Online Analysis of High Fidelity Simulation Data

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Abstract

This paper describes the online analysis of simulation data in real time using the Crew Activity Tracking System (CATS). CATS compares actual operator actions to a model of nominal operator procedures to track operator activities and detect possible operator errors. A suite of system state visualization tools, together with CATS, enables researchers to detect problematic operator-automation interactions as they occur, and replay the data to investigate interesting issues in detail.

1. Introduction

High fidelity simulations are an essential enabling technology for the design of complex process control systems, because they allow safety-critical operations to be examined in real-world settings without the associated risks. For example, new Air Traffic Management (ATM) automation is under development at NASA. The new technology is designed to increase airspace capacity by enabling precise control of aircraft, in accordance with the capabilities of the airborne automation [6] [9]. This research uses large scale, high fidelity simulations to evaluate new procedures and interfaces. This in turn requires an efficient means for analyzing the large amounts of data such simulations produce. Human performance data can be especially difficult to analyze in detail using conventional techniques.

2. Computer-aided performance analysis using CATS

This paper describes a Java™-based performance analysis tool comprised of the Crew Activity Tracking System (CATS) and a suite of process visualization displays. CATS predicts and interprets operator actions in

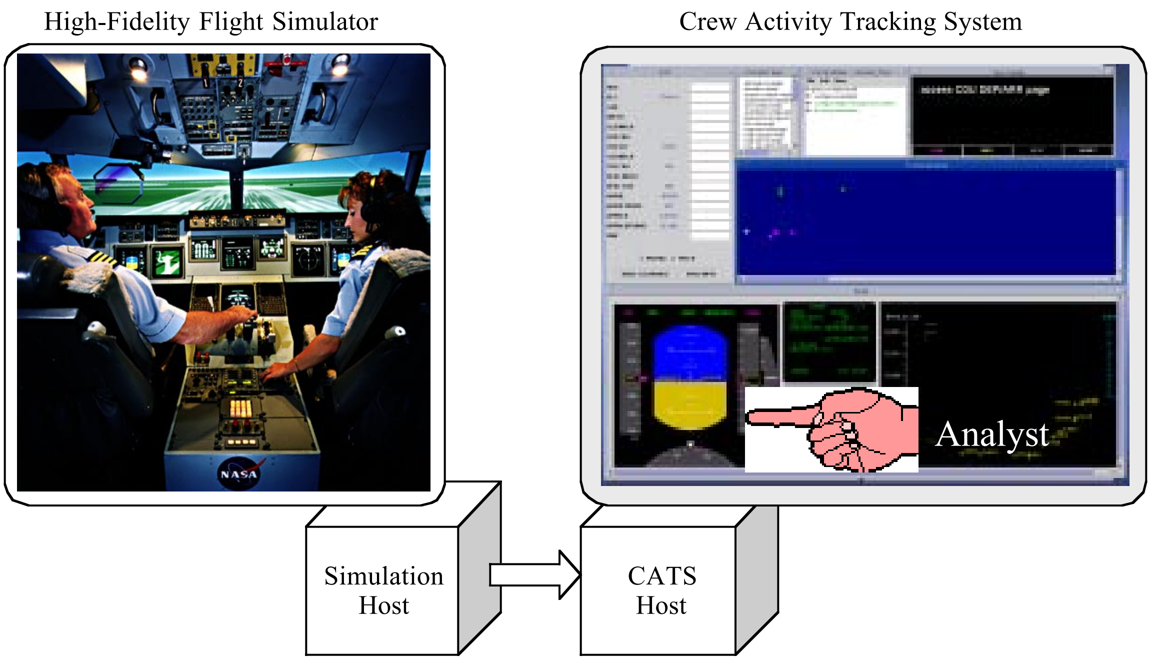

Figure 1. Online operator performance analysis concept.

real time using a model of correct operating procedures. Analysts can detect problematic operator-automation interactions as they occur, and replay the data at variable speed for debriefing and detailed analysis. A real-time configuration, in which CATS is connected to the full-mission Advanced Concepts Flight Simulator (ACFS) at NASA Ames, is depicted in Figure 1.

