ARTIFICIAL INTELLIGENCE AND HUMAN ERROR PREVENTION: 
A COMPUTER AIDED DECISION MAKING APPROACH

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1. INTRODUCTION

Research continued on the conceptual design of an onboard computer software system for enhancing the safety of commercial airline flights. Work was performed in four areas.

The first area was that of flight crew member interviews. A brief trip was made to Purdue University to observe crew members being trained on a simulator for a 707. The purpose of this trip was to prepare us for the visit to the United Airlines Training Center in Denver. The results of our observations and discussions with crew members at Denver were again encouraging. It was pointed out to us that automatic procedure monitoring, and automatic checklisting would be of help during abnormal flight conditions. In addition, it was pointed out that automatic procedure monitoring would be useful during normal flight conditions, particularly during the adjustment period after changes in operational procedures have been made by airline policymakers.

The second area was that of instrument verification. The Instrument Verification System was augmented to allow the utilization of second order effects to verify instruments which measure rates of change of various parameters. As a result, the rate of fuel consumption can be verified against the fuel flow instruments and the rate of change of altitude can be verified against the rate of climb instrument.

The third area was that of script based monitoring. A set of scripts was implemented to describe a complete flight. The Script Based Monitor then follows through the scripts and monitors the progress of the aircraft. When deviations from the script are detected, it informs the pilot. Several other
scripts were implemented to describe alternate procedures for recovering from single engine failures before and after VI.

The fourth area was that of the aircraft simulator. Several new features were added to improve the interface with the experimenter. Several pre-programmed scenarios were created to allow the instrument verification and monitoring capabilities to be demonstrated.

On July 13, 1978 the status of this project was demonstrated to members of the FAA and the DOT in Washington, D. C.
2. VISIT TO UNITED AIRLINES FLIGHT TRAINING CENTER

During this quarter, two field trips were made to better acquaint the project personnel with actual airline cockpit procedures. The first was a half day visit to the Boeing 707 flight simulation facility at Purdue University in preparation for the second trip, to United Airlines Flight Training Center in Denver. The Purdue trip, made in a University of Illinois Piper Lance, flown by the two pilot-advisors for the project, also illustrated the operation of a typical light airplane in IFR operations.

A visit was made to the United Airlines Flight Training Center in Denver on July 5, 1978. The day began with a briefing with Captain Dale Cavanagh, head of their flight training operations. Dr. Chien gave a brief overview of our project and all discussed some of its concepts and goals. Capt. Cavanagh then explained their program and what we would be observing for the day. He explained that all United flight crew members begin their training at the facility there in Denver. They start with self paced audio-visual courses covering the fundamentals such as aerodynamics, powerplants, and meteorology. As each lesson is completed, a test is taken before continuing. These tests are administered and graded via terminals connected to the PLATO computer system. The next training phase pertains to the particular aircraft to be flown and would be also used whenever a crew member changes seats or airplanes. It consists of morning classroom sessions on the particular aircraft's procedures and systems, with afternoons spent in the cockpit procedure trainer. The classroom lectures are also based on audio-visual presentations, but an instructor is present to guide and answer questions. The material is also available in a library for additional out of class study. The CPT (Cockpit Procedure Trainer) is a mockup of the actual airplane, and
although it does not simulate flight, the switches and indicators function like the actual systems. Thus afternoons are spent drilling on checklists and procedures, both normal and emergency.

After about two weeks of this phase, the crew begins work in a fully equipped simulator. The simulators have a complete functioning cockpit, an instructor's console, a limited motion system, and a visual display. The display consists of either a set of computer generated lights representing a night landing or a video image from a camera which follows a terrain map. Certain of the simulators are so realistic that the FAA has certified them for landing experience. This phase provides approximately 12 to 14 hours of hands on experience plus an equal amount of time acting in other flight crew capacities, and covers all phases of flight. Then only the captains receive a two hour flight in a real airplane before all are FAA checked during an actual flight.

