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RESEARCH ON COMPUTER AIDED TESTING OF PILOT RESPONSE TO CRITICAL IN-FLIGHT EVENTS

Walter C. Giffin, Thomas H. Rockwell and Philip J. Smith
Department of Industrial and Systems Engineering

For the Period
January 1, 1983 - March 31, 1984

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Ames Research Center
Moffett Field, California 94035

Grant No. NAG 2-112

June 1, 1984

OSU
The Ohio State University
Research Foundation
1314 Kinnear Road
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The NASA Technical Officer for this Grant is:

Dr. John A. Lauber
Man-Vehicle Systems Research Division
NASA Ames Research Center
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Abstract

This report describes final experiments on pilot decision making concluding the work performed under a series of NASA-Ames grants (NAS 2-10047, NAG 2-75, NAG 2-112). The focus in this report is on the development of models of pilot decision making in critical in-flight events (CIFE). Analyses reported here include development of: 1) a frame system representation describing how pilots use their knowledge in a fault diagnosis task (developed from an analysis of verbal protocols from an experiment involving twenty instrument rated pilots); 2) assessment of script norms, distance measures, and Markov models developed from computer aided testing (CAT) data involving forty instrument rated pilots; and 3) performance ranking of subject data by a group of six recognized expert pilots.

This research has demonstrated that interactive computer aided testing either by touch CRT's or personal computers is a useful research and training device for measuring pilot information management in diagnosing system failures in simulated flight situations. Performance is dictated not so much by flight hours, ratings and experience with in-flight problems as it is by knowledge of aircraft subsystems, initial pilot structuring of the failure symptoms and efficient testing of plausible causal hypotheses.

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I. Background

A critical in-flight event (CIFE) is a situation that either develops quickly or over time. It is unexpected, unplanned, and unanticipated, and is perceived by the pilot in command to threaten the safety of the aircraft. In the CIFEs studied here, safety of the aircraft depends more on the pilot's cognitive processes than on skilled motor performance. This report covers the last of three studies directed to CIFE research.

The objectives of the initial project effort were to:

1) Describe and define the scope of the critical in-flight event with emphasis on pilot management of available resources.
2) Develop detailed scenarios for both full mission simulation and paper and pencil (P/P) testing of pilot response to CIFE's.
3) Develop statistical relationships among pilot characteristics and observed responses to CIFE's.

A subsequent grant focused on the use of computer aided techniques to study pilot responses to CIFE's. Using touch CRT's, scenarios developed from earlier paper and pencil tests were adapted to computer testing using a PLATO®[1] system. This permitted an efficient, virtually experimenter-free study of pilot diagnosis and destination diversion decisions.

The rationale behind the research has remained the same through the initial contract and subsequent grant, namely, to understand how pilots:

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[1] PLATO® is a Control Data Corporation system involving interactive computer operations with touch response.

a) detect CIFE's

b) obtain information on which to base diagnosis

c) make decisions about destination diversions and

d) execute these decisions.

A. Previous Results[1]

Figure 1-1 depicts the overall project accomplishments. The initial contract produced:

1) a test for pilot knowledge of aircraft systems and instrument procedures
2) a series of CIFE scenarios for General Aviation Trainer (GAT) simulation
3) the execution of GAT CIFE experiments
4) the development of paper/pencil CIFE tests
5) the development of paper/pencil destination diversion tests
6) performance measurements of forty instrument rated pilots on the above tests.

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1 For more details on research findings, see "An Investigation Into Pilot and System Response to Critical In-Flight Events," Final Report, NASA, NAG2-10047 and NAG2-75, June, 1981.

Figure 1-1

CIFE RESEARCH MILESTONES

1) Development of Knowledge Tests of Aircraft Subsystems
2) Development of CIFE Scenarios for GAT Simulation
3) Subject Testing with GAT Simulations
4) Development of Paper and Pencil CIFE Scenarios
5) Development of Paper/Pencil Destination Diversion Tests
6) Testing of Forty Subjects in Paper/Pencil Scenarios
7) Adaptation of Paper/Pencil Tests to Interactive Computer-Aided Testing, Including Knowledge, Diagnostic, and Destination Division Tests
8) Testing of Forty Subjects in Computer-Aided Testing Format
9) Within Session Learning Studies
10) Combining Destination Diversion with CIFE Diagnosis in Computer-Aided Testing
11) Descriptive Modeling of Test Results

The highlights of the GAT experiments were:

1) Cockpit managmement style varies widely among pilots, for example, some are extremely self-reliant, others want immediate and extensive help from ATC, while still others make the decision making process a joint effort with ATC.

2) Good stick and rudder pilots seem to have excess capability and maintain good stick and rudder performance before, during and after the CIFE. More marginal stick and rudder pilots, on the other hand, show increased frequency and amplitude of heading and altitude excursions, and experience communication difficulties in the face of a CIFE.

3) Pilots who score well on the knowledge test instruments tend to perform well in problem diagnosis and decision making.

The paper and pencil test results were analyzed with respect to knowledge and biographical data. The findings were:

1) Knowledge is inversely related to total diagnostic inquiries, e.g., knowledgeable pilots reach conclusions (right or wrong) more rapidly than others.

2) Total diagnostic inquiries is inversely related to correctness. This implies that undirected experimentation is a poor diagnosis style.

3) Diagnosis performance is correlated with knowledge scores.

4) Knowledge score is correlated with pilot ratings held.

5) Civil trained pilots place a higher worth on ATC service in diversion decisions than do military pilots.

6) Private pilots place a higher worth on weather factors in diversion decisions than do commercial and ATP rated pilots.

7) ATP rated pilots place high worth on time in diversion decisions.

In general the pilots with good diagnostic performance were characterized as knowledgeable about aircraft systems, employed few logic tracks to get at an answer, used few inquiries per track, and emphasized time in their destination diversion decision. They were not differentiated by flight hours, ratings, training, or type of flying.

B. Results from the Second Study[1]

In order to avoid experimenter bias and to increase the efficiency of CIFE testing, considerable effort was devoted in the second study to the adaptation of paper and pencil scenarios to computer aided testing using PLATO®. Appendix A includes sample displays presented to the subject in the course of testing. The router provides the display mechanism to select the major program modules, namely:

1) biographical data
2) knowledge tests
3) practice with VORs and Autopilot (to be discussed below)
4) six CIFE scenarios
5) the destination diversion scenario
6) the airport ranking exercise
7) a combination CIFE diagnosis and destination diversion scenario

The unique advantages of the PLATO® system include:

1) little experimenter interaction required, hence minimal experimenter effects on subject performance
2) use of touch response to eliminate the need for keyboard activation - a special lexicon was developed to assist subjects in specifying their diagnoses

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1 For more details of research findings see "Use of Computer-Aided Testing In the Investigation of Pilot Response to Critical In-Flight Events, Final Report, NASA, NAG2-112, December 30, 1982.

3) precise records for timing of inquiries and intervals between inquiries

4) the ability to introduce dynamics such as altitude loss during a scenario involving power loss

5) documentation - ability to call up any subject data and to add new test data for subjects previously tested

6) the ability to test subjects at one of the many CDC PLATO® testing centers around the country with such data made available in Columbus for analysis

Forty subjects have been tested to date using the PLATO® approach. A list of the scenarios and appropriate diagnoses is shown in Appendix B. Typical subject data are shown in Appendix C. Some subjects were used for special purposes. These included:

1) protocol analysis - having the subjects think aloud during their information search

2) scenario order changes to establish learning within test sessions

3) limiting the number of subject information inquiries while relaxing the four minute time constraint

4) having subjects write out candidate hypotheses as their diagnostic search progressed

While the original thrust of the research involved instrument rated pilots, in this PLATO® testing phase a small sample of high and low time non-instrument rated pilots were tested as well. This was done to estimate pilot rating effect on diagnostic strategies.

C. Descriptive Modeling for Diagnosis of CIFE's

Figures 1-3 and 1-4 depict a way to view subject information seeking patterns during diagnosis testing. Sources within logic tracks are identified for each scenario. The pilot information plots (PIP's) are a quick way to visualize:

a) the number of logic tracks employed

b) the order of inquiries within and between tracks

c) the time between inquiries

d) the number of track returns and the information resampled

Using these PIP's various management information seeking strategies can be observed. For the suction failure problem as shown in Figure 1-2, Figure 1-3 depicts a subject with a logical and efficient approach to diagnosis. Figure 1-4 depicts an almost random inquiry.

Preliminary findings for the diagnosis portion of the PLATO® test include:

1) Subjects are easily motivated using PLATO® testing.

2) Learning within scenario test sessions takes place in terms of reduced amount of time between inquiries. The number of repeat samples on tracks and the number of tracks sampled are scenario dependent.

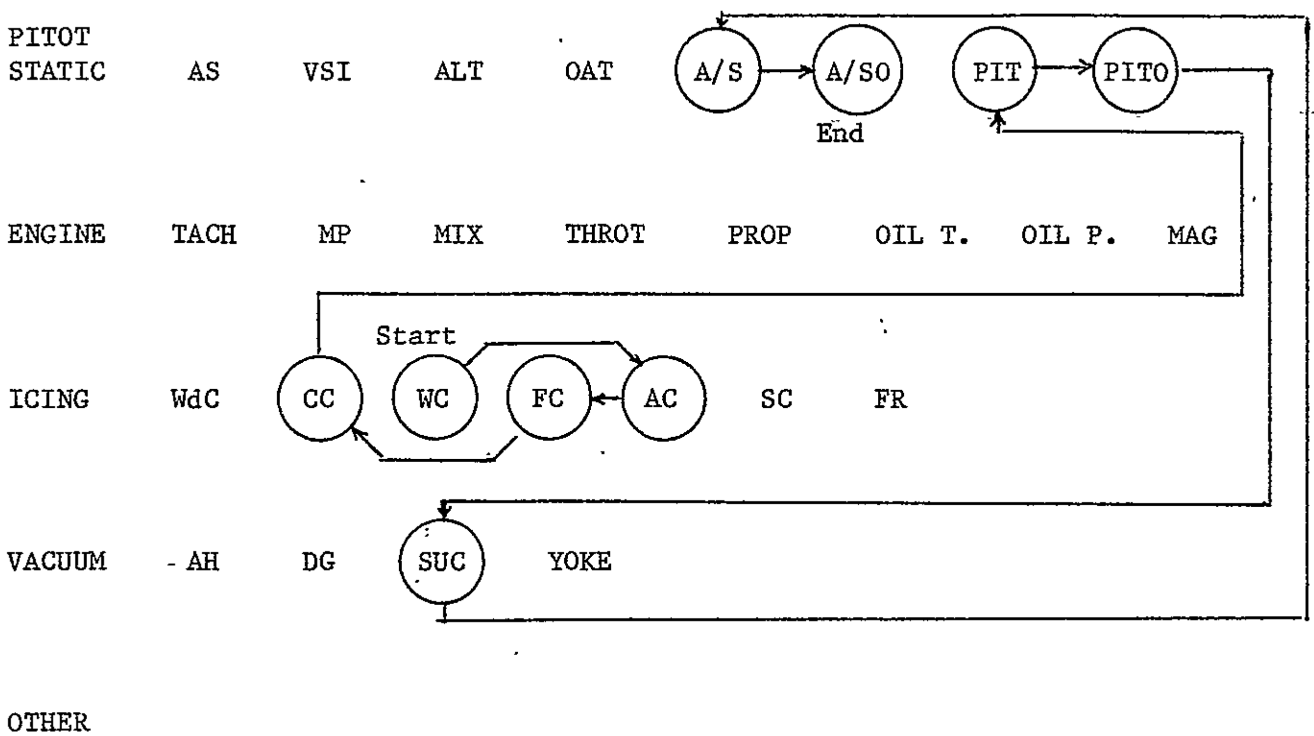
SCENARIO

You are making a day trip from Augusta, ME to Lebanon, NH. You fly out of Augusta at 9:00 a.m., cleared Victor 39 to Neets intersection, Victor 496 to Lebanon. You climb to a cruising altitude of 6000 ft. After 15 minutes of routine IMC flying in instrument conditions, your instruments indicate an increase in airspeed and steadily decreasing altitude while maintaining level flight attitude. How would you identify your problem?

Our Diagnosis of the Problem Was the Following:

Your vacuum pump failed as indicated by the low reading of the suction gauge. The vacuum pump drives the attitude and directional gyros. As the artificial horizon lost its drive it started to sag to the right and you compensated by turning left, leveling the artificial horizon and putting the plane in a slow, descending left bank. The airspeed increase was due to the slight nose-down attitude.

Figure 1-2. Suction Failure Problem and Diagnosis



RESPONSE: Gyro Broken

CONFIDENCE IN RESPONSE: 7

CRITICALITY: 5

TOTAL FLIGHT TIME: 100-300 Hrs.

TOTAL DIAGNOSIS TIME: 78 Sec.

