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Contract Entity GTRC

Prime Contract Number

Title HUMAN-CENTERED DESIGN OF HUMAN-COMPUTER-HUMAN DIALOGS IN AEROSPACE SYSTEMS

Effective Completion Date 31-JUL-1997 (Performance) 31-OCT-1997 (Reports)

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Project File	Y

NOTE: Final Patent Questionnaire sent to PDPI

E-24-X30
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Human-Centered Design of Human-Computer-Human Dialogs

in

Aerospace Systems

NASA grant (NASA Ames control number NCC 2-824)

Semi-Annual Reports: #1

July 31, 1993 through January 31, 1994

E-24-X30

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The initial six months of this grant saw the transition of students with several students supported by the grant leaving and several other joining. Todd Callantine is the exception--Todd Callantine continues to put final touches on his crew activity tracking system. A short description of Todd's activities follows.

Georgia Tech Crew Activity Tracking System: Research Progress and Future Work (Todd J. Callantine)

This section outlines research progress on a glass cockpit crew intent inferencer, now called the Georgia Tech Crew Activity Tracking System (GT-CATS). One focus of recent research has been to formalize the GT-CATS methodology. In particular, the scope of the methodology has been narrowed to primarily address how pilots use modes of automation to control the aircraft. The results of these efforts have, in turn, led to modifications to the GT-CATS code.

The GT-CATS methodology is designed to track operator activities in real time to produce an 'understanding' of how operators use automated modes to control complex dynamic systems. First, it attempts to predict which level of automation the operator is likely to select, and when, to achieve a desired system state. It also predicts how and when the operator will setup, engage, monitor, and adjust the selected mode. Further, the methodology attempts to understand when the operator is expecting and monitoring an automatic mode transition, and to which mode. Finally, it provides a means for assessing whether the operator is actually performing actions appropriate for the situation.

In applying the GT-CATS methodology to the domain of glass cockpit aviation, GT-CATS has undergone a number of important modifications. The first of these addresses the limiting operating envelope, a construct which represents the sequence of constraints imposed on the aircraft's flight path by the flight plan. The limiting operating envelope representation has been streamlined, and procedures for modifying it as new Air Traffic Control (ATC) clearances are received have been implemented in GT-CATS. These refinements have improved the limiting operating envelope's utility for generating an adequate description of the current flight situation for use by GT-CATS' inferencing procedures.

Another area of progress concerns the Operator Function Modeling (OFM) approach taken to represent the activities of the pilots as they use the automated flight systems in the glass cockpit. The model structure has been formalized, and is now called the OFM for systems with Automatic Control Modes (OFM-ACM). The OFM-ACM hierarchy first decomposes the activities in each phase and subphase of flight into functions relevant to each (sub)phase. These functions are then decomposed into the modes that can be used for performing them. Finally, each mode selection is decomposed into the tasks, subtasks, and actions important for using the selected mode. The OFM-ACM is used by GT-CATS to construct a dynamic representation of pilot-automation interaction to support inferencing.

Along with the above modifications, a scheme for enhancing GT-CATS' state space representation has also been developed. The purpose of the state space enhancements is to provide additional variables for comparison with the limiting operating envelope in assessing the current flight situation. In particular, variables that can improve GT-CATS' effectiveness in understanding Flight Management System (FMS) modes, such as Vertical Navigation (VNAV) mode are candidates for addition to the state space representation. By including such variables in the state space, GT-CATS may no longer needs to compute predictive information to effectively understand VNAV usage. Thus, required processing will be reduced.

A final area of progress on GT-CATS concerns the interface with the glass cockpit part-task simulator (GT-EFIRT). GT-CATS has been enhanced to run "live", in real-time, with the simulator, so that it may track pilot actions as they are performed. A large part of this effort was invested in modifications to GT-EFIRT that will enable it to be connected to GT-CATS. Such modifications included alterations to the data-passing interface to filter out spurious actions (e.g., mouse clicks that occur in the process of setting MCP values, but are not important for understanding the final setting). An interface was also added to GT-EFIRT for the purpose of displaying ATC directives sent from GT-CATS as part of an experimental flight scenario. In this way, ATC commands received by pilots flying the simulator are synced to the GT-CATS inferencing process.

Transitions in Graduate Student Involvement

Due to the student transition we spent a great deal of time learning the major software systems that developed during the previous grant. These include GT-EFIRT (Georgia Tech Electronic Flight Instrument Research Tool) our Sun-based 757/767 part task simulator; the VNAV Tutor; and the Spatial Situation Indicator (SSI) display. GT-EFIRT is designed to facilitate research relating to the interaction between the pilot and the aircraft's flight management system (FMS). It is the simulator that was used to demonstrate and evaluate both the VNAV Tutor and the SSI display. It is also likely to be the host for the initial research sponsored by the current grant.

Initially, we looked at a range of possible research topics. The initial GT-CATS work is nearing completion. Possibilities included extensions of the GT-CATS, the VNAV Tutor, a CTAS Tutor, further work on CFIT displays. Personnel and financial resources limited the number of things that Georgia Tech could pursue concurrently. At this point, we are focusing on making the VNAV Tutor a more intelligent tutor--with a variation of GT-CATS providing the intelligence. Alan Chappell will be the primary student involved in this work. It will comprise his Ph.D. thesis. The next six months of this grant will include allowing Alan to become familiar with auto flight systems and flight management systems (he is currently attending Delta's training), the related training needs in these areas, and possible research issues.

A brief summary of Alan's activities for the last six months...

Alan R. Chappell
September - December, 1993

This period saw the addition of a new student, Alan Chappell, in September. Having previous experience in automation of wind tunnel control and software systems for evaluating fighter aircraft performance, Alan started with a good aviation background. However, none of this experience included commercial aviation issues. His work during this period, hence, has been in becoming familiar with these issues and the ongoing research supported by this grant.

Specifically, the VNAV Tutor operation, the research flight simulator, and the software environment were investigated. Time was spent learning to demonstrate the VNAV Tutor in order to gain familiarity with the system capabilities and experience with commercial cockpit control issues. A primer was written describing the GT-EFIRT (Georgia Tech Electronic Flight Instrument Research Tool) instrumentation and its use in control and navigation. Several bugs were corrected in the spatial situation indicator (SSI) and mode control panel (MCP) software in order to enhance the systems and to learn more about the software structure and environment.

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Human-Centered Design of Human-Computer-Human Dialogs

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Semi-Annual Reports: #2

February 1, 1994 through July 31, 1994

E-24-X30

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The second six months of this grant saw further development of GT-CATS--the Georgia Tech Crew Activity Tracking System and progress on research exploring tutoring concepts for tutors for mode management. The latter included data analysis and a preliminary paper summarizing the development and evaluation of the VNAV Tutor. A follow-on to the VNAV Tutor is planned. Research in this direction will examine the use of OFMspert and GT-CATS to create an 'intelligent' tutor for mode management, a more extensive domain of application than only vertical navigation, and alternative pedagogy, such as substituting focused 'cases' of reported mode management situations rather than lessons defined by full LOFT scenarios.

The following sections further describe each of these areas. They include copies of conference papers and presentations.

GT-CATS

Overview

The Georgia Tech Crew Activity Tracking System (GT-CATS) is a computer system which embodies a methodology and architecture for understanding how operators select and use modes of automation to control complex dynamic systems. GT-CATS has been implemented specifically to track the activities of "glass cockpit" pilots as they use modes of automation to fly a desired flight path. GT-CATS' activity tracking methodology specifically involves: (1) hypothesizing the mode configuration the operator will select in the current operational setting; (2) confirming that actual operator actions support the hypothesized mode configuration; (3) determining whether a detected operator action in fact supports a valid alternative mode configuration, or whether the action is in error; and (4) identifying missed or late actions. The centerpiece of GT-CATS' methodology is the capacity to revise an incorrect hypothesis about the expected mode configuration to arrive at accurate explanations for operator actions that support an alternative valid mode configuration. A block diagram of GT-CATS is depicted in Figure 1.

