn fuel selector valve handle to 'Both'
Apply carburetor heat Turn carburetor heat control knob to "On"	(*no carburetor heat control knob on the simulator*)
Enrich fuel mixture Turn mixture control knob to "Rich"	Enrich fuel mixture Extend mixture lever to "Rich"
Apply flaps (up to 40° for the Cessna 172M) Check airspeed indicator, make sure airspeed is less than or equal to 85 knots, V_{FE} (maximum flap extended speed) Turn wing flap switch	Apply flaps (up to 30° for the Cessna 172R simulator) Check airspeed indicator, make sure airspeed is less than or equal to 85 knots, V_{FE} (maximum flap extended speed) Press wing flap switch
	continued...

Adjust elevator trim as necessary to relieve excessive back-pressure on yoke. Turn elevator trim wheel down for nose-up trim.	Adjust elevator trim (*same procedure, but no realistic feedback on yoke*) Press elevator trim tab down for nose-up trim (*trim tab located in unrealistic position*).
Note outer marker (OM), visual flash and tone	Note outer marker (OM), visual flash and tone
Check timer	Check timer
At decision height (1660 MSL), check to see if runway is visible If runway visible, continue descent, switch to visual If runway not visible, execute missed approach	At decision height (1360 MSL for simulator scenario), check to see if runway is visible If runway visible, continue descent, switch to visual If runway not visible, execute missed approach
Note middle marker (MM), visual flash and tone	Note middle marker (MM), visual flash and tone
Execute flare Increase back-pressure on yoke just above runway.	Execute flare Increase back-pressure on yoke just above runway.
Execute touchdown and roll-out. Use rudder to maintain directional control Hold back pressure on the yoke to keep nosewheel up, gradually release pressure	Execute touchdown and roll-out. Use rudder to maintain directional control Hold back pressure on the yoke to keep nosewheel up, gradually release pressure (*but no realistic feedback on yoke*)

Note: Several of the steps are not necessarily performed in this order. The order of steps is situation and pilot dependent. Also, pilots often pre-program communication and navigation frequencies for standby they know will be used later in the flight. When the frequency is needed, they simply hit the flip/flop button on the radio to transfer the frequency from standby to current.

TABLE 30

Task Analysis and Procedural Comparison of Visual Approach from Field Flight and Simulator

ACTUAL (FIELD) Cessna 172M 1975	SIMULATOR (LAB) Cessna 172R 1997-2001
Listen to Roanoke ATIS Turn radio knobs to set communication frequency to 118.65 Press flip/flop button to transfer	Read Roanoke ATIS (ATIS is text only on simulator display) Turn radio knobs to set frequency to 118.65 Press flip/flop button to transfer

frequency from ‘standby’ to ‘use’. Acquire relevant information (e.g, weather, NOTAMs, ATIS code).	frequency from ‘standby’ to ‘use’. Acquire relevant information (weather only for simulator).
Contact to Roanoke Approach Turn radio knobs to set communication frequency to 118.15 Give Roanoke Approach your aircraft identification, your current position, your intentions, and your ATIS code.	(*no ATC communications with simulator*)
Set transponder to code provided by Roanoke Approach Turn transponder knobs to, for example, 0331	
Tune radio frequency to Woodrum VOR	Tune radio frequency to Woodrum VOR
Turn radio knobs to set navigation frequency to 114.9	Turn radio knobs to set navigation frequency to 114.9
Press flip/flop button on radio to enter frequency as current.	Press flip/flop button on radio to enter frequency as current.
Press ident button on radio to receive navigational aid’s Morse code to confirm navigational aid is working properly.	Press ident button on radio to receive navigational aid’s Morse code to confirm navigational aid is working properly.
Set ADF for Vinton NDB (optional) Turn ADF knobs to set navigation frequency for 277 Press ident button on radio to receive navigational aid’s Morse code to confirm navigational aid is working properly.	Set ADF for Vinton NDB (optional) Turn ADF knobs to set frequency for 277 Press ident button on radio to receive navigational aid’s Morse code to confirm navigational aid is working properly.
Inform Roanoke Approach when airport is in site.	(*no ATC communications with simulator*)
Enter traffic pattern.	Straight-in visual approach for simulator due to the field of view, no traffic pattern.
Contact Roanoke Tower at Roanoke Approaches’s command Turn radio knobs to set frequency to 118.3 Press flip/flop button on radio to enter frequency as current. Inform tower of status	(*no ATC communications with simulator*)
Adjust pitch to control vertical speed to establish an appropriate descent rate (approximately -500 feet per minute). Increase back-pressure on yoke to pitch up.	Adjust pitch to control vertical speed to establish an appropriate descent rate (approximately -500 feet per minute). Increase back-pressure on yoke to pitch up.

Adjust power to control airspeed to establish a speed of approximately 70 mph/60 knots Move throttle toward closing position to achieve desired power	Adjust power to control airspeed to establish a speed of approximately 70 mph/60 knots Move throttle toward closing position to achieve desired power
Maintain localizer and glide slope with GSI	Maintain localizer and glide slope with GSI
Ensure fuel selector valve is set to 'Both' If it is not, turn fuel selector valve handle to 'Both'	Ensure fuel selector valve is set to 'Both' (*location of fuel selector valve on simulator is not accurate*) If it is not, turn fuel selector valve handle to 'Both'
Apply carburetor heat Turn carburetor heat control knob to "On"	(*no carburetor heat control knob on the simulator*)
Enrich fuel mixture Turn mixture control knob to "Rich"	Enrich fuel mixture Extend mixture lever to "Rich"
Apply flaps (up to 40° for the Cessna 172M) Check airspeed indicator, make sure airspeed is less than or equal to 85 knots, V_{FE} (maximum flap extended speed) Turn wing flap switch	Apply flaps (up to 30° for the Cessna 172R simulator) Check airspeed indicator, make sure airspeed is less than or equal to 85 knots, V_{FE} (maximum flap extended speed) Press wing flap switch
Adjust elevator trim as necessary to relieve excessive back-pressure on yoke. Turn elevator trim wheel down for nose-up trim.	Adjust elevator trim (*same procedure, but no realistic feedback on yoke*) Press elevator trim tab down for nose-up trim (*trim tab located in unrealistic position*).
Execute flare Increase back-pressure on yoke just above runway.	Execute flare Increase back-pressure on yoke just above runway.
Execute touchdown and roll-out. Use rudder to maintain directional control Hold back pressure on the yoke to keep nosewheel up, gradually release pressure	Execute touchdown and roll-out. Use rudder to maintain directional control Hold back pressure on the yoke to keep nosewheel up, gradually release pressure (*but no realistic feedback on yoke*)

Note: Several of the steps are not necessarily performed in this order. The order of steps is situation and pilot dependent. Also, pilots often pre-program communication and navigation frequencies for standby they know will be used later in the flight. When the frequency is needed, they simply hit the flip/flop button on the radio to transfer the frequency from standby to current.

This task analysis was performed so that the procedures could be compared between the field and the laboratory. That is, how well do the tasks performed in an actual Cessna 172 as a pilot conducts an approach to Roanoke Runway 33 match the tasks performed as a pilot conducts the same approach with the iGATE simulator? These procedural comparisons can to increase our understanding of how to increase the validity associated with using the simulator in research. The results of this comparison are discussed in the next chapter beginning on p. 149.

Chapter 5. DISCUSSION

The results from both the field and the laboratory are discussed in this chapter. Statistical findings on flight performance, workload, and situation awareness are discussed from the laboratory experiment. Findings from the field, where the ME/DC method was executed, are discussed. Integration of the two studies is also discussed; specifically, the effect of weather and night conditions studied in the laboratory on systems-oriented cognitive models developed from the field study, procedural comparisons between the simulator and actual Cessna 172, and evaluation and comparison of the ME/DC method between the field and laboratory studies.

LABORATORY EXPERIMENT

Table 31 summarizes the hypotheses from the laboratory experiment and indicates which of them were supported, partially supported, or not supported at all. Also, the statistical tests used to test each hypothesis are listed.

TABLE 31
Summary of Hypothesis Testing

HYPOTHESIS	RESULT	STATISTICAL PROCEDURES
Within VFR, Day vs. Night, poorer flight performance during night	Not supported	ANOVA
Within VFR, Day vs. Night, greater workload during night	Not supported	Wilcoxon Signed Ranks Test
Within VFR, Day vs. Night, reduced situation awareness during night	Partially supported (only during static weather)	Wilcoxon Signed Ranks Test
Within VFR, Static vs. Dynamic Weather, poorer flight performance with dynamic weather	Not supported	ANOVA

continued…

Within VFR, Static vs. Dynamic Weather, greater workload with dynamic weather	Partially supported (only during day time)	Wilcoxon Signed Ranks Test
Within VFR, Static vs. Dynamic Weather, reduced situation awareness with dynamic weather	Partially supported (only during day time)	Wilcoxon Signed Ranks Test
Within IFR, Day vs. Night, poorer flight performance during night	Not supported	ANOVA
Within IFR, Day vs. Night, greater workload during night	Not supported	Wilcoxon Signed Ranks Test
Within IFR, Day vs. Night, reduced situation awareness during night	Not supported	Wilcoxon Signed Ranks Test
Within IFR, Static vs. Dynamic Weather, no difference in flight performance	Supported	ANOVA
Within IFR, Static vs. Dynamic Weather, no difference in workload	Supported	Wilcoxon Signed Ranks Test
Within IFR, Static vs. Dynamic Weather, no difference in situation awareness	Not supported (SA is reduced during dynamic weather)	Wilcoxon Signed Ranks Test
Between VFR and IFR, Day, poorer performance for VFR pilots	Not supported	ANOVA and landing statistics
Between VFR and IFR, Day, greater workload for VFR pilots	Not supported (VFR workload is less than IFR workload with static weather)	Kolmogorov-Smirnov Test and Mann-Whitney Test
Between VFR and IFR, Day, reduced situation awareness for VFR pilots	Supported	Kolmogorov-Smirnov Test and Mann-Whitney Test
Between VFR and IFR, Night, poorer performance for VFR pilots	Not supported	ANOVA and landing statistics
Between VFR and IFR, Night, greater workload for VFR pilots	Not Supported	Kolmogorov-Smirnov Test and Mann-Whitney Test
Between VFR and IFR, Night, reduced situation awareness for VFR pilots	Supported	Kolmogorov-Smirnov Test and Mann-Whitney Test
Between VFR and IFR, Static Weather, poorer performance for VFR pilots	Not supported	ANOVA and landing statistics

Between VFR and IFR, Static Weather, greater workload for VFR pilots	Not supported (VFR workload is less than IFR workload during day time)	Kolmogorov-Smirnov Test and Mann-Whitney Test
Between VFR and IFR, Static Weather, reduced situation awareness for VFR pilots	Supported	Kolmogorov-Smirnov Test and Mann-Whitney Test
Between VFR and IFR, Dynamic Weather, poorer performance for VFR pilots	Not supported	ANOVA and landing statistics
Between VFR and IFR, Dynamic Weather, greater workload for VFR pilots	Not Supported	Kolmogorov-Smirnov Test and Mann-Whitney Test
Between VFR and IFR, Dynamic Weather, reduced situation awareness for VFR pilots	Supported	Kolmogorov-Smirnov Test and Mann-Whitney Test

Flight Performance Variables

Any one of the 13 flight performance measures used with the flight simulator by itself is not necessarily a clear indicator of flight performance. It is the battery of measures used together which gives an account of overall flight performance. In general, results from the analysis of the 13 objective flight performance variables do not indicate significant performance differences for any of the independent variables. There were a few exceptions as discussed below.

ANOVA for the 2x2x2 mixed factors design revealed a main effect of daytime versus nighttime approaches on flight path angle, $F\ (1,14) = 6.28$, $p = 0.025$. That is, flying an approach during daytime as compared to flying an approach during night time had a significant effect on the approach angle of the aircraft. The mean approach angle during daytime was -2.29° compared to night time which was -2.27°. Considering only the VFR pilot group, the mean approach angle was -2.30° during daytime and -2.29° during nighttime; this difference is not statistically significant, $F\ (1,7) = 0.48$, $p > 0.05$. Considering only the IFR pilot group, the mean approach angle was -2.28° during daytime and -2.25° during nighttime. This was a significant result, $F(1,7) = 18.78$, $p = 0.003$. Thus is seems that most of the variance for flight path angle found in the overall 2x2x2 design seems to be in the IFR pilot group.

While statistically significant, this difference in flight path angle observed within the IFR group does not seem to be consequential in terms of flight performance. IFR pilots used the ILS glide slope for vertical path navigation while descending to the runway. However, ANOVA for ILS glide slope CDI did not reveal any significant differences for the IFR group for day vs. night flights, $F(1,7) = 0.25$, $p > 0.05$, or for the clear vs. poor weather conditions, $F(1,7) = 0.03$, $p > 0.05$. Nor was a significant difference expected as IFR pilots rely solely on their instruments and not the external visual view when using the ILS. The mean ILS glide slope CDI value for the IFR group was -0.09 dots during daytime and -0.08 dots during nighttime, where each dot represents approximately four-tenths degrees vertical deviation from the 3° glide slope centerline. Variation observed in flight path angle therefore likely occurred before pilots intercepted the glide slope and/or after pilots switched to visual upon reaching the decision height. In this case, we cannot say that the variation in flight path angle is a reliable indication of flight performance. ILS glide slope CDI is a more accurate indication of flight performance and was not found to be statistically significant for any of the independent variables.

There was a main effect of pilot type observed for ILS localizer CDI, $F(1,14) = 7.84$, $p = 0.014$. ILS localizer CDI measures horizontal deviation from the glide slope path as opposed to ILS glide slope CDI which measures vertical deviation. This result was expected as VFR pilots do not use the ILS during the approach.

An interaction effect of pilot type by day/night (AxB) was observed for altitude, $F(1,14) = 5.93$, $p = 0.029$. Figure 29 shows that while the mean altitude during the approach for IFR pilots remained relatively the same across the day and night, the mean altitude for VFR pilots during the approach increased during nighttime. Starting altitude for both pilot types in the simulation was 3800 feet above MSL or 2624 feet AGL (the elevation of the Roanoke Regional Airport is 1176 feet above MSL). Since the IFR pilots fly a precision approach with the glide slope to the airport, we would not expect a difference between day and night for the IFR pilots. However, the VFR pilots demonstrated a tendency to maintain a higher altitude level during a night approach to Roanoke. At night, many of the visual cues are lost during VFR flying (e.g., Mertens and Lewis, 1982; Leland, 2001) and distances are more difficult to judge. Indeed, participant VFR06 commented, "It is very hard to judge distances at night, might as well fly IMC." This may help explain the tendency for pilots to approach the airport at a higher altitude at nighttime than during daytime.

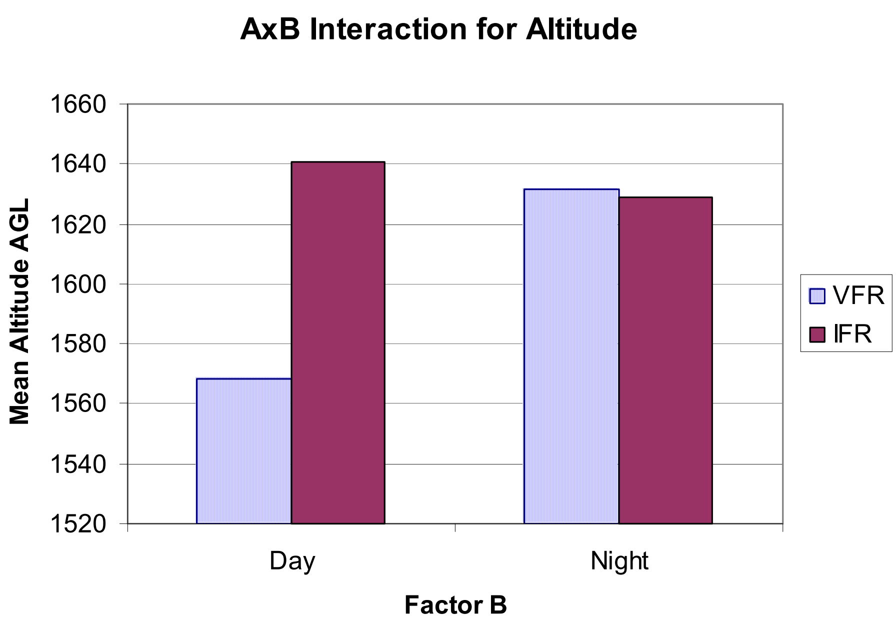

Figure 29. *Interaction effect for altitude.*

Within the VFR group, the hypotheses that pilot performance, as measured by the objective flight performance measures, would indicate significant performance degradation during nighttime and during deteriorating weather conditions was not supported. ANOVA did not reveal significant differences for any of the flight performance variables when considering only the VFR group. It should be noted that there was one aborted landing during nighttime with dynamic weather conditions with the VFR pilot group. However, an aborted landing is not considered a result of poor flight performance. Indeed, it can be considered an exercise of good pilot judgment.

Within the IFR group, significant differences in flight performance were not expected to be observed for IFR pilots between weather conditions as IFR pilots rely on their instrumentation during an approach and not the external view for the 'above cloud ceiling' portion of the approach. This hypothesis was supported as ANOVA did not reveal significant differences for any of the flight performance variables except flight path angle. However, this result was determined to be inconsequential in terms of flight performance as there were no significant differences for ILS glide slope CDI, a more accurate measure of vertical flight path deviation.

It was also hypothesized that there would be a significant difference in flight performance within the IFR pilot group when comparing day versus night operations. This hypothesis was based on statistics that show a higher accident rate for nighttime IFR approaches than daytime IFR approaches. Since ANOVA did not reveal significant differences in flight performance, this hypothesis was not supported. As with the VFR pilot group, there was also one aborted landing during nighttime with dynamic weather conditions with the IFR pilot group.

VFR pilots were expected to have poorer flight performance compared to the IFR pilots since IFR pilots undergo more training and can rely on their instruments during nighttime and poor weather conditions. This hypothesis was not supported as ANOVA did not reveal any main effects of pilot type on any of the flight performance variables except ILS localizer CDI. However, the ILS localizer is only used by the IFR pilot group so this is not a valid comparison measures between IFR and VFR pilots. There were no differences is flight performance measures that can be used as comparison measures such as heading, indicated airspeed, roll angle, etc. Further, the landing statistics for the VFR pilots and IFR pilots were identical (Table 26, Results). Although there were no consequential differences in flight performance as measured by the objective flight performance measures, there were several significant differences in workload and situation awareness between the VFR and IFR pilots and within the pilot groups as indicated by the subject rating scales. These differences are discussed in the following sections.

Workload

Considering all conditions, the Kolmogorov-Smirnov Test did not indicate an *overall* increase in workload for VFR pilots compared to workload for IFR pilots. The mean overall VFR workload rating was 2.5 on the MCH scale compared to 2.8 for IFR pilots. The Mann-Whitney Test was conducted to check for workload differences between VFR and IFR pilots for *each* specific condition and revealed that VFR workload was not significantly greater than IFR workload for any of the specific conditions and VFR workload was actually significantly *less* than IFR workload ($p = 0.0229$) with static, clear weather during daytime (the control condition). For this condition, the mean VFR workload rating was 1.6 compared to 2.4 for IFR pilots. Flying by instruments in favorable weather conditions seems to involve more cognitive effort than flying visually. Pilots flying by instruments must coordinate between multiple instruments whereas pilots flying visual fly by visual cues such as the horizon. The hypothesis that VFR pilots would experience significantly higher workload than IFR pilots as measured by the MCH scale during this experiment was not supported, even for the most difficult condition, with deteriorating weather during nighttime.

Within each pilot group however, a significant difference in workload was revealed between two of the experimental conditions for the VFR pilot group. The Wilcoxon Signed Ranks Test was used to test for workload differences within both pilot groups. Within the VFR group during daytime approaches, workload was significantly higher during deteriorating weather conditions than during static, clear weather. The mean rating for daytime approaches during static, clear weather was 1.6 compared to 2.9 during deteriorating weather. The mean rating for the clear weather approach at night was 2.5 compared to 3.1 with deteriorating weather at night. This latter difference was not statistically significant, nor was the differences between day versus night approaches for either of the weather conditions. Thus the hypothesis that VFR pilots would experience greater workload at night and during deteriorating weather conditions was partially supported. It should be noted that the MCH scale makes a distinction between workload rating ranges. On the MCH scale, a rating in the range of 1-3 indicates that mental workload is at an acceptable level. Within a range of 4-6, the scale indicates that workload is high and should be reduced. The mean rating for the deteriorating weather at night approach was 3.1; two of the eight participants found the workload for this condition to be unacceptable. Figure 30 shows the workload ratings for each condition for the VFR pilot group.

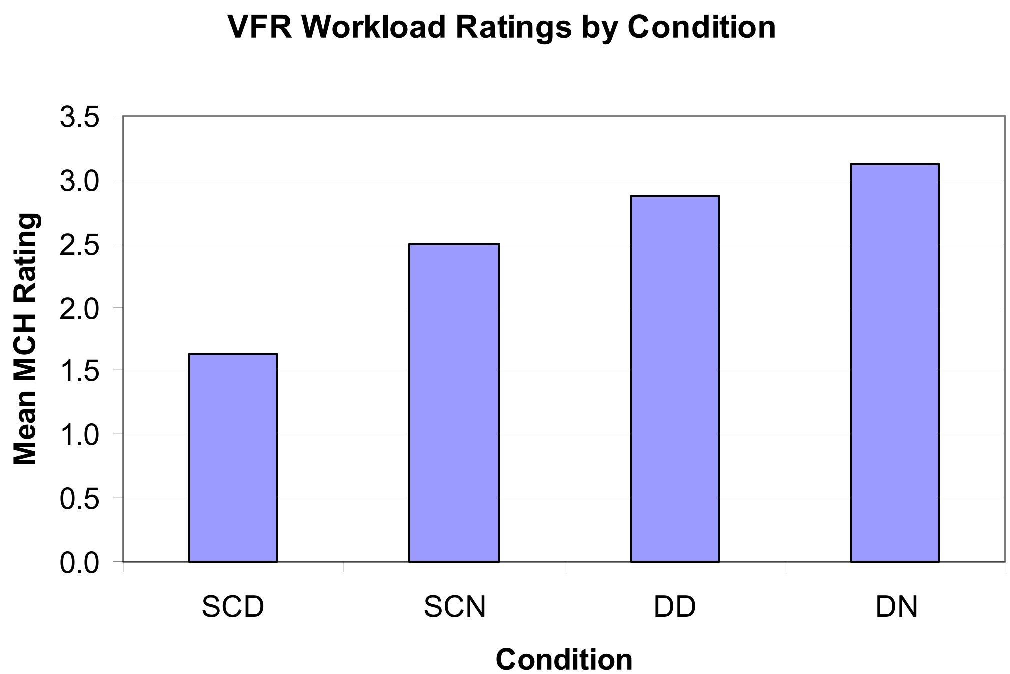

Figure 30. *Workload ratings, VFR group. Static, clear weather during daytime = SCD; static, clear weather during nighttime = SCN; dynamic weather during daytime = DD; dynamic weather during nighttime = DN.*

Within the IFR pilot group, no statistically significant differences in workload were found using the Wilcoxon Signed Ranks Test. Thus the hypothesis that no significant differences in workload across weather condition for IFR pilots was supported. However, the hypothesis that IFR pilots would experience significantly higher workload at night was not supported. The mean workload ratings for IFR pilots during static, clear weather conditions during daytime was 2.4 and for nighttime was 2.9. Mean workload rating for deteriorating weather during daytime for IFR pilots was 3.0

and during nighttime was 3.1. Figure 31 shows the workload ratings for each condition for the IFR pilot group.

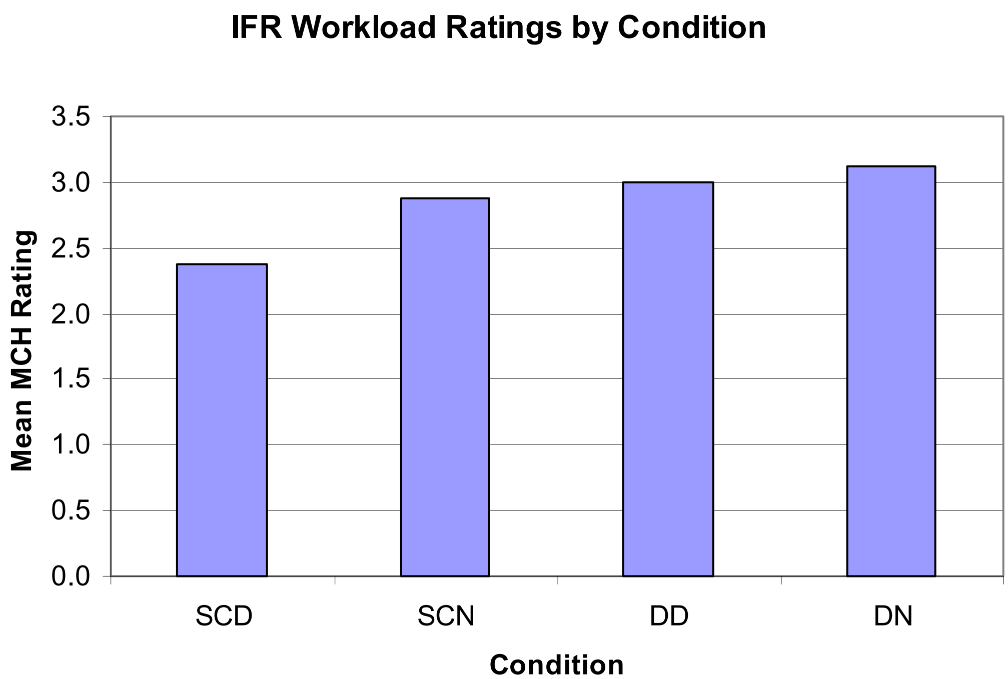

Figure 31. *Workload ratings, IFR group. Static, clear weather during daytime = SCD; static, clear weather during nighttime = SCN; dynamic weather during daytime = DD; dynamic weather during nighttime = DN.*

Situation Awareness

The Kolmogorov-Smirnov Test revealed that, overall, VFR pilots had reduced situation awareness compared to IFR pilots as measured by the SART rating scale. The mean SART rating for VFR pilots was 23.4 compared to 29.9 for IFR pilots. The SART rating scale uses 10 independent dimensions that were elicited from knowledge of aircrew and therefore, the scale has high ecological validity (Taylor, 1990). The 10 dimensions are organized into three major groupings or 'domains': demand, supply, and understanding. User ratings from these domains are combined to provide an overall situation awareness score for the system (understanding total + supply total – demand total). A higher overall rating indicates a higher degree of situation awareness.

The Mann-Whitney Test was conducted to check for situation awareness differences between VFR and IFR pilots for each specific condition ($p < 0.05$) and revealed that VFR situation awareness was significantly less than IFR situation awareness for each of the specific conditions except static, clear weather at night time ($p = 0.0571$). Although this particular condition was not significant, the p value shows a trend for lower situation awareness for VFR pilots. Figure 32 illustrates the mean situation awareness ratings for VFR and IFR pilots across each condition. The hypothesis that VFR pilots would have reduced situation awareness compared to IFR pilots for night operations and deteriorating weather conditions was supported.

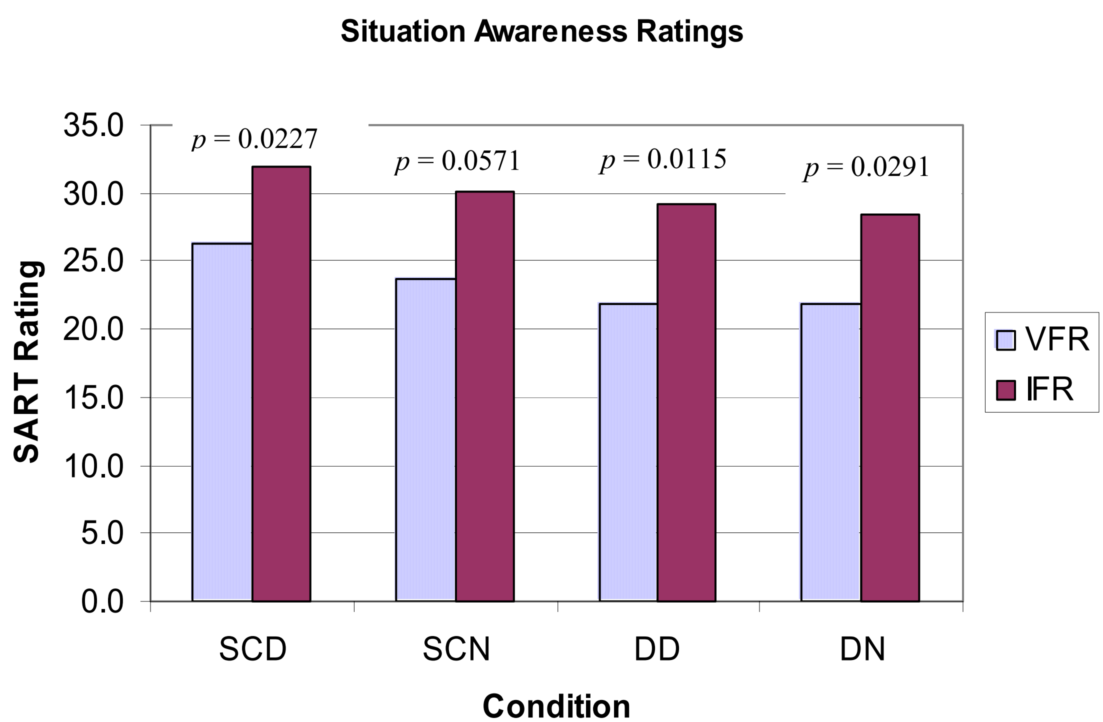

Figure 32. *Situation awareness ratings, VFR and IFR pilots. Static, clear weather during daytime = SCD; static, clear weather during nighttime = SCN; dynamic weather during daytime = DD; dynamic weather during nighttime = DN.*

Within the IFR pilot group, the Wilcoxon Signed Ranks Test was used for situation awareness comparisons. Two statistically significant differences were found. IFR situation awareness with dynamic weather was significantly different (reduced) compared to IFR situation awareness with static weather, during day time *and* during nighttime with a significance level of 0.05. It was hypothesized that there would be no significant difference in situation awareness for IFR pilots across weather conditions, as IFR pilots rely on their instruments and not the external visual view. Since statistical analyses revealed that situation awareness was significantly reduced during deteriorating weather conditions, this hypothesis was not supported. For IFR pilots, the mean SART ratings for the simulated approach to Roanoke Regional Airport in deteriorating weather conditions was 29.1 during daytime and 28.4 during nighttime compared to favorable weather conditions during daytime (32.0) and during nighttime (30.1).

Based on statistics that show IFR accident rate during nighttime approaches is higher than daytime IFR accident rate, it was hypothesized that IFR pilots would experience reduced situation at night during the approach. However, this hypothesis was not supported as no significant difference in IFR situation awareness was found during nighttime approaches compared to daytime approaches as examined by the Wilcoxon Signed Ranks Test for the mean SART ratings. Situation awareness was significantly reduced during poor weather conditions as discussed above, but not for nighttime approaches. Figure 33 shows the situation awareness ratings for the IFR pilot group across each condition.

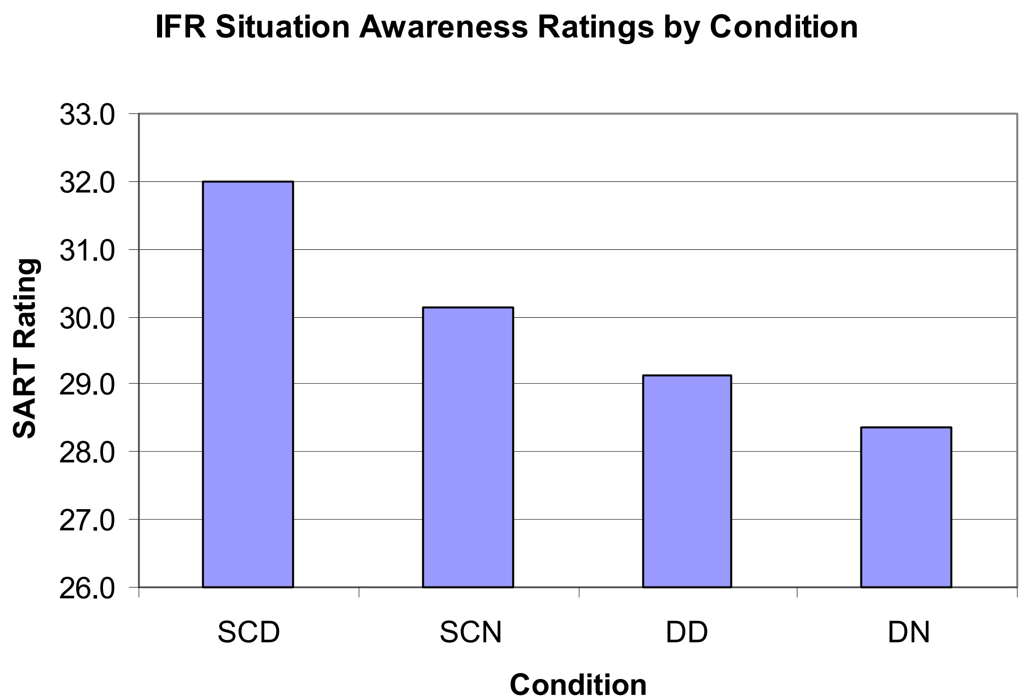

Figure 33. *Situation awareness ratings, IFR group. Static, clear weather during daytime = SCD; static, clear weather during nighttime = SCN; dynamic weather during daytime = DD; dynamic weather during nighttime = DN.*

Within the VFR group, the Wilcoxon Signed Ranks Test revealed two statistically significant results. VFR situation awareness at night (mean rating = 23.6) was significantly reduced compared to VFR situation awareness during the day (mean rating = 26.3) when weather was favorable. In deteriorating weather, VFR situation awareness was the same for both day and night approaches (mean rating = 21.9). VFR situation awareness in deteriorating weather was significantly reduced compared to VFR situation awareness with favorable weather during daytime approaches but not nighttime approaches. Thus the hypothesis that VFR pilots would have reduced situation awareness at night and in deteriorating weather conditions was partially supported. Situation awareness at nighttime compared to daytime was significantly reduced only when weather was favorable and situation awareness was reduced in deteriorating weather conditions compared to favorable weather conditions only during daytime approaches. Figure 34 shows the situation awareness ratings for the VFR pilot group across each condition.

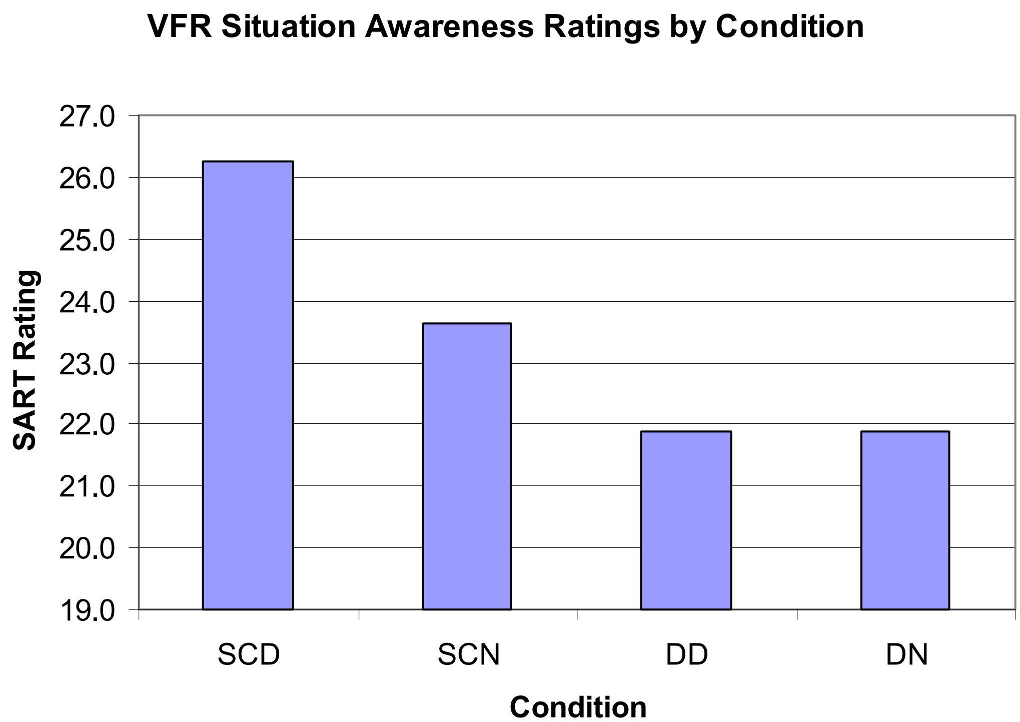

Figure 34. *Situation awareness ratings, VFR group. Static, clear weather during daytime = SCD; static, clear weather during nighttime = SCN; dynamic weather during daytime = DD; dynamic weather during nighttime = DN.*

<u>VFR Landings in Deteriorating Weather</u>

VFR weather minimums in the Class C airspace surrounding Roanoke Regional Airport specify that visibility must be at least three statute miles and that distance from the pilot's aircraft to nearby clouds cannot be closer than 500 feet below, 1000 feet above, or 2000 feet horizontal. In the simulated approaches to Roanoke for the laboratory experiment, cloud ceiling was never less than 1000 feet above the aircraft. However, for the dynamic weather condition, the simulator was programmed to gradually decrease the visibility during the approach to the airport from five miles (marginal VMC) to two miles (IMC). Pilots were instructed to land only if they felt it was safe to do so. Otherwise pilots had the option to abort the landing by performing a go-around or diverting outside of the airspace. There was only one case where a VFR pilot aborted the landing during one of the runs in deteriorating weather conditions (participant VFR06). For the other three runs in deteriorating weather conditions, participant VFR06 chose to land the aircraft in IMC with two miles visibility. The other seven VFR pilots landed the aircraft at Roanoke during all runs in deteriorating weather conditions, violating the VFR minimums for Class C airspace. Several pilots chose to continuously monitor Roanoke ATIS for current weather information, which for the simulator was displayed as flashing text across the top of the visual display rather than as audio through the headset. These pilots were aware of the visibility deteriorating past the VFR minimum yet chose to land the aircraft regardless rather than divert. Some of the participants may have not have perceived that visibility had deteriorated from marginal VFC to IMC. Others were unwilling to abort the approach. These results are consistent with results found by Goh and Wiegmann (2001).

In a simulator study that had pilots fly in weather conditions that deteriorated from marginal VMC to IMC (Goh and Wiegmann, 2001), 22 of the 32 participants chose to fly a Cessna 172 into deteriorating weather rather than divert the flight. The authors found that the pilots who chose to continue into deteriorating weather rated their skill and judgment as higher than the pilots who chose to divert, suggesting that hey had greater confidence in their abilities to pilot the aircraft. The authors also found that an inaccurate diagnosis of visibility conditions by pilots who chose to continue also contributed. These results of a majority of VFR pilots choosing to continue into IMC are consistent with the laboratory experiment performed for this dissertation. Some of the pilots may not have perceived the visibility to be below the VFR minimum. However, several of the pilots were aware of the visibility deteriorating past marginal VMC to IMC by monitoring current weather conditions through Roanoke ATIS. It could be that participants exercise different judgment in a simulator than during an actual flight as the consequences of crashing a simulated flight do not compare to the consequences of crashing an actual flight. It should be noted that the iGATE simulator does not simulate ATC commands for Roanoke Regional Airport and thus for the simulated approach, Roanoke Regional Airport was essentially as uncontrolled airport. In real life, ATC at Roanoke would have to give clearance for pilots to land in such conditions.

FIELD STUDY

The field study allowed for the examination of this aviation system as it exists in its naturalistic state. The actual system is too complex to be completely simulated in the laboratory. Further, the field study allowed for the use of the method developed for this dissertation, based on both macroergonomics and distributed cognition frameworks to account for the organizational/system components and the cognitive aspects of this aviation system. Both of these frameworks that the ME/DC method is based upon are designed for field application. The system this ME/DC method was applied to was that of the pilot/cockpit system in a Cessna 172 and its related components within Roanoke airspace during an approach to Runway 33.

Since data collected in the field was guided by the ME/DC method, the results from the ME/DC method are discussed here, in the context of the field study. Data collection, as guided by the ME/DC method, was used to constructed systems-oriented cognitive models for both VFR and IFR pilots as they performed an approach to the ROA, Runway 33. This data included video records, pilot/ATC communications transcriptions, retrospective pilot reports, informal interview questions, field notes, and GPS flight path data. The actual output of the ME/DC method, including the systems-oriented cognitive models for both VFR and IFR pilots, is given in the Results chapter. This section provides a summary discussion of that output, along with differences identified between the VFR and IFR models, as well as pilot errors observed in-flight.