Once a year thereafter, all flight crew members participate in a half day proficiency check as required by FAA Part 121. These are held in the flight simulators and cover a set of required procedures under the supervision of a check pilot. Six months later, and on a yearly basis, the crew members are scheduled for proficiency training. This session is less structured than the above checks with emphasis on emergencies and unusual situations that may be encountered. Since actual emergencies and equipment failures are so rare in actual flight, this training is often the crew's only real chance to exercise the special procedures originally taught during earlier training. It also gives the instructors an opportunity to demonstrate conditions which have led to true inflight emergencies, thus hopefully avoiding future repeated incidents.
Our group was split into three pairs due to space limitations within the simulators. One pair first toured the facility visiting the audio-visual and training classrooms, the libraries, the CPTs, the terrain map used in some of the displays, and inspected the various simulators including those of the 727, the DC8, and the larger DC10 and 747.

After lunch we were introduced to Capt. Lloyd Tomak and check pilot Walt Bally, and observed about two hours of their proficiency training. It included normal takeoff and landings, stalls, steep turns, and many simulated malfunctions. Some of these were a total hydraulic system failure necessitating a no flaps, no brakes landing, and many lesser subsystem failures such as circuit breakers popping and faulty indicators. In one case, the flap indicator showed that the inboard flaps had not deployed, and a partial hydraulic system failure was assumed. After following the recommended procedure for backup extension, the inboard flaps still indicated up. Since the backup procedure was unsuccessful, the crew resumed the flight according to procedures for limited flap operations. The instructor intervened to ask whether the flaps had indeed not extended, or whether the indicator had failed. When the crew did not know, he pointed out that the slats indicated proper extension and were on the same system as the inboard flaps. Thus the flaps had extended properly and it was the indicator that had failed, and no special flap operation was necessary. This demonstrated a case where an intelligent instrument verification system such as proposed by SECURE would have identified the problem readily and eliminated the improper conclusion.

The second pair first observed a morning proficiency check in a 727 simulator with Capt. Jim Morrison conducted by check pilot Jim Shaffer. The flight began as a low visibility daytime flight from Chicago to Denver, then
was interrupted to practice stalls. While following further clearances, emergencies such as a generator failure and an engine flameout were simulated. Other situations practiced were low visibility approaches, missed approaches, unexpected autopilot shutoff, and an engine failure at rotation. The procedures for solving these problems are found in the manual in the form of a flowchart. Particularly for multiple failures, the chart becomes difficult to follow and incomplete when most crucial. Most accidents happen from a chain of events, where an intelligent computer aiding the pilot could provide better and more timely nonstandard procedure checklists and help sort out multiple failures. During the afternoon, a proficiency training session was observed which simulated a flameout, smoke in the cockpit, decompression, a flap malfunction, and other lesser difficulties.

The third pair observed a DC8 morning session with Capt. Bob Dooley and check pilot Donald King. This flight also began routinely with a normal takeoff after all checklists were satisfied. This crew then practiced entering a stall situation, observing the stick-shaker, and recovering properly. They continued with a number of instrument approaches to minimums followed by a missed approach. Typical emergencies encountered were an engine fire, an engine flameout, and an electrical bus failure causing a temporary blackout. These were usually handled by the first and second officers while the captain continued to fly. Our observers again noticed the difficulties in using the emergency checklists, particularly in finding the appropriate one for a multiple failure. This afternoon session was similar to the others with many simulated failures including a decompression and a double engine failure.
About mid-afternoon, the group reassembled for a discussion with Capt. Cavanagh, Capt. Shaffer, Brian Drissel (Program Development Manager), and others. One of the topics was the problems associated with cockpit warning devices. A number of different visual, aural, and tactile warnings can occur and may be caused by different malfunctions depending on the flight regime. Due to the complexity of the warning signals, some confusion usually occurs and in fact, the credibility of the signal is sometimes questioned. Furthermore, the time and degree of warning needs more evaluation, because whenever a loud continuous horn sounded, all three crew member's top priority seemed to be to disable the noise.

