DOCUMENT RESUME

ED 384 677 TM 023 999

AUTHOR	Steinberg, Linda S.; Gitomer, Drew H.
TITLE	Cognitive Task Analysis, Interface Design, and Technical Troubleshooting.
INSTITUTION	Educational Testing Service, Princeton, N.J.
REPORT NO	ETS-RR-92-73
PUB DATE	Dec 92
NOTE	19p.
PUB TYPE	Reports - Evaluative/Feasibility (142)
EDRS PRICE	MF01/PC01 Plus Postage.
DESCRIPTORS	*Cognitive Processes; *Computer Interfaces; *Hydraulics; *Intelligent Tutoring Systems; *Job Skills; *Troubleshooting
IDENTIFIERS	Aircraft Design; Expert Novice Paradigm; *Task Content; User Aids

ABSTRACT

A model of the interface design process is proposed that makes use of two interdependent levels of cognitive analysis: the study of the criterion task through an analysis of expert/novice differences and the evaluation of the working user interface design through the application of a practical interface analysis methodology (GOMS model). This dual analysis is reviewed in the context of HYDRIVE, a video-based intelligent tutoring system designed to facilitate the development of troubleshooting skills for technicians working on aircraft hydraulics systems. The initial cognitive task analysis enabled the identification of critical troubleshooting skills and troubleshooting procedures. It is found that, even with an in-depth initial cognitive task, the GOMS interface analysis resulted in significant and beneficial design changes. Two figures illustrate the discussion. (SLD)

RR-92-73

RESEARCH REPORT

COGNITIVE TASK ANALYSIS, INTERFACE DESIGN, AND TECHNICAL TROUBLESHOOTING

Linda S. Steinberg
Drew H. Gitomer

Educational Testing Service
Princeton, New Jersey
December 1992

COGNITIVE TASK ANALYSIS, INTERFACE DESIGN, AND TECHNICAL TROUBLESHOOTING

Linda S. Steinberg and Drew H. Gitomer

Educational Testing Service
Rosedale Road
Princeton, NJ 08541
Phone: (609)734-5512
E-Mail: LSS6511@rosedale.bitnet

ABSTRACT

We propose a model of the interface design process that makes use of two interdependent levels of cognitive analysis: 1) the study of the criterion task through an analysis of expert/novice differences and; 2) the evaluation of the working user interface design through the application of a practical interface analysis methodology (GOMS model). We review this dual analysis in the context of HYDRIVE, a video-disc based intelligent tutoring system designed to facilitate the development of troubleshooting skills for aircraft hydraulics systems. The initial cognitive task analysis enabled the identification of critical troubleshooting skills and troubleshooting procedures. We find, though, that even with an in-depth initial cognitive task analysis, the GOMS interface analysis resulted in significant and beneficial design changes.

KEYWORDS

Cognitive task analysis, hydraulics maintenance, intelligent tutoring system, interface design, troubleshooting.

INTRODUCTION

Intelligent tutoring systems necessarily rely on an abstracted representation of a target task. Even in a reasonably faithful simulation environment, there are significant distinctions between a target task and its representation in a tutoring system. Good system design ensures that the most critical and cognitively demanding features of the target task are well-represented by the system. Features of a target task which are not as determinant of performance may be ignored in a tutoring environment. So, for example, in the domain of mechanical troubleshooting, the ability to use a screwdriver may be universally mastered, and thus not related to performance skill nor a potential object for consideration in a tutoring environment.

Conceiving of the development of tutoring environments as the deliberate selection of critical cognitive features implies a two-tiered level of cognitive task analysis. First, the target task must be analyzed to understand origins of task difficulty and individual differences in performance. Such analysis informs decisions about the focus of the tutoring system. With the focus determined, a key question is whether the system's interface simulates and supports performance of critical actions in a direct and seamless fashion. The cognitive analysis of performance using the tutoring system's interface represents the second level of cognitive task analysis.

The purpose of this paper is to describe the development of an interface for HYDRIVE, a PC/video-disc based intelligent tutoring system designed to help U.S. Air Force fighter aircraft maintenance personnel, specifically F-15 hydraulics technicians, acquire a powerful and generalizable set of troubleshooting skills which they can apply in fulfilling their day to day maintenance responsibilities. Through the example of HYDRIVE, we discuss the application of a two-tiered cognitive task analysis to design of an interface that supports the important aspects of hydraulic system troubleshooting.

