Human-Centered Design

of

Human-Computer-Human Dialogs in Aerospace Systems

Final Report

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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.
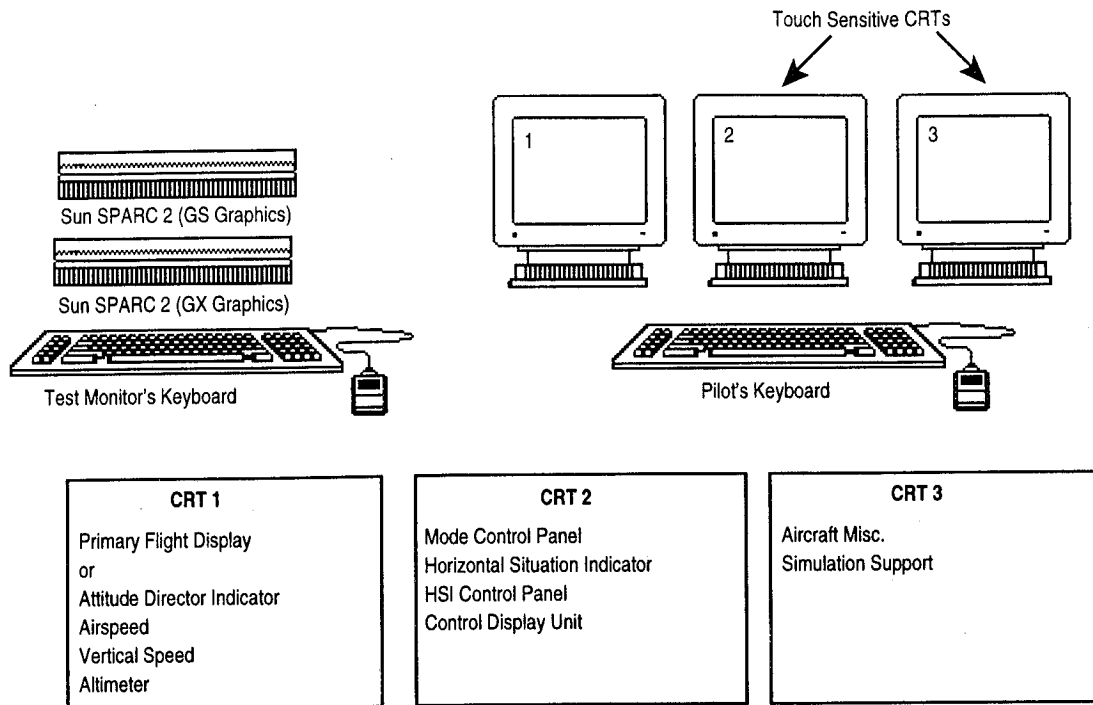
The simulator provides high fidelity representations of the interfaces and responses of the autoflight and instrumentation systems while remaining low-cost, rapidly re-configurable, and portable. Its object-oriented design allows new displays to be prototyped quickly and evaluated through flight scenarios 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.
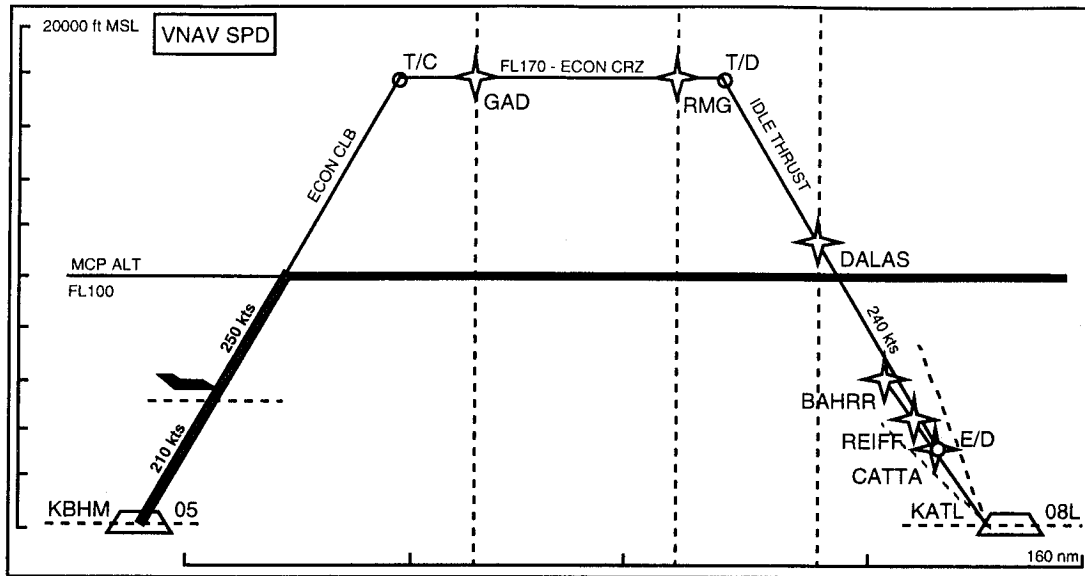
Extensive data collection capabilities are built into GT-EFIRT for both system and pilot monitoring. A data log is maintained for each session whose contents are selectable by the researcher. Events which can be monitored include pilot input, auto pilot state changes, aircraft dynamics, and aircraft 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.