Other projects within the industry aimed at helping in the cockpit were then mentioned. These included (with reference):

1. A failure display system developed for BOAC; Capt. John Wilson (British Aerospace Corp.)

2. An automatic emergency checklist system developed by Garrett Air Research, found to be a luxury which could not be economically justified; George Jansen (Douglass Aircraft).

3. Lockheed C5 currently has 3 CRTs showing status of 800 systems. Also, a recent study by Boeing showing that a more sophisticated electronic pilot aid system was not cost effective.

The time spent observing was most interesting and pertinent to our work, and resulted in a better understanding of the cockpit environment during encountered difficulties and in a better understanding of the types of failures and warnings that exist. The particular excess and overlap of warnings in present use, and the problems in sorting out failures, demonstrated further the need for an intelligent cockpit monitoring system. In addition, any future cockpit aids will have to be cost effective while showing a significant increase in the safety and reliability of the aircraft.
3. THE INSTRUMENT VERIFICATION SYSTEM

During this quarter, work continued on the conceptual design of the Instrument Verification System (IVS). Techniques were developed to implement second order effects to be used to establish the consistency between various instruments. Specifically, the IVS was augmented to allow the comparison of fuel flow rates with the rate of change of the fuel level, and to allow the comparison of the rate of climb with the rate of change of altitude. In implementing these verification schemes, several factors had to be considered in determining the time interval for sampling the instruments involved.

First, to compute the derivative of certain parameters numerically, the IVS needs data at two different instances in time. If the two instances are close enough, the variations of the observed parameter can be assumed linear so that ideally the computation of the rate of change of that parameter closely approximates the time derivative of that parameter at the midpoint of the interval. However, the accuracy of the computation of the derivative of a parameter is dependent on the accuracy of the instrument measurement of that parameter and on the roundoff error in both subtraction and division of the computer. Furthermore, in determining the consistency between related instruments, since the results of computations on the outputs of two or more instruments must be compared, it is important that the tolerance ranges be kept small relative to the values computed in order to make reliable comparisons. This means that if the measurement interval is too short, grossly erroneous results may occur in the computed derivative.
Secondly, abrupt changes in the computed parameter must be dealt with. It is important that the IVS establish the consistency of the instruments as quickly as possible in these circumstances. These abrupt changes can arise from several sources. For instance, the aircraft could be changing state, as when it changes pitch to begin a rapid climb or descent. A system or an instrument could have failed. Or a momentary aberration could have occurred such as a power surge. Such an aberration should not affect the determination of consistency among the instruments, however, repeated occurrences of such transients may indicate the imminent failure of a system or the existence of a "flaky" instrument.

When the aircraft changes state, the rapid change of a measured parameter may yield a derivative value which is temporarily inconsistent with the instrument being verified. In this case the decision of whether the instrument is consistent with the rate of change of the second instrument should be deferred until either the transient has dissipated or it is apparent that there is a permanent inconsistency.

From these considerations it is apparent that, on the one hand, the IVS should have a longer observation interval to improve the sensitivity and the accuracy of the differentiation result. On the other hand, the IVS should have a shorter observation period to shorten the response time and the transient period. Tradeoffs among these factors should result in a proper observation interval for a given parameter.

In the implementation of these features into the IVS, two key concepts, the Event Queue and the Virtual Instrument, are introduced. The Event Queue implements the use of past status of parameters. It keeps a record of all the events, together with their context, to be initiated in the future. These
events are ordered by their maturation time as they enter the queue. Such mechanisms have been used in controlling the repeating rate of the consistency check processes so that the computing resources can be properly distributed to various monitoring tasks.