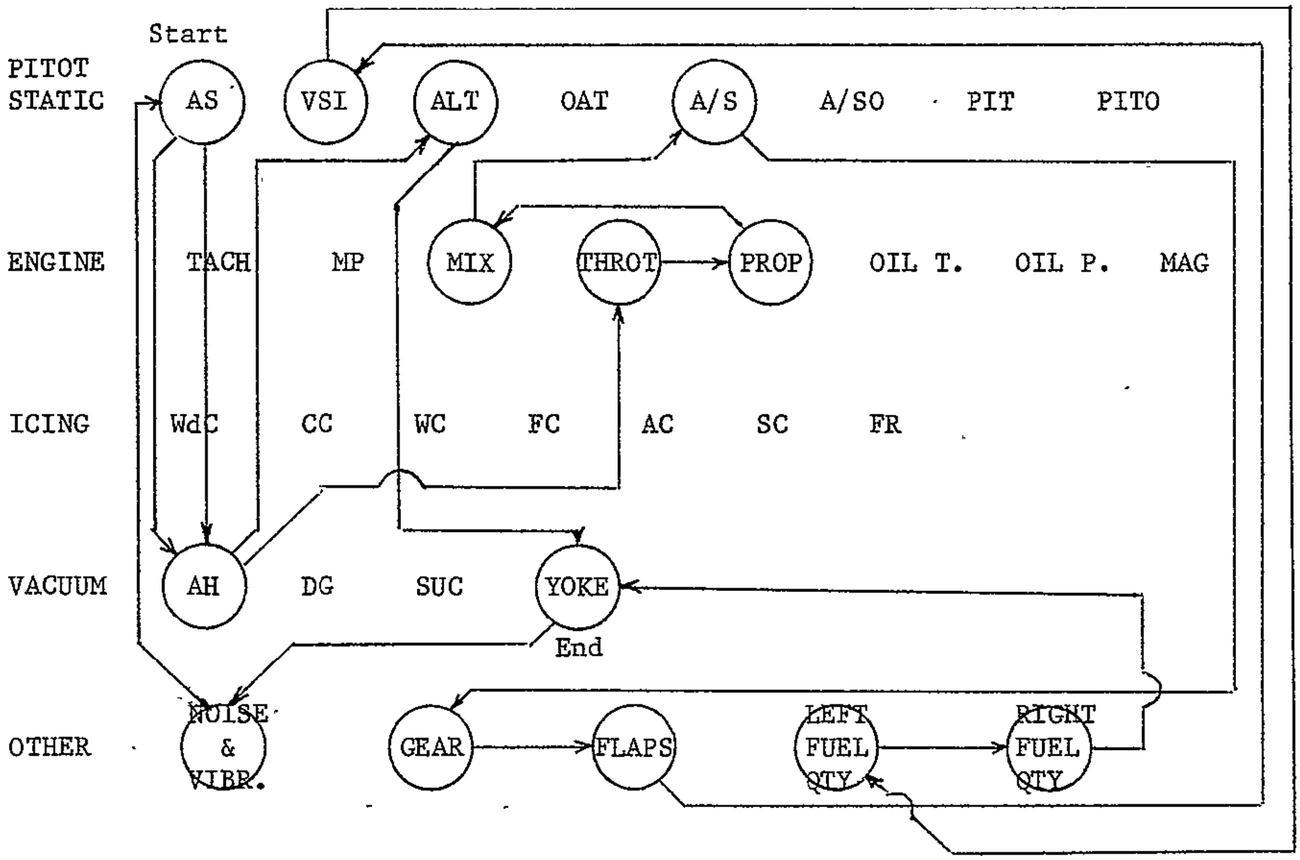
RATING: Private

KEY TERM: N (Y)

TOTAL NO. INQUIRIES: 9

KNOWLEDGE SCORE: 60%

Figure 1-3. Pilot Information Plot for Scenario #2, Subject #53



RESPONSE: Elevator Control Pressure

CONFIDENCE IN RESPONSE: 7

CRITICALITY: 1

TOTAL FLIGHT TIME: 100 Hrs.

TOTAL DIAGNOSIS TIME: 211 Sec.

RATING: Private

KEY TERM: (N) Y

TOTAL NO. INQUIRIES: 20

KNOWLEDGE SCORE: 50%

Figure 1-4. Pilot Information Pilot for Scenario #2, Subject #67

3) Instrument rated pilots perform better in general and are more efficient than non-instrument rated pilots.

4) CIFE experiences of test subjects influence their information seeking strategies.

Based on PLATO® and paper and pencil test results, idealized information searching can be hypothesized. The ideal pilot first confirms the symptoms given him. He then establishes whether his engine status is threatened by whatever cause lies behind the symptoms. Usually oil temperature and pressure and manifold pressure suffice to test this condition. Next he generates two or more hypotheses as to the cause, and makes a determination of the plausibility of these hypotheses with a minimal number of inquires within the appropriate tracks. He rarely needs to go over old logic tracks sampled. Finally, given a logical cause of the symptoms (usually from the key information element), he will often make sure alternative hypotheses are still not viable.

D. Combining Destination Division With Diagnosis

Scenario #5, described in Figure 1-5 was designed to meet two purposes:

1) It was a "no win" problem, i.e., no pilot would really be able to find the true cause from the symptoms presented. Hence, it would avoid a pilot stumbling into the key information item and force the pilot to examine all possible hypotheses.

2) It combined on the touch CRT both the destination diversion decision and the problem of diagnoses.

Appendix D shows the displays used in advanced PLATO® testing. This includes a simulated low altitude chart. A program has been developed for PLATO® which locates the aircraft relative to the map co-ordinates allows heading changes and allows the position of the aircraft to be determined from the VOR radials as the aircraft moves at some selected speed and heading. It should be noted that attempts to develop pilot positional awareness were used throughout. These included position reports to ATC based on dual VOR location assessment, auto-pilot heading change requirements, new clearances and even a concerned passenger requesting a return to the departure airport. Test scenarios employed some dynamics, i.e., loss of altitude with neutral forces on the yoke and attendant changes in VSI and airspeed with control inputs. As the flight progressed, the VOR needle showed a deflection. The scenario permitted communication with ATC and allowed for declaring emergencies.

Scenario #5

Consult attached simplified low altitude chart.

You are on an IFR flight from Utah Municipal Airport to Haven County Airport. You depart on V-110 at 6000 ft. in your Cherokee Arrow (N123B) which is equipped with a 3-axis autopilot. There is a NOTAM out which reports that Colorado VOR is out of service during the period you plan to navigate. Navigate using Ohigh and California VORs. You have been enroute 60 minutes from Utah Municipal Airport. You are on the gauges but the ride is smooth. Weather briefing indicated that winds at 6000 were expected to be light and variable.

You have one passenger aboard.

Weather at:

Haven County Airport = 2000 & 5
Ohigh = 1000 & 3
Wind Falls = 1000 & 3 by a C-172
(10 Minutes Ago)

Cleve Center calls and reports radar contact is lost. Please report present condition.

Clearance

ATC Response:

N123B, thanks for the position report.
Here is your new clearance:
proceed direct California VOR direct
Haven Count Airport at 6000.

There will be opposite traffic at 5000 . . . . maintain 6000.

Please confirm your new heading and altitude after your turn.

Scenario Change

While practicing hand flying with your autopilot disengaged, you notice that increased nose-up trim is required to maintain a constant indicated altitude and that your IAS has decreased 20 kts. from normal cruise.

Your passenger notes this problem, and suggests that you turn back to Utah Municipal.

Determine the nature of the problem, and your destination decision.

Figure 1-5. Combined Diagnosis and Destination Diversion Scenario.

Early tests suggest most pilots were preoccupied with diagnosis and seemed to lose positional awareness. This result is supported by typical experiences of pilots and ATC personnel.

E. Destination Diversion Descriptive Modeling

Appendix E presents the CRT displays given to the subject for the destination diversion phase of testing. In this scenario the pilot loses his alternator in IMC conditions beyond the range of his destination or departure airports. Under time constraints he must choose between alternate airports with different attributes. Such attributes include ceiling, visibility, bearing and distance, navigation aids, presence of ATC support and terrain. In this test there is no absolute answer. Rather the test seeks to see how pilots weight attribute information about alternative airports.

Table 1-1 summarizes for twenty-two subjects the attributes selected by airport. Note ceiling, visibility, and approach aids dominate the inquires.

These graphs, called DIG's for destination information graphs, give a quick picture of how pilots evaluate diversion airport attributes. There appears to be no biographical or knowledge predictors for these graphs. The relationship of DIG's to CIFE PIP's will require further study.

Airport \ Info	Bearing and Distance 1	Ceiling 2	Visibility 3	Approach Aids 4	ATC Services 5	Terrain 6	Total
1	8	11	11	10	6	8	54
2	0	0	0	0	0	0	0
3	14	15	15	14	11	11	(80)
4	0	1	1	1	0	1	4
5	9	18	17	13	9	9	75
6	10	13	12	12	6	6	59
7	2	2	2	2	0	0	8
8	10	15	14	12	9	10	70
9	9	13	13	8	5	4	52
10	3	8	8	5	2	6	32
11	3	5	3	4	1	1	17
12	2	4	4	1	3	3	17
13	1	1	1	1	1	1	6
14	8	15	11	10	6	9	59
15	0	0	0	0	0	0	0
16	1	3	4	2	2	3	15
Total	10	(124)	116	95	61	72	

Number of Subjects = 22

Table 1-1. Frequency of Information Type for Each Airport.

II. Research Objectives for the Current Study

The basic aim of this third study was to add depth of understanding to pilot information seeking and decision making in the face of critical in-flight events. The past research program sought to apply human factors concepts to pilot information processing and decision making in order to:

a) ascertain the role of pilot background, experience and knowledge in problem diagnosis and decision making,

b) describe problem solving paths in sufficient detail to permit the identification of various general strategies used by pilots, and

c) identify generalizable formal structures to describe CIFE decision making and diagnostic behavior.

Experiments in the first two studies resulted in a wealth of data from some eighty pilots who were subjected to a set of diagnostic and decision making scenarios. Those data have been used to develop simple graphical models to depict information gathering behavior and have been subjected to an exhaustive set of statistical tests to demonstrate relationships between pilot backgound and scenario test scores. The major task remaining for this, the third phase, was to develop formal structures to generalize behaviors observed in the graphical models (PIP's) and more fully exploit available data.

To accomplish a general description of pilot diagnostic behavior concepts from cognitive psychology and artificial intelligence will be employed as well as more traditional mathematical models from the theory of stochastic processes.

Over the last decade, significant strides have been made toward understanding how people acquire and utilize knowledge. Contributions from the fields of cognitive psychology and artificial intelligence emphasize the critical role that the organization of knowledge in the mind plays in determining performance. Of particular interest to understanding the diagnostic behavior of pilots are the (closely related) concepts of frames (Minsky, 1975), schemata (Thorndyke and Hayes-Roth, 1979) and scripts (Schank and Abelson, 1977).

The goal of this research is to develop a more formal description of a pilot's diagnostic behavior. An operating hypothesis is that a pilot's behavior in response to a given scenario will be mediated in part by the relevant knowledge structures contained in that pilot's memory. This hypothesis suggests three basic research questions:

1) What knowledge does a pilot have? This might be thought of as an unordered list of propositions.

2) How is this knowledge organized in memory? Models of human associative memory (Anderson and Bower, 1980) and schemata-based theories seem most promising in answering this question.

3) How are knowledge and organizing knowledge structures used by pilots in attempting to diagnose the causes of critical in-flight events? Commonly hypothesized cognitive structures and processes such as control elements, activation thresholds, push-down stacks, and priming may prove to be applicable. Concepts borrowed from artificial intelligence research, such as production and frame systems, may be useful.

III. The Role of Knowledge Structures in Fault Diagnosis

The study discussed below addresses the question of how domain-specific knowledge is used in fault diagnosis (Rasmussen and Rouse, 1981). The fault studied is the failure of the vacuum system in an airplane. The domain-specific knowledge of interest is the knowledge that instrument rated pilots have stored in their memories.

It is hypothesized that such knowledge is organized in a pilot's memory as a frame system. The basic knowledge structure within such a system is a frame. Minsky (1975) defines a frame as:

> "a data structure for representing a stereotyped situation, like being in a living room or going to a child's birthday party. Attached to each frame are several kinds of information. Some of this information is about how to use the frame. Some is about what one can expect to happen next. Some is about what to do if these expectations are not confirmed" (p. 212)

In an aviation setting one frame or "stereotyped situation" might be a plane in a descent. Such a data-structure would contain information about expected instrument readings (e.g., the altimeter should show decreasing altitude). It could also contain labeled slots indicating relevant pieces of information that should be collected (e.g., what is the indicated airspeed?). Associated with each such slot (Winston, 1984; Schank and Riesbeck, 1981) is a set of permissible slot-fillers (e.g., increasing, constant or decreasing airspeed).

If a slot has several alternative slot-fillers, one of these may be marked as the default value. It is the value most likely to be correct if the situation described by the frame occurs.

Within this framework, fault diagnosis consists of:

1) Focusing attention on a particular frame.

2) Using the knowledge contained in that frame to generate information requests and to make inferences.

3) Using the information collected to confirm or reject the activated frame as an appropriate representation of the situation.