WHAT THE HYDRAULICS TECHNICIAN DOES

The F-15 hydraulics technician maintains the aircraft's hydraulic power system, which generates hydraulic power, and all other F-15 systems which use hydraulic power: the flight controls, the landing gear, the canopy (transparent bubble through which the pilot enters and exits the aircraft), the jet fuel starter system for the aircraft engines and the aerial refueling system. The hydraulics technician is responsible for diagnosing and fixing aircraft problems while the F-15 is still on the flightline, the place from which the aircraft taxis to takeoff and returns after landing. The technician is present when the pilot checks out the aircraft just before takeoff and is the first person to be briefed by the pilot immediately after landing. The priority in flightline maintenance is to find the faulty component as quickly as possible and replace it. The cost of any given flightline maintenance job is measured largely in terms of how long it takes: the more time the technician requires to troubleshoot the problem correctly, the longer the aircraft is not able to fly and the higher the cost. During troubleshooting, the technician has access to technical materials, including step-by-step fault isolation guides, descriptions of general systems and principles of operation, schematic diagrams and step-by-step maintenance procedure guides. Diagnosing and fixing a defective component is a maintenance shop job and not the responsibility of the flightline technician.

Generally speaking, hydraulic systems consist of a limited number of physically accessible components that have restricted sets of well-defined functions. Not only is it possible, then, for hydraulics technicians to "know" the systems they have to deal with (where "knowing" means having some idea, or mental model, of how the components in a given system work together to accomplish the system's task, like opening or closing the canopy), but it is also possible to get a great deal of information from observing actual aircraft operation. Failures of the canopy to open or the rudders to move under emergency conditions provide immediate and important clues about the cause of the failure. The technician is likely to run a system through various conditions to obtain a better sense of when and how failures occur. The relatively transparent nature of the hydraulic system can be contrasted with digital circuitry in which the mapping between component function and system operation is much less obvious.

The hydraulics job, like most flightline jobs, requires social problem-solving. The interdependence of avionic, electrical, hydraulic and mechanical systems means that technicians from different specialties need to work together to find where the failure is located. The hydraulics technician frequently will ask an electrician to test wiring in order to determine if some part of a specific hydraulics system is functional. Thus, the hydraulics technician needs to understand the relation between different aircraft power systems and to obtain and use information from other individuals to make judgments about the hydraulics system.

The team approach, however, can sometimes be detrimental to the learning of critical skills. A great deal of the hydraulics maintenance job is physically time-consuming. For example, it may take eight hours to replace a valve not because it was so difficult to figure out that the valve was defective, but rather because the valve is wedged under several other components which, in turn, lie under an exterior aircraft panel secured with 240 bolts. In flightline maintenance, a division of labor can occur in which some personnel routinely take on the cognitive tasks while other, less-experienced personnel take on the physical tasks. Thus it is possible for a technician to have several years of experience without ever having developed necessary troubleshooting skills.

WHY AN INTELLIGENT TUTORING SYSTEM?

Justification for developing an intelligent tutoring system in this domain is provided by Means and Gott [4]. They point out that the increasing complexity of military equipment systems has resulted in the automation of many routine maintenance tasks. This automation has not only **not** produced the diagnostic successes hoped for, but has also had the unwelcome effect of depriving technicians (up to 25% of whom may be new to the job) of important hands-on learning opportunities. Formal training, which is still oriented toward either theory or rote procedure, provides little relevant troubleshooting practice. In the field, the priority is to keep systems operational. If automated or routine tests fail to diagnose a problem, expert problem solvers, frequently civilians, step in, thereby limiting opportunities for experience with nonroutine faults.

Intelligent tutoring systems help produce better job performance by providing a full range of domain problems (from the routine to the exotic) presented in a simulated context of on-the-job conditions and sequenced to match the current proficiency of the student. Working through an entire problem set not only provides the student with much greater exposure to practical troubleshooting, but it also allows learning in an environment that minimizes the unimportant and physically tedious parts of the job (eg., unscrewing bolts) and emphasizes the cognitively challenging aspects. Knowledge acquired in this way can be more easily transferred into the actual job situation because of similarities between learning and working environments and because the equipment system itself can be presented in a way that stresses functional characteristics most salient to effective troubleshooting. In addition, learning can take place without reliance on actual equipment systems and without the associated safety and equipment availability concerns.