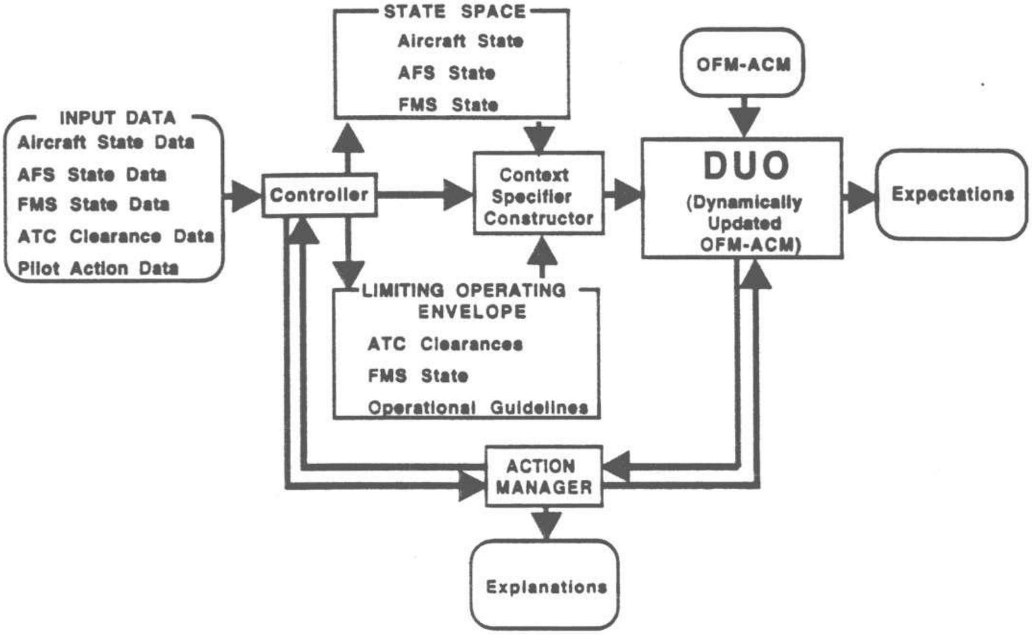


Figure 1. GT-CATS Block Diagram

Current Work

Recent GT-CATS research has focused primarily on preparing for a formal evaluation of GT-CATS' activity tracking capabilities. The planned evaluation seeks to demonstrate

GT-CATS' use and effectiveness for understanding how operators select and use modes of automation. The evaluation requires fifteen Boeing 757/767 type-rated pilots to verbalize the reasoning behind their autoflight system mode manipulations as they fly five flight scenarios on the Georgia Tech Electronic Flight Instrument Research Testbed (GT-EFIRT) simulator. The study will then compare the pilots' explanations to the expectations and explanations issued by GT-CATS. Output from GT-CATS should agree closely with the pilots' explanations, if GT-CATS' activity tracking method is to prove successful.

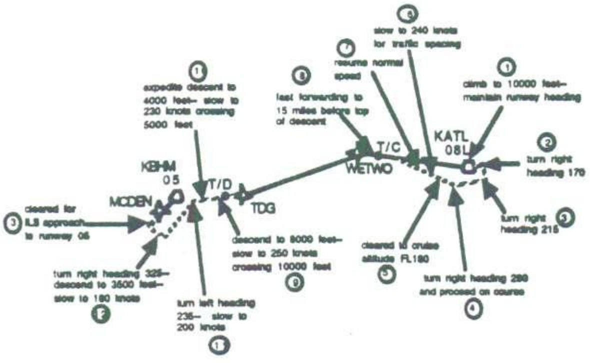
A considerable share of the evaluation preparations addressed the development of the experimental flight scenarios, to ensure adequate representiveness and realism. Flight scenarios from a major airline and a NASA Ames LOFT form the basis for the planned scenarios. The scenarios (Figures 2a and 2b) incorporate clearances designed to elicit a range of automation mode selections/transitions. Test runs have aimed toward ensuring that clearances are issued at appropriate times, and that selected automation modes perform in the required capacity (e.g., ensuring that the GT-EFIRT simulator observes a programmed crossing restriction in VNAV). As part of this process, consultations with actual Boeing 757/767 pilots helped to identify and correct problems with the GT-EFIRT simulator and scenarios.

Along with the development and testing of the experimental setup, GT-CATS research efforts also addressed the development of a preliminary plan for analyzing the data obtained in the planned evaluation. Recent refinements to the plan enable more effective examination of GT-CATS' activity tracking capabilities. The plan now allows for evaluation of the activity tracking methodology on an action-by-action basis, to assess in detail: (1) how well GT-CATS understands each type of pilot action, (2) which specific situations cause GT-CATS to revise explanations, and (3) which types of situations result in degraded understanding. Modifications to GT-CATS' output now make this additional information available. The output data will be formatted with the aid of a special analysis program. The program is designed to tabulate, by action type, how each action is interpreted, and generate summary information that describes GT-CATS' performance at a level adequate for assessing its strengths and weaknesses.

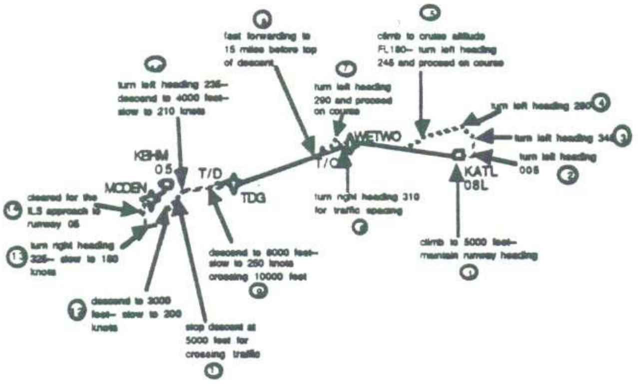
Presentations

Much of this work was formally presented at the 1994 IEEE Conference on Systems, Man, and Cybernetics in San Antonio, Texas. A companion paper entitled "A Methodology for Understanding How Operators Select and Use Automation to Control Complex Dynamic Systems" appeared in the conference proceedings. The paper and presentation are included as Appendix A1 and A2 of this report. A presentation on GT-

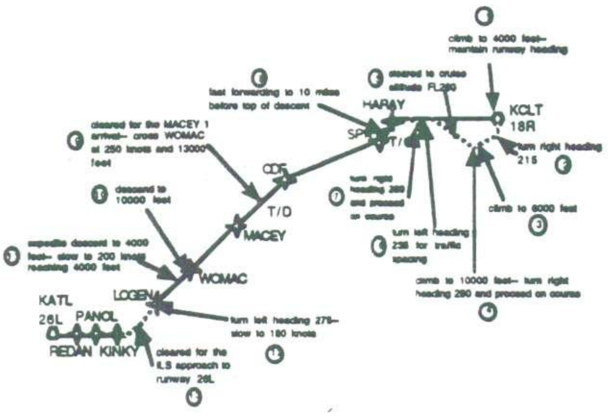
CATS was also given at the NASA Ames Training For Automation workshop (Appendix A3). Subsequent discussions explored possibilities for integrating GT-CATS into an intelligent tutoring system for advanced cockpit automation.



