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Error Generation in CATS-Based Agents

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Summary

This research presents a methodology for generating errors from a model of nominally preferred correct operator activities, given a particular operational context, and maintaining an explicit link to the erroneous contextual information to support analyses. It uses the Crew Activity Tracking System (CATS) model as the basis for error generation. This report describes how the process works, and how it may be useful for supporting agent-based system safety analyses. The report presents results obtained by applying the error-generation process and discusses implementation issues. The research is supported by the System-Wide Accident Prevention Element of the NASA Aviation Safety Program.

Introduction

Computer-based agents that err in realistic ways are an attractive enabling technology for system safety analyses. Simulations in which agents probabilistically err, in ways that a human operator might, may help researchers assess the robustness of human-machine systems. Design efforts may then focus on preventing and recovering from errors that, when simulated in the overall system environment, lead to poorly understood or dangerous situations. Such an approach may reduce the time spent designing for relatively benign human error-related problems to the exclusion of unforeseen problems that deserve close attention. This report describes how agents based on the Crew Activity Tracking System (CATS) can make errors in support of such an approach. In order to focus the research, and connect it to related error-detection research, this research seeks to demonstrate how agents based on CATS can make errors that CATS itself can detect.

CATS is a methodology for 'activity tracking' implemented in a computer-based system (Callantine, Mitchell, and Palmer, 1999). The CATS activity tracking methodology entails predicting the set of expected nominal operator activities for the current operational context, then comparing actual operator actions to these expectations to ensure operators performed correct activities. In some situations, various methods or techniques for controlling some aspect of a system may be acceptable. Therefore the methodology also includes a mechanism for determining that, although operator actions do not match expectations exactly, the actions are nonetheless correct. In this sense, CATS is designed to 'track' flight crew activities in real time and determine that they are error-free.

CATS identifies two types of errors, should they occur: errors of omission, and errors of commission. It further identifies errors of commission that result when the 'right action' is performed with the 'wrong value' (e.g., setting the correct automation target, but setting it to an incorrect value). CATS does not base these determinations on a 'formulaic' representation of how such errors would appear in a trace of operator activities, nor attempt to further classify errors (e.g., 'reversals'). Instead, CATS simply determines whether actions operators perform (or do not perform) are contained in the set of actions that need to be performed, given the current operational context.

While the literature contains assertions about the necessity of examining detailed error 'phenotypes' (e.g., Hollnagel, 1991, 1993), the CATS error-detection scheme works given only a context, and an operator action (or inaction). The CATS representation of context includes only relevant system states and constraints, and

salient relationships between them. State and constraint information is represented at multiple levels of abstraction, and does include historic and predicted information as necessary to establish the current context. Given that the system is functioning correctly, so that the effects of past operator actions are reflected in the system state, past operator actions are irrelevant. If desired, error phenotypes may be assessed via post hoc analysis of the actual observed sequence of operator actions.

CATS Architecture and Processing

Figure 1 generically depicts information flow in CATS, between a controlled system and CATS, and between CATS and applications based on it. CATS uses representations of the current state of the controlled system and constraints imposed by the environment (including performance limits on the controlled system) to derive the current operational context. CATS then uses this representation to generate predictions from its model of operator activities.

As CATS detects operator actions during runtime, it compares them to predicted activities. Actions that match predictions are correct in the current context. CATS assesses actions that it cannot immediately interpret as matching a prediction by periodically referencing the activity model until it receives enough new contextual information to disambiguate possible interpretations. If after a specified period of time CATS fails to detect an action that matches a predicted activity, or at least an action that supports an alternative valid method of addressing the required function, CATS 'flags' a potential error of omission.

Two processing threads are at work in CATS: a 'prediction thread' responsible for generating the context information necessary to predict nominal activities, and an 'interpretation thread' that interprets operator actions. The result of the activity tracking process supplies the knowledge required for several useful applications. Displays of the resulting interpretations—together with displays for visualizing the input data, current

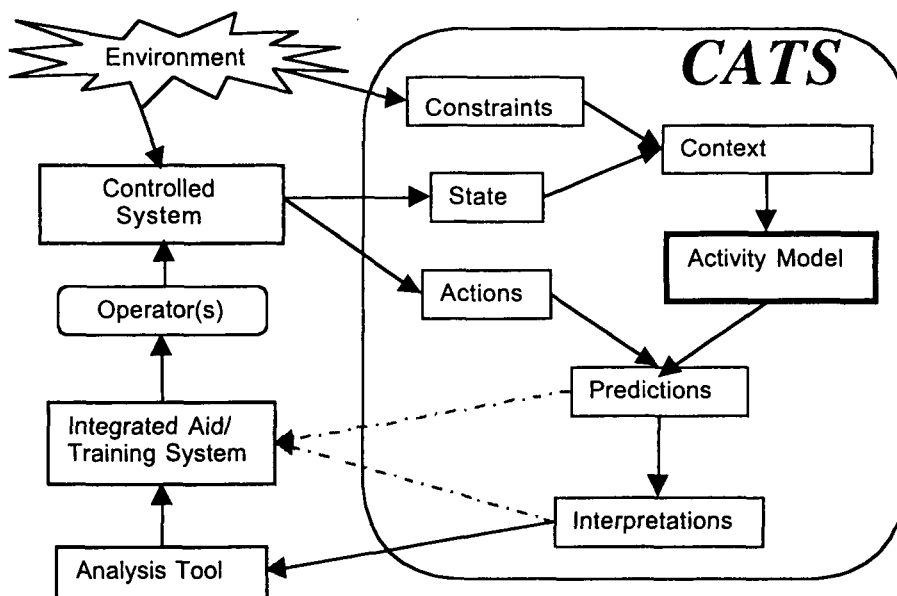


Figure 1. Information flow within and between CATS and a generic human-machine system, and applications to error analysis, aiding, and training.

operational context, and activity model—comprise a CATS-based analysis tool (Callantine and Crane, 2000; Callantine, 2000a, 2001b). Predictions and interpretations supply the information necessary for an operator aiding system that is integrated into the interface of the controlled system or, in the case of a tutoring system, a high-fidelity simulation of the controlled system. The CATS predictions may also be executed directly on the simulated controlled system, effectively creating an intelligent agent useful for analyses of system operation.

Error Simulation in CATS-based Agents

Previous research has investigated various ways of implementing CATS-based agents (Callantine, 2001a, 2002c), as well as ways to simulate operator errors (Callantine, 2002b). For example, CATS-based air traffic controller agents maintain a representation of aircraft flow-spacing and separation problems. Manipulating the context representation in these agents through a mechanism that probabilistically ‘forgets’ various information, or ‘confuses’ aircraft, causes errors of varying severity (Callantine, 2002b). However, for the air traffic controller agents, the CATS model served only to structure the ‘flow’ of high-level air traffic control activities. Much of the air traffic controller agent knowledge was represented outside the CATS model in a ‘skill library’ and strategy-selection ‘control rules.’ Because of this ‘external’ knowledge, the correspondence of the errors generated to those detectable by an activity tracking version of CATS was not clear.

The present research takes as its starting point a CATS activity tracking implementation for the aircraft flight deck, in which the procedural knowledge required for the piloting task is fully represented in the CATS model. The

specific version of CATS was used to detect pilot errors from NASA Langley Boeing 757 ARIES aircraft flight data (Callantine, 2002a). This research uses the same version of CATS to ensure that the errors that are generated map clearly to those it is designed to detect.

CATS Error Generation Mechanism and Validation Methodology

To generate errors as it might when used as the basis as an intelligent pilot agent, CATS was first modified to identify those points when its predictions change as a result of a salient change in the operational context. Additional Java™ code was then added to manipulate the resultant context representation to create a representation that was incorrect. Given the incorrect context, CATS generates predictions that are in error. Unlike the error mechanisms developed in Callantine (2002b), this procedure produces errors that are guaranteed by the structure of the CATS model to be relevant in the current operational context, and that are detectable by a CATS activity tracking implementation with the same model. This section of the report details this process together with the CATS knowledge representations that support it.

CATS Model and Context Representation

Figure 2 depicts a fragment of the CATS model developed for the Boeing 757 piloting task, as reported in Callantine (2002b). The model decomposes the highest level activity, ‘fly glass cockpit aircraft,’ into sub-activities as necessary down to the level of pilot actions. Figure 2 illustrates eight leaf nodes that represent detectable pilot actions. The complete model includes all actions derivable from the available flight data.

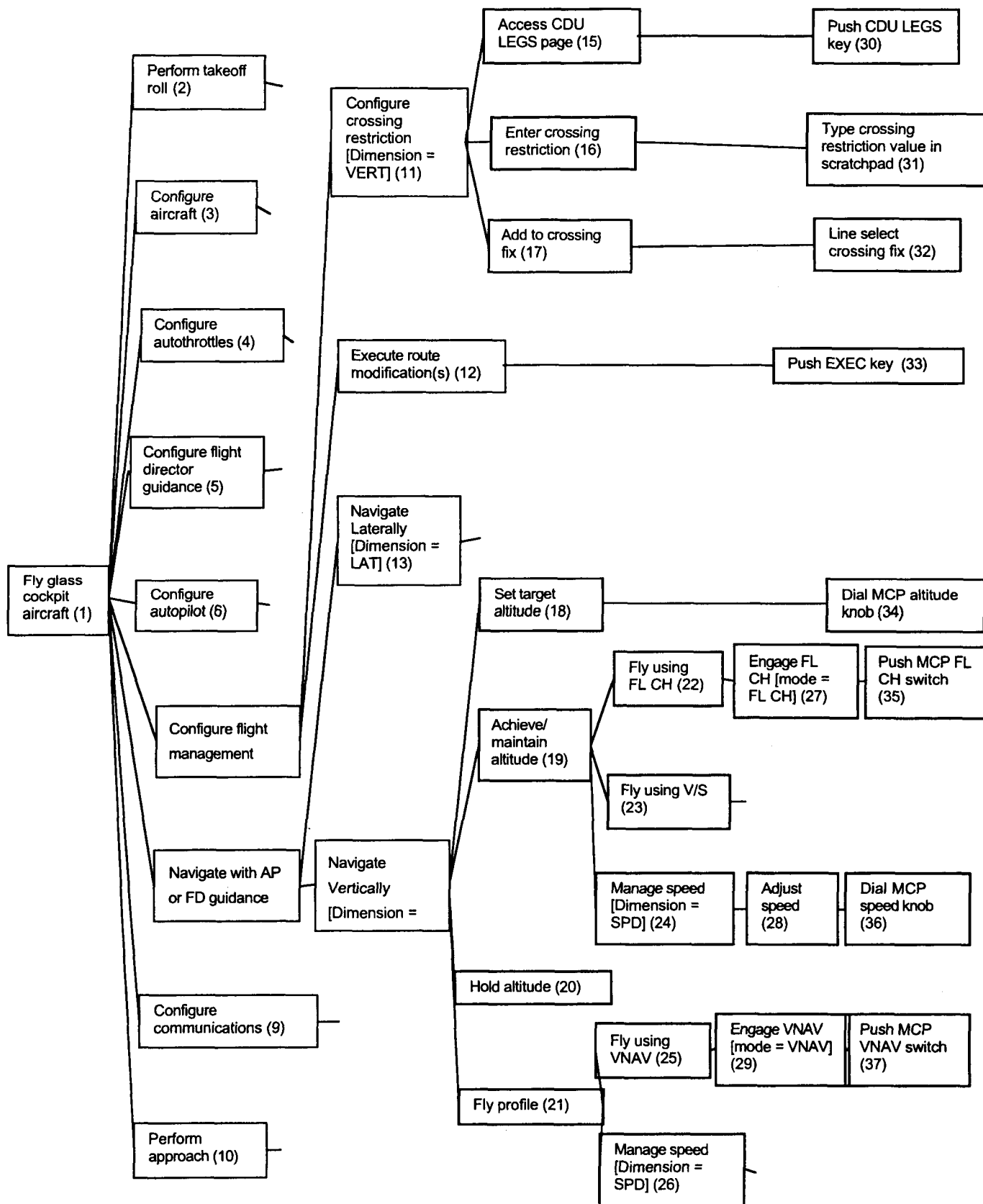


Figure 2. Fragment of CATS model for B757 operations highlighting low-level subtasks and actions.