The boundaries of the system studied were described in terms of the observed function of the system, its physical features, resources, temporal distribution, communicative pathways, and the coordination of all of these structures as the information flows through the system. The overall system, which is the airspace system in the Class C airspace surrounding Roanoke as controlled by Roanoke ATC was described in detail using organizational constructs (complexity, formalization, centralization, and technological, social, and environmental subsystems). For example, the entire system is heavily integrated with a formal communications system that uses various radio frequencies, and a control system that coordinate all of the aircraft in the Roanoke airspace and at the airport itself. The system studied is extremely formalized, where all communications and navigational procedures within the Roanoke airspace are standardized. Also, the system is centralized to a very high degree, where most of the decision making inside the airspace is performed by Roanoke ATC. Three subsystems were explored. For example, a major component of this aviation system's environmental subsystem is the legal environment, affecting the system all the way down through specific piloting tasks. Strict FAA rules and regulations on every aspect of aviation govern the environment (U.S. Government, 2003), including those procedures used by pilots during an approach to Roanoke, and even the types of pilots who could be compensated for participating in this study.

The video records, communications transcriptions, retrospective reports, and field notes were used to develop models of the information flow in the system during an approach to Roanoke for both VFR and IFR flights. These systems-oriented cognitive models show how the information in the system travels from the various system resources and are transformed into particular representations. Several of the components in the system studied were distributed, not confined to the pilot/cockpit interaction. For example, there was significant interaction and information flow between the pilot and air traffic control, including Roanoke Approach and Roanoke Tower. Communicative pathways between the pilot and air traffic control included the radio communications frequencies between the pilot and air traffic controllers and the transponder signal between the aircraft's transponder and the ATC radar. Information exchanged between ATC and the pilot included particular frequencies, navigational vectors, altitude assignments, error checking, traffic avoidance instructions, clearance to land on a particular runway, and other navigational commands. For example, in the case of vector assignments, the model illustrated how the pilot tracks a target state and current state on the heading indicator. The vector command originated from the air traffic controller and was transferred to the pilot in the aircraft though the communications frequency. The pilot heard the target heading, and confirmed it by repeating to the air traffic controller (error checking). Rather than retaining the target heading as an internal, remembered representation, the pilot finds the target heading on the heading indicator. Thus, both the current and target headings are external representations on the heading indicator, and the pilot turns the aircraft left and tracks the heading indicator until the current state matches the target state. The organizational influences, previously described in terms of macroergonomics concepts, on the information flow between the pilot and air traffic controller for this illustration is apparent. For example, decision making is centralized, with ATC, and the pilot follows established procedures as governed by the strong legal environment, such as repeating communications back to ATC.

Other distributed components to the system included navigational aids located at the Roanoke Regional Airport and at Vinton. For example, The IFR pilots used the ILS for Runway 33 and the NDB located at Vinton. The ILS antenna at the airport and the NDB at Vinton both transmitted navigational information to the aircraft over their respective frequencies which the pilot had programmed into the navigation radio. The information is received by the aircraft and transformed into external representations on the glide slide indicator and ADF bearing indicator that are understood by the pilot. The pilot uses these information representations for successful navigation by instruments for the approach to Roanoke, Runway 33.

<u>Differences Between the IFR and VFR Systems-Level Cognitive Models</u>

It was hypothesized that the information flow observed in the pilot/cockpit system would differ between VFR and IFR pilots in certain respects during approach procedures. This hypothesis was supported as there were clearly differences in the information flow of the system during these two types of approaches. Much of the instrumentation and procedures used by each of the VFR and IFR pilots differ during a landing approach.

During the approach to Roanoke, the VFR pilot flies directly to Roanoke, usually on a single heading toward the traffic pattern at the airport for Runway 33. The IFR pilot is given a series of vectors over time by ATC that brings the aircraft south and east around the edge of Roanoke airspace in order to intercept the ILS localizer for Runway 33. For the IFR model, there is an information exchange over time between the air traffic controller, the air traffic controller's radar screen, the pilot, and the heading indicator. The air traffic controller determines a vector for Cessna 61891 after viewing the radar screen to assess potential conflicting traffic and then communicates the vector (e.g., 110°) to the pilot over the communications frequency, 118.5 MHz. The pilot repeats the vector back to ATC for error checking and then uses the heading indicator to coordinate and match the current state (e.g., 070°) with the target state (110°), both of which are externally represented on the heading indicator. These course corrections are repeated several times to guide the pilot for ILS localizer interception. The VFR pilot, on the other hand, usually flies a singe heading toward Roanoke, relying on external visual cues to find the airport.

The IFR pilot tunes the navigation radio to the frequency for ILS 33 (109.7 MHz) and tunes the ADF to the frequency for Vinton NDB (277 kHz). The localizer and glide slope signals that are continuously transmitted from the ILS antenna by Runway 33 are received by the aircraft's on-board antenna system. The signal is processed by the ILS computer and then sent to and displayed on the glide slope indicator. Similarly, the Vinton NDB transmits its signal and the position of the station is represented on the ADF bearing indicator. The information transmitted by the ILS and the Vinton NDB over the communicative pathways are not understood by the pilot until it is transformed and represented on the glide slope indicator and the ADF bearing indicator respectively. Both are important navigational aids for the pilot during the approach to Runway 33.

In contrast, the only "navigation aids" the VFR pilot needs to use for the approach are the external visual cues surrounding Roanoke (e.g., familiar terrain, landmarks, lights). Some VFR pilots, like the VFR participant in this field study, will use the Woodrum VOR as a back-up. The pilot tunes the navigational radio to 114.9 MHz for the Woodrum VOR which is located at the Roanoke Airport. The navigational information from the Woodrum VOR is received over this frequency and translated onto the VOR bearing indicator into an external representation understood by the pilot. If the pilot becomes lost or confused with his position from visual navigation, he can use the VOR bearing indicator to find the proper heading to the Woodrum VOR and thus the Roanoke Regional Airport.

During the VFR approach, the pilot is responsible for maintaining separation from nearby traffic. The pilot attends to the communications from ATC and other pilots in the airspace and develops a four dimensional, internal representation of surrounding traffic. The representation involves four dimensions because the pilot must project relevant parts of this traffic pattern into the future to assess potential effects on his/her flight path and scans for traffic that is nearby to his/her position until he/she has visual contact with that traffic. In IFR piloting, however, the pilot is flying solely by instruments, and since head-down time is virtually 100%, he/she cannot see surrounding traffic. It is the air traffic controller's responsibility to keep the IFR aircraft separated from nearby traffic. For VFR traffic to legally operate in Roanoke's Class C airspace, visibility must be greater than or equal to three miles. This rule is not necessarily designed to protect the VFR aircraft, but to protect the IFR traffic *from* the VFR aircraft.

During final approach, as the IFR pilot descends to Runway 33, he/she maintains horizontal and vertical position by monitoring the glide slope indicator. The pilot makes adjustments to maintain the vertical localizer needle in the center of the glide slope indicator to keep the aircraft lined up with the runway centerline and to maintain the horizontal glide slope needle in the center of the glide slope indicator to keep the aircraft on the 3° vertical glide path to the runway. Navigational information is completely represented on the instruments before the IFR pilot. The VFR pilot, on the other hand, does not use instruments to fly down the glide slope as in the instrument approach. Rather, the pilot has the runway in site before entering the traffic pattern and visually navigates around the pattern for Runway 33. Navigational information is in the form of external visual cues for the VFR pilot. For the entire decent to the runway, the pilot also monitors both airspeed and vertical speed while maintaining visual contact with the runway.

<u>Rare Events</u>

Pilot errors were observed in the field and documented in the Results chapter (Table 28 on p. 119). These rare events (i.e., errors) are discussed here as they were likely related to workload and had an effect on the system being studied, and provide support for redesign.

<u>VFR01</u>. During the visual approach to Runway 33, participant VFR01 received the following communication from Roanoke Approach (Appendix O: A23-A24):

P = Pilot (Subject VFR01); RAD = Roanoke Approach and Departure

Code	Time	Source	Communication
A23	6:55	RAD	Cessna eight-niner-one, enter left traffic Runway 33, and contact the tower one-one-eight point three.
A24	7:00	P	Left traffic for three-three, eight-niner-one.

The pilot acknowledged the command to enter left traffic pattern for Runway 33 but did not acknowledge the command to contact tower. During the retrospective report, the pilot stated that he did not contact the tower at that point because he had not yet entered the left traffic pattern for Runway 33 (Appendix O: B36). However, circumstances suggest the pilot may have missed this command. The pilot failed to repeat the command to contact tower back to Roanoke Approach, as is routine. Further, when Roanoke Approach gives a command, it is meant to be followed promptly, unless otherwise specified. Therefore, it may be true that the pilot was waiting until he was on the left traffic pattern before contacting the tower. However, it seems as if the command was afterward forgotten as over three minutes passed and then Roanoke Approach had to repeat the command as follows (Appendix O: A32-A36):

P = Pilot (Subject VFR01); RAD = Roanoke Approach; Tower = Roanoke Tower

Code	Time	Source	Communication
A32	10:16	RAD	Cessna eight-niner-one contact the tower, one-one-eight-point-three.
A33	10:20	P	[Cessna?], tower, eight-point-three.
A34	10:24	P	Hello tower, Cessna eight-niner-one is with you, ah, descending down, [inaudible].
A35	10:28	Tower	Cessna six-one-eight-niner-one! Roanoke Tower, make a hard right turn for me heading about one-two-zero for right now please, vector away from departure traffic.
A36	10:35	P	One-two-zero, eight-niner-one.

After the pilot contacted the Roanoke Tower, the tower air traffic controller hurriedly instructed the pilot to make a hard right to avoid departing traffic. Had the pilot contacted tower earlier, he likely would have received navigational commands to avoid this potential conflict.

IFR01. Another error occurred during the hand-off to Roanoke tower from Roanoke Approach with participant IFR01 during the instrument approach. The pilot was on final approach for Runway 33, but mistakenly requested Runway 6 when making initial contact with the tower (it not uncommon to fly the ILS for Runway 33 and then enter the airport's traffic pattern and land on a different runway). The initial communications with Roanoke tower were as follows (Appendix P: C127-C133):

P = Pilot (Subject IFR01); SP = Safety Pilot; Tower = Roanoke Tower

Code	Time	Source	Communication
C127	22:34	P	Calling tower Cessna eight-niner-one on the ILS three-three request a touch-and-go to Runway six if not then full stop to Runway six.
C128	22:43	SP	Three!
C129	22:44	P	Three-three, I'm sorry, Runway three-three.
C130	22:45	Tower	[inaudible] continue.
C131	22:47	P	I say again? Eight-niner-one.
C132	22:59	Tower	And, ahh, six-one-eight-niner-one, just ahh, continue [inaudible] you can plan a right base for Runway six when you're ready.
C133	23:04	P	Plan a right base six eight-niner-one.

The pilot mistakenly requested Runway 6 and the safety pilot caught the error and yelled "three!" for Runway 33 to the pilot. The pilot tried to correct his mistake with the tower but their communications interfered with each other as they communicated at the same time. The tower did not receive the correction and informed the pilot to plan a right base for Runway 6. Both pilots who flew the ILS approach to Runway 33 indicated in their retrospective reports that it is at this time during the flight that the pilot has the highest workload (see Appendix P: D89, D93, D102-D104; and Appendix Q: F85). During this time, the pilot is performing motor tasks as he/she pilots the aircraft, visual-spatial tasks by aligning the localizer and glide slope needles, and auditory when listening for air traffic control commands and then repeating the commands back for error-checking. At this time, the aircraft is close to or over the Vinton NDB, so the pilot also is watching for the ADF bearing indicator to swing as the aircraft passing over the NDB station at Vinton.

Approximately one minute later, the pilot contacted tower again and requested and received clearance for Runway 33 rather than Runway 6. Had the safety pilot not been present to catch the error, it is possible that the pilot would have continued down and landed Runway 33, thinking he had asked for and received clearance for 33, while the tower was expecting him to land Runway 6. It is not difficult to imagine the potential hazard this could have caused.

IFR02. The second participant who flew the instrument approach committed a less dramatic error when she failed to attend to a course correction given by Roanoke Approach at time index 16:11 (Appendix Q, E76, E78-E79).

P = Pilot (Subject IFR02); RAD = Roanoke Approach and Departure

Code	Time	Source	Communication
E76	16:11	RAD	Eight-niner-one, turn left heading of zero-five-zero.
			[*pilot fails to respond*]
E78	16:22	RAD	Number six-one-eight-niner-one, turn left heading of zero-four-zero now.
E79	16:26	P	Left heading zero-four-zero, eight-niner-one.

Not hearing a response from Cessna 61891, the air traffic controller would know that the pilot did not copy the command. The air traffic controller simply gave another course correction command 11 seconds later and this time, the pilot heard the command and responded. In her retrospective report, the participant conformed that she did indeed miss the original course correction command. The video playback shows the safety pilot look over at the pilot, noticing that the pilot failed to attend the command. Had the error been a more critical one, as the one discussed for participant IFR01, the safety pilot would have informed the pilot of the error.

The errors discussed here support practical design implications given on p. 158. While each of these pilots committed errors, it should be noted that all three of them rated their workload as ≤ 3 on the MCH rating scale for their respective flights (Table 27 in Results chapter). Ratings ≤ 3 on the MCH scale correspond to an “acceptable” level of workload. Workload ratings of ≤ 3 was also the case for both pilot types in the control condition of the flight simulator experiment. Situation awareness scores on the SART scale was 30 and 38 for participant IFR01 and IFR02 respectively. Comparatively speaking, the mean SART rating for IFR pilots in the flight simulator for the control condition (clear weather during daytime) was 32. Participant VFR01 gave a SART rating of 35 for the field flight. The mean SART rating for VFR pilots in the flight simulator for the control condition was 26.25. Thus workload and situation awareness ratings in the field are similar to those in the control condition of the flight simulator experiment for both pilot types except situation awareness for VFR pilots, where the pilot in the single field VFR flight gave a substantially higher indication of situation awareness than the VFR pilots in the flight simulator. However, the field ratings are based on two IFR observations/flights and one VFR flight and thus not statistically meaningful and are therefore only used for descriptive comparison.

INTEGRATION OF LABORATORY AND FIELD STUDIES

The use of a field study and laboratory experiment was meant to be a complementary approach to examining the same basic work system. This section discusses the effect of weather and night conditions studied in the laboratory on systems-oriented cognitive models developed from the field study, procedural comparisons between the simulator and actual Cessna 172, and evaluation and comparison of the ME/DC method between the field and laboratory studies. The relative contributions each study provided in examining this aviation system are explored in Chapter 6, Conclusion.

Effect of Weather and Night Conditions on Systems-Oriented Cognitive Model

One research question asks how the introduction of poor weather conditions and nighttime operations in the laboratory would affect the systems-level cognitive model derived from the application of the ME/DC method during the field study (for both pilot types). Statistical analysis in the laboratory experiment revealed that these conditions had no effect on flight performance or workload for IFR pilots. However, situation awareness was found to be reduced during deteriorating weather conditions. These conditions had a greater effect on the VFR pilot group. Statistical analysis from the laboratory experiment revealed that VFR pilot workload is greater and situation awareness is reduced in deteriorating weather conditions during daytime approaches. Situation awareness was also found to be reduced during night approaches when weather is static for VFR pilots.

For the VFR group, since workload was significantly higher in deteriorating weather conditions, we could expect pilots' working memory "left-over" capacity to be reduced. Considering the systems-oriented cognitive model, this in turn would affect the pilots' ability to store information in working memory that is coming in from ATC such as frequencies, vector assignments, altitude assignments, and other commands from ATC. For both pilot groups, where situation awareness was found to be reduced, pilot attention may be affected. A reduction of situation awareness can lead to a lower degree of concentration, and a narrowing of one's attention (inability to distribute one's attention to several simultaneous tasks). Considering the systems-oriented cognitive model, this in turn could limit the amount of knowledge received and understood from the resources in the system (e.g., instruments, communications) or decrease the value of the information that is received by the pilot.

<u>Procedural Comparison between Field and Simulator</u>

Procedural comparison between the actual and simulated systems, which was not part of the ME/DC method, was performed with task analyses of an approach to Roanoke for both VFR and IFR pilots using the iGATE simulator and an actual Cessna 172 (Tables 29 and 30 in Results Chapter) so that the procedures could be compared between the field and the laboratory. That is, do the tasks performed in an actual Cessna 172 by the pilot match the tasks performed with the simulator? The task in both studies was the same for VFR and IFR pilots; an approach to Roanoke Runway 33.

The most glaring difference in the procedures from the field and the laboratory is that the simulator does not provide for ATC. Simulated ATC is possible with the iGATE simulator only for selected approaches in the southern California area. Since pilots in the laboratory experiment experienced no ATC communications, the Roanoke airport was essentially an uncontrolled airport in the laboratory experiment rather than a controlled airport as in the field. Many of the procedures in the field related directly to ATC communications, from commands given by ATC to the pilot, to programming the communications radio and transponder to appropriate frequencies. In the laboratory, the pilots did not have a need to tune the communications radio to 118.15 MHz (Roanoke Approach) or 118.3 MHz (Roanoke Tower) as required in an actual approach to Roanoke. Laboratory participants did have the opportunity to tune the communication radio to Roanoke ATIS (118.65 MHz) for weather information. However, the weather information is displayed as text across the top of the visual display rather than as an automated voice through the headset as in the field, and the information displayed by the simulator includes only limited weather information, not supplementary weather information and additional information such as notices to airmen (NOTAMs), as in the field. These differences between the field and the laboratory regarding communications were the same for both VFR and IFR pilots.

Another major difference between the studies was the external visual view of the simulator compared to an actual Cessna 172. The simulator display gives only a small external forward view, with no corresponding peripheral view. In an actual aircraft, the pilot has an external visual view of approximately 180 degrees. This difference is only consequential to VFR pilots as IFR pilots fly by the aircraft's instruments. An external visual system that gives the iGATE simulator a more realistic, 180° visual view does exist. However, this component is not part of Virginia Tech's iGATE simulator; the cost of this external visual system was prohibitive. Since the simulator external view was limited to a forward view, VFR pilots in the laboratory were restricted to flying straight-in approaches to Runway 33. In an actual VFR approach, pilots usually enter the traffic pattern around the airport, as was the case with the visual approach observed in the field study, and then turn the aircraft for Runway 33 rather than fly a straight in approach. If a VFR pilot attempted to enter the airport traffic pattern when flying the simulator, he/she would not have the peripheral visual cues to make an accurate turn for Runway 33. The pilot would not have visual contact with the airport or Runway 33 on the downwind or base legs of the traffic pattern. Thus pilots flew straight-in approaches with the simulator as opposed to entering the traffic pattern in an actual VFR approach.

The simulator controls and instrumentation was found to be particularly realistic for both VFR and IFR piloting aside from a few exceptions. The elevator trim control wheel in an actual Cessna 172 is located below the console at knee-level to the right of the pilot and the fuel selector valve is located on the floor to the right of the pilot. Since only the console itself is represented by the simulator, except for the rudder pedals, the elevator trim control is located on the yoke as a switch and the fuel selector value is located on the far right of the simulator console. Thus for the simulator, the elevator trim and fuel selector valve is located in unrealistic positions. Also, the elevator trim on the simulator is a switch control instead of a wheel control. Additionally, the simulator does not have a control knob for carburetor heat as in an actual Cessna 172. Carburetor heat is used when the pilot reduces the engine RPM below the normal operating range during final approach.

Finally, the simulator yoke control does not give realistic back-pressure feedback. Several participants in the laboratory experiment noted this. When landing the aircraft, the pilot executes a flare just before touchdown, where the pilot raises the nose of the aircraft with the yoke and holds the aircraft just off the runway to settle the plane down slowly. This is accomplished by increasing the back pressure the pilot feels on the yoke. While it is possible to execute a flare with the simulator by pulling back on the yoke, the pilot feels little back pressure as would exist when piloting an actual Cessna 172. The pilot also gradually releases the back pressure on the yoke at touchdown after the back-wheels touch the runway to slowly allow the nose wheel to settle down on the runway. Since the simulator does not give this back-pressure on the yoke, the pilot must 'guess' the appropriate yoke position during touchdown.

Considering the complexity of an aircraft's control and instrumentation system, the external validity of the iGATE simulator is high; the simulator's controls, instrumentation, and radio stack replicate their counterparts from the actual Cessna 172. For example, the simulated glide slope indicator works just as precisely as the one in the actual aircraft works. The differences discussed above are a few exceptions in a large number of controls, instruments, and procedures. The iGATE simulator is a fixed-based simulator and thus the pilot does not experience the motions he/she would when piloting an actual aircraft. However, the iGATE simulator is certified by the FAA for IFR instruction, thus the external validity of the simulator was expected to be high. The most significant limitations of the simulator are the non-existence of ATC communications and the limited external visual view for VFR piloting. Attending to and responding to ATC communications seems to add significant workload for a pilot, especially during final approach. This observation is supported by participant IFR01's retrospective report, *"Sometimes he'll* [ATC] *give you all sorts of stuff at once, that's when your workload really gets going. He'll give you heading, an altitude, and a clearance for the approach."* (APPENDIX P: D89).

Evaluation of ME/DC Method; Reliability and Validity

The ME/DC method is based on two well established frameworks, the macroergonomics analysis and design (MEAD) framework (e.g., Hendrick and Kleiner, 2001) and DC (e.g., Hollan, Hutchins, and Kirsh, 2000a). Therefore, the hybrid approach used for this dissertation was expected to have reliability and validity. The ME/DC method itself was evaluated in two ways. First, the consistency of observations across participants (Step 5 in the ME/DC method) was assessed; this relates to reliability. That is, the ME/DC method was expected to give a consistent description of how the structures in the functional system are coordinated across participants (e.g., similar information flow and representation, similar communicative pathways, etc.). Secondly, the systems-level cognitive model as described by the application of the ME/DC method in the field was expected to be replicated in the flight simulator experiment. For example, was the information propagation and representation as observed in the field similar to that observed in the laboratory? This relates to validity.

The methodology in the field was consistent insofar as observations in the field gave a consistent description of the transformation and propagation of information in the Roanoke airspace as a pilot performs an instrument approach. For the two IFR field participants, the same information flow, information representations, coordination of structures, communicative pathways, etc., were produced and documented. For example, the information flow between Roanoke ATC and the pilot is conducted over the same communicative pathways (118.15 MHz, 118.3 MHz), and with the same resources; communications radio and transponder in the aircraft, radar display at ATC. The information flow between the pilot and his/her navigational aids (ILS, Vinton NDB) is the same, uses the same communicative pathways (109.7 MHz, 277 kHz), and is transformed and represented in the same fashion (glide slope indicator, ADF bearing indicator).

There was only one VFR participant in the field study and thus similar comparisons cannot be made for the system between VFR pilots. However, there is substantial overlap between the IFR and VFR systems. For example, the communication structures between the pilot and the ATC controller are identical. However, much of the information exchanged differs. The ATC controller communicates several vectors to the IFR pilot for future ILS localizer acquisition that the VFR pilot would not receive. Information representations also differ, not just the externally represented information on the aircraft's instruments. The VFR pilot constructs an internal representation of the surrounding traffic from the communications whereas the IFR pilot relies on ATC for aircraft separation, where traffic information is externally represented on a radar display. Similarities between the VFR and IFR models, aside from the communications structures, includes information acquisition from Roanoke ATIS, retrieval of frequencies from long-term memory or from external notes, matching current and goals states on instruments (e.g., airspeed indicator).

Applying the same ME/DC method that was used in the field to the system simulated in the laboratory produces less consistency, much of which can be attributed to the fidelity of the simulator-based system itself. Table 32 gives a comparison of the steps from the ME/DC method as applied to the field to the simulated system in the laboratory.

TABLE 32

Comparison of ME/DC Method between Field and Laboratory Systems

ME/DC Method	Field Study	Laboratory Experiment
Step 1: *Define Boundaries of Unit of Analysis*	Boundaries of the functional system by defining the system's purpose, resources, communicative pathways, and how the structures of the system are coordinated.	Similar output. However, the entire functional system is not represented in the laboratory (ATC and corresponding resources, other traffic.)
Step 2: *Overall System Scan*	Overall system scan by defining the complexity, formalization and centralization of the overall work system (Roanoke airspace system) and by describing the technological, social, and environmental subsystems.	Must assume that the output is same for simulated system as actual system. However, no means to confirm this or study the overall system without a field study.
Step 3: *Bounded System Scan*	Bounded system scan by defining the technological, social, and environmental components of the functional system.	The system simulated in the lab is the "bounded system", but only partially represented.
Step 4: *Develop Scenario for Bounded System*	A scenario consisting of a landing approach to the Roanoke Regional Airport in a GA aircraft (both VFR and IFR).	Same scenario, simulated.
Step 5: *Conduct Observations based on the Scenario*	Participant observation, video/audio recording, field notes, retrospective protocol, interviewing, flight performance measures, and workload and situation awareness rating scales.	Same observational techniques, however, much less "rich" without ATC communications.
Step 6: *Determine Bounded System's, Function, Task, and Information Distribution*	Development of the systems-level cognitive models for both VFR and IFR pilots.	Models limited by the fidelity of the simulated system.

Step 1: *Define Boundaries of Unit of Analysis*

The boundaries of the unit of analysis for the simulated system cannot be described as comprehensively as they were for the actual system in the field study. The physical space of the system can be described as the interior cockpit of the Cessna 172 aircraft, which is represented in the laboratory, the Class C airspace surrounding Roanoke, and Runway 33 at the Roanoke Regional Airport, which are simulated by the simulator's software. However, the Roanoke air traffic control tower is not simulated.

Several of the system's resources are missing from the simulated system. Specifically, the air traffic controllers (including Roanoke Approach and Departure and Roanoke Tower), the pilots in other aircraft within the Roanoke airspace at any given time, and the technological artifacts associated with these individuals such as the ATC radar display. The pilot's resources and information communicative pathways are present and simulated to a high degree. These resources include the flight instruments on the cockpit instrument panel, the radio communication and navigation system, and several gauges (e.g., fuel and oil gauges) and switches (e.g., light switches, radio selector switches).

Step 2: *Overall System Scan*

We can assume the output is the same for simulated system as for the actual system (description of the complexity, formalization, centralization of the overall aviation system as well as the social, technological, and environmental subsystems). However, there is no means to confirm this or study the overall system within the limitations of the laboratory. What are the various subsystems of the Roanoke airspace system? How are all the aircraft coordinated, and is decision making decentralized amongst the pilots or centralized with ATC? What is the complexity and formalization of the overall system? What are the external environments (e.g., legal), and how do they affect the system? These questions cannot be answered with simply a flight simulator in the laboratory.

Step 3: *Bounded System Scan*

While the flight simulator itself represents the main component of the bounded system, other components are not simulated in the laboratory. The pilot is the only social resource represented in the laboratory. Air traffic control, and its related resources were not simulated in the laboratory. The communicative pathways between the pilot and ATC were simulated, but the communications themselves were not.

The aircraft's resources were simulated to a very high degree. These include the flight instruments; the altimeter, vertical speed indicator, airspeed indicator, heading indicator, attitude indicator, turn coordinator, and magnetic compass. Instrumentation used with external navigational aids; ILS indicator, VOR bearing indicator, and ADF bearing indicator. The radio stack was also represented, including the components for communication and navigation radios and the transponder. The flight control mechanisms; yoke, throttle, carburetor heat control knob, fuel mixture control knob, elevator trim wheel, wing flap control, and rudder pedals.

Step 4: *Develop Scenario for Bounded System*

The scenario for the IFR-rated pilots was to perform an ILS approach to the Roanoke Regional Airport, Runway 33. The VFR pilots performed a visual landing approach to the same runway. These scenarios for the two pilot types were the same for the field and the laboratory studies. However, for the laboratory study, the VFR pilots were restricted to performing a straight-in approach to Runway 33 rather than enter the traffic pattern and turn for Runway 33 as they would in an actual VFR approach, due to the simulator's limited forward external view.

Step 5: *Conduct Observations based on the Scenario*

The same observational techniques were applied to both studies. However, since the field study was naturalistic, the data collected was very rich. For the field study, communications in the system were captured not only between the participant and ATC, but also from the other traffic in the Roanoke airspace. The additional traffic in the system does have an effect on ATC and the participant. The more traffic an ATC is responsible for, the higher his/her workload is expected to be. This is turn affects communications between ATC and the pilot. Heavy traffic in the airspace also affects the participant's tasks as he/she must maintain separation from nearby traffic and in some cases may have to alter his/her course. The simulator's inability to simulate this portion of the system makes the video recordings much less rich and realistic than the same recordings from the field study. An enormous advantage the simulator had over the field study was its ability to simulated night and deteriorating weather conditions, and their affect on pilot performance, which would be too dangerous to observe in the field.

Step 6: *Determine Bounded System's, Function, Task, and Information Distribution*

To construct systems-oriented cognitive models for VFR and IFR pilots during an approach to Roanoke for the field study, the transcriptions of the pilot-ATC communications in the system were essential. The simulated work system in the laboratory was essentially an approach to an uncontrolled airport without ATC. Most of the information flow is lost in the laboratory. The information flow that exists in the simulated system is restricted between the pilot the aircraft's instruments. For example, the retrieval of communications and navigations frequencies from pilot long-term memory, or from resources such as an approach plate, and the transformation of that information to external representations on the radio stack is the same as in the field. Also, information representations on navigational instruments such as the glide slope indicator, ADF bearing indicator, and VOR indicator, are accurately simulated in the laboratory, as if the corresponding navigational aids in the Roanoke area were transmitting these signals to the aircraft.

In sum, there seemed to be consistency of observations across participants in the field study, thus demonstrating *reliability*, but transfer of the ME/DC method to the laboratory is limited as a result of the fidelity of the simulated system. The ME/DC method is a hybrid method designed to treat the organizational and cognitive components of a system as equally important. The frameworks that the ME/DC method is based on, which are the macroergonomics analysis and design framework and the distributed cognition framework, were both intended for field application. An organizational work system is difficult to replicate in a laboratory, and an assumption behind distributed cognition theory is that cognition should be studied as it exists in its natural environment.

However, in terms of an aircraft's control and instrumentation system, the external validity of the iGATE simulator is high; the simulator's controls, instrumentation, and radio stack replicate their counterparts from the actual Cessna 172 to a very high degree. In this context, translation of the ME/DC method to the simulated system was sufficient, as the identical information flow between the pilot and cockpit is observed. For example, Figure 21 shows the internal to external information representations of a communication frequency for Roanoke ATIS. These information transformations and representations between the pilot and communication radio are the same in both the field and the simulated system. Further, the same information representations on the displays and instruments are produced in both the field and laboratory. For example, Figure 24 shows how glide slope indicator represents lateral and vertical guidance information that is transmitted from the ILS at the airport. These information representations are identical in the simulated system (see Figures 23, 26 for additional examples of identical information representations observed in both the field and the laboratory). In this manner, *validity* of the ME/DC method is demonstrated for pilot/cockpit interaction. This type of comparison for the larger system is not possible, since the ATC component of the system, for example, is not simulated.

Future research could further assess the potential value of the ME/DC method by applying to domains outside of aviation. The steps of the method are generalizable for application to sociotechnical systems, not restricted to the aviation environment studied for this dissertation.

Design Implications

Research for this dissertation examined the current GA environment and may provide a baseline for future research involving the transition of the current GA environment to future ones involving, for example, free flight and new technologies. However, results from this research do carry some design implications. Indeed, findings from this research widely support new designs and technologies envisioned for future aviation systems that would assist the pilot during a landing approach.

In the laboratory experiment, VFR workload was significantly greater during deteriorating weather than VFR workload during the control condition. Further, situation awareness was reduced for both pilot groups in night conditions and during deteriorating weather conditions, and VFR pilots experienced significantly reduced situation awareness compared to IFR pilots in nighttime and during deteriorating weather. These results underscore the need for technologies such as aviation weather information systems inside the aircraft and for new displays such as head-up displays and displays that employ synthetic vision. Weather information systems should be used in GA aircraft, displaying the aircraft's position with GPS on a moving map with *visual* weather information (as well as text) overlaid on top of the moving map. With real-time weather information that is continuously updated would allow the pilot to divert from hazardous weather and even the destination airport, into more favorable conditions, thus avoiding a reduction of situation awareness. One such example is the new system developed by Avidyne called 'FlightMax Entegra', specifically designed for small, GA aircraft. This product is a comprehensive aviation information system, including visual weather information, which can help maintain pilot situation awareness in poor weather conditions.

"Synthetic" vision displays, which combine GPS data with terrain databases, can provide the pilot with clear visibility in nighttime and during poor weather conditions, also preventing a reduction of situation awareness. Chelton flight systems, for example, uses synthetic vision in combination with Highway-In-The-Sky (HITS) technology, where a three-dimensional "tunnel" is depicted along the pilot's desired flight path on the synthetic vision display.

Displaying this information with a head-up display would also benefit the pilot. These types of displays, envisioned as new aviation technologies, would display the information on a transparent screen on the cockpit window, thus allowing the pilot to simultaneously maintain contact with the external visual view. These types of technologies may increase the situation awareness of pilots, perhaps making it less likely for VFR pilots to continue a flight into deteriorating weather, as was the case in the laboratory experiment.

The systems-oriented cognitive models produced from the field research, which documented the information flow of the system, expose difficult instances during the approach that could benefit from redesign. Consider the busiest point of the instrument approach, for example (see Appendix P: D89, D93, D102-D104; and Appendix Q: F85). At approximately the point of glide slope interception for the instrument approach, Roanoke Approach commands the pilot to contact Roanoke Tower. Not only must the pilot attend to incoming communications, he/she must establish contact with Tower at the appropriate time. During this time, the pilot is performing motor tasks as he/she pilots the aircraft, visual-spatial tasks by aligning the localizer and glide slope needles (Figure 35), and auditory tasks when listening for air traffic control commands and then repeating the commands back for error-checking. The pilot is also watching for the ADF bearing indicator to swing as the aircraft passing over the NDB station at Vinton, and preparing to set the timer for missed approach. In terms of the information flow of this system, the information is converging on the pilot at this point during the approach. It was at this point during the instrument approach, while performing these tasks concurrently, that participant IFR01 made a critical error of requesting the incorrect runway (see p. 146).

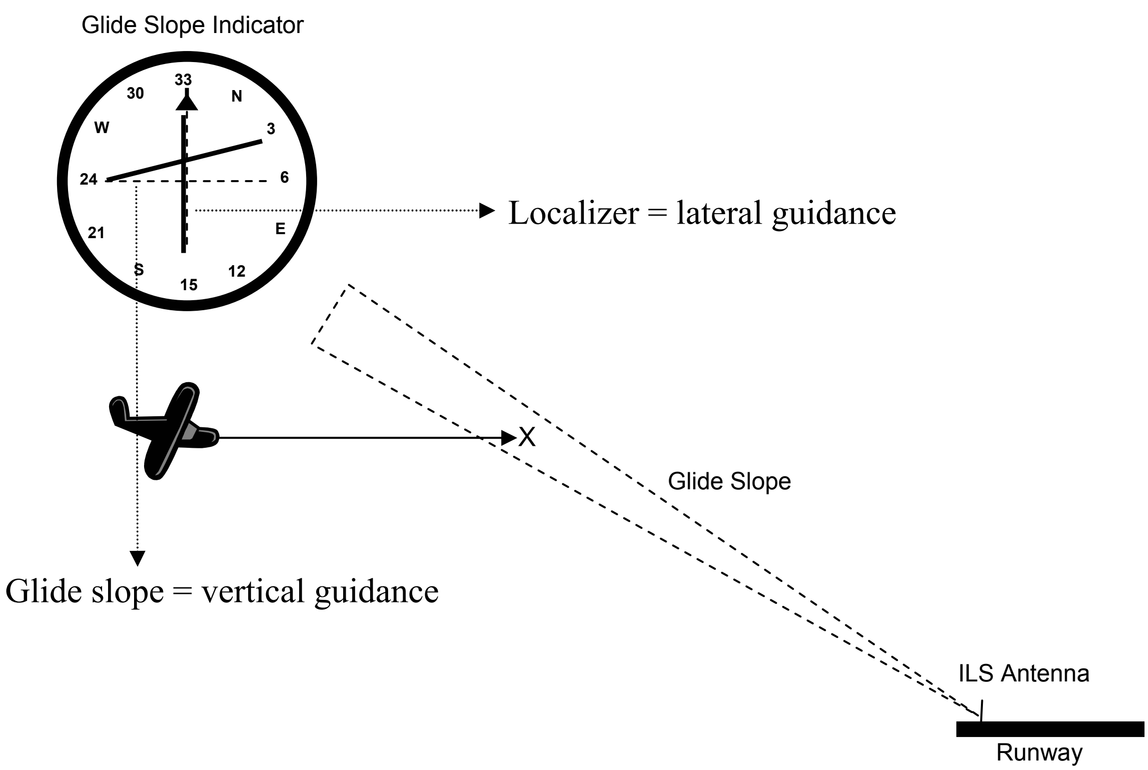

Figure 35. *Localizer and glide slope flight path guidance.*

In this case, clearly the pilot would benefit from increased automation in the cockpit at this point to alleviate some of the burden from the pilot. Increasing the automation of the aircraft could include automating some of the piloting controls and automating guidance along the glide path, rather than having the pilot maintain glide path by adjusting the flight controls to keep the needles lined up on the glide slope indicator. Automated flight path guidance is a practical means of reducing pilot workload during a landing approach.

Another design improvement would be to have the system filter out ATC communications that are not relevant to the pilot. The pilot receives most of the ATC communications occurring in the airspace as much of the traffic uses the same frequency. The more traffic in the airspace, the greater number of communications that are not relevant to the pilot. For example, consider the following excerpt from the flight communications from participant IFR02 (APPENDIX Q: E60-E79):

P = Pilot (Subject IFR02); RAD = Roanoke Approach and Departure; Tower = Roanoke Tower; OA1 = Other Aircraft 1; OA2 = Other Aircraft 2

E60	10:06	RAD	Eight-niner-one, turn ten degrees left.
E61	10:08	P	Eight-niner-one, ten degrees left.
E62	11:26	P	[Oil temps?], all looking good, ammeter good.
E63	14:06	RAD	Blueridge one-ninety-five, Roanoke approach, Roanoke altimeter, three-zero-one-niner, can you accept runway two-four, wind two-niner-zero at twelve?
E64	14:15	RAD	Blueridge one-ninety-five, descend and maintain niner-thousand, and be vectored to runway visual two-four. Traffic one-o'clock four miles west bound eight-thousand-five-hundred Cherokee.
E65	14:56	OA1	Roanoke departure, one-nine-three-two-papa, two-point-five, climbing five thousand, and we're coming left two-two-zero degrees.
E66	15:09	RAD	Blueridge one-ninety-five, as soon as you get past that traffic I'll have [inaudible] just off you two-o'clock now and two miles, and I don't have him on my frequency so I'll have to wait 'till he gets on me.
E67	15:24	OA1	And departure, one-nine-three-two-papa, climbing five thousand, heading two-two-zero.
E68	15:29	RAD	[inaudible] three-two-papa, radar contact, climb and maintain one-zero thousand and, ahh, turn left heading one-eight-zero.
E69	15:37	OA1	Okay, one-zero, ten thousand, left turn heading one-eight-zero, three-two-papa.
E70	15:44	OA2	Roanoke approach, Cherokee four-three-one-two-six with you.
E71	15:47	RAD	Cherokee four-three-one-two-six, Roanoke approach, Roanoke altimeter, three-zero-one-niner, you have traffic just

			off your eleven-o-clock about at about a mile at nine-thousand three hundred for nine thousand, you have him in site?
E72	15:56	OA2	Affirmative, one-two-six, I have him, I'd like to begin my descent.
E73	15:59	RAD	One-two-six, maintain visual with that traffic, he's going to continue the decent, altitude at your discretion.
E74	16:03	RAD	Blueridge one-ninety-five, descend ahh disregard, you said you had the airport?
E75	16:07	OA2	Ahh, negative, but I'm at eight-thousand five hundred, I gotta loose some of this.
E76	16:11	RAD	Eight-niner-one, turn left heading of zero-five-zero. [*Subject failed to respond!*]
E77	16:16	RAD	Blueridge one-ninety-five, cleared visual approach runway two-four.
E78	16:22	RAD	Number six-one-eight-niner-one, turn left heading of zero-four-zero now.
E79	16:26	P	Left heading zero-four-zero, eight-niner-one.