Scenario 1: KATL-KBHM

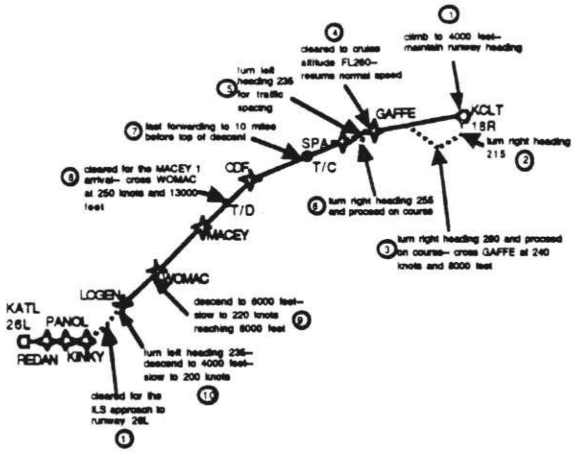


Scenario 2: KATL-KBHM1

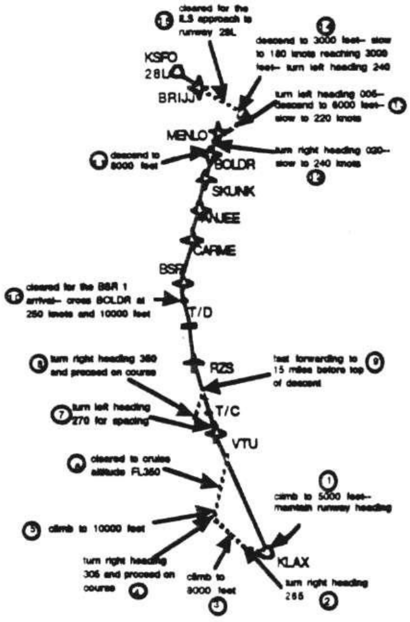


Scenario 3: KCLT-KATL

Figure 2a. Scenarios 1-3.



Scenario 4: KCLT-KATL1



Scenario 5: KLAX-KSFO

Figure 2b. Scenarios 4-5.

APPENDIX A1

GT-CATS SMC Paper

Callantine, T. J., and Mitchell, C. M. (1994). A methodology for understanding how operators use modes of automation to control complex dynamic systems. *Proceedings of the 1994 International Conference on Systems, Man, and Cybernetics*, San Antonio, TX.

APPENDIX A2

GT-CATS SMC Presentation

Presentation Entitled "A Methodology for Understanding How Operators Use Modes of Automation to Control Complex Dynamic Systems" presented at the 1994 International Conference on Systems, Man, and Cybernetics, San Antonio, TX, October, 1994.

APPENDIX A3

GT-CATS Training for Automation Workshop Presentation

Presentation Entitled “The Georgia Tech Crew Activity Tracking System” presented at the NASA Ames Training for Automation Workshop, Moffett Field, CA, August, 1994.

Training Systems for Automation

One of the primary research efforts for this grant is training systems for automation. In the past six months this effort included several complementary activities: evaluation and documentation of the VNAV Tutor, conceptual design of a case-based mode management tutor, and the establishment of a Silicon Graphics research environment, and participation in the Training for Automation Workshop. Progress on each of these activities is discussed below.

VNAV Tutor

A statistical analysis of the data from the initial evaluation of the VNAV Tutor was completed. This evaluation used five pilots transitioning from non-FMS aircraft to a glass cockpit aircraft. The major findings from this analysis show that students learn the actions associated with VNAV well (see Figure 1). In most cases they successfully learn the relationship between the MCP and the FMS as it relates to VNAV (see Figure 2). However, the students are less proficient at identifying data sources to confirm the accuracy of their actions or the accuracy of the VNAV control mode operation. The data supporting these findings and more detailed interpretation are presented in Appendix B1.

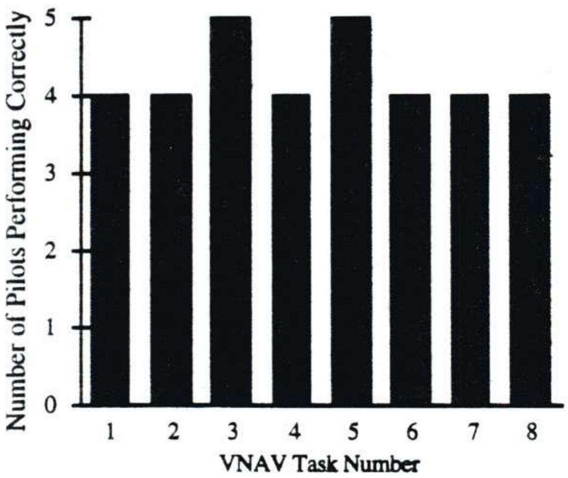


Figure 1. Number of pilots performing correctly on VNAV tasks.

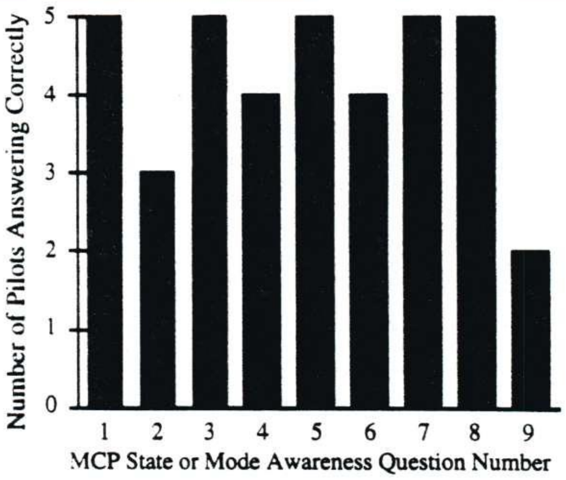


Figure 2. Number of pilots correctly answering questions about the MCP state and mode transitions.

A paper titled "VNAV Tutor: System Knowledge Training for Improving Pilots' Mode Awareness" which documents the VNAV Tutor and the results of the evaluation was written. This paper was presented at the 1994 IEEE International Conference on Systems, Man, and Cybernetics and published in the conference proceedings. A copy of this paper and the presentation appear in this report as Appendices B1 and B2, respectively.

In addition, we started the formulation of a plan for the follow-on evaluation of the VNAV Tutor. The VNAV related functions, data sources, and operations taught by the VNAV Tutor were identified and enumerated. This list extracts and summarizes the salient points of each tutor message in the four training scenarios. Such a set of training objectives defines the starting point for a thorough evaluation of the effectiveness of the VNAV tutor. Preliminary versions of the revised pre- and post- tutor questionnaires have been completed. The in-flight evaluation focusing on VNAV use and mode awareness has also been developed. These evaluation tools provide insights into the capabilities and limitations of the VNAV Tutor. The information gained through this evaluation will guide future Georgia Tech research in training systems.

Case-Based Mode Management Tutor

In order to build on the lessons learned from the VNAV Tutor and other developments in training systems research we initiated the conceptual design for a new tutoring system, a case-based mode management tutor. This proposed system incorporates a case-base of flight scenarios (i.e., incidents and accidents drawn from the relevant literature, such as the ASRS data base). These scenarios are used to configure focused tutoring scenarios that highlight mode management, transition, and interaction. The tutoring system monitors pilot actions in order to control training both within and between scenarios. Within a scenario, the tutor uses a combination of expert and student models to guide the pilot's focus of attention and flight control actions. Expert and student models also guide the selection of new scenarios to systematically broaden the pilot's exposure to mode operation and potential mode management problems. Such an instructional system, combining case-based reasoning (CBR) and intelligent tutoring system (ITS) technologies, may provide an environment and instructional content capable of teaching pilots the wide range of complex and varied modes of control in modern glass cockpit aircraft.

Silicon Graphics Research Environment

A Silicon Graphics Inc. (SGI) Indigo 2 was purchased and configured. This dual head graphics engine duplicates the Mini-ACFS environment at Ames Research Center. A comparable configuration promotes better software transfer from Georgia Tech to Ames and other Ames grantees. Future Georgia Tech aviation research will develop and evaluate proposed systems on the SGI . Experiments will be conducted with the research software running on the SGI communicating via UNIX interprocess protocols with the GT-EFIRT simulator running on a Sun SPARCstation 10.