Every activity in the model is represented with conditions that express the context in which the activity is nominally preferred, given policies and procedures governing flight operations. The parenthesized numbers in Figure 2 refer to Table 1, which lists the ‘and-or trees’ that comprise these rules. The rules incorporate so-called ‘context specifiers’ that summarize key contextual information. Each context specifier denotes that some salient contextual description holds at the current time. The presence or absence of a particular context specifier in the current set determines whether the condition for predicting a particular activity evaluates true or false.

The structure of the CATS model enables identification of valid alternative methods for performing required functions, because all activities that an operator may correctly perform in support of a given function appear below that function in the CATS model. For a given operational context, only one alternative method is designated as preferred. Put another way, every activity in a CATS model is, in some context, part of a preferred way to accomplish a required function, and there are no contexts in which the preferred method is ambiguous.

CATS Prediction Process

To predict the currently preferred set of activities, CATS searches its model top-down, so that higher level activities ‘subsume’ their children (i.e., the conditions on an activity must be met before CATS can predict any of its children). CATS makes predictions and interpretations at every level of abstraction represented in the model.

Procedural steps are represented in the model using conditions that reflect contextual changes, not by rules conditioned by events, or even actions

themselves, such as “do action *B* when action *A* has been done.” Instead, conditions for performing *B* are those reflected in the system state when *A* has been properly performed. A consequence of supplying conditions for when the operator should perform any given activity is that CATS predicts activities independently. If two procedures are in progress, CATS predicts the steps in each that the operator should perform next as an *unordered* set containing the two actions (along with the higher-level activities each action supports).

CATS-based agents observe a convention that ensures direct correspondence between agent behavior and CATS error-detection capabilities and also provides a basis for validating the error-generation process: the agent must explicitly predict an action through the CATS prediction process in order to ‘officially execute’ the action.

Error Generation

This research seeks an error-generation process that utilizes a principled approach in generating errors, so that the errors produced are both plausible and truly errors, as opposed to random actions or actions that may be actually correct, if not preferred. The process also seeks to maintain a link between the errors that are generated, and the erroneous context representation that produces them.

A ‘probabilistic approach’ of randomly altering some context specifier or set of context specifiers (or simply selecting actions at random) unfortunately may produce actions whose relationship to the correct response is tenuous. For example, in a situation that calls *only* for an autopilot mode selection, randomly including a ‘comm-freq-outside-limits’

Table 1. 'And-or' trees of conditions under which the CATS model in Figure 2 represents activities as 'nominally preferred.'

- (1) start-of-run
- (2) (not above-runway-elevation)
- (3) (and (not above-clean-speed) (not flight-surfaces-within-limits) (not gear-within-limits))
- (4) (not autothrottle-armed)
- (5) (not flight-director-on)
- (6) [(and (not autopilot-cmd-mode-engaged) above-1000-feet-AGL)]
- (7) (or (not programmed-route-within-limits) route-uplink-received)
- (8) (and above-1000-feet-AGL (or autopilot-cmd-mode-engaged flight-director-on))
- (9) (not comm-frequency-within-limits)
- (10) (or approaching-glideslope-intercept-point approach-localizer-intercept-point)
- (11) (not crossing-restriction-within-limits)
- (12) route-modifications-within-limits
- (13) (or autopilot-cmd-mode-engaged flight-director-on)
- (14) (or autopilot-cmd-mode-engaged flight-director-on)
- (15) (not cdu-page-LEGS)
- (16) (and cdu-page-LEGS (not crossing-restriction-built))
- (17) (and cdu-page-LEGS crossing-restriction-built)
- (18) (not mcp-altitude-within-limits)
- (19) (or (and (not current-altitude-within-limits) (not profile-within-limits-for-now)) expedite-needed)
- (20) (and current-altitude-within-limits (not profile-within-limits-for-now))
- (21) profile-within-limits-for-now
- (22) (or (not altitude-close-to-target) expedite-needed)
- (23) altitude-close-to-target
- (24) (or fl-ch-engaged vs-engaged)
- (25) profile-within-limits-for-now
- (26) vnav-engaged
- (27) (not fl-ch-engaged)
- (28) (not target-speed-within-limits)
- (29) (and (not vnav-engaged) (not capturing-required-altitude))
- (30) (not cdu-page-LEGS)
- (31) (not crossing-restriction-built)
- (32) crossing-restriction-built
- (33) route-modifications-within-limits
- (34) (not mcp-altitude-within-limits)
- (35) mcp-altitude-within-limits
- (36) (not target-speed-within-limits)
- (37) mcp-altitude-within-limits

context specifier (indicating the primary VHF radio channel is not set to the assigned frequency), for example, leads the agent to tune the radio — not altogether impossible, and definitely an error, but an unlikely one. An incorrect

mode selection is a more likely error, and one likely to yield greater insights into system safety impacts. In fact, random manipulations more often produce inaction, or prevent errors of commission, because there is only one combination of

context specifiers that enable the search to proceed until it reaches an erroneous action, but numerous ways to stop the CATS prediction search above an action 'leaf node.'s

Given these considerations, an error generation process, referred to as the 'combinatorial approach', was developed. The process works as follows: First, the process identifies any actions the operator should perform through a normal prediction process using the set of context specifiers that accurately represent the current operational context. It then uses a preset 'level' in the model to identify a set that contains all the activities in the *currently predicted* 'branches' of the model's tree structure within a certain distance from an action. A slight variation, referred to as using the 'expanded' set, selects activities not only from the currently predicted branches in the tree, but from *all* branches below a predicted activity at a certain level. The results show that applying the combinatorial error generation process with the expanded set of activities is sometimes useful. (In some cases, for 'narrow' branches in the CATS model, both variations produce the same results.)

Having identified a set of relevant activities, the process next identifies *every* context specifier that appears in the CATS model conditions for performing each activity in the relevant set. By comparing this set to the set of true context specifiers, the process next identifies those that are 'not present, but could be if the context is erroneously formulated' and those that are 'present, but might not be if the context is erroneously formulated.' The process then follows a strict procedure that adds or removes, as necessary, *all combinations* of context specifiers from the true set. Thus, for each chosen combination of context specifiers, the process adds the ones that do not appear and removes the ones that

do appear in the true set. The process then predicts activities based on each of these revised sets.

Once it has produced a set of potentially erroneous predictions, the process invokes several filters. From each set of predicted activities, the process identifies actions, removes actions that happen to match correct actions, and removes duplicate sets of predicted actions. The process is summarized in Figure 3.

Let n denote the number of context specifiers that might erroneously appear, and m the number that might be erroneously left out of the current set. For a given true context, with $n + m$ possible context specifiers present in the selected branch(es) of the CATS model, the number of possible other erroneous context specifier combinations N_e is:

$$N_e = \sum_{r=1}^{r=n+m} \frac{(n+m)!}{r!(n+m-r)!}$$

Thus, if six context specifiers appear in the selected branch(es) of the CATS model, and three are present in the true context set, there are 63 potentially erroneous context specifier combinations in which between one and six context specifiers have added and/or removed as required from the true set.

The process was validated using the version of CATS developed for Callantine (2002c). CATS was first modified to identify those points when its predictions change as a result of a salient change in the operational context. The error generation process was then performed, and the results were output to files. Appendix A compiles the results (with highly similar results deleted for brevity).

Each error-generation example in Appendix A shows the results of the error-generation process, first when applied to

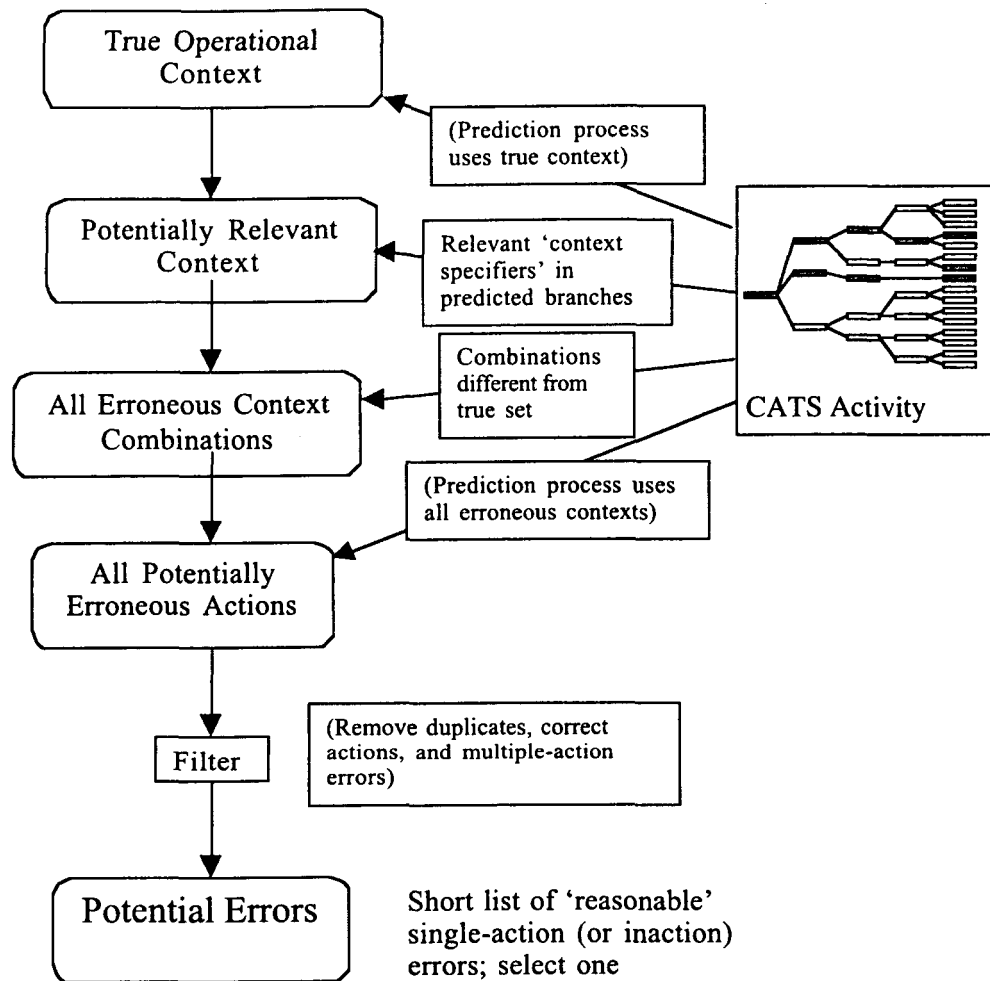


Figure 3. CATS agent error-generation process, which uses the CATS model and prediction process to produce errors 'related' to correct actions in a given context, and maintain links to the error context.

only the predicted branch(es) of the CATS model (from a selected predicted activity down to the predicted actions) then when applied to all branches that fall under a selected predicted activity. The results show that in every case, one possibility is for an error of omission; an agent using this approach would fail to perform a required action. In addition, the errors of commission that the process produces relate closely to the correct action that needs to be performed. The set of likely errors of commission expands to include a greater variety of errors when the error-generation process is applied to all branches, but the errors are still 'in the

neighborhood' of the true predicted action(s).

Comparison of Error-Generation Results to Error-Detection Results

Callantine (2002a) presents the results of research in which CATS detected a flight crew error using flight data from the NASA Langley Boeing 757 ARIES aircraft. Specifically, the crew received a clearance to climb to a new altitude, and rather than first setting the new target altitude and then engaging a autopilot mode to climb, the crew slipped and

attempted to engage a autopilot mode without setting the new target altitude.