Computer-aided performance analysis is used in many industrial settings. Telemetry data from a controlled process can provide information ranging from simple plots of historical data or out-of-tolerance conditions, to more complex process diagnostics and analyses. The commercial aviation industry is beginning to apply such techniques through the use of Flight Operations Quality Assurance (FOQA) data, and systems such as the Aviation Performance Measuring System (APMS) [1] [2].

The method described in this paper is unique because it includes a method to 'track' operator activities by referencing a model of correct operating procedures. This capability, sometimes referred to as intent inferencing, has long been recognized as a way to support context-specific aids/tutors that provide real time advice and reminders to human operators [3] [7] [8]. The present application affirms the viability of activity tracking for the design and analysis of new operator procedures. Together with more conventional remote process visualization techniques, it can greatly reduce the overhead associated with detailed data analysis such as that required for full-mission, high-fidelity simulations.

3. Activity Tracking

Two primary processes comprise activity tracking. First, the system predicts activities an operator is likely to perform given the current operational context. To accomplish this, information about the state of the controlled system and operational constraints is used to identify relevant activities from a task-analytic operator model. Next, the activity tracking process interprets actual operator actions to determine whether they support predicted activities, or some acceptable alternative. An operator error may be signaled if an action does not support any acceptable methods for meeting current operational constraints, or if no action occurs to support a needed activity within some specified interval.

Activity tracking is well suited for online human performance analysis. Because predictions are made as soon as the operational context allows the activities to be performed, activity latencies can be determined by comparing the time when the actual activities are performed against the time when the activity was predicted. Activities that are not performed soon after the predicted time may be inadequately cued. Other activities may confound performance, suggesting conflicting task demands and resources. Operational difficulties that may arise in a research environment are also distinguishable from operator performance problems.

3.1. Crew Activity Tracking System (CATS)

CATS implements a methodology for activity tracking in a computer-based system that has been validated to work in real time [5]. The next two sections describe the elements of CATS with illustrations in the context of the ACFS, which is designed to simulate an advanced commercial glass cockpit aircraft. First the knowledge representations required by the CATS activity tracking methodology are described. Then an overview of how CATS processes these representations is presented.

```
{ task "enter descent speed"
conditions predicted
      "fms-des-spd-outside-
limits"

{ action "enter descent speed
on DES page"
conditions predicted
       ( and "cdu-page-DES"
             "des-spd-built" )
}
```

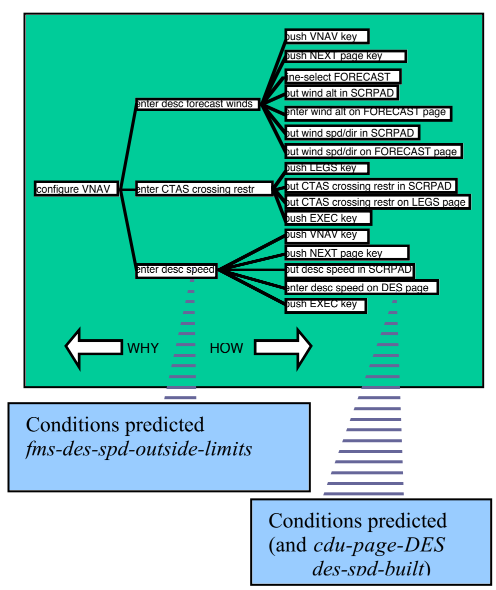

Figure 2. CATS model fragment in computer-readable text and graphical form. ‘Context specifiers’ are italicized.

4. Knowledge Representation in CATS

CATS has four knowledge representations. The first is a computational model of operator activities that represents both preferred and correct alternative methods for accomplishing system objectives. The CATS model is a normative model that allows high-level activities to be decomposed as necessary to adequately represent the human-machine interactions of interest, down to the level of specific actions. Each activity is represented to contain conditions under which it is to be performed. The conditions take the form of AND/OR trees comprised of clauses that summarize operational context, called 'context specifiers.' The generic CATS model structure is shown in Figure 2.

The second knowledge representation encapsulates the current status of the controlled system. The fidelity of the state space is defined by the elements of state knowledge available in the data, and the form in which the data is received. While process data may be available at high update rates, the ACFS uses event-filtering mechanisms to provide the data to CATS as events, reducing the size of data files produced and the effort required to process data in real time. The CATS state representation includes current aircraft position, autoflight system modes and target values, and information programmed into the flight management system.