4) Using the contents of the frame to activate or focus attention on additional relevant frames.

METHOD

Pilots were read a scenario that provided certain instrument indications and background information pertaining to a flight over the New England area. They were told that a problem existed at the point in time described by the scenario, and were asked to try to diagnose the cause of the problem. In order to perform this task they were allowed to request any information that would normally be available to a pilot under the conditions specified by the scenario. Requested information was provided verbally by an experimenter.

Each subject was tested in a separate session. The entire session was tape-recorded.

Subjects

Twenty-six pilots with instrument ratings served as subjects. Pilots were paid $10 for a single session that lasted from one to two hours. Additional biographical information is summarized in the Results and Discussion section.

Procedure

The two primary tasks involved fault diagnosis (Task 1) and a memory (recall) test (Task 2). In addition, four other supplementary tasks were performed. Tasks were run in numerical order for all subjects. Since Tasks 1 and 2 were always run first, there is a potential for confounding of results on the remaining tasks. Consequently, the information provided by these latter tasks will be presented only in so far as it supports or contradicts conclusions drawn from the two primary tasks. Similar caution must be applied when interpreting results from Task 2.

Task 1. Each subject was asked to describe what "a pilot should do in order to determine the cause of a problem that has developed while flying a Cherokee Arrow, with a 200 horsepower, fuel-injected Lycoming engine. This particular plane is not turbocharged and does not have an autopilot."

The subject was asked to think out loud as he tried to diagnose the problem, telling the experimenter not only what information a pilot should collect but also why he should collect that information.

A sample verbal protocol was read to the subject in order to illustrate what was meant by thinking out loud. This example involved deciding how to get to work rather than fault diagnoses while in flight.

The pilot was then asked to practice thinking out loud using a scenario involving selection of a restaurant. Thus, this practice did not deal with fault diagnosis or with flying.

Pilots were told specifically not to try to correct the problem. Their sole objective was to determine the cause of the problem. It was pointed out that this was therefore a different task from the one faced by a pilot who was actually flying under such conditions.

Pilots were further informed that this was a static "simulation," that the information provided in response to their requests referred to the same point in time at which the scenario was read. (The plane did not continue to fly during the time taken to diagnose the problem.)

Quantitative readings were provided in response to information requests whenever appropriate (e.g., the vertical speed indicator shows a descent at a rate of 600 feet per minute). Whenever appropriate, it was also stated whether the quantitative reading would be a normal one for the plane while cruising at the intended altitude (e.g., the oil temperature gauge reads 140°F, which is normal).

The responses provided were developed by an expert pilot and listed for the experimenter to read in response to a subject's requests. The accuracy of the responses was tested by simulating the scenario conditons in an actual flight.

Two experimenters were present for each session. One provided the responses to the information requests. The other gave the instructions and prompted the subject to continue thinking out loud when necessary. The prompts consisted of two questions:

1. What are you thinking now? (if the pilot became silent)
2. Why are you interested in that information? (if the pilot asked for information without explaining why he wanted it)

The scenario (presented below) was one in which a plane's vacuum pump failed. This fact was indicated by a zero reading on the suction gauge. The vacuum pump drives the artificial horizon and directional gyro. As the artificial horizon lost its drive, it started to sag to the right and the pilot compensated (unconsciously) by turning left. This leveled the artificial horizon and put the plane in a descending left bank. The resulting nose-down attitude caused an increase in airspeed and a descent.

At the point in time represented in the scenario the plane had faulty readings on the artificial horizon and directional gyro. The plane was descending nose-down and was in a left bank while these instruments indicated straight and level flight.

The scenario is given below.

> Imagine that this pilot is making a day trip from Augusta, Maine to Lebanon, New Hampshire. He flies out of Augusta at 9 a.m. cleared Victor 39 to Neets intersection, Victor 496 to Lebanon. He climbs to a cruising altitude of 6000 feet.
>
> After 15 minutes of routine flying in instrument conditions in the clouds, the instruments indicate an increase in airspeed, a steadily decreasing altitude, and zero pitch.
>
> So, the instruments indicate an increase in airspeed, a steadily decreasing altitude, and zero pitch.
>
> How should this pilot go about identifying his problem?

After hearing the scenario, pilots began requesting information in an effort to diagnose the fault. They continued until they arrived at a conclusion or decided that, with the information available, it was impossible to arrive at a conclusion.

Pilots stating a conclusion were asked to rate their confidence in it on a scale from one to ten. A rating of one indicated the lowest level of confidence while ten indicated the highest.

Task 2. Pilots were asked to recall everything they remembered about this flight. They were told to be very specific about any instrument readings or conditions they remembered.

Task 3. Pilots were given a knowledge test. They were asked to describe the information they would collect in order to determine whether a plane had one of the following problems:

1. Structural icing
2. Directional gyro malfunction (mechanical failure)
3. Suction gauge malfunction (mechanical failure)
4. Vacuum pump failure
5. Iced-up pitot tube
6. Accidentally extended gear
7. Iced-up static port
8. Accidental change of the yoke position (with the pilot unaware of this fact)
9. Artifical horizon malfunction (mechanical failure)
10. Reduction in power or thrust from the engine or prop.

They were told to assume the plane was cruising in the clouds at the time one of these problems occurred.

Task 4. Pilots were asked to think back to the original problem-solving task. They were asked to describe their impression of the plane's physical orientation while they were trying to diagnose the problem.

Task 5. Pilots were asked whether they formed a visual (mental) image of an instrument panel while performing Task 1. If the answer was yes, they were asked what they visualized.

Task 6. Pilots were asked to provide the following biographical information:

1. Whether they had ever personally experienced problems with icing or the vacuum system while flying
2. Age

3. Total hours of flying experience

4. Highest airman's certificate

5. Ratings in addition to instrument rating.

RESULTS AND DISCUSSION

Before presenting summary statistics for the results of the experiment, three full verbal protocols will be presented:

Subject #17

Query 1: "What if I open my alternate static source?"
[Why?] "To see if I have a clogged port."
Query 2: "You said the airspeed was increasing and the altitude was decreasing?"
[Why?] "That suggests that you're descending."
Query 3: "What is the outside air temperature?"
[Why?] "Because there could be ice on the wings causing descent."
Query 4: "What is the RPM?"
[Why?] "To see if there's a loss of engine power."
Query 5: "Can you see ice on the wings?"
Conclusion: "I can't tell."

Subject #3

Query 1: "Steadily decreasing altitude. Then I would also assume that that also includes then a showing a descent on the vertical velocity indicator?" [Why?] "Is the vertical speed indicator having a reading consistent with the altimeter. To try to narrow down is it a pitot-static system problem."
"That indicates to me that the vertical speed indicator is consistent with the altimeter."
Query 2: "To clarify. Is my, the altitude indicator also going down?"
Query 3: "At this point, then, I would then change my attention away from the, no I take that back. The airspeed indicator is indicating an increase in airspeed. Is that correct?"
"At this point, I will rule out the pitot-static system. Those instruments all seem to be consistent."

Query 4: "With an increase in airspeed, then, the next question is, is the manifold pressure, what is the trend of the manifold pressure gauge?" [Why?] "To try to narrow down is it an engine problem of some sort, am I losing engine power."

Query 5: "Also with regard the engine just to get information as to whether the engine and prop in this case is working correctly, what is the RPM reading?"
"At this point it seems that the pitot-static system is correct. The engine seems to be functioning correctly. The engine seems to be running, producing power."

Query 6: "My next line of thought would be some sort of control problem. I was going to ask a question about the trim, but I'm assuming the trim hasn't been played with. I just, a new thought came to mind and the new thought is that if I am decreasing altitude and zero pitch change, in other words, I haven't evidently put in any control input to affect the elevator. Well, let me phrase it as a question. Is there ice, am I receiving ice on the wings of any sort?"
"That takes care of that problem."

Query 7: "Then let's go back to the controls. Is the pitch trim operating correctly, the trim wheel? Has the trim wheel changed position?"

Query 8: "At this point I'm becoming stumped. Let me ask another question which maybe clarifies the initial conditions. That is, I have zero pitch, meaning that indicates that I haven't had a forward deflection in the control wheel. I haven't added down elevator. I'm losing altitude, gaining airspeed, but have not had a, is the nose pitched over is what I'm trying to determine at this point. I'm in the clouds. The only way to determine that is either through the altitude change, which obviously is down, but the next thing to check would be the attitude indicator and I'm assuming that the attitude indicator is indicating level because the initial condition saying there was no pitch change. Ah! I have just rung a bell! Next question: Is the vacuum, what is the reading on the vacuum gauge?"

Conclusion: "My problem is with the vacuum system and I'm losing pressure to my gyroscopic instruments."

<u>Subject #1</u>

Query 1: "The first thing I would think about is with the decreasing altitude and increasing airspeed, that for some reason the plane is starting to go down and I would look to confirm that right away with the attitude indicator. There is zero pitch in there. It should show down pitch. So the first instrument I would look at since it runs off of suction, would be over at the suction, to see if it's producing any vacuum. What does the suction gauge show?"

Conclusion: "You have a nose-down attitude and the vacuum pump's gone."

These three protocols illustrate the apparent heterogeneity of the subjects' performances. Subject #1 asked one question while Subject #3 asked eight, yet both arrived at the same conclusion. Subject #17 made five queries, none of which matched the query made by Subject #1, and decided he could not determine the cause of the problem with the available information.

Although data were collected for twenty-six subjects, the following analysis will be based on only twenty of these pilots. Since the objective of this study was to model the way pilots use their knowledge structures (as opposed to whether they have the necessary knowledge), any subject demonstrating knowledge errors (Task 3) that would prevent him from solving the problem was deleted from the data set. Four subjects were deleted for this reason. All four thought the vacuum system was connected to the static port. One of these four thought the altimeter and airspeed indicator were vacuum driven instruments. Another did not know which instruments were part of the vacuum system and which were part of the pitot-static system.

Not surprisingly, three of these four subjects concluded that it was impossible to determine the cause of the problem. The fourth decided that the problem was a malfunction of the artificial horizon.

All four of these pilots had between 500 and 2000 hours of flying experience and were between the ages of 41 and 70. Three had private pilot licenses and one a commercial license. (All subjects in the experiment were current instrument rated pilots.)

A fifth subject was deleted for failing to follow instructions. He insisted on trying to fly the plane in order to halt the descent, rather than attempting to determine what was causing the problem.

A sixth subject was eliminated because he misinterpreted the meaning of the scenario. He interpreted zero pitch to mean that the vertical speed indicator showed zero and the artificial horizon indicated the plane's nose on the horizon. This misinterpretation was corrected when it was discovered (after his first query). He was then allowed to proceed, and concluded that the cause of the problem could not be determined.

His comments after hearing the solution to the problem at the end of the experiment are worth noting:

> "I had it [the scenario events] happen. It's interesting that I had it happen and I didn't relate to it. But, so you were getting a correct indication from the airspeed and the altimeter. You were incorrect from the attitude indicator and you were actually in a turn. If I'd checked my heading, I'd have been alright. ... When I lost the attitude indicator [in the actual flight], it didn't feel right in the airplane. I felt almost like I was getting vertigo because I was in IFR conditions and kind of in and out of the clouds and things just didn't feel right. I was still following that dumb attitude indicator. Then I noticed I was off my heading, there was something wrong, and I looked and the suction gauge was showing zero."

So, the scenario can happen.

Summary Statistics

Of the twenty final subjects, eleven concluded there was a vacuum system failure (Group A), four stated that the problem was a malfunctioning artificial horizon (Group B), one decided the problem was a downdraft (Group C), and three concluded that the problem could not be diagnosed with the available information (Group D). A final pilot (Group E) detected the faulty artificial horizon but then concluded that he could not diagnose the problem (for reasons that will be explained later). Certain characteristics of these pilots are summarized in Table 3-1 (by group).

The conclusions of the four groups are summarized in Table 3-2, along with the pilots' confidence ratings.

In Task 4, pilots were asked what their final conclusion was regarding the plane's physical orientation (at the end of the Scenario Task). Fourteen reported that they thought the plane was in a straight nose-down descent. Five (all in Group A) thought the plane was descending in a left-bank with the nose down. The pilot in Group C thought the plane was in a straight and level descent, with the nose on the horizon.

In the recall task, the question of interest is whether the pilots remembered the three instrument indications given in the scenario. Assuming that the probability of retreiving information from memory is related to the amount of attention it was given during the problem solving task, this provides evidence of the salience of these three instrument readings. The results are summarized in Table 3-3. Note that none of the subjects in Group D recalled the zero pitch indication. Below is the full response of one pilot in Group D to the recall task. He failed to recall the pitch indication despite his overall high recall performance.

> "You were first cleared from Augusta, Maine to Neets intersection via Victor 23 to Lebanon, New Hampshire at 6000 feet in instrument conditions at 9:00 a.m. You explained that we were showing an increase in airspeed, an airspeed of 140 and increasing, an altitude of 5600 and decreasing and a vertical speed decreasing at 600 feet per minute. I then asked what the manifold pressure was and you said 22.5 inches, and I asked RPMs. You said it was 2300 RPMs. I asked about the control column and what position it was and you said it was in the neutral position. I also asked about the trim tab and he explained to me that the trim tab was set for level flight. I asked him if he could see any icing on the wings and he said we couldn't see any. I also asked, I think that's basically all I asked."