The situation when the crew first needs to set the new target altitude corresponds to the output at time 52875.07 in the results in Appendix A. The CATS prediction of the preferred action is for the crew to perform the 'dial MCP altitude knob' action to set the new target altitude. Using only the predicted branch of the CATS model, the error-generation process yields three 'single-element' errors: '[no action],' 'push FL CH switch,' and 'push LNAV switch.' In Callantine (2002a), the crew is noted to have actually performed the 'push VNAV switch' action. The reduced set of errors generated from only the predicted branch of the CATS model does not list this option; however, the potential errors generated from the expanded set activities does. Thus, this example supports the notion that using the expanded set of activities as input to the error generation process yields the required set of 'reasonable' errors that might occur in a particular operational context.

Conclusions and Further Research

This research demonstrates that a CATS-based agent can produce the errors CATS detects using the combinatorical error generation process. For a full implementation, the error generation process would 'fire' probabilistically and, in addition, would probabilistically select a single error from the possible set. A rigorous validation strategy would entail connecting both a CATS-based agent and a CATS activity tracking implementation to the same controlled system. Then, when the CATS-based agent applies the error generation process to produce an error, CATS would detect the error online.

Further research is needed to construct such a test bed. In addition, research is required on how to make a given erroneous context persist long enough to produce 'lasting errors' that CATS would detect. In essence, the error-generation process would need to 'freeze' the erroneous context so that the agent would not correctly perform the action that was erroneously omitted on the next processing cycle. Also, if the context is allowed to shift to the true context, an error of commission would be followed immediately by a corrective action. This would limit the utility of a safety analysis utilizing such agents, because the agent would correct its errors before their effects could be manifested in the system.

The combinatorical error-generation process described here produces errors that are reasonable for a given context; the errors generated are not 'too far' from the correct actions in the true context. The process yields either 'inaction' or incorrect actions that appear in the same branch(es) of the CATS model as the correct actions. However, simply selecting these actions as possible errors does not provide information about the context that led to the error. The error generation process, on the other hand, automatically specifies the link between errors and context representation that may lead an operator to make them.

Sets of possible errors together with contextual information provide the necessary information for 'cognitive walkthrough'-style system safety analyses (Smith and Polson, 1999; Polson, Lewis, Rieman, and Wharton, 1992) for systems for which CATS models and prototype simulations can be constructed. With potential errors in hand, the analyst can focus examining aspects of the system's user interface that enable the operator to figure out what to do, whether what was done produced the desired effect, or

whether the action was in fact an error that needs to be corrected. The approach also may be thought of as automating aspects of related scenario-based analysis techniques, such as the Technique for Human Error Assessment (THEA) (Pocock, Harrison, Wright, and Johnson, 2001; Fields, Harrison, and Wright, 1997), because the errors derive from actual system context. The context-oriented focus also enables the error generation approach to support analyses of situation assessment problems that lead to errors (Endsley, 1999).

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Appendix A

Output from Error Generation Test


```

===== Error data at time 52584.395 =====
Predicting erroneous activities...
----- Vis a Vis Predicted Subtasks/Actions -----
Present, but need not be:
1: current-hdg-is-rwy-hdg
2: fd-on
Not present, but could be:
1: takeoff-thrust-set
2: thr-mode-engd
3: hdg-hold-engd
  [ 31 erroneous context specifier combinations]
Of 11 potentially erroneous predictions, 7 involve actions, and 4 do not

==> 5 possible errors (correct actions removed):
push N1 switch
push N1 switch set flight director switch
push HDG HOLD switch
[ no action]
set flight director switch
=====> 4 single-element errors:
push N1 switch
push HDG HOLD switch
[ no action]
set flight director switch

----- With All Subtasks/Actions In Play -----
Present, but need not be:
1: current-hdg-is-rwy-hdg
2: fd-on
Not present, but could be:
1: takeoff-thrust-set
2: thr-mode-engd
3: hdg-hold-engd
  [ 31 erroneous context specifier combinations]
Of 11 potentially erroneous predictions, 7 involve actions, and 4 do not

==> 5 possible errors (correct actions removed):
push N1 switch
push N1 switch set flight director switch
push HDG HOLD switch
[ no action]
set flight director switch
=====> 4 single-element errors:
push N1 switch
push HDG HOLD switch
[ no action]
set flight director switch

----- TRUE CONTEXT -----
start-of-run
at-armed
fd-on
programmed-route-within-limits
above-clean-speed
flight-surfaces-within-limits
gear-within-limits
current-hdg-is-rwy-hdg
target-alt-matches-after-takeoff-clb-alt
comm-freq-within-limits
mcp-alt-within-limits
not-capturing-rqd-alt
current-alt-within-limits
profile-okay-for-now
downpath-wpt-within-limits

```

intcpt-leg-to-wpt-within-limits

----- TRUE PREDICTIONS -----

fly glass cockpit aircraft
perform takeoff roll
initiate takeoff roll
set takeoff thrust
engage thrust mode
push N1 switch
hold runway heading
hold rwy hdg using HDG HOLD
engage HDG HOLD
push HDG HOLD switch

----- TRUE PREDICTIONS (ACTIONS ONLY) -----

push N1 switch push HDG HOLD switch

```

===== Error data at time 52660.87 =====
Predicting erroneous activities...
----- Vis a Vis Predicted Subtasks/Actions -----
Present, but need not be:
1: profile-okay-for-now
2: not-capturing-rqd-alt
3: mcp-alt-within-limits
Not present, but could be:
1: track-okay-for-now
2: current-hdg-within-limits
3: vnav-engd
   [ 63 erroneous context specifier combinations]
Of 20 potentially erroneous predictions, 16 involve actions, and 4 do not

==> 9 possible errors (correct actions removed):
[no action]
dial MCP altitude knob
push LNAV switch push VNAV switch
dial speed knob set speed brakes
push LNAV switch
push LNAV switch dial MCP altitude knob
dial MCP altitude knob dial speed knob set speed brakes
push LNAV switch dial speed knob set speed brakes
push LNAV switch dial MCP altitude knob dial speed knob set speed brakes
=====> 3 single-element errors:
[no action]
dial MCP altitude knob
push LNAV switch

----- With All Subtasks/Actions In Play -----
Present, but need not be:
1: target-heading-within-limits
2: hdg-sel-engd
3: profile-okay-for-now
4: not-capturing-rqd-alt
5: mcp-alt-within-limits
Not present, but could be:
1: track-okay-for-now
2: current-hdg-within-limits
3: hdg-hold-engd
4: vnav-engd
5: fms-target-speed-within-limits
6: speed-window-blank
7: target-speed-within-limits
8: drag-within-limits
   [ 2537 erroneous context specifier combinations]
Of 134 potentially erroneous predictions, 126 involve actions, and 8 do not

==> 78 possible errors (correct actions removed):
dial heading knob push VNAV switch
push heading knob push VNAV switch
[no action]
dial heading knob push heading knob push VNAV switch
dial heading knob
dial heading knob dial MCP altitude knob
push LNAV switch push VNAV switch
dial heading knob dial speed knob set speed brakes
push heading knob
push heading knob dial MCP altitude knob
push HDG HOLD switch push VNAV switch
push heading knob dial speed knob set speed brakes
dial heading knob push heading knob
dial heading knob push heading knob dial MCP altitude knob
dial heading knob push heading knob dial speed knob set speed brakes

```

push LNAV switch
 push LNAV switch dial MCP altitude knob
 dial MCP altitude knob
 dial heading knob dial MCP altitude knob dial speed knob set speed brakes
 push LNAV switch dial speed knob set speed brakes
 dial speed knob set speed brakes
 dial heading knob set speed brakes
 dial heading knob push speed knob dial speed knob set speed brakes
 dial heading knob dial speed knob
 push HDG HOLD switch
 push HDG HOLD switch dial MCP altitude knob
 dial heading knob push heading knob dial MCP altitude knob dial speed knob set speed brakes
 push HDG HOLD switch dial speed knob set speed brakes
 dial heading knob push heading knob set speed brakes
 dial heading knob push heading knob push speed knob dial speed knob set speed brakes
 dial heading knob push heading knob dial speed knob
 push LNAV switch dial MCP altitude knob dial speed knob set speed brakes
 dial MCP altitude knob dial speed knob set speed brakes
 dial heading knob dial MCP altitude knob set speed brakes
 dial heading knob dial MCP altitude knob push speed knob dial speed knob set speed brakes
 dial heading knob dial MCP altitude knob dial speed knob
 push LNAV switch set speed brakes
 push LNAV switch push speed knob dial speed knob set speed brakes
 push LNAV switch dial speed knob
 set speed brakes
 push speed knob dial speed knob set speed brakes
 dial speed knob
 dial heading knob push speed knob set speed brakes
 dial heading knob push speed knob dial speed knob
 push HDG HOLD switch dial MCP altitude knob dial speed knob set speed brakes
 dial heading knob push heading knob dial MCP altitude knob set speed brakes
 dial heading knob push heading knob dial MCP altitude knob push speed knob dial speed knob set speed brakes
 dial heading knob push heading knob dial MCP altitude knob dial speed knob
 push HDG HOLD switch set speed brakes
 push HDG HOLD switch push speed knob dial speed knob set speed brakes
 push HDG HOLD switch dial speed knob
 dial heading knob push heading knob push speed knob set speed brakes
 dial heading knob push heading knob push speed knob dial speed knob
 push LNAV switch dial MCP altitude knob set speed brakes
 push LNAV switch dial MCP altitude knob push speed knob dial speed knob set speed brakes
 push LNAV switch dial MCP altitude knob dial speed knob
 dial MCP altitude knob set speed brakes
 dial MCP altitude knob push speed knob dial speed knob set speed brakes
 dial MCP altitude knob dial speed knob
 push HDG HOLD switch dial MCP altitude knob set speed brakes
 push HDG HOLD switch dial MCP altitude knob push speed knob dial speed knob set speed brakes
 push HDG HOLD switch dial MCP altitude knob dial speed knob
 dial heading knob push heading knob dial MCP altitude knob push speed knob set speed brakes
 dial heading knob push heading knob dial MCP altitude knob push speed knob dial speed knob
 push LNAV switch push speed knob set speed brakes
 push LNAV switch push speed knob dial speed knob
 push HDG HOLD switch push speed knob set speed brakes
 push HDG HOLD switch push speed knob dial speed knob
 dial heading knob push heading knob push speed knob
 push LNAV switch dial MCP altitude knob push speed knob set speed brakes
 push LNAV switch dial MCP altitude knob push speed knob dial speed knob
 push HDG HOLD switch dial MCP altitude knob push speed knob set speed brakes

push HDG HOLD switch dial MCP altitude knob push speed knob dial speed knob
dial heading knob push heading knob dial MCP altitude knob push speed knob
push LNAV switch push speed knob
push speed knob set speed brakes
push speed knob dial speed knob
push HDG HOLD switch push speed knob

=====> 8 single-element errors:

[no action]

dial heading knob
push heading knob
push LNAV switch
dial MCP altitude knob
push HDG HOLD switch
set speed brakes
dial speed knob

----- TRUE CONTEXT -----

start-of-run
above-runway-elev
above-1000-feet-AGL
at-armed
fd-on
takeoff-thrust-set
programmed-route-within-limits
above-clean-speed
flight-surfaces-within-limits
gear-within-limits
target-alt-matches-after-takeoff-clb-alt
comm-freq-within-limits
mcp-alt-within-limits
not-capturing-rqd-alt
profile-okay-for-now
hdg-sel-engd
target-heading-within-limits
downpath-wpt-within-limits
intcpt-leg-to-wpt-within-limits

----- TRUE PREDICTIONS -----

fly glass cockpit aircraft
navigate with AP or FD guidance
navigate laterally
fly heading
fly using HDG SEL
navigate vertically
fly profile
fly using VNAV
engage VNAV
push VNAV switch