ATC contacted participant IFR02 at time index 10:06 (E60) for a course correction and the participant immediately responded (E61). However, a little over six minutes pass before ATC contacted participant IFR02 again at time index 16:11 (E76) and participant IFR02 missed the communication! ATC had to repeat the command (E78). In the six minutes that transpired between contact with ATC, 13 communications were transmitted over the same frequency (E63-E75), none of which were relevant to participant IFR02. Rather than the pilot attending to all communications and processing those which are relevant, the system could be designed to pass only relevant communications, thus reducing the burden on the pilot, and the potential for missing the communication as illustrated in this example.

There are several cases during the landing approach where the pilot must process and retain information in working memory that is communicated from ATC. Such information includes specific course headings, altitudes, frequencies, and traffic information of nearby aircraft, etc. For example, the following are communications from ATC to participant IFR01 that contain a heading, altitude, frequency, and traffic information that must be remembered by the pilot (Appendix P: C86, C124, C136):

RAD = Roanoke Approach and Departure; Tower = Roanoke Tower

C86	15:38	RAD	Cessna eight-niner-one, turn left heading zero-six-zero. Suggested altitude for the ILS approach will be three-thousand-eight-hundred.
C124	22:16	RAD	Cessna six-one-eight-niner-one, you're at Vinton, contact tower one-one-eight-point-three and he will assign which runway for touch-and-go.
C136	23:27	Tower	Piedmont thirty-three-twenty-six, cleared for takeoff runway three-three, turn left heading two-five-zero.

This information could be "remembered" by the system rather than the pilot. Such a redesign would reduce pilot workload since the pilot would not need to immediately attend to incoming ATC communications for this information. Rather, the pilot could access this information from a display at a later time if he/she was not able to process the information immediately (Figure 36). The pilot would still hear incoming ATC communications in real-time over the communication radio. However, the display would not only act as a redundant source of information in case the pilot failed to attend to the communication(s), but the display would also serve as a reference for error checking.

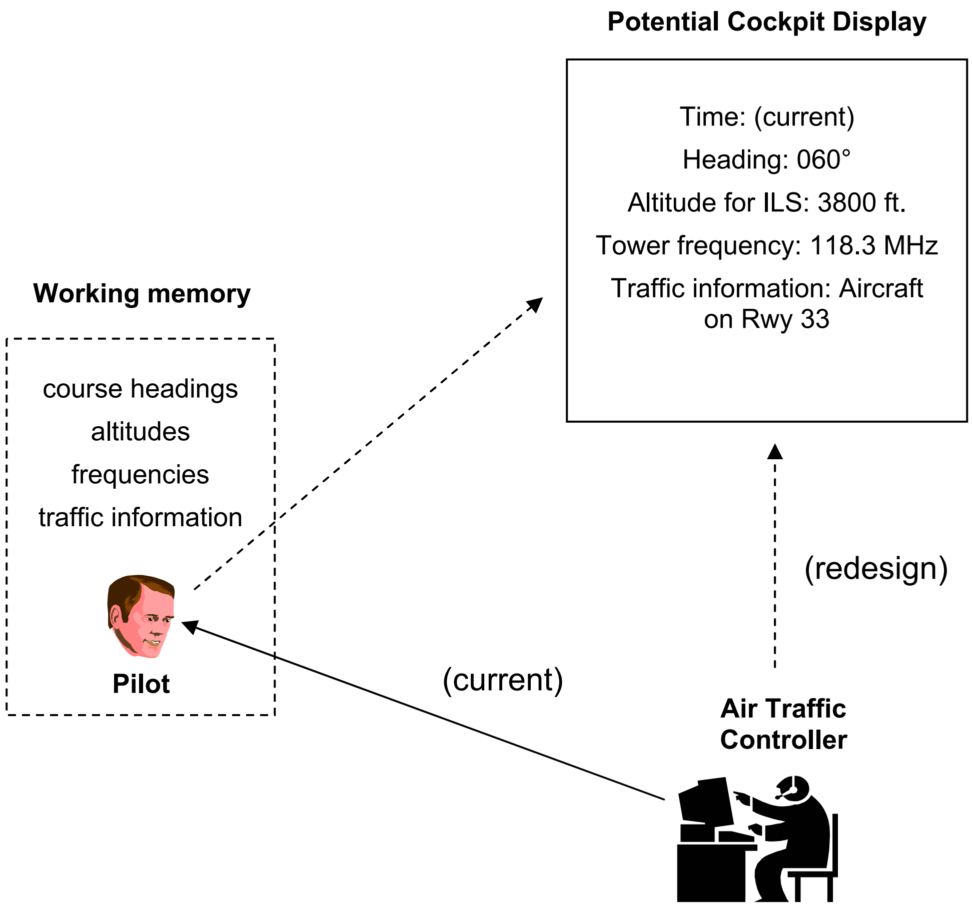

Figure 36. *Information represented and remembered by pilot versus display.*

One new system that can filter incoming communications and display them is the Controller-Pilot Data Link Communication (CPDLC) system. This system reduces the number of voice communications by displaying the routine communications digitally on a computer display. Thus, actual voice communications are restricted to non-routine communications. This particular system is currently being tested in the Miami Center airspace.

Traffic avoidance is another area of concern in the aviation domain and is underscored by the data collected from participant VFR01. Recall that the pilot in a VFR flight is responsible for maintaining clearance from nearby traffic. ATC will sometimes assist in VFR traffic separation, but the primary responsibility is the pilot's during VFR flights. The pilot receives positional information for surrounding traffic through ATC communications, as was the case for participant VFR01 (APENDIX O: A18, A35):

RAD = Roanoke Approach and Departure; Tower = Roanoke Tower

A18	6:13	RAD	Blueridge four-zero-four, turn right heading zero-five-zero, direct Montebello.
A35	10:28	Tower	Cessna six-one-eight-niner-one! Roanoke Tower, make a hard right turn for me heading about one-two-zero for right now please, vector away from departure traffic.

The pilot listens to the communications from the air traffic controller and other pilots and develops an internal representation of surrounding traffic. Relevant parts of this traffic pattern are projected into the future for potential effects on his/her flight path. The pilot visually scans for traffic that is close to his/her aircraft until he/she has visual contact with that traffic. Recall the representation presented previously of the information flow of this traffic information (Figure 37).

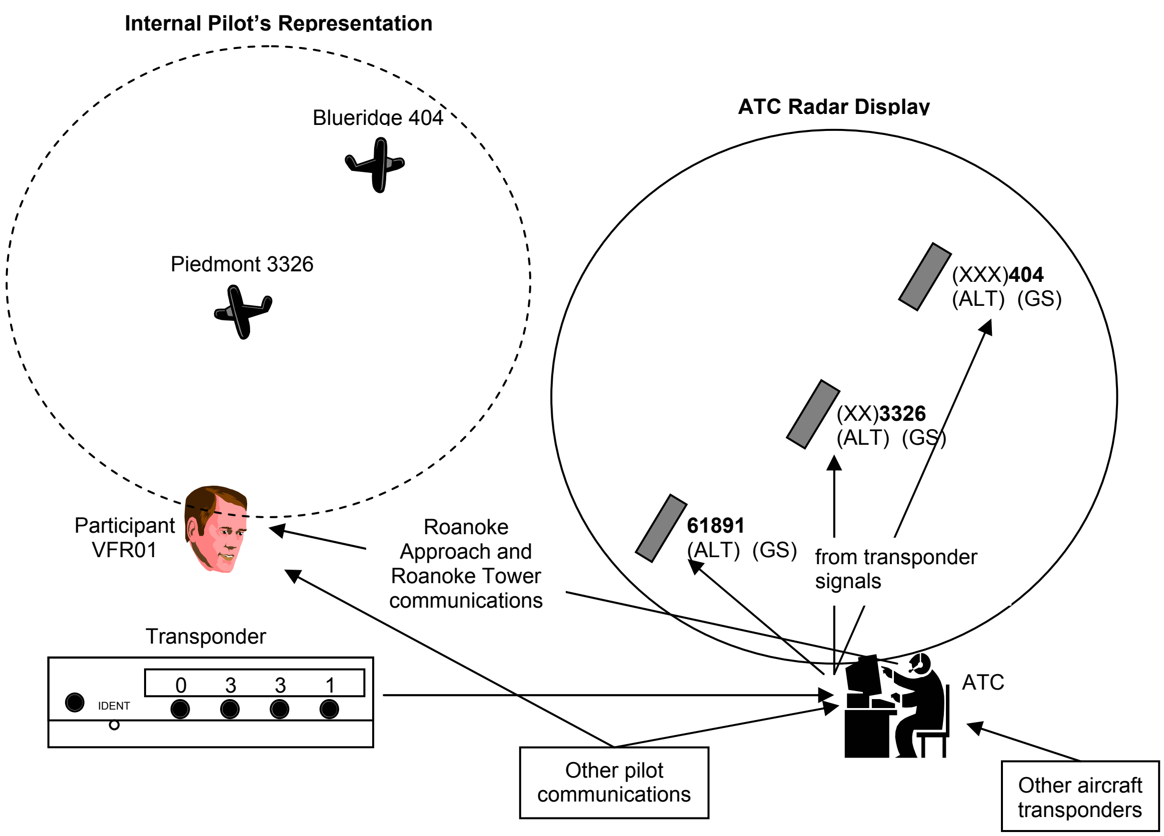

Figure 37. *Representations of traffic information.*

As the pilot receives relevant traffic positional information from the communications, this information is transformed and represented internally in the pilot's working memory. In this case, the pilot would benefit from an auditory display of this traffic information. Three-dimensional auditory displays are one of the new technologies envisioned for future aviation systems. Aural alerts of nearby traffic would allow the pilot to perceive the direction of nearby traffic, thus facilitating visual contact with traffic that may pose a potential collision hazard. Participant VFR01 had to rely on ATC for traffic avoidance of an approaching aircraft (APENDIX O: A35). An aural alert could have allowed participant VFR01 to pinpoint the relative direction of the other aircraft, potentially increasing his spatial situation awareness.

A traffic information systems (TIS) could also assist a GA pilot with traffic avoidance. Aircraft can be equipped with new Mode S transponders which are data-link capable. That is, they can receive data such as traffic information that is displayed in the cockpit with a TIS. A pilot can initiate a request for traffic information. Position, altitude, and distance information for nearby aircraft is then received through the data-link and displayed for the pilot.

These are the types of advances in aviation design, as supported by this dissertation's results, needed for future airspace systems, such as free-flight. Advances envisioned for future aviation systems, such as weather information systems, synthetic vision displays, increased automation, three-dimensional auditory displays, etc., are being developed by government, commercial, and academic organizations. Results from this dissertation underscore the importance of these new technologies.

Chapter 6. CONCLUSIONS

This dissertation employed a combination of methods to examine a small sociotechnical aviation system. Landing approaches, both visual and instrument, with a Cessna 172 to the Roanoke Regional Airport (ROA) was the unit of analysis. The field provided an opportunity to study the system in its naturalistic setting, capturing great detail and characteristics of the system that are lost in the laboratory. Simulating the system in a controlled laboratory setting, on the other hand, provided an opportunity to study the effect of hazardous conditions on the system and statistical analysis of pilot performance. The system was examined using a multidisciplinary approach (ME/DC method), combining different lines of research (macroergonomics, distributed cognition). This effort was fruitful as it allowed for the examination of the HCI of a sociotechnical system rather than the interaction of just the pilot and a single control or display, while also considering the influence of the organizational/structural components of the system. Indeed, this provided a greater understanding of the system, yielding an examination of this aviation system as the pilot performed a landing approach from a perspective of information transmissions and representations. This unique analysis carries practical design implications (p. 158) in this important aviation domain.

Figure 38 adapts the research model used for this dissertation (from Figure 1) by illustrating what was contributed by this work; the individual contributions are added to the figure. These contributions included a novel methodological approach in order to treat the cognitive aspects of a sociotechnical system as equally important as the organizational components and a systems-oriented cognitive model for both VFR and IFR pilots performing a landing approach in a GA aircraft. Also contributed by this work is a description of differences between VFR and IFR pilots during a landing approach in terms of the information flow in the pilot/cockpit system (through field study) and in terms of flight performance, workload, and situation awareness under varying environmental conditions (through laboratory experiment). Statistical comparisons between VFR and IFR pilots and within each pilot group during the landing approach was provided through controlled laboratory experimentation and procedural comparisons between the simulated and actual systems is additionally contributed by this work. Finally, the results from this dissertation carry practical implications for design.

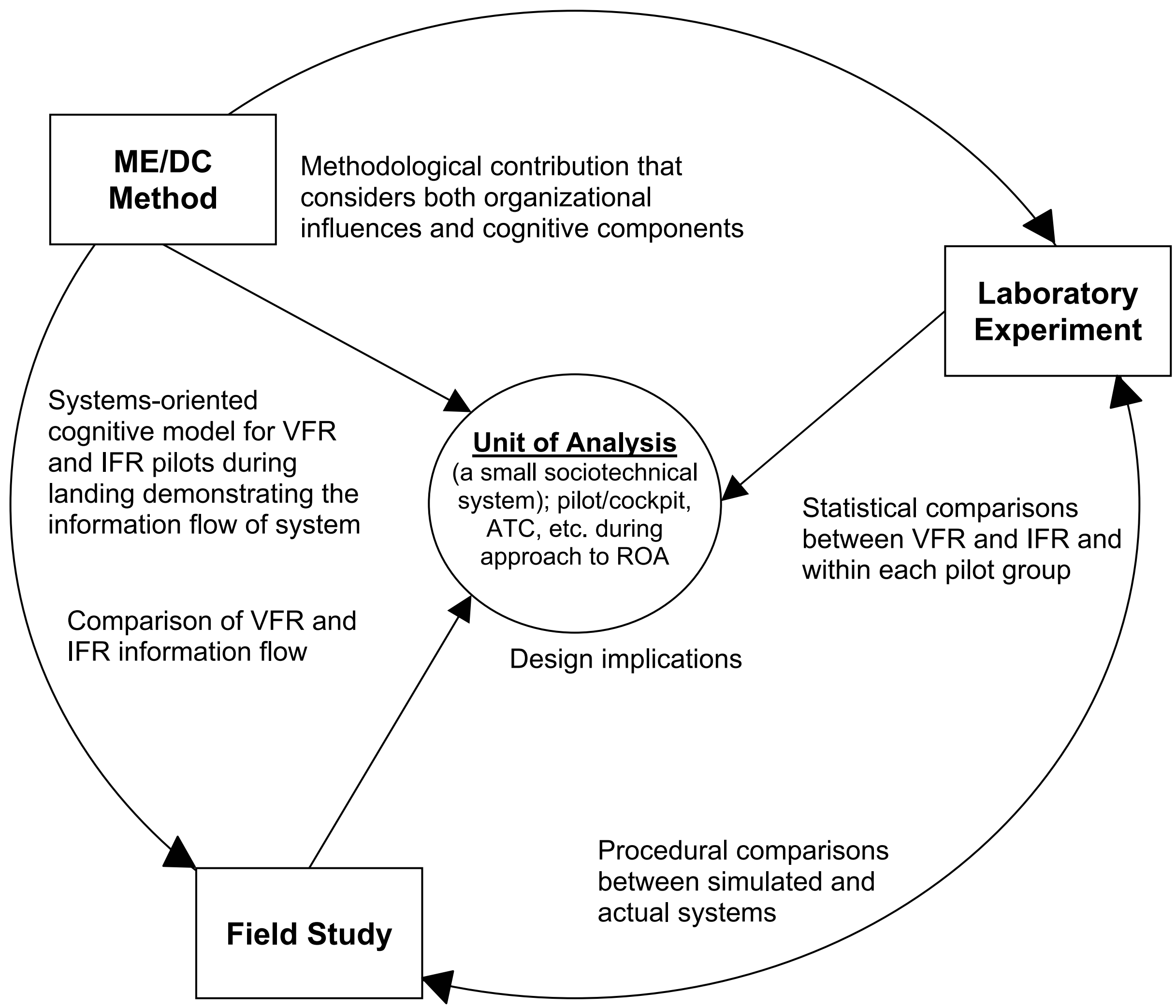

Figure 38. *Multi-method approach to understand pilot performance in a sociotechnical aviation system; contributions*.

Conclusions

Based on the results of the studies conducted for this dissertation, several conclusions can be made.

1. There are few statistically significant differences between VFR and IFR pilots, or within each of the two pilot groups, in terms of objective flight performance.

Generally, ANOVA revealed no significant differences between the VFR and IFR pilot groups, between day and night approaches, or between weather conditions as measured by the 13 objective flight performance variables during the approach to the Roanoke Regional Airport. The landing statistics for both the VFR and IFR pilot groups supports the lack of difference in flight performance as a result of any of the independent variables. Table 26 shows similar successful landing statistics between VFR and IFR pilots and between conditions.

It was hypothesized that VFR pilots would have poorer flight performance for night operations and poorer weather conditions compared to the IFR pilots as measured by the variation of the objective flight performance measures. This hypothesis was not supported by the ANOVA results. Considering the IFR group only, it was hypothesized that IFR pilots would exhibit poorer performance at night than during daytime. This hypothesis was based on previous accident statistics that suggest single pilot IFR accident rate during night time is greater than the accident rate of day IFR approaches (Bennett and Schwirzke, 1992). However, the results of this study do not support this hypothesis. IFR pilot performance during nighttime was not significantly different than during daytime based on the objective flight performance measures. One could argue that since IFR pilots rely solely on their instruments during an approach, we would not expect to see a difference between nighttime and daytime approaches. After the pilot reaches the decision altitude during an approach, he/she switches to visual, and if the runway is visible, proceeds with the landing. The accidents statistics cited by Bennett and Schwirzke (1992) must relate to this final visual portion of the landing since the authors cite the lack of daytime visual cues during night operations as the probable cause for the higher accident rate. Though there was no difference in the successful landing statistics between daytime and nighttime approaches for this laboratory simulation. In contrast to daytime versus nighttime approaches, it was hypothesized that there would be no significant difference in flight performance across weather conditions for IFR pilots. This hypothesis was supported by ANOVA for the flight performance measures.

Considering the VFR group only, it was hypothesized that VFR pilots would experience poorer flight performance during night operations and during deteriorating weather conditions. However, ANOVA did not support this hypothesis, as VFR performance as measured by the objective flight performance measures did not significantly differ during nighttime and during deteriorating weather as compared to the control (daytime, clear weather). While all pilots demonstrated their ability to control and land the aircraft during these conditions, there were several cases where workload was found to be increased and situation awareness reduced, which leads to the next conclusion.

2. Key differences in workload and situation awareness are exhibited between VFR and IFR pilots, and within the two pilot groups, when conducting an approach under varying environmental conditions (nighttime, deteriorating weather).

It was hypothesized that VFR pilots would experience greater workload when conducting approaches compared to IFR pilots, especially during nighttime and during deteriorating weather conditions. This hypothesis was based on previous literature that suggests that there is less risk during the approach and landing phase of IFR flights as compared to VFR flights (Bennett and Schwirzke, 1990; Bennett and Schwirzke, 1992). This hypothesis was not supported. IFR pilots have the advantage of being able to rely solely on the aircrafts' instruments during an approach, no matter what the external conditions may be. However, the act of flying by instruments seemed to demand greater workload than flying by visual flight rules. This was indeed the case with the control condition for the laboratory experiment. The previous literature that suggests higher risk for VFR pilots during an approach uses accident statistics to measure risk. However, the accident statistics do not seem to correlate well with workload, at least during ideal conditions. For this dissertation, VFR workload was found to be significantly *less* than IFR workload during daytime and when weather conditions were favorable. When hazardous conditions were introduced (nighttime and deteriorating weather), no significant differences were found between VFR and IFR pilots for workload. Workload was constant for IFR pilots across conditions. However, VFR workload was significantly greater during deteriorating weather than VFR workload during the control condition, but not significantly different than IFR workload during deteriorating weather conditions or during nighttime. Figure 39 illustrates these trends.

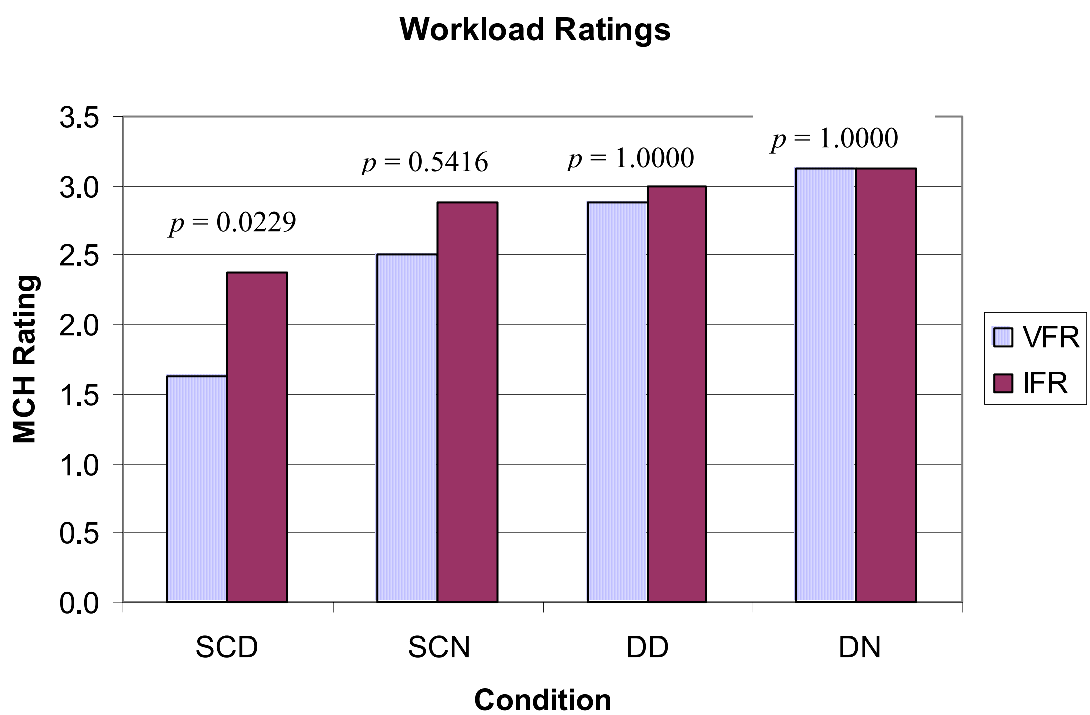

Figure 39. *Workload ratings, VFR and IFR pilots. Static, clear weather during daytime = SCD; static, clear weather during nighttime = SCN; dynamic weather during daytime = DD; dynamic weather during nighttime = DN.*

It was hypothesized that VFR pilots would experience greater workload during night operations and during deteriorating weather conditions. This hypothesis was only partially supported, while as VFR pilots did experience significantly greater workload during deteriorating weather, they did not experience significantly greater workload during nighttime, as compared to the control condition (SCD). Since workload was not found to be significantly different across conditions for IFR pilots, the hypothesis that workload would be greater during nighttime was not supported, but the hypothesis that IFR workload would not differ across weather conditions was supported. Since IFR pilots rely solely on their instruments during an approach, the piloting tasks during the approach are the same regardless of the external conditions, and thus it seems reasonable that workload should not differ significantly across conditions for IFR pilots.

Although defined differently than mental workload, since situation awareness is found to be correlated with workload (e.g., Selcon et al., 1991), the same hypotheses that were made relating to workload were inversely made relating to situation awareness. That is, an increase in workload would suggest a reduction of situation awareness. Thus it was hypothesized that VFR pilots would have reduced situation awareness compared to IFR pilots during an approach with in deteriorating weather conditions and during nighttime. This hypothesis was supported by statistical analysis of the subjective SART ratings. Figure 40 illustrates the mean, overall SART ratings by pilot type and by condition.

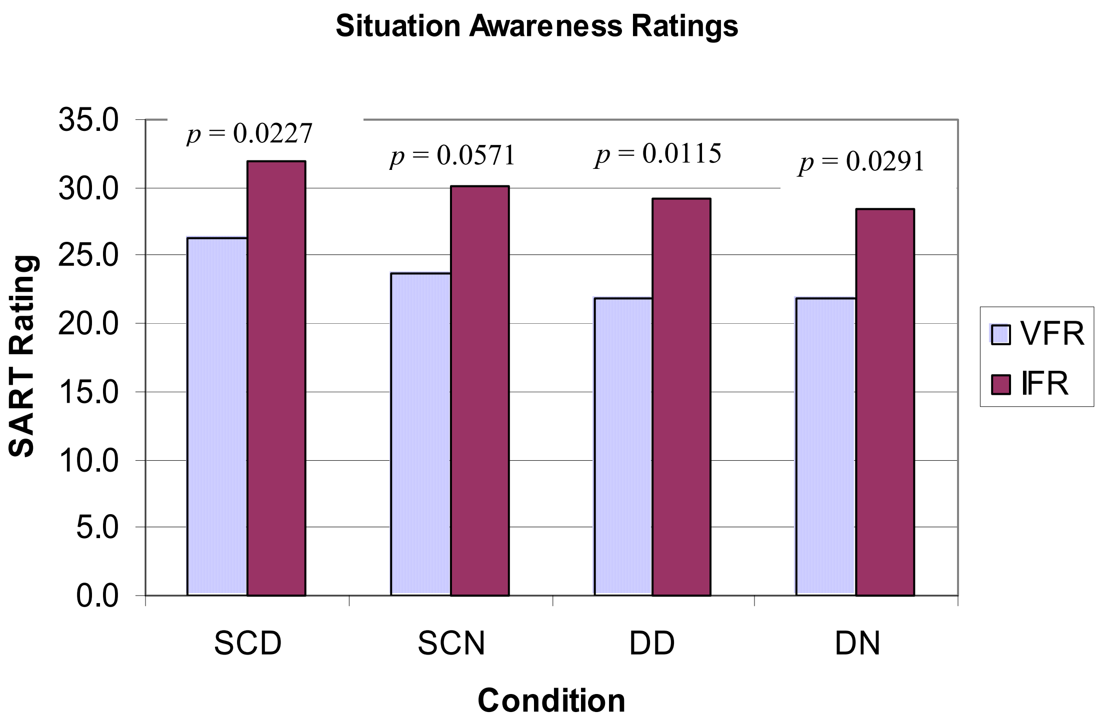

Figure 40. *Situation awareness ratings, VFR and IFR pilots. Static, clear weather during daytime = SCD; static, clear weather during nighttime = SCN; dynamic weather during daytime = DD; dynamic weather during nighttime = DN.*

Within each pilot group, there was a trend for decreasing situation awareness as external conditions became more "difficult". Within the IFR pilot group, situation awareness with dynamic weather was significantly reduced compared to situation awareness with static weather, during day time and during nighttime. Within the VFR group, situation awareness at night was significantly reduced compared to situation awareness during the day when weather was favorable. Also, situation awareness in deteriorating weather was significantly reduced compared to situation awareness with favorable weather during daytime approaches but not nighttime approaches. Situation awareness for the VFR pilot group was unchanged between DD and DN. That is, when weather conditions were poor, with visibility deteriorating to 2 miles, it made no difference if it was daytime or nighttime. With visibility this low, the VFR pilot seemed to have already lost any visual cues that are absent in nighttime flying.

Although workload is generally thought to have an inverse correlation with situation awareness (higher workload often relates to increased situation awareness), this correlation was not observed in the laboratory simulation. There was a trend for lower workload for VFR pilots compared to IFR pilots across conditions (Figure 39). However, there was also a trend for lower situation awareness for VFR pilots compared to IFR pilots across conditions (Figure 40). Logically, if VFR pilots experienced lower situation awareness compared to IFR pilots, they should have experienced *greater* workload than IFR pilots. This lack of expected correlation between workload and situation awareness results in the laboratory may possibly be attributed to the types of rating scales used for the study (MCH, SART) or perhaps low statistical power in the analysis. Future studies should use a battery of measures to give a more comprehensive assessment of workload and situation awareness, with a larger number of participants for greater statistical power.

The workload and situation awareness results from this dissertation have implications for future aviation design considerations (see Design Implications section, p. 158).

3. VFR pilots have a tendency to continue from marginal VMC into IMC during an approach.

VFR pilots tended to continue into deteriorating weather conditions and land the aircraft rather than abort and divert out of the poor visibility. As with previous research (Goh and Wiegmann, 2001), some of the pilots may not have perceived the visibility to be below the VFR minimum. However, several of the pilots were aware of the visibility deteriorating past marginal VMC to IMC by monitoring current weather conditions through Roanoke ATIS, yet chose to continue with the landing regardless. It seems that, at least for this study, participants exercise different judgment in a simulator than during an actual flight as the consequences of crashing a simulated flight do not compare to the consequences of crashing an actual flight. In reality, Roanoke ATC would not have permitted visual landings in IMC. However, ATC was not simulated in the laboratory.

4. Execution of the ME/DC method gave a unique understanding the system.

Development and execution of this novel approach for system analysis provided a unique understanding of the system than by using previous methods. The ME/DC method was multidisciplinary, combining frameworks from different lines of research. This method examined the aviation system as a small, scoiotechnical system, and treated the organizational/structural components and cognitive aspects as equally important. The examination of the aviation system in this dissertation benefited from a top-down macroergonomics perspective, while simultaneously utilizing a bottom-up distributed cognition perspective, where the unit of analysis was expanded such that the sociotechnical system itself was considered as a form of cognitive architecture for the purpose of tracking the information flow of the system. For example, external environmental conditions were considered from a top-down approach, such as the effect of the legal environment on the system. Yet using a bottom-up perspective allowed for the understanding of how the resources within the system are coordinated to produce the observed information flow.

5. The information flow within the system differs to a great extent between VFR and IFR flights.

Key differences found in the information flow between the IFR and VFR flights resulted largely from ATC communications, use of navigations aids, and traffic representations. During the approach to Roanoke, the VFR pilot flies direct to Roanoke, usually on a single heading toward the traffic pattern at the airport for runway 33. The IFR pilot is given a series of vectors over time by ATC that brings the aircraft south and east around the edge of Roanoke airspace in order to intercept the ILS localizer for runway 33. For the IFR model, there is an information exchange over time between the air traffic controller, the air traffic controller's radar screen, the pilot, and the pilot's heading indicator. An increase in the quantity of information during the IFR flight is evident, as the IFR pilot uses the ILS and Vinton NDB as external navigational aids to conduct the approach. Since the VFR pilot flies by external visual cues, he/she uses navigational aids only as a back-up (e.g., the Woodrum VOR). Information pertaining to surrounding traffic is represented differently for VFR and IFR pilots. The IFR pilot relies on ATC for separation from surrounding traffic, whereas the VFR pilot is responsible for traffic separation. The VFR pilot listens to the communications from the air traffic controller and other pilots and develops an internal representation of surrounding traffic. The pilot projects relevant parts of this traffic pattern into the future for potential effects on his/her flight path and scans for traffic that is close to his/her aircraft until visual contact is established.

6. The fidelity of the flight simulator is generally high in terms of controls and instrumentation, but does not recreate all components of the system in reality (e.g., ATC communications).

A procedural comparison between the simulator from the laboratory experiment and the actual Cessna 172 from the field was performed, with corresponding task analyses. The most conspicuous difference between the simulated system and the actual system was the simulator's inability to simulated ATC for the Roanoke airspace. Attending and responding to ATC logically adds workload when piloting the aircraft during an approach. Another major difference between the studies was the external visual view of the simulator compared to an actual Cessna 172. The simulator used for the laboratory gives only a small external forward view, with no corresponding peripheral view, whereas in an actual aircraft, the pilot has an external visual view of approximately 180 degrees. This difference is only consequential to VFR pilots as IFR pilots fly be the aircrafts instruments. Since the simulator external view was limited to a forward view, VFR pilots in the laboratory were restricted to flying straight-in approaches to Runway 33, as opposed to approaching from an angle and entering the traffic pattern before turning for Runway 33. The simulator controls and instrumentation was found to be particularly realistic for both VFR and IFR piloting aside from a few exceptions, including placement of the elevator trim wheel and fuel selector valve, and absence of a control knob for carburetor heat. Finally the simulator lacks realistic feedback/back-pressure on the yoke during touchdown, as a pilot would experience in an actual aircraft. Considering the complexity of an aircraft's control and instrumentation system, the external validity of the simulator seems to be fairly high; the differences noted are a few exceptions in a large number of controls, instruments, and procedures. The absence of ATC communications is the most significant difference in the simulated system compared to the one studied in the field.

7. The ME/DC method does not translate well from the field to the laboratory in terms of the larger system, but translates sufficiently in terms of pilot/cockpit interaction.

The simulated system's "incompleteness" as compared to the actual system, particularly the absence of ATC communications, was especially apparent when comparing application of the ME/DC method between the studies. Much of the information flow in the field involved communications between ATC and the pilot. Translation of the ME/DC method to the laboratory was limited as a result of the fidelity of the simulated system. However, the frameworks that the ME/DC method is based on, which are the macroergonomics analysis and design framework and the distributed cognition framework, were both intended for field application.

In terms of an aircraft's control and instrumentation system, the external validity of the iGATE simulator is high; the simulator's controls, instrumentation, and radio stack replicate their counterparts from the actual Cessna 172 to a very high degree. In this context, translation of the ME/DC method to the simulated system was sufficient, as the identical information flow between the pilot and cockpit is observed (e.g., see Figure 21). Further, the same information representations on the displays and instruments are produced. For example, the simulated glide slope indicator represented lateral and vertical guidance information in the exact same manner as the actual system in the field (see Figure 24). Also, see Figures 23, 26 for additional examples of identical information representations observed in both the field and the laboratory. In this manner, validity of the ME/DC method is demonstrated for pilot/cockpit interaction. This type of comparison for the larger system is not possible, since the ATC component of the system, for example, is not simulated.

8. Results from this dissertation support new designs envisioned for future aviation systems.

This research widely supports new designs and technologies envisioned for future aviation systems that would assist the pilot during a landing approach. The importance of these technologies, such as weather information systems, head-up displays, synthetic vision, three-dimensional auditory displays, increased automation, and communications filters are supported by quantitative and qualitative findings from both the laboratory and the field studies in this dissertation (see p. 158, Design Implications). Actual design change in the current GA system has advanced little since World War II relative to aviation research. Revolutionary advances to aviation design, such as those discussed in this dissertation, have been researched extensively over the last few decades. There seems to be a considerable lag between aviation research and actual design change, as implementing aviation redesign is dominated by a strong legal external environment, as revealed by a macroergonomics system scan. Specifically, an extensive and rigorous FAA certification plan is required for any aviation design/redesign.

While increased automation in the cockpit may benefit the pilot as in the example given where the error committed by pilot IFR01 may have been avoided (see p. 146 and p. 160), there are pitfalls to automation that should be considered. For example, adequate feedback must be provided to the pilot by the automated system to keep the human in the loop, avoiding a potential reduction of situation awareness. With this in mind, expected benefits of automation include a reduction of operator workload and fewer errors (e.g., Sarter, Woods, and Billings, 1997). Further, increased automation in the cockpit is necessary to support the move in GA toward single pilot operations in free flight, where the pilot performs the role of a supervisory controller, as related in the Introduction (see Table 1, p. 2).

Simulator Research vs. Field Research

The laboratory and field approaches to study this aviation system were meant to complement each other. One point of interest was how the introduction of poor weather conditions and nighttime operations in the laboratory would affect the systems-level cognitive model derived from the application of the ME/DC method during the field study. Statistical analysis in the laboratory experiment revealed that these conditions had few effects on IFR pilots and had greater effects on VFR pilots. To understand how the results from the laboratory can affect the field findings, a brief review of the laboratory findings are summarized: Situation awareness was found to be reduced for IFR pilots during deteriorating weather conditions. VFR pilot workload was greater and situation awareness was reduced in deteriorating weather conditions during daytime approaches. Situation awareness was also found to be reduced during night approaches when weather was static for VFR pilots.

Based on these laboratory results, for the VFR group, since workload was significantly higher in deteriorating weather conditions, we could expect pilots' working memory capacity to be reduced. Considering the systems-oriented cognitive model from the field, this in turn would affect the pilots' ability to store information in working memory that is generated from ATC such as frequencies, vector assignments, altitude assignments, and other commands from ATC. For both pilot groups, where situation awareness was found to be reduced, pilot attention may be affected. A reduction of situation awareness can lead to a lower degree of concentration, and a narrowing of one's attention (inability to distribute one's attention to several simultaneous tasks). Considering the systems-oriented cognitive model, this in turn could limit the amount of knowledge received and understood from the resources in the system (e.g., instruments, communications) or decrease the value of the information that is received by the pilot.

When comparing the IFR and VFR systems-oriented cognitive models from the field (as part of the ME/DC method output), an increase in the quantity of information during the IFR flight is evident, as the IFR pilot uses the ILS and Vinton NDB as external navigational aids to conduct the approach. The VFR pilot, on the other hand, flies by external visual cues. This difference between the IFR and VFR models observed in the field support why VFR workload was found to be significantly less that IFR workload in the laboratory for the control condition. Flying by instruments requires the pilot to attend to several instruments for navigation, while the VFR pilot navigates by the horizon and familiar landmarks which are easily distinguished in favorable weather conditions.

There were pilot errors observed in the field, the most notable of which was committed during one of the IFR flights and was likely related to workload, anecdotally supporting the workload findings from the laboratory (i.e., IFR workload greater than VFR workload in favorable conditions). Participant IFR01 was on final approach for Runway 33 and mistakenly requested Runway 6 instead of Runway 33 when making initial contact with the tower. This error occurred at the point during the approach when both IFR participants remarked that workload was greatest (near glide slope acquisition) during their retrospective reports (see Appendix P: D89, D93, D102-D104; and Appendix Q: F85). At this point in the approach, the pilot is performing motor tasks as he/she pilots the aircraft, visual-spatial tasks by aligning the localizer and glide slope needles, and auditory tasks when listening for air traffic control commands and then repeating the commands back for error-checking, and watching for the ADF bearing indicator to swing as the aircraft passing over the NDB station at Vinton.

The laboratory and field studies were complementary and both made valuable contributions toward understanding the same system. The laboratory experiment with the flight simulator allowed for controlled experimentation and for the introduction of hazardous conditions that would not be possible to study in the field safely, ethically, and systematically. These conditions included deteriorating weather and night-time operations. While pilots fly in these conditions in reality, it is inappropriate to expose participants of a study to such risks. A simulated environment allows the researcher to study the effect of these potentially hazardous conditions. Furthermore, the controlled, academically rigorous nature of the laboratory experiment and relatively large number of participants allowed for hypothesis testing backed by statistical analyses with high confidence. Cost was another advantage, as aircraft rental costs are not insignificant.

The field study, on the other hand, was critical for understanding this system as it exists in reality. Procedural comparison between the simulated and actual systems showed that much was lost in the simulated system (e.g., ATC communications). The

ME/DC method, which guided analysis of the system in the field, is based on frameworks designed for naturalistic study. Although the data was predominately qualitative, video and audio recordings of the pilot conducting an approach in the actual aircraft was extremely rich, as were the retrospective pilot reports. An accurate depiction of the system's coordination of resources and information flow was only possible with study of the actual system in the field, as much of the information flow was spawned from and influenced by ATC communications and surrounding traffic, neither of with was simulated in the laboratory. Although the field study included fewer participants than the laboratory experiment, relative costs and time invested in preparing for and executing the field study was substantially greater than that of the laboratory experiment. Data collected from both the field and laboratory were valuable for understanding the system as each study had certain advantages.

Based on the experiences of employing the methods of this dissertation, triangulation of the methods in future research in any domain could make use of field study first, with the ME/DC method to guide data collection, and controlled laboratory experimentation to corroborate findings in the field and to further improve the field methods. In the field, the greater organizational influences on the unit of analysis being studied can be understood, as well as the coordination of structures and resources to produce the information flow and information representation of the system. In this ME/DC method, the unit of analysis, a small sociotechnical system, is treated as a form of cognitive architecture such that the information flow can be tracked as it is coordinated across the various persons and technology in the system, while also understanding the greater organizational influences. This cannot be done in the laboratory, as much of the system, at least to a certain degree, is not represented in a simulation, and nor are the greater organizational influences that may affect the workings and thus information flow of the system. Controlled laboratory experimentation can then be used to simulate at least parts of the system, where observations in the field can be replicated and confirmed in a controlled setting. Further, simulation can test scenarios that could not be safely or ethically studied with the actual system. Laboratory experimentation can also serve as a method for testing and formatively evaluating the ME/DC method, as an independent source from the field.