APPENDIX B1

VNAV Tutor SMC Paper

Crowther, E. G., Chappell, A. R., and Mitchell, C. M. (1994). VNAV Tutor: System knowledge training for improving pilots' mode awareness. *Proceedings of the 1994 International Conference on Systems, Man, and Cybernetics*, San Antonio, TX.

APPENDIX B2

VNAV Tutor SMC Presentation

Presentation Entitled "VNAV Tutor: System Knowledge Training for Improving Pilots' Mode Awareness" presented at the 1994 International Conference on Systems, Man, and Cybernetics, San Antonio, TX, October, 1994.

E-24-X30
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Human-Centered Design of Human-Computer-Human Dialogs

in

Aerospace Systems

NASA grant (NASA Ames control number NCC 2-824)

Dr. Everett Palmer
Technical Monitor
NASA Ames Research Center
Code 513.1
Moffett Field, CA

Semi-Annual Reports: #4

February 1, 1995 through July 31, 1995

E-24-X30

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This research consists of two primary activities: the continued development and evaluation of GT-CATS (Georgia Tech Crew Activity Tracking System) and the exploration of intelligent tutoring systems to support mode awareness for pilots on sophisticated commercial flight decks. A summary of the activities completed in each of these areas follows.

GT-CATS

Overview

The Georgia Tech Crew Activity Tracking System (GT-CATS) is a computer system designed to understand how operators select and use modes of automation to control complex dynamic systems. As implemented, GT-CATS (1) hypothesizes the autoflight modes Boeing 757/767 pilots will select in the current operational setting, (2) confirms that actual operator actions support the hypothesized mode configuration, (3) determines whether operator actions support an alternative valid mode configuration, or whether actions are in error, and (4) identifies missed or late actions. Crucial to GT-CATS is the capability to revise an incorrect hypothesis about the expected mode configuration to arrive at accurate explanations for operator actions that support an alternative valid mode configuration.

Current Work

Recent GT-CATS research has focused on formally evaluating GT-CATS activity tracking capabilities. A major milestone was accomplished, as all data required for the evaluation have been collected. The evaluation involved ten Boeing 757/767 type-rated pilots flying five scenarios each on the Georgia Tech Electronic Flight Instrument Research Testbed (GT-EFIRT) simulator. Each pilot first received instruction designed to familiarize them with GT-EFIRT that included a short training scenario. Following the orientation phase, pilots “flew” the five experimental scenarios. Pilots then completed a questionnaire designed to illicit their opinions on the reasonableness, representativeness, and realism of GT-EFIRT simulator performance, and the experimental scenarios. Each experimental session lasted approximately four and one half hours.

Figure 1 depicts the experimental setup used in the evaluation. The experimenter acted as Air Traffic Control, and monitored the operation of GT-CATS and GT-EFIRT. The subject pilot’s activities were audio and video recorded. Data were recorded via computer;

GT-EFIRT simulator data were recorded on one SparcStation and GT-CATS output data were recorded on the other. The GT-EFIRT data include the values of the relevant simulator state data recorded and time-stamped every five seconds, along with time-stamped ATC clearances. GT-CATS output data were the hypothesized operator actions, detected actions, and explanations for actions, all time-stamped with the time they were issued. GT-CATS data also included the time-stamped ATC clearances and entries made by the experimenter indicating whether or not explanations produced by GT-CATS were correct, insofar as they accurately described the mode that a given pilot action supported. The full data set encompassing all 50 experimental scenarios yielded 2078 pilot actions.

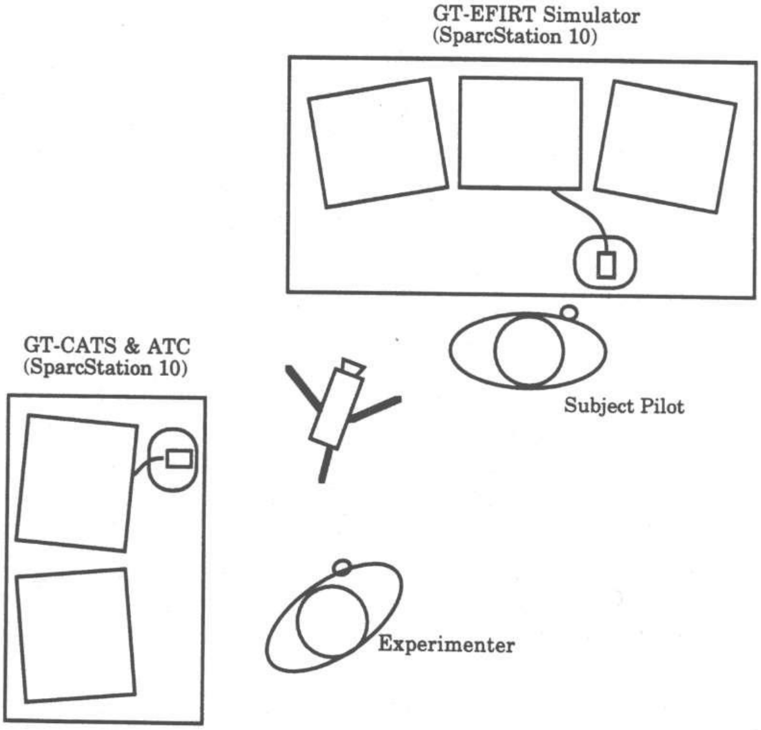

Figure 1. Experimental Setup

Preliminary analysis of the data from the evaluation study has been completed. A second phase of analysis intended to closely examine and account for any misunderstood actions is ongoing. The preliminary data are encouraging. They show that GT-CATS understands the great majority of pilot actions, and that GT-CATS' explanation revision process indeed performs an important function. The overall data is depicted in Figure 1.

In addition to examining the GT-CATS' overall understanding of pilot actions, the analysis seeks to investigate the accuracy of the hypotheses about pilot mode selections, and the reasons behind any misunderstandings. The expectations generated by GT-CATS for each scenario for all subjects are categorized and charted in Figure 2. "Correct Explanations" result when GT-CATS' expects an action and the subject pilot then performs the action to support the hypothesized mode. "Incorrect Explanations" result when an action is expected, and indeed performed by the pilot, but the pilot performed the action to support a mode other than the one hypothesized. "Unfulfilled Expectations" refer to actions hypothesized by GT-CATS, but that the subject pilot did not perform. The detailed explanations for discrepancies between pilot actions and GT-CATS are the subject of the second phase analysis.

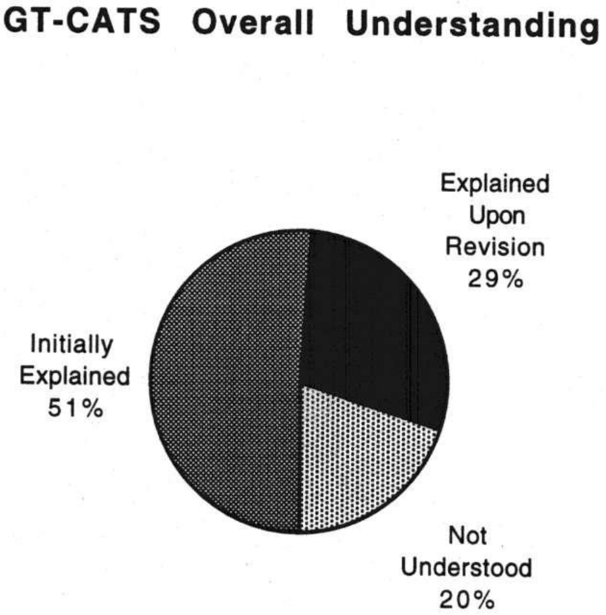

Figure 2.