To compute the time derivative of a given parameter by this mechanism, a pre-differentiation process, when activated, creates a post-differentiation process and places it into the Event Queue to be initiated after a proper observation interval. The pre-differentiation process passes to the post-differentiation process the current values of the parameter and the current time. The post-differentiation process, when initiated, will compute the rate-of-change of the parameter during the observation interval. This is shown in Figure 1 where a pre-differentiation process is initiated every $t_s$ seconds and the derivative is computed $t_0$ seconds later.

The communication between the differentiation processes and the consistency check processes, is accomplished by an asynchronous scheme by concept called the Virtual Instrument. At the first request to use the differentiation information of a given parameter, the IVS will automatically create a "soft" instrument with an unique name. The supporting mechanism for this virtual instrument is the differentiation process, repeating itself indefinitely, and updating the reading of the virtual instrument constantly. In this manner, the differentiation process is isolated from the application processes so that the IVS does not have the burden of synchronizing the differentiating processes and their application processes. As shown in Figure 1 the IVS requests a consistency check every $t_c$ seconds and needs only to compare the results of the Virtual Instrument with that of the instrument in question.
The control structure for the IVS is shown in Figure 2. As part of the initialization process of the SECURE system the communication link to the simulator is initialized and the event queue is zeroed. Then in an infinite loop the instruments are first read from the simulator data base and the events are executed one at a time and then removed. Included in the events to be executed are commands to verify each of the instruments.
Figure 1. Control Sequence for the IVS.
4. THE SCRIPT BASED MONITOR

During this quarter, the first operational version of the script-based monitor was completed. The script-based monitor has a library of twenty-four scripts that cover a complete flight from the preflight calculations to the landing roll. Twenty of these scripts describe a complete flight, one script describes recovery procedures for single engine failures occurring before the critical takeoff speed, $V_{t}$, and three scripts describe recovery procedures for single engine failures after $V_{t}$.

The script-based monitor was designed to operate on a hypothetical commercial three-engine jet aircraft. The aircraft is simulated by a computer program that provides realistic aerodynamic, engine system, and navigational models of the aircraft. The flight procedure we chose is that recommended by McDonald Douglass and United Airlines for the DC-10. Hence, the aircraft simulator is tuned to the performance of a typical DC-10. This simulator generally performs close to the DC-10, but the few performance differences necessarily force different flight procedures.

4.1. The Aircraft Flight Profile

The scripts presently do not describe the horizontal motion of the aircraft. The aircraft motion is presumed to be locked in a vertical plane between the origin and destination runways. Thus the script-based monitor is aware of the correct vertical flight profile only. The script-based monitor is presently able to track the changing contexts, and with the normal condition specification of the present script, it is able to detect and to notify the pilot of abnormal states of airspeed, rate of climb, altitude, gear
deployments, control surface deployments, throttle settings, and so forth.

The vertical flight profile coded into the script is diagrammed in Figure 3. The normal flight profile starts at the beginning of the runway with the flaps and slats properly deployed and the engines partially spooled up. Upon receiving the clearance for takeoff, the throttles are pushed to 100%. When the rotational speed, VR, is obtained, the aircraft is pitched up to climb at a speed of ten knots above the climb speed, $V_2+10$ knots. The gears are retracted on confirmation of positive rate of climb. At 1,000 ft, the aircraft is pitched down slightly to climb at roughly 1,500 ft/min. The flaps and slats are retracted at their respective retraction speed of $V_2+\text{flap}$ and $V_2+45$ knots. At 1,500 ft, the throttles are reduced to climb power, and the aircraft is pitched to climb at roughly 1,000 ft/min. At 10,000 ft, the throttles are further reduced and the plane is pitched to climb at a rate of 500 ft/min and to accelerate to 300 kias. The altimeter is set to 29.92 when 18,000 ft is reached. When the cruising altitude of 31,000 ft is reached, the throttles are pulled back to cruise power, and the aircraft accelerates to 340 kias.