----- TRUE PREDICTIONS (ACTIONS ONLY) -----

push VNAV switch

```

===== Error data at time 52715.12 =====
Predicting erroneous activities...
----- Vis a Vis Predicted Subtasks/Actions -----
Present, but need not be:
1: profile-okay-for-now
2: vnav-engd
Not present, but could be:
1: track-okay-for-now
2: current-hdg-within-limits
3: target-heading-within-limits
4: mcp-alt-within-limits
   [ 63 erroneous context specifier combinations]
Of 23 potentially erroneous predictions, 17 involve actions, and 6 do not

```

```

==> 5 possible errors (correct actions removed):

```

```

push LNAV switch dial MCP altitude knob
dial MCP altitude knob
dial heading knob
push LNAV switch
[ no action]

```

```

=====> 4 single-element errors:

```

```

dial MCP altitude knob
dial heading knob
push LNAV switch
[ no action]

```

```

----- With All Subtasks/Actions In Play -----

```

```

Present, but need not be:

```

```

1: hdg-sel-engd
2: profile-okay-for-now
3: vnav-engd
4: fms-target-speed-within-limits
5: speed-window-blank
6: drag-within-limits

```

```

Not present, but could be:

```

```

1: track-okay-for-now
2: current-hdg-within-limits
3: target-heading-within-limits
4: hdg-hold-engd
5: mcp-alt-within-limits
6: not-capturing-rqd-alt
7: target-speed-within-limits

```

```

   [ 2537 erroneous context specifier combinations]

```

```

Of 103 potentially erroneous predictions, 100 involve actions, and 3 do not

```

```

==> 73 possible errors (correct actions removed):

```

```

dial heading knob push heading knob dial MCP altitude knob
dial heading knob dial MCP altitude knob push speed knob dial speed knob
dial heading knob push heading knob dial MCP altitude knob push speed knob dial speed
knob
dial heading knob push heading knob dial MCP altitude knob set speed brakes
push LNAV switch dial MCP altitude knob
push HDG HOLD switch dial MCP altitude knob
push heading knob dial MCP altitude knob
dial heading knob push heading knob
dial MCP altitude knob
dial heading knob
dial heading knob push heading knob dial MCP altitude knob dial speed knob
dial heading knob push heading knob dial MCP altitude knob push speed knob dial speed
knob set speed brakes
push LNAV switch dial MCP altitude knob push speed knob dial speed knob
push HDG HOLD switch dial MCP altitude knob push speed knob dial speed knob
push heading knob dial MCP altitude knob push speed knob dial speed knob
dial heading knob push heading knob push speed knob dial speed knob

```

dial heading knob push heading knob dial MCP altitude knob push speed knob
 push LNAV switch dial MCP altitude knob set speed brakes
 push HDG HOLD switch dial MCP altitude knob set speed brakes
 push heading knob dial MCP altitude knob set speed brakes
 dial heading knob push heading knob set speed brakes
 push LNAV switch
 push HDG HOLD switch
 push heading knob
 dial heading knob push heading knob push VNAV switch
 dial heading knob push heading knob dial MCP altitude knob dial speed knob set speed
 brakes
 push LNAV switch dial MCP altitude knob dial speed knob
 push HDG HOLD switch dial MCP altitude knob dial speed knob
 push heading knob dial MCP altitude knob dial speed knob
 dial heading knob push heading knob dial speed knob
 push LNAV switch dial MCP altitude knob push speed knob dial speed knob set speed
 brakes
 push HDG HOLD switch dial MCP altitude knob push speed knob dial speed knob set speed
 brakes
 push heading knob dial MCP altitude knob push speed knob dial speed knob set speed
 brakes
 dial heading knob push heading knob push speed knob dial speed knob set speed brakes
 dial heading knob push heading knob dial MCP altitude knob push speed knob set speed
 brakes
 push LNAV switch push speed knob dial speed knob
 push LNAV switch dial MCP altitude knob push speed knob
 dial MCP altitude knob push speed knob dial speed knob
 push HDG HOLD switch push speed knob dial speed knob
 push HDG HOLD switch dial MCP altitude knob push speed knob
 push heading knob push speed knob dial speed knob
 push heading knob dial MCP altitude knob push speed knob
 dial heading knob push heading knob push speed knob
 push LNAV switch set speed brakes
 dial MCP altitude knob set speed brakes
 push HDG HOLD switch set speed brakes
 push heading knob set speed brakes
 [no action]
 push LNAV switch push VNAV switch
 push HDG HOLD switch push VNAV switch
 push heading knob push VNAV switch
 push LNAV switch dial MCP altitude knob dial speed knob set speed brakes
 push HDG HOLD switch dial MCP altitude knob dial speed knob set speed brakes
 push heading knob dial MCP altitude knob dial speed knob set speed brakes
 dial heading knob push heading knob dial speed knob set speed brakes
 push LNAV switch dial speed knob
 dial MCP altitude knob dial speed knob
 push HDG HOLD switch dial speed knob
 push heading knob dial speed knob
 push LNAV switch push speed knob dial speed knob set speed brakes
 push LNAV switch dial MCP altitude knob push speed knob set speed brakes
 dial MCP altitude knob push speed knob dial speed knob set speed brakes
 push HDG HOLD switch push speed knob dial speed knob set speed brakes
 push HDG HOLD switch dial MCP altitude knob push speed knob set speed brakes
 push heading knob push speed knob dial speed knob set speed brakes
 push heading knob dial MCP altitude knob push speed knob set speed brakes
 dial heading knob push heading knob push speed knob set speed brakes
 push LNAV switch push speed knob
 push speed knob dial speed knob
 dial MCP altitude knob push speed knob
 push HDG HOLD switch push speed knob
 push heading knob push speed knob
 push VNAV switch
 =====> 7 single-element errors:
 dial MCP altitude knob

dial heading knob
push LNAV switch
push HDG HOLD switch
push heading knob
[no action]
push VNAV switch

----- TRUE CONTEXT -----

start-of-run
above-runway-elev
above-1000-feet-AGL
at-armed
fd-on
programmed-route-within-limits
above-clean-speed
flight-surfaces-within-limits
gear-within-limits
comm-freq-within-limits
profile-okay-for-now
hdg-sel-engd
vnav-engd
drag-within-limits
vs-within-limits
speed-window-blank
fms-target-speed-within-limits
downpath-wpt-within-limits
intcpt-leg-to-wpt-within-limits

----- TRUE PREDICTIONS -----

fly glass cockpit aircraft
navigate with AP or FD guidance
navigate laterally
fly heading
fly using HDG SEL
adjust heading
dial heading knob
navigate vertically
set target altitude
dial MCP altitude knob
fly profile
fly using VNAV
manage speed

----- TRUE PREDICTIONS (ACTIONS ONLY) -----

dial heading knob dial MCP altitude knob


```

===== Error data at time 52795.094 =====
Predicting erroneous activities...
----- Vis a Vis Predicted Subtasks/Actions -----
Present, but need not be:
1: profile-okay-for-now
2: vnav-engd
Not present, but could be:
1: track-okay-for-now
2: current-hdg-within-limits
3: target-heading-within-limits
   [ 31 erroneous context specifier combinations]
Of 11 potentially erroneous predictions, 7 involve actions, and 4 do not

```

```

==> 5 possible errors (correct actions removed):

```

```

dial heading knob push VNAV switch
push LNAV switch
[ no action]
push LNAV switch push VNAV switch
push VNAV switch
=====> 3 single-element errors:
push LNAV switch
[ no action]
push VNAV switch

```

```

----- With All Subtasks/Actions In Play -----

```

```

Present, but need not be:
1: hdg-sel-engd
2: profile-okay-for-now
3: vnav-engd
4: not-capturing-rqd-alt
5: mcp-alt-within-limits
6: fms-target-speed-within-limits
7: speed-window-blank
8: drag-within-limits
Not present, but could be:
1: track-okay-for-now
2: current-hdg-within-limits
3: target-heading-within-limits
4: hdg-hold-engd
5: target-speed-within-limits
   [ 2537 erroneous context specifier combinations]
Of 91 potentially erroneous predictions, 86 involve actions, and 5 do not

```

```

==> 64 possible errors (correct actions removed):

```

```

dial heading knob push heading knob
dial heading knob push VNAV switch
dial heading knob push heading knob push VNAV switch
dial heading knob push heading knob dial MCP altitude knob
dial heading knob push heading knob push speed knob dial speed knob
dial heading knob push heading knob set speed brakes
push LNAV switch
push HDG HOLD switch
push heading knob
dial heading knob dial MCP altitude knob
[ no action]
push LNAV switch push VNAV switch
push HDG HOLD switch push VNAV switch
push heading knob push VNAV switch
dial heading knob push heading knob dial MCP altitude knob push speed knob dial speed
knob
dial heading knob push heading knob dial MCP altitude knob set speed brakes
push LNAV switch dial MCP altitude knob
push HDG HOLD switch dial MCP altitude knob
push heading knob dial MCP altitude knob

```

```

dial heading knob push heading knob dial speed knob
dial heading knob push heading knob push speed knob dial speed knob set speed brakes
push LNAV switch push speed knob dial speed knob
push HDG HOLD switch push speed knob dial speed knob
push heading knob push speed knob dial speed knob
dial heading knob push heading knob push speed knob
push LNAV switch set speed brakes
push HDG HOLD switch set speed brakes
push heading knob set speed brakes
push VNAV switch
dial heading knob push heading knob dial MCP altitude knob dial speed knob
dial heading knob push heading knob dial MCP altitude knob push speed knob dial speed
knob set speed brakes
push LNAV switch dial MCP altitude knob push speed knob dial speed knob
push HDG HOLD switch dial MCP altitude knob push speed knob dial speed knob
push heading knob dial MCP altitude knob push speed knob dial speed knob
dial heading knob push heading knob dial MCP altitude knob push speed knob
push LNAV switch dial MCP altitude knob set speed brakes
push HDG HOLD switch dial MCP altitude knob set speed brakes
push heading knob dial MCP altitude knob set speed brakes
dial MCP altitude knob
dial heading knob push heading knob dial speed knob set speed brakes
push LNAV switch dial speed knob
push HDG HOLD switch dial speed knob
push heading knob dial speed knob
push LNAV switch push speed knob dial speed knob set speed brakes
push HDG HOLD switch push speed knob dial speed knob set speed brakes
push heading knob push speed knob dial speed knob set speed brakes
dial heading knob push heading knob push speed knob set speed brakes
push LNAV switch push speed knob
push speed knob dial speed knob
push HDG HOLD switch push speed knob
push heading knob push speed knob
set speed brakes
dial heading knob push heading knob dial MCP altitude knob dial speed knob set speed
brakes
push LNAV switch dial MCP altitude knob dial speed knob
push HDG HOLD switch dial MCP altitude knob dial speed knob
push heading knob dial MCP altitude knob dial speed knob
push LNAV switch dial MCP altitude knob push speed knob dial speed knob set speed
brakes
push HDG HOLD switch dial MCP altitude knob push speed knob dial speed knob set speed
brakes
push heading knob dial MCP altitude knob push speed knob dial speed knob set speed
brakes
dial heading knob push heading knob dial MCP altitude knob push speed knob set speed
brakes
push LNAV switch dial MCP altitude knob push speed knob
dial MCP altitude knob push speed knob dial speed knob
push HDG HOLD switch dial MCP altitude knob push speed knob
push heading knob dial MCP altitude knob push speed knob
=====> 7 single-element errors:
push LNAV switch
push HDG HOLD switch
push heading knob
[no action]
push VNAV switch
dial MCP altitude knob
set speed brakes
----- TRUE CONTEXT -----
start-of-run
above-runway-elev
above-1000-feet-AGL
at-armed

```

fd-on
programmed-route-within-limits
above-clean-speed
flight-surfaces-within-limits
gear-within-limits
comm-freq-within-limits
mcp-alt-within-limits
not-capturing-rqd-alt
profile-okay-for-now
hdg-sel-engd
vnav-engd
drag-within-limits
speed-window-blank
fms-target-speed-within-limits
downpath-wpt-within-limits
intcpt-leg-to-wpt-within-limits