Third, CATS represents the constraints of the operating environment—the so-called 'limiting operating envelope.' Represented constraints include those imposed by Air Traffic Control (ATC), the preplanned flight path, and operational guidelines.

During run time, CATS transforms the specific values contained in the state and constraints into a fourth knowledge representation: a set of Boolean-valued context specifiers that summarize the current operational context. As noted above, context specifiers comprise the conditions under which it is appropriate to predict the activity. For example, when the context specifier 'altitude-below-limits' is `true`, it suggests the function 'climb to altitude' is appropriate. The context specifier 'FMS-descent-speed-not-entered' is considerably more complex; it indicates that there is a speed entered in the 'scratchpad' of the Flight Management Computer (FMC) Control and Display Unit (CDU) that has not yet been selected to the descent speed location on the CDU page. Each context specifier has rules that express when it is `true` for the current operating context.

5. CATS Activity Tracking Process

During run-time, as the state and constraint representations are updated, CATS updates the values of context specifiers and uses them to dynamically predict their associated operator activities. When an activity is predicted, CATS starts a timer and waits for the operator to execute the activity. CATS attempts to interpret operator actions by linking them the predicted activities, and failing that, to acceptable alternatives. In this way, CATS interprets actions to support specific steps of the modeled procedures. Actions that CATS cannot interpret ('uninterpretable' actions) may represent operator errors (or they may simply represent actions that CATS receives as data, but are not included in the CATS model). Possible

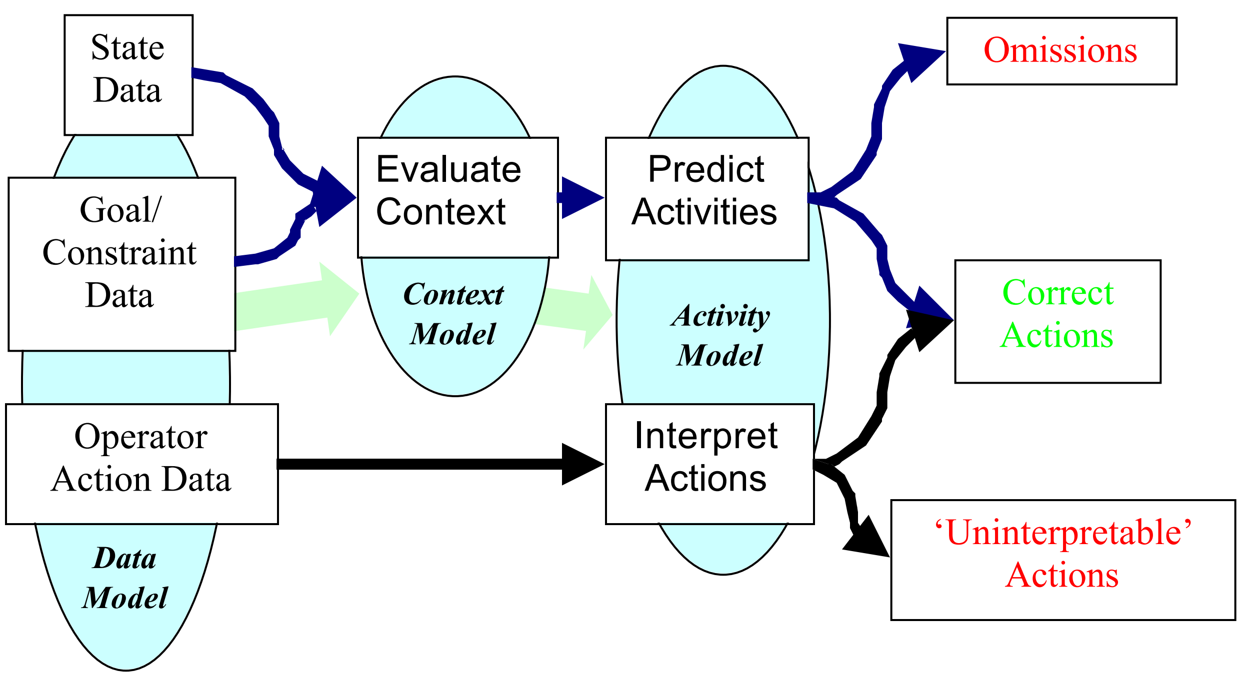

Figure 3. Activity tracking representations, tracking process, and outcomes.