![Figure 3a. Normal flight profile.](image-url)
Figure 3b. Normal flight profile (cont.).

Figure 3c. Normal flight profile (cont.).
Figure 3d. Normal flight profile (cont.).

Figure 3e. Normal flight profile (cont.).
When approaching the destination, the throttles are pulled back, and the aircraft is pitched such that the aircraft descends at roughly 1,500 ft/min and 340 kias. Passing through 18,000 ft, the altimeter is reset to the local setting. At 10,000 ft, the aircraft is decelerated to 250 kias. At 5,000 ft, the aircraft is further decelerated to 200 kias. Preliminary flap and slat deployment may take place at this point. At 3,000 ft, the aircraft will hold the altitude until capturing the glide slope. After capturing the glide slope, the flaps and slats are advanced to 50%, and the airspeed is further decreased to 170 kt. The gears are lowered, and the flaps and slats are advanced to 100%. The throttles are pushed forward until the final approach speed of 160 kt is stabilized. At 50 ft, the throttles are pulled back and the flare initiated. Upon contact with the runway, the spoilers are activated, the brakes are applied, and the reversers are engaged. When the airspeed has decreased to 60 kt, the reversers are disengaged.

Figure 4. Engine failure after $V_1$ flight profile.
The single engine failure before VI script is essentially the landing roll of the normal flight scripts. The single engine failure after VI flight profile is shown in Figure 4. If the engine fails before attaining 1,000 ft, the throttle of the failed engine is pulled back to idle, the aircraft is pitched to climb at V2, and the gears are raised on positive rate of climb. At 1,000 ft, the aircraft is pitched level, and the flaps and slats are retracted at their normal retraction speeds. When both the flaps and slats are retracted, the throttles for the two good engines are set to climb power, and the aircraft climbs to 3,000 ft at 210 kt. Should the engine fail after attaining 1,000 ft, the throttle of the failed engine is pulled back to idle, the aircraft is pitched level, the flaps and slats are retracted on normal schedule, and the aircraft is on climb power and climbs to 3,000 ft at 210 kt.

4.2. Implementation of the Flight Scripts

The monitor is presently able to perform the preflight calculation of determining VI, VR, V2, takeoff power setting, and climb power setting. An associative relational data base of the relevant tables in the United Airline DC-10 Flight Procedure Manual is implemented. The monitor is told of the relevant parameters such as the aircraft weight, runway elevation, and runway temperature. Pattern matching techniques are then used to retrieve the critical takeoff parameters, and these parameters are then loaded into the scripts.

The script body defined in the last quarter has been divided into several segments in consideration of efficiency. In the following definitions, parentheses and capitalized symbols are terminal symbols. The script's main body is defined as follows:
In addition to their main bodies, each script has a threshold value, a list of entry procedures, and a list of exit procedures. The threshold value is used to eliminate undesirable transient errors. The entry procedures are executed upon entry into the script in order to set up the proper environment. The exit procedures are executed on leaving of the script in order to clean up the residual effect of this script on the system. The entry and exit procedures of each script can modify the script body, or add and delete procedures from the "joblist."

The joblist is a list of jobs. Each job is a procedure associated with a predicate and an identification tag. When the joblist is evaluated, a procedure is executed if its associated predicate is true. After the execution of the job's procedure, the job is automatically deleted. The identification tag for each job facilitates the identification and deletion of the job from the joblist.
The joblist is formally defined below:

```
JOBLIST ::= ( <job>* )
<job> ::= ( <job id> <job predicate> <job procedure> )
<job id> ::= ( JOB-NAME SCRIPT-NAME )
<job predicate> ::= <predicate>
  ::= ( OR <job predicate>+ )
  ::= ( AND <job predicate>+ )
<job procedure> ::= a LISP procedure.
```

Each execution cycle consists of a test for script transition, a check for the present script's normal states, and an evaluation of the joblist. On script transition, the old script's exit procedures and the new script's entry procedures are executed. The entry procedures, exit procedures, and jobs are all capable of modifying scripts and the joblist.
5. THE AIRCRAFT SIMULATOR