LEVEL 1 COGNITIVE TASK ANALYSIS - WHAT IS THE TECHNICIAN'S TASK?

The precondition to starting work on HYDRIVE's design, indeed the precondition for many intelligent tutoring systems, was the completion of a cognitive analysis of the target task, namely hydraulics troubleshooting. A cognitive task analysis attempts to provide an understanding of how people at different levels of expertise gather the information necessary to perform a particular task, how they process that information and how they deploy it. The analysis was done in three parts. The first phase consisted of orientation visits to Air Force base maintenance sites. The second phase was a data collection effort using an analytic methodology known as PARI (*P*recursor, *A*ction, *R*esult, *I*nterpretation) analysis, which was developed in the Basic Job Skills Program [4,5]. Working with a set of twelve problems which had been generated by experts, each of approximately twenty technicians, ranging from novice to expert, used the PARI structure to generate solutions to at least two of the problems. In the last phase of the task analysis, experts provided follow-up advice and feedback.

An Example of Expert Troubleshooting

Presented below is an example PARI interaction of an expert troubleshooter. The PARI is annotated with interpretations of actions within a cognitive framework. The term PARI derives from the steps of the cognitive task analysis, in which P stands for the precursor or working hypothesis, A is the action taken to test that hypothesis, R is the observed result of the action and I represents the interpretation drawn from that result. The interpretation often forms the basis for a new working hypothesis (next precursor).

Initially, the expert is given a fault description and asked to represent the candidate problem space with a block diagram. Figure 1 is a schematized version of the subject matter expert's (SME) initial representation of the fault description "Prior to taxi, the aircraft had no rudder deflection." This problem was designed so that the cause of the fault was due to the breaking or shearing of a mechanical linkage (the splitter or rudder breakout assembly) that controls the operation of both rudders.

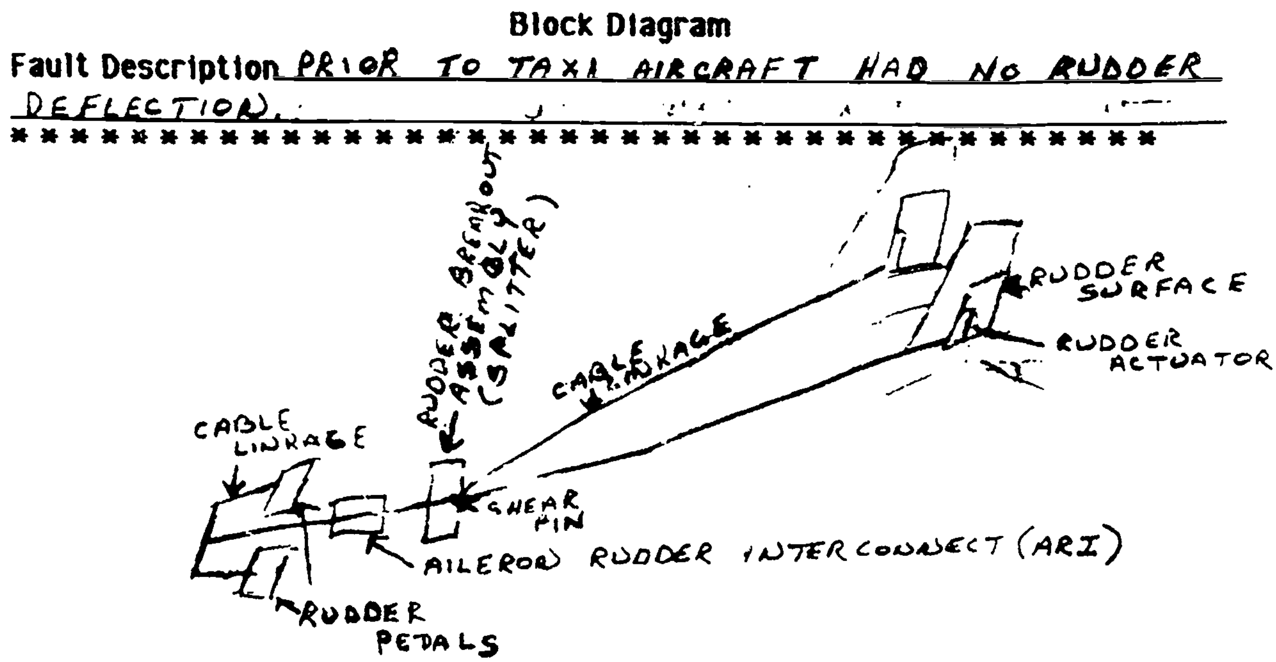

Figure 1. SME Block Diagram

Step 1

P: Check for hydraulic power (all flight controls receive hydraulic power to actuators through circuits on reservoir)

A: Check for Circuit A or B lights in cockpit if pilot has not already done so

R: No lights in cockpit

I: Hydraulic pressure is normal according to indicators in cockpit.