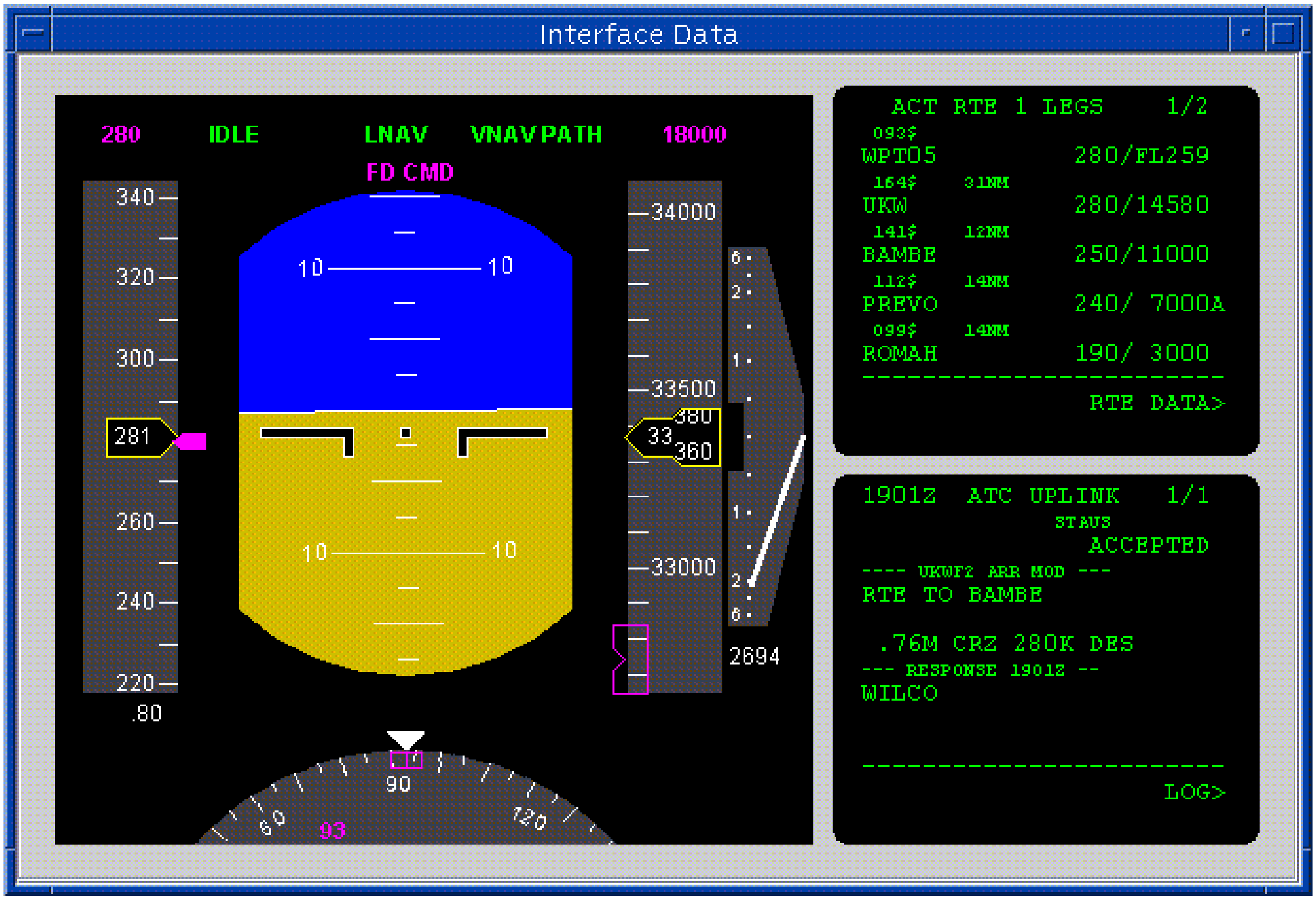

Figure 4. Primary Flight Display and CDU displays.

errors of omission are signaled when a timer expires before the operator performs a predicted or alternative valid action. The activity tracking process and supporting knowledge representations are depicted in Figure 3.