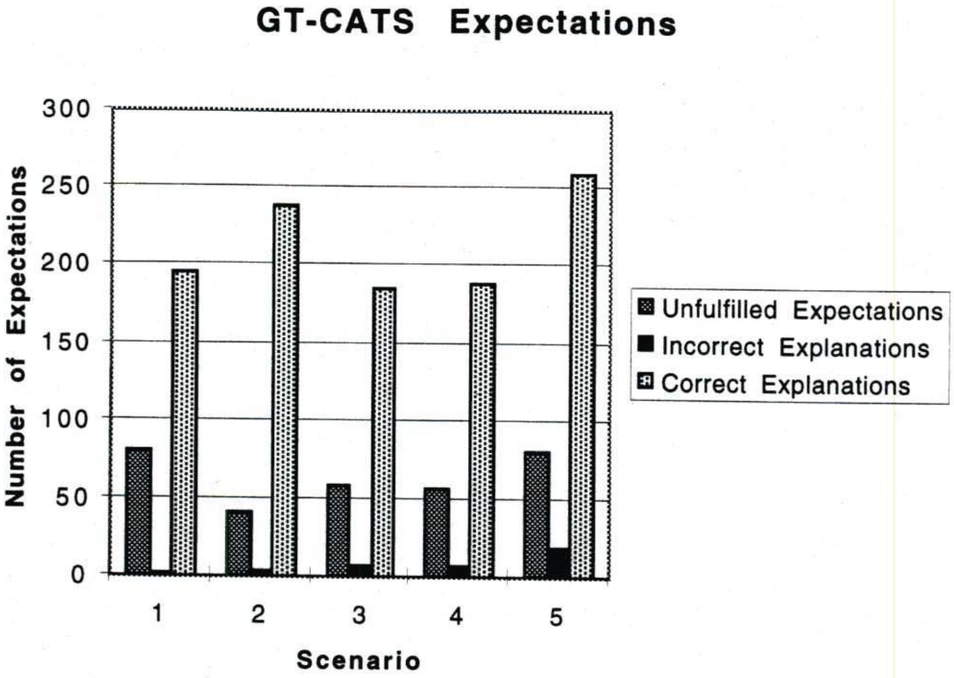

Figure 3.

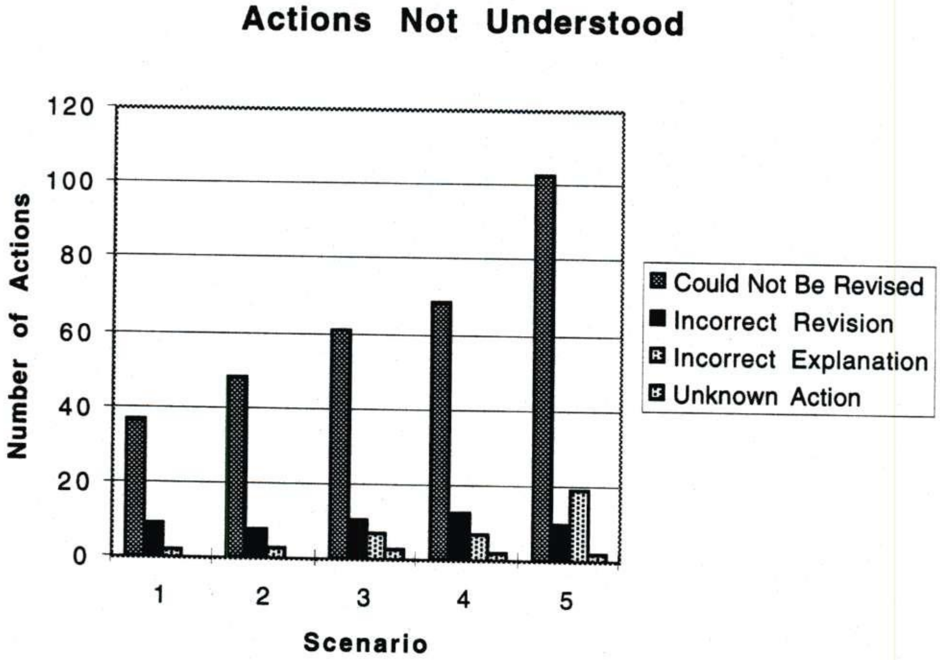

Figure 4.

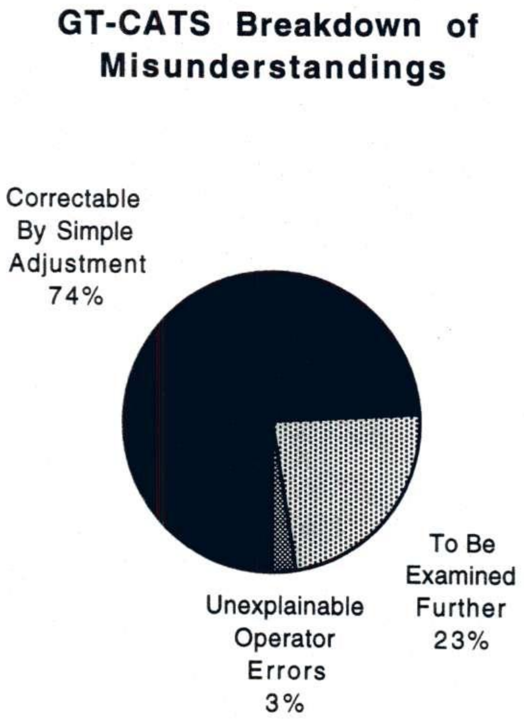

Figure 5.

The misunderstandings for each scenario are similarly charted in Figure 4. Actions are not understood if they are incorrectly explained after being properly expected ("Incorrect Explanation"), if the revision process produces an incorrect explanation ("Incorrect Revision"), or if the revision process fails outright, such that it cannot produce an explanation for the action ("Could Not Be Revised"). In addition, actions that are not modeled to occur during the subphase of flight in which they were detected are designated "Unknown Actions"

In investigating GT-CATS' capabilities to expect and accurately explain operator actions, as presented here in Figures 2-4, several issues deserve close inspection. These issues form the basis for the second phase of analysis, which is devoted to examining and cataloging the circumstances surrounding all undesirable determinations made by GT-CATS. In other words, the reasons why GT-CATS generated unfulfilled explanations, expectations that led to incorrect explanations, or the reasons surrounding the failure or incorrect results of the revision process are examined for each such occurrence. Many such cases can be explained in terms of errors in GT-CATS' Operator Function Model for systems with Automatic Control Modes (OFM-ACM). Others can results when the action in question is in fact an operator error (an action for which GT-CATS cannot produce a revised explanation may likely be in error). Similarly, unfulfilled explanations are commonly produced when an operator chooses an alternative mode, also valid for the situation, but not normatively expected by GT-CATS. Careful analysis of these issues is vital to understanding how the small number of misunderstandings can be further reduced through modifications to GT-CATS or its OFM-ACM.

Figure 5 gives a breakdown of the 20% of actions not understood. The figure indicates that 74% of these actions could be understood by correcting modeling problems or through other simple adjustments to GT-CATS. 3% of the misunderstood actions should not be understood, as they are errors committed by the pilots. The figure also shows that 23% of misunderstood actions (4.6% overall) require further work in order to understand them.

Appendix 1 contains a copy of the presentation summarizing the GT-CATS data analysis. Currently, a thesis documenting the development, implementation, and evaluation of GT-CATS is in preparation.

Training Systems for Automation

One of the primary research efforts for this grant is training systems for automation. In the past six months this effort involved several activities including communication of research efforts through conference paper preparation, development of a research program and proposal for a new training system, and conversion of GT-CATS to a platform independent system. Progress on each of these activities is discussed below.

Two conference papers were written this period. The first, "Task Models to Guide Analysis: Use of the Operator Function Model to Represent Mode Transitions" was prepared for the Eighth International Symposium on Aviation Psychology and is included as Appendix 2. This paper, written in conjunction with another NASA Ames grantee, details the use of the Operator Function Model to model and analyze mode transition incidents in glass cockpit aircraft. The second, "Intelligent Tutoring Systems to Support Mode Awareness in the 'Glass Cockpit' " was prepared for the 1995 IFAC Symposium on Man Machine Systems, and was presented at the conference meeting. The paper and the presentation are included as Appendices 3 and 4 respectively. This paper discussed the motivation, design, and results of the VNAV Tutor and presented a proposed direction for further research based on the lessons learned from those results.