----- TRUE PREDICTIONS -----

fly glass cockpit aircraft
navigate with AP or FD guidance
navigate laterally
fly heading
fly using HDG SEL
adjust heading
dial heading knob
navigate vertically
fly profile
fly using VNAV
manage speed

----- TRUE PREDICTIONS (ACTIONS ONLY) -----

dial heading knob

```

===== Error data at time 52875.07 =====
Predicting erroneous activities...
----- Vis a Vis Predicted Subtasks/Actions -----
Present, but need not be:
1: profile-okay-for-now
Not present, but could be:
1: track-okay-for-now
2: current-hdg-within-limits
3: mcp-alt-within-limits
4: vnav-engd
   [ 31 erroneous context specifier combinations]
Of 17 potentially erroneous predictions, 15 involve actions, and 2 do not

```

```

==> 9 possible errors (correct actions removed):
push LNAV switch dial MCP altitude knob
[no action]
dial MCP altitude knob dial speed knob set speed brakes
push FL CH switch
push LNAV switch
push LNAV switch dial MCP altitude knob dial speed knob set speed brakes
dial speed knob set speed brakes
push LNAV switch push FL CH switch
push LNAV switch dial speed knob set speed brakes
=====> 3 single-element errors:
[no action]
push FL CH switch
push LNAV switch

```

```

----- With All Subtasks/Actions In Play -----
Present, but need not be:
1: target-heading-within-limits
2: hdg-sel-engd
3: profile-okay-for-now
Not present, but could be:
1: track-okay-for-now
2: current-hdg-within-limits
3: hdg-hold-engd
4: mcp-alt-within-limits
5: vnav-engd
6: not-capturing-rqd-alt
7: fms-target-speed-within-limits
8: speed-window-blank
9: target-speed-within-limits
10: drag-within-limits
   [ 2537 erroneous context specifier combinations]

```

Of 137 potentially erroneous predictions, 133 involve actions, and 4 do not

```

==> 86 possible errors (correct actions removed):
dial heading knob dial MCP altitude knob
push heading knob dial MCP altitude knob
push LNAV switch dial MCP altitude knob
dial heading knob push heading knob dial MCP altitude knob
dial heading knob
dial heading knob dial MCP altitude knob dial speed knob set speed brakes
push HDG HOLD switch dial MCP altitude knob
push heading knob
push heading knob dial MCP altitude knob dial speed knob set speed brakes
dial heading knob push heading knob
dial heading knob push heading knob dial MCP altitude knob dial speed knob set speed
brakes
dial heading knob push FL CH switch
push LNAV switch
push LNAV switch dial MCP altitude knob dial speed knob set speed brakes

```

[no action]
 dial MCP altitude knob dial speed knob set speed brakes
 dial heading knob dial speed knob set speed brakes
 dial heading knob push VNAV switch
 dial heading knob dial MCP altitude knob set speed brakes
 dial heading knob dial MCP altitude knob push speed knob dial speed knob set speed
 brakes
 dial heading knob dial MCP altitude knob dial speed knob
 push heading knob push FL CH switch
 push HDG HOLD switch
 push HDG HOLD switch dial MCP altitude knob dial speed knob set speed brakes
 dial heading knob push heading knob push FL CH switch
 dial heading knob push heading knob dial speed knob set speed brakes
 dial heading knob push heading knob push VNAV switch
 dial heading knob push heading knob dial MCP altitude knob set speed brakes
 dial heading knob push heading knob dial MCP altitude knob push speed knob dial speed
 knob set speed brakes
 dial heading knob push heading knob dial MCP altitude knob dial speed knob
 push LNAV switch push FL CH switch
 push FL CH switch
 push LNAV switch dial speed knob set speed brakes
 push LNAV switch push VNAV switch
 push LNAV switch dial MCP altitude knob set speed brakes
 push LNAV switch dial MCP altitude knob push speed knob dial speed knob set speed
 brakes
 push LNAV switch dial MCP altitude knob dial speed knob
 dial speed knob set speed brakes
 push VNAV switch
 dial MCP altitude knob set speed brakes
 dial MCP altitude knob push speed knob dial speed knob set speed brakes
 dial MCP altitude knob dial speed knob
 dial heading knob set speed brakes
 dial heading knob push speed knob dial speed knob set speed brakes
 dial heading knob dial speed knob
 dial heading knob dial MCP altitude knob push speed knob set speed brakes
 dial heading knob dial MCP altitude knob push speed knob dial speed knob
 push HDG HOLD switch push FL CH switch
 push HDG HOLD switch dial speed knob set speed brakes
 push HDG HOLD switch push VNAV switch
 push HDG HOLD switch dial MCP altitude knob set speed brakes
 push HDG HOLD switch dial MCP altitude knob push speed knob dial speed knob set speed
 brakes
 push HDG HOLD switch dial MCP altitude knob dial speed knob
 dial heading knob push heading knob set speed brakes
 dial heading knob push heading knob push speed knob dial speed knob set speed brakes
 dial heading knob push heading knob dial speed knob
 dial heading knob push heading knob dial MCP altitude knob push speed knob set speed
 brakes
 dial heading knob push heading knob dial MCP altitude knob push speed knob dial speed
 knob
 push LNAV switch set speed brakes
 push LNAV switch push speed knob dial speed knob set speed brakes
 push LNAV switch dial speed knob
 push LNAV switch dial MCP altitude knob push speed knob set speed brakes
 push LNAV switch dial MCP altitude knob push speed knob dial speed knob
 set speed brakes
 push speed knob dial speed knob set speed brakes
 dial speed knob
 push HDG HOLD switch set speed brakes
 push HDG HOLD switch push speed knob dial speed knob set speed brakes
 push HDG HOLD switch dial speed knob
 push HDG HOLD switch dial MCP altitude knob push speed knob set speed brakes
 push HDG HOLD switch dial MCP altitude knob push speed knob dial speed knob
 dial heading knob push heading knob push speed knob set speed brakes

dial heading knob push heading knob push speed knob dial speed knob
 dial heading knob push heading knob dial MCP altitude knob push speed knob
 push LNAV switch push speed knob set speed brakes
 push LNAV switch push speed knob dial speed knob
 push LNAV switch dial MCP altitude knob push speed knob
 dial MCP altitude knob push speed knob set speed brakes
 dial MCP altitude knob push speed knob dial speed knob
 push HDG HOLD switch push speed knob set speed brakes
 push HDG HOLD switch push speed knob dial speed knob
 push HDG HOLD switch dial MCP altitude knob push speed knob
 dial heading knob push heading knob push speed knob
 push LNAV switch push speed knob
 push speed knob set speed brakes
 push speed knob dial speed knob

=====> 9 single-element errors:

dial heading knob
 push heading knob
 push LNAV switch
 [no action]
 push HDG HOLD switch
 push FL CH switch
 push VNAV switch
 set speed brakes
 dial speed knob

----- TRUE CONTEXT -----

start-of-run
 above-runway-elev
 above-1000-feet-AGL
 at-armed
 fd-on
 programmed-route-within-limits
 above-clean-speed
 flight-surfaces-within-limits
 gear-within-limits
 comm-freq-within-limits
 profile-okay-for-now
 alt-hold-in-progress
 alt-hold-engd
 hdg-sel-engd
 target-heading-within-limits
 alt-far-from-target
 current-heading-within-limits
 downpath-wpt-within-limits
 intcpt-leg-to-wpt-within-limits

----- TRUE PREDICTIONS -----

fly glass cockpit aircraft
 navigate with AP or FD guidance
 navigate laterally
 fly heading
 fly using HDG SEL
 navigate vertically
 set target altitude
 dial MCP altitude knob
 fly profile
 fly using VNAV
 engage VNAV

----- TRUE PREDICTIONS (ACTIONS ONLY) -----

dial MCP altitude knob

===== Error data at time 52883.12 =====

Predicting erroneous activities...

----- Vis a Vis Predicted Subtasks/Actions -----

Present, but need not be:

1: profile-okay-for-now

2: vnav-engd

Not present, but could be:

1: track-okay-for-now

2: current-hdg-within-limits

3: mcp-alt-within-limits

4: fms-target-speed-within-limits

5: target-speed-within-limits

[127 erroneous context specifier combinations]

Of 29 potentially erroneous predictions, 23 involve actions, and 6 do not

====> 9 possible errors (correct actions removed):

dial MCP altitude knob

push LNAV switch dial MCP altitude knob dial speed knob

dial speed knob

push LNAV switch dial MCP altitude knob

push FL CH switch

[no action]

push LNAV switch dial speed knob

push LNAV switch push FL CH switch

push LNAV switch

=====> 5 single-element errors:

dial MCP altitude knob

dial speed knob

push FL CH switch

[no action]

push LNAV switch

----- With All Subtasks/Actions In Play -----

Present, but need not be:

1: target-heading-within-limits

2: hdg-sel-engd

3: profile-okay-for-now

4: vnav-engd

5: drag-within-limits

Not present, but could be:

1: track-okay-for-now

2: current-hdg-within-limits

3: hdg-hold-engd

4: mcp-alt-within-limits

5: not-capturing-rqd-alt

6: fms-target-speed-within-limits

7: speed-window-blank

8: target-speed-within-limits

[2537 erroneous context specifier combinations]

Of 157 potentially erroneous predictions, 151 involve actions, and 6 do not

====> 94 possible errors (correct actions removed):

dial heading knob dial MCP altitude knob dial speed knob

push heading knob dial MCP altitude knob dial speed knob

dial MCP altitude knob

dial heading knob push heading knob dial MCP altitude knob dial speed knob

dial heading knob dial MCP altitude knob

dial heading knob dial MCP altitude knob dial speed knob set speed brakes

push LNAV switch dial MCP altitude knob dial speed knob

dial heading knob dial speed knob

dial heading knob dial MCP altitude knob push speed knob dial speed knob

push heading knob dial MCP altitude knob

push heading knob dial MCP altitude knob dial speed knob set speed brakes

push HDG HOLD switch dial MCP altitude knob dial speed knob

push heading knob dial speed knob
 push heading knob dial MCP altitude knob push speed knob dial speed knob
 dial heading knob push heading knob dial MCP altitude knob
 dial heading knob push heading knob dial MCP altitude knob dial speed knob set speed
 brakes
 dial heading knob push heading knob dial speed knob
 dial heading knob push heading knob dial MCP altitude knob push speed knob dial speed
 knob
 push LNAV switch dial MCP altitude knob
 dial heading knob push FL CH switch
 dial heading knob
 push LNAV switch dial MCP altitude knob dial speed knob set speed brakes
 dial MCP altitude knob dial speed knob set speed brakes
 dial heading knob dial speed knob set speed brakes
 dial heading knob dial MCP altitude knob set speed brakes
 dial heading knob dial MCP altitude knob push speed knob dial speed knob set speed
 brakes
 push LNAV switch dial speed knob
 push LNAV switch dial MCP altitude knob push speed knob dial speed knob
 dial speed knob
 dial MCP altitude knob push speed knob dial speed knob
 dial heading knob push speed knob dial speed knob
 dial heading knob dial MCP altitude knob push speed knob
 push HDG HOLD switch dial MCP altitude knob
 push heading knob push FL CH switch
 push heading knob
 push HDG HOLD switch dial MCP altitude knob dial speed knob set speed brakes
 dial heading knob push heading knob push FL CH switch
 dial heading knob push heading knob
 dial heading knob push heading knob dial speed knob set speed brakes
 dial heading knob push heading knob dial MCP altitude knob set speed brakes
 dial heading knob push heading knob dial MCP altitude knob push speed knob dial speed
 knob set speed brakes
 push HDG HOLD switch dial speed knob
 push HDG HOLD switch dial MCP altitude knob push speed knob dial speed knob
 dial heading knob push heading knob push speed knob dial speed knob
 dial heading knob push heading knob dial MCP altitude knob push speed knob
 push LNAV switch push FL CH switch
 push FL CH switch
 push LNAV switch
 [no action]
 dial heading knob push VNAV switch
 push LNAV switch dial speed knob set speed brakes
 push LNAV switch dial MCP altitude knob set speed brakes
 push LNAV switch dial MCP altitude knob push speed knob dial speed knob set speed
 brakes
 dial speed knob set speed brakes
 dial MCP altitude knob set speed brakes
 dial MCP altitude knob push speed knob dial speed knob set speed brakes
 dial heading knob set speed brakes
 dial heading knob push speed knob dial speed knob set speed brakes
 dial heading knob dial MCP altitude knob push speed knob set speed brakes
 push LNAV switch push speed knob dial speed knob
 push LNAV switch dial MCP altitude knob push speed knob
 push speed knob dial speed knob
 dial MCP altitude knob push speed knob
 dial heading knob push speed knob
 push HDG HOLD switch push FL CH switch
 push HDG HOLD switch
 dial heading knob push heading knob push VNAV switch
 push HDG HOLD switch dial speed knob set speed brakes
 push HDG HOLD switch dial MCP altitude knob set speed brakes
 push HDG HOLD switch dial MCP altitude knob push speed knob dial speed knob set speed
 brakes