A more detailed presentation and discussion of results is given below.

Table 3-1a. Biographical Data.

Group	Ages (number of pilots in each category)					Total Hours of Flying Experience					
	21-30	31-40	41-50	51-60	61-70	101-300	301-500	501-1000	1001-2000	2001-3000	>20,000
A	6	2	2	1	0	1	1	5	2	1	1
B	2	1	1	0	0	1	2	3	0	0	0
C	0	0	0	1	0	0	0	0	1	0	0
D	3	0	0	0	0	0	0	2	1	0	0
E	1	0	0	0	0	0	1	0	0	0	0

Table 3-1b. Biographical Data (continued)

Group	Highest Airman Certificate			Ratings in Addition to Instrument Rating and Airplane Single-Engine Land		
	Private	Commercial	Air Transport Pilot	Flight Instructor	Airplane Multi-Engine Land	Airframe and Powerplant Mechanic
A	3	7	1	6	7	1
B	2	2	0	2	1	0
C	1	0	0	0	0	0
D	0	3	0	3	2	0
E	0	1	0	1	1	0

Table 3-1c. Biographical Data (continued)

Group	Vacuum System Fail While Flying?		Structural Icing While Flying?		Pitot Tube Icing While Flying?	
	Yes	No	Yes	No	Yes	No
A	2	9	8	3	4	7
B	0	4	4	0	1	3
C	0	1	1	0	0	1
D	1	3	3	1	0	4
E	0	1	1	0	0	1

Table 3-2. Conclusions at the End of the Scenario Task.

Group	Conclusion: Vacuum System Malfunction	Conclusion: Artificial Horizon Malfunction	Conclusion: Downdraft	Conclusion: Can't Tell	Confidence Rating* 6	7	8	9	10
A	11	0	0	0	1	0	0	4	6
B	0	4	0	0	0	1	1	1	1
C	0	0	1	0	0	0	0	1	0
D	0	0	0	3	-	-	-	-	-
E	0	0	0	1	-	-	-	-	-

*10 indicates the highest level of confidence in a conclusion. 1 indicates the lowest level of confidence. No rating was stated if the pilot concluded he could not tell what the problem was. The dashes indicate that no confidence rating was given because the pilot failed to arrive at a diagnosis.

Table 3-3. Recall of the Three Original Instrument Indications (Task 2).

Group	Increasing Airspeed	Decreasing Altitude	Zero Pitch	Number of Subjects
A	11	10*	11	11
B	4	4	4	4
C	1	1	1	1
D	3	3	0	3
E	1	1	0	1

*The other subject did recall a descent indicated on the vertical speed indicator.

Preview

In the analysis to follow, verbal protocols have been used to help identify patterns in the pilots' information requests and diagnoses. These patterns have then been used to make inferences about the underlying mental processes and structures (Gentner and Stevens, 1983).

Some strong assumptions have been made in order to map out a parsimonious general model of performance. When made, they will be explicitly stated. The impact of these assumptions upon the final model will be evaluated at the close of the discussion.

Initially Activiated Frames

Before asking how frames are activated in the memory of a pilot, we must first determine what frames are being activated. Three sources of data are relevant to this question:

1. The spontaneous comments made by the pilot before making his first query.
2. The first query made by the pilot.
3. The statements made by the pilot immediately after his first query (either spontaneously or in response to the experimenter's prod: Why are you interested in that information?).

The following assumptions will be made to infer the existence of particular frames:

1. Frames are prototypes (Aikens, 1983; Sowa, 1984) representing states of nature (e.g., the plane is descending or the static port is blocked).
2. Queries (e.g., What does the altimeter show?) are generated by activated frames. Thus, the questions a pilot asks should provide insights into states of nature represented by the activated frames.
3. The activated frame provides the answer to the question: Why are you interested in that information? (See Schank and Riesbeck, 1981; Winston, 1984.)

Suppose there exists a frame labeled DESCENT that has a slot indicating an expected reading on the altimeter. When activated, this frame directs the pilot to determine whether all expectations are met (see Figure 3-1). Thus, the instructions for use (Minsky, 1975) direct the pilot to ask: What does the ALTIMETER show? If the pilot is then asked why he is interested in this information, he looks at the label for the activated frame and responds: Because I want to see whether the plane is in a DESCENT. In this manner, frames are used to generate and to respond to questions.

Frame Label: DESCENT

Expectations: DECREASE SHOWN ON ALTIMETER

Instructions for Use: CHECK TO SEE WHETHER
EXPECTATIONS ARE MET

Figure 3-1. Sample Frame.

Consider the following verbal protocol.

Pilot:

> "Steadily decreasing altitude. Then I would also assume that that also includes then a showing a descent on the vertical velocity indicator. What does the vertical speed indicator show?"

Experimenter:

> "Why are you interested in that?"

Pilot:

> "Is the vertical speed indicator having a reading consistent with the altimeter to try to narrow down is it a pitot-static problem?"

From this data, we would infer the existence of a frame labeled PITOT-STATIC SYSTEM MALFUNCTION.

Table 3-4 shows the initial queries for the 20 pilots studied. Based on an analysis of the associated verbal protocols, labels for ten frames were identified:

1. The Plane is in a DESCENT.

   Three subjects appeared to generate their first queries using this frame. Two asked what the vertical speed indicator was showing. The other asked about the tachometer reading. Comments supporting this inference included:

   > "If it's [the vertical speed indicator's] reading correctly it'll read whether you're descending."

"Is it [the plane] going down?"

"We seem to be in a descent."

2. There is a POWER LOSS.

Four pilots activated this frame, three inquiring about the manifold pressure gauge and one about the tachometer. Associated comments indicating that the POWER LOSS frame had been activated included:

"What's happening to my power? Very definitely we have a situation where we seem to be losing power."

"Let's find out what the engine is doing."

"I'm going down and what I have to do is figure out why I'm going down. I'd look for power."

3. There is ICING.

One subject used this frame to generate a question about the presence of visible moisture "because it might be in regards to icing".

4. There is a PITOT-STATIC SYSTEM MALFUNCTION.

Two subjects requested the reading on the vertical speed indicator after activating this frame. A third asked about the outside air temperature.

Consistent statements included the sample subject discussed earlier who wondered:

"Is it a pitot-static problem."

Other comments were:

"It appears it could be a problem with the pitot-static system."

"My first thoughts are that there's definitely going to be a problem with the pitot-static system."

5. There is STATIC PORT ICING.

This subject inquired about the reading on the outside air temperature gauge, stating:

"The first thing I would think of would be a problem with the static port because I'm thinking it could be a possibility of something freezing."

6. There is a BLOCKED STATIC PORT.

Both of these pilots wondered what would happen to the instrument readings if the alternate static source was opened because they were concerned with a blocked static port:

"There may be a blockage in the static system that's causing faulty instrument readings."

[There may be a] "clogged port."

7. There is PITOT TUBE ICING.

This subject asked if the pitot heat was on, saying:

"I was wondering if there might be in that area [the pitot tube] icing. Picked up some icing."

8. There is an AIRSPEED INDICATOR MALFUNCTION.

This pilot checked to see whether there was in increase in air stream noise as:

"This would indicate an increase in airspeed, would back up that instrument indication."

9. There is a VACUUM SYSTEM MALFUNCTION.

Two pilots asked for the suction gauge reading to:

"see if it is producing any vacuum."

10. My MEMORY may be in ERROR.

Two subjects seem to have a frame dealing with beliefs about their own limitations and abilities (Norman, 1983). This frame is concerned with the possibility that the pilot has not recalled the scenario information correctly. The first query is intended:

"to make sure I'm right on the scenario."

One subject asked whether the airspeed indicator showed an increase (it did). The second subject asked whether his airspeed indicator was showing a decrease.

Table 3-4. Initial Queries

	Number of Subjects Asking
What is the reading on the:	
Vertical Speed Indicator?	4
Airspeed Indicator?	2
Manifold Pressure Gauge?	3
Tachometer?	2
Outside Air Temperature Gauge?	2
Suction Gauge?	2
What happens if:	
The Alternate Static Source is Opened?	2
Is:	
The Pitot Heat On?	1
There Visible Moisture in the Air?	1
There an Increase in Wind Noise Outside the Plane?	1

The above cited evidence indicates that a variety of frames exist in pilots' memories. Furthermore, it suggests that the same "stimulus" (reading of the scenario) can lead to the activation of different frames in different pilots' memories. In some cases the frames that have been activated are very similar to one another (e.g., STATIC PORT ICING and BLOCKED STATIC PORT). In other cases, however, they are radically different (e.g., VACUUM SYSTEM MALFUNCTION versus POWER LOSS).

Initial Activation of Frames

The above analysis identified ten frames that were used by the twenty pilots to generate their initial queries. (Not all pilots activated the same frame.) This subsection addresses the next question: How were these frames activated? The goal is to better understand the mental processes that occurred between the time the experimenter began reading the scenario and the time at which the pilot made his first query.

By its very nature, protocol analysis provides only fleeting glimpses into the mental processes occurring within any one subject. Subjects do not report all of their thoughts. Furthermore, even if two subjects activate the same set of mental processes, their comments may provide evidence relevant to different portions of these processes. Thus, in order to construct a model that is even somewhat complete, it is desirable to make an assumption:

Unless evidence to the contrary exists, assume that if two pilots ask the same question (e.g., What is the reading on the manifold pressure gauge?), the same mental processes (at least in terms of important characteristics) produced that query. This assumption is based on an objective of developing a parsimonious explanation of performance (a desire to introduce individual differences only when necessary). Its implications and applications will be made clearer in the following analyses.

The scenario that was read can be thought of as a set of cues or clues indicating what the problem was. The first questions to be addressed are:

1. What are the cues that subjects are attending to?

2. What frames are being activated by these cues?

(Pauker, Gorry, Kassirer and Schwartz, 1976.)

Evidence that a cue has been given attention is the fact that the pilot repeats it out loud. There may, of course, be other cues that have received attention, but that the pilot has not repeated. Consider the following comments made by pilots after hearing the scenario:

S#1. "The first I would think about is with decreasing altitude and increasing airspeed, that for some reason the plane is starting to go down."

S#2. "It would appear that he's descending."

S#5. "If increasing airspeed, altimeter unwinding, those are pretty good clues he's descending."

S#6. "I'm going down and what I have to do is figure out why I'm going down. I'd look for power."

These protocols contain evidence regarding the activation of two frames (DESCENT and POWER LOSS) resulting from attention to two cues (increasing airspeed and decreasing altitude). Based on this data alone, the most parsimonious model is one in which:

1. Two cues, an increase shown on the airspeed indicator and a decrease shown on the altimeter, activate the DESCENT frame.
2. The Instructions for Use in the DESCENT frame direct the pilot to look for possible causes of descent, resulting in activation of the POWER LOSS frame (see Figure 3-2).

The comments by Subjects #1 and #5 both provide evidence regarding their attention to these two external cues and the activation of the DESCENT frame. For the purpose of developing a general model, it is assumed that Subject #2 also attended to both cues and activated the DESCENT FRAME, even though complete evidence to support this is lacking. (There is no contradictory evidence.) Subject #6 provides evidence that two frames were activated, the DESCENT frame followed by the POWER LOSS frame. It is assumed that he attended to the two external cues shown in Figure 3-2, even though he provides no evidence of this (i.e., it is assumed that his behavior was like that of the other subjects since no evidence to the contrary exists).

This type of analysis will now be applied to the data for all twenty subjects. The data to be used for the following analysis will be the spontaneous comments of a pilot before his first query, his first query, and his comments immediately after the first query (spontaneous or in response to the prod: Why are you interested in that information?). Thus, the data to be used consists of all statements made after the reading of the scenario, but before the asking of a second query by the pilot.

Nose-Down DESCENT. Figure 3-3(a-d) shows the model constituents supported by the data for each of seven subjects. Associated comments are also quoted to indicate the support for model constituents. When the data for a given subject provides no evidence in support of a given model constituent, that constituent has not been filled in.

Figure 3-3 indicates that these seven subjects activated three types of frames (DESCENT, POWER LOSS and VACUUM SYSTEM MALFUNCTION). A total of six variants on these three types of frames was observed.

The general model of performance assumes that all seven subjects activated the DESCENT frame first because they focused their attention on two cues, a decrease on the altimeter and an increase on the airspeed indicator. When asked later (Task 4) what they believed the plane's orientation to be at the beginning of the scenario task, all seven subjects stated that it was in a straight, nose-down descent. Comments included:

> "Descending like this [straight descent shown with hand] in a nose-down attitude."
>
> "Descending straight ahead, slight nose-down."
>
> "Straight, nose-down."