A new research effort in training was initiated. This effort aims to address the performance difference between the pilot just finishing transition training, and the experienced/expert pilot on a given aircraft type. Especially with respect to the automation in glass cockpits, this difference in performance is due to many factors including breadth of knowledge, integration of various types of knowledge, and experience with nominal and off-nominal operation. This research proposes a Case-Based Intelligent Tutoring System to address this performance gap. A research proposal detailing the genesis of the gap, some of its effects on operation, and the conceptual design of the proposed training system is included as Appendix B4.

Conversion of GT-CATS from LISP to C++ was initiated. This conversion is an effort to broaden the research team's knowledge of the CATS system in preparation for using these capabilities as the basis of expert and student models in future training systems, and to provide this functionality in a more widely usable form. This new version is written to be platform independent where possible, currently running on both Sun and SGI architectures. Progress thus far includes reading and processing of the model into appropriate data structures; parsing flight plans, ATC messages, and state data; a display interface written in the TCL graphics scripting language; and the generation of action expectations. Efforts are currently directed toward verifying that these expectations match the expectations of the LISP version.

APPENDIX 1

Presentation of GT-CATS Data

APPENDIX 2

Mode Transition Aviation Psychology Paper

Degani, A., Mitchell, C. M. & Chappell, A. R. (1995). Task models to guide analysis: Use of the Operator Function Model to represent mode transitions. *Proceedings of the Eighth International Symposium on Aviation Psychology*, Columbus, OH.

APPENDIX 3

Mode Awareness Training IFAC Paper

Chappell, A. R. & Mitchell, C. M. (1995). Intelligent tutoring systems to support mode awareness in the "glass cockpit". *Proceedings of the 6th IFAC/IFIP/IFOR/IEA Symposium on Analysis, Design, and Evaluation of Man Machine Systems*, Boston, MA.

APPENDIX 4

Mode Awareness Training IFAC Presentation

Presentation entitled "Intelligent Tutoring Systems to Support Mode Awareness in the "Glass Cockpit"" presented at the 6th IFAC/IFIP/IFOR/IEA Symposium on Analysis, Design, and Evaluation of Man Machine System, Boston, MA, 1995.

APPENDIX 5

Case-Based Intelligent Tutoring System Research Proposal

Chappell, A. R. (1995). *Addressing the trained novice/expert performance gap in complex dynamic systems: A case-based intelligent tutoring system* (Ph.D. research proposal). Center for Human-Machine Systems Research, Georgia Institute of Technology, Atlanta, GA.

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CENTER FOR
**HUMAN-MACHINE
SYSTEMS RESEARCH**

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August 5, 1998

Dr. Everett A. Palmer, III
Mail Stop 262-4
NASA--Ames Research Center
Moffet Field, CA 94035

Dear Dr. Palmer:

The enclosed report closes out NCC 2-824, Human-Centered Design of Human-Computer-Human Dialogs in Aerospace Systems. The bean counters at GT inform me that this report is 364 days overdue. Sorry!!

I believe you have copies of all the intellectual products (and persons) produced so far—though Alan is getting close! This copy with attachments is going to you directly, just incase we missed something. Other copies, without attachments, will wind their way through GT and to your accounting office, and probably to you again. I tried to save at least a few trees by deleting copies of the papers from the bean-counter version.

Regards,

Christine M. Mitchell

Human-Centered Design

of

Human-Computer-Human Dialogs in Aerospace Systems

Final Report

NASA Ames Research Center
NCC 2-824
(E 24-X30)

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Final Report

August 1998

Summary

This grant spanned several projects, completing some and initiating others. The major components of research that comprised the past three years are described below.

GT-EFIRT

A series of ongoing research programs at Georgia Tech established a need for a simulation support tool for aircraft computer-based aids. This led to the design and development of the Georgia Tech Electronic Flight Instrument Research Tool (GT-EFIRT). GT-EFIRT is a part-task flight simulator specifically designed to study aircraft display design and single pilot interaction. The simulator, using commercially available graphics and Unix workstations, replicates to a high level of fidelity the Electronic Flight Instrument Systems (EFIS), Flight Management Computer (FMC) and Auto Flight Director System (AFDS) of the Boeing 757/767 aircraft. The simulator can be configured to present information using conventional looking B757/767 displays or next generation Primary Flight Displays (PFD) such as found on the Beech Starship and MD-11.

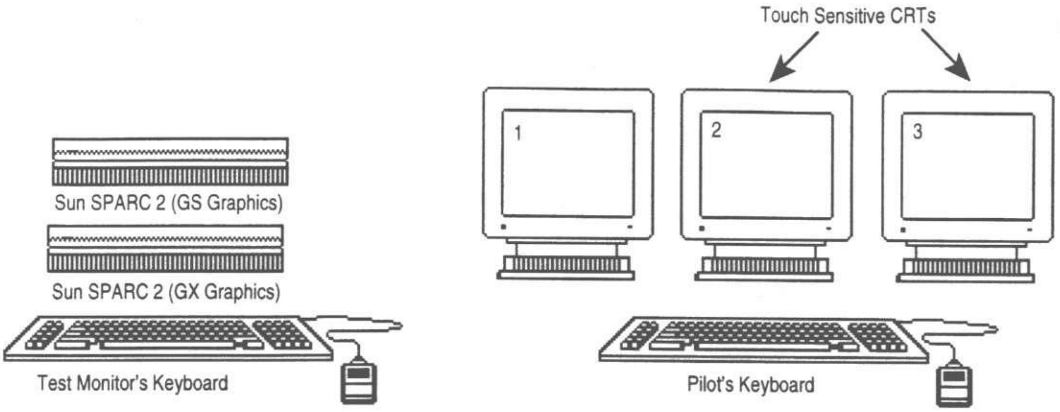
The simulator provides high fidelity representations of the interfaces and responses of the autoflight and instrumentation systems while remaining low-cost, rapidly re-configurable, and portable. Its object-oriented design allows new displays to be prototyped quickly and evaluated through flight scenarios with complete data logging of pilot and systems performance. All navigation related aural and visual alerts/warnings are modeled including the ground proximity warning system (GPWS).

As in the figure below the baseline version of GT-EFIRT utilizes two computers and three monitors. The right two monitors are touch sensitive and all pilot interactions can be performed using touch input. The workstations are connected via a local area network (LAN). A Sun SPARC 2 workstation with a GS graphics accelerator card drives the left most monitor. This monitor and CPU are specifically design for the 3-D flight path and terrain displays associated with the PFD. The UNIX operating system and the Sun OpenLook Toolkit provide flexibility in allocating displays among the CPUs and monitors. The typical configuration is identified in the figure, but any combination of monitors and display windows can be requested. For example, the simulation support panel, which is used by the researcher, can be allocated to a workstation anywhere on a local area network.

Air traffic control (ATC) interaction is carried out by the researcher with real-time event logging in the data collection file. Modular design and rapid reconfiguration were the driving factors in designing the structure of GT-EFIRT. An object-oriented architecture was chosen which is implemented not only in the source programming language, but also in the selection of Sun PHIGS+ as the graphics support language and the Sun OpenLook Toolkit for window management. The underlying simulation is based on a three degree of freedom point mass model of the B757. This model provides sufficient fidelity of aircraft dynamics since no hand flying is implemented. As such, pitch and thrust are the driving forces with no modeling of aircraft control surfaces. The control loops for the auto flight system can operate in several different modes, ranging from simple altitude and heading hold to a full lateral and vertical path guidance based on FMC programmed routes. Localizer and glideslope tracking modes can be engaged for final approach and provide for complete category III full stop landings including the flare maneuver. Computational speed has been enhanced by parallel processing the simulation task across two CPUs. The flight model, FMC and AFDS are allocated to one CPU, while the navigation and moving map are allocated to the other. The two CPUs are synchronized via message traffic on the local area network.