dial heading knob push heading knob set speed brakes
 dial heading knob push heading knob push speed knob dial speed knob set speed brakes
 dial heading knob push heading knob dial MCP altitude knob push speed knob set speed
 brakes
 push HDG HOLD switch push speed knob dial speed knob
 push HDG HOLD switch dial MCP altitude knob push speed knob
 dial heading knob push heading knob push speed knob
 push LNAV switch push VNAV switch
 push VNAV switch
 push LNAV switch set speed brakes
 push LNAV switch push speed knob dial speed knob set speed brakes
 push LNAV switch dial MCP altitude knob push speed knob set speed brakes
 set speed brakes
 push speed knob dial speed knob set speed brakes
 push HDG HOLD switch push VNAV switch
 push HDG HOLD switch set speed brakes
 push HDG HOLD switch push speed knob dial speed knob set speed brakes
 push HDG HOLD switch dial MCP altitude knob push speed knob set speed brakes
 dial heading knob push heading knob push speed knob set speed brakes
 push LNAV switch push speed knob
 push HDG HOLD switch push speed knob
 push LNAV switch push speed knob set speed brakes
 dial MCP altitude knob push speed knob set speed brakes
 push HDG HOLD switch push speed knob set speed brakes
 push speed knob
 =====> 11 single-element errors:
 dial MCP altitude knob
 dial heading knob
 dial speed knob
 push heading knob
 push FL CH switch
 push LNAV switch
 [no action]
 push HDG HOLD switch
 push VNAV switch
 set speed brakes
 push speed knob

----- TRUE CONTEXT -----

start-of-run
 above-runway-elev
 above-1000-feet-AGL
 at-armed
 fd-on
 programmed-route-within-limits
 above-clean-speed
 flight-surfaces-within-limits
 gear-within-limits
 comm-freq-within-limits
 profile-okay-for-now
 alt-hold-in-progress
 alt-hold-engd
 hdg-sel-engd
 vnav-engd
 drag-within-limits
 target-heading-within-limits
 alt-far-from-target
 current-heading-within-limits
 downpath-wpt-within-limits
 intcpt-leg-to-wpt-within-limits

----- TRUE PREDICTIONS -----

fly glass cockpit aircraft
 navigate with AP or FD guidance
 navigate laterally

fly heading
fly using HDG SEL
navigate vertically
set target altitude
dial MCP altitude knob
fly profile
fly using VNAV
manage speed
engage Speed Intervention
dial speed knob

----- TRUE PREDICTIONS (ACTIONS ONLY) -----
dial MCP altitude knob dial speed knob

```

===== Error data at time 54310.76 =====
Predicting erroneous activities...
----- Vis a Vis Predicted Subtasks/Actions -----
Present, but need not be:
1: track-okay-for-now
2: alt-far-from-target
3: flch-engd
Not present, but could be:
1: mcp-alt-within-limits
2: expedite-needed
3: current-alt-within-limits
4: profile-okay-for-now
5: vs-engd
6: target-speed-within-limits
  [ 511 erroneous context specifier combinations]
  Of 80 potentially erroneous predictions, 75 involve actions, and 5 do not

==> 23 possible errors (correct actions removed):
dial heading knob push heading knob dial MCP altitude knob dial speed knob
dial MCP altitude knob
dial speed knob
dial MCP altitude knob push ALT HOLD switch
dial heading knob push heading knob dial MCP altitude knob
dial heading knob push heading knob dial speed knob
dial heading knob push heading knob dial MCP altitude knob push ALT HOLD switch
push FL CH switch
push ALT HOLD switch
[ no action]
dial MCP altitude knob dial speed knob push ALT HOLD switch
dial heading knob push heading knob push FL CH switch
dial heading knob push heading knob push ALT HOLD switch
dial heading knob push heading knob
dial heading knob push heading knob dial MCP altitude knob dial speed knob push ALT
HOLD switch
push FL CH switch dial speed knob
dial speed knob push ALT HOLD switch
dial heading knob push heading knob push FL CH switch dial speed knob
dial heading knob push heading knob dial speed knob push ALT HOLD switch
push FL CH switch push ALT HOLD switch
dial heading knob push heading knob push FL CH switch push ALT HOLD switch
push FL CH switch dial speed knob push ALT HOLD switch
dial heading knob push heading knob push FL CH switch dial speed knob push ALT HOLD
switch
=====> 5 single-element errors:
dial MCP altitude knob
dial speed knob
push FL CH switch
push ALT HOLD switch
[ no action]
----- With All Subtasks/Actions In Play -----
Present, but need not be:
1: track-okay-for-now
2: lnav-engd
3: alt-far-from-target
4: flch-engd
Not present, but could be:
1: mcp-alt-within-limits
2: expedite-needed
3: current-alt-within-limits
4: profile-okay-for-now
5: alt-close-to-target
6: vs-engd
7: vs-within-limits
8: target-speed-within-limits

```

[4095 erroneous context specifier combinations]
Of 432 potentially erroneous predictions, 424 involve actions, and 8 do not

==> 131 possible errors (correct actions removed):
dial heading knob push heading knob dial MCP altitude knob dial speed knob
push LNAV switch dial MCP altitude knob dial speed knob
dial MCP altitude knob
dial speed knob
dial MCP altitude knob push ALT HOLD switch
dial MCP altitude knob push V/S switch dial V/S wheel dial speed knob
dial heading knob push heading knob dial MCP altitude knob
dial heading knob push heading knob dial speed knob
dial heading knob push heading knob dial MCP altitude knob push ALT HOLD switch
dial heading knob push heading knob dial MCP altitude knob push V/S switch dial V/S
wheel dial speed knob
push LNAV switch dial MCP altitude knob
push LNAV switch dial speed knob
push LNAV switch dial MCP altitude knob push ALT HOLD switch
push LNAV switch dial MCP altitude knob push V/S switch dial V/S wheel dial speed knob
push FL CH switch
dial MCP altitude knob push V/S switch dial V/S wheel
push ALT HOLD switch
[no action]
push V/S switch dial V/S wheel dial speed knob
dial MCP altitude knob dial speed knob push ALT HOLD switch
dial MCP altitude knob dial V/S wheel dial speed knob
dial MCP altitude knob push V/S switch dial speed knob
dial heading knob push heading knob push FL CH switch
dial heading knob push heading knob dial MCP altitude knob push V/S switch dial V/S
wheel
dial heading knob push heading knob push ALT HOLD switch
dial heading knob push heading knob
dial heading knob push heading knob push V/S switch dial V/S wheel dial speed knob
dial heading knob push heading knob dial MCP altitude knob dial speed knob push ALT
HOLD switch
dial heading knob push heading knob dial MCP altitude knob dial V/S wheel dial speed
knob
dial heading knob push heading knob dial MCP altitude knob push V/S switch dial speed
knob
push LNAV switch push FL CH switch
push LNAV switch dial MCP altitude knob push V/S switch dial V/S wheel
push LNAV switch push ALT HOLD switch
push LNAV switch
push LNAV switch push V/S switch dial V/S wheel dial speed knob
push LNAV switch dial MCP altitude knob dial speed knob push ALT HOLD switch
push LNAV switch dial MCP altitude knob dial V/S wheel dial speed knob
push LNAV switch dial MCP altitude knob push V/S switch dial speed knob
push FL CH switch push V/S switch dial V/S wheel
push FL CH switch dial speed knob
dial MCP altitude knob push V/S switch
dial speed knob push ALT HOLD switch
dial V/S wheel dial speed knob
push V/S switch dial speed knob
push V/S switch dial V/S wheel
dial MCP altitude knob push V/S switch dial V/S wheel dial speed knob push ALT HOLD
switch
dial MCP altitude knob dial V/S wheel
dial heading knob push heading knob push FL CH switch push V/S switch dial V/S wheel
dial heading knob push heading knob push FL CH switch dial speed knob
dial heading knob push heading knob dial MCP altitude knob push V/S switch
dial heading knob push heading knob dial speed knob push ALT HOLD switch
dial heading knob push heading knob dial V/S wheel dial speed knob
dial heading knob push heading knob push V/S switch dial speed knob
dial heading knob push heading knob push V/S switch dial V/S wheel

dial heading knob push heading knob dial MCP altitude knob push V/S switch dial V/S
 wheel dial speed knob push ALT HOLD switch
 dial heading knob push heading knob dial MCP altitude knob dial V/S wheel
 push LNAV switch push FL CH switch push V/S switch dial V/S wheel
 push LNAV switch push FL CH switch dial speed knob
 push LNAV switch dial MCP altitude knob push V/S switch
 push LNAV switch dial speed knob push ALT HOLD switch
 push LNAV switch dial V/S wheel dial speed knob
 push LNAV switch push V/S switch dial speed knob
 push LNAV switch push V/S switch dial V/S wheel
 push LNAV switch dial MCP altitude knob push V/S switch dial V/S wheel dial speed knob
 push ALT HOLD switch
 push LNAV switch dial MCP altitude knob dial V/S wheel
 push FL CH switch push ALT HOLD switch
 push FL CH switch dial V/S wheel dial speed knob
 push FL CH switch push V/S switch
 dial MCP altitude knob push V/S switch dial V/S wheel push ALT HOLD switch
 push V/S switch dial V/S wheel dial speed knob push ALT HOLD switch
 dial V/S wheel
 push V/S switch
 dial MCP altitude knob dial V/S wheel dial speed knob push ALT HOLD switch
 dial MCP altitude knob push V/S switch dial speed knob push ALT HOLD switch
 dial heading knob push heading knob push FL CH switch push ALT HOLD switch
 dial heading knob push heading knob push FL CH switch dial V/S wheel dial speed knob
 dial heading knob push heading knob push FL CH switch push V/S switch
 dial heading knob push heading knob dial MCP altitude knob push V/S switch dial V/S
 wheel push ALT HOLD switch
 dial heading knob push heading knob push V/S switch dial V/S wheel dial speed knob
 push ALT HOLD switch
 dial heading knob push heading knob dial V/S wheel
 dial heading knob push heading knob push V/S switch
 dial heading knob push heading knob dial MCP altitude knob dial V/S wheel dial speed
 knob push ALT HOLD switch
 dial heading knob push heading knob dial MCP altitude knob push V/S switch dial speed
 knob push ALT HOLD switch
 push LNAV switch push FL CH switch push ALT HOLD switch
 push LNAV switch push FL CH switch dial V/S wheel dial speed knob
 push LNAV switch push FL CH switch push V/S switch
 push LNAV switch dial MCP altitude knob push V/S switch dial V/S wheel push ALT HOLD
 switch
 push LNAV switch push V/S switch dial V/S wheel dial speed knob push ALT HOLD switch
 push LNAV switch dial V/S wheel
 push LNAV switch push V/S switch
 push LNAV switch dial MCP altitude knob dial V/S wheel dial speed knob push ALT HOLD
 switch
 push LNAV switch dial MCP altitude knob push V/S switch dial speed knob push ALT HOLD
 switch
 push FL CH switch push V/S switch dial V/S wheel push ALT HOLD switch
 push FL CH switch dial speed knob push ALT HOLD switch
 push FL CH switch dial V/S wheel
 dial MCP altitude knob push V/S switch push ALT HOLD switch
 dial V/S wheel dial speed knob push ALT HOLD switch
 push V/S switch dial speed knob push ALT HOLD switch
 push V/S switch dial V/S wheel push ALT HOLD switch
 dial MCP altitude knob dial V/S wheel push ALT HOLD switch
 dial heading knob push heading knob push FL CH switch push V/S switch dial V/S wheel
 push ALT HOLD switch
 dial heading knob push heading knob push FL CH switch dial speed knob push ALT HOLD
 switch
 dial heading knob push heading knob push FL CH switch dial V/S wheel
 dial heading knob push heading knob dial MCP altitude knob push V/S switch push ALT
 HOLD switch
 dial heading knob push heading knob dial V/S wheel dial speed knob push ALT HOLD
 switch