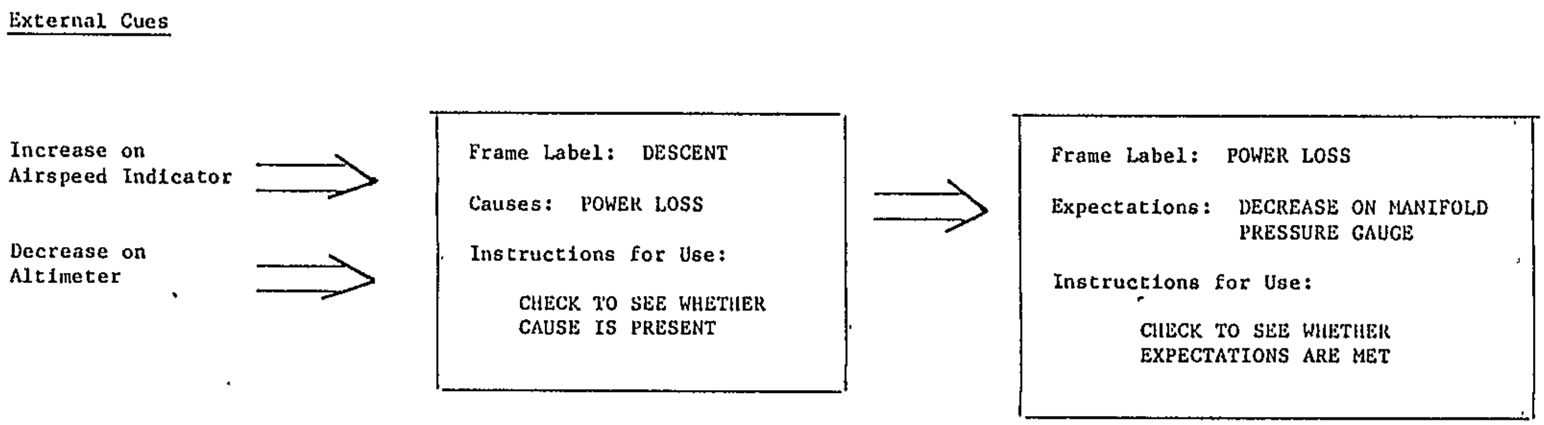


Figure 3-2. A Partial Model of the Frame Activation Process.

External Cues*

Frame Label: DESCENT

Expectations: DESCENT INDICATED ON VERTICAL SPEED INDICATOR

Instructions: CHECK TO SEE WHETHER EXPECTATIONS ARE MET

Supporting Comments: S#2 - "It would appear that [the plane's] descending. What does the vertical speed indicator show?"

S#10 - "What does the vertical speed indicators show?" [Why?] "If it's reading correctly it will read whether you are descending."

Figure 3-3a. Subjects #2 and #10.

(Note: No evidence was present regarding external cues. Therefore, this part of the system was not filled in for Subjects #2 and #10).

· External Cues

Frame Label: DESCENT

Causes: POWER LOSS

Instructions: CHECK TO SEE WHETHER CAUSE IS PRESENT

⟹

Frame Label: POWER LOSS

Expectations: DECREASE ON MANIFOLD PRESSURE GAUGE

Instructions: CHECK TO SEE WHETHER EXPECTATIONS ARE MET

Supporting Comments: S#4 – "I'm going down and what I have to do is figure out why I'm going down. I'd look for power. What is the manifold pressure?"

S#6 – "What's the manifold pressure read?" [Why?] "Find out what the engine is doing."

Figure 3-3b. Subjects #4 and #6.

External Cues

Frame Label: DESCENT
*

⟹

Frame Label:

Expectations: CHANGE IN TACHOMETER READING

Instructions: CHECK TO SEE WHETHER EXPECTATIONS ARE MET

Supporting Comments: "What is the RPM?" [Why?]
"We seem to be in a descent."

Figure 3-3c. Subject #18.

*It is probable that this subject has activated the POWER LOSS frame as a possible cause of DESCENT. There is no direct evidence of this in the verbal protocol, however. Consequently, these portions of the frames have been left blank.

External Cues

Decrease On Altimeter ⟹

Increase On Airspeed Indicator ⟹

Frame Label: DESCENT

Expectation: PITCH DOWN ON ARTIFICIAL HORIZON

Instructions: CHECK TO SEE WHETHER EXPECTATIONS ARE MET. IF NOT, ACTIVATE THE ASSOCIATED INSTRUMENT MALFUNCTION FRAME

⟹

Frame Label: VACUUM SYSTEM MALFUNCTION

Expectations: LOW READING ON SUCTION GAUGE

Instructions: CHECK TO SEE WHETHER EXPECTATIONS ARE MET

Supporting Comments: "The first I would think about is with the decreasing altitude and increasing airspeed, that for some reason the plane is starting to go down and I would look to confirm that right away with the attitude indicator [the artifical horizon]. There is zero pitch in there. It should show down pitch. So the first instrument I would look at, since it runs off of suction, would be over at the suction gauge, to see if its producing any vacuum."

"If increasing airspeed, altimeter unwinding, those are pretty good cues he's descending and that he's got a nose-down attitude. But since it's not being indicated on the gyro horizon there's a pretty good chance that he's lost his vacuum. What does the vacuum gauge show?"

Figure 3-3d. Subjects #1 and #5.

Figure 3(a-d). Activation of Initial Frames for Seven Subjects Focusing on a Nose-Down Descent.

This assumption makes sense in terms of the DESCENT frame as defined. If the plane is in a straight nose-down descent, the airspeed will increase and the altitude will decrease.

Having activated the (nose-down) DESCENT frame, four subjects elected to "test the hypothesis" that this was the correct frame (was a valid model of the state of nature) by checking to see whether the instrument indications were consistent with this model. A descending plane should show a DESCENT INDICATED ON VERTICAL SPEED INDICATOR, so two subjects checked this expectation (see Figure 3-3a). The other two subjects checking for instrument indications looked for an indication of PITCH DOWN ON ARTIFICIAL HORIZON (see Figure 3-3d). Since this information was available in their (short-term) memories, they answered the question without requesting this information from the experimenter. This expectation was found to be invalid (the artificial horizon showed zero pitch), suggesting the possibility of an instrument failure (specifically, a failure of the artifical horizon). As a result, the frame labeled VACUUM SYSTEM MALFUNCTION was activated, since such a problem could cause a false reading on the artificial horizon. This frame instructed them to CHECK TO SEE WHETHER the associated EXPECTATIONS ARE MET producing their first query: What is the reading on the suction gauge?

The remaining three subjects (Figures 3b and c) took a different approach. They assumed the plane was in a (nose-down) DESCENT and started looking for possible causes of such a descent. They therefore activated the POWER LOSS frame, which instructed them to test for power loss, checking for expected readings on either the manifold pressure gauge or the tachometer.

Figure 4 summarizes the alternative questions considered by these seven subjects during their efforts to generate an initial query. Thus far, then, we have developed the following model:

1. Frames represent prototypical states of nature. (Labels for ten such states have been identified.)
2. A frame is activated either by data that has been collected or by another frame that has been activated (i.e., by some set of enabling events). A number of such enabling events have been identified for particular frames.
3. Once activated, a frame can be used to generate a query in order to seek additional information.
4. An activated frame can be used to answer the question: Why are you interested in that information?
5. The Instructions for Use in frames are based on three lines of reasoning:
   a. If a frame is a valid representation of the state of nature, (e.g., nose-down DESCENT), then the expected readings on certain instruments (listed by that frame) should be present. To assess that frame's validity, the pilot should ask for the readings on those instruments.
   b. If an instrument reading is inconsistent with the hypothesized state of nature (i.e., the activated frame), that instrument may be malfunctioning.
   c. If a frame is a valid representation of the state of nature, then something must have caused that state of

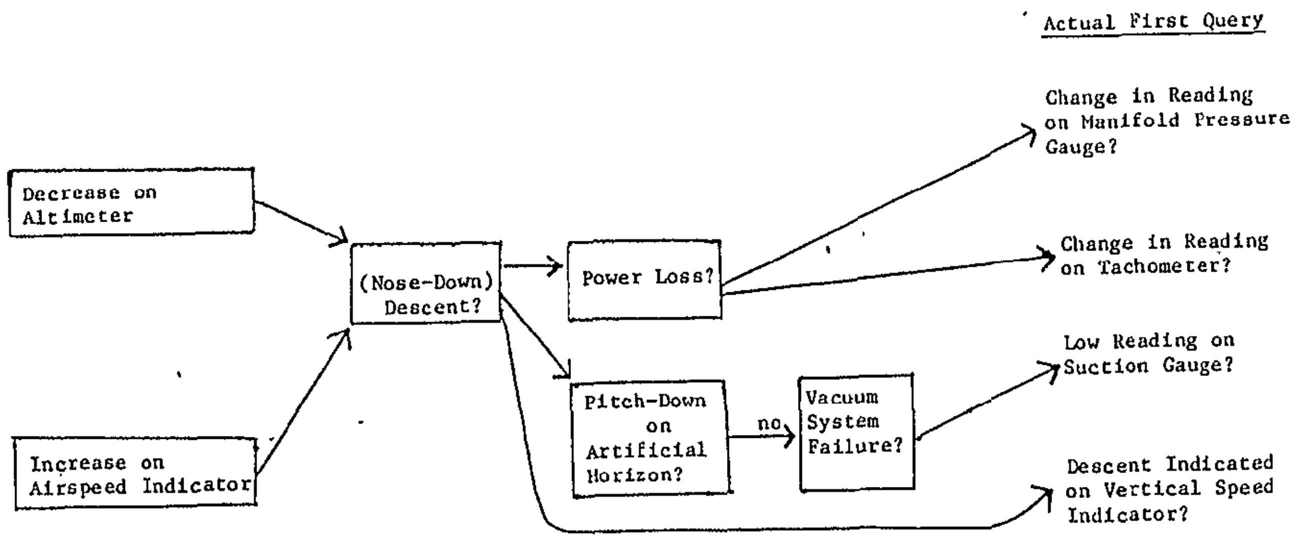


Figure 3-4. Alternate Paths Leading to Initial Queries for Seven Subjects Activating the (Nose-Down) DESCENT Frame.

nature to occur. Assume the frame is valid and look for possible causes.

6. Subjects differ in terms of:

   a. The instructions contained in particular frames.

   b. The slot-fillers within a frame that are (first) acted on when following an instruction (check manifold pressure for expected reading vs. check tachometer).

In addition, the frame system developed thus far indicates that subjects may not use all of the available cues or data in order to activate an initial frame. The scenario that was read stated twice in a row:

> "The instruments indicate an increase in airspeed,
> a steadily decreasing altitude, and zero pitch."

Yet the evidence reviewed above indicates that these pilots initially focused their attention on the indicated increase in airspeed and decrease in altitude. These two cues are both indicative of a nose-down DESCENT. The third instrument indication (zero pitch) is inconsistent with this hypothesis. (If the plane is descending with increasing airspeed, the nose should be pitch down. If the pitch is zero and the airspeed is increasing, the plane should not show a decrease in altitude.)

What, then, were the determinants of attention for these subjects? What made the airspeed and altitude information more salient initially? Three possible causes come to mind:

1. Studies of human perception and attention suggest that:

   > "the perceptual system actively attempts to
   > reconstruct the external environment in an effort to cope
   > with the massive volume of information it continually

> encounters. ... the 'match-mismatch' notion clearly identifies the unexpected as a, if not the, crucial determinant of attention" (Dember and Warm, 1979, p. 131).

Extending the same concept to the "perception" or comprehension of text (the scenario), it is predictable that, in this problem, the indications regarding airspeed and altitude should be more salient than that of pitch. Prior to hearing about these instruments indications, the subject was told that the plane has been cruising for 15 minutes at a constant altitude. Thus, a mental model or reconstruction of the situation would indicate a constant airspeed, no change in altitude, and zero pitch. This means that two of the cues, an increase in airspeed and a decrease in altitude are unexpected and hence predicted to be highly salient. The third cue, zero pitch, is consistent with the constructed mental model, and therefore not as likely to attract attention.

2. Studies of human word recognition suggest that specific feature detectors (letters, shapes, etc.) are activated when a word is presented and that these feature detectors in turn activate word detectors (Morton, 1970; Rummelhart and Siple, 1974). Meyer, Schvaneveldt, and Ruddy (1975) have suggested that when a word detector is activated, it may prime its associated feature detectors. The net result is that if a new word with some of the same feature detectors is presented, these feature detectors will fire faster than usual (i.e.,

these features will be noticed more rapidly, will be more salient) and the new word will be identified sooner.

The same type of process could occur during the reading of the scenario. The pilot has been told that a problem exists and that he must diagnose its cause. It is quite plausible that, before listening to the scenario, the pilot speculates on possible problems. An unplanned descent is a common problem (relatively speaking) that is also very serious. Hence, it is a problem that the pilot is likely to conjecture about prior to hearing the scenario. Such a conjecture about DESCENT could prime associated triggers (such as decreasing altitude), increasing their salience.

3. Bower, Black and Turner (1979) state that:

> "according to schema theory the understander must commit himself to some initial schema in order to understand sentences; yet the most diagnostic information may not appear in the text until later. That is, one can be lead down 'garden path' stories" (p. 340).