In this first step, the SME wants to ascertain the general status of the hydraulic system. Finding no warning lights in the cockpit indicating faulty hydraulic pressure, the SME concludes that the problem is not due to general hydraulic failure.

Step 2

P: Verify problem. Check electrical and hydraulic in dynamic test. Want to make all relevant checks there with pilot present and engines running.

A: Put Anti-Skid on (to check flight controls through stick). Cycle flight controls with stick.

R: All flight control surfaces move except both rudders.

I: Hydraulic power is getting to the flight control system; it is eliminated as a possible cause. Rudder hydraulic servoactuators are eliminated due to infrequency of both failing simultaneously. The control stick is eliminated as a possible cause since it would have to have no effect on any of the flight controls in order to become suspect.

In step 2, the SME performs a dynamic test of the flight control system to determine the functionality of different components within the system. This test requires that the technician manipulate the system through controls in the cockpit and observe the functioning of flight control surfaces on the exterior of the aircraft. Proper functioning of systems that have components in common with the rudder system leads to the inference that the common components are not faulty. This dynamic test has isolated the problem to a set of components that are associated only with rudder control.

Step 3

P: Check pedals to see if they are rigged properly (pedals are controlling input to rudders). Check Aileron Rudder Interconnect for proper mechanical function.

A: Put mule on. (Mule is hydraulic power source for aircraft when engines are shut down). Set Anti-Skid switch to off (to control rudders through pedals). Move rudder pedals. Check mechanical linkage from rudder pedals to Aileron Rudder Interconnect. Check mechanical linkage from Aileron Rudder Interconnect to splitter.

R: All linkages are moving.

I: All linkage from cockpit to splitter (not including splitter) is OK. Aileron Rudder Interconnect is OK since the linkage which goes to it and exits it is working properly.

In Step 3, cockpit controls (the rudder pedals) are being manipulated to determine movement of mechanical linkages within the rudder system. The technician then must check movement of mechanical linkages in the fuselage of the aircraft. This requires the opening of doors on the fuselage to allow observation of the linkages. The SME finds that all linkages up to the Aileron Rudder Interconnect are operational.

Step 4

P: Check splitter in dynamic test for conclusive (more than visual check) evidence of fault in splitter.

A: With another person working pedals, check in Bay 5 for movement of two cables, each leaving Rudder Breakout Assembly and going to a rudder actuator.

R: No movement.

I: Splitter is faulty. Call mechanical technician to replace shear bolt on splitter. Problem solved.

In Step 4, the SME continues to trace the path of mechanical linkages, with cockpit control from the rudder pedals. The SME finds that there is no mechanical movement as output from the Rudder Breakout Assembly and therefore has isolated the fault to this component.

The PARI analysis was applied to a number of problems using a group of technicians who varied in skill level from novice to highly expert. Two types of information were obtained. First, the nature of expert/novice differences became apparent, enabling a definition of the most critical skills to be addressed in the tutoring system [2]. The second outcome was to obtain a very clear sense of the types of troubleshooting interactions that a technician uses to solve a problem.

The Nature of Troubleshooting Skill

The following is a brief summary of important skills identified through the PARI cognitive task analysis.

Attendance to Physical Clues. As previously mentioned, overt problem symptoms, observable at the level of the overall behavior of the aircraft, provide a significant amount information to hydraulics technicians.

Presence of Mental Models. Expert technicians have explicit mental models of aircraft system operation which they use to direct their troubleshooting behavior. These models tend to be accurate representations of the system, including flow of control between components and between power systems and the operation of components within the system. However, because flightline troubleshooting entails diagnosis and replacement, not repair, even expert technicians may not understand the internal workings of replaceable components. Experts are able to evaluate results of troubleshooting actions in terms of this system model and make determinations of the integrity of different parts of the aircraft. Novices are able to access, at best, severely impoverished mental models, and, therefore, had no basis for troubleshooting decisions.