dial heading knob push heading knob push V/S switch dial speed knob push ALT HOLD
 switch
 dial heading knob push heading knob push V/S switch dial V/S wheel push ALT HOLD
 switch
 dial heading knob push heading knob dial MCP altitude knob dial V/S wheel push ALT
 HOLD switch
 push LNAV switch push FL CH switch push V/S switch dial V/S wheel push ALT HOLD switch
 push LNAV switch push FL CH switch dial speed knob push ALT HOLD switch
 push LNAV switch push FL CH switch dial V/S wheel
 push LNAV switch dial MCP altitude knob push V/S switch push ALT HOLD switch
 push LNAV switch dial V/S wheel dial speed knob push ALT HOLD switch
 push LNAV switch push V/S switch dial speed knob push ALT HOLD switch
 push LNAV switch push V/S switch dial V/S wheel push ALT HOLD switch
 push LNAV switch dial MCP altitude knob dial V/S wheel push ALT HOLD switch
 push FL CH switch dial V/S wheel dial speed knob push ALT HOLD switch
 push FL CH switch push V/S switch push ALT HOLD switch
 dial V/S wheel push ALT HOLD switch
 push V/S switch push ALT HOLD switch
 dial heading knob push heading knob push FL CH switch dial V/S wheel dial speed knob
 push ALT HOLD switch
 dial heading knob push heading knob push FL CH switch push V/S switch push ALT HOLD
 switch
 dial heading knob push heading knob dial V/S wheel push ALT HOLD switch
 dial heading knob push heading knob push V/S switch push ALT HOLD switch
 push LNAV switch push FL CH switch dial V/S wheel dial speed knob push ALT HOLD switch
 push LNAV switch push FL CH switch push V/S switch push ALT HOLD switch
 push LNAV switch dial V/S wheel push ALT HOLD switch
 push LNAV switch push V/S switch push ALT HOLD switch
 push FL CH switch dial V/S wheel push ALT HOLD switch
 dial heading knob push heading knob push FL CH switch dial V/S wheel push ALT HOLD
 switch
 push LNAV switch push FL CH switch dial V/S wheel push ALT HOLD switch
 =====> 8 single-element errors:
 dial MCP altitude knob
 dial speed knob
 push FL CH switch
 push ALT HOLD switch
 [no action]
 push LNAV switch
 dial V/S wheel
 push V/S switch

----- TRUE CONTEXT -----

start-of-run
 above-runway-elev
 above-1000-feet-AGL
 at-armed
 fd-on
 programmed-route-within-limits
 above-clean-speed
 flight-surfaces-within-limits
 gear-within-limits
 comm-freq-within-limits
 track-okay-for-now
 flch-engd
 lnav-engd
 alt-far-from-target
 downpath-wpt-within-limits
 intcpt-leg-to-wpt-within-limits

----- TRUE PREDICTIONS -----

fly glass cockpit aircraft
 navigate with AP or FD guidance
 navigate laterally
 fly track

fly using LNAV
navigate vertically
set target altitude
dial MCP altitude knob
achieve/maintain altitude
fly using FL CH
manage speed
adjust speed
dial speed knob

----- TRUE PREDICTIONS (ACTIONS ONLY) -----
dial MCP altitude knob dial speed knob

```

===== Error data at time 54440.086 =====
Predicting erroneous activities...
----- Vis a Vis Predicted Subtasks/Actions -----
Present, but need not be:
1: track-okay-for-now
2: alt-far-from-target
3: mcp-alt-within-limits
Not present, but could be:
1: expedite-needed
2: current-alt-within-limits
3: profile-okay-for-now
4: flch-engd
    [ 127 erroneous context specifier combinations]
Of 40 potentially erroneous predictions, 39 involve actions, and 1 do not

```

```

==> 29 possible errors (correct actions removed):
dial heading knob push heading knob push FL CH switch
[ no action]
dial MCP altitude knob
push ALT HOLD switch
push speed knob dial speed knob
dial speed knob
dial heading knob push heading knob
dial heading knob push heading knob dial MCP altitude knob
dial heading knob push heading knob push ALT HOLD switch
dial heading knob push heading knob push speed knob dial speed knob
dial heading knob push heading knob dial speed knob
dial MCP altitude knob push ALT HOLD switch
dial MCP altitude knob push speed knob dial speed knob
dial MCP altitude knob dial speed knob
push FL CH switch push ALT HOLD switch
push FL CH switch push speed knob dial speed knob
dial heading knob push heading knob dial MCP altitude knob push ALT HOLD switch
dial heading knob push heading knob dial MCP altitude knob push speed knob dial speed
knob
dial heading knob push heading knob dial MCP altitude knob dial speed knob
dial heading knob push heading knob push FL CH switch push ALT HOLD switch
dial heading knob push heading knob push FL CH switch push speed knob dial speed knob
dial speed knob push ALT HOLD switch
dial speed knob push speed knob dial speed knob
dial heading knob push heading knob dial speed knob push ALT HOLD switch
dial heading knob push heading knob dial speed knob push speed knob dial speed knob
dial MCP altitude knob dial speed knob push ALT HOLD switch
dial MCP altitude knob dial speed knob push speed knob dial speed knob
dial heading knob push heading knob dial MCP altitude knob dial speed knob push ALT
HOLD switch
dial heading knob push heading knob dial MCP altitude knob dial speed knob push speed
knob dial speed knob
=====> 4 single-element errors:
[ no action]
dial MCP altitude knob
push ALT HOLD switch
dial speed knob

```

```

----- With All Subtasks/Actions In Play -----
Present, but need not be:
1: track-okay-for-now
2: lnav-engd
3: alt-far-from-target
4: mcp-alt-within-limits
Not present, but could be:
1: expedite-needed
2: current-alt-within-limits
3: profile-okay-for-now

```


4: flch-engd
 5: alt-close-to-target
 6: vs-engd
 7: vs-within-limits
 8: target-speed-within-limits
 [4095 erroneous context specifier combinations]
 Of 456 potentially erroneous predictions, 451 involve actions, and 5 do not

==> 218 possible errors (correct actions removed):
 dial heading knob push heading knob push FL CH switch
 push LNAV switch push FL CH switch
 [no action]
 dial MCP altitude knob
 push ALT HOLD switch
 push speed knob dial speed knob
 dial speed knob
 push FL CH switch push V/S switch dial V/S wheel
 push FL CH switch dial speed knob
 dial heading knob push heading knob
 dial heading knob push heading knob dial MCP altitude knob
 dial heading knob push heading knob push ALT HOLD switch
 dial heading knob push heading knob push speed knob dial speed knob
 dial heading knob push heading knob dial speed knob
 dial heading knob push heading knob push FL CH switch push V/S switch dial V/S wheel
 dial heading knob push heading knob push FL CH switch dial speed knob
 push LNAV switch
 push LNAV switch dial MCP altitude knob
 push LNAV switch push ALT HOLD switch
 push LNAV switch push speed knob dial speed knob
 push LNAV switch dial speed knob
 push LNAV switch push FL CH switch push V/S switch dial V/S wheel
 push LNAV switch push FL CH switch dial speed knob
 push V/S switch dial V/S wheel
 dial MCP altitude knob push ALT HOLD switch
 dial MCP altitude knob push speed knob dial speed knob
 dial MCP altitude knob dial speed knob
 dial MCP altitude knob push V/S switch dial V/S wheel
 push FL CH switch push ALT HOLD switch
 push FL CH switch push speed knob dial speed knob
 push speed knob
 push V/S switch dial V/S wheel dial speed knob
 push FL CH switch dial V/S wheel dial speed knob
 push FL CH switch push V/S switch
 dial heading knob push heading knob push V/S switch dial V/S wheel
 dial heading knob push heading knob dial MCP altitude knob push ALT HOLD switch
 dial heading knob push heading knob dial MCP altitude knob push speed knob dial speed knob
 dial heading knob push heading knob dial MCP altitude knob dial speed knob
 dial heading knob push heading knob dial MCP altitude knob push V/S switch dial V/S wheel
 dial heading knob push heading knob push FL CH switch push ALT HOLD switch
 dial heading knob push heading knob push FL CH switch push speed knob dial speed knob
 dial heading knob push heading knob push V/S switch dial V/S wheel dial speed knob
 dial heading knob push heading knob push FL CH switch dial V/S wheel dial speed knob
 dial heading knob push heading knob push FL CH switch push V/S switch
 push LNAV switch push V/S switch dial V/S wheel
 push LNAV switch dial MCP altitude knob push ALT HOLD switch
 push LNAV switch dial MCP altitude knob push speed knob dial speed knob
 push LNAV switch dial MCP altitude knob dial speed knob
 push LNAV switch dial MCP altitude knob push V/S switch dial V/S wheel
 push LNAV switch push FL CH switch push ALT HOLD switch
 push LNAV switch push FL CH switch push speed knob dial speed knob
 push LNAV switch push speed knob

dial heading knob push heading knob dial MCP altitude knob push V/S switch dial speed
 knob push ALT HOLD switch
 dial heading knob push heading knob dial MCP altitude knob dial V/S wheel push ALT
 HOLD switch
 dial heading knob push heading knob dial MCP altitude knob push V/S switch dial speed
 knob push speed knob dial speed knob
 dial heading knob push heading knob dial MCP altitude knob dial V/S wheel push speed
 knob
 dial heading knob push heading knob dial MCP altitude knob push V/S switch push speed
 knob
 dial heading knob push heading knob dial V/S wheel push ALT HOLD switch
 dial heading knob push heading knob push V/S switch push ALT HOLD switch
 dial heading knob push heading knob dial V/S wheel push speed knob
 dial heading knob push heading knob push V/S switch push speed knob
 push LNAV switch dial MCP altitude knob push V/S switch dial speed knob push ALT HOLD
 switch
 push LNAV switch dial MCP altitude knob dial V/S wheel push ALT HOLD switch
 push LNAV switch dial MCP altitude knob push V/S switch dial speed knob push speed
 knob dial speed knob
 push LNAV switch dial MCP altitude knob dial V/S wheel push speed knob
 push LNAV switch dial MCP altitude knob push V/S switch push speed knob
 push LNAV switch dial V/S wheel push ALT HOLD switch
 push LNAV switch push V/S switch push ALT HOLD switch
 push LNAV switch dial V/S wheel push speed knob
 push LNAV switch push V/S switch push speed knob
 =====> 8 single-element errors:

[no action]
 dial MCP altitude knob
 push ALT HOLD switch
 dial speed knob
 push LNAV switch
 push speed knob
 push V/S switch
 dial V/S wheel

----- TRUE CONTEXT -----

start-of-run
 above-runway-elev
 above-1000-feet-AGL
 at-armed
 fd-on
 programmed-route-within-limits
 above-clean-speed
 flight-surfaces-within-limits
 gear-within-limits
 comm-freq-within-limits
 track-okay-for-now
 mcp-alt-within-limits
 not-capturing-rqd-alt
 lnav-engd
 vnav-engd
 drag-within-limits
 speed-window-blank
 alt-far-from-target
 downpath-wpt-within-limits
 intcpt-leg-to-wpt-within-limits