Given the predicted salience of the increasing airspeed and decreasing altitude (the unexpected events) and the fact that these two cues are presented first, the pilot may already have been in a DESCENT down the "garden path" before hearing about the zero pitch.

If the activated frame (DESCENT) instructed him to consider the reading on the vertical speed indicator (Subjects #2 and #10) or to consider a possible power loss (Subjects #4, #6, and #18), the information about zero pitch might easily have been ignored as irrelevant.

If, on the other hand, the activated frame instructed the pilot to consider the reading on the artificial horizon (Subjects #1 and #5), the salience of the third instrument indication, zero pitch, would be increased and the cue would likely be noticed.

In order to avoid information overload, then, the pilots may have used these types of mechanisms to focus attention selectively on some subset of the cues available in the scenario.

Nose-Level DESCENT. The seven pilots discussed above reported that they thought the plane was in a nose-down descent. Subject #16, on the other hand, thought the plane was in a:

> "straight and level descent, nose on the horizon" (Task 4).

He proceeded to check for possible causes of descent after activating the frame for Nose-level DESCENT (see Figure 3-5).

Subject #13 also activated the DESCENT frame as evidenced by his comment that "we are basically in a situation where we are losing altitude." The evidence indicates that he, like Subject #16, activated a frame representing Nose-Level DESCENT. When asked about his impression of the plane's physical orientation (Task 4) he stated that initially he thought:

External Cues

Frame Label: DESCENT (NOSE-LEVEL)*

Causes: POWER LOSS

Instructions: CHECK TO SEE WHETHER CAUSE IS PRESENT

⟹

Frame Label: POWER LOSS

Expectations: CHANGE IN TACHOMETER READING

Instructions: CHECK TO SEE WHETHER EXPECTATIONS ARE MET

Supporting Comments: "Start checking the power instruments. What does the tachometer show?"

*This label is supported by the data from Task 4 (see text).

Figure 3-5. Subject #16.

"the plane was descending in a straight and level cruise situation but that I'm losing altitude. Nose on the the horizon."

This recollection is consistent with his statements at the beginnning of the problem solving task:

S#13: "What is the manifold pressure?"

Experimenter: "Why are you interested in that?"

S#13: "Very definitely we have a situation where we seem to be losing power. The fact that we're decreasing in altitude and our airspeed is remaining steady indicates to me that we are basically in a situation where we are losing altitude. I would expect the airspeed to stay fairly constant if we're coming down."

These three conditions (losing power, decreasing altitude and constant airspeed) are consistent with the behavior of a plane that is in a nose-level descent due to a loss of power.

These data would suggest, then, that this pilot activated a frame for Nose-Level DESCENT by attending to two cues: a decrease shown on the altimeter and zero pitch shown on the artificial horizon. Having activated this frame, an associated default value (constant airspeed) was also activated, in spite of the fact that it contradicted information given in the scenario (see Figure 3-6).

What is even more interesting is the fact that immediately before he asked for the reading on the manifold pressure gauge (see the quotation above), Subject #13 said:

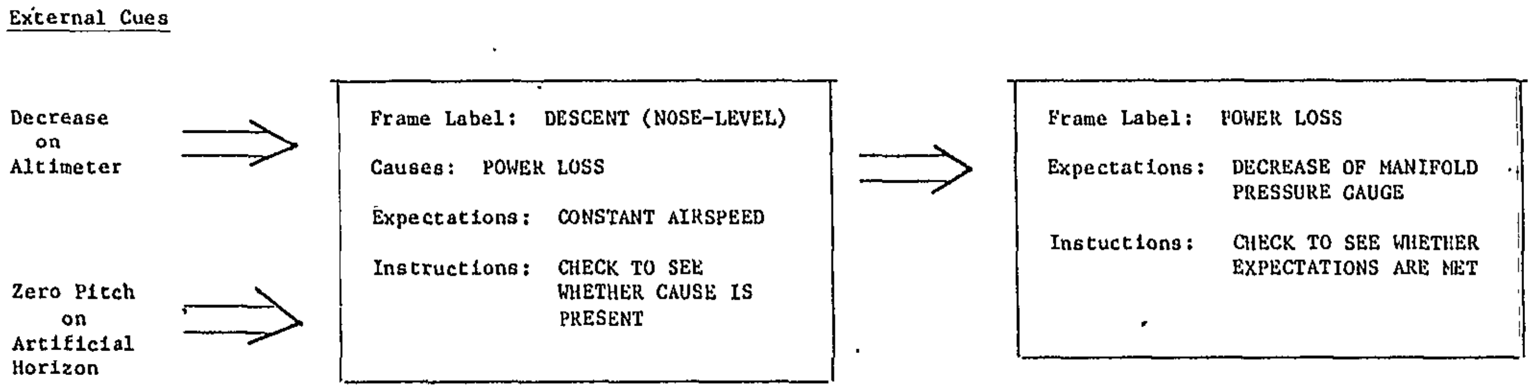


Figure 3-6. Activation of Initial Frames for Subject #13.

> "Let me get this straight now. Increasing airspeed, decreasing altitude and you mean pitch as far as being above or below the horizon based on the attitude [artificial] horizon." [This was a statement, not a question. No response was given.]

Thus, this pilot heard all three cues initially. Then, paying attention to the pitch and altitude information, he activated the Nose-Level DESCENT frame. He also activated this frame's default value for the reading on the airspeed indicator (constant airspeed), distorting his memory. He believed (stated) at this point that the scenario indicated a constant airspeed. All of this occurred in a time period of less than one minute.

Having activated the Nose-Level DESCENT frame, Subject #13 then followed its instructions and checked for a possible cause of descent. This resulted in the activation of the POWER LOSS frame, which generated his first query: "What is the manifold pressure?" (See Figure 3-6.)

Subject #11 also initially activated the Nose-level DESCENT frame. His recollection (Task 4) that:

> "my first impression was level descent"

is consistent with his statements immediately after hearing the scenario:

> "The first thing he should do is check his power. ... If power has not changed, then in level flight his airspeed wouldn't change. To make sure I'm right on the scenario, what does the airspeed indictor show?"

Unlike Subject #13, this pilot did not distort his memory when the Nose-Level DESCENT frame was activated. He noted the possible inconsistency between the expected airspeed and his recall of the scenario-given airspeed, and checked to make sure his recall was correct before continuing (see Figure 3-7). (After learning that the airspeed was in fact increasing he rejected the Nose-Level DESCENT frame in favor of the Nose-Down DESCENT frame.)

MEMORY ERROR. Subject #9 also activated a MEMORY ERROR frame. He asked:

"You say he's decreasing airspeed?"

How he distorted his recall (the indicated airspeed was increasing) or how he arrived at the MEMORY ERROR frame cannot be determined from his data. After asking the above question and correcting his memory error, he activated the Nose-Down DESCENT frame.

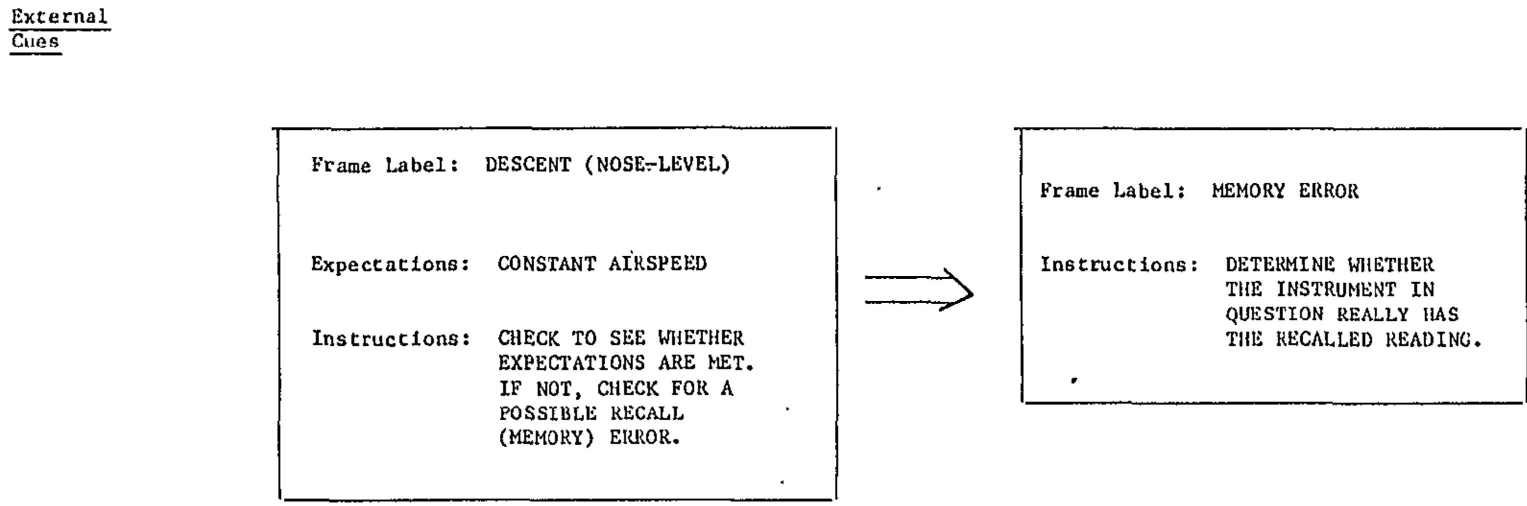


Figure 3-7. Initially Activated Frames for Subject #11.

PITOT-STATIC SYSTEM MALFUNCTION. The subjects discussed above activated a DESCENT frame. The seven subjects to be discussed next, however, initially focused their attention on the possibility of a PITOT-STATIC SYSTEM MALFUNCTION.

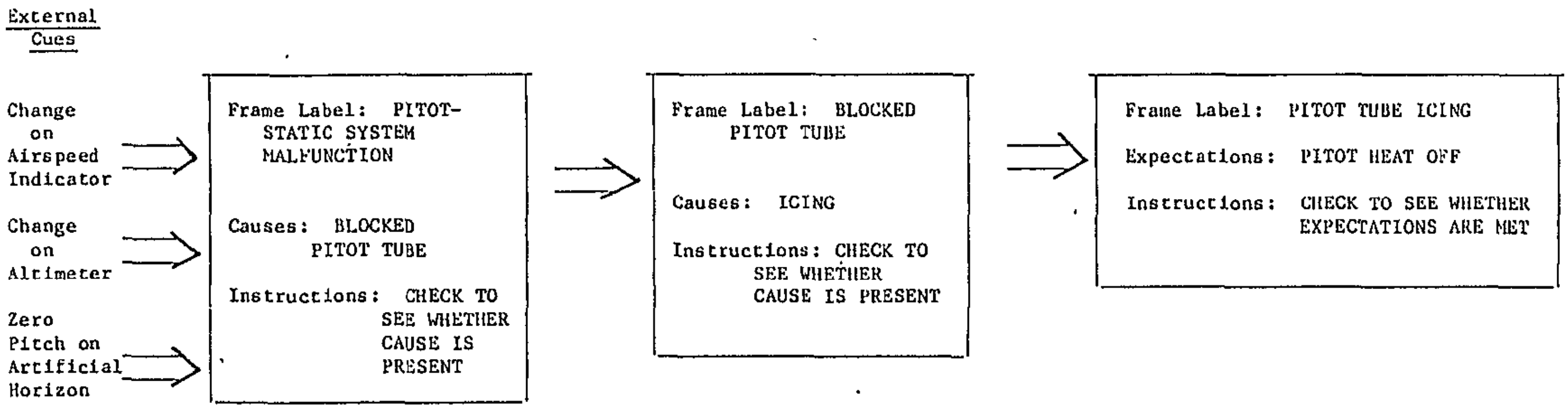
Figure 3-8(a-e) shows the frame system constituents supported by the data from these seven subjects. Again, comments are provided to indicate the data supporting the proposed model.

The evidence suggests that these subjects activated the PITOT-STATIC SYSTEM MALFUNCTION frame because they noticed an unexpected change in the readings on two pitot-static system instruments, the altimeter and the airspeed indicator. Their attention appeared to focus on the fact that there was an unexpected change. They did not appear to consider whether the stated changes were actually consistent with a pitot-static system malfunction (they were not).

There is again evidence of memory distortions once the PITOT STATIC SYSTEM MALFUNCTION frame was activated:

> "To be honest with you, at first I thought you said the airspeed was decreasing and the altitude was showing a decrease, you know, a loss of altitude. So I was thinking that those were exactly backwards."

> "When we first started the problem, I misunderstood the indications... I thought you said the opposite, like the airspeed was increasing, and the altitude was increasing. That's what made me go to the static source at first" (data from Task 4).



Supporting Comments:

"The airspeed and the altimeter are both part of the pitot-static system and if he's been using a constant power and a constant attitude, power plus attitude is equal to performance so there should have been no change in performance. Is the pitot heat on?" [Why?] "I was wondering if there might be in that area icing. Picking up some icing."

Figure 3-8a. Subject #14.