Procedural Expertise. Every component can be acted on with a variety of procedures; experts are particularly adept at disabling aircraft systems, thereby determining that large portions of the problem area are functional or problematic. Novices are generally limited to removing and replacing components or following the procedures specified in the Fault Isolation Guide.

Functional Classification. Experts generally have a hierarchically organized understanding of the functional characteristics of classes of components beyond the specific instances occurring on the F-15. This ability to identify the shared and discrete characteristics of components also extends to the overall function of different hydraulic systems.

Knowledge of Failure Characteristics. Experts use their knowledge of failure characteristics to isolate the problem to a particular power system or component type.

Flexibility in Strategy Selection. Experts exhibit a great deal of variation in their problem solutions. For numerous legitimate reasons, individuals may choose to approach a problem in different ways. Most strategies, however, involve space splitting of some sort. Experts usually attempt to isolate the problem to a particular power system first, then work within that power system. A frequent exception to this general rule is when an exceptionally cheap action is available that will provide some information about the system.

Cost/Benefit Awareness. Experts try to use strategies that maximize information gained while minimizing cost. As a rule, they use space splitting strategies that attempt to rule out large sections of the problem area through application of relatively inexpensive procedures, where cost is directly proportional to the amount of time required to execute the procedure. The ability to balance cost and information is one of the hallmarks of expertise in this domain. A novice's strategic repertoire is frequently limited to removing and replacing components; for him, cost is not a consideration.

Use of Consultation. Because of the complexity and inter-relatedness of the aircraft's systems, technicians from different specialties need to work together to solve a problem. Therefore, the hydraulics technician needs to know when other expertise is required and how to integrate information gained from such consultation into his mental model.

Troubleshooting Interactions

The PARI analysis also highlighted the types of troubleshooting actions engaged in by a technician during problem solving. Many of these actions are evident in the example and include:

Reading gauges and indicators

Setting switches and controls

Initiating dynamic tests (moving controls)

Observing the operation of components

Powering the aircraft or subsystems of the aircraft

Testing electrical and mechanical function

Removing and replacing components

Disabling subsystems of the aircraft

Requesting assistance from colleagues with other aircraft responsibilities

The interface was designed with this set of interactions in mind.

HYDRIVE'S NTERFACE

The challenge presented in the design and implementation of the HYDRIVE tutor was to build an interface informed by and consistent with the findings of the cognitive task analysis. The interface would be supported by the standard models: the system model representing domain knowledge, the student model representing an estimate of what the student knows or doesn't know and an instructional model to provide coaching in the domain as guided by the student model. Using the data incorporated into these models, HYDRIVE's interface would not only have to present a faithful rendering of the conditions, operations and interactions of the flightline hydraulics maintenance job, but would also have to define and facilitate acquisition of effective troubleshooting skills without guiding the student to a degree that compromised the assessment, and thus the instructional, functions.

HYDRIVE's interface uses video scenarios of dramatized flightline situations to present its problem set to the student. In, for example, the rudder deflection problem, the student witnesses a conversation between the pilot in the aircraft just prior to take off and the hydraulics technician who is with the pilot on the flightline. Air Force personnel were used for the filming and created the dialogue which explores the symptoms of the failure in characteristic terminology.