----- TRUE PREDICTIONS -----

fly glass cockpit aircraft
 navigate with AP or FD guidance
 navigate laterally
 fly track
 fly using LNAV
 navigate vertically
 achieve/maintain altitude

fly using FL CH
engage FL CH
push FL CH switch

----- TRUE PREDICTIONS (ACTIONS ONLY) -----
push FL CH switch

```

===== Error data at time 54577.984 =====
Predicting erroneous activities...
----- Vis a Vis Predicted Subtasks/Actions -----
Present, but need not be:
1: track-okay-for-now
2: profile-okay-for-now
Not present, but could be:
1: lnav-engd
2: vnav-engd
  [ 15 erroneous context specifier combinations]
  Of 8 potentially erroneous predictions, 7 involve actions, and 1 do not

==> 8 possible errors (correct actions removed):
dial heading knob push heading knob
push LNAV switch dial speed knob
[ no action]
push LNAV switch dial speed knob set speed brakes
dial heading knob push heading knob dial speed knob
dial heading knob push heading knob dial speed knob set speed brakes
dial speed knob
dial speed knob set speed brakes
=====> 2 single-element errors:
[ no action]
dial speed knob

----- With All Subtasks/Actions In Play -----
Present, but need not be:
1: track-okay-for-now
2: profile-okay-for-now
3: mcp-alt-within-limits
Not present, but could be:
1: lnav-engd
2: vnav-engd
3: not-capturing-rqd-alt
4: fms-target-speed-within-limits
5: speed-window-blank
6: target-speed-within-limits
7: drag-within-limits
  [ 1023 erroneous context specifier combinations]
  Of 81 potentially erroneous predictions, 77 involve actions, and 4 do not

==> 56 possible errors (correct actions removed):
dial heading knob push heading knob
push LNAV switch dial speed knob
push LNAV switch dial MCP altitude knob
[ no action]
push LNAV switch dial speed knob set speed brakes
push LNAV switch push VNAV switch
dial heading knob push heading knob dial speed knob
dial heading knob push heading knob dial MCP altitude knob
dial heading knob push heading knob dial speed knob set speed brakes
dial heading knob push heading knob push VNAV switch
push LNAV switch dial MCP altitude knob dial speed knob
dial speed knob
dial MCP altitude knob
push LNAV switch dial MCP altitude knob dial speed knob set speed brakes
dial speed knob set speed brakes
push VNAV switch
push LNAV switch set speed brakes
push LNAV switch push speed knob dial speed knob set speed brakes
push LNAV switch dial speed knob
dial heading knob push heading knob dial MCP altitude knob dial speed knob
dial heading knob push heading knob dial MCP altitude knob dial speed knob set speed
brakes

```

```

dial heading knob push heading knob set speed brakes
dial heading knob push heading knob push speed knob dial speed knob set speed brakes
dial heading knob push heading knob dial speed knob
dial MCP altitude knob dial speed knob
dial MCP altitude knob dial speed knob set speed brakes
push LNAV switch dial MCP altitude knob set speed brakes
push LNAV switch dial MCP altitude knob push speed knob dial speed knob set speed
brakes
push LNAV switch dial MCP altitude knob dial speed knob
set speed brakes
push speed knob dial speed knob set speed brakes
dial speed knob
push LNAV switch push speed knob set speed brakes
push LNAV switch push speed knob dial speed knob
dial heading knob push heading knob dial MCP altitude knob set speed brakes
dial heading knob push heading knob dial MCP altitude knob push speed knob dial speed
knob set speed brakes
dial heading knob push heading knob dial MCP altitude knob dial speed knob
dial heading knob push heading knob push speed knob set speed brakes
dial heading knob push heading knob push speed knob dial speed knob
dial MCP altitude knob set speed brakes
dial MCP altitude knob push speed knob dial speed knob set speed brakes
dial MCP altitude knob dial speed knob
push LNAV switch dial MCP altitude knob push speed knob set speed brakes
push LNAV switch dial MCP altitude knob push speed knob dial speed knob
push speed knob set speed brakes
push speed knob dial speed knob
push LNAV switch push speed knob
dial heading knob push heading knob dial MCP altitude knob push speed knob set speed
brakes
dial heading knob push heading knob dial MCP altitude knob push speed knob dial speed
knob
dial heading knob push heading knob push speed knob
dial MCP altitude knob push speed knob set speed brakes
dial MCP altitude knob push speed knob dial speed knob
push LNAV switch dial MCP altitude knob push speed knob
push speed knob
dial heading knob push heading knob dial MCP altitude knob push speed knob
dial MCP altitude knob push speed knob
=====> 7 single-element errors:
[ no action]
dial speed knob
dial MCP altitude knob
push VNAV switch
set speed brakes
dial speed knob
push speed knob
----- TRUE CONTEXT -----
start-of-run
above-runway-elev
above-1000-feet-AGL
at-armed
fd-on
programmed-route-within-limits
above-clean-speed
flight-surfaces-within-limits
gear-within-limits
comm-freq-within-limits
track-okay-for-now
mcp-alt-within-limits
current-alt-within-limits
profile-okay-for-now
alt-hold-in-progress
alt-hold-engd

```


downpath-wpt-within-limits
intcpt-leg-to-wpt-within-limits

----- TRUE PREDICTIONS -----

fly glass cockpit aircraft
navigate with AP or FD guidance
navigate laterally
fly track
fly using LNAV
engage LNAV
push LNAV switch
navigate vertically
fly profile
fly using VNAV
engage VNAV

----- TRUE PREDICTIONS (ACTIONS ONLY) -----

push LNAV switch

```

===== Error data at time 54586.91 =====
Predicting erroneous activities...
----- Vis a Vis Predicted Subtasks/Actions -----
Present, but need not be:
1: track-okay-for-now
2: profile-okay-for-now
Not present, but could be:
1: lnav-engd
2: mcp-alt-within-limits
3: vnav-engd
    [ 31 erroneous context specifier combinations]
    Of 17 potentially erroneous predictions, 17 involve actions, and 0 do not

==> 17 possible errors (correct actions removed):
dial heading knob push heading knob dial MCP altitude knob
push LNAV switch dial MCP altitude knob push ALT HOLD switch
dial MCP altitude knob
push LNAV switch push VNAV switch
push LNAV switch dial MCP altitude knob dial speed knob set speed brakes
dial heading knob push heading knob dial MCP altitude knob push ALT HOLD switch
dial heading knob push heading knob push VNAV switch
dial heading knob push heading knob dial MCP altitude knob dial speed knob set speed
brakes
dial MCP altitude knob push ALT HOLD switch
push LNAV switch push ALT HOLD switch
push VNAV switch
dial MCP altitude knob dial speed knob set speed brakes
push LNAV switch dial speed knob set speed brakes
dial heading knob push heading knob push ALT HOLD switch
dial heading knob push heading knob dial speed knob set speed brakes
push ALT HOLD switch
dial speed knob set speed brakes
=====> 3 single-element errors:
dial MCP altitude knob
push VNAV switch
push ALT HOLD switch

----- With All Subtasks/Actions In Play -----
Present, but need not be:
1: track-okay-for-now
2: profile-okay-for-now
3: not-capturing-rqd-alt
Not present, but could be:
1: lnav-engd
2: mcp-alt-within-limits
3: vnav-engd
4: fms-target-speed-within-limits
5: speed-window-blank
6: target-speed-within-limits
7: drag-within-limits
    [ 1023 erroneous context specifier combinations]
    Of 75 potentially erroneous predictions, 72 involve actions, and 3 do not

==> 56 possible errors (correct actions removed):
dial heading knob push heading knob dial MCP altitude knob
push LNAV switch dial MCP altitude knob push ALT HOLD switch
dial MCP altitude knob
push LNAV switch push VNAV switch
push LNAV switch dial MCP altitude knob dial speed knob set speed brakes
dial heading knob push heading knob dial MCP altitude knob push ALT HOLD switch
dial heading knob push heading knob push VNAV switch
dial heading knob push heading knob dial MCP altitude knob dial speed knob set speed
brakes
dial MCP altitude knob push ALT HOLD switch

```

```

push LNAV switch push ALT HOLD switch
push LNAV switch
push VNAV switch
dial MCP altitude knob dial speed knob set speed brakes
push LNAV switch dial speed knob set speed brakes
push LNAV switch dial MCP altitude knob set speed brakes
push LNAV switch dial MCP altitude knob push speed knob dial speed knob set speed
brakes
push LNAV switch dial MCP altitude knob dial speed knob
dial heading knob push heading knob push ALT HOLD switch
dial heading knob push heading knob
dial heading knob push heading knob dial speed knob set speed brakes
dial heading knob push heading knob dial MCP altitude knob set speed brakes
dial heading knob push heading knob dial MCP altitude knob push speed knob dial speed
knob set speed brakes
dial heading knob push heading knob dial MCP altitude knob dial speed knob
push ALT HOLD switch
[ no action]
dial speed knob set speed brakes
dial MCP altitude knob set speed brakes
dial MCP altitude knob push speed knob dial speed knob set speed brakes
dial MCP altitude knob dial speed knob
push LNAV switch set speed brakes
push LNAV switch push speed knob dial speed knob set speed brakes
push LNAV switch dial speed knob
push LNAV switch dial MCP altitude knob push speed knob set speed brakes
push LNAV switch dial MCP altitude knob push speed knob dial speed knob
dial heading knob push heading knob set speed brakes
dial heading knob push heading knob push speed knob dial speed knob set speed brakes
dial heading knob push heading knob dial speed knob
dial heading knob push heading knob dial MCP altitude knob push speed knob set speed
brakes
dial heading knob push heading knob dial MCP altitude knob push speed knob dial speed
knob
set speed brakes
push speed knob dial speed knob set speed brakes
dial speed knob
dial MCP altitude knob push speed knob set speed brakes
dial MCP altitude knob push speed knob dial speed knob
push LNAV switch push speed knob set speed brakes
push LNAV switch push speed knob dial speed knob
push LNAV switch dial MCP altitude knob push speed knob
dial heading knob push heading knob push speed knob set speed brakes
dial heading knob push heading knob push speed knob dial speed knob
dial heading knob push heading knob dial MCP altitude knob push speed knob
push speed knob set speed brakes
push speed knob dial speed knob
dial MCP altitude knob push speed knob
push LNAV switch push speed knob
dial heading knob push heading knob push speed knob
push speed knob
=====> 8 single-element errors:
dial MCP altitude knob
push LNAV switch
push VNAV switch
push ALT HOLD switch
[ no action]
set speed brakes
dial speed knob
push speed knob
----- TRUE CONTEXT -----
start-of-run
above-runway-elev
above-1000-feet-AGL

```

at-armed
fd-on
programmed-route-within-limits
above-clean-speed
flight-surfaces-within-limits
gear-within-limits
comm-freq-within-limits
track-okay-for-now
not-capturing-rqd-alt
current-alt-within-limits
profile-okay-for-now
downpath-wpt-within-limits
intcpt-leg-to-wpt-within-limits

----- TRUE PREDICTIONS -----

fly glass cockpit aircraft
navigate with AP or FD guidance
navigate laterally
fly track
fly using LNAV
engage LNAV
push LNAV switch
navigate vertically
set target altitude
dial MCP altitude knob
fly profile
fly using VNAV
engage VNAV

----- TRUE PREDICTIONS (ACTIONS ONLY) -----

push LNAV switch
dial MCP altitude knob

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13. ABSTRACT (Maximum 200 words) This research presents a methodology for generating errors from a model of nominally preferred correct operator activities, given a particular operational context, and maintaining an explicit link to the erroneous contextual information to support analyses. It uses the Crew Activity Tracking System (CATS) model as the basis for error generation. This report describes how the process works, and how it may be useful for supporting agent-based system safety analyses. The report presents results obtained by applying the error-generation process and discusses implementation issues. The research is supported by the System-Wide Accident Prevention Element of the NASA Aviation Safety Program.				
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