Future Research

Follow-up research could replicate the methodology of the laboratory experiment, using different measures of workload and situation awareness to corroborate the results found in this study with the MCH and SART scales. In addition using subjective rating scales for these measures, objective measures of workload could be used such as physiological, primary task, and secondary task measures like those listed in Table 3 (p. 31). Exploring the effect of pilot experience on the dependent measures from the laboratory study would also be worthy of further study. Pilots who fly VFR compared to those who are rated to fly IFR does reflect a difference in pilot experience and training. However, it would be interesting to add a level for pilots who are have recently become IFR-rated compared to those who have a substantial number of IFR flight hours. Furthermore, would pilot experience influence the information flow models developed from the field study? For each pilot who participated in the laboratory experiment, pilot experience in terms of number of total flight hours (VFR and IFR) were recorded. One idea for how to further analyze flight experience in the laboratory would be to use analysis of covariance (ANCOVA) with flight hours of piloting experience as a covariate.

For further research in the field, which could study the pilot performing an approach to one of the nation's busiest airports, that is, one surrounded by Class B airspace, would add further complexity to the system studied for this dissertation. How would an increase in communications and traffic, for example, affect the systems-oriented cognitive models described for Roanoke airspace (Class C). And would the organizational characteristics of Class B airspace affect the system differently? For example, the rules that govern different classes of airspace do differ, and the resources within each system may also vary.

The method based on ME and DC developed for this research is designed for analysis of a work system through research of a domain, where observations are conducted based on a scenario in the work system within the domain. Findings from applying this method can then lead to design/redesign recommendations for the work system. These design changes could include physical changes to the structure of the system, hardware and/or software design changes, changes to the communicative pathways of the system, and changes to function, task, and/or information distribution and representation of the system. Further exploration and refinement of the ME/DC method is an obvious next step. Refinement of the ME/DC method could be iterative process of application and improvement, as part of a formative evaluation plan. For example, based on the results of applying the ME/DC method in this dissertation, an improvement to the method would involve explicitly defining the study of rare events / errors. The method was sensitive to recognize and capture these events (see Table 28, p. 119), but the importance of these events, and their potential to drive redesign recommendations, were not explicitly defined in the ME/DC method.

The idea of using the particular frameworks the method was based on in this dissertation is not as important as the idea of an analysis method that considers both the organizational components and cognitive aspects of a work system as equally influential. In other words, the main contribution of marrying these two frameworks was to recognize and address the importance of considering the organizational/work system components along with the cognitive aspects of the system. Different approaches to work system design and cognition within the system should be considered for future study.

Future research could also further assess the potential value of the ME/DC method by applying it to domains outside of aviation. The steps of the method were made to be generalizable, not restricted to the aviation environment studied for this dissertation. Rather, other sociotechnical systems could be explored in the same fashion. The aviation domain itself has centralized decision making with ATC and is highly formalized, where procedures and tasks in the work system are standardized and driven by FAA regulations. Aviation technologies are generally "routine" (see Table 6 on p. 43) where problems are well-defined and analyzable and task variability is routine with few exceptions. Since the step of the ME/DC method were meant to be generalizable, the method should also work well for a domain with decentralized decision making and low formalization (i.e., "craft" and/or "non-routine" technologies in Table 6). However, a greater number of observations (Step 5, ME/DC method) may be needed to investigate such a domain since task variability is greater with non-routine technologies.

For the aviation domain, further research in both the laboratory and the field should focus on future technologies for GA aircraft that can reduce pilot workload and increase situation awareness. These technologies, such as weather information systems, head-up displays, synthetic vision, three-dimensional auditory displays, increased automation, and communications filters, can be examined for the same system studied for this dissertation. For example, field research provided specific instances through naturalistic observation where pilots could have possibly benefited from redesigns of the current system (see p. 158-166). Future research could then empirically test these redesigns through controlled experimentation in the laboratory to investigate potential improvements in flight performance, reduced workload, and/or increased situation awareness. Laboratory results in this dissertation provide a baseline for such testing.

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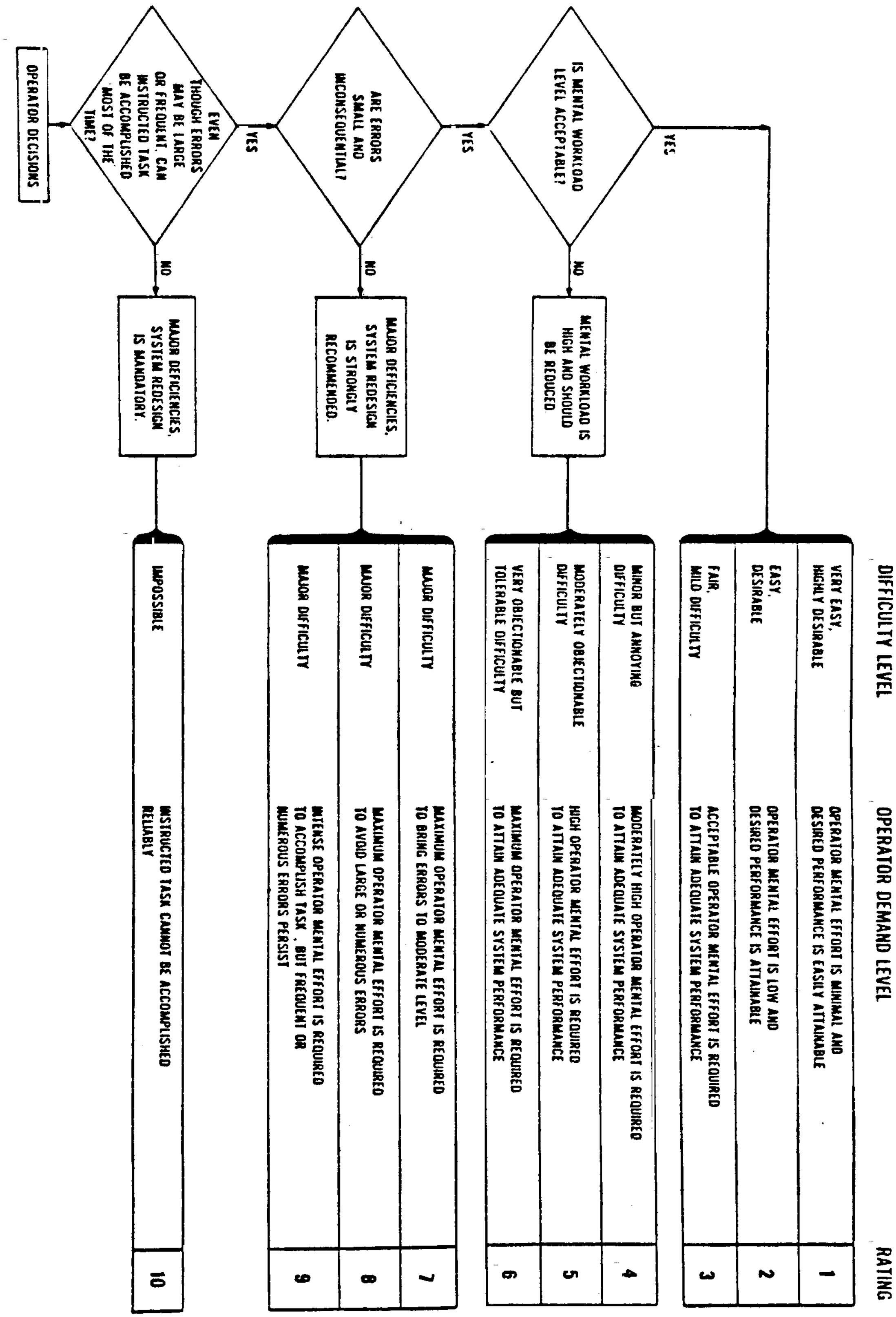
LIST OF APPENDICES

APPENDIX A: Modified Cooper-Harper Scale



APPENDIX B1: Situation Awareness Rating Technique (SART)

	LOW						HIGH
	1	**2**	**3**	**4**	**5**	**6**	**7**
DEMAND							
Instability of Situation							
Variability of Situation							
Complexity of Situation							
SUPPLY							
Arousal							
Spare Mental Capacity							
Concentration							
Division of Attention							
UNDERSTANDING							
Information Quantity							
Information Quality							
Familiarity							
SITUATION AWARENESS							

APPENDIX B2: Explanation of SART Constructs

Instability of Situation – Likeliness of situation to change suddenly

Variability of Situation – Number of variables which require one's attention

Complexity of Situation – Degree of complication (number of closely connected parts) of situation

Arousal – Degree to which one is ready for activity (sensory excitability)

Spare Mental Capacity – Amount of mental ability available to apply to new variables

Concentration – Degree to which one's thoughts are brought to bear on the situation

Division of Attention – Degree of distribution or focusing of one's perceptive abilities

Information Quantity – Amount of knowledge received and understood

Information Quality – Degree of goodness or value of knowledge communicated

Familiarity – Degree of acquaintance with situation experience

From Taylor (1990), p. 3-6

APPENDIX C: Flight Performance Variables Collected by the iGATE Simulator

Item	Value	Unit	Int	Dec	size
0	Simulation Time Stamp	sec	5	2	8
1	Aircraft Angle of Attack	deg	3	2	6
2	Aircraft Sideslip Angle	deg	3	2	6
3	Aircraft Flight Path Angle	deg	3	2	6
4	Aircraft Heading	deg	3	2	6
5	Aircraft Pitch Attitude	deg	3	2	6
6	Aircraft Roll Angle	deg	3	2	6
7	Yaw Angle Rate	deg/sec	3	2	6
8	Pitch Angle Rate	deg/sec	3	2	6
9	Roll Angle Rate	deg/sec	3	2	6
10	Aircraft Magnetic Heading	deg	3	2	6
11	Aircraft True Heading	deg	3	2	6
12	Aircraft Magnetic Track Angle	deg	3	2	6
13	Aircraft True Track Angle	deg	3	2	6
14	Aircraft Latitude (WGS-84)	Deg	2	6	9
15	Aircraft Longitude (WGS-84)	deg	3	6	10
16	Aircraft altitude above MSL	ft	5	0	5
17	Aircraft altitude AGL	ft	5	0	5
18	Aircraft Ground Speed	kts	3	1	5
19	Aircraft Indicated Airspeed	kts	3	1	5
20	Aircraft Indicated Airspeed Rate	kts/sec	3	1	5
21	Aircraft True Airspeed	kts	3	1	5
22	Aircraft Vertical Speed	ft/min	6	0	6
23	Aircraft Pressure Altitude (indicated on instrument)	ft	5	0	5
24	Aircraft Radio Altimeter Altitude (if indication)	ft	5	0	5
25	Aircraft Longitudinal acceleration along flight path	G	1	2	4
26	Normal (vertical) G-Load	G	2	2	5
27	Flight Director (FD) Status	encoded	12	0	12
28	FD Pitch Command (Degs)	deg	2	2	5
29	FD Roll Command (Degs)	deg	2	2	5
30	DME - Distance from station tuned into DME	nm	3	1	5
31	ILS Glideslope CDI from station tuned into NAV1	dots	2	2	5
32	ILS Glideslope Validity on NAV 1	encoded	1	0	1
33	ILS Localizer CDI from station tuned into NAV1	dots	2	2	5
34	ILS Localizer Validity on NAV 1	encoded	1	0	1
35	Baro Setting, In of Hg (set on instrument)	In Hg	2	2	5
36	Prevailing Wind Direction at Aircraft Altitude	deg	3	0	3
37	Prevailing Wind Magnitude at Aircraft Altitude	kts	3	1	5
38	Pilot's Longitudinal input	-99 to 99	3	0	3
39	Pilot's Lateral Input	-99 to 99	3	0	3
40	Pilot's Directional Input	-99 to 99	3	0	3
41	Pilot's Left Brake Input	0 to 99	2	1	4
42	Pilot's Right Brake Input	0 to 99	2	1	4
43	Pilot's Left Throttle Input	0 to 99	2	1	4
44	Left engine mixture input	0 to 99	2	1	4

(Continued on next page)

(Continued)

45	Left prop rpm input	0 to 99	2	1	4
46	Pilot's Right Throttle Input	0 to 99	2	1	4
47	Right engine mixture input	0 to 99	2	1	4
48	Right prop rpm input	0 to 99	2	1	4
49	Left prop rpm	rpm	4	0	4
50	Right prop rpm	rpm	4	0	4
51	Flap Deflection	deg	2	1	4
52	Flap Deflection input	deg	2	1	4
53	Elevator trim activation on the yoke	encoded	1	0	1
54	Landing gear selector	encoded	1	0	1
55	Cowl flap selector (1)	0 - 1	2	0	2
56	Cowl flap selector (2)	0 - 1	2	0	2
57	Outside visibility as reported at present location	nm	2	1	4
58	Lowest cloud layer as reported at present location	ft msl	5	0	5
59	Lowest cloud layer coverage at location	1/8	1	0	1
60	Event marker on yoke (squawk)	encoded	1	0	1
61	OBS 2 From/To indication tuned to NAV2	encoded	1	0	1
62	VOR OBS Course Selector tuned to NAV2	deg	3	1	5
63	CDI2 VOR deviation indication tuned to NAV2	deg	2	1	4
64	NDB needle bearing to station tuned to ADF	deg	3	1	5

Encoded values:

Item	Descr.	size	syntax
27	Flight Director	12	0 set by API, 1 set in ACFT
32	Glideslope Valid Nav 1	1	1 valid, 0 invalid
34	Localizer Validity Nav 1	1	1 valid, 0 invalid
53	Elevator Trim activation	1	0 neutral, -1 trim down, +1 trim up
54	Landing gear selector	1	0 down, 1 up
60	Squawk	1	0 off, 1 pressed
61	OBS2 From/To	1	0 from, to 1, off 2

APPENDIX D: Roanoke Regional Airport ILS Runway 33 Approach Plate

Removed. See <http://edj.net/cgi-bin/echoplate.pl> *for information on how to view this approach plate.*

APPENDIX E: Informed Consent for Laboratory Experiment

VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY

**Informed Consent for Participants
in Research Projects Involving Human Subjects**

Title of Project: Understanding Visual Flight Rules (VFR) and Instrument Flight Rules (IFR) Pilot Performance Using a Cognitive Work System Design Approach

Investigators: Jason J. Saleem, M.S., and Brian M. Kleiner, Ph.D.

I. Purpose of this Research

This research is the principal investigator's (Jason Saleem) dissertation research project needed to complete the Ph.D. program in the Department of Industrial and Systems Engineering. The study will examine human-machine performance for a General Aviation (GA) environment under dynamic conditions (i.e., weather ceiling and visibility) using a combination of field research and laboratory experimentation. Using this combination of methods, pilots performing a landing approach with a Cessna 172 to the Roanoke Regional Airport will be described and analyzed. This form is for the **laboratory** portion of this research. The purpose of this research is to provide a greater understanding of the GA pilot/cockpit system and to produce a model of how the pilot interacts with the aircraft controls/instruments and with air traffic control during a landing approach. This aviation environment will be studied using both visual flight rules (VFR) and instrument flight rules (IFR). Also of interest is how pilot performance, workload, and situation awareness are affected by the introduction of dynamic environmental conditions to this GA environment. These conditions will be introduced in the laboratory with a flight simulator. There will be 16 participants in this laboratory study. Eight of the participants will fly VFR with a flight simulator and the other eight will fly IFR with the simulator and be IFR certified and current. All participants are at least 18 years of age and equal opportunity for participation is given to both males and females.

II. Procedures

The laboratory experiment involves a familiarization session and an experimental session. Each session will last no more than 1 hour.

Familiarization session. For the purpose of familiarizing yourself with the iGATE PCATD flight simulator, you will practice several approaches to the Roanoke Regional Airport (runway 33). If you are IFR certified and current, all of your approaches will be instrument approaches. Otherwise you will fly VFR. The relevant approach plates will be provided. Each practice run will begin 10 n.m. from the airport and begin with a 3°

approach angle. Conditions will be daylight, unlimited ceiling and visibility, and with no wind or precipitation. There will be no programmed aircraft failures. You can repeat this same landing approach until you feel comfortable with the simulator and its controls or for up to 1 hour. If after 1 hour, you have not successfully completed at least two consecutive landings, you participation in this study will end at this point. That is, you will not be permitted to continue with the experimental session and you will be compensated up to this point at a prorated rate of $20/hr. If you have successfully completed at least two consecutive landings upon conclusion of the familiarization session, you will be given a 10 minute break before the beginning the experimental session.

Experimental session. For the experimental session, you will fly the same approach to the Roanoke Regional Airport as in the familiarization session, except with different environmental conditions. Each run will begin 10 n.m. from the airport and begin with a 3° approach angle. If you are IFR certified and current, all of your approaches will be instrument approaches. Otherwise you will fly VFR. There will be four conditions presented in random order:

1. Static and clear weather conditions in day time
2. Static and clear weather conditions in night time
3. Dynamic weather conditions starting at 5000’ ceiling, 5 mi. visibility in day time
4. Dynamic weather conditions starting at 5000’ ceiling, 5 mi. visibility in night time

For each of these four conditions, you will be asked to perform 2 consecutive runs (landing approaches). Therefore there will be a total of 8 runs in the experimental session. For each run, you should land at the airport only if you feel it is safe to do so. Otherwise you may perform a ‘go-around’ or abort the landing. Each simulation run will be frozen and reset for the next run after you land the plane or it is apparent that you intend to abort the landing. After 2 consecutive runs at each condition, you will asked to rate your perceived workload and situation awareness for that particular condition. Like the familiarization session, the experimental session is not expected to last more than 1 hour.

III. Risks

For the laboratory portion of the study, there have been no reported risks associated with use of the iGATE PCATD flight simulator by the manufacturer or in the literature. Since the flight simulator produces simulated engine noise, you will wear an active noise reduction (ANR) aviation headset for protection against any potential noise overexposure (Bose Aviation ANR Headset X).

IV. Benefits

Participants benefit directly from this research by receiving approximately 2 hours of simulator time on a state-of-the-art PCATD flight simulator. Larger societal benefits include contributions toward understanding differences between VFR and IFR pilots in terms of the information flow of the pilot/cockpit system and in terms of flight performance, workload, and situation awareness. No promise or guarantee of benefits has been made to encourage you to participate. If you would like to receive a summary of this research when it is completed, please contact the principal investigator, Jason Saleem (see last page for contact information).

V. Extent of Anonymity and Confidentiality

The data from this study will be kept strictly confidential. At no time will the researchers release the results of the study to anyone other than individuals working on the project without your written consent. The information you provide will have your name removed and only a subject number will identify you during any written reports of the research. All subject numbers will be secure and stored on the principal investigator's (Jason Saleem) own personal computer. Only Jason Saleem will have access to this computer as it will be password protected.

Data collection techniques for this study necessitate the use of video and audio recordings. Upon completion of the session each day, all video and audio records will be transferred to and stored on the principal investigator's own personal computer, which will be password protected. Only the principal investigator will have access to these video and audio records and he will be the only one transcribing and coding/scoring them. The video and audio records may also be viewed/heard by Jason Saleem's major advisor and co-investigator, Dr. Brian Kleiner, and the rest of Jason Saleem's Ph.D. advisory committee. Since the video and audio records are expected to be a rich source of data, they will be kept indefinitely for potential future evaluation and study after this dissertation is completed. However, the video and audio records will only be kept indefinitely if you sign to give your permission to use the data in the future (see section XI, "Participant's Permission"). If you do not sign to give your permission, then the video and audio records will be permanently deleted upon successful completion of Jason Saleem's dissertation.

All other data (other than video and audio recordings) such as rating scale data and flight performance variables will also be stored and secured in the same fashion on the principal investigator's own personal computer (password protected). Again, only the principal investigator will have access to this data.

VI. Compensation

You will be paid $20/hr for participation in this study ($5 for each 15 minutes). Payment will be made immediately at the conclusion of the experiment.

VII. Freedom to Withdraw

You are free to withdraw from this study at any time for any reason with no penalty. However, if you decide to withdraw during the field portion of the study during the actual flight, you must still, of course, return and land the aircraft at the Virginia Tech Airport. You will be compensated for your participation up to the point of withdrawal at a pro-rated payment of $20/hr ($5 for each 15 minutes).

VIII. Approval of Research

This research has been approved, as required, by the Institutional Review Board (IRB) for projects involving human subjects at the Virginia Polytechnic Institute and State University and by the Department of Industrial and Systems Engineering.

________9-9-02________________	_________9-9-03_________________
IRB Approval Date	Approval Expiration Date

IX. Participant's Responsibilities

I voluntarily agree to participate in this study. I have the following responsibilities:

1) I should not participate in this study if I do not have a valid pilot's license.

2) I should notify the experimenter if at any time I do not want to continue my participation.

3) I should answer all questions truthfully.

X. Participant's Permission

I have read and understand the informed consent and conditions of this project. I have had all my questions answered. I hereby acknowledge the above and give my voluntary consent for participation in this project.

________________________ ______________________________________

Print name Subject's signature Date

I hereby grant permission for the video and audio records of my participation in this study to be kept indefinitely by the principal investigator, Jason Saleem, and his Ph.D. advisory committee for potential future evaluation and study after this dissertation is completed.

____

Subject's signature Date

Should I have any pertinent questions about this research or its conduct and research subjects' rights, I may contact:

Jason J. Saleem (Investigator) - 540-552-7149 / jsaleem@vt.edu

Dr. Brian M. Kleiner (Faculty Advisor, Investigator) - 540-231-4926 / bkleiner@vt.edu

Dr. Robert J. Beaton (Departmental Reviewer) - 540-231-8748 / bobb@vt.edu

<u>David M. Moore</u> 540-231-4991 / moored@vt.edu
Chair, IRB
Office of Research Compliance
Research & Graduate Studies

This Informed Consent is valid from ___9-9-02__ to __9-9-03___.

APPENDIX F: Informed Consent for Field Study

VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY

Informed Consent for Participants
in Research Projects Involving Human Subjects

Title of Project: Understanding Visual Flight Rules (VFR) and Instrument Flight Rules (IFR) Pilot Performance Using a Cognitive Work System Design Approach

Investigators: Jason J. Saleem, M.S., and Brian M. Kleiner, Ph.D.

I. Purpose of this Research

This research is the principal investigator's (Jason Saleem) dissertation research project needed to complete the Ph.D. program in the Department of Industrial and Systems Engineering. The study will examine human-machine performance for a General Aviation (GA) environment under dynamic conditions (i.e., weather ceiling and visibility) using a combination of field research and laboratory experimentation. Using this combination of methods, pilots performing a landing approach with a Cessna 172 to the Roanoke Regional Airport will be described and analyzed. This form is for the **field** portion of this research. The purpose of this research is to provide a greater understanding of the GA pilot/cockpit system and to produce a model of how the pilot interacts with the aircraft controls/instruments and with air traffic control during a landing approach. This aviation environment will be studied using both visual flight rules (VFR) and instrument flight rules (IFR). Also of interest is how pilot performance, workload, and situation awareness are affected during a landing approach. There will be 2-4 participants in this field study and all participants will have a commercial pilot certificate. All participants are at least 18 years of age and equal opportunity for participation is given to both males and females.

II. Procedures

Before participation in this study, in addition to reading and signing this informed consent, you will be asked to complete a health screening and demographics form. On the day of participation, you, the participant, and I, the researcher (Jason Saleem), will report to the Virginia Tech Airport (BCB) for the field portion of the study, which involves the use of a Cessna 172 general aviation aircraft. A safety pilot, Howard Swingle, will join us at the airport and participate in the flight. Howard Swingle is a licensed private pilot and is certified for IFR piloting.

All data collection in the aircraft will be observational, passive, and non-intrusive. All equipment used during data collection in the aircraft will be battery powered. This includes one miniature video camera, DAT recorder, Global Positioning System (GPS) unit, and laptop PC.

You, the participant, will take off from the Virginia Tech Airport (BCB) toward the Roanoke Regional Airport (ROA) with a Cessna 172. The safety pilot, Howard Swingle, will be sitting in the co-pilot's seat. The researcher, Jason Saleem, will be sitting in one of the back seats of the aircraft. You will fly either IFR or VFR depending on which you were recruited to fly. If you are flying IFR, you will perform an instrument approach procedure (3° glide slope angle) to Roanoke Regional Airport (runway 33). VFR pilots will perform a visual landing approach to ROA runway 33. Of course, the air traffic controller will give permission for landing and if runway 33 is not being used, you, the participant, will follow the controller's directions (e.g., use runway 06 with LDA GS). The flight from the Virginia Tech Airport to the Roanoke Regional Airport is approximately 20 minutes. The landing at the Roanoke Regional Airport will be "**touch-and-go**" (touch down on the runway and then immediately taking off again to return to the Virginia Tech Airport). Upon returning to the Virginia Tech Airport, there will be a debriefing session.

Debriefing will include retrospective verbal reports, an informal exit interview, and the same workload and situation awareness rating scales that were used in the laboratory portion of the study. The retrospective verbal reports involve showing you a play-back of the video and audio that was recorded during the landing approach. You will be asked to describe aloud what you were doing as you see/hear the video and audio playback (e.g., manipulation of particular aircraft controls to achieve a certain task during the landing approach). The informal exit interview will be open-ended as the questions will be geared toward filling in missing information (e.g., helping the researcher understand some of the activities and pilot/ATC communication that took place during the landing scenario). The entire field portion of the study (including the debriefing session) is expected to last approximately 2 hours.

III. Risks

Flying involves inherent risks that are greater than those encountered in everyday life. These risks include, but are not limited to, mechanical failure of the aircraft such as engine failure or structural failure, in-flight collision with other aircraft or birds, and health emergency (asthma, heart attack, stroke) involving the pilot during a flight. In this study, you will not be exposed to risks other than the inherent risks that you are exposed to in your normal piloting outside of this study (i.e., those risks already mentioned above). Furthermore, all piloting during the field portion of the study, including IFR piloting, will only be conducted during above marginal Visual Meteorological Conditions ("good" weather conditions).

Participants who have had previous eye injuries and/or surgeries are at an increased risk of further eye injury by participating in this study where the possibility of collision is one of the inherent risks of piloting an aircraft.

All data collection in the aircraft will be observational, passive, and non-intrusive. The field portion of the study does not include any extraordinary elements. That is, the only "controlled" part of the field portion of this study is that you are asked to make a touch-and-go landing at the Roanoke Regional Airport and then immediately return to the Virginia Tech Airport. However, once we report to the Virginia Tech Airport to begin the field portion of this study, you (and the air traffic controllers) will have complete control of all proceedings, just as you would for any flight. All procedures will be normal aircraft procedures and all equipment used for data collection will be unobtrusive to you and unobtrusive to aircraft operations.

IV. Benefits

Societal benefits include contributions toward understanding differences between VFR and IFR piloting in terms of the information flow of the pilot/cockpit system and in terms of flight performance, workload, and situation awareness. No promise or guarantee of benefits has been made to encourage you to participate. If you would like to receive a summary of this research when it is completed, please contact the principal investigator, Jason Saleem (see last page for contact information).

V. Extent of Anonymity and Confidentiality

The data from this study will be kept strictly confidential. At no time will the researchers release the results of the study to anyone other than individuals working on the project without your written consent. The information you provide will have your name removed and only a subject number will identify you during any written reports of the research. All subject numbers will be secure and stored on the principal investigator's (Jason Saleem) own personal computer. Only Jason Saleem will have access to this computer as it will be password protected.

Data collection techniques for this study necessitate the use of video and audio recordings. Upon completion of the session each day, all video and audio records will be transferred to and stored on the principal investigator's own personal computer, which will be password protected. Only the principal investigator will have access to these video and audio records and he will be the only one transcribing and coding/scoring them. The video and audio records may also be viewed/heard by Jason Saleem's major advisor and co-investigator, Dr. Brian Kleiner, and the rest of Jason Saleem's Ph.D. advisory committee. Since the video and audio records are expected to be a rich source of data, they will be kept indefinitely for potential future evaluation and study after this dissertation is completed. However, the video and audio records will only be kept indefinitely if you sign to give your permission to use the data in the future (see section XI, "Participant's Permission"). If you do not sign to give your permission, then the video and audio records will be permanently deleted upon successful completion of Jason Saleem's dissertation.

All other data (other than video and audio recordings) such as rating scale data and flight performance variables will also be stored and secured in the same fashion on the principal investigator's own personal computer (password protected). Again, only the principal investigator will have access to this data.

VI. Compensation

You will be paid $24/hr for participation in this study ($6 for each 15 minutes). Payment will be made immediately at the conclusion of the study (i.e., the end of the debriefing session). In addition to the $24/hr compensation, you will not have to pay for any flight time (i.e., there will be no rental costs to you). The cost of renting the Cessna 172 at the Virginia Tech Airport is $62.00/hr and will be covered by the principal investigator.

VII. Freedom to Withdraw

You are free to withdraw from this study at any time for any reason with no penalty. However, if you decide to withdraw during the actual flight, you must still, of course, return and land the aircraft at the Virginia Tech Airport. You will be compensated for your participation up to the point of withdrawal at a pro-rated payment of $24/hr ($6 for each 15 minutes).

VIII. Medical Treatment and Insurance

The co-investigators of this study and the Department of Industrial and Systems Engineering will not provide accident or death insurance, or cover any medical expenses for participants should injury occur. Rather, these items are covered by the University's insurance policy for the Cessna 172. To fly the Cessna 172, Virginia Tech's insurance policy requires that you must have previously flown the Cessna 172 at least once within the last 60 days. The insurance policy covers accidental damage to the plane and/or to other property as a result of piloting the aircraft. The policy also covers medical expenses resulting from injury to the pilot or others. A copy of the aircraft insurance policy is available upon request. If you have questions about the aircraft insurance policy, you can ask the principal investigator, Jason Saleem, and you can also contact the Virginia Tech Airport (540-231-4444).

IX. Approval of Research

This research has been approved, as required, by the Institutional Review Board (IRB) for projects involving human subjects at the Virginia Polytechnic Institute and State University and by the Department of Industrial and Systems Engineering.

________9-9-02________________	_________9-9-03_________________
IRB Approval Date	Approval Expiration Date

X. Participant's Responsibilities

I voluntarily agree to participate in this study. I have the following responsibilities:

1) I should not participate in this study if I do not have a valid pilot's license and commercial certificate or if I am not in good health. A valid pilot's license includes a current medical certificate from an FAA authorized aviation medical examiner.

2) I should notify the experimenter if at any time I do not want to continue my participation.

3) I should operate the aircraft in a safe and responsible manner.

4) I should answer all questions truthfully.

XI. Participant's Permission

Check one of the following:

____ I have **not** had an eye injury/eye surgery (including, but not limited to, LASIK, Radial Keratotomy, and cataract surgery).

____ I **have** had eye injury/eye surgery and I have been informed of the possible risks to participants who have had eye surgery. I choose to accept this possible risk to participate in this study.

I have read and understand the informed consent and conditions of this project. I have had all my questions answered. I hereby acknowledge the above and give my voluntary consent for participation in this project.

_________________________ ______________________________________

Print name Subject's signature Date

I hereby grant permission for the video and audio records of my participation in this study to be kept indefinitely by the principal investigator, Jason Saleem, and his Ph.D. advisory committee for potential future evaluation and study after this dissertation is completed.

____

Subject's signature Date

Should I have any pertinent questions about this research or its conduct, and research subjects' rights, and whom to contact in the event of research-related injury, I may contact:

Jason J. Saleem (Investigator) - 540-552-7149 / jsaleem@vt.edu

Dr. Brian M. Kleiner (Faculty Advisor, Investigator) - 540-231-4926 / bkleiner@vt.edu

Dr. Robert J. Beaton (Departmental Reviewer) - 540-231-8748 / bobb@vt.edu

David M. Moore 540-231-4991 / moored@vt.edu
Chair, IRB
Office of Research Compliance
Research & Graduate Studies

This Informed Consent is valid from __9-9-02___ to __9-9-03___.

APPENDIX G: Health Screening and Demographics Form for Field Study

Health Screening and Demographics Form for Field Study

1. Do you have a valid pilot's license and a commercial certificate? A valid pilot's license includes a current medical certificate from an FAA authorized aviation medical examiner.

   Yes _____ No _____

2. Have you flown Virginia Tech's Cessna 172 within the last 60 days?

   Yes _____ No _____

3. List all piloting ratings you have (e.g., instrument, commercial, flight instructor?):

4. What are your total flight hours?

   Total hours:
   Instrument (if applicable):

5. How old are you? ______

6. Do you have a history of any of the following? If yes, please explain.

   Stroke No____ Yes________________________________
   Brain tumor No____ Yes________________________________
   Head injury No____ Yes________________________________
   Epileptic seizures No____ Yes________________________________
   Motion sickness No____ Yes________________________________
   Inner ear problems No____ Yes________________________________
   Dizziness, vertigo, or other balance problems
   No____ Yes________________________________
   Diabetes No____ Yes________________________________
   Migraine, tension headaches
   No____ Yes________________________________
   Respiratory disorders (asthma, chronic obstructive pulmonary disease, pulmonary fibrosis, any oxygen requirement, reactive airway disease, pneumothorax, pleural effusion)
   No____ Yes________________________________

7. (Females only, of course) Are you currently pregnant?

Yes _____ No _____

If "yes" then read this statement: *It is not recommended that pregnant women participate in this study. However, female subjects who are pregnant and wish to participate must first consult with their personal physician for advice and guidance regarding participation in a study where risks include those inherent in piloting an aircraft. These risks include, but are not limited to, mechanical failure of the aircraft such as engine failure or structural failure, in-flight collision with other aircraft or birds, and health emergency (asthma, heart attack, stroke) involving the pilot during a flight.*

8. Are you currently taking any medications (prescription or Over the Counter) on a regular basis? If yes, please list them.

Yes _____ ____

No _____

9. Do you have normal or corrected to normal hearing and vision as required in your last FAA medical exam?

<u>Vision requirement</u>: 20/40 or better in each eye separately, with or without correction.

<u>Hearing requirement</u>: Demonstrate hearing of an average conversational voice in a quiet room, using both ears at 6 feet, with the back turned to the examiner or pass an audiometric test.

Yes _____
No _____
If no, please explain: ____

Please list your name, phone number and email address where you can be reached and hours/days when it's best to reach you.

Name ____
Male/Female

Phone Numbers ____

Best Time to Call ____

Email ____

We ask that all subjects refrain from drinking alcohol and taking any substances that will impair their ability to pilot an aircraft prior to participating in our study.

Criteria for Participation:

1. ***Must hold a valid pilot's license and a commercial certificate.***
2. ***Must be at least 18 years of age.***
3. ***Must have flown Virginia Tech's Cessna 172 within the last 60 days.***
4. ***Must have normal (or corrected to normal) hearing and vision.***
5. ***Must be able to fly a Cessna 172 without special equipment.***
6. ***Must not have previously caused an injurious aviation accident.***
7. ***Cannot have lingering effects of brain damage from stroke, tumor, head injury, recent concussion, or infection. Cannot have had, at any time, epileptic seizures, respiratory disorders, motion sickness, inner ear problems, dizziness, vertigo, balance problems, diabetes for which insulin is required, chronic migraine or tension headaches.***
8. ***Cannot currently be taking any substances that may interfere with piloting ability (cause drowsiness or impair motor abilities).***

Over the Counter Medications Check-List

Please do not take the following Over the Counter (OTC) medications on the day of your participation in the simulator and flight portions of the study:

- *Any* allergy remedies (such as, but not limited to, Benadryl)
- *Any* cough/cold remedies (such as, but not limited to, Sudafed)
- *Any* motion sickness remedies (such as, but not limited to, Dramamine)
- Any supplements or remedies bought at a "health food" store as these are not tested by the Food and Drug Administration (FDA).

APPENDIX H: Field Study Instructions

<u>Task</u>

You have been asked to perform either a visual or ILS approach to Roanoke runway 33. The landing will be touch-and-go with immediate return to Blacksburg. This is basically the only instructions for this study. Conduct the flight and approach as you normally would. Regardless of the approach, we will only fly when the weather is above marginal VMC and when runway 33 is the active runway.

<u>Some general guidelines</u>:

Any communications with the safety pilot should be related to piloting the aircraft and not "personal chatter" since audio communications are being recorded by the researcher.

If you are flying the ILS 33, attach hood that clips onto baseball cap shortly after takeoff from Blacksburg (e.g., 1000' AGL). The safety pilot, Howard Swingle, will take the controls as you attach the hood.

State your intentions to Roanoke ATC

If you are flying the instrument approach, request VFR practice ILS 33 with touch-and-go and return to Blacksburg.

If you are flying the visual approach, request touch-and-go at Roanoke and return to Blacksburg.

Follow ATC instructions, of course, even if request is denied.

When you are asked by Roanoke ATC to contact Roanoke tower, ask tower for touch-and-go with return to Blacksburg.

If you are flying the instrument approach (ILS 33), remove hood at missed approach point (500' AGL).