External Cues

Frame Label: PITOT-STATIC SYSTEM MALFUNCTION

Causes: BLOCKED PITOT TUBE

Instructions: CHECK TO SEE WHETHER CAUSE IS PRESENT

⟹

Frame Label: BLOCKED PITOT TUBE

Causes: ICING

Instructions: CHECK TO SEE WHETHER CAUSE IS PRESENT

⟹

Frame Label: PITOT TUBE ICING

Expectations: LOW READING ON OUTSIDE AIR TEMPERATURE GAUGE

Instructions: CHECK TO SEE WHETHER EXPECTATIONS ARE MET

Supporting Comments:

"My first thoughts are that there's definitely going to be a problem with the pitot-static system. What's the outside air temperature reading?" [Answer given: 37°F.] "There's still a possibility of icing build-up so part of the way to determine that would be to flip on the pitot heat."

Figures 3-8b. Subject #20.

External Cues

Decrease on Altimeter ⟹

Frame Label: PITOT-STATIC SYSTEM MALFUNCTION

Expectations: INCONSISTENT READING ON VERTICAL SPEED INDICATOR

Instructions: CHECK TO SEE WHETHER EXPECTATIONS ARE MET

Supporting Comments:

S#3 - "Steadily decreasing altitude. Then I would also assume that includes then a showing a descent on the vertical speed indicator having a reading consistent with the altimeter. To try to narrow down is it a pitot-static system problem."

S#19 - "Number one, look at the vertical speed indicator. It appears that it could be a problem with the pitot-static system."

Figure 3-8c. Subjects #3 and #19.

External
Cues

Frame Label: PITOT-STATIC SYSTEM MALFUNCTION

Causes: BLOCKED STATIC PORT

Instructions: CHECK TO SEE WHETHER CAUSE IS PRESENT

⟹

Frame Label: BLOCKED STATIC PORT

Causes: ICING

Instructions: CHECK TO SEE WHETHER CAUSE IS PRESENT

⟹

Frame Label: STATIC PORT ICING

Expectations: LOW READING ON OUTSIDE AIR TEMPERATURE GAUGE

Instructions: CHECK TO SEE WHETHER EXPECTATIONS ARE MET

Supporting Comments:

"My first thing that I would think of would be something to do with either the static port or the pitot tube since those instruments, the airspeed and the static port are different, so I would think, also, the altimeter I know is getting its reading from the static port so the first thing I would think of would be a problem with the static port. What is the outside air temperature?" [Why?] "'Cause I'm thinking it could be a possibility of something freezing."

Figure 3-8d. Subject #8.

External Cues

Zero Pitch on Artificial Horizon ⟹

Frame Label: *

⟹

Frame Label:	BLOCKED STATIC PORT
Expectations:	INSTRUMENT READINGS RETURN TO NORMAL IF ALTERNATE STATIC SOURCE OPENED
Instructions:	CHECK TO SEE WHETHER EXPECTATIONS ARE MET

Supporting Comments:

S#12 - "What happens if I open the alternate static source?" [Why?] "I suspect from what is happening, since there is no pitch change, that there may be a blockage in the system that's causing faulty instrument readings. I don't know yet what but that's my first indication."

S#17 - "What if I open my alternate static source?" [Why?] "To see if I have a clogged port."

Figure 3-8e. Subjects #12 and #17.

*To be consistent with subject #8 (see Figure 8d) the frame for BLOCKED STATIC PORT should be accessed through another frame (PITOT-STATIC SYSTEM MALFUNCTION).
Figure 8(a-e). Activation of Initial Frames for Seven Subjects Focusing on a Pitot-Static System Malfunction.

Thus, because they had activated the PITOT-STATIC SYSTEM MALFUNCTION frame, the pilots reconstructed their memories (Zechmeister and Nyberg, 1982) to be consistent with such a state of nature.

Figure 3-9 summarizes the alternative mental processes exhibited by these seven pilots while selecting their initial queries.

ICING. Like three of the pilots who activated the PITOT-STATIC SYSTEM MALFUNCTION frame, Subject #7 thought that icing was causing the problem. We cannot tell, however, whether he was concerned with icing of some particular part of the plane:

> "You're in IFR conditions, so was there any visible moisture outside?" [Why?] "Because it might be in regards to icing."

AIRSPEED INDICATOR MALFUNCTION. Subject #15 asked:

> "Is there an increase in noise outside the plane?" [Why?] "That would indicate an increase in airspeed, would back up that instrument indication."

These comments make it clear that the pilot was attending to the indicated increase in airspeed, but provide little other insights into his mental processes.

Summary. The goal of this subsection on the Initial Activation of Frames was to describe the mental processes that generated pilots' first queries. If we look at the information requests above, we see one "stimulus" (the scenario plus associated instructions) resulting in ten different initial responses (first queries) from a total of twenty subjects (see Table 3-4). Two general questions arise:

1. Why does a particular subject request a given piece of information?
2. Why do not all subjects ask for the same piece of information?

The frame system model outlined thus far indicates that there is a substantial amount of information processing that occurs before a pilot makes his first query. Individuals differ in the cues to which they attend while listening to the scenario, in the lines of reasoning that they apply once a frame has been activated, and in the slot-fillers contained in a given frame (Expectations: DESCENT INDICATED ON VERTICAL SPEED INDICATOR vs. Expectations: PITCH DOWN ON ARTIFICIAL HORIZON). They may also distort their memory to be consistent with the activated frame. These differences can account for the great heterogeneity found in the initial queries.

Subjects activating the Nose-Down DESCENT frame (see Figure 3-3) were attending to two cues, an indicated increase in airspeed and decrease in altitude. Those activating the PITOT-STATIC SYSTEM MALFUNCTION frame (see Figure 3-8), on the other hand, appeared to focus on the information that there was <u>some</u> unexpected change in the readings on the airspeed indicator and the altimeter. They did not attend to the specific directions of these changes when activating this MALFUNCTION frame. Such differences in cue selection led to radically different questions, ranging from queries about a POWER LOSS to tests for a BLOCKED STATIC PORT.

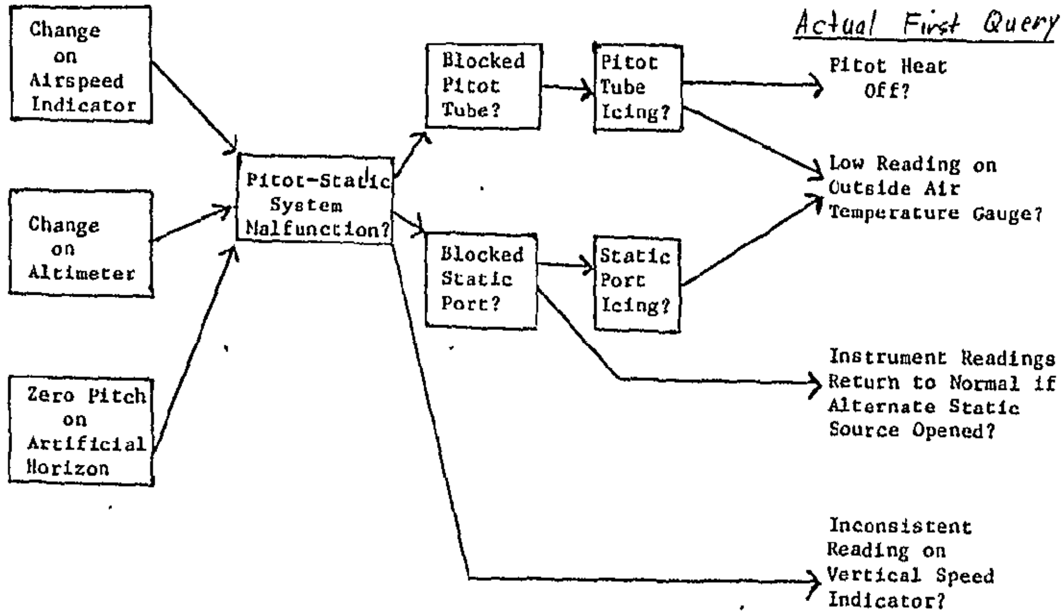


Figure 3-9. Alternative Paths Leading to Initial Queries for Seven Subjects Activating the PITOT-STATIC SYSTEM MALFUNCTION Frame.

Even when two pilots activated the same initial frame (such as Nose-Down DESCENT) they sometimes applied different heuristics to further evaluate that frame. Subjects #2 and #10 activated the DESCENT frame and tested its validity by looking at the vertical speed indicator for the expected reading. Subjects #4, #6, and #18 also activated the DESCENT frame, but checked for a possible cause of DESCENT, a POWER LOSS. Thus, the application of different "Instructions for Use" resulted in significantly different queries.

Finally, even if two pilots activated the same frame and applied the same instructions, they still sometimes asked different questions. Subjects #6 and #18 were both concerned with POWER LOSS, but one checked the manifold pressure gauge for the expected reading while the other checked the tachometer. (The reading on the tachometer is actually uninformative since the Cherokee Arrow has a constant speed prop.)

Organization of the Knowledge Structures

The previous analysis identified ten different frame labels, based on the pilots' first queries and associated statements. Applying the same form of analysis to the remainder of the verbal protocols, we find evidence for eight additional frames:

1. ARTIFICIAL HORIZON MALFUNCTION

   "Because there could be a malfunction with the artificial horizon."

   "I'm thinking that the artificial horizon's not working."

2. STRUCTURAL ICING (WINGS)

"Is there ice on the wings?" [Why?]
"It gives you more drag and it adds weight."

"Is there ice, am I receiving ice on the wings?"

3. TRIM WHEEL MISPOSITIONED

"Let's check trim to see if had disturbed it, although I should see something on the pitch attitude indicator if I did have a problem with trim. What is the position of the trim tab?"

4. DOWNDRAFT

"At 6000 feet you could have turbulence which would cause a problem with maintaining altitude ... could indicate whether it's turbulent air, downdrafts."

5. GEAR DOWN

"If the landing gear's down for some reason..."

"Is the gear extended?"

6. FLAPS DOWN

"Are the flaps down? If the plane is trimmed for cruise flight, clean, then if you induce any drag that could take care of your airspeed and start a descent for us."

7. BANKED PLANE

"What does the artificial horizon show?" [Why?] "Are we in a bank?"

8. YOKE MISPOSITIONED

"If the pilot has decreased backpressure, pushed the elevator forward...which causes the nose to go down... What is the yoke position currently?"

All of the queries made by the twenty pilots can be accounted for in terms of attempts to access or to test the validity of the eighteen frames that have been defined. Below is an exhaustive mapping of the interrelationships among these frames and the queries they generated. This mapping is consistent with all of the data. Not all pilots that activated a given frame made all of the queries listed. Also, the ordering is arbitrary in the listings of slot-fillers. Note that there are seven high-level frames (indicated by Roman numerals) in this frame system. (V and VI may not be high-level frames, but the available evidence did not establish at which lower levels they would belong.)

I. NOSE-DOWN DESCENT
  A. Causes:
    1. POWER LOSS
    Queries: Check for Expected Readings From:
      a. Manifold Pressure Gauge
      b. Tachometer
      c. Oil Pressure Gauge
      d. Oil Temperature Gauge
      e. Effect of an Increase in Power Using the Throttle.
    2. STRUCTURAL ICING
      Queries: Check for
      a. Visible Ice on Wings
      b. Visible Ice on Windshield
      c. Visible Ice on Temperature Probe
      d. Reading on Outside Air Temperature Gauge
      e. Visible Moisture in Air.
    3. DOWNDRAFT
      Queries: Check
      a. Weather Reports
      b. Whether Air (Ride) Feels Rough
      c. Outside Air Temperature Gauge
      d. Mountainous Terrain.
    4. GEAR DOWN
      Queries: Check
      a. Gear Down Light.
    5. TRIM WHEEL MISPOSITIONED
      Queries: Check
      a. Trim Wheel Position
      b. Artificial Horizon.

6. YOKE MISPOSITIONED (DECREASED BACKPRESSURE)
   Causes:
   a. ARTIFICIAL HORIZON MALFUNCTION
   Queries: Check
   a. Yoke Position.
7. FLAPS DOWN
   Queries: Check
   a. Flap Switch Position
   b. (Visible) Position of Flap.
8. BANKED PLANE
   Causes:
   a. YOKE MISPOSITIONED (LEFT TURN)
      Causes:
      1. ARTIFICIAL HORIZON MALFUNCTION
   Expectations/Queries:
   a. Bank shown on turn and bank indicator
   b. Bank shown on artificial horizon.

B. Expectations/Queries: Check for
   1. Nose-down on artificial horizon
   2. Descent shown on altimeter
   3. Descent shown on vertical speed indicator
   4. Increase shown on airspeed indicator
   5. If backpressure applied to yoke, instrument indications of descent will cease or be reduced in magnitude.

II. NOSE-LEVEL DESCENT

A. Causes:
   1. POWER LOSS
      Queries: Check for Expected Readings From:
      a. Manifold Pressure Gauge
      b. Tachometer
      c. Oil Pressure Gauge
      d. Oil Temperature Gauge.
   2. STRUCTURAL ICING
      Queries: Check for
      a. Visible Ice on Wings
      b. Reading on Outside Air Temperature Gauge.
   3. GEAR DOWN
      Queries: Check
      a. Gear Down Light.
   4. FLAPS DOWN
      Queries: Check
      a. Flap Switch Position.
   5. BANKED PLANE
      Queries: Check
      a. Artificial Horizon.