Extensive data collection capabilities are built into GT-EFIRT for both system and pilot monitoring. A data log is maintained for each session whose contents are selectable by the researcher. Events which can be monitored include pilot input, auto pilot state changes, aircraft dynamics, and aircraft related alerts (e.g., flap and gear warnings). Events are recorded with a time stamp. GT-EFIRT served as the part-task simulator for all the research described below.

Note, over the years since GT-EFIRT was first developed, it has migrated to increasingly powerful Sun SPARC Unix workstations and currently only one SPARC 10 is required to run the simulation and drive the three graphics monitors.



CRT 1

Primary Flight Display
or
Attitude Director Indicator
Airspeed
Vertical Speed
Altimeter

CRT 2

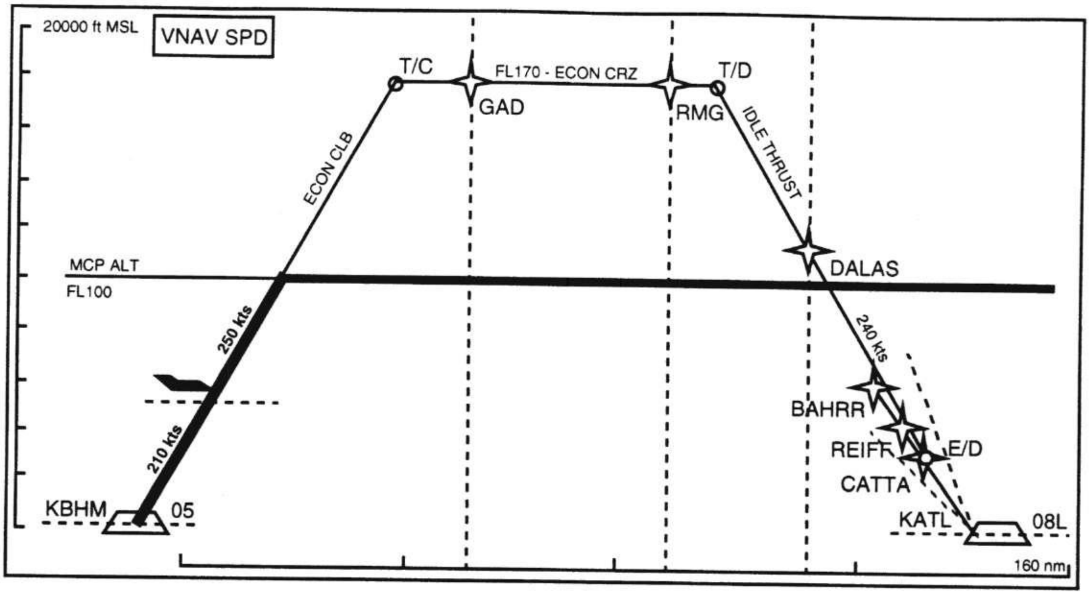
Mode Control Panel
Horizontal Situation Indicator
HSI Control Panel
Control Display Unit

CRT 3

Aircraft Misc.
Simulation Support

The VNAV Tutor: A Flight Management System Vertical Navigation Tutor.

Vertical navigation capabilities of the Flight Management System (FMS) in modern "glass-cockpit" aircraft are often under-utilized or misused by pilots. This can be attributed at least in part to an inadequate understanding by pilots of how the FMS interprets and executes a flight plan, which they have entered. This project combines a unique vertical profile display with a part-task airline transport simulator. The display provides an otherwise unavailable visual representation of FMS and other vertical navigation modes of the aircraft. A control architecture is embedded into the system to allow for the creation of routine flights which the tutor uses as lessons that address key training issues. The tutor controls flight scenarios which help the student pilot explore the content of the FMS vertical profile, FMS execution of that profile through use of the VNAV function, interaction between FMS and other vertical navigation modes, and the use of FMS vertical navigation by the pilot for the completion of various in-flight maneuvers. This system is being evaluated on-site in the flight training department of an U.S. airline. The evaluation takes approximately six hours per pilot. The initial session is used to assess the subject's knowledge regarding FMS and VNAV; a formal questionnaire is administered. Four training sessions with the VNAV tutor follow. The tutorial environment consists of the two-monitor 757/767 simulator, augmented with voice and text-based ATC and tutorial messages, and a third monitor containing the VNAV Profile Display. After the four tutorial sessions, the pilot flies a fifth, and final, evaluation session that does not incorporate the tutor or the Vertical Profile Display. This session has periodic interruptions at predetermined points in order to allow the experimenter to ask the pilot specific questions focusing on vertical navigation awareness regarding the state of the FMS and other auto flight equipment. These questions are used to determine the subject's understanding of the training material. Next, a questionnaire, similar in content to that used prior to the first session, is administered. The comparison of the answers to the two questionnaires serves as a primary source of data in the evaluation. Finally, the evaluation for a particular subject concludes by soliciting pilot reactions and opinions about the VNAV tutor. Citations for this work follow.



3D Primary Flight Display with Terrain Information

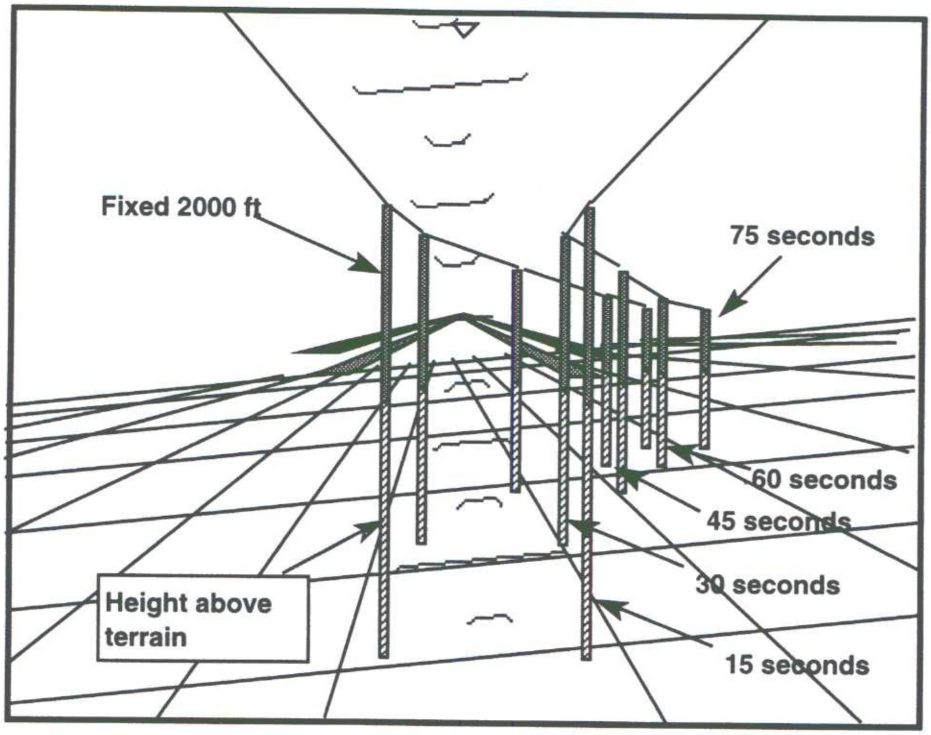
An important worldwide aviation safety problem is still the controlled-flight-into-terrain or CFIT accident. Area navigation and onboard terrain elevation databases offer the potential for improved cockpit displays of near by terrain. This project has developed a prototype primary flight display format designed to re-enforce the pilot's model of both lateral and vertical navigation in near-terrain situations. This new display format is referred to as the Spatial Situation Indicator (SSI). Specific emphasis has been placed on the terminal phase of flight with terrain modeling in the vicinity of the departing and destination airport.