APPENDIX I: Means, Flight Performance Variables, Laboratory Experiment

Subject	Condition	Run	Order	TimeStamp	FlightPathAngle	Heading
1	IFR-Day-Static	a	1	414.40	-2.37	327.28
1	IFR-Day-Static	b	1	399.08	-2.32	327.30
1	IFR-Night-Static	a	2	399.53	-2.33	327.30
1	IFR-Night-Static	b	2	406.55	-2.27	327.26
1	IFR-Day-Dynamic	a	4	409.40	-2.27	327.21
1	IFR-Day-Dynamic	b	4	396.40	-2.24	327.25
1	IFR-Night-Dynamic	a	3	412.92	-2.25	327.27
1	IFR-Night-Dynamic	b	3	399.71	-2.23	327.24
2	IFR-Day-Static	a	3	460.55	-2.27	327.25
2	IFR-Day-Static	b	3	460.36	-2.24	327.34
2	IFR-Night-Static	a	1	464.35	-2.24	327.57
2	IFR-Night-Static	b	1	457.95	-2.27	327.63
2	IFR-Day-Dynamic	a	2	458.52	-2.28	327.20
2	IFR-Day-Dynamic	b	2	461.19	-2.29	327.34
2	IFR-Night-Dynamic	a	4	452.78	-2.26	327.27
2	IFR-Night-Dynamic	b	4	463.48	-2.26	327.06
3	IFR-Day-Static	a	4	432.73	-2.29	327.27
3	IFR-Day-Static	b	4	435.63	-2.25	327.53
3	IFR-Night-Static	a	3	452.08	-2.22	327.16
3	IFR-Night-Static	b	3	436.75	-2.27	327.48
3	IFR-Day-Dynamic	a	1	423.31	-2.32	327.52
3	IFR-Day-Dynamic	b	1	421.71	-2.30	328.08
3	IFR-Night-Dynamic	a	2	445.75	-2.22	327.24
3	IFR-Night-Dynamic	b	2	444.42	-2.25	327.26
4	IFR-Day-Static	a	2	360.58	-2.23	327.36
4	IFR-Day-Static	b	2	358.31	-2.27	327.38
4	IFR-Night-Static	a	4	363.83	-2.27	327.40
4	IFR-Night-Static	b	4	357.63	-2.31	327.39
4	IFR-Day-Dynamic	a	3	350.42	-2.33	327.76
4	IFR-Day-Dynamic	b	3	371.85	-2.30	327.40

4	IFR-Night-Dynamic	a	1	451.70	-2.24	327.36
4	IFR-Night-Dynamic	b	1	358.58	-2.24	327.39
5	IFR-Day-Static	a	4	445.77	-2.39	327.36
5	IFR-Day-Static	b	4	452.75	-2.32	327.32
5	IFR-Night-Static	a	3	443.97	-2.32	327.34
5	IFR-Night-Static	b	3	449.88	-2.35	327.35
5	IFR-Day-Dynamic	a	1	433.83	-2.32	327.31
5	IFR-Day-Dynamic	b	1	444.03	-2.34	327.39
5	IFR-Night-Dynamic	a	2	448.87	-2.32	327.99
5	IFR-Night-Dynamic	b	2	448.61	-2.29	327.44
6	IFR-Day-Static	a	2	375.91	-2.24	327.28
6	IFR-Day-Static	b	2	373.85	-2.25	327.29
6	IFR-Night-Static	a	4	381.17	-2.21	327.34
6	IFR-Night-Static	b	4	397.18	-2.24	327.24
6	IFR-Day-Dynamic	a	3	405.05	-2.19	327.21
6	IFR-Day-Dynamic	b	3	394.61	-2.21	327.26
6	IFR-Night-Dynamic	a	1	390.08	-2.24	327.32
6	IFR-Night-Dynamic	b	1	378.65	-2.21	327.24
7	IFR-Day-Static	a	4	389.72	-2.21	326.98
7	IFR-Day-Static	b	4	394.47	-2.26	327.12
7	IFR-Night-Static	a	3	397.42	-2.23	327.50
7	IFR-Night-Static	b	3	406.95	-2.13	327.52
7	IFR-Day-Dynamic	a	1	394.74	-2.26	327.37
7	IFR-Day-Dynamic	b	1	398.28	-2.23	327.09
7	IFR-Night-Dynamic	a	2	400.29	-2.20	326.93
7	IFR-Night-Dynamic	b	2	397.58	-2.24	327.12
8	IFR-Day-Static	a	3	359.03	-2.32	327.28
8	IFR-Day-Static	b	3	360.48	-2.18	327.26
8	IFR-Night-Static	a	1	366.71	-2.18	327.30
8	IFR-Night-Static	b	1	379.74	-2.24	327.34
8	IFR-Day-Dynamic	a	2	371.11	-2.23	327.30
8	IFR-Day-Dynamic	b	2	393.17	-2.36	327.32
8	IFR-Night-Dynamic	a	4	360.09	-2.30	327.30

8	IFR-Night-Dynamic	b	4	364.02	-2.22	327.28
9	VFR-Day-Static	a	3	432.73	-2.40	327.40
9	VFR-Day-Static	b	3	407.58	-2.35	327.31
9	VFR-Night-Static	a	1	404.98	-2.31	327.57
9	VFR-Night-Static	b	1	389.30	-2.27	327.49
9	VFR-Day-Dynamic	a	2	440.25	-2.32	327.11
9	VFR-Day-Dynamic	b	2	459.07	-2.22	328.04
9	VFR-Night-Dynamic	a	4	450.90	-2.28	327.60
9	VFR-Night-Dynamic	b	4	460.50	-2.25	327.29
10	VFR-Day-Static	a	4	418.90	-2.34	327.40
10	VFR-Day-Static	b	4	435.79	-2.34	326.98
10	VFR-Night-Static	a	3	392.48	-2.27	327.38
10	VFR-Night-Static	b	3	431.78	-2.38	327.27
10	VFR-Day-Dynamic	a	1	375.46	-2.16	327.51
10	VFR-Day-Dynamic	b	1	387.96	-2.26	327.97
10	VFR-Night-Dynamic	a	2	388.25	-2.14	327.41
10	VFR-Night-Dynamic	b	2	391.05	-2.22	327.37
11	VFR-Day-Static	a	2	421.11	-2.31	327.30
11	VFR-Day-Static	b	2	383.19	-2.30	327.58
11	VFR-Night-Static	a	4	450.84	-2.40	327.45
11	VFR-Night-Static	b	4	428.01	-2.34	327.38
11	VFR-Day-Dynamic	a	3	419.02	-2.35	327.01
11	VFR-Day-Dynamic	b	3	414.39	-2.26	326.26
11	VFR-Night-Dynamic	a	1	450.55	-2.37	328.04
11	VFR-Night-Dynamic	b	1	448.20	-2.33	327.70
12	VFR-Day-Static	a	1	474.17	-2.28	327.06
12	VFR-Day-Static	b	1	499.23	-2.26	327.96
12	VFR-Night-Static	a	2	483.35	-2.26	327.95
12	VFR-Night-Static	b	2	462.41	-2.26	327.38
12	VFR-Day-Dynamic	a	4	460.39	-2.27	327.69
12	VFR-Day-Dynamic	b	4	481.47	-2.25	327.75
12	VFR-Night-Dynamic	a	3	485.11	-2.27	327.63
12	VFR-Night-Dynamic	b	3	471.95	-2.24	327.91

13	VFR-Day-Static	a	2	382.83	-2.50	327.30
13	VFR-Day-Static	b	2	370.73	-2.31	327.16
13	VFR-Night-Static	a	4	446.16	-2.36	327.53
13	VFR-Night-Static	b	4	432.76	-2.41	327.45
13	VFR-Day-Dynamic	a	3	414.81	-2.25	327.05
13	VFR-Day-Dynamic	b	3	414.78	-2.38	327.04
13	VFR-Night-Dynamic	a	1	416.54	-2.38	326.98
13	VFR-Night-Dynamic	b	1	421.62	-2.33	327.17
14	VFR-Day-Static	a	1	448.40	-2.30	327.08
14	VFR-Day-Static	b	1	450.44	-2.35	327.70
14	VFR-Night-Static	a	2	468.13	-2.29	318.83
14	VFR-Night-Static	b	2	467.64	-2.12	319.96
14	VFR-Day-Dynamic	a	4	457.61	-2.30	327.20
14	VFR-Day-Dynamic	b	4	499.15	-2.25	327.01
14	VFR-Night-Dynamic	a	3	461.69	-2.30	327.89
14	VFR-Night-Dynamic	b	3	461.42	-2.27	327.00
15	VFR-Day-Static	a	3	422.51	-2.33	327.36
15	VFR-Day-Static	b	3	411.11	-2.31	327.54
15	VFR-Night-Static	a	1	429.01	-2.34	325.52
15	VFR-Night-Static	b	1	404.95	-2.29	327.35
15	VFR-Day-Dynamic	a	2	439.92	-2.27	327.38
15	VFR-Day-Dynamic	b	2	401.96	-2.24	327.24
15	VFR-Night-Dynamic	a	4	409.14	-2.29	327.71
15	VFR-Night-Dynamic	b	4	416.63	-2.27	327.19
16	VFR-Day-Static	a	4	468.94	-2.26	327.83
16	VFR-Day-Static	b	4	451.02	-2.25	327.84
16	VFR-Night-Static	a	3	452.50	-2.32	327.46
16	VFR-Night-Static	b	3	452.25	-2.25	327.62
16	VFR-Day-Dynamic	a	1	406.31	-2.37	328.56
16	VFR-Day-Dynamic	b	1	434.94	-2.26	327.27
16	VFR-Night-Dynamic	a	2	453.48	-2.30	327.67
16	VFR-Night-Dynamic	b	2	442.46	-2.28	328.10

Continued, variables 4-8

Subject	PitchAttitude	RollAngle	AltitudeAGL	GroundSpeed	IndicatedAirspeed
1	-2.41	0.25	1642.21	93.53	88.71
1	-2.70	0.24	1685.17	97.57	92.32
1	-2.64	0.26	1593.84	97.35	92.18
1	-2.83	0.30	1672.54	96.36	91.38
1	-2.49	0.28	1634.54	94.92	90.08
1	-2.61	0.25	1685.58	98.32	93.07
1	-2.37	0.27	1635.67	94.93	90.00
1	-2.51	0.26	1661.64	97.74	92.56
2	-0.86	0.43	1628.03	85.11	81.13
2	-1.35	0.37	1634.14	85.91	81.85
2	-1.19	0.13	1621.50	85.59	81.58
2	-1.21	0.08	1655.58	85.75	81.68
2	-0.80	0.27	1606.74	85.48	81.48
2	-0.72	0.20	1623.67	84.86	80.89
2	-1.39	0.23	1621.82	87.00	82.84
2	-1.16	1.04	1625.25	84.84	80.90
3	0.03	0.23	1639.35	89.86	85.27
3	-0.15	0.13	1640.84	89.92	85.34
3	0.08	0.29	1632.73	87.64	83.28
3	-0.26	0.14	1614.45	90.42	85.78
3	-0.25	0.13	1681.89	91.14	86.39
3	-0.17	-0.08	1666.27	91.92	87.11
3	0.21	0.24	1624.70	88.96	84.47
3	0.50	0.25	1668.40	88.37	83.92
4	-1.38	0.23	1582.84	109.51	102.94
4	-1.47	0.23	1585.13	109.73	103.14
4	-1.35	0.22	1632.75	108.30	101.79
4	-1.41	0.22	1636.08	108.13	101.64
4	-1.55	0.06	1561.91	110.17	103.57
4	-1.13	0.21	1667.90	105.07	98.85
4	-1.57	0.21	1663.79	111.34	104.50

4	-1.53	0.23	1620.18	110.18	103.51
5	-1.23	0.25	1669.29	86.48	82.28
5	-1.29	0.26	1608.66	86.44	82.34
5	-0.64	0.25	1561.58	88.70	84.38
5	-0.39	0.24	1561.19	86.29	82.20
5	-1.79	0.25	1652.38	90.18	85.68
5	-1.45	0.22	1635.26	88.37	84.02
5	-1.85	0.01	1628.48	87.57	83.43
5	-0.89	0.33	1533.70	87.93	83.74
6	-3.79	1.13	1666.79	104.83	99.13
6	-4.08	0.27	1635.81	105.29	99.58
6	-3.60	1.26	1619.06	105.20	99.38
6	-3.60	0.26	1605.37	99.51	94.34
6	-3.65	0.31	1596.68	98.48	93.51
6	-3.71	0.29	1603.85	100.51	95.30
6	-3.13	0.23	1628.37	102.49	96.87
6	-3.96	0.28	1584.76	105.37	99.71
7	-0.49	0.37	1702.53	100.70	94.94
7	-0.39	0.30	1635.58	99.22	93.67
7	-0.44	0.15	1646.93	99.21	93.65
7	0.03	0.13	1748.70	97.38	91.95
7	-0.42	0.18	1671.30	98.90	93.36
7	-0.36	0.31	1654.51	98.64	93.15
7	-0.35	0.41	1649.58	98.95	93.43
7	-0.41	0.34	1630.40	98.96	93.45
8	-1.75	0.22	1623.53	107.12	100.81
8	-1.26	0.24	1696.64	108.38	101.88
8	-1.07	0.23	1654.25	107.03	100.65
8	-0.78	0.22	1614.64	102.60	96.74
8	-0.86	0.23	1678.01	104.82	98.66
8	-0.76	0.21	1612.14	97.66	92.34
8	-1.90	0.27	1618.82	107.79	101.46
8	-1.49	0.25	1650.80	106.79	100.48

9	-0.48	0.19	1559.03	89.44	84.93
9	-0.90	0.24	1577.82	95.62	90.43
9	-1.50	0.15	1634.94	97.41	92.03
9	-1.21	0.17	1708.30	100.60	94.86
9	-2.09	0.39	1793.69	103.45	97.35
9	-1.28	-0.11	1836.75	85.87	81.74
9	-0.46	0.10	1656.98	87.41	83.08
9	0.47	0.23	1681.31	86.32	82.09
10	-0.23	0.20	1491.87	92.83	88.06
10	0.06	0.35	1543.50	89.73	85.22
10	-0.41	0.20	1540.17	100.09	94.55
10	-0.36	0.23	1508.35	90.31	85.80
10	-0.89	0.28	1054.71	105.87	100.42
10	-0.42	-0.09	1721.46	100.86	95.11
10	-0.38	0.18	1827.23	101.73	95.77
10	-0.40	0.17	1522.51	100.53	95.02
11	-1.42	0.26	1400.71	92.20	87.66
11	-1.51	0.13	1371.37	101.73	96.17
11	-1.46	0.19	1463.86	86.89	82.75
11	-1.59	0.23	1552.88	91.68	87.08
11	-1.10	0.35	1380.04	92.52	87.90
11	-0.84	0.68	1255.66	94.20	89.61
11	-1.51	0.00	1626.40	87.43	83.12
11	-1.70	0.09	1595.15	88.08	83.77
12	-2.30	0.40	1619.29	82.45	78.92
12	-1.29	-0.05	1566.30	77.61	74.51
12	-2.18	-0.04	1626.39	80.87	77.52
12	-2.25	0.20	1615.39	84.45	80.77
12	-2.43	0.06	1641.44	84.06	80.46
12	-2.09	0.02	1687.14	80.48	77.14
12	-2.32	0.08	1645.17	80.50	77.16
12	-2.51	-0.02	1606.85	83.25	79.76
13	-2.17	0.25	1838.00	102.02	95.95

13	-1.87	0.26	1669.65	105.20	99.01
13	-0.34	0.19	1708.82	86.54	82.23
13	-1.16	0.14	1621.62	89.51	85.03
13	0.37	0.34	1656.30	93.66	88.69
13	-0.85	0.28	1771.55	93.02	88.01
13	-1.01	0.33	1783.56	93.91	88.80
13	-1.10	0.24	1916.62	92.91	87.77
14	-1.08	0.30	1502.96	87.76	83.63
14	-1.98	0.03	1643.69	86.91	82.80
14	-2.50	0.63	1691.06	85.58	81.72
14	0.00	0.19	1639.78	89.30	84.83
14	-1.47	0.26	1577.27	85.96	82.04
14	-1.62	0.40	1472.78	79.91	76.68
14	-0.91	0.46	1722.34	85.41	81.29
14	-1.09	0.42	1581.47	85.39	81.35
15	-0.86	0.23	1494.38	92.31	87.60
15	-0.43	0.14	1587.75	94.91	89.83
15	-1.30	1.05	1466.07	91.86	87.31
15	-1.01	0.21	1532.49	97.08	91.84
15	-0.27	0.21	1490.03	89.80	85.35
15	-0.90	0.24	1608.41	98.02	92.61
15	-0.66	0.07	1640.99	95.39	90.24
15	-0.41	0.29	1614.51	94.15	89.13
16	0.64	0.01	1565.31	83.86	80.00
16	0.29	0.00	1613.02	86.99	82.76
16	-0.02	0.18	1593.52	86.54	82.31
16	-0.16	0.09	1670.74	87.19	82.89
16	-1.15	-0.41	1516.39	99.17	93.80
16	0.19	0.22	1680.33	89.84	85.24
16	0.24	0.07	1597.30	86.71	82.56
16	-0.03	-0.12	1614.75	88.47	84.09

Continued, variables 9-13

Subject	VerticalSpeed	ILS-GS-CDI	ILS-Localizer-CDI	LeftThrottleInput	FlapDeflection
1	-377.11	-0.03	-0.03	23.68	0.37
1	-392.04	0.07	0.00	24.83	0.30
1	-392.22	-0.11	-0.04	24.43	0.32
1	-384.54	0.00	-0.05	25.89	0.38
1	-381.70	-0.13	0.02	23.14	0.35
1	-394.89	-0.02	0.00	24.96	0.28
1	-379.38	-0.07	0.01	22.47	0.31
1	-391.50	-0.03	0.05	23.70	0.29
2	-340.79	-0.15	0.03	18.10	0.20
2	-340.13	-0.08	0.01	18.15	0.31
2	-336.82	-0.11	0.00	18.21	0.30
2	-342.44	-0.03	0.06	18.30	0.29
2	-341.33	-0.17	0.02	18.68	0.20
2	-339.44	-0.15	-0.02	17.96	0.20
2	-345.73	-0.12	0.01	18.48	0.29
2	-337.59	-0.14	-0.02	18.52	0.30
3	-362.04	-0.04	0.00	19.60	0.13
3	-359.26	-0.05	-0.04	19.48	0.15
3	-347.32	0.03	-0.02	19.85	0.19
3	-359.79	0.02	-0.06	20.11	0.17
3	-369.92	0.01	-0.05	20.04	0.16
3	-371.04	0.03	0.01	19.05	0.11
3	-351.12	-0.03	-0.01	19.22	0.12
3	-352.12	0.02	0.00	19.15	0.10
4	-434.17	-0.15	-0.02	35.06	0.02
4	-437.57	-0.18	0.02	35.38	0.04
4	-431.06	0.01	0.04	34.23	0.05
4	-437.70	-0.10	-0.06	35.37	0.06
4	-446.73	-0.22	0.05	38.54	0.05
4	-420.96	0.10	0.02	31.52	0.05

4	-440.57	-0.06	-0.02	38.38	0.03
4	-436.92	0.01	0.04	35.83	0.03
5	-351.42	-0.14	0.00	18.27	0.26
5	-346.08	-0.13	-0.03	18.65	0.27
5	-352.68	-0.19	-0.02	20.78	0.18
5	-347.95	-0.21	-0.02	18.26	0.22
5	-360.63	-0.05	0.02	20.25	0.32
5	-352.29	-0.06	0.02	19.44	0.25
5	-348.53	-0.01	0.00	19.48	0.41
5	-348.25	-0.30	0.00	19.64	0.26
6	-418.52	-0.14	-0.10	30.27	0.40
6	-420.57	-0.17	0.02	31.31	0.40
6	-412.22	-0.04	-0.03	28.93	0.30
6	-395.26	-0.17	0.02	26.60	0.41
6	-386.05	-0.21	-0.02	28.00	0.41
6	-396.39	-0.21	-0.02	26.98	0.42
6	-401.78	-0.02	-0.02	26.70	0.25
6	-413.03	-0.23	-0.03	30.54	0.38
7	-401.90	-0.02	0.04	24.35	0.01
7	-396.77	-0.14	0.01	23.68	0.01
7	-393.41	-0.06	0.03	22.78	0.03
7	-385.58	0.10	0.00	21.59	0.01
7	-396.81	-0.04	0.03	22.74	0.02
7	-393.04	-0.10	0.01	22.56	0.03
7	-390.92	-0.09	0.03	23.81	0.02
7	-394.15	-0.08	0.02	23.58	0.03
8	-436.10	-0.14	0.00	31.16	0.12
8	-436.31	0.12	0.04	34.11	0.07
8	-427.47	-0.20	-0.02	31.75	0.03
8	-413.53	-0.25	-0.03	25.74	0.04
8	-422.65	-0.10	-0.04	27.50	0.01
8	-398.32	-0.14	0.02	22.63	0.13
8	-435.54	0.05	0.00	34.84	0.16

8	-430.02	-0.08	-0.02	32.03	0.12
9	-361.39	-0.16	0.00	19.98	0.26
9	-383.26	-0.09	0.00	24.41	0.16
9	-386.73	0.07	-0.04	26.48	0.21
9	-401.95	0.11	-0.08	24.78	0.09
9	-403.84	0.73	0.21	33.61	0.22
9	-340.86	0.32	0.15	19.96	0.37
9	-346.55	0.07	0.01	19.86	0.26
9	-339.73	-0.12	0.02	18.59	0.08
10	-373.54	-0.23	0.14	19.85	0.09
10	-359.33	-0.07	-0.10	19.88	0.12
10	-399.94	-0.30	-0.08	22.96	0.00
10	-362.69	-0.09	-0.11	20.41	0.18
10	-418.27	-1.80	0.86	29.36	0.00
10	-404.09	0.23	-0.06	25.04	0.00
10	-403.97	0.31	-0.25	26.39	0.00
10	-400.82	-0.46	-0.32	23.45	0.00
11	-371.55	-0.56	0.03	20.87	0.25
11	-408.52	-0.53	0.01	28.37	0.18
11	-346.43	-0.19	-0.02	21.66	0.43
11	-365.73	-0.16	-0.01	21.81	0.29
11	-374.34	-0.63	-0.05	22.81	0.28
11	-378.11	-1.19	0.18	24.27	0.18
11	-348.05	0.28	0.26	21.41	0.42
11	-349.30	-0.05	0.14	23.09	0.45
12	-330.35	-0.17	0.02	23.02	0.62
12	-313.43	-0.31	0.02	19.60	0.58
12	-323.88	-0.22	-0.04	21.39	0.63
12	-338.89	-0.18	0.00	21.23	0.52
12	-340.17	-0.13	0.01	22.17	0.60
12	-324.93	-0.13	-0.02	21.04	0.61
12	-322.81	-0.15	0.03	21.51	0.67
12	-331.64	-0.20	-0.04	22.46	0.62

13	-407.82	1.52	0.03	30.12	0.19
13	-420.52	0.31	0.04	30.20	0.11
13	-348.86	0.27	0.05	21.27	0.29
13	-359.02	0.16	-0.01	22.37	0.33
13	-377.02	-0.08	0.02	20.48	0.00
13	-376.31	0.44	-0.04	24.38	0.19
13	-375.49	0.64	0.01	24.08	0.21
13	-370.54	1.24	0.03	23.53	0.23
14	-349.73	-0.30	-0.11	20.66	0.33
14	-347.55	0.08	-0.01	22.46	0.50
14	-334.61	0.12	-0.03	28.18	0.63
14	-334.82	-0.20	0.48	20.85	0.16
14	-342.08	-0.39	0.09	21.14	0.40
14	-313.59	-0.43	0.01	20.58	0.61
14	-335.76	-0.07	0.00	21.56	0.38
14	-339.15	-0.22	0.10	23.09	0.44
15	-370.78	-0.21	0.02	21.31	0.23
15	-380.96	-0.01	0.07	20.73	0.08
15	-364.80	-0.08	-0.04	26.47	0.31
15	-386.53	-0.12	0.00	23.54	0.17
15	-355.87	-0.25	0.03	19.86	0.20
15	-389.31	-0.04	0.00	24.87	0.14
15	-382.66	-0.02	0.00	21.25	0.12
15	-375.94	0.01	0.01	21.63	0.12
16	-333.60	-0.18	0.03	15.69	0.15
16	-347.12	-0.16	0.04	17.27	0.14
16	-346.11	0.01	-0.01	18.16	0.19
16	-346.10	0.08	0.00	18.58	0.17
16	-385.64	0.61	0.08	30.56	0.17
16	-360.16	0.15	0.02	19.70	0.09
16	-345.26	-0.02	0.04	18.00	0.13
16	-353.87	0.06	0.03	18.91	0.14

APPENDIX J: Raw Rank Data, Laboratory Experiment

SUBJECT IFR-01	MCH	SART Instability	Variability	Complexity	DEMAND TOTAL	Arousal	Spare Mental	Concentration	Div of Attention	SUPPLY TOTAL	Info Quantity	Info Quality	Familiarity	UNDER-STANDING TOTAL	OVERALL SART RATING [U+S-D]
C1: Static Clear Day	2	1	1	2	4	2	7	4	4	17	3	6	7	16	29
C2: Static Clear Night	3	3	5	4	12	5	6	5	4	20	5	5	4	14	22
C3: Dynamic Day	5	6	6	5	17	7	7	6	6	26	6	6	4	16	25
C4: Dynamic Night	5	6	6	5	17	7	6	6	6	25	6	7	1	14	22

SUBJECT IFR-02	MCH	SART Instability	Variability	Complexity	DEMAND TOTAL	Arousal	Spare Mental	Concentration	Div of Attention	SUPPLY TOTAL	Info Quantity	Info Quality	Familiarity	UNDER-STANDING TOTAL	OVERALL SART RATING [U+S-D]
C1: Static Clear Day	2	3	3	3	9	4	5	4	4	17	6	6	6	18	26
C2: Static Clear Night	3	4	5	5	14	6	4	6	5	21	5	6	4	15	22
C3: Dynamic Day	3	3	4	5	12	5	4	5	4	18	5	6	4	15	21
C4: Dynamic Night	3	4	4	5	13	5	4	6	5	20	6	6	4	16	23

SUBJECT IFR-03	MCH	SART Instability	Variability	Complexity	DEMAND TOTAL	Arousal	Spare Mental	Concentration	Div of Attention	SUPPLY TOTAL	Info Quantity	Info Quality	Familiarity	UNDER-STANDING TOTAL	OVERALL SART RATING [U+S-D]
C1: Static Clear Day	2	3	3	4	10	4	6	5	5	20	6	5	6	17	27
C2: Static Clear Night	3	4	5	5	14	5	5	5	6	21	6	6	5	17	24

	MCH	Instability	Variability	Complexity	DEMAND TOTAL	Arousal	Spare Mental	Concentration	Div of Attention	SUPPLY TOTAL	Info Quantity	Info Quality	Familiarity	UNDER-STANDING TOTAL	OVERALL SART RATING [U+S-D]
C3: Dynamic Day	3	2	6	5	13	5	2	6	5	18	6	6	4	16	21
C4: Dynamic Night	4	3	4	5	12	5	2	6	6	19	6	5	3	14	21

		SART													
SUBJECT IFR-04	**MCH**	Instability	Variability	Complexity	DEMAND TOTAL	Arousal	Spare Mental	Concentration	Div of Attention	SUPPLY TOTAL	Info Quantity	Info Quality	Familiarity	UNDER-STANDING TOTAL	OVERALL SART RATING [U+S-D]
C1: Static Clear Day	2	2	2	3	7	6	5	5	5	21	5	5	7	17	31
C2: Static Clear Night	2	2	2	2	6	6	5	5	5	21	6	5	6	17	32
C3: Dynamic Day	2	3	2	3	8	6	5	6	5	22	6	5	6	17	31
C4: Dynamic Night	2	2	3	3	8	6	5	5	5	21	6	6	4	16	29

		SART													
SUBJECT IFR-05	**MCH**	Instability	Variability	Complexity	DEMAND TOTAL	Arousal	Spare Mental	Concentration	Div of Attention	SUPPLY TOTAL	Info Quantity	Info Quality	Familiarity	UNDER-STANDING TOTAL	OVERALL SART RATING [U+S-D]
C1: Static Clear Day	3	2	3	3	8	5	6	6	6	23	6	6	7	19	34
C2: Static Clear Night	3	1	2	3	6	6	6	7	6	25	6	6	7	19	38
C3: Dynamic Day	2	2	2	3	7	7	5	5	6	23	7	7	7	21	37
C4: Dynamic Night	3	2	4	5	11	6	5	7	6	24	6	6	7	19	32

		SART													
SUBJECT IFR-06	**MCH**	Instability	Variability	Complexity	DEMAND TOTAL	Arousal	Spare Mental	Concentration	Div of Attention	SUPPLY TOTAL	Info Quantity	Info Quality	Familiarity	UNDER-STANDING TOTAL	OVERALL SART RATING [U+S-D]
C1: Static Clear Day	2	1	5	5	11	7	5	7	7	26	7	7	7	21	36
C2: Static Clear Night	2	1	5	5	11	7	5	7	7	26	7	7	7	21	36

C3: Dynamic Day	2	1	5	5	11	7	5	7	7	26	7	7	7	21	36
C4: Dynamic Night	2	1	5	5	11	7	4	7	7	25	7	7	7	21	35
		SART													
SUBJECT IFR-07(09)	**MCH**	Instability	Variability	Complexity	DEMAND TOTAL	Arousal	Spare Mental	Concentration	Div of Attention	SUPPLY TOTAL	Info Quantity	Info Quality	Familiarity	UNDER-STANDING TOTAL	OVERALL SART RATING [U+S-D]
C1: Static Clear Day	3	2	5	5	12	7	5	7	6	25	5	7	7	19	32
C2: Static Clear Night	3	2	5	5	12	7	5	7	5	24	6	7	7	20	32
C3: Dynamic Day	3	2	5	5	12	7	5	7	6	25	5	7	7	19	32
C4: Dynamic Night	3	2	6	5	13	7	5	7	6	25	6	7	7	20	32
		SART													
SUBJECT IFR-08	**MCH**	Instability	Variability	Complexity	DEMAND TOTAL	Arousal	Spare Mental	Concentration	Div of Attention	SUPPLY TOTAL	Info Quantity	Info Quality	Familiarity	UNDER-STANDING TOTAL	OVERALL SART RATING [U+S-D]
C1: Static Clear Day	3	1	1	4	6	7	6	7	6	26	7	7	7	21	41
C2: Static Clear Night	4	1	3	3	7	4	3	7	7	21	7	7	7	21	35
C3: Dynamic Day	4	4	6	6	16	7	4	7	7	25	7	7	7	21	30
C4: Dynamic Night	3	2	5	6	13	7	5	7	6	25	7	7	7	21	33
		SART													
SUBJECT VFR-01	**MCH**	Instability	Variability	Complexity	DEMAND TOTAL	Arousal	Spare Mental	Concentration	Div of Attention	SUPPLY TOTAL	Info Quantity	Info Quality	Familiarity	UNDER-STANDING TOTAL	OVERALL SART RATING [U+S-D]
C1: Static Clear Day	1	2	2	3	7	4	6	2	3	15	5	5	6	16	24
C2: Static Clear Night	3	3	2	4	9	5	6	5	4	20	5	5	6	16	27

C3: Dynamic Day	3	6	6	6	18	7	3	5	5	20	6	6	5	17	19
C4: Dynamic Night	3	6	6	6	18	6	5	6	6	23	6	6	7	19	24

		SART													
SUBJECT VFR-02	**MCH**	Instability	Variability	Complexity	DEMAND TOTAL	Arousal	Spare Mental	Concentration	Div of Attention	SUPPLY TOTAL	Info Quantity	Info Quality	Familiarity	UNDER-STANDING TOTAL	OVERALL SART RATING [U+S-D]
C1: Static Clear Day	1	2	2	2	6	3	5	3	3	14	5	5	4	14	22
C2: Static Clear Night	2	2	3	3	8	3	4	3	4	14	4	4	3	11	17
C3: Dynamic Day	2	3	3	3	9	4	4	4	4	16	5	6	3	14	21
C4: Dynamic Night	3	3	4	4	11	4	3	5	4	16	3	3	3	9	14

		SART													
SUBJECT VFR-03	**MCH**	Instability	Variability	Complexity	DEMAND TOTAL	Arousal	Spare Mental	Concentration	Div of Attention	SUPPLY TOTAL	Info Quantity	Info Quality	Familiarity	UNDER-STANDING TOTAL	OVERALL SART RATING [U+S-D]
C1: Static Clear Day	2	2	3	3	8	3	6	5	4	18	6	6	6	18	28
C2: Static Clear Night	4	3	4	4	11	4	5	4	4	17	6	6	5	17	23
C3: Dynamic Day	4	5	5	5	15	4	4	5	5	18	5	5	4	14	17
C4: Dynamic Night	6	6	5	5	16	6	4	6	5	21	4	5	2	11	16

		SART													
SUBJECT VFR-04	**MCH**	Instability	Variability	Complexity	DEMAND TOTAL	Arousal	Spare Mental	Concentration	Div of Attention	SUPPLY TOTAL	Info Quantity	Info Quality	Familiarity	UNDER-STANDING TOTAL	OVERALL SART RATING [U+S-D]
C1: Static Clear Day	1	1	2	1	4	4	7	4	3	18	4	7	7	18	32
C2: Static Clear Night	1	2	2	2	6	3	7	3	3	16	2	7	5	14	24

C3: Dynamic Day	1	2	3	2	7	4	7	5	4	20	2	7	5	14	27
C4: Dynamic Night	1	2	3	2	7	4	7	5	3	19	2	7	5	14	26

		SART													
SUBJECT VFR-05	**MCH**	Instability	Variability	Complexity	DEMAND TOTAL	Arousal	Spare Mental	Concentration	Div of Attention	SUPPLY TOTAL	Info Quantity	Info Quality	Familiarity	UNDER-STANDING TOTAL	OVERALL SART RATING [U+S-D]
C1: Static Clear Day	2	3	4	3	10	4	3	4	5	16	4	4	5	13	19
C2: Static Clear Night	4	6	6	6	18	6	6	6	5	23	6	5	4	15	20
C3: Dynamic Day	4	6	6	6	18	5	6	6	6	23	6	5	4	15	20
C4: Dynamic Night	4	5	6	5	16	4	5	6	5	20	6	5	4	15	19

		SART													
SUBJECT VFR-06	**MCH**	Instability	Variability	Complexity	DEMAND TOTAL	Arousal	Spare Mental	Concentration	Div of Attention	SUPPLY TOTAL	Info Quantity	Info Quality	Familiarity	UNDER-STANDING TOTAL	OVERALL SART RATING [U+S-D]
C1: Static Clear Day	3	2	2	2	6	5	5	6	3	19	4	5	6	15	28
C2: Static Clear Night	3	3	4	4	11	5	3	5	5	18	6	6	6	18	25
C3: Dynamic Day	3	2	4	4	10	5	4	5	5	19	6	6	5	17	26
C4: Dynamic Night	3	3	3	4	10	5	4	5	5	19	6	6	5	17	26

		SART													
SUBJECT VFR-07	**MCH**	Instability	Variability	Complexity	DEMAND TOTAL	Arousal	Spare Mental	Concentration	Div of Attention	SUPPLY TOTAL	Info Quantity	Info Quality	Familiarity	UNDER-STANDING TOTAL	OVERALL SART RATING [U+S-D]
C1: Static Clear Day	2	2	4	4	10	5	6	5	3	19	5	6	6	17	26
C2: Static Clear Night	2	2	3	5	10	6	5	6	2	19	6	7	4	17	26

C3: Dynamic Day	3	2	3	4	9	5	6	6	5	22	3	5	3	11	24
C4: Dynamic Night	3	2	3	5	10	6	5	6	4	21	3	6	2	11	22

		SART													
SUBJECT VFR-08	**MCH**	Instability	Variability	Complexity	DEMAND TOTAL	Arousal	Spare Mental	Concentration	Div of Attention	SUPPLY TOTAL	Info Quantity	Info Quality	Familiarity	UNDER-STANDING TOTAL	OVERALL SART RATING [U+S-D]
C1: Static Clear Day	1	1	2	3	6	4	7	4	3	18	6	6	7	19	31
C2: Static Clear Night	1	1	1	3	5	5	5	4	3	17	6	6	3	15	27
C3: Dynamic Day	3	2	3	3	8	4	4	5	4	17	6	5	1	12	21
C4: Dynamic Night	2	1	3	3	7	6	5	5	3	19	7	6	3	16	28

APPENDIX K: ANOVA Tables for Flight Performance Variables

2x2x2 Mixed-Factors

A=Pilot Type; B=Day/Night; C=Weather

Analysis of Variance for Total Time

Source	DF	SS	MS	F	P
A	1	10400.4	10400.4	2.79	0.117
B	1	682.4	682.4	3.53	0.081
C	1	115.0	115.0	0.35	0.562
S(A)	14	52122.4	3723.0		
A*B	1	14.9	14.9	0.08	0.785
A*C	1	9.0	9.0	0.03	0.870
B*C	1	0.1	0.1	0.00	0.980
B*S(A)	14	2702.7	193.0		
C*S(A)	14	4550.8	325.1		
A*B*C	1	0.0	0.0	0.00	0.992
Error	14	3014.1	215.3		
Total	63	73611.9			

Analysis of Variance for Flight Path Angle

Source	DF	SS	MS	F	P	
A	1	0.0162562	0.0162562	3.02	0.104	
B	1	0.0042250	0.0042250	6.28	0.025	*
C	1	0.0056250	0.0056250	2.52	0.135	
S(A)	14	0.0753438	0.0053817			
A*B	1	0.0010562	0.0010562	1.57	0.231	
A*C	1	0.0045563	0.0045563	2.04	0.175	
B*C	1	0.0004000	0.0004000	0.47	0.506	
B*S(A)	14	0.0094187	0.0006728			
C*S(A)	14	0.0312187	0.0022299			
A*B*C	1	0.0014062	0.0014062	1.64	0.221	
Error	14	0.0119938	0.0008567			
Total	63	0.1615000				

Analysis of Variance for Heading

Source	DF	SS	MS	F	P
A	1	0.411	0.411	0.34	0.569
B	1	0.812	0.812	0.83	0.379
C	1	1.320	1.320	1.41	0.255
S(A)	14	16.964	1.212		
A*B	1	0.863	0.863	0.88	0.365
A*C	1	1.325	1.325	1.42	0.254
B*C	1	1.116	1.116	1.02	0.330
B*S(A)	14	13.759	0.983		
C*S(A)	14	13.085	0.935		
A*B*C	1	1.999	1.999	1.83	0.198
Error	14	15.332	1.095		
Total	63	66.985			

Analysis of Variance for Pitch Attitude

Source	DF	SS	MS	F	P
A	1	3.2265	3.2265	0.87	0.366
B	1	0.0405	0.0405	0.47	0.506
C	1	0.0124	0.0124	0.12	0.739
S(A)	14	51.7183	3.6942		
A*B	1	0.0051	0.0051	0.06	0.812
A*C	1	0.0375	0.0375	0.35	0.563
B*C	1	0.0015	0.0015	0.01	0.940
B*S(A)	14	1.2145	0.0868		
C*S(A)	14	1.4973	0.1070		
A*B*C	1	0.3379	0.3379	1.34	0.267
Error	14	3.5373	0.2527		
Total	63	61.6288			

Analysis of Variance for Roll Angle

Source	DF	SS	MS	F	P
A	1	0.10160	0.10160	2.14	0.165
B	1	0.00660	0.00660	0.61	0.448
C	1	0.02600	0.02600	1.12	0.308
S(A)	14	0.66317	0.04737		
A*B	1	0.00004	0.00004	0.00	0.953
A*C	1	0.00013	0.00013	0.01	0.942
B*C	1	0.00170	0.00170	0.10	0.753
B*S(A)	14	0.15178	0.01084		
C*S(A)	14	0.32570	0.02326		
A*B*C	1	0.06064	0.06064	3.68	0.076
Error	14	0.23068	0.01648		
Total	63	1.56805			

Analysis of Variance for Altitude AGL

Source	DF	SS	MS	F	P	
A	1	19435	19435	1.14	0.304	
B	1	10343	10343	2.70	0.123	
C	1	4635	4635	3.13	0.099	
S(A)	14	239438	17103			
A*B	1	22699	22699	5.93	0.029	*
A*C	1	5879	5879	3.97	0.066	
B*C	1	3741	3741	0.96	0.345	
B*S(A)	14	53611	3829			
C*S(A)	14	20713	1479			
A*B*C	1	3455	3455	0.88	0.363	
Error	14	54767	3912			
Total	63	438715				

Analysis of Variance for Ground Speed

Source	DF	SS	MS	F	P
A	1	569.90	569.90	2.80	0.117
B	1	9.46	9.46	1.30	0.273
C	1	0.00	0.00	0.00	0.994
S(A)	14	2851.86	203.70		
A*B	1	14.18	14.18	1.96	0.184
A*C	1	0.68	0.68	0.06	0.814
B*C	1	0.43	0.43	0.03	0.855
B*S(A)	14	101.47	7.25		
C*S(A)	14	164.07	11.72		
A*B*C	1	12.85	12.85	1.04	0.325
Error	14	173.03	12.36		
Total	63	3897.91			

Analysis of Variance for Indicated Airspeed

Source	DF	SS	MS	F	P
A	1	458.602	458.602	2.82	0.115
B	1	8.294	8.294	1.42	0.254
C	1	0.004	0.004	0.00	0.985
S(A)	14	2275.613	162.544		
A*B	1	12.338	12.338	2.11	0.169
A*C	1	0.508	0.508	0.05	0.821
B*C	1	0.209	0.209	0.02	0.886
B*S(A)	14	81.955	5.854		
C*S(A)	14	134.292	9.592		
A*B*C	1	11.290	11.290	1.16	0.301
Error	14	136.802	9.772		
Total	63	3119.906			

Analysis of Variance for Vertical Speed

Source	DF	SS	MS	F	P
A	1	9598.4	9598.4	2.87	0.112
B	1	455.0	455.0	3.77	0.073
C	1	6.8	6.8	0.04	0.850
S(A)	14	46781.7	3341.5		
A*B	1	171.6	171.6	1.42	0.253
A*C	1	6.6	6.6	0.04	0.852
B*C	1	16.5	16.5	0.09	0.770
B*S(A)	14	1689.3	120.7		
C*S(A)	14	2562.7	183.1		
A*B*C	1	108.3	108.3	0.58	0.458
Error	14	2609.7	186.4		
Total	63	64006.7			

Analysis of Variance for ILS Glide Slope CDI

Source	DF	SS	MS	F	P
A	1	0.01960	0.01960	0.11	0.748
B	1	0.08266	0.08266	2.10	0.169
C	1	0.00160	0.00160	0.08	0.780
S(A)	14	2.56414	0.18315		
A*B	1	0.06002	0.06002	1.52	0.237
A*C	1	0.00076	0.00076	0.04	0.848
B*C	1	0.06003	0.06003	0.86	0.368
B*S(A)	14	0.55107	0.03936		
C*S(A)	14	0.27639	0.01974		
A*B*C	1	0.04306	0.04306	0.62	0.444
Error	14	0.97167	0.06940		
Total	63	4.63099			

Analysis of Variance for ILS Localizer CDI

Source	DF	SS	MS	F	P	
A	1	0.014702	0.014702	7.84	0.014	*
B	1	0.012939	0.012939	0.99	0.336	
C	1	0.010252	0.010252	3.79	0.072	
S(A)	14	0.026247	0.001875			
A*B	1	0.007439	0.007439	0.57	0.463	
A*C	1	0.003452	0.003452	1.28	0.278	
B*C	1	0.005077	0.005077	0.69	0.420	
B*S(A)	14	0.182597	0.013043			
C*S(A)	14	0.037872	0.002705			
A*B*C	1	0.007877	0.007877	1.07	0.318	
Error	14	0.102822	0.007344			
Total	63	0.411273				

Analysis of Variance for Throttle Input

Source	DF	SS	MS	F	P
A	1	83.311	83.311	1.06	0.321
B	1	1.015	1.015	0.41	0.535
C	1	0.122	0.122	0.03	0.873
S(A)	14	1100.690	78.621		
A*B	1	4.623	4.623	1.85	0.196
A*C	1	1.995	1.995	0.43	0.521
B*C	1	0.005	0.005	0.00	0.980
B*S(A)	14	35.076	2.505		
C*S(A)	14	64.352	4.597		
A*B*C	1	20.430	20.430	2.59	0.130
Error	14	110.251	7.875		
Total	63	1421.871			