6. Process Visualization

CATS also provides additional visualization capabilities commonly found in traditional computer-based process analysis tools. Although not directly linked to activity tracking, the data to be visualized are often also required for the activity process. It is therefore straightforward to include these visualization capabilities in an integrated CATS-based online data analysis tool (see [4]). Visualization displays that represent the state history of the controlled process are extremely useful, as are those that recreate the appearance of actual process monitoring displays. Whether the analyst is overseeing a human-in-the-loop trial or replaying data for analysis, remotely viewing the effects of each operator action on the appearance of the actual displays provides great insight.

7. Analyzing Pilot Performance Online

The CATS analysis tool has been developed for the NASA Ames ACFS glass cockpit flight simulator, a high fidelity full motion simulator with outside visuals. CATS analyzes the performance of flight crews in the simulator using new cockpit procedures, as well as data link communications technology, in the context of a much larger ATM system simulation. The data will be analyzed to assess the human factors of new interfaces and procedures. The analysis tool is located remotely from the simulator. As the crew flies the simulator, the analysis tool displays a facsimile of the aircraft's Primary Flight Display, the FMC CDUs. (Figure 4). It also provides a trace of the aircraft's location, together with the speed and altitude profiles, and engaged automation modes (Figures 5 & 6). Using this data, the analyst can determine if the aircraft is properly complying with the clearances it receives, and pinpoint the context in which any observed procedural deviations occur.

In addition to the data provided by these displays, CATS can analyze the actions performed by the flight

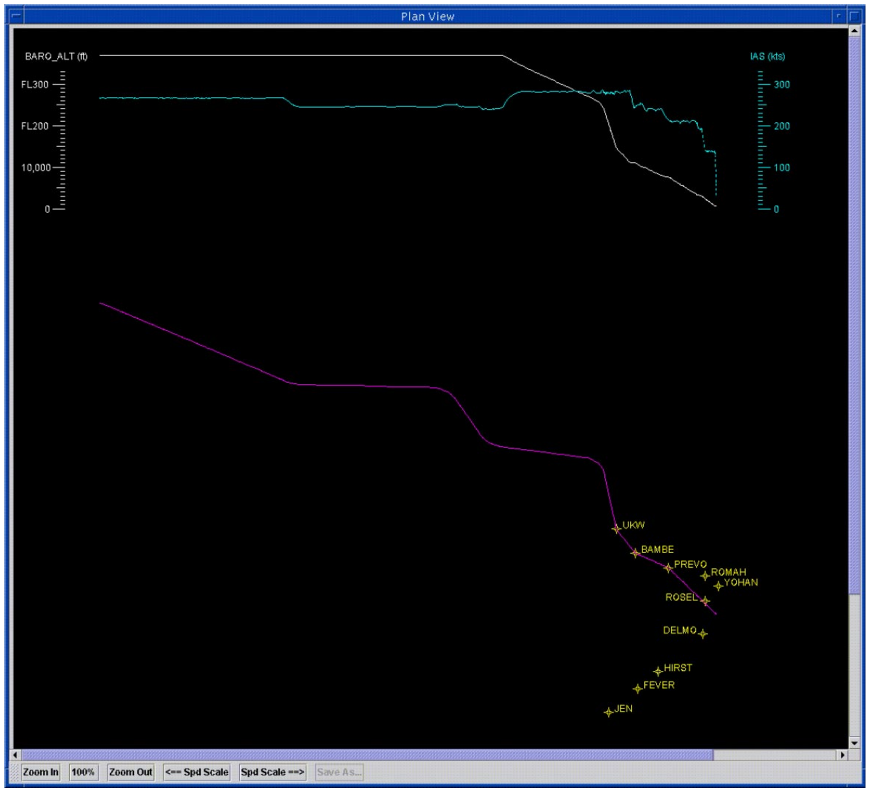

Figure 5. Lateral profile display, plus altitude and speed profiles along the route (top).