Touch Sensitive CRTs

Sun SPARC 2 (GS Graphics)

Sun SPARC 2 (GX Graphics)

Test Monitor's Keyboard

1

2

3

Pilot's Keyboard

CRT 1	CRT 2	CRT 3
Primary Flight Display or Attitude Director Indicator Airspeed Vertical Speed Altimeter	Mode Control Panel Horizontal Situation Indicator HSI Control Panel Control Display Unit	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.

VNAV SPD

T/C   FL170 - ECON CRZ   T/D

GAD   RMG

ECON CLB   IDLE THRUST

MCP ALT   DALAS

FL100

250 Kts   240 Kts

210 Kts

BAHRR

REIFR   E/D

CATTA

KBHM   05   KATL   08L

160 nm

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.
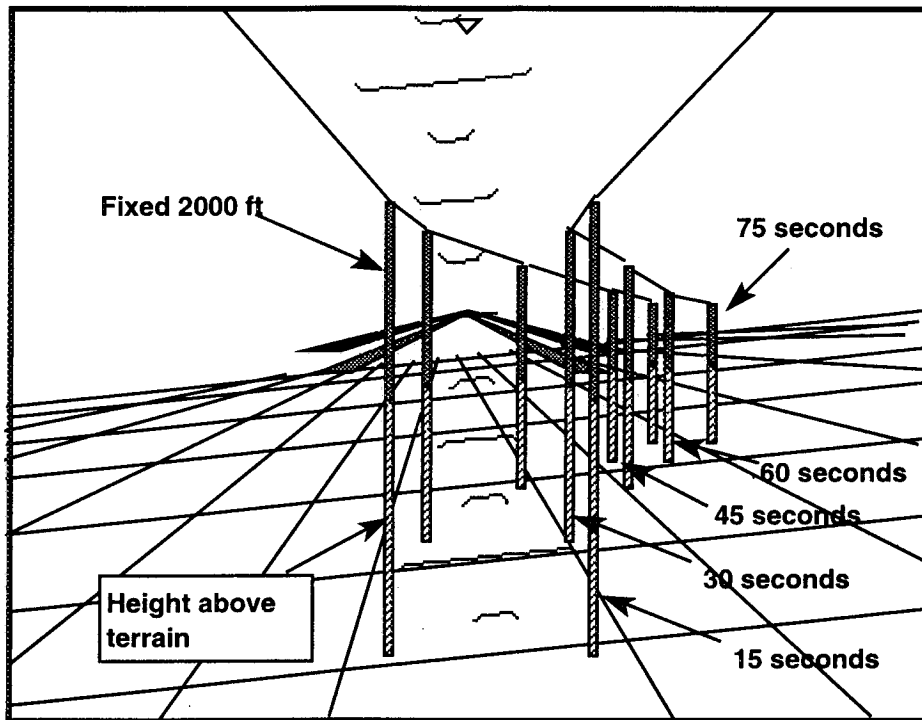

GT-CATS: The Georgia Tech Crew Activity Tracking Systems

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.
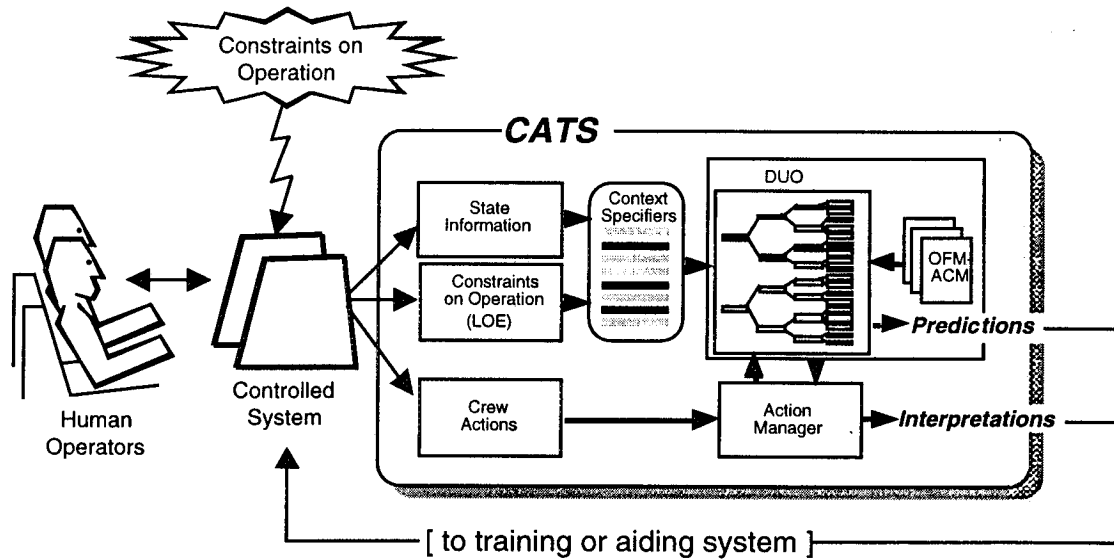
Citations for Papers Describing the Research Supported by this Grant [*]

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