The unique design incorporated perspective symbology that depicts a prediction of the aircraft's predicted position and terrain clearance information for up to 75 seconds ahead of the aircraft. Projection of the flight path is based on a "fast time" modeling technique described by Grunwald (1985). Traditional flight paths use the "tunnel in the sky" approach which present no reference to the ground elevation e.g., Grunwald (1982). The technique developed for this research utilized roll stabilized vertical lines "whiskers" positioned at 15 second intervals out to 75 seconds. The figure illustrates the virtual "whiskers" and flight path. The whiskers are displayed in pairs of equal distant widths so that in steady level flight a perspective path is projected. The whiskers are color coded using green and yellow. The green lower portion extends from the predicted aircraft altitude at that interval to the terrain below. Its length therefore is a direct representation of the terrain clearance at that point in the aircraft's path, given there are no changes in aircraft flight path.

The display also incorporated a dynamically color-coded terrain grid. The color-coding is based upon aircraft predicted height and terrain spot elevations. The color-coding uses dark green for safe terrain and dark red for dangerous terrain. The terrain grid is comprised of a triangular mesh with each triangle having sides of 2 nautical miles (NM). Man-made obstructions such as radio towers are also shown on the terrain grid. Information for building the terrain and obstruction files is obtained from the approach plates for each runway in the scenario.

An experimental evaluation of the display was conducted on-site at a major U.S. airline. Experimental participants are current glass cockpit flight instructors. Each experimental subject, after training to familiarize him/herself with the part-task aircraft simulator and interface, flies three scenarios based on actual controlled flight into or toward terrain as described by Bateman (1991).

Each experimental participant uses one of the two displays: the baseline cockpit display, and this display with flight path predictor and ground terrain information. A total of eighteen pilots will participate, nine with each display. Attention diverting tasks are implemented to match as closely as possible the scenarios as they are described by Bateman. ATC communications are implemented using simple voice communications without supporting electronic intercoms. The experimenter carries out the air traffic controller (ATC) communications. The goal of the experiments is to measure how quickly pilots can detect dangerous terrain with the three different display formats. Response time of the pilot for corrective action is recorded as well as MCP inputs. Analysis of these data is in process. Citations for this work follow.

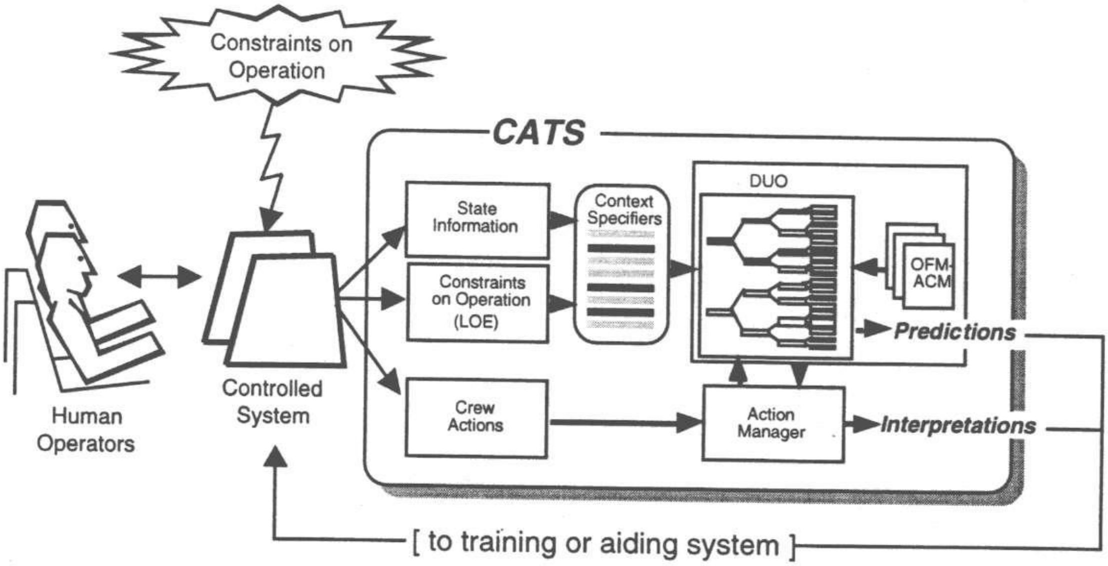


GT-CATS: The Georgia Tech Crew Activity Tracking Systems

Billings (1991) states the following requirements for the design of human-centered systems: First, the human operator must be able to monitor the automated system. Second, the automated system must be able to monitor the human operator. And, finally, each of these two elements must have knowledge of the other's intent. Billings points out that cross monitoring can only be effective if the intentions of the human or automated systems are known. Researchers at Georgia Tech are exploring one method of meeting this requirement. They are developing an activity tracking system that attempts to understand the activities performed by crews of glass cockpit aircraft. The activity tracker focuses specifically on those activities that affect the mode awareness of the crew, such as autoflight mode selection and engagement, and associated planning and monitoring activities. The technology permits the design of systems that can provide crews with context-sensitive advice, reminders, and assistance based on its dynamic understanding of pilot intent.

CATS uses a task-analytic model of crew-automation interactions as its source of knowledge about crew activities. The model of crew activities is structured as a functional decomposition; each phase of flight is decomposed into crew functions, which are in turn decomposed into subfunctions, autoflight mode selections, tasks, subtasks, and, at the lowest level, observable actions. Each activity in the model has an associated set of conditions for determining the status of the activity based on the occurrence of a particular event or events. By noting the status of activities in the model (e.g., "active," "pending," "done"), a useful description of the crew's current activities is produced. The CATS system analyses real-time data from a part-task airline transport simulator. CATS accepts aircraft and auto flight system state data, along with data about actions performed by the pilots "flying" the simulator. These data are used to generate expectations and explanations about the activities in real-time.

An evaluation will be conducted in which airline pilots "fly" the part-task simulator. This data will include concurrent verbal protocols from the pilots to be used in assessing the degree of match between the expectations and explanations of CATS and those of the pilots. This phase of the study will follow the method of Jones et al, to validate empirically the adequacy of a computer-based activity tracking system to correctly infer operator intent.



Citations for Papers Describing the Research Supported by this Grant *

Williams, J. A., & Mitchell, C. M. (1993). Effect of integrated flight and terrain displays on controlled flight into terrain. *Proceedings of the 1995 IEEE International Conference on Systems, Man, and Cybernetics*, Le Touquet, France, 120-125.

Callantine, T. J., & Mitchell, C. M. (1994). A methodology for understanding how operators select and use modes of automation to control complex dynamic systems. *Proceedings of the 1994 IEEE International Conference on Systems, Man, and Cybernetics*, San Antonio, Texas, 1751-1756.

Callantine, T. (1996). *Tracking operator activities in complex systems.* Ph.D. Thesis, School of Industrial and Systems Engineering, Georgia Institute of Technology, Atlanta, Georgia.

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Chappell, A. R., & Mitchell, C. M. (1996). Use of visualization and contextualization in training operators of complex systems. *Proceedings of the Human Factors and Ergonomics Society, 40th Annual Meeting*, Philadelphia, PA, 264-268.

Chappell, A. R., Crowther, E. G., Mitchell, C. M., & Govindaraj, T. (1997). The VNAV Tutor: Addressing a mode awareness difficulty for pilots of glass cockpit aircraft. *IEEE Transactions on Systems, Man, and Cybernetics, 27*(3), 327-385.

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* For copies of these references please contact Dr. Christine M. Mitchell, Center for Human-Machine Systems Research, School of Industrial & Systems Engineering, Georgia Institute of Technology, Atlanta, Georgia 30332-0205, +1 404 894-4321, +1 404 894-2301 (fax), cm@chmsr.gatech.edu.