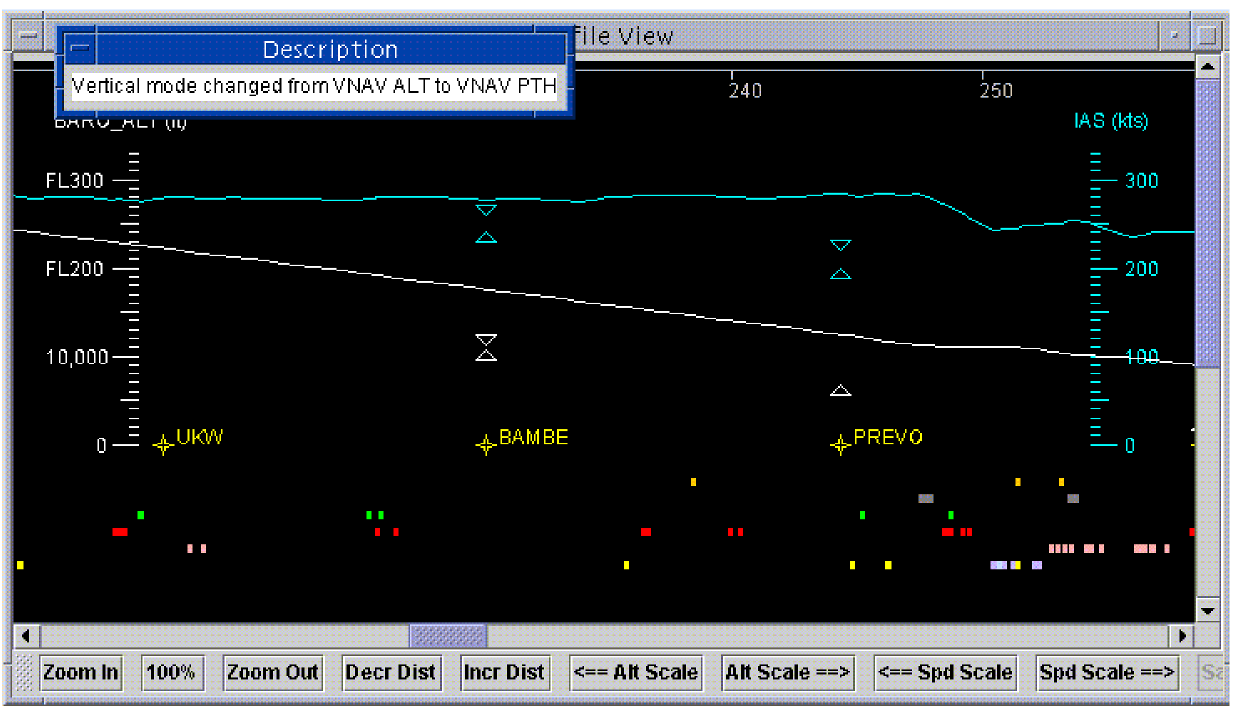

Figure 6. Vertical profile display, showing a segment of the altitude and speed profiles as they relate to required crossing speeds and altitudes (top). Note violations at 'BAMBE' and 'PREVO' waypoints. Events are depicted as color-coded dots (bottom); clicking on a dot displays a description, as shown.