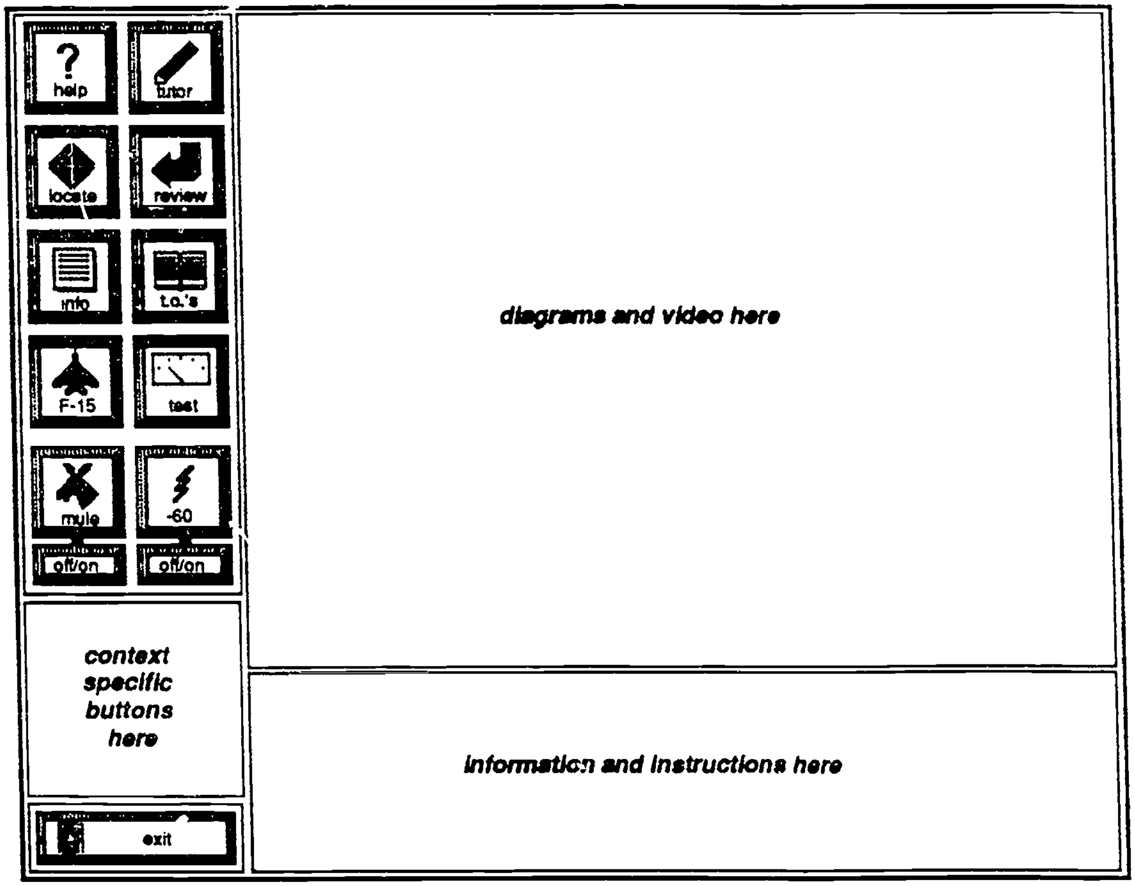

Figure 2. Interface screen layout[1]

Students can orient themselves visually outside the aircraft, then climb on board any area. They can locate and act on any system component and, through video, graphics and audio, see and hear what's happening. They can start one or both engines, shut them down or hook up alternate power sources and test equipment. They can read gauges and indicators, set switches, and initiate aircraft operations. They can call on other technical specialists to perform tests and provide results. Until the problem is solved, all aircraft system behavior presents appropriate manifestations of the fault; after the problem is solved, the aircraft operations return to normal. At all times during the troubleshooting process, students have on-line access to the technical materials they customarily use, including fault isolation guides, system descriptions and schematic diagrams.

HYDRIVE's interface design originally incorporated the premise that the student's primary troubleshooting methodology was reducible to the performance of a series of actions on a series of components: he reads a gauge (visual inspection), flips a switch (set), moves the control stick (manipulate), has the electrician do an electrical test (electrical inspection).

The consequences of this premise produced the following student/interface interaction:

1) student locates component to act on (e.g., student locates control stick)

2) student chooses action (e.g., student moves control stick left and right)

This pairing of locate component/act on component repeats (with necessary diversions into instruction, technical documentation and help) until the problem is solved and is accomplished through the interface as follows:

1) the student begins from the outside of the F-15 by clicking on one of several external aircraft video shots (top, bottom, left, right, Cockpit views);

2) if an area other than the cockpit is chosen, the student is sent to a component location guide to find the desired component;

3) when selection is accomplished, a video of the component appears with its list of possible actions;

4) the student selects an action (which may or may not cause a change in the state of the aircraft) and is returned to the exterior aircraft shots to locate the next component;

5) the student can click on the Cockpit to see video of five interior views of the cockpit;

6) clicking on one interior view gets a menu of components in that area;

7) when a component is selected, a video shot appears along with the action menu;

8) selection of an action (for example, manipulating the control stick) causes an appropriate video to appear;

9) at this point the student can exit to the exterior shots of the aircraft and begin another locate component/act on component sequence.