During this quarter, improvements were made to the three-engined jet aircraft simulation program. The main function of the simulator thus far is to maintain the aircraft's position, speed and attitude via a simple aerodynamic model and to simulate the various engine parameters. The aircraft systems which are currently being simulated are summarized below:

1. Flight
   
   controls - aileron, elevator, flaps, speed brake
   attitude - pitch, bank
   speed - air speed, rate of climb
   altitude - radio altimeter, barometric altimeter

2. Navigation
   
   inertial nav. - latitude, longitude, heading
   radio nav. - VOR, DME, ADF

3. Engine
   
   thrust
   fuel - fuel flow, fuel quantity
   engine instruments - EPR, EGT, N1, N2
   engine starters

4. Miscellaneous
   
   landing gear
   wheel brakes
   thrust reversers
   time
Faults are introduced into the simulator by breaking the update path to certain variables in the simulator. These variables will remain at their current value unless changed by the action of the experimenter. For example, a flameout of the number one engine is introduced by failing the variable VTHRUST1 and then setting VTHRUST1 to zero. Similarly, the failure of the barometric altimeter would be accomplished by failing the sensor variable SBARALT and then setting SBARALT to an erroneous value.

Two ADF systems have been added to the navigation systems. The aerodynamic model has been modified and wheel brakes have been added so that the simulator may reasonably portray the aircraft on the ground.

The engine parameters, EGT, EPR, N1 and N2 are now being simulated. These parameters are computed as linear functions of the throttle setting. In addition a time constant is introduced to simulate the delay as the engines spool up and down.

A new display has been added to the simulator. The simulator displays on a Vistar-II compatible terminal all the aircraft sensors currently being simulated. The sensors are clearly labeled and blocked out into five major groups: controls, flight instruments, navigation instruments, engine instruments and miscellaneous sensors.

Work has been completed on the interface between the simulator and the rest of the SECURE system programs. The sensor values maintained by the simulator are available in a sensor vector which may be passed to other programs via the IPCF facility of the PDP-10 operating system. To read the sensors, a program sends the simulator a message requesting all or part of the sensor vector. The simulator then composes a reply containing the requested
Three new commands have been added to the simulator which significantly improve the simulator's interface with the experimenter. The commands allow the use of command files to step the simulator through pre-programmed flight scenarios. The abort command allows the experimenter to abort a command file before its normal termination. The type command allows the experimenter to imbed comments into command files. These comments are displayed when the file is executed and aid the experimenter in following the scenario. The wait command allows the experimenter to control the processing of his command file based on various conditions within the simulator.
6. FUTURE PLANS

During the final quarter of this contracting period, the major emphasis will be on the conceptual design of a system which is capable of generating plans for diagnosing faults, for producing procedures to correct various faults and for producing alternate scripts which allow degraded modes of operation and general changes in the original script of the flight. In addition, this design will include the capability of generating plans for correcting trends leading to imminent failures or other types of difficulties.

The system will be designed to operate in a problem solving environment and will be heavily dependent on the knowledge base. The knowledge base will contain information about each of the aircraft systems and will be structured to reflect both the qualitative and the quantitative functioning of these systems.

Some of the questions we shall be concerned with are:

1. How can a hierarchical structure be imposed on the knowledge base in order to allow the system to "reason" about consequences of states of the aircraft and changes in the state of the aircraft?

2. Are there ways to distinguish between pilot "blunders" and malfunctions of aircraft systems?

3. What kind of problem solving environment best reflects the situations likely to occur on commercial aircraft and will allow effective planning of recovery procedures?
QUARTERLY EXPENDITURE

The total expenditure during the period May 3, 1978 to August 3, 1978 was $32,170.

The $18,810 of remaining contract funds will be expended during the fourth quarter.