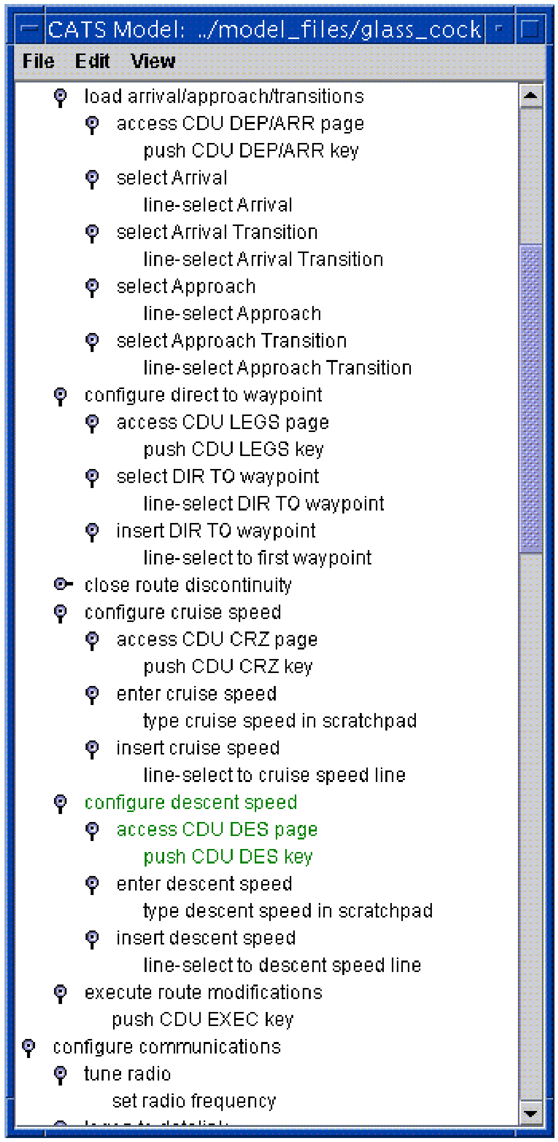

Figure 7. Portion of CATS model of crew procedures.

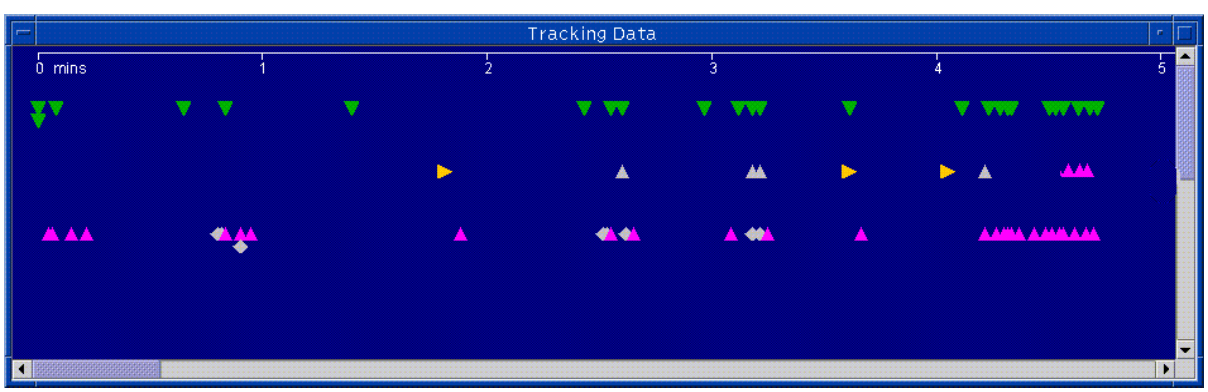

Figure 8. CATS activity tracking output. Activity predictions are down-arrows. Up-arrows are crew actions that match predictions. Diamonds represents actions that are not explicitly represented in the CATS model. Right-arrows indicate potential errors of omission.

crew via activity tracking. CATS uses a model of nominal crew procedures to generate predictions about the activities the crew will perform (Figure 7). CATS shows the output of the activity tracking process on another display (Figure 8). The analyst can use the activity tracking data to determine whether procedural errors by the flight crew contributed to any observed aircraft non-compliance. For example, if trajectory trace indicates that the aircraft is flying at an excessive speed, the associated tracking data will show whether the flight crew failed to extend the aircraft's speed brakes. The analyst may then use other visible information to determine what the crew was doing, and suggest reasons for the oversight. Thus, the tool allows detailed analysis of human factors by providing information about operations at the time when a problem occurs.

11. Conclusion

The proposed online data analysis method has several advantages. First, the analysis is produced immediately. This may be helpful for performing focused debriefings of subject crews. The analysis is also accurate (to the precision afforded by the model and displays) and consistent across experimental trials; it can be easily modified to include additional measures, and it is precisely preserved for use in later studies. Analyses performed using conventional techniques, such as analysis of videotape, are tedious and subject to inconsistencies (although such techniques may be used in conjunction with the proposed method).

A second advantage relates to studies of new procedures: the analysis may be based on the same model of a procedure that was used to develop the procedure (see [10]). This guarantees that the analysis will focus on behaviors that measure the effectiveness of the procedure, while also possibly revealing other interesting behaviors.

Finally, through the use of dynamic data visualization interfaces, analysts can understand operator performance together with the specific operational context in which it occurred. For example, a barely noticeable display cue might accompany an operator error; the analyst can detect this relationship easily with a visualization interface on which the cue is more salient. The online CATS analysis tool this paper presents is valuable for analyzing operator procedures, and should be a standard instrument with which to assess full mission simulation data. It offers several advantages over conventional analysis techniques and fits within the framework of a model-based procedure design process.

13. References

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