Analysis of Variance for Flap Deflection

Source	DF	SS	MS	F	P
A	1	0.093789	0.093789	0.93	0.350
B	1	0.002377	0.002377	0.49	0.495
C	1	0.000077	0.000077	0.03	0.867
S(A)	14	1.404359	0.100311		
A*B	1	0.002889	0.002889	0.60	0.453
A*C	1	0.000564	0.000564	0.21	0.650
B*C	1	0.000264	0.000264	0.21	0.657
B*S(A)	14	0.067809	0.004844		
C*S(A)	14	0.036834	0.002631		
A*B*C	1	0.000977	0.000977	0.76	0.397
Error	14	0.017934	0.001281		
Total	63	1.627873			

2x2 Within-Subjects [VFR Pilots Only]

A=Day/Night; B=Weather

Analysis of Variance for Total Time

Source	DF	SS	MS	F	P
A	1	449.6	449.6	1.50	0.261
B	1	29.8	29.8	0.05	0.824
S	7	18830.2	2690.0		
A*B	1	0.1	0.1	0.00	0.983
A*S	7	2103.6	300.5		
B*S	7	3929.1	561.3		
Error	7	1951.1	278.7		
Total	31	27293.4			

Analysis of Variance for Flight Path Angle

Source	DF	SS	MS	F	P
A	1	0.0005281	0.0005281	0.48	0.509
B	1	0.0101531	0.0101531	3.45	0.106
S	7	0.0397219	0.0056746		
A*B	1	0.0016531	0.0016531	1.67	0.237
A*S	7	0.0076469	0.0010924		
B*S	7	0.0206219	0.0029460		
Error	7	0.0069219	0.0009888		
Total	31	0.0872469			

Analysis of Variance for Heading

Source	DF	SS	MS	F	P
A	1	1.674	1.674	0.86	0.384
B	1	2.645	2.645	1.43	0.270
S	7	16.725	2.389		
A*B	1	3.050	3.050	1.41	0.274
A*S	7	13.589	1.941		
B*S	7	12.934	1.848		
Error	7	15.140	2.163		
Total	31	65.758			

Analysis of Variance for Pitch Attitude

Source	DF	SS	MS	F	P
A	1	0.0084	0.0084	0.08	0.784
B	1	0.0465	0.0465	0.31	0.592
S	7	12.4344	1.7763		
A*B	1	0.1922	0.1922	0.47	0.516
A*S	7	0.7294	0.1042		
B*S	7	1.0339	0.1477		
Error	7	2.8800	0.4114		
Total	31	17.3248			

Analysis of Variance for Roll Angle

Source	DF	SS	MS	F	P
A	1	0.00281	0.00281	0.15	0.712
B	1	0.01125	0.01125	0.84	0.389
S	7	0.34810	0.04973		
A*B	1	0.02101	0.02101	1.32	0.288
A*S	7	0.13359	0.01908		
B*S	7	0.09345	0.01335		
Error	7	0.11139	0.01591		
Total	31	0.72160			

Analysis of Variance for Altitude AGL

Source	DF	SS	MS	F	P
A	1	31843	31843	4.76	0.065
B	1	10477	10477	4.25	0.078
S	7	227565	32509		
A*B	1	7193	7193	0.95	0.363
A*S	7	46798	6685		
B*S	7	17265	2466		
Error	7	53215	7602		
Total	31	394355			

Analysis of Variance for Ground Speed

Source	DF	SS	MS	F	P
A	1	23.39	23.39	1.76	0.227
B	1	0.36	0.36	0.02	0.901
S	7	775.09	110.73		
A*B	1	4.29	4.29	0.22	0.657
A*S	7	93.24	13.32		
B*S	7	153.36	21.91		
Error	7	139.67	19.95		
Total	31	1189.40			

Analysis of Variance for Indicated Air Speed

Source	DF	SS	MS	F	P
A	1	20.43	20.43	1.89	0.211
B	1	0.30	0.30	0.02	0.901
S	7	603.22	86.17		
A*B	1	4.21	4.21	0.27	0.620
A*S	7	75.53	10.79		
B*S	7	125.71	17.96		
Error	7	109.72	15.67		
Total	31	939.13			

Analysis of Variance for Vertical Speed

Source	DF	SS	MS	F	P
A	1	592.8	592.8	2.78	0.139
B	1	0.0	0.0	0.00	0.999
S	7	13007.7	1858.2		
A*B	1	20.1	20.1	0.07	0.799
A*S	7	1492.7	213.2		
B*S	7	2352.0	336.0		
Error	7	2003.0	286.1		
Total	31	19468.4			

Analysis of Variance for ILS Glide Slope CDI

Source	DF	SS	MS	F	P
A	1	0.1418	0.1418	1.89	0.212
B	1	0.0023	0.0023	0.06	0.811
S	7	2.4923	0.3560		
A*B	1	0.1024	0.1024	0.76	0.411
A*S	7	0.5259	0.0751		
B*S	7	0.2586	0.0369		
Error	7	0.9371	0.1339		
Total	31	4.4603			

Analysis of Variance for ILS Localizer CDI

Source	DF	SS	MS	F	P
A	1	0.02000	0.02000	0.77	0.409
B	1	0.01280	0.01280	2.65	0.148
S	7	0.01960	0.00280		
A*B	1	0.01280	0.01280	0.89	0.377
A*S	7	0.18145	0.02592		
B*S	7	0.03385	0.00484		
Error	7	0.10085	0.01441		
Total	31	0.38135			

Analysis of Variance for Throttle

Source	DF	SS	MS	F	P
A	1	4.98	4.98	1.21	0.307
B	1	1.55	1.55	0.19	0.679
S	7	62.13	8.88		
A*B	1	10.55	10.55	1.01	0.348
A*S	7	28.74	4.11		
B*S	7	58.21	8.32		
Error	7	73.11	10.44		
Total	31	239.28			

Analysis of Variance for Flap Deflection

Source	DF	SS	MS	F	P
A	1	0.005253	0.005253	0.65	0.448
B	1	0.000528	0.000528	0.15	0.713
S	7	0.896322	0.128046		
A*B	1	0.001128	0.001128	0.99	0.353
A*S	7	0.056972	0.008139		
B*S	7	0.025197	0.003600		
Error	7	0.007997	0.001142		
Total	31	0.993397			

2x2 Within-Subjects [IFR Pilots Only]

A=Day/Night; B=Weather

Analysis of Variance for Total Time

Source	DF	SS	MS	F	P
A	1	247.8	247.8	2.89	0.133
B	1	94.3	94.3	1.06	0.337
S	7	33292.2	4756.0		
A*B	1	0.0	0.0	0.00	0.990
A*S	7	599.1	85.6		
B*S	7	621.7	88.8		
Error	7	1063.0	151.9		
Total	31	35918.1			

Analysis of Variance for Flight Path Angle

Source	DF	SS	MS	F	P	
A	1	0.0047531	0.0047531	18.78	0.003	*
B	1	0.0000281	0.0000281	0.02	0.895	
S	7	0.0356219	0.0050888			
A*B	1	0.0001531	0.0001531	0.21	0.660	
A*S	7	0.0017719	0.0002531			
B*S	7	0.0105969	0.0015138			
Error	7	0.0050719	0.0007246			
Total	31	0.0579969				

Analysis of Variance for Heading

Source	DF	SS	MS	F	P
A	1	0.00038	0.00038	0.02	0.904
B	1	0.00000	0.00000	0.00	0.991
S	7	0.23892	0.03413		
A*B	1	0.06390	0.06390	2.33	0.171
A*S	7	0.16955	0.02422		
B*S	7	0.15102	0.02157		
Error	7	0.19202	0.02743		
Total	31	0.81580			

Analysis of Variance for Pitch Attitude

Source	DF	SS	MS	F	P
A	1	0.0371	0.0371	0.54	0.488
B	1	0.0034	0.0034	0.05	0.827
S	7	39.2839	5.6120		
A*B	1	0.1472	0.1472	1.57	0.251
A*S	7	0.4852	0.0693		
B*S	7	0.4634	0.0662		
Error	7	0.6573	0.0939		
Total	31	41.0775			

Analysis of Variance for Roll Angle

Source	DF	SS	MS	F	P
A	1	0.00383	0.00383	1.47	0.264
B	1	0.01488	0.01488	0.45	0.525
S	7	0.31507	0.04501		
A*B	1	0.04133	0.04133	2.43	0.163
A*S	7	0.01820	0.00260		
B*S	7	0.23225	0.03318		
Error	7	0.11930	0.01704		
Total	31	0.74485			

Analysis of Variance for Altitude AGL

Source	DF	SS	MS	F	P
A	1	1198.5	1198.5	1.23	0.304
B	1	36.9	36.9	0.07	0.792
S	7	11872.7	1696.1		
A*B	1	2.8	2.8	0.01	0.913
A*S	7	6812.6	973.2		
B*S	7	3448.3	492.6		
Error	7	1552.1	221.7		
Total	31	24924.1			

Analysis of Variance for Ground Speed

Source	DF	SS	MS	F	P
A	1	0.238	0.238	0.20	0.666
B	1	0.316	0.316	0.21	0.663
S	7	2076.778	296.683		
A*B	1	8.989	8.989	1.89	0.212
A*S	7	8.226	1.175		
B*S	7	10.703	1.529		
Error	7	33.360	4.766		
Total	31	2138.609			

Analysis of Variance for Indicated Airspeed

Source	DF	SS	MS	F	P
A	1	0.200	0.200	0.22	0.655
B	1	0.213	0.213	0.17	0.689
S	7	1672.389	238.913		
A*B	1	7.287	7.287	1.88	0.212
A*S	7	6.422	0.917		
B*S	7	8.581	1.226		
Error	7	27.078	3.868		
Total	31	1722.170			

Analysis of Variance for Vertical Speed

Source	DF	SS	MS	F	P
A	1	33.9	33.9	1.21	0.308
B	1	13.4	13.4	0.45	0.526
S	7	33773.9	4824.8		
A*B	1	104.8	104.8	1.21	0.308
A*S	7	196.5	28.1		
B*S	7	210.7	30.1		
Error	7	606.6	86.7		
Total	31	34939.9			

Analysis of Variance for ILS Glide Slope CDI

Source	DF	SS	MS	F	P
A	1	0.000903	0.000903	0.25	0.632
B	1	0.000078	0.000078	0.03	0.866
S	7	0.071822	0.010260		
A*B	1	0.000703	0.000703	0.14	0.717
A*S	7	0.025172	0.003596		
B*S	7	0.017797	0.002542		
Error	7	0.034572	0.004939		
Total	31	0.151047			

Analysis of Variance for ILS Localizer CDI

Source	DF	SS	MS	F	P
A	1	0.0003781	0.0003781	2.31	0.173
B	1	0.0009031	0.0009031	1.57	0.250
S	7	0.0066469	0.0009496		
A*B	1	0.0001531	0.0001531	0.54	0.485
A*S	7	0.0011469	0.0001638		
B*S	7	0.0040219	0.0005746		
Error	7	0.0019719	0.0002817		
Total	31	0.0152219			

Analysis of Variance for Throttle Input

Source	DF	SS	MS	F	P
A	1	0.653	0.653	0.72	0.424
B	1	0.564	0.564	0.64	0.449
S	7	1038.563	148.366		
A*B	1	9.890	9.890	1.86	0.214
A*S	7	6.333	0.905		
B*S	7	6.142	0.877		
Error	7	37.139	5.306		
Total	31	1099.284			

Analysis of Variance for Flap Deflection

Source	DF	SS	MS	F	P
A	1	0.000013	0.000013	0.01	0.931
B	1	0.000112	0.000112	0.07	0.802
S	7	0.508037	0.072577		
A*B	1	0.000113	0.000113	0.08	0.786
A*S	7	0.010838	0.001548		
B*S	7	0.011638	0.001663		
Error	7	0.009937	0.001420		
Total	31	0.540688			

APPENDIX L: Mann-Whitney Test for Workload Comparisons, VFR vs. IFR

Mann-Whitney Test and CI: SCD-VFR, SCD-IFR (Upper-tailed)

```
SCD-VFR    N =   8     Median =       1.500
SCD-IFR    N =   8     Median =       2.000
Point estimate for ETA1-ETA2 is      -1.000
95.9 Percent CI for ETA1-ETA2 is (-0.999,0.000)
W = 50.0
Test of ETA1 = ETA2  vs  ETA1 > ETA2
Cannot reject since W is < 68.0
```

Mann-Whitney Test and CI: SCD-VFR, SCD-IFR (Two-tailed)

```
SCD-VFR    N =   8     Median =       1.500
SCD-IFR    N =   8     Median =       2.000
Point estimate for ETA1-ETA2 is      -1.000
95.9 Percent CI for ETA1-ETA2 is (-0.999,0.000)
W = 50.0
Test of ETA1 = ETA2  vs  ETA1 not = ETA2 is significant at 0.0661
The test is significant at 0.0458 (adjusted for ties)
```

Mann-Whitney Test and CI: SCD-VFR, SCD-IFR (Lower-tailed)

```
SCD-VFR    N =   8     Median =       1.500
SCD-IFR    N =   8     Median =       2.000
Point estimate for ETA1-ETA2 is      -1.000
95.9 Percent CI for ETA1-ETA2 is (-0.999,0.000)
W = 50.0
Test of ETA1 = ETA2  vs  ETA1 < ETA2 is significant at 0.0330
The test is significant at 0.0229 (adjusted for ties)
```

Mann-Whitney Test and CI: SCN-VFR, SCN-IFR (Upper-tailed)

```
SCN-VFR    N =   8     Median =       2.500
SCN-IFR    N =   8     Median =       3.000
Point estimate for ETA1-ETA2 is      -0.000
95.9 Percent CI for ETA1-ETA2 is (-2.000,1.000)
W = 62.0
Test of ETA1 = ETA2  vs  ETA1 > ETA2
Cannot reject since W is < 68.0
```

Mann-Whitney Test and CI: SCN-VFR, SCN-IFR (Two-tailed)

```
SCN-VFR    N =   8     Median =       2.500
SCN-IFR    N =   8     Median =       3.000
Point estimate for ETA1-ETA2 is      -0.000
95.9 Percent CI for ETA1-ETA2 is (-2.000,1.000)
W = 62.0
Test of ETA1 = ETA2  vs  ETA1 not = ETA2 is significant at 0.5635
The test is significant at 0.5416 (adjusted for ties)

Cannot reject at alpha = 0.05
```

Mann-Whitney Test and CI: DD-VFR, DD-IFR (Upper-tailed)

```
DD-VFR     N =   8     Median =       3.000
DD-IFR     N =   8     Median =       3.000
Point estimate for ETA1-ETA2 is      -0.000
95.9 Percent CI for ETA1-ETA2 is (-0.999,1.000)
W = 68.5
Test of ETA1 = ETA2  vs  ETA1 > ETA2 is significant at 0.5000
The test is significant at 0.5000 (adjusted for ties)

Cannot reject at alpha = 0.05
```

Mann-Whitney Test and CI: DD-VFR, DD-IFR (Two-tailed)

```
DD-VFR     N =   8     Median =       3.000
DD-IFR     N =   8     Median =       3.000
Point estimate for ETA1-ETA2 is      -0.000
95.9 Percent CI for ETA1-ETA2 is (-0.999,1.000)
W = 68.5
Test of ETA1 = ETA2  vs  ETA1 not = ETA2 is significant at 1.0000
The test is significant at 1.0000 (adjusted for ties)

Cannot reject at alpha = 0.05
```

Mann-Whitney Test and CI: DN-VFR, DN-IFR (Upper-tailed)

```
DN-VFR     N =   8     Median =       3.000
DN-IFR     N =   8     Median =       3.000
Point estimate for ETA1-ETA2 is      -0.000
95.9 Percent CI for ETA1-ETA2 is (-1.000,1.000)
W = 67.5
Test of ETA1 = ETA2  vs  ETA1 > ETA2
Cannot reject since W is < 68.0
```

Mann-Whitney Test and CI: DN-VFR, DN-IFR (Two-tailed)

```
DN-VFR     N =   8     Median =       3.000
DN-IFR     N =   8     Median =       3.000
Point estimate for ETA1-ETA2 is      -0.000
95.9 Percent CI for ETA1-ETA2 is (-1.000,1.000)
W = 67.5
Test of ETA1 = ETA2  vs  ETA1 not = ETA2 is significant at 1.0000
The test is significant at 1.0000 (adjusted for ties)

Cannot reject at alpha = 0.05
```

APPENDIX M: Wilcoxon Signed Ranks Test for Workload Ratings

VFR, Static Clear Weather during Daytime (SCD) vs. Static Clear Weather during Nighttime (SCN)

Subjects	Day	Night	d	Rank of d
1	1	3	2	(+) 7
2	1	2	1	(+) 5
3	2	4	2	(+) 7
4	1	1	0	2.5
5	2	4	2	(+) 7
6	3	3	0	2.5
7	2	2	0	2.5
8	1	1	0	2.5

H_0: $X_{0(VFR,\ SCN)} = X_{0(VFR,\ SCD)}$

H_1: $X_{0(VFR,\ SCN)} > X_{0(VFR,\ SCD)}$

$S_+ = (7+5+7+7) = 26$

$C_1 = 30$ [tabled value, $p(S+ \geq 30) = 0.055$]

Rejection Region: $S+ \geq C_1$

26 not $\geq$ 30, Do not reject H_0;

VFR workload at night is not significantly higher than VFR workload during the day when weather is static (alpha level approximately 0.05).

VFR, Dynamic Weather during Daytime (DD) vs. Dynamic Weather during Nighttime (DN)

Subjects	Day	Night	d	Rank of d
1	3	3	0	3
2	2	3	1	(+) 6.5
3	4	6	2	(+) 8
4	1	1	0	3
5	4	4	2	3
6	3	3	0	3
7	3	3	0	3
8	3	2	-1	(-) 6.5

H_0: $X_{0(VFR,\ DN)} = X_{0(VFR,\ DD)}$

H_1: $X_{0(VFR,\ DN)} > X_{0(VFR,\ DD)}$

$S_+ = (6.5+8) = 14.5$

$C_1 = 30$ [tabled value, $p(S+ \geq 30) = 0.055$]

Rejection Region: $S+ \geq C_1$

14.5 not $\geq$ 30, Do not reject H_0;

VFR workload at night is not significantly higher than VFR workload during the day when weather is dynamic (alpha level approximately 0.05).

VFR, Static Clear Weather during Daytime (SCD) vs. Dynamic Weather during Daytime (DD)

Subjects	Static	Dynamic	d	Rank of d
1	1	3	2	(+) 6.5
2	1	2	1	(+) 3.5
3	2	4	2	(+) 6.5
4	1	1	0	1.5
5	2	4	2	(+) 6.5
6	3	3	0	1.5
7	2	3	1	(+) 3.5
8	1	3	2	(+) 6.5

H_0: $X_{0(VFR, DD)} = X_{0(VFR, SCD)}$

H_1: $X_{0(VFR, DD)} > X_{0(VFR, SCD)}$

$S_+ = (6.5+3.5+6.5+6.5+3.5+6.5) = 33$

$C_1 = 30$ [tabled value, $p(S+ \geq 30) = 0.055$]

Rejection Region: $S+ \geq C_1$

$33 > 30$, Reject H_0;

VFR workload with dynamic weather is significantly greater than VFR workload with static weather, during day time (alpha level approximately 0.05).

VFR, Static Clear Weather during Nighttime (SCN) vs. Dynamic Weather during Nighttime (DN)

Subjects	Static	Dynamic	d	Rank of d
1	3	3	0	2.5
2	2	3	1	(+) 6
3	4	6	2	(+) 8
4	1	1	0	2.5
5	4	4	0	2.5
6	3	3	0	2.5
7	2	3	1	(+) 6
8	1	2	1	(+) 6

H_0: $X_{0(VFR, DN)} = X_{0(VFR, SCN)}$

H_1: $X_{0(VFR, DN)} > X_{0(VFR, SCN)}$

$S_+ = (6+8+6+6) = 26$

$C_1 = 30$ [tabled value, $p(S+ \geq 30) = 0.055$]

Rejection Region: $S+ \geq C_1$

26 not $\geq$ 30, Do not reject H_0;

VFR workload with dynamic weather is not significantly greater than VFR workload with static weather, during night time (alpha level approximately 0.05).

IFR, Static Clear Weather during Daytime (SCD) vs. Static Clear Weather during Nighttime (SCN)

Subjects	Day	Night	d	Rank of d
1	2	3	1	(+) 6.5
2	2	3	1	(+) 6.5
3	2	3	1	(+) 6.5
4	2	2	0	2.5
5	3	3	0	2.5
6	2	2	0	2.5
7	3	3	0	2.5
8	3	4	1	(+) 6.5

H_0: $X_{0(IFR,\ SCN)} = X_{0(IFR,\ SCD)}$

H_1: $X_{0(IFR,\ SCN)} > X_{0(IFR,\ SCD)}$

$S_+ = (6.5+6.5+6.5+6.5) = 26$

$C_1 = 30$ [tabled value, $p(S+ \geq 30) = 0.055$]

Rejection Region: $S+ \geq C_1$

26 not $\geq$ 30, Do not reject H_0;

IFR workload at night is not significantly higher than IFR workload during the day when weather is static (alpha level approximately 0.05).

IFR, Dynamic Weather during Daytime (DD) vs. Dynamic Weather during Nighttime (DN)

Subjects	Day	Night	d	Rank of d
1	5	5	0	3
2	3	3	0	3
3	3	4	1	(+) 7
4	2	2	0	3
5	2	3	1	(+) 7
6	2	2	0	3
7	3	3	0	3
8	4	3	-1	(-) 7

H_0: $X_{0(IFR,\ DN)} = X_{0(IFR,\ DD)}$

H_1: $X_{0(IFR,\ DN)} > X_{0(IFR,\ DD)}$

$S_+ = (7+7) = 14$

$C_1 = 30$ [tabled value, $p(S+ \geq 30) = 0.055$]

Rejection Region: $S+ \geq C_1$

14 not $\geq$ 30, Do not reject H_0;

IFR workload at night is not significantly higher than IFR workload during the day when weather is dynamic (alpha level approximately 0.05).

IFR, Static Clear Weather during Daytime (SCD) vs. Dynamic Weather during Daytime (DD)

Subjects	Static	Dynamic	d	Rank of d
1	2	5	3	(+) 8
2	2	3	1	(+) 5.5
3	2	3	1	(+) 5.5
4	2	2	0	2
5	3	2	-1	(-) 5.5
6	2	2	0	2
7	3	3	0	2
8	3	4	1	(+) 5.5

H_0: $X_{0(IFR, DD)} = X_{0(IFR, SCD)}$

H_1: $X_{0(IFR, DD)}$ not = $X_{0(IFR, SCD)}$

$S_+ = (8+5.5+5.5+5.5) = 24.5$

$C_1 = 32$; $C_2 = 4$ [tabled values, $p(S+ \geq 32) = 0.054 = p(S+ \leq 4)$]

Rejection Region: Either $S+ \geq C_1$ or $S+ \leq C_2$

24.5 not $\geq$ 32, 24.5 not $\leq$ 4; Do not reject H_0;

IFR workload with dynamic weather is not significantly different than IFR workload with static weather, during day time (alpha level approximately 0.05).

IFR, Static Clear Weather during Nighttime (SCN) vs. Dynamic Weather during Nighttime (DN)

Subjects	Static	Dynamic	d	Rank of d
1	3	5	2	(+) 8
2	3	3	0	3
3	3	4	1	(+) 6.5
4	2	2	0	3
5	3	3	0	3
6	2	2	0	3
7	3	3	0	3
8	4	3	-1	(-) 6.5

H_0: $X_{0(IFR, DN)} = X_{0(IFR, SCN)}$

H_1: $X_{0(IFR, DN)}$ not = $X_{0(IFR, SCN)}$

$S_+ = (8+6.5) = 14.5$

$C_1 = 32$; $C_2 = 4$ [tabled values, $p(S+ \geq 32) = 0.054 = p(S+ \leq 4)$]

Rejection Region: Either $S+ \geq C_1$ or $S+ \leq C_2$

14.5 not $\geq$ 32, 24.5 not $\leq$ 4; Do not reject H_0;

IFR workload with dynamic weather is not significantly different than IFR workload with static weather, during night time (alpha level approximately 0.05).

APPENDIX N: Wilcoxon Signed Ranks Test for Situation Awareness Ratings

VFR, Static Clear Weather during Daytime (SCD) vs. Static Clear Weather during Nighttime (SCN)

Subjects	Day	Night	d	Rank of d
1	24	27	3	(+) 3.5
2	22	17	-5	(-) 6.5
3	28	23	-5	(-) 6.5
4	32	24	-8	(-) 8
5	19	20	1	(+) 2
6	28	25	-3	(-) 3.5
7	26	26	0	1
8	31	27	-4	(-) 5

H_0: $X_{0(\text{VFR, SCN})} = X_{0(\text{VFR, SCD})}$

H_1: $X_{0(\text{VFR, SCN})} < X_{0(\text{VFR, SCD})}$

$S_+ = (3.5+2) = 5.5$

$C_1 = 30$; $C_2 = 6$ [tabled value, $p(S+ \geq 30) = 0.055 = p(S+ \leq 6)$]

Rejection Region: $S+ \leq C_2$

$5.5 < 6$, Reject H_0;

VFR situation awareness at night is significantly reduced compared to VFR situation awareness during the day when weather is static (alpha level approximately 0.05).

VFR, Dynamic Weather during Daytime (DD) vs. Dynamic Weather during Nighttime (DN)

Subjects	Day	Night	d	Rank of d
1	19	24	5	(+) 6
2	21	14	-7	7.5
3	17	16	-1	3
4	27	26	-1	3
5	20	19	-1	3
6	26	26	0	1
7	24	22	-2	5
8	21	28	7	(+) 7.5

H_0: $X_{0(\text{VFR, DN})} = X_{0(\text{VFR, DD})}$

H_1: $X_{0(\text{VFR, DN})} < X_{0(\text{VFR, DD})}$

$S_+ = (6+7.5) = 13.5$

$C_1 = 30$; $C_2 = 6$ [tabled value, $p(S+ \geq 30) = 0.055 = p(S+ \leq 6)$]

Rejection Region: $S+ \leq C_2$

13.5 not ≤ 6, Do not reject H_0;

VFR situation awareness at night is not significantly reduced compared to VFR workload during the day when weather is dynamic (alpha level approximately 0.05).

VFR, Static Clear Weather during Daytime (SCD) vs. Dynamic Weather during Daytime (DD)

Subjects	Static	Dynamic	d	Rank of d
1	24	19	-5	5.5
2	22	21	-1	1.5
3	28	17	-11	8
4	32	27	-5	5.5
5	19	20	1	(+) 1.5
6	28	26	-2	3.5
7	26	24	-2	3.5
8	31	21	-10	67

H_0: $X_{0(VFR, DD)} = X_{0(VFR, SCD)}$

H_1: $X_{0(VFR, DD)} < X_{0(VFR, SCD)}$

$S_+ = 1.5$

$C_1 = 30$; $C_2 = 6$ [tabled value, $p(S+ \geq 30) = 0.055 = p(S+ \leq 6)$]

Rejection Region: $S+ \leq C_2$

$1.5 < 6$, Reject H_0;

VFR situation awareness with dynamic weather is significantly reduced compared to VFR situation awareness with static weather, during day time (alpha level approximately 0.05).

VFR, Static Clear Weather during Nighttime (SCN) vs. Dynamic Weather during Nighttime (DN)

Subjects	Static	Dynamic	d	Rank of d
1	27	24	-3	5.5
2	17	14	-3	5.5
3	23	16	-7	8
4	24	26	2	(+) 4
5	20	19	-1	2
6	25	26	1	(+) 2
7	26	22	-4	7
8	27	28	1	(+) 2

H_0: $X_{0(VFR, DN)} = X_{0(VFR, SCN)}$

H_1: $X_{0(VFR, DN)} < X_{0(VFR, SCN)}$

$S_+ = (4+2+2) = 8$

$C_1 = 30$; $C_2 = 6$ [tabled value, $p(S+ \geq 30) = 0.055 = p(S+ \leq 6)$]

Rejection Region: $S+ \leq C_2$

8 not ≤ 6, Do not reject H_0;

VFR situation awareness with dynamic weather is not significantly reduced compared to VFR situation awareness with static weather, during night time (alpha level approximately 0.05).

IFR, Static Clear Weather during Daytime (SCD) vs. Static Clear Weather during Nighttime (SCN)

Subjects	Day	Night	d	Rank of d
1	29	22	-7	8
2	26	22	-4	5.5
3	27	24	-3	4
4	31	32	1	(+) 3
5	34	38	4	(+) 5.5
6	36	36	0	1.5
7	32	32	0	1.5
8	41	35	-6	7

H_0: $X_{0(IFR, SCN)} = X_{0(IFR, SCD)}$

H_1: $X_{0(IFR, SCN)} < X_{0(IFR, SCD)}$

$S_+ = (3+5.5) = 8.5$

$C_1 = 30$; $C_2 = 6$ [tabled value, $p(S+ \geq 30) = 0.055 = p(S+ \leq 6)$]

Rejection Region: $S+ \leq C_2$

8.5 not $\leq$ 6, Do not reject H_0;

IFR situation awareness at night is not significantly reduced compared to IFR situation awareness during the day when weather is static (alpha level approximately 0.05).

IFR, Dynamic Weather during Daytime (DD) vs. Dynamic Weather during Nighttime (DN)

Subjects	Day	Night	d	Rank of d
1	25	22	-3	7
2	21	23	2	(+) 5.5
3	21	21	0	1.5
4	31	29	-2	5.5
5	37	32	-5	8
6	36	35	-1	3.5
7	32	32	0	1.5
8	30	31	1	(+) 3.5

H_0: $X_{0(IFR, DN)} = X_{0(IFR, DD)}$

H_1: $X_{0(IFR, DN)} < X_{0(IFR, DD)}$

$S_+ = (5.5+3.5) = 9$

$C_1 = 30$; $C_2 = 6$ [tabled value, $p(S+ \geq 30) = 0.055 = p(S+ \leq 6)$]

Rejection Region: $S+ \leq C_2$

9 not $\leq$ 6, Do not reject H_0;

IFR situation awareness at night is not significantly reduced compared to IFR situation awareness during the day when weather is dynamic (alpha level approximately 0.05).

IFR, Static Clear Weather during Daytime (SCD) vs. Dynamic Weather during Daytime (DD)

Subjects	Static	Dynamic	d	Rank of d
1	29	25	-4	5
2	26	21	-5	6
3	27	21	-6	7
4	31	31	0	2
5	34	37	3	(+) 4
6	36	36	0	2
7	32	32	0	2
8	41	30	-11	8

H_0: $X_{0(IFR, DD)} = X_{0(IFR, SCD)}$

H_1: $X_{0(IFR, DD)}$ not = $X_{0(IFR, SCD)}$

$S_+ = 4$

$C_1 = 32$; $C_2 = 4$ [tabled values, $p(S+ \geq 32) = 0.054 = p(S+ \leq 4)$]

Rejection Region: Either $S+ \geq C_1$ or $S+ \leq C_2$

4 = 4, Reject H_0;

IFR situation awareness with dynamic weather is significantly different (reduced) compared to IFR situation awareness with static weather, during day time (alpha level approximately 0.05).

IFR, Static Clear Weather during Nighttime (SCN) vs. Dynamic Weather during Nighttime (DN)

Subjects	Static	Dynamic	d	Rank of d
1	22	22	0	1.5
2	22	23	+1	(+) 3.5
3	24	21	-3	6.5
4	32	29	-3	6.5
5	38	32	-6	8
6	36	35	-1	3.5
7	32	32	0	1.5
8	35	33	-2	5

H_0: $X_{0(IFR, DN)} = X_{0(IFR, SCN)}$

H_1: $X_{0(IFR, DN)}$ not = $X_{0(IFR, SCN)}$

$S_+ = 3.5$

$C_1 = 32$; $C_2 = 4$ [tabled values, $p(S+ \geq 32) = 0.054 = p(S+ \leq 4)$]

Rejection Region: Either $S+ \geq C_1$ or $S+ \leq C_2$

$3.5 < 4$; Reject H_0;

IFR situation awareness with dynamic weather is significantly different (reduced) compared to IFR situation awareness with static weather, during night time (alpha level approximately 0.05).

APPENDIX O: Transcriptions of Flight Communications and Retrospective Report for Pilot VFR01

VFR01 Flight Transcription

P: Pilot (Subject)
SP: Safety Pilot
R: Researcher
RAD: Roanoke Approach and Departure
ATIS: Automatic Terminal Information Service
Tower: Roanoke Tower
OAi: Other Aircraft 1, 2, 3, …i

Grey highlight = communications directly involving Cessna 61891

Some pilot-to-RAD communications from other aircraft are not heard (and thus do not appear in the transcription) because the controller is having some aircraft use different frequencies (RAD is always heard because it is transmitted on all three frequencies being used). Communications from other pilots using the same frequency as Cessna 61891 appear in the transcription.

Code	Time	Source	Communication
A01	0:12	P	Virginia Tech traffic, Cessna six-one-eight-niner-one, departing pattern north east, Virginia Tech.
A02	0:52	ATIS	Roanoke Regional Airport, information yankee-one-niner-five-four-Zulu, wind two-two-zero at five, visibility one-zero, clear skies, temperature eight, dew point minus three, altimeter three-zero-two-six, visual approaches runway two-four also departing runway two-four. Notices to airmen, the north one thousand one hundred twenty feet of runway one-five, three-three is closed. There is four thousand feet available of runway one-five, three-three. ILS at three-three is out of service, taxiway alpha is closed north of runway six, two-four. Terrain two-six-zero-feet AGL one thousand one hundred feet south of runway two-four centerline and one thousand eight hundred feet east of runway three-three centerline. Advised initial contact, information yankee. (*repeated once*)
A03	1:41	P	We may need to do a full stop taxi back. Half the runway is closed.
A04	1:46	SP	[inaudible] four-thousand.
A05	2:39	P	Roanoke approach, Cessna six-one-eight-niner-one.
A06	2:42	RAD	Cessna six-one-eight-niner-one, Roanoke Approach.
A07	2:45	P	Uh, yeah, Cessna six-one-eight-niner-one, we’re two miles east of Blacksburg, requesting touch-and-go to runway 33 at 4000 feet with yankee.

A08	2:55	RAD	Cessna six-one-eight-niner-one, squawk zero-three-three-one.
A09	2:58	P	Zero-three-three-one.
A10	3:04	RAD	[inaudible] three-five-kilo [inaudible] Roanoke Approach, good afternoon, altimeter three-zero-two-six.
A11	3:27	RAD	Cessna six-one-eight-niner-one, radar contact 4 miles east of Blacksburg, altimeter is three-zero-two-six five-zero point
A12	3:34	P	Roger that, uhh, eight-niner-one.
A13	4:29	OA1	Departure, Blueridge four-zero-four, checking in, passing four thousand for five thousand.
A14	4:33	RAD	Blueridge four-zero-four, Roanoke Approach, radar contact, turn right heading three-one-zero vector free to climb, climb and maintain one-zero-thousand.
A15	4:43	OA1	Ahh, one-zero-thousand, right turn to three-one-zero vector, free to climb, Blueridge four-zero-four.
A16	5:48	RAD	Cessna eight-niner-one, verify that after this touch-and-go runway 33, you are VFR back to Blacksburg?
A17	5:53	P	That's affirmative, eight-niner-one.
A18	6:13	RAD	Blueridge four-zero-four, turn right heading zero-five-zero, direct Montebello.
A19	6:18	OA1	Zero-five-zero, direct Montebello, Blueridge four-zero-four.
A20	6:30	RAD	Blueridge four-zero-four, climb and maintain one-two thousand.
A21	6:33	OA1	Up to one-two thousand, Blueridge four-zero-four.
A22	6:51	P	OK Roanoke, Cessna eight-niner-one, has the runway in site.
A23	6:55	RAD	Cessna eight-niner-one, enter left traffic runway 33, and contact the tower one-one-eight point three. [*participant does not to contact tower!*]
A24	7:00	P	Left traffic for three-three, eight-niner-one.
A25	7:04	RAD	Blueridge four-four, contact Washington Center, one-two-seven point niner-two.
A26	7:08	OA1	Twenty seven niner-two, Blueridge four-zero-four, switching, have a good day.
A27	8:45	RAD	November three-two-four-one-three, this is Roanoke Approach. November three-two-four-one-three, this is Roanoke Approach.
A28	9:12	RAD	Bearing seven-eight three, juliet-romeo contact Greensboro approach one-two-four point three-five.
A29	9:28	RAD	Foxtrot-four-one-two-lima-golf, Roanoke approach.
A30	9:36	RAD	Foxtrot-four-one-two-lima-golf, [inaudible] altimeter three-zero-two-six, still below radar coverage, report, ahhh, seven now.
A31	9:55	RAD	[South?] one-two-seven-three-uniform Roanoke approach, Roanoke altimeter three-zero-two-six.
A32	10:16	RAD	Cessna eight-niner-one, contact the tower, one-one-eight-point-three.

A33	10:20	P	[Cessna?], tower, eight-point-three.
A34	10:24	P	Hello tower, Cessna eight-niner-one is with you, ah, descending down, [inaudible].
A35	10:28	Tower	Cessna six-one-eight-niner-one! Roanoke Tower, make a hard right turn for me heading about one-two-zero for right now please, vector away from departure traffic.
A36	10:35	P	One-two-zero, eight-niner-one.
A37	10:38	Tower	Piedmont three-three twenty-six, wind two-four-zero at seven, runway two-four, cleared for take-off.
A38	10:43	OA2	Cleared for take-off, and what was heading for Piedmont thirty-three twenty-six?
A39	10:47	Tower	It's a right turn, heading at two-five-zero.
A40	10:49	OA2	Alright, two-fifty on a heading, cleared to go, runway two-four, Piedmont thirty-three.
A41	11:36	Tower	Cessna eight-niner-one, you can turn left heading zero-niner-zero, what are your intentions now?
A42	11:40	P	Zero-nine-zero, and our intentions are touch-and-go three-three, departure back to Blacksburg.
A43	11:46	Tower	Six-one-eight-niner-one, roger. Runway three-three, you're cleared touch and go. After the touch and go turn left heading two-five-zero maintain at or below four thousand five hundred.
A44	11:56	P	Roger that, cleared for touch-and-go three-three, and after departure turn left to two-five-zero, below forty-five, eight-niner-one.
A45	12:07	Tower	Piedmont three-three-twenty-six, contact departure, see you now.
A46	12:11	OA2	Contact departure, we'll see you, Piedmont three-three-twenty-six.
A47	13:26	Tower	Cessna eight-niner-one, uhh, we got some word that you needed to do some kind of data check or something, but I mean you're just going to do the touch-and-go and that's all it's going to need?
A48	13:33	P	That's affirmative, yeah, just an ordinary touch-and-go and back to Blacksburg.
A49	13:37	Tower	Okay, what does that have to do with this call about the data check or something?
A50	13:43	SP	Cessna, six-one-eight-niner-one, we're collecting some data in the plane with a GPS and TV camera, that's all sir.
A51	13:51	Tower	Okay, that's fine.
A52	13:55	SP	We, appreciate your help letting us do it on three-three.
A53	13:57	Tower	Yeah, sure, no problem.
A54	14:00	Tower	Wind check two-six-zero at seven.
A55	14:40		[Touchdown]

VFR01 Retrospective Report Transcription

P: Pilot (Subject)
R: Researcher

The times can be cross-referenced with the actual flight transcription.