LEVEL 2 COGNITIVE TASK ANALYSIS - STRUCTURE OF THE INTERFACE

The preliminary interface described above was successful in accomplishing many important design goals, i.e., permitting the user to engage in troubleshooting actions important to the actual job. However, the initial design suffered from a lack of detailed cognitive analysis of the relation of user goals to the procedures required by the interface. With the urging and guidance of David Kieras, a GOMS (*G*oals, *O*perators, *M*ethods, *S*election rules) interface analysis [1,3] was conducted using the PARI data illustrated above.

GOMS analysis is a practical methodology that seeks to supply a model of how a user employs interface functions to accomplish cognitive goals. The model can then be studied to see how the interface functions, or the sequencing of functions, promote or impede the user's performance of the target task. A GOMS model partitions task performance into four components. Goals are cognitive (not observable) and represent the objective of the user; they can be divided into a hierarchical and/or linear series of subgoals. A high level goal in hydraulics troubleshooting would be to determine if the flight control system were operating correctly. Operators are physical (observable) and are defined by the functions available through the interface. In other words, every time the user *does* something, s/he is employing an operator. Manipulation of the control stick would be considered an operator. A method is a set of operators organized to accomplish a specific goal (or subgoal). For example, to determine whether the hydraulic system is working (goal), the user might employ the method of checking for warning lights in the cockpit, which would involve using the operators of turning on power and checking various indicating systems in the cockpit. Selection rules are used by an individual to select a method from multiple candidates.

The GOMS analysis presented below can be mapped to Steps 1 and 2 of the PARI example previously presented, but is representative of troubleshooting behavior in general. The analysis revealed a functional pairing of operations at a higher level than choose component/choose action: supply input/observe output. Because input is generally activated through one component (e.g., the control stick), and output observed through another (e.g., the rudders), and because one input can be linked to multiple outputs (e.g., the ailerons and stabilators as well), it becomes clear that the interface must provide simultaneous access to the input and output components. A GOMS analysis of a portion of a troubleshooting sequence illustrates this need.

The first method presented is a high-level generic sequence:

Method for accomplishing goal of troubleshooting problem

Step 1. Enter troubleshooting mode

User sees: HYDRIVE troubleshooting menu

Step 2. Think of something-to-do

Step 3. Accomplish goal of doing something-to-do

Step 4. If problem solved, return with goal accomplished

Step 5. Go to 2.

Something-to-do represents a range of methods which can be defined by the application of a limited set of selection rules. The user can consult technical materials (TO's), can directly test a single component (e.g., is a leak observable?), or can evaluate the output of one component based on input to another (e.g., move control stick and observe rudder movement).

Selection Rule set for accomplishing goal of doing something-to-do

If something-to-do is consult TO's (technical documentation),

then accomplish goal of consulting TO

If something-to-do is running a single-component test,

then accomplish goal of running a single-component test

If something-to-do is running an input-output test,

then accomplish goal of running an input-output test

Accomplishing the first two something-to-do's was easily handled through the preliminary interface. However, an analysis of the input-output test method revealed that the preliminary interface was less than optimal. The GOMS analysis reveals the complexity of the input-output test.

First, the user must define input(s) to the system.

Method for accomplishing goal of running an input-output test

Step 1. Accomplish goal of supply the inputs

Display is now of input component and input selection options

Method for accomplishing goal of supply inputs

Step A1. Get the next component input to supply

Step A2. Decide: If no more inputs to supply, then return with goal accomplished

Step A3. Accomplish goal of supply an input to a component

Method for accomplishing goal of supply an input to a component

Step A1a. Find the input component

Step A2a. Select the input component

Step A3a. Select the input action

Step A4a. Return with goal accomplished

Step A4. Go to A1

Once the user has defined inputs, the user has to decide what output(s) will be observed. The option is left up to the user for pedagogical reasons. From one input, however, we see that it is important to permit multiple output observations.

Step 2. Decide: If observe outputs, then accomplish goal of observe outputs

Display is now of output component and output selection options

Method for accomplishing goal of observe outputs

Step B1. Get the next component output to observe

Step B2. Decide: If no more outputs to observe, return with goal accomplished

Step B3. Accomplish goal of observe the output of the component

Assuming that display returns to input display to maintain context

Method for accomplishing goal of observe an output of a component

Step B1a. Find the output component

Step B2a. Select the output component

Step B3a. Note the behavior of the component output

Step B4a. Return with goal accomplished

Step B4. Go to B1

Because it makes sense to allow multiple observations based on a single input, it becomes important to allow the user to stop the input in a straightforward manner. Without that ability, the flight controls will continue to move even after the user has decided to shift attention to another set of input/output components.