Code	Cross-ref	Source	Communication
B01	0:12	P	What I'm doing right now, I just told traffic that I was departing the pattern to the north, north east. Telling them that I was going to Roanoke.
B02	0:52	P	Now, I've contacted ATIS. Right now, why the reason you don't hear ATIS, automatic terminal information service, is because it's [inaudible]. They were [changing?] it at the time, so I'm waiting for it to come on, that's why I just looked at my watch just a second ago. And it should come on and tell me the information around Roanoke airport. It's required to get that information in order to land at an airport. You're like [inaudible] to have that information. That's information "yankee" is telling me the wind, which runway it's favoring, runway two-four.
B03		R	Why do you say "yankee"?
B04		P	Umm yankee means the umm, every hour they have a different letter they use, yankee, alpha, bravo, charlie, delta, phonetic alphabet. And when you contact tower, you first tell them that you have that information yankee…ATIS is the weather information around that airport.
B05		P	Now, the reason why I say we need to do a full stop taxi-back because ATIS information for runway three-three says half the runway is actually closed. So I wasn't too sure if we had a chance to make it but it looked like a go. And I was kind of concerned about a touch-and-go so I decided we might do a full stop taxi-back. But they didn't see a problem with that, and I didn't see a problem with it. [inaudible]
B06		R	Is the ILS is out of service because half that runway is closed?
B07		P	Exactly.
B08		R	Not that the ILS is down for maintenance or something?
B09		P	Well, I'm not too sure they just told us on the ATIS that the ILS is out of service - they didn't tell us the reason why it's out of service.
B10	2:39	P	Oh, right now I'll contact Roanoke, I'm going to say who I am, where I'm at, and what I want.
B11	2:45		Now I told them who I was, where I was, and what I wanted. I told them I was two miles east of Blacksburg, climbing up

			to four thousand feet, and I was requesting a touch-and-go at runway three-three. Even though two-four was being used we contacted the tower prior to our flight and that's how they new we wanted a touch-and-go at three-three. Or they would have said two-four is being used and we just would have had to deal with that.
B12	2:55	R	What did that mean, "squawk" something?
B13		P	Now that squawk code, it's…alright, now when he told me to squawk code zero-three-three-one, what that is, is umm, on his radar screen, he'll get a bleep for Cessna six-one-eight-niner-one, and he'll know what altitude I'm at and where I'm at exactly on his radar screen. And that's the code that he wanted me to put in, in order for him to see me.
B14		P	And what I'm doing now, I'm just setting the power for cruise and right now I'm just having a nice cruise flight, maintaining four-thousand feet. Finger flying basically and not getting too stressed out in this situation.
B15		P	Now I'm just waiting for myself to see the airport. At this time, I wasn't 100% sure that I had the airport in site, but I wanted to be 110% sure that I had it in site. And that's when I contacted him, when I do have the airport in site.
B16	4:29	R	He's talking to other traffic, right?
B17		P	Right, he's talking to other traffic right now. I'm looking for "eight-niner-one", and that's how I know he's talking to me.
B18		P	Obviously right now, I'm just holding four thousand feet, flying directly to the airport. Umm, I'm checking my airspeed, my altitude, looking outside scanning for traffic at this point. My head's turning left and right, checking all my instruments, looking down, a conscious scan going on.
B19		R	What instruments are you maintaining? You maintain a certain altitude, a certain airspeed…
B20		P	Right now, I'm holding a certain altitude of four thousand feet because that's what I told him I was going to do that. When you're in controlled airspace with radar, you don't want to tell him where you are, you want to stay there. You want to stay at four thousand feet inbound to Roanoke. So, I want to maintain four thousand feet. My airspeed, indicated airspeed indicator, I want to be within certain limits on the airspeed indicator.
B21	5:48	R	Why do you have to verify?
B22		P	Umm, basically just for his concerns I guess. He really didn't mention why. He just wanted to know.
B23	6:13	P	Umm, before you saw me kind of fiddle with an instrument about ahh, a minute ago. That was, ahh, setting in the VOR [that's set on the field of perimeter?].
B24		R	Woodrum VOR?

B25		P	Yeah, the Woodrum VOR that last instrument on the top right corner, if you see that left of the radios, that was uhh, if you notice that the needles are kind of centered up and I'm flying…and notice that I'm holding that needle in the center.
B26	6:51	P	And then as he tells me to fly directly into Roanoke, that needle kind of moves around because I do have the airport in site. And this is a VFR flight, so I'm not really flying by instruments, I just use that as a back-up. [inaudible].
B27	7:00	R	What's your heading right now?
B28	7:04	P	My heading is, ahh, almost zero-eight-zero at this point. Heading almost directly east.
B29		R	That's because the controller told you to go zero-eight-zero?
B30		P	Well no, not really, not necessarily. I was flying to Roanoke. Before I got into their airspace, I told them where I was, where I wanted to go. I told them four thousand feet heading to Roanoke. They just accept that.
B31		R	They don't assign you a vector?
B32		P	Umm, not for this particular flight. Basically, just, if you're an IFR flight, they'll tell you what heading to go.
B33		P	There is a part in here of the flight where he tells me to take a right turn to one-two-zero because there was traffic that was leaving runway one-five, taking off runway one-five, and I was kind of in the middle of his approach, oh, his departure path, so they told me to take a right turn to get out of his way. And that's something you have to listen to ATC.
B34		P	Uh, now I'm just holding and maintaining four thousand feet.
B35		R	Did you already confirm that you saw the airport yet?
B36		P	Yeah, I confirmed that I had the airport in site. He told me to enter left traffic pattern for runway three-three and contact tower. Umm, at this point I haven't contacted tower yet because I wasn't on the left traffic pattern for runway three-three.
B37	8:45	P	So what I'm doing now, I'm starting to descend, I might… Oh, no, still maintaining four thousand feet. In just a little while…I'll start descending to traffic pattern altitude which is a thousand feet above the airport elevation, which was twenty-one hundred feet. *[NOTE: ROA airport elevation is 1175 ft MSL and pattern altitude is actually 800 feet above this (1975 ft MSL). He must have been confusing BCB (2132 ft MSL airport elevation with traffic pattern altitude 1000 ft above this) with ROA]*.
B38		P	More power there, kinda of slowing up on that. Sometimes the throttle comes out.
B39	9:28	P	The reason why you don't hear the other side of the traffic talking is because ATC is talking on three different frequencies at the same time, but he receives one at a time on

			the other frequencies. You can hear him but you can't hear the other [inaudible].
B40	9:55	R	Your hand is on the throttle there?
B41		P	Yeah, hand is on the throttle, I'm starting to descend now to the airport. I set my power.
B42		P	I start monitoring tower. Make sure they weren't trying to contact me on tower.
B43		P	Right, there what I am doing with my finger there? I was setting trim so I wouldn't have to have too much torque on the yoke while I'm flying.
B44	10:16	P	Now he told me to contact tower. And I acknowledged by saying that I'm going to tower. And now I'll contact tower.
B45	10:28	P	OK, there's my hard right turn. There's my hard right turn that I was talking about earlier. Right now we're kinda crossing over the departure end of runway one-five and there was an airplane taking off to our left side. And we're just flying by. We were definitely clear, out of its way.
B46		R	[inaudible], telling you to do the hard right?
B47		P	Yeah, we just, hurray up, you know, more like an expedite. Everything went fine.
B48		R	Now, are you in final approach here? Or are you coming back on your…
B49		P	No, right now I'm kind of flying away from the airport. Well, not really away from the airport, the airport is to my left, where I just pointed, that's where the airplane was departing.
B50		R	Oh, okay.
B51	11:36	P	He told me to turn back [inaudible].
B52	11:56	P	Now what I just did there was acknowledge exactly what he told me.
B53			Now I'm turning back to do my [inaudible], back to the airport and he told me I was cleared for touch-and-go, runway three-three. So I basically have the whole airport to myself.
B54		P	Setting power down. Carb heat, carburetor heat, basically engine-heated air going through the carburetor. I'm starting my descent to land. Adding flaps here. [inaudible] on the air speed indicator, that's how I know it's safe for me to use flaps and I wont create any flap damage.
B55		R	How many degrees of flaps did you use?
B56		P	I used about ten degrees at this point to get me down a little quicker. It kind of gets be prepared for the final approach.
B57		P	Right now I should be on base at this point. Now on base I had twenty degrees for flaps, I didn't put any flaps at this point – now I'm putting ten degrees. I'm on a very extended left base for runway three-three.
B58	14:00	P	Okay, now I'm on final.
B59		P	Okay, I'm almost touching down right at this point. Actually

			the video's a little ahead…
B60		R	Well, I recorded about a minute after you landed.
B61		P	Okay.
B62		R	Is that what you're thinking?
B63		P	Yeah, well it's not a minute, it looks like it's it about five seconds off, the voice and the video. The voice comes first then the video. [*the subject is incorrect, the video and audio are time synchronized*]
B64	14:40	P	See when I move to the right, that's when…the video goes to the left, that's when we landed. The reason why I'm doing that, I'm landing, I'll show you, here we go, we just landed. Okay, now you notice I had to put full left aileron. Crosswind - I had the wind coming to my left side, and it's just kind of a safety margin knowing that [inaudible] even though I'm on the ground.
B65		R	Did the flaps stay down the whole time?
B66		P	No, I raised everything back up, I cleaned up once the touch-and-go was accomplished.

APPENDIX P: Transcriptions of Flight Communications and Retrospective Report for Pilot IFR01

IFR01 Flight Transcription

P: Pilot (Subject)
SP: Safety Pilot
R: Researcher
RAD: Roanoke Approach and Departure
ATIS: Automatic Terminal Information Service
Tower: Roanoke Tower
OAi: Other Aircraft 1, 2, 3, …i

Grey highlight = communications directly involving Cessna 61891

Some pilot-to-RAD communications from other aircraft are not heard (and thus do not appear in the transcription) because the controller is having some aircraft use different frequencies (RAD is always heard because it is transmitted on all three frequencies being used). Communications from other pilots using the same frequency as Cessna 61891 appear in the transcription.

Code	Time	Source	Communication
C01	0:21	OA1	Danville traffic, this is Warrior, Warrior-eight-four-six-one-tango, approximately one mile north of the airfield, [inaudible] thousand feet, [inaudible] VOR outbound, two-zero approach, [inaudible] what's your altitude sir?
C02	0:39	P	Okay safety pilot, you want to take the plane for me?
C03	0:41	SP	I have the plane.
C04	0:42	P	You have the plane.
C05	0:44	SP	I got it right here.
C06	0:45	P	Thank you.
C07	0:46	SP	Sorry about that.
C08	0:59	OA1	Twin Cessna out of Danville, what's your position and altitude sir?
C09	1:03	P	Okay, I have the plane.
C10	1:04	SP	You have the pane.
C11	1:05	OA2	Okay, we're five miles to the north of the field, ahh, right now we're going down through four thousand three-hundred, pitching to enter downwind for two at Danville.
C12	1:15	OA1	Eight-four-six-one-tango, we're approximately eight miles north of the airfield tracking zero-one-two tracking radial outbound at two-thousand.
C13	1:21	ATIS	Roanoke Regional Airport information, quebec. One-eight-five-four-zulu weather. Wind zero-niner-zero at six, visibility one-zero, ceiling four-thousand-six-hundred, temperature four, dew point minus six, altimeter three-zero-three-zero.

			Visual approach in use, landing and departing runway six. Notices to airmen, taxiway alpha-two closed. North, one-hundred and fifty feet of runway one-five three-three ungrooved. Six-hundred fifty foot crane and building obstructing one-hundred feet south of runway two-four, eighteen-hundred feet east of runway three-three. All aircraft advised, you've received quebec. (*this first part repeated*) Roanoke Regional Airport information, quebec. One-eight-five-four-zulu weather. Wind zero-niner-zero at six.
C14	2:29	P	Roanoke approach, Cessna six-one-eight-niner-one.
C15	2:38	RAD	Cessna six-one-eight-niner-one, Roanoke approach.
C16	2:42	P	On approach, Cessna six-one-eight-niner-one, Cessna 172, approximately twenty miles to the west, four-thousand-five-hundred. Like to practice ILS three-three, and land or do a touch-and-go on three-three, and direct Virginia Tech VFR.
C17	2:58	P	With quebec.
C18	3:08	RAD	Cessna six-one-eight-niner-one, squawk zero-three-two-two.
C19	3:12	P	Zero-three-two-two.
C20	3:22	OA3	Roanoke approach, one-niner-three-three-mike with you at two-thousand-one-hundred, climbing to five-thousand.
C21	3:28	RAD	One-niner-three-three-mike, Roanoke approach, you're radar contact, climb and maintain five-thousand.
C22	3:34	OA3	Five-thousand, three-three-mike.
C23	3:44	RAD	Cessna six-one-eight-niner-one, you're radar contact, five miles southeast of Blacksburg airport showing four-thousand-four-hundred now.
C24	3:52	P	Four-thousand-five-hundred, eight-niner-one.
C25	3:55	RAD	Alright, heading one-one-zero for now. Vectored for ILS three-three, final approach course, maintain VFR. And we'll decide when we get closer whether we're going to do the touch-and-go on three-three or maybe circle to six. Runway six is active.
C26	4:09	P	Affirm, one-one-zero VFR, eight-niner-one.
C27	4:12	RAD	It's just going to be the one touch-and-go and back to Blacksburg?
C28	4:14	P	Affirmative.
C29	4:44	SP	I presume if they wont let you touch-and-go on three-three, they wont let you land there either?
C30	4:50	P	We'll do a touch-and-go on whatever runway they give us I guess. Six was favored on the wind.
C31	5:00	SP	Hey [Researcher], do you want to do, umm…would you rather do a full stop on three-three? Or touch-and-go on another runway? If they wont give us…we don't know, it'll depend on traffic, that's what it'll depend on.
C32	5:17	R	Preferably full stop on three-three.
C33	5:20	SP	Okay.

C34	5:30	SP	Because you can stop and hold short, huh [Pilot]?
C35	5:32	P	Yeah.
C36	5:33	RAD	One-niner-three-three-mike, turn right heading one-zero-zero. When receiving Lynchburg proceed direct.
C37	5:41	OA3	One-zero-zero. When receiving Lynchburg proceed direct, three-three-mike.
C38	6:41	OA4	Roanoke departure, Piedmont thirty-four-forty-nine, out of two-[point?]-five, for five-thousand, turning right heading one-eight-zero.
C39	6:47	RAD	Piedmont thirty-four-forty-nine, radar contact, climb and maintain one-zero-thousand.
C40	6:52	OA4	Climb and maintain one-zero-thousand, Piedmont thirty-four-forty-nine.
C41	7:53	RAD	Piedmont thirty-four-forty-nine, continue right turn heading two-two-zero. Join victor-one-zero-three, resume your own navigation.
C42	8:00	OA4	Two-two-zero, join victor-one-zero-three [inaudible].
C43	8:12	RAD	King Air niner-five-five-romeo-alpha, Roanoke departure, radar contact, climb and maintain one-zero-thousand.
C44	8:40	RAD	King Air five-romeo-alpha, you can turn left proceed direct [inaudible].
C45	8:52	RAD	Skylane four-two-six-sierra-papa, contact Atlanta Center, one-three-two-point-niner. See you now.
C46	8:59	OA5	One-three-two-point-niner, four-two-six-sierra-papa.
C47	9:22	RAD	Twin Comanche eight-two-three-three-yankee, Roanoke approach.
C48	9:30	RAD	Alright, I've got you [inaudible] this is going to be a full route for you here, and let me know when you're ready to copy.
C49	9:38	RAD	Twin Comanche eight-two-three-three-yankee is cleared to the Charlotte airport. It's going to be via direct to Roanoke, direct to Roanoke, then victor one-zero-three, Greensboro, victor one-forty-three, gizmo, direct Charlotte. Climb and maintain six-thousand. Expect eight-thousand within one-zero minutes, after you departure. Departure control frequency, one-two-six-point-niner. Squawk six-five-two-six, hold for release.
C50	10:24	RAD	Okay, which runway and about how soon until you're ready to go?
C51	10:31	RAD	Okay, hold for release, give me a call when you're ready to go.
C52	10:35	RAD	King Air niner-five-five-romeo-alpha, contact Washington Center one-two-seven-point-niner-two, we'll see you.
C53	10:44	OA6	Single Cessna niner-one-eight-delta-tango with you level at six-thousand five-hundred.
C54	11:04	RAD	Beechjet triple-one-charlie-x ray, Roanoke departure, radar contact, climb and maintain one-zero-thousand.

C55	11:26	RAD	Skylane three-three-mike, say your altitude.
C56	11:28	OA3	Ahh, fifty knots at five-thousand.
C57	11:30	RAD	Thanks.
C58	11:34	RAD	Is your transponder working okay there for ahh, three-three-mike? Showing a blank.
C59	11:39	OA3	Ahh, three-three-mike, it's blinking, looks like it works.
C60	11:42	RAD	Alright.
C61	11:44	RAD	Citation one, err, Beechjet triple-one-charlie-x ray turn left, left turn three-zero-zero
C62	11:54	OA6	Single Cessna niner-one-eight-delta-tango with you.
C63	12:02	RAD	Okay, this november-one-eight-delta-tango, I don't have you on radar. You might go back to your other frequency and check with them, ahh, you're not in my airspace at this time.
C64	12:11	OA6	Okay, thank you.
C65	12:30	RAD	Twin Comanche three-three-yankee, roger. You are released for outgoing approach, give me a call then when airborne on one-two-six-point-niner. We wont go all the way to Roanoke. Once I get you on radar, we'll angle down towards, uhh, Taber so to join victor one-zero-three.
C66	12:46	RAD	Altimeter is three-zero-three-zero.
C67	13:04	OA7	Piedmont thirty-four-zero-two, Roanoke approach, good afternoon. descend and maintain one-zero thousand and expect the visual approach, left downwind runway six.
C68	13:16	OA6	Roanoke approach, Cessna niner-one-eight-delta-tango.
C69	13:20	RAD	November-delta-tango(!), will you just stand by for a minute, I don't have you on radar right now and I've got a lot of different things going on at the moment.
C70	13:28	RAD	Beechjet triple-one-charlie-x ray, turn left, direct Bluefield.
C71	13:39	RAD	Cessna six-one-eight-niner-one turn left, left-turn heading zero-seven-zero.
C72	13:44	P	Left zero-seven-zero, eight-niner-one.
C73	14:00	RAD	Skylane one-niner-three-three-mike, contact Roanoke approach please on one-three-five-point-zero [*Smith Mountain Lake*].
C74	14:12	OA3	One-three-five-point-zero for three-three-mike, good day.
C75	14:14	RAD	Good day.
C76	14:17		Beechjet triple-one-charlie-x ray, contact Washington Center, one-two-seven-point-niner-two, see ya now.
C77	14:31	RAD	Piedmont thirty-four-zero-two, descend and maintain six-thousand.
C78	14:45	RAD	Piedmont thirty-four-forty-nine, contact Greensboro approach, one-two-zero-point-niner, we'll see you now.
C79	14:52	OA4	One-two-zero-point-niner, Piedmont thirty-four-forty-nine, so long.
C80	14:56	RAD	Alright now, november-niner-one-eight-delta-tango, Roanoke

			approach, what's your request?
C81	15:01	OA4	Yes, ahh, eight-delta-tango, Greensboro said they were having difficulty handing me off to you VFR, so we're at twenty-five for Roanoke, at six-thousand-five-hundred feet, squawking two-zero-zero-five.
C82	15:13	RAD	Alright, Centurion eight-delta-tango, ident please.
C83	15:17	OA4	Eight-delta-tango, ident.
C84	15:23	RAD	Centurion niner-one-eight-delta-tango, you're radar contact about two-two miles southwest of the Roanoke vortex. I'm showing six-thousand four hundred. Roanoke altimeter three-zero-three-zero.
C85	15:34	OA4	Eight-delta-tango, thank you.
C86	15:38	RAD	Cessna eight-niner-one, turn left heading zero-six-zero. Suggested altitude for the ILS approach will be three-thousand-eight-hundred.
C87	15:46	P	Zero-six-zero, we'll descent to three-thousand-eight-hundred, eight-niner-one.
C88	15:54	RAD	Piedmont thirty-four-zero-two, roger, ahh, that's on request. I'd rather put you on six. Any particular reason you don't want to do six?
C89	16:08	RAD	Alright, we're going to plan a left downwind which is basically straight ahead from where you are now. Maintain six-thousand, expect left downwind six.
C90	16:22	P	[Researcher], whatever runway they give me do you want a full stop or touch-and-go [inaudible].
C91	16:27	SP	Well, when they go to the tower, right? We want to request touch-and-go and if they won't give us that we want a full stop on three-three.
C92	16:33	R	Correct.
C93	16:34	P	Okay.
C94	16:35	SP	Oh, I'm sorry, I didn't…
C95	16:44	RAD	Twin Comanche eight-two-three-three-yankee, ident.
C96	16:48	OA8	Three-three-yankee, ident.
C97	16:54	SP	You ought to be able to hold well short of six.
C98	16:54	RAD	Piedmont thirty-four-zero-two, descent and maintain four-thousand-two-hundred.
C99	17:06	RAD	Twin Comanche three-three-yankee, radar contact over Blacksburg, I'm showing five-thousand-five-hundred?
C100	17:11	OA8	Uhh, that's affirmative.
C101	17:13	RAD	Okay, Twin Comanche three-three-yankee, maintain…I'll tell you what, climb and maintain eight-thousand. Eight thousand, good rate up [through?] seven for me if you can. And heading one-zero-zero vector to join victor one-zero-three south of Roanoke.
C102	17:28	OA8	Okay, we'll step on it and get up [through?] seven, one-zero-zero.

C103	17:31	RAD	Piedmont thirty-four-zero-two, descend and maintain four-thousand-two-hundred.
C104	17:39	RAD	Cessna eight-niner-one, turn left heading zero-three-zero.
C105	17:43	P	Left zero-three-zero, eight-niner-one.
C106	18:12	RAD	Piedmont thirty-four-zero-two, verify you have the airport in site.
C107	18:18	RAD	Cleared visual approach left downwind six, Piedmont thirty-four-zero-two.
C108	18:25	RAD	Cessna six-one-eight-niner-one, turn left heading zero-two-zero.
C109	18:30	P	Left zero-two-zero, eight-niner-one.
C110	18:33	RAD	The Twin Comanche three-three-yankee, you can go back to a regular climb right now, I was trying to get you above some sixty-five hundred traffic which we've done, thank you.
C111	18:40	OA8	Twin Comanche, roger.
C112	18:42	RAD	Piedmont thirty-four-zero-two, tower, one-one-eight-point-three.
C113	19:11	RAD	And Cessna six-one-eight-niner-one, you're four miles from Vinton, turn left heading three-six-zero, maintain three-thousand-eight-hundred until established on localizer you're cleared ILS runway three-three approach.
C114	19:20	P	Left three-six-zero, three-thousand-eight-hundred until established, cleared ILS three-three approach, eight-niner-one.
C115	19:30	RAD	Twin Comanche three-three-yankee, turn right heading one-two-zero.
C116	19:34	OA8	One-two-zero, three-three-yankee.
C117	20:08	RAD	[inaudible] calling Roanoke, say again?
C118	20:38	RAD	Blue Ridge four-zero-four, Roanoke departure, did you call?
C119	20:45	RAD	Blue Ridge four-zero-four, Roanoke departure, you're radar contact, climb and maintain niner-thousand.
C120	21:06	RAD	Beechjet two-one-five-tango-papa, Roanoke approach. I do have the flight plan. What, ahh, what is the destination and on course heading out of Pulaski?
C121	21:27	RAD	Alright, Beechjet two-one-five-tango-papa, you ready to copy that?
C122	21:34	RAD	Alright, Beechjet two-one-five-tango-papa is cleared to the bravo-india-victor airport as filed. Climb and maintain six-thousand. Expect [flight level?] three-five-zero, one-zero minutes after departure. Departure control frequency one-two-six-point-zero, squawk two-four-six-one, hold for release.
C123	22:10	RAD	Blue Ridge four-zero-four, turn left, direct Montebello.
C124	22:16	RAD	Cessna six-one-eight-niner-one, you're at Vinton, contact tower one-one-eight-point-three and he will assign which runway for touch-and-go.

C125	22:23	P	Eighteen-three, eight-niner-one.
C126	22:26	RAD	Alright, Beechjet five… *[transmission cut off as pilot (subject) switches frequency from RAD to Tower]*
C127	22:34	P	Calling tower Cessna eight-niner-one on the ILS three-three request a touch-and-go to runway six if not then full stop to runway six.
C128	22:43	SP	Three!
C129	22:44	P	Three-three, I'm sorry, runway three-three.
C130	22:45	Tower	[inaudible] continue.
C131	22:47	P	I say again? Eight-niner-one.
C132	22:59	Tower	And, ahh, six-one-eight-niner-one, just ahh, continue [inaudible] you can plan a right base for runway six when you're ready.
C133	23:04	P	Plan a right base six eight-niner-one.
C134	23:15	Tower	Piedmont thirty-four-zero-two, right turn [whenever?] nine-point-nine.
C135	23:21	SP	You asked for six, so you got six. Can we go back and ask for either full stop or touch-and-go on three-three?
C136	23:27	Tower	Piedmont thirty-three-twenty-six, cleared for takeoff runway three-three, turn left heading two-five-zero.
C137	23:33	OA9	Cleared for take-off, that'll be left two-five-zero, Piedmont thirty-three-twenty-six.
C138	23:37	Tower	Piedmont thirty-four-zero-two, right turn, ground point-nine.
C139	23:40	OA10	Thirty-four-zero-two.
C140	23:43	P	[inaudible] eight-niner-one, like to touch-and-go three-three [inaudible].
C141	23:46	Tower	Eight-niner-one, that'll work just fine, runway three-three cleared touch-and-go.
C142	23:52	P	Cleared for touch-and-go three-three, Cessna eight-niner-one.
C143	24:37	Tower	Piedmont thirty-three-twenty-six, contact departure, good day.
C144	24:40	OA9	[inaudible], thirty-three-twenty-six.
C145	25:28	OA9	Tower, thirty-three-twenty-six, ahh, ahh, eighteen-three, there's no one answering.
C146	25:35	Tower	One-two-six-point-nine.
C147	25:37	OA9	Thank you.
C148	25:39	OA11	[inaudible] zero-two-zero-zulu we're just on the north side of the mountain now at the second site, about a mile south of the centerline of six two-four
C149	25:49	Tower	Two-zero-zulu, roger.
C150	26:57	P	I am at sixteen-sixty, decision height, breaking out.
C151	28:13		[Touchdown]

<u>IFR01 Retrospective Report Transcription</u>

P: Pilot (Subject)
R: Researcher

The times can be cross-referenced with the actual flight transcription.

Code	Cross-ref	Source	Communication
D01	0:21	R	What's ATC doing now? Are they just communicating with other traffic?
D02		P	Umm, right now we're on the unicom, number one radio, so I had not switched to number two where ATC is. We are not talking to…we hadn't heard Roanoke yet.
D03	0:39	R	What altitude do you do the switch at? Do you remember?
D04		P	Umm, from number one to number two?
D05		R	When you put the hood on?
D06		P	I'm thinking. I don't know. I think at like, thirty-eight hundred.
D07	1:21	P	That's when I switched to com two.
D08		R	Now what does that mean, switching from one to two?
D09		P	We had two radios and you can switch the radio you transmit on.
D10		R	So when you switched to two, that's Roanoke?
D11		P	Well I programmed Roanoke in there.
D12		R	Is that ATIS at Roanoke?
D13		P	That's ATIS, yeah.
D14		R	So, what heading are you flying now?
D15		P	Right now I'm flying heading one-two-zero.
D16	2:29	R	And you set that?
D17		P	I set that. I knew that would get me in a rough heading to general area of where they would want me to go.
D18	2:58	R	What's that mean?
D19		P	I told him I had an ATIS code quebec. Each hour they change it. [inaudible].
D20	3:55	P	I'm flying heading one-twenty and the initial heading he gives me is one-one-zero so we're only ten degrees off which wasn't too bad.
D21		R	Now he's just going to give you different vectors depending on the traffic in the area?
D22		P	Yep.
D23		R	Everybody's using runway six so [inaudible] we're going out of the way because we're going to runway three-three.
D24		R	Did he give you a specific altitude?
D25		P	He asked me what my altitude was and verified on his radar.

			He sees my altitude in hundreds of feet. So he saw me at forty-four, but I was going forty-five.
D26		R	Does air traffic control just give you vectors or do they usually give you an altitude? Or all the traffic…
D27		P	In IFR they actually give you an altitude. Since I'm VFR he just told me to maintain VFR which means altitude my discretion.
D28		R	Oh, okay.
D29	4:50	P	What are you doing, back and forth there? Is that throttle and trim?
D30		P	Uhh, yeah, trim's on the bottom right now…right now my hand's on the throttle.
D31		P	I'm used to flying in the right seat and my right hand is used to grabbing something so when I'm over there I'm sorta awkward, so…grabbing the throttle [inaudible].
D32	5:32	R	Do you remember what, ahh, airspeed you were flying?
D33		P	Hundred and twenty miles per hour indicated.
D34		R	So right now it's smooth sailing? You're just making sure you're on the correct vector?
D35		P	Yep. There you see me looking at my compass, I noticed my compass was off, I adjusted to correct [inaudible] then I corrected for the heading.
D36		P	They're just taking me out towards the Smith Mountain Lake area where the localizer is and I'll intercept that somewhere out there...small turns to the left.
D37	6:41	R	What are you doing up here?
D38		P	I'm identifying the Vinton NDB – non directional beacon. Which is the [inaudible].
D39		R	Is that over here? That beacon?
D40		P	That's Morse code. You identify it by Morse code.
D41		P	And what that was was 'v-i-t' in Morse code. I'll identify some other things down the road.
D42		P	Here I'm putting the tower frequency in the standby on my radio because I know that'll be my very next frequency. Trying to minimize my workload.
D43		R	This was all [inaudible] at some point, like what was on the radio stack?
D44		P	Yeah, just dialed in eighteen-three here. Which was [inaudible].
D45	7:53	R	What are all these different ones?
D46		P	This is Tech unicom. That's Tech AWOS. That's ILS at three-three, localizer frequency. I originally had ATIS in there which is…but now I put tower, approach/departure tower. I think that was left in there I didn't so that. [*sketch of this is in subject's file folder*].
D47		R	Roanoke what?

D48		P	That's uh, Roanoke departure or approach, depends on which way you're going, in or out. Same people.
D49	8:40	R	Now, how do you know when you're supposed to intercept and then follow the needles?
D50		P	He'll eventually give me a heading and tell me to maintain that heading until established on the localizer and then cleared ILS approach. Once he tells me I'm cleared for approach then I can turn as necessary to maintain my own navigation on the localizer. Otherwise I'd still have to hold the heading he last told me.
D51	9:30	R	So this is a straight-in approach to three-three. Do you know what angle you intercepted the localizer?
D52		P	He told me to fly a heading of north, which was…I could not give you the angle. Heading north.
D53		R	And acquisition is like eight miles out or something?
D54		P	It's generally just outside of Vinton NDB. [inaudible] a couple [inaudible] to Vinton. I think Vinton is about six miles…five or six mile to the south of the airport. [inaudible]
D55		R	Now you haven't reached Vinton NDB yet, right?
D56		P	Nope.
D57	10:44	R	Are you tracking that NDB?
D58		P	No, I'm monitoring it, it should always point to my left. But right now all I'm doing is just flying the heading he gave me.
D59		R	Oh, okay.
D60		P	If you want radar contact they'll tell you go direct to the Vinton NDB then you put in a approach.
D61		P	Right now I'm just depending totally on the controller to tell me what to do. Otherwise I'd be navigating off Vinton.
D62	11:34	R	Is there a separate, to get the signal from the Vinton NDB is that a programmed system?
D63		P	In the bottom right hand instrument, there's another radio [inaudible] it points to the station, like two-nine-two, it points to where the station is [inaudible] Roanoke.
D64	12:30	R	So nothing going on here? Just scanning, umm, three or four instruments?
D65		P	Yeah. Occasionally, you'll see me look over to the right like right there. I'm looking at my fuel gauges, oil pressure, oil temperature, ammeter. Those are not right in my [field?], so they're easy to forget sometimes.
D66		P	Right now I'm going to find again Localizer and ILS, that's again Morse code. I'm looking down at my [inaudible] right now [inaudible]. If I'm looking down and I look back up I'm all [inaudible]
D67	13:20	R	What was going on there?
D68		P	Greensboro was trying to hand him off to Roanoke…and the controller at Roanoke was too busy, he was getting a little

			aggravated with him.
D69		R	Oh.
D70	13:39	R	I'm assuming he's telling you to do that just because there's other traffic?
D71		P	What he's doing is he's slowing making my angle, this might be the localizer, and I've got a good angle off of him, he's slowing angling me in.
D72		R	Oh, okay.
D73		P	The heading I was on, one-one-zero, that was taking me actually away from the airport. He's got to start turning me back toward the airport sometime.
D74		P	So the heading he has me on now is almost ninety degrees I'm almost perpendicular to the approach course.
D75	14:31	R	Is that the approach plate?
D76		P	Yeah, I'm probably looking at, ahh…[inaudible]
D77	15:01	R	How does the hood work? How is that obstructing your view?
D78		P	It does a good job.
D79		R	Hmm, I didn't see…I didn't actually see the front.
D80		P	You can't see out of that thing. That thing is…that's a good hood. You're looking out of tunnel vision. So if I have to look at an approach plate, I have to look down. Whereas if I were flying with natural conditions with no restriction on my head, I can actually look at the approach plate [inaudible].
D81	15:54	P	Thirty-eight hundred is the recommended altitude for a flight approach in VFR, but I can do what I want. In real life he would have demanded me to go down to thirty-eight hundred.
D82	16:44	R	You haven't…you're not lined up with the localizer yet?
D83		P	No, he's got my heading zero-six-zero, which is exactly ninety degrees off from the approach course. Right now I'm perpendicular as I can be, about ninety degrees off the course, approaching it.
D84	17:13	R	Based on the air traffic controller, can you tell about how many planes he's trying to direct?
D85		P	Umm, I bet he's got at least a dozen.
D86	17:39	P	A lot of times you'll here him talk…a lot of times you'll here him talk and there's no one responding, he's talking to several different frequencies and we're not on that frequency that the other guy is talking.
D87		P	Right now he's got me on zero-three-zero, that's exactly sixty degrees off the approach course. Now I went from ninety degrees to sixty degrees angle. He's slowly turning me in.
D88	18:30	P	Now he's got me fifty degrees off.
D89		P	Sometimes he'll give you all sorts of stuff at once, that's when your workload really gets going. He'll give you heading, an altitude, and a clearance for the approach.

D90	19:11	R	That's why it was probably a little confusing at the end. I think you said "six", and you meant three-three?
D91		P	Yeah that was on tower, we're still on approach right now.
D92		R	Oh okay.
D93		P	Right now he's turning me in right at, umm, on a heading of north, which is thirty degrees off. By the time I got to north I looked at my CDI, course deviation indicator, and it told me I was almost right on course so I just went ahead and continued my turn to a heading of three-three-zero, which is for runway three-three. And that worked out well. And now I'm waiting for my glide slope needle to intercept. About the time he tells me that is when I'm over Vinton NDB. Then my Vinton NDB needle swings, glide slope comes, and he tells me to contact the tower, so lots going on right there that hadn't come up yet.
D94	20:38	R	If I'm seeing that right, that's lined up with the localizer
D95		P	Yeah, I did pretty good. It didn't get much off. I don't think it got more than a dot off…if it did that much.
D96	21:06	R	Now do you do anything special between the time you intercept the localizer and until you intercept the glide slope? Do you have to get the speed…a particular speed or anything?
D97		P	Umm, not really. I do like to keep it at cruise airspeeds because at Roanoke everyone is always passing you and everything and everyone is always telling you to peddle faster or go faster on the airspeed so I'm just keeping it cruise power.
D98	22:10	R	Looks like that the needle dropped, the glide slope needle?
D99		P	It's almost…almost on glide slope. The perpendicular, right in the middle, the…
D100	22:16	P	That needle's moving now?
D101		R	Yeah.
D102		P	I'm hitting my timer for missed approach, and it does have me right on…glide slope. So all things happening at one time.
D103	22:34	P	What happened there was, uh, I said the wrong runway, [safety pilot] corrected for me, and I tried to go back and correct it but they were talking to me so we stepped on each other. And I said, "say again". So I said "say again", he didn't hear a response from me, so I guess he came back and just told me that [22:59]. And [safety pilot] comes in here at some time and tells me if I can get three-three [23:21].
D104	23:27	R	This whole time you're trying to keep the needles are lined up…
D105		P	Yep.
D106		R	…in addition to…That's gotta be tough.

D107	23:46	P	It especially helped me out [inaudible] in the airplane that I'm instructing in. [inaudible] in Roanoke all the time, approach that shot many times. You put me in a different airplane, different airport, workload would have been a lot higher.
D108		R	Yeah.
D109		P	I know these controllers' voices so well, I can tell just who are the good controllers, bad controllers…
D110	24:37	R	And how do you know when to, uhh, take the hood off? Is that at your missed approach point?
D111		P	Yeah, you get to what we call the decision height, they call it decision altitude these days, but uhh… One-thousand-six-hundred sixty indicated, that's the lowest you can go and at that point you have to make a decision. If you see the runway you can continue down, if you don't see the runway you have to miss. I got to sixteen-sixty which is the lowest I can go, but I imagine I saw the runway, which I did, when I take the hood off.
D112		P	Looks like right now I'm at, umm, twenty-five hundred. So we've got nine-hundred more feet to go.
D113	25:37	P	Another way to tell is time. When he took me over Vinton, I hit the timer.
D114		S	What instruments are you using for tracking the time?
D115		P	On the ADF there's an actual digital timer. When I go over Vinton, about the time he called me and told me to contact tower, you saw me punch something up there, I was hitting my timer. Otherwise [inaudible] but the airplane doesn't have it. There's a distance from the final approach fix to the missed point, and there's a time on the approach plate based on your ground speed, how long it will take you to reach that.
D116		R	Now there's only three minutes left in the video and I kept the video running a couple minutes after…a minute, maybe a minute after you landed.
D117		P	Right now we're at, umm, seventeen…looks like, eighteen hundred. Seventeen hundred, somewhere in that range. I got about hundred and some odd more feet before I, umm, hit the magic point and take the hood off. I got seventeen there so I should have forty more to go.
D118	26:57	P	Okay, there's the middle marker going off, in the background. You didn't hear the marker unless I was talking because I had on the speaker. It's so loud when it goes through the headset they just [inaudible] you. So you didn't get to hear the marker.
D119		R	I recorded them actually, when I saw the flash for the outer marker and the middle marker, I wrote down the time index.
D120		P	But the, uhh, audio didn't catch it. Unless I was talking. [inaudible] at least.

D121		R	Well the ahh, GPS data [inaudible].
D122		P	See I'm throwing some trim in to help elevate the nose up for the landing.
D123	28:13	R	Touchdown right there.
D124		P	Yep.
D125		P	Carb heat, flaps, course I didn't use any flaps but I verified that they were up…
D126		R	So you didn't…you didn't need any flaps for the landing?
D127		P	Mainly because of the crosswind. The more crosswind you have the less flaps that you have, the easier it is [inaudible].
D128		R	But is it safe to have crosswind? Otherwise you'd…
D129		P	No. Think about taking a paper bag and going outside on a windy day, the wind just grabs it and throws it all over the place. What would want to do is be more streamlined. And the flaps up is more streamlined.

APPENDIX Q: Transcriptions of Flight Communications and Retrospective Report for Pilot IFR02

IFR02 Flight Transcription

P: Pilot (Subject)
SP: Safety Pilot
R: Researcher
RAD: Roanoke Approach and Departure
ATIS: Automatic Terminal Information Service
Tower: Roanoke Tower
OAi: Other Aircraft 1, 2, 3, …i
GV: Ground Vehicle

Grey highlight = communications directly involving Cessna 61891

Some pilot-to-RAD communications from other aircraft are not heard (and thus do not appear in the transcription) because the controller is having some aircraft use different frequencies (RAD is always heard because it is transmitted on all three frequencies being used). Communications from other pilots using the same frequency as Cessna 61891 appear in the transcription.