Step 3. Stop the input. (E.g., control stick has been left moving while rudder is observed, so it should be stopped.)

Step 4. Return with goal accomplished.

A primary revelation from the GOMS analysis was that although each element in the input/output pair may involve multiple components, the physical focal point of this type of activity is the cockpit. This means that the student must be able to remain in the cockpit during the entire process of supplying input to the aircraft and be returned there automatically after each output observation. Until the student chooses to stop the action of the aircraft (eg., choose the Stop action for the control stick), every time s/he returns to the cockpit, the video of the control stick shows continuing motion.

The final implementation of the interface took this analysis into account. The interaction of student and interface, for the purpose of choosing components to act on when troubleshooting, now flows as follows:

1) student clicks on one of two parts of a split video shot which divides the aircraft into Cockpit and Other (a click on Other takes the student to a component location guide where component selection and action selection proceed as before);

2) if Cockpit chosen, then video of five different views of the Cockpit appears;

3) student clicks on one cockpit view and a list of components in that area appears, each with a representation of its current state in the aircraft, if applicable (eg., gauge values, indicators lit or unlit);

4) student clicks on component and gets action menu with video of component in current state (eg., control stick not moving, flaps switch set to Down);

5) student chooses action and again gets appropriate video (if control stick manipulated, then motion shot of control stick);

6) at any time student can click on an Observe button which takes the student out of the cockpit to a component location guide where a component(s) can be selected for observation;

7) screens displaying components outside the cockpit contain a Cockpit button so the student can toggle back and forth between the cockpit and other areas of the aircraft at will.

CONCLUSION

The Level 2 GOMS analysis was able to draw on and extend the PARI Level 1 analysis to contribute to the interface design. The GOMS analysis provided a useful evaluation of a preliminary interface based only on the Level 1 analysis. Modifications, then, entailed design changes to flow of control within the interface rather than to actual screen content and basic function (with some minor exceptions). These changes have produced an interface with a high degree of fidelity to the technician's working experience. Therefore, the results of this experience, so far, argue for the wisdom of interface design review, using a GOMS model (or other methodology which deploys interface means to serve cognitive ends), at a point in the development process where interface functions (operators) have been sufficiently defined to allow for a detailed 'walk through' of sample problems. More complete data relating to the interface will be available only after HYDRIVE is field tested (some time in the next few months). An analysis of those results, however, must be careful to separate the pedagogical and assessment issues from those involving interface design alone.

NOTES

[1] HYDRIVE's interface makes extensive use of graphics and colors which are not easily reproduced in this paper form.

ACKNOWLEDGEMENTS

This work was supported through contracts from Armstrong Laboratories, United States Air Force. No endorsement of the contents of this work is implied. The authors would like to acknowledge the contributions of Wendy Cohen, Randy Kaplan and Harriet Trenholm, without whom HYDRIVE's interface would not exist. The authors would also like to thank Irvin Katz and Howard Wainer for their thoughtful reviews of previous drafts of this paper and Wendy Cohen for her assistance with the figures.

REFERENCES

1. Card, S.K., Moran, T.P. and Newell, A. *The Psychology of Human-Computer Interaction.* Lawrence Erlbaum Associates, Hillsdale, New Jersey, 1983.
2. Gitomer, D.H., Cohen, W., Gallagher, A., Kaplan, R., Steinberg, L.S., Swinton, S. and Trenholm, H. Design Rationale and Data Analysis for HYDRIVE Content and Structure. Educational Testing Service, Princeton, 1991.
3. Kieras, D.E. Towards a practical GOMS model methodology user interface design. In *Handbook of Human-Computer Interaction*, M. Helander, Ed., Elsevier, Amsterdam, 1988, pp.135-158.
4. Means, B. and Gott, S. Cognitive task analysis as a basis for tutor development: Articulating abstract knowledge representations. In *Intelligent tutoring systems: Lessons learned*, J. Pstotka, L.D. Massey and S.A. Mutter, Eds., Lawrence Erlbaum Associates, Hillsdale, New Jersey, 1988, pp.35-57.
5. Pokorny, R.A and Gott, S.P. The evaluation of a real-world instructional system: Using technical experts as raters. Air Force Human Resources Laboratory, Brooks AFB TX, 1990.