Code	Time	Source	Communication
E01	0:07	RAD	Cardinal six-one-eight-niner-one, was that you who called?
E02	0:10	P	Uh, yeah, this is Skyhawk six-one-eight-niner-one over Blacksburg VFR with information sierra. I request one ILS three-three followed by a touch-and-go and then back to Blacksburg.
E03	0:26	SP	Raise the hood.
E04	0:29	P	Okay.
E05	0:30	RAD	Skyhawk eight-niner-one, Roanoke altimeter three-zero-one-niner, squawk zero-three-three-four, maintain VFR, again squawk zero-three-three-four.
E06	0:44	P	Zero-three-three-four and we'll maintain VFR.
E07	0:48	P	So, thirty-eight-hundred okay?
E08	0:50	SP	I think so.
E09	0:51	P	Okay, just keep me out of the mountains then.
E10	0:53	SP	Yes ma'am.
E11	1:09	P	Tell me when you think we're okay for altitude.
E12	1:12	SP	I'd just go to thirty-eight-hundred. We'll just see.
E13	1:15	P	Well you know Poor Mountain is thirty-nine hundred.
E14	1:25	SP	Well we're a long way from there.
E15	1:27	P	Okay.
E16	1:49	RAD	Six-one-eight-niner-one, ident.
E17	1:52	P	Eight-niner-one.
E18	2:20	RAD	Six-one-eight-niner-one, you're radar contact two south of

			Blacksburg, and fly heading of, ahh, one-zero-zero, vectors for the ILS.
E19	2:28	P	Heading one-zero-zero, vectors ILS, Cessna six-one-eight-niner-one.
E20	2:37	P	Okay, can you read my compass for me?
E21	2:40	SP	That's affirmative, it's, ahh, nine-five-nine-six.
E22	2:48	P	Okay, thank you.
E23	4:00	SP	What I think we ought to do, is ahh, we ought to get your advice Lisa, but what I'm tempted to do is fly 'till we get over to the ledge, VFR, and uhh, and then you go under again when we get out where the terrain is clear. We may have to divert around here but…
E24	4:31	P	Oh, we're fine, just let me know when we get closer. [inaudible] a little to the right. That's the highest point ever there.
E25	4:37	SP	Okay.
E26	4:37	RAD	Eight-niner-one, are you [conscious?] of the mountain ridge and antenna straight ahead?
E27	4:42	P	Eight-niner-one, we do have terrain in site, and uhh, we can climb a hundred feet and still be VFR.
E28	4:49	RAD	Okay, roger that, I just wanted to make sure you knew they were there, I was showing them on my map as four-thousand, four-thousand-two-hundred.
E29	4:56	P	Eight-niner-one roger, we may have to divert a little to the right as well.
E30	5:02	RAD	Okay, do whatever you need to do to avoid the terrain.
E31	5:06	P	Will do, eight-niner-one.
E32	5:08	SP	Uh, let's go twenty right.
E33	5:11	P	And we go up to four-thousand. We'll probably set off their ground proximity warning system.
E34	5:19	P	How's this?
E35	5:20	SP	That's looking real good to me.
E36	5:21	P	Okay, I'm going to stay at four-thousand then.
E37	5:27	P	Ah, this looks to me like we can climb from here.
E38	5:31	SP	Well…
E39	5:36	P	We'll try forty-two hundred and see if that works.
E40	5:40	SP	You're well clear.
E41	5:42	P	Okay.
E42	6:12	RAD	Cessna eight-niner-one, ahh, radar contact lost seventeen southwest of the airport. Resume your own navigation. If you can, just proceed east bound, I'll advise when I pick you back up.
E43	6:23	P	Six-one-eight-niner-one, roger.
E44	6:30	P	Knew that was going to happen.
E45	6:34	SP	He'll get us right back.

E46	6:37	P	I know.
E47	6:38	SP	As soon as we come around the corner here.
E48	6:57	P	What's the temperature out here, out of curiosity? Can you see it?
E49	7:01	SP	Yeah, just a minute, loosen up my seat belt to find it.
E50	7:13	SP	Eighteen Fahrenheit.
E51	7:15	P	Wow, that is cold, ha ha ha. Okay.
E52	7:26	SP	Looking real good. Clearance-wise.
E53	7:49	RAD	Cessna eight-niner-one, ident again please.
E54	7:52	P	Eight-niner-one.
E55	8:02	RAD	Cessna eight-niner-one, radar contact fifteen miles south of the Roanoke airport, heading one-zero-zero, again, maintain VFR.
E56	8:10	P	Eight-niner-one, heading one-zero-zero.
E57	8:35	P	We have some mountain wave here!
E58	8:40	SP	Thought that was PIO. [*pilot induced oscillation*].
E59	10:03	P	Good, strong reception on the ADF.
E60	10:06	RAD	Eight-niner-one, turn ten degrees left.
E61	10:08	P	Eight-niner-one, ten degrees left.
E62	11:26	P	[Oil temps?], all looking good, ammeter good.
E63	14:06	RAD	Blueridge one-ninety-five, Roanoke approach, Roanoke altimeter, three-zero-one-niner, can you accept runway two-four, wind two-niner-zero at twelve?
E64	14:15	RAD	Blueridge one-ninety-five, descend and maintain niner-thousand, and be vectored to runway visual two-four. Traffic one-o'clock four miles west bound eight-thousand-five-hundred Cherokee.
E65	14:56	OA1	Roanoke departure, one-nine-three-two-papa, two-point-five, climbing five thousand, and we're coming left two-two-zero degrees.
E66	15:09	RAD	Blueridge one-ninety-five, as soon as you get past that traffic I'll have [inaudible] just off you two-o'clock now and two miles, and I don't have him on my frequency so I'll have to wait 'till he gets on me.
E67	15:24	OA1	And departure, one-nine-three-two-papa, climbing five thousand, heading two-two-zero.
E68	15:29	RAD	[inaudible] three-two-papa, radar contact, climb and maintain one-zero thousand and, ahh, turn left heading one-eight-zero.
E69	15:37	OA1	Okay, one-zero, ten thousand, left turn heading one-eight-zero, three-two-papa.
E70	15:44	OA2	Roanoke approach, Cherokee four-three-one-two-six with you.
E71	15:47	RAD	Cherokee four-three-one-two-six, Roanoke approach, Roanoke altimeter, three-zero-one-niner, you have traffic just off your eleven-o-clock about at about a mile at nine-thousand

			three hundred for nine thousand, you have him in site?
E72	15:56	OA2	Affirmative, one-two-six, I have him, I'd like to begin my descent.
E73	15:59	RAD	One-two-six, maintain visual with that traffic, he's going to continue the decent, altitude at your discretion.
E74	16:03	RAD	Blueridge one-ninety-five, descend ahh disregard, you said you had the airport? [*talking to one-ninety-five but OA2 responded?*]
E75	16:07	OA2	Ahh, negative, but I'm at eight-thousand five hundred, I gotta loose some of this.
E76	16:11	RAD	Eight-niner-one, turn left heading of zero-five-zero. [*Subject failed to respond!*]
E77	16:16	RAD	Blueridge one-ninety-five, cleared visual approach runway two-four.
E78	16:22	RAD	Number six-one-eight-niner-one, turn left heading of zero-four-zero now.
E79	16:26	P	Left heading zero-four-zero, eight-niner-one.
E80	16:31	P	Go left.
E81	16:45	RAD	[inaudible] three-two-papa, proceed direct Winston, indian-november-tango.
E82	16:48	OA1	[inaudible] three-two-papa.
E83	17:13	RAD	Blueridge one-ninety-five, you are cleared visual runway two-four, tower one-one-eight-point-three, see ya.
E84	17:23	RAD	Six-one-eight-niner-one, turn left heading of three-six-zero, you're eight miles from Vinton, maintain VFR, cleared ILS three-three approach.
E85	17:31	P	That's heading three-six-zero, VFR, cleared ILS three-three, six-one-eight-niner-one.
E86	18:03	P	Okay, glide slope is coming alive.
E87	18:10	P	We're pretty good, turn.
E88	18:21	P	'Cause the wind was three-seven-zero, so…
E89	18:31	RAD	Cessna eight-niner-one, tower one-one-eight-point-three, see ya.
E90	18:34	P	Eight-niner-one, over to tower, one-one-eight-point-three, see ya.
E91	18:42	P	Roanoke tower, Skyhawk six-one-eight-niner-one, I'm outside of Vinton, ILS three-three.
E92	18:47	Tower	Skyhawk six-one-eight-niner-one, Roanoke tower, continue route for three-three, there's a vehicle on the runway.
E93	18:52	P	Eight-niner-one.
E94	18:58	OA3	Roanoke tower, Sundowner-five-one-five-five-mike is holding short of runway three-three, ready for takeoff.
E95	19:05	Tower	Vehicle eleven, hold short of runway three-three on taxiway echo.
E96	19:09	GV	Hold short of runway three-three on taxiway echo, vehicle

			eleven.
E97	19:12	Tower	Sundowner-five-one-five-five-mike, Roanoke tower, wind two-eight-zero at one-one, runway three-three cleared for takeoff.
E98	19:18	OA3	Cleared for takeoff runway three-three, Sundowner-five-one-five-five-mike.
E99	19:22	P	Okay, we're established on the localizer.
E100	19:41	P	It's not on the glide slope, but what am I doing climbing? I don't want to climb.
E101	19:54	P	I'll hold about forty-two hundred.
E102	20:20	P	I've never had to do this in a Skyhawk, ha!
E103	20:27	Tower	Vehicle eleven, you can continue with the inspection, hold short of runway two-four on runway three-three.
E104	20:32	GV	Continue with the inspection, hold short of runway two-four on runway three-three, vehicle eleven.
E105	21:32	Tower	Blueridge one-ninety-five, wind two-eight-zero at one-zero, runway two-four, cleared to land.
E106	21:37	OA4	Cleared to land, Blueridge one-ninety-five.
E107	21:45	P	Okay, ahh, mixture full rich, [inaudible] is down. [inaudible]. Seatbelts fastened?
E108	21:57	Tower	Sundowner-five-five-mike, contact departure, so long.
E109	22:01	OA3	Going to departure, have a great day, Sundowner-five-one-five-five-mike.
E110	22:05	P	Belts?
E111	22:06	SP	Affirmative.
E112	22:07	P	Okay, [Researcher] seatbelt?
E113	22:09	R	Yes.
E114	22:10	P	Okay.
E115	22:11	SP	Umm, [Pilot], do you think it would be worth reminding them that we want to do a touch-and-go on three-three because they're doing some kind of…probably snow inspection or something. At an appropriate time I mean.
E116	22:20	P	Okay.
E117	22:25	P	Glide slope intercepts. A little to the right of the localizer.
E118	22:48	P	Ahh, tower, this is eight-niner-one, ahh, will it be possible to do a touch-and-go?
E119	22:52	Tower	Cessna eight-niner-one, it will be, ahh, he's on the runway right now, he's just doing an inspection so he'll be off in a couple minutes.
E120	22:58	P	Thank you, eight-niner-one.
E121	23:16	P	Okay, we're on glide slope. [inaudible] on the localizer.
E122	23:25	Tower	Blueridge one-ninety-five, turn left on alpha, then [contact?] ground, point niner, so long.
E123	23:29	OA4	Alpha, ground, Blueridge one-ninety-five.
E124	23:33	P	There's Vinton, turn, no turn.

E125	23:36	Tower	Vehicle eleven, you can cross runway two-four and continue.
E126	23:37	P	Timer.
E127	23:39	GV	Cross runway two-four and continue with airfield inspection.
E128	23:39	P	[No?] twisting. Throttle. [No?] talk. [Okay?].
E129	24:51	P	When do you want me to take the hood off?
E130	24:53	SP	At MDA. [*minimum descent altitude*]
E131	24:55	P	Okay. Decision height.
E132	25:00	SP	Yeah, I was just [inaudible].
E133	25:03	P	Ah, ha, ha.
E134	25:06	P	Sixteen sixty.
E135	25:35	P	[inaudible (minutes)?].
E136	26:24	P	Outer marker. But there's no sound.
E137	26:38	Tower	Cessna eight-niner-one, runway three-three cleared touch-and-go. After departing you can turn left direct Blacksburg.
E138	26:43	P	Eight-niner-one, after touch and go…we're cleared touch-and-go, after that left turn to Blacksburg.
E139	26:50	P	That's why I like you. [*in reference to the safety pilot turning on the sound for the outer marker*]
E140	27:07	GV	Vehicle eleven, clear of runway area, have a good day.
E141	27:10	Tower	Vehicle eleven, you too, so long.
E142	27:36	P	Too fast.
E143	27:50	P	Five hundred feet to go.
E144	28:25	P	Four hundred feet.
E145	28:30	P	[inaudible]
E146	28:32	Tower	Cessna eight-niner-one, there is a vehicle and personnel at taxiway charlie off the right edge of runway three-three. They're clear of the pavement, they're working on some field lighting.
E147	28:42	P	Eight-niner-one, roger.
E148	28:46	P	Okay, that is [inaudible]. [*in reference to the loudness of the middle marker*]
E149	28:49	OA5	Roanoke tower, Cherokee four-three-one-two-six with you for three-three.
E150	28:53	Tower	Cherokee four-three-one-two-six, Roanoke tower, runway three-three cleared to land, there is a vehicle at taxiway Charlie and personnel as well. Ahh, they are clear of the runway off the right edge, working on some field lighting.
E151	29:04	OA5	One-two-six, I'll watch for them, cleared three-three landing.
E152	29:18	P	Okay, [inaudible] mixture.
E153	29:46		[touchdown]

<u>IFR02 Retrospective Report Transcription</u>

P: Pilot (Subject)
R: Researcher

The times can be cross-referenced with the actual flight transcription.

Code	Cross-ref	Source	Communication
F01	0:26	R	Why did he tell you to raise the hood?
F02		P	Umm, because he thought we were going into the clouds.
F03		R	Oh.
F04		P	We were up to thirty-five-hundred and we were getting really close.
F05		P	So…
F06	0:51	R	So you flew at thirty-eight hundred all the way there?
F07		P	No we went down to thirty-eight hundred to stay out of the clouds, but at that altitude we were still going into the mountains which is thirty-nine-hundred. So four-thousand is the first altitude that will get you over…the antenna. What we did we went to the side, the right side, which is the lower terrain, and as soon as we were past those clouds I went up to forty-two hundred and was able to maintained forty-two-hundred for the rest of the flight.
F08		R	Okay.
F09	1:25	P	Our high terrain is to the left.
F10		R	Yeah I remember at this point looking out the window and seeing how close the mountains were.
F11		P	Forty-five hundred is lowest VFR altitude, five-thousand is lowest IFR altitude.
F12	1:49	R	What are you turning there?
F13		P	The mixture.
F14		R	The mixture.
F15		P	I'm reducing the amount of fuel that goes into the engine because we have reduced the power for straight-and-level.
F16		R	That's the trim?
F17		P	That's the trim wheel.
F18	2:28	R	So periodically, he kept giving you different vectors to fly. Was there any pattern to that or is he just getting you away from other traffic?
F19		P	I departed VFR out of Blacksburg and I know it's a south-easterly heading. Then what he does is he vectors you around all the way outside of the Vinton, ahh, beacon. And he can vector you close or farther out, usually they vector you around [Cahos?] Mountain. If you get close in, you're too close in to make the last turn. So, he first has to see us on the

			radar, when he said "radar contact"… After he had us on radar, he started giving us directions.
F20		R	You just checked your…is that the, umm, approach plate?
F21		P	Probably. Yes.
F22	4:00	R	So, if this is BCB, Roanoke, about [inaudible]?
F23		P	Let me draw it on a different piece of paper. Takeoff on runway three-zero, make a left turn out. Then I took up a heading of about one-two-zero. I was trying to get us ILS three-three. Vinton is about here. So he's got us on a hundred degree heading which will probably get us about here. And that's [inaudible] [Cahos?] Mountain. We can't go straight, we have to fly eleven miles east. There's mountain there that actually run this way, and Poor Mountain is the highest one. So we…he's taking us out to the right to avoid the highest part. [*this sketch is in the subject's file folder*]
F24	5:21	R	What's the highest point called again?
F25		P	Poor Mountain.
F26		R	Poor Mountain? I'll have to look at my chart. And what's this one called?
F27		P	Cahos Mountian. c-a-h-o-[s?]. It's the one peak sticking out there.
F28	5:42	P	They did give us a warning about terrain too. If an airplane gets too close they have ahh, above ground, ahh, ground proximity warning system. And they will ask us, "do we have that terrain in site?".
F29		R	Oh, wow, I didn't know they had that.
F30		P	Uh huh, they do. I've set it off several times, ha, ha. If I say that the [tower?] says that we…
F31	6:12	R	What did he say?
F32		P	He lost us off the radar. We're now behind the mountain and the radar can't see through.
F33		R	Ohh.
F34		P	So by the…by the time that we have past it [the radar will?] pick us up again.
F35		R	I didn't pick up on that during the flight, that's interesting.
F36		P	If we were at five-thousand where we're supposed to be, of course we would have [inaudible] right over that. But we're too low, we're VFR. So after he says, you know, ahh…
F37	7:26	P	It's a bit bumpy.
F38		R	You know, I was so focused on the data collection that I didn't…I didn't realize how bumpy it might have been.
F39	7:49	R	Is your hand on the throttle now?
F40		P	Yes. What happens to… After a storm passes, the air, which has been moving over the mountains [inaudible]. So, I have a tendency to think I have to add power to hold my altitude and then all of a sudden we have a five hundred foot climb rate.

F41	8:02	P	He's pick us up again there. And giving us a vector again.
F42		P	I'm looking at my approach plate there.
F43		R	What kind of information are you looking for when you just looked at it?
F44		P	Ahh, the ahh, Morse code.
F45		R	Oh.
F46		P	I'm identifying the, ahh…
F47	8:35	R	What did you just say?
F48		P	"There is some mountain wave here."
F49	8:40	P	He says, "pilot induced oscillation".
F50		R	Oh, ha, ha, ha!
F51		P	Ha, ha, ha, I'm going up and down. And it…it is a bit turbulent out there.
F52		P	I'm identifying the Morse code on the, uh, ILS, and I had to look that one up and then the other one was Vinton, VIT. The ADF, the only way you know that it works, is by listening to the Morse code. That's the one I that I keep on. The other one, after I've established that it works, ahh, you can turn it off. From that point on, if the needles work correctly the way they should, you know that it's working. The ADF, you have no indication. The ADF is in the background.
F53		R	What does ADF stand for?
F54		P	"Automatic direction finder". It is the airborne component to the non-directional beacon that's on the chart. Vinton, VIT. Third instrument down the [inaudible].
F55		R	Okay. I think I remember that from the simulator…configuration.
F56		P	That's were you [inaudible] the glide slope and that's the thing that also…falls to the back.
F57	10:08	R	So when you're flying straight-and-level flight, you're monitoring, umm, like four different instruments? And, you're monitoring you altitude and your airspeed…
F58		P	The main instrument for maintaining straight-and-level is your attitude indicator right in front of you. But when we fly IFR, we have to have quality of flight. That means that we have to have a heading and an altitude. And you have to fly and hold the wings level and go up and down in a thunderstorm with holding the wings level [inaudible] going left and right. So my pattern is attitude indicator, double check your heading, attitude indicator, double check your altitude. Then I'll look [occasionally?] back to your airspeed. If you hold straight-and-level, and you don't have up and down draft, your airspeed should be fairly stable.
F59		R	And so you just repeat that scan pattern.
F60		P	Yeah, we call it a [inaudible] scan, where every time you move to another one you go through the attitude indicator

			again. My airspeed actually went up and down, it varied about twenty miles an hour, here and there.
F61		R	You haven't reached, ahh, Vinton NDB yet, right?
F62		P	No. He just told me to turn ninety degrees left so I'm still, umm, still going eastbound very much.
F63		R	Okay.
F64		P	I'm now on a heading of zero-niner-zero. But as I go to the left, the yellow needle on the ADF always points to the beacon. So as I'm going east, and that needle tells me about ninety degree…to the left, I know that I'm directly south of Vinton. So I know my next turn is going to be a left turn. That's what I'm waiting for.
F65		R	What type of hood were you wearing? It was something attached to your glasses?
F66		P	They're called foggles. They are like flip-up sunglasses. Except that, you know, they only have the little bit on the bottom. [inaudible] foggles. They're much easier because they don't put space between your headset. The big glasses put a lot of space between your ears and your headset.
F67	14:15	R	Do the foggles give you a tunnel vision then? That's how you see?
F68		P	Put them over your head and you'll see, and what you see, it's just kind of the instruments in front of you and not out the window. [inaudible] instruments.
F69		R	That's neat.
F70	14:56	P	Umm hmm, they're called foggles, it's just easier than the other glass types.
F71		R	Mind if I take a photograph of that?
F72		P	No that's fine.
F73	15:37	R	How much traffic, would you think, is in Roanoke airspace based on the communications you're hearing?
F74		P	There wasn't any when we started and then suddenly there's like three aircraft in the area. That's the way it always happens. Most of those [inaudible], they were just flying over.
F75	16:11	P	I missed the first transmission.
F76		R	Did he have to repeat it?
F77		P	Yeah. [inaudible].
F78	17:13	P	He's starting to turn me left, zero-five-zero. When he gives me a heading within thirty degrees of the final heading, I know that I'm on my intercept for the final approach course. [inaudible] all they do is thirty degrees. Depending on [winds?], it doesn't always work that way, but…
F79	17:31	P	Basically at that point I had my approach [clear?]. Now I'm going to [inaudible].
F80		R	Why do you have your approach [planned?] at this point?

F81		P	He gave me the last intercept, zero-five-zero [*note: is was actually zero-six-zero*], cleared ILS.
F82		R	Oh, okay.
F83		P	So from this point on, I fly [myself?].
F84	18:34	R	Is there a set point where they always turn you over to tower?
F85		P	Usually right over Vinton, when you're most busy.
F86	19:22	R	Now, ahh, how far do you have to go before, ahh, you intercept the glide slope?
F87	19:41	P	At thirty-eight hundred, you will intercept the glide slope just before Vinton. But I was at forty-three hundred. Actually, I gained another feet. I just said there I don't want to climb. I gained another feet when I was slowing down, about a hundred feet. So I intercepted it outside of Vinton, about ahh, two or three.
F88	20:32	R	What were they doing?
F89		P	They were checking the runway for snow or something. By having a vehicle on the runway, they would have to clear before we could get our touch-and-go. But I'm on the ILS but I haven't gotten my landing clearance yet.
F90	21:32	R	Now at this point when you're umm, lining up the needles as you go down the glide slope, are you checking any other instruments while you do that?
F91		P	You're still flying heading and altitude.
F92		R	Uh-huh.
F93		P	Uhh, the heading is three-three-four, is the final heading, so… So I'm still flying three-three-zero plus or minus. Instead of looking at the altimeter you look at the GSI [inaudible] at five hundred feet.
F94	22:25	P	I sometimes brief myself verbally of where I am with respect to the localizer, [as do other pilots?].
F95	23:39	R	What were you just…that routine you were…?
F96		P	That's a checklist you use for eyes [inaudible]. If you do that in order. Especially on the visual approaches, but it also works for instrument approaches. It's a mind organizer. Turn, should I make a turn? How's my timer, if you're doing a non-precision approach do you need your timer? Twist, twist the VOR is you have to or twist any other needle [or?] radial. And then there's throttle, do I have to go up or down? Talk, should I talk to the controller? Stay on track. When things get tight and you get in a hurry, that's the checklist that you do, you never forget anything. And what I did out there when I said turn and twist, I turned off the ADF because we were past it.
F97	24:53	P	MDA, minimum descent altitude, is the term used for non-precision approaches. I'm talking here about decision height. The one thing I did not plan on was the marker, the sound of

			the marker beacon. [inaudible], I'm supposed to hear the marker but I didn't hear it [inaudible] up on the panel.
F98	26:24	R	Now why was there no sound?
F99		P	Because I didn't push the button. [inaudible].
F100	28:46	R	Middle marker.
F101		P	[inaudible].
F102	29:46	R	You said there was a bad cross-wind, right?
F103		P	Hmm. I should have know I was keeping a ten degree wind correction angle into the wind the whole time. When I landed, I didn't correct for it. It wasn't perfect, let's put it that way.
F104		R	What did you say?
F105		P	That wasn't quite straight, ha, ha.
F106		R	Oh.
F107		P	Now I looked at the wind sock and I realized I should have put in a lot more right rudder on the landing. You don't want to have your wheels go that way, and the airplane that way. [At least when it's on camera.?]
F108		R	Did you lift back off at this point?
F109		P	Yeah. Yeah, I've already put up the flaps and given full power?
F110		R	Did you use any flaps on the landing?
F111		P	Yeah.
F112		R	How many did you use?
F113		P	Ahh, [not?] full, probably about [twenty-five?] degrees.

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APPENDIX R: Correlation Matrix and Multivariate Analysis

Correlation Matrix of the 13 objective flight performance variables:
(Grey areas indicate areas of relatively high correlation; where |r| > 0.30)

	Total Time	Flgiht Path Angle	Heading	Pitch Attitude	Roll Angle	Altitude AGL	Ground Speed	Indicated Airspeed	Vertical Speed	ILS GS CDI	ILS Localizer CDI	Throttle Input	Flap Deflection
Total Time	1												
Flgiht Path Angle	-0.12537	1											
Heading	-0.0995	-0.15151	1										
Pitch Attitude	0.199655	-0.00792	0.031114	1									
Roll Angle	-0.12458	0.09259	-0.33407	-0.25472	1								
Altitude AGL	0.000151	0.023005	-0.01167	-0.04591	-0.09929	1							
Ground Speed	-0.94164	0.210707	0.044624	-0.24362	0.143376	0.026351	1						
Indicated Airspeed	-0.94131	0.215872	0.043186	-0.2575	0.14842	0.013205	0.999759	1					
Vertical Speed	0.955444	-0.15868	-0.0934	0.23121	-0.12641	-0.02542	-0.99284	-0.99221	1				
ILS GS CDI	-0.03423	-0.34084	0.03119	-0.00888	-0.14849	0.822226	0.050776	0.036644	-0.04435	1			
ILS Localizer CDI	0.053953	0.119025	-0.18949	0.059186	-0.06843	-0.34074	0.004223	0.009015	0.031882	-0.28036	1		
Throttle Input	-0.73811	0.114072	-0.06559	-0.45692	0.155142	0.034088	0.858699	0.86126	-0.84578	0.090764	0.040765	1	
Flap Deflection	0.586961	-0.17492	-0.09429	-0.60113	0.056588	-0.01364	-0.58277	-0.57158	0.585462	-0.03794	-0.02876	-0.22093	1

continued…

Multivariate analysis continued

Variables partitioned into three separate groups based on relatively high correlation with each other:

Group 1: Ground Speed, Indicated Airspeed, Vertical Speed, Throttle Input, Flap Deflection, Total Time, Pitch Attitude

Group 2: Altitude AGL, ILS Glideslope CDI, ILS Localizer CDI, flight path angle

Group 3: Heading, Roll Angle

MANOVA performed on each of the three groups of variables:

2x2x2 Mixed-Factors; model: A B C S(A) A*B A*C B*C B*S C*S A*B*C B*C*S

A=Pilot Type; B=Day/Night; C=Weather

Group 1 MANOVA

```
MANOVA for A                    s =  1    m =  2.5    n =     3.0

Criterion        Test Statistic           F            DF        P
Wilk's                  0.43054       1.512   (  7,     8)  0.287
Lawley-Hotelling        1.32269       1.512   (  7,     8)  0.287
Pillai's                0.56946       1.512   (  7,     8)  0.287
Roy's                   1.32269

These tests use error term = S(A)


MANOVA for B                    s =  1    m =  2.5    n =     3.0

Criterion        Test Statistic           F            DF        P
Wilk's                  0.29503       2.731   (  7,     8)  0.091
Lawley-Hotelling        2.38947       2.731   (  7,     8)  0.091
Pillai's                0.70497       2.731   (  7,     8)  0.091
Roy's                   2.38947

These tests use error term = B*S(A)


MANOVA for C                    s =  1    m =  2.5    n =     3.0

Criterion        Test Statistic           F            DF        P
Wilk's                  0.64874       0.619   (  7,     8)  0.730
Lawley-Hotelling        0.54145       0.619   (  7,     8)  0.730
Pillai's                0.35126       0.619   (  7,     8)  0.730
Roy's                   0.54145

These tests use error term = C*S(A)
```

```
MANOVA for A*B                  s =  1    m =  2.5    n =     3.0

Criterion        Test Statistic          F           DF        P
Wilk's                  0.38492       1.826   (  7,     8)  0.208
Lawley-Hotelling        1.59797       1.826   (  7,     8)  0.208
Pillai's                0.61508       1.826   (  7,     8)  0.208
Roy's                   1.59797

These tests use error term = B*S(A)


MANOVA for A*C                  s =  1    m =  2.5    n =     3.0

Criterion        Test Statistic          F           DF        P
Wilk's                  0.53340       1.000   (  7,     8)  0.494
Lawley-Hotelling        0.87476       1.000   (  7,     8)  0.494
Pillai's                0.46660       1.000   (  7,     8)  0.494
Roy's                   0.87476

These tests use error term = C*S(A)


MANOVA for B*C                  s =  1    m =  2.5    n =     3.0

Criterion        Test Statistic          F           DF        P
Wilk's                  0.61091       0.728   (  7,     8)  0.656
Lawley-Hotelling        0.63691       0.728   (  7,     8)  0.656
Pillai's                0.38909       0.728   (  7,     8)  0.656
Roy's                   0.63691


MANOVA for A*B*C                s =  1    m =  2.5    n =     3.0

Criterion        Test Statistic          F           DF        P
Wilk's                  0.44472       1.427   (  7,     8)  0.313
Lawley-Hotelling        1.24861       1.427   (  7,     8)  0.313
Pillai's                0.55528       1.427   (  7,     8)  0.313
Roy's                   1.24861
```

<u>Group 2 MANOVA</u>

** indicates significant result ($p \leq 0.05$)*

```
MANOVA for A                    s =  1    m =  1.0    n =     4.5

Criterion        Test Statistic          F           DF        P
Wilk's                  0.46967       3.105   (  4,    11)  0.061
Lawley-Hotelling        1.12916       3.105   (  4,    11)  0.061
Pillai's                0.53033       3.105   (  4,    11)  0.061
Roy's                   1.12916

These tests use error term = S(A)
```

```
MANOVA for B                    s =  1    m =  1.0    n =     4.5

Criterion        Test Statistic           F           DF       P
Wilk's                  0.42001       3.797   (  4,    11)  0.035 *
Lawley-Hotelling        1.38089       3.797   (  4,    11)  0.035 *
Pillai's                0.57999       3.797   (  4,    11)  0.035 *
Roy's                   1.38089

These tests use error term = B*S(A)


MANOVA for C                    s =  1    m =  1.0    n =     4.5

Criterion        Test Statistic           F           DF       P
Wilk's                  0.70552       1.148   (  4,    11)  0.385
Lawley-Hotelling        0.41740       1.148   (  4,    11)  0.385
Pillai's                0.29448       1.148   (  4,    11)  0.385
Roy's                   0.41740

These tests use error term = C*S(A)


MANOVA for A*B                  s =  1    m =  1.0    n =     4.5

Criterion        Test Statistic           F           DF       P
Wilk's                  0.38498       4.393   (  4,    11)  0.023 *
Lawley-Hotelling        1.59753       4.393   (  4,    11)  0.023 *
Pillai's                0.61502       4.393   (  4,    11)  0.023 *
Roy's                   1.59753

These tests use error term = B*S(A)


MANOVA for A*C                  s =  1    m =  1.0    n =     4.5

Criterion        Test Statistic           F           DF       P
Wilk's                  0.72941       1.020   (  4,    11)  0.439
Lawley-Hotelling        0.37097       1.020   (  4,    11)  0.439
Pillai's                0.27059       1.020   (  4,    11)  0.439
Roy's                   0.37097

These tests use error term = C*S(A)


MANOVA for B*C                  s =  1    m =  1.0    n =     4.5

Criterion        Test Statistic           F           DF       P
Wilk's                  0.88262       0.366   (  4,    11)  0.828
Lawley-Hotelling        0.13299       0.366   (  4,    11)  0.828
Pillai's                0.11738       0.366   (  4,    11)  0.828
Roy's                   0.13299


MANOVA for A*B*C                s =  1    m =  1.0    n =     4.5

Criterion        Test Statistic           F           DF       P
Wilk's                  0.80517       0.665   (  4,    11)  0.629
Lawley-Hotelling        0.24197       0.665   (  4,    11)  0.629
Pillai's                0.19483       0.665   (  4,    11)  0.629
Roy's                   0.24197
```

Group 3 MANOVA

```
MANOVA for A                s =  1    m =  0.0    n =     5.5

Criterion        Test Statistic          F            DF       P
Wilk's                  0.73702      2.319   (  2,    13)  0.138
Lawley-Hotelling        0.35682      2.319   (  2,    13)  0.138
Pillai's                0.26298      2.319   (  2,    13)  0.138
Roy's                   0.35682

These tests use error term = S(A)


MANOVA for B                s =  1    m =  0.0    n =     5.5

Criterion        Test Statistic          F            DF       P
Wilk's                  0.93993      0.415   (  2,    13)  0.669
Lawley-Hotelling        0.06391      0.415   (  2,    13)  0.669
Pillai's                0.06007      0.415   (  2,    13)  0.669
Roy's                   0.06391

These tests use error term = B*S(A)


MANOVA for C                s =  1    m =  0.0    n =     5.5

Criterion        Test Statistic          F            DF       P
Wilk's                  0.82667      1.363   (  2,    13)  0.290
Lawley-Hotelling        0.20967      1.363   (  2,    13)  0.290
Pillai's                0.17333      1.363   (  2,    13)  0.290
Roy's                   0.20967

These tests use error term = C*S(A)


MANOVA for A*B              s =  1    m =  0.0    n =     5.5

Criterion        Test Statistic          F            DF       P
Wilk's                  0.89725      0.744   (  2,    13)  0.494
Lawley-Hotelling        0.11452      0.744   (  2,    13)  0.494
Pillai's                0.10275      0.744   (  2,    13)  0.494
Roy's                   0.11452

These tests use error term = B*S(A)


MANOVA for A*C              s =  1    m =  0.0    n =     5.5

Criterion        Test Statistic          F            DF       P
Wilk's                  0.90752      0.662   (  2,    13)  0.532
Lawley-Hotelling        0.10190      0.662   (  2,    13)  0.532
Pillai's                0.09248      0.662   (  2,    13)  0.532
Roy's                   0.10190

These tests use error term = C*S(A)
```

```
MANOVA for B*C                   s =  1    m =  0.0    n =     5.5

Criterion        Test Statistic          F           DF        P
Wilk's                  0.91090      0.636   (  2,    13)  0.545
Lawley-Hotelling        0.09781      0.636   (  2,    13)  0.545
Pillai's                0.08910      0.636   (  2,    13)  0.545
Roy's                   0.09781


MANOVA for B*S(A)                s =  2    m =  5.5    n =     5.5

Criterion        Test Statistic          F           DF        P
Wilk's                  0.36070      0.618   ( 28,    26)  0.893
Lawley-Hotelling        1.39809      0.599   ( 28,    24)  0.903
Pillai's                0.77430      0.632   ( 28,    28)  0.885
Roy's                   1.03725


MANOVA for C*S(A)                s =  2    m =  5.5    n =     5.5

Criterion        Test Statistic          F           DF        P
Wilk's                  0.21020      1.097   ( 28,    26)  0.408
Lawley-Hotelling        2.49723      1.070   ( 28,    24)  0.436
Pillai's                1.05470      1.116   ( 28,    28)  0.387
Roy's                   1.79524


MANOVA for A*B*C                 s =  1    m =  0.0    n =     5.5

Criterion        Test Statistic          F           DF        P
Wilk's                  0.75713      2.085   (  2,    13)  0.164
Lawley-Hotelling        0.32077      2.085   (  2,    13)  0.164
Pillai's                0.24287      2.085   (  2,    13)  0.164
Roy's                   0.32077
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VITA

Jason J. Saleem

Department of Industrial and Systems Engineering
Virginia Polytechnic Institute and State University, Blacksburg, VA 24061-0118
E-mail: jsaleem@vt.edu

EDUCATION

Doctor of Philosophy, Industrial and Systems Engineering, July 2003
Virginia Polytechnic Institute and State University (Virginia Tech), Blacksburg, VA
Dissertation: Multi-method approach to understand pilot performance in a sociotechnical aviation system
Advisor: Brian M. Kleiner

Master of Science, Industrial and Systems Engineering, December 1999
Virginia Polytechnic Institute and State University (Virginia Tech), Blacksburg, VA
Thesis: Quantifying the participatory ergonomic effects of training and a work analysis tool on operator performance and well-being
Advisor: Brian M. Kleiner

Bachelor of Science, Industrial Engineering, December 1997
University of Pittsburgh, Pittsburgh, PA

EXPERIENCE

Virginia Tech, Industrial and Systems Engineering Department

UPS Fellowship, January 1999-December 1999 and August 2001-August 2002

Used second UPS Fellowship funding to conduct research on the NASA Small Aircraft Transportation System (SATS)

Used first UPS Fellowship funding to conduct Masters thesis research in the Macroergonomics and Group Decision Systems Laboratory

Graduate Teaching Assistant, January 2000-May 2001 and August 2002-May 2003

Teaching Assistant for Work Measurement and Methods Engineering (1 semester), Macroergonomics (1 semester), and Theory of Organization (4 semesters)

NASA Langley Research Center, Crew/Vehicle Integration Branch

Langley Aerospace Research Summer Scholar, June-August 2000

Set-up, debugged, and evaluated several aviation weather information (AWIN) and GPS display systems. The systems were analyzed using task analysis and usability investigations.

University of Pittsburgh, Industrial Engineering Department

Visiting Research Assistant, May-August 1998
Undergraduate Research Assistant, September-December 1997

Fulfilled managerial and administrative responsibilities for the study entitled “Understanding How Engineering Students Approach Open-Ended Problems – Implications for Engineering Education”

Westinghouse Electric Corporation, Electro-Mechanical Division (EMD)

Industrial Engineering Cooperative Education Student, August-December 1996

Developed programs and databases for plant-wide use

Pennsylvania Department of Transportation, Operations Review Group (ORG)

Industrial Engineering Cooperative Education Student, May-August 1995 and January-April 1996

Performed traditional industrial engineering tasks

AFFILIATIONS

- Human Factors and Ergonomics Society, January 1998 – present
- Alpha Pi Mu – Industrial Engineering Honor Society, November 1998 – present

RESEARCH INTERESTS

- Human factors in aviation; pilot performance, attention, workload, situation awareness
- Participatory ergonomics; involving workers in the redesign of their own jobs
- Occupational biomechanics (e.g., effect of wear on the protective features of running shoes)
- Human factors applications (e.g., cognitive demands of mail sorters at the post office, evaluation of weather information systems)
- Human computer interaction (HCI), models and theories of HCI (e.g., distributed cognition)
- Usability engineering, design and evaluation of computer interfaces
- Computer supported cooperative work, macroergonomics, group decision making
- Work system design, considering both the organizational and cognitive components of a work system

GRADUATE COURSEWORK

Usability Engineering	Human Physical Capabilities	Human Factors Systems Design I & II
Human-Information Processing	Occupational Safety and Hazard Control	Human Factors Research Design I & II
Cognitive Psychology	Human Audition and Auditory Display Design	Applied Multivariate Analysis
Human Computer Systems	Analysis of Air Transportation Systems	Training Systems Design
Models of Human Computer Interaction	Digital Systems and Media Science	Macroergonomics
Visual Display Systems	Simulation	Management of Change, Innovation & Performance in Organizational Systems
College Teaching		

PUBLICATIONS

Saleem J. J., Kleiner, B. M., Nussbaum, M. A. (2003). Empirical evaluation of training and a work analysis tool for participatory ergonomics. International Journal of Industrial Ergonomics, 31(6), 387-396.

Lancaster, J.A., Saleem, J.J., Robinson, G.S., Kleiner, B.M., and Casali, J.G. (2003). Preliminary study on the effects of approach angle and lower landing minimum level on pilot performance in a low-fidelity static aircraft simulator. Accepted for publication in Proceedings of the 12th Biennial International Symposium on Aviation Psychology. Dayton, Ohio.

Lancaster, J.A., Saleem, J.J., Robinson, G.S., Kleiner, B.M., and Casali, J.G. (2002). Preliminary study on the effects of approach angle and lower landing minimum level on pilot performance in a low-fidelity static aircraft simulator. (Audio Lab Report No. 9/04/02-3-HP; ISE Dept. Report No. 200203). Blacksburg, VA: Virginia Polytechnic Institute and State University.

Lancaster, J.A., Saleem, J.J., Robinson, G.S., Kleiner, B.M., and Casali, J.G. (2002). The effect of a six-degree approach angle and lower landing minimum level on pilot performance in a low-fidelity static aircraft simulator. (Audio Lab Report No. 9/04/02-4-HP; ISE Dept. Report No. 200204). Blacksburg, VA: Virginia Polytechnic Institute and State University.

Saleem J. J. (2000). Evaluation and Comparison of Aviation Weather Information Systems. In Langley Aerospace Research Summer Scholars Technical Reports, June 5 - August 11, 2000, Part Two, (pp. 754-763). Hampton, VA: NASA Langley Research Center.

Saleem J. J., and Kleiner, B. M. (2000). Can TQM be Quantified? In Proceedings of the Human Factors and Ergonomics Society 44th Annual Meeting (pp. 2-499 - 2-502). Santa Monica, CA: Human Factors and Ergonomics Society.

Kirst, M. and Saleem, J. (2000). Overcoming mail-sorting overload. Ergonomics in Design, 8(1), 10-17.