B. Expectations/Queries: Check for
   1. Zero pitch on artificial horizon
   2. Descent on altimeter
   3. Descent on vertical speed indicator

4. Constant airspeed
5. If backpressure applied to yoke, instrument indications of descent will cease or be reduced in magnitude.

III. PITOT-STATIC SYSTEM MALFUNCTION
- A. Causes:
  - 1. BLOCKED STATIC PORT
    - a. Causes: 1. ICED STATIC PORT
      - Expectations/Queries: Check
        - a. Outside air temperature gauge.
    - b. Expectations/Queries: Check
      - 1. To see if instrument readings return to normal after alternate static source is opened.
  - 2. BLOCKED PITOT TUBE
    - a. Causes: 1. PITOT TUBE ICING
      - Expectations/Queries: Check
        - a. To see if pitot heat is off
        - b. Outside air temperature gauge.
- B. Expectations/Queries: Check
  - 1. To see if the readings on the altimeter, vertical speed indicator and airspeed indicator are inconsistent with one another.

IV. ARTIFICIAL HORIZON MALFUNCTION
- A. Causes
  - 1. VACUUM SYSTEM MALFUNCTION
    - a. Expectations/Queries: Check for
      - 1. Low reading on suction gauge
      - 2. (Possible) Inconsistent readings on the artificial horizon and directional gyro as compared with the turn and bank indicator, magnetic compass and course deviation indicator.
- B. Expectations/Queries: Check
  - 1. For the effect of a left turn input (with yoke) on the artificial horizon.

V. AIRSPEED INDICATOR MALFUNCTION
- A. Expectations/Queries: Check
  - 1. For an increase in air stream noise outside cockpit.

VI. ICING
- A. Expectations/Queries: Check for
  - 1. Visible moisture in the air
  - 2. Visible ice on the wings
  - 3. Visible ice on the temperature probe.

VII. MEMORY ERROR
- A. Expectations/Queries: Check the accuracy of recall for:
  - 1. The airspeed indicator.

It is clear that such a frame system could be expanded to include more levels (POWER LOSS is caused by FUEL STARVATION, INDUCTION ICING, etc.) and additional hierarchies. These additional frames are unnecessary, however, to account for the data from this experiment.

Each frame contains two slots, one for causes of that state of nature and one for expected instrument readings and observable conditions (visible ice on wings, etc.) if that state of nature exists. Each of these slots contains one or more entries (a list of possible causes or expected readings). Figure 3-10 summarizes this basic frame structure.

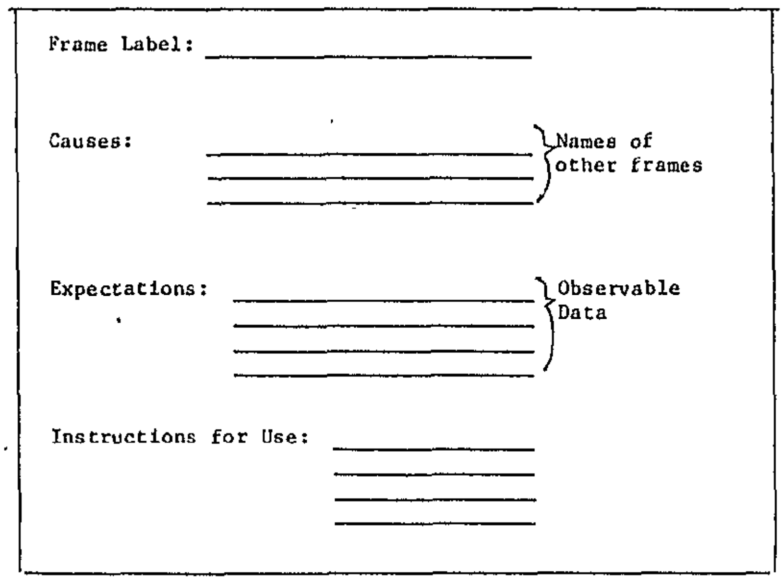


Figure 3-10. Frame Structure.

Searching for Goal-States

In this experiment, the pilots were told that:

1. There is a problem.

2. The goal is to determine the cause of the problem.

In terms of the proposed knowledge structures, this goal can be translated as follows: Complete the sentence:

1. The problem is X;

2. The cause of the problem is Y;

where X is a Frame Label belonging to some "Problem" set:

Problem = [NOSE-DOWN-DESCENT,
POWER LOSS, etc.]

and Y is one of the slot-fillers for the "Causes" slot in the frame with label X.

Fault diagnosis can be described as a task of:

1. Hypothesizing the presence of a particular problem (e.g., NOSE-DOWN DESCENT).

2. Deciding whether this problem exists (e.g., checking the vertical speed indicator for a descent, etc.).

3. Determining the cause of this problem (e.g., checking for POWER LOSS, DOWNDRAFT, etc.).

Because the problem may actually be a causally-connected chain of events, it may be necessary to repeat this task in a recursive fashion until the initiating cause is discovered.

This problem-solving process can be illustrated by looking at the data for Subject #1. (See the beginning of the Results and Discussion section for his verbal protocol.)

Step 1.

Hypothesized Problem: Unexpected decrease in altitude and increase in airspeed.

Possible Cause: NOSE-DOWN DESCENT

Step 2.

Hypothesized Problem: NOSE-DOWN DESCENT

Test of hypothesis: Check for pitch down on artificial horizon

Conclusions: Either the plane is not in a NOSE-DOWN DESCENT or there is an ARTIFICIAL HORIZON MALFUNCTION

Step 3.

Hypothesized Problem: ARTIFICIAL HORIZON MALFUNCTION

Possible Cause: VACUUM SYSTEM MALFUNCTION

Step 4.

Hypothesized Problem: VACUUM SYSTEM MALFUNCTION

Test of hypothesis: Check for low reading on suction gauge.

Subject #1's conclusion was that:

"You have a nose-down attitude and the vacuum pump's gone."

Although no direct evidence is available to substantiate it, it is plausible that this statement implies the activation or development of a script (Schank and Riesbeck, 1981) describing the following set of events:

VACUUM SYSTEM FAILURE

caused

ARTIFICIAL HORIZON MALFUNCTION

caused

YOKE MISPOSITIONED (DECREASED BACKPRESSURE)

caused

NOSE-DOWN DESCENT.

Fault diagnosis then, can be described as a process of recursively identifying problems and their causes until the person decides he has found the initiating cause. The data indicate that, in order to drive this process, subjects attempt to answer six types of questions:

1. Is the currently activated frame a goal-state? (Have I achieved the goal of finding the (initiating) problem X and its cause Y?)
2. What is the cause of the state of nature represented by this frame?
3. Is this frame a valid representation of the state of nature? Are the expected instrument readings and conditions present?

4. If the currently activated frame has been rejected as a possible state of nature, can I find another frame to activate?
5. Is there a recall (memory) error?
6. Is there an instrument malfunction?

The performances of the twenty pilots in terms of pursuing these fundamental questions (asking about causes, expectancies, etc.) are summarized in Figures 3-11 to 3-15. A path from a high-level frame (e.g., NOSE-DOWN DESCENT) to a node labeled "Expectations" means that the pilot checked for presence of one or more of the instrument readings and conditions predicted to be present by that frame (e.g., DESCENT SHOWN ON VERTICAL SPEED INDICATOR). A path from a high-level frame to a node labeled "Causes" indicates that the pilot tested for the presence of one or more of the possible causes associated with that frame. A path to a new high-level frame means that that frame was activated (and the originating frame de-activated). Paths leading from "Expectations" or "Causes" back to a high-level frame indicate that the pilot proceeded to ask another one of the six questions listed above with respect to the same high-level frame.

The number next to a link indicates the number of pilots who followed that path at least once (no pilot followed a path more than twice, and even this was unusual). The dotted arrows indicate special cases, where the pilots went directly from a violation of an expectation (the artificial horizon showed nose-level when it was expected to indicate nose-down) to a new frame (artificial horizon malfunction), or from checking for possible causes directly to a conclusion. The only result not shown on these figures is the finding that Subject #7 discovered the vacuum system failure, then checked for another possible failure in the pitot-static system (rejecting this possibility), finally returning to vacuum system failure as his conclusion.

Note that Group A (Figure 3-11) consists of the eleven subjects who diagnosed the problem as a vacuum system failure. Group B (Figure 3-12) pilots concluded that there was an artificial horizon malfunction. Group C (Figure 3-13) concluded the problem was a downdraft. Group D pilots (Figure 3-14) concluded the cause of the problem could not be determined with the available information.

Group E (Subject #20) discovered the presence of the artificial horizon malfunction. At that point he thought the plane was in a straight, nose-down descent that was not being indicated on the artificial horizon. He asked what would happen if he applied backpressure on the yoke to arrest the descent. When the expected response did not occur (because the plane was actually in a left spiral), he decided there must be some other problem. He failed to discover the left bank and concluded that he could not determine what the problem was (see Figure 3-15).

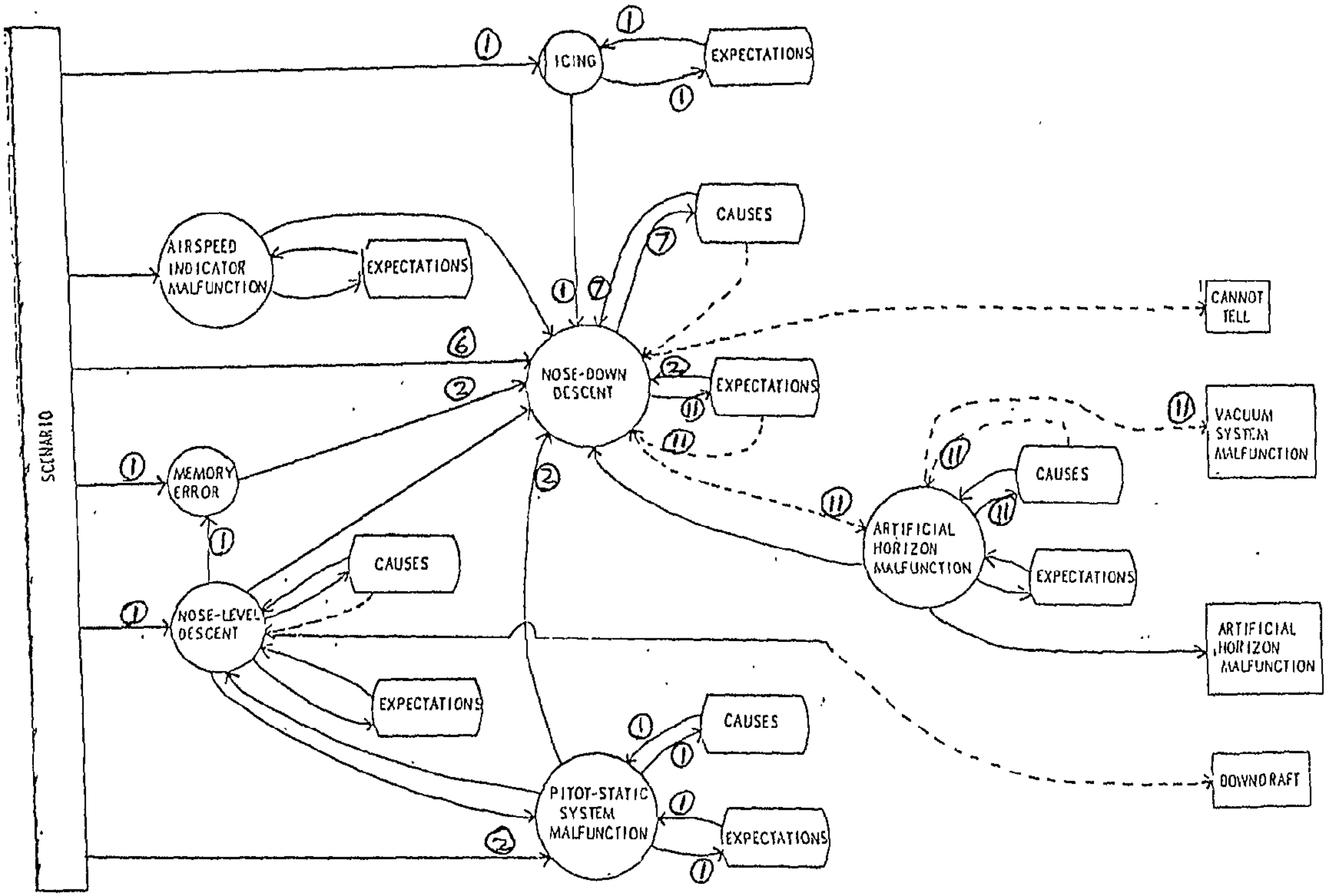


Figure 3-11. Processing by Subjects #1-11 (Group A).

Circled numbers indicate the number of subjects taking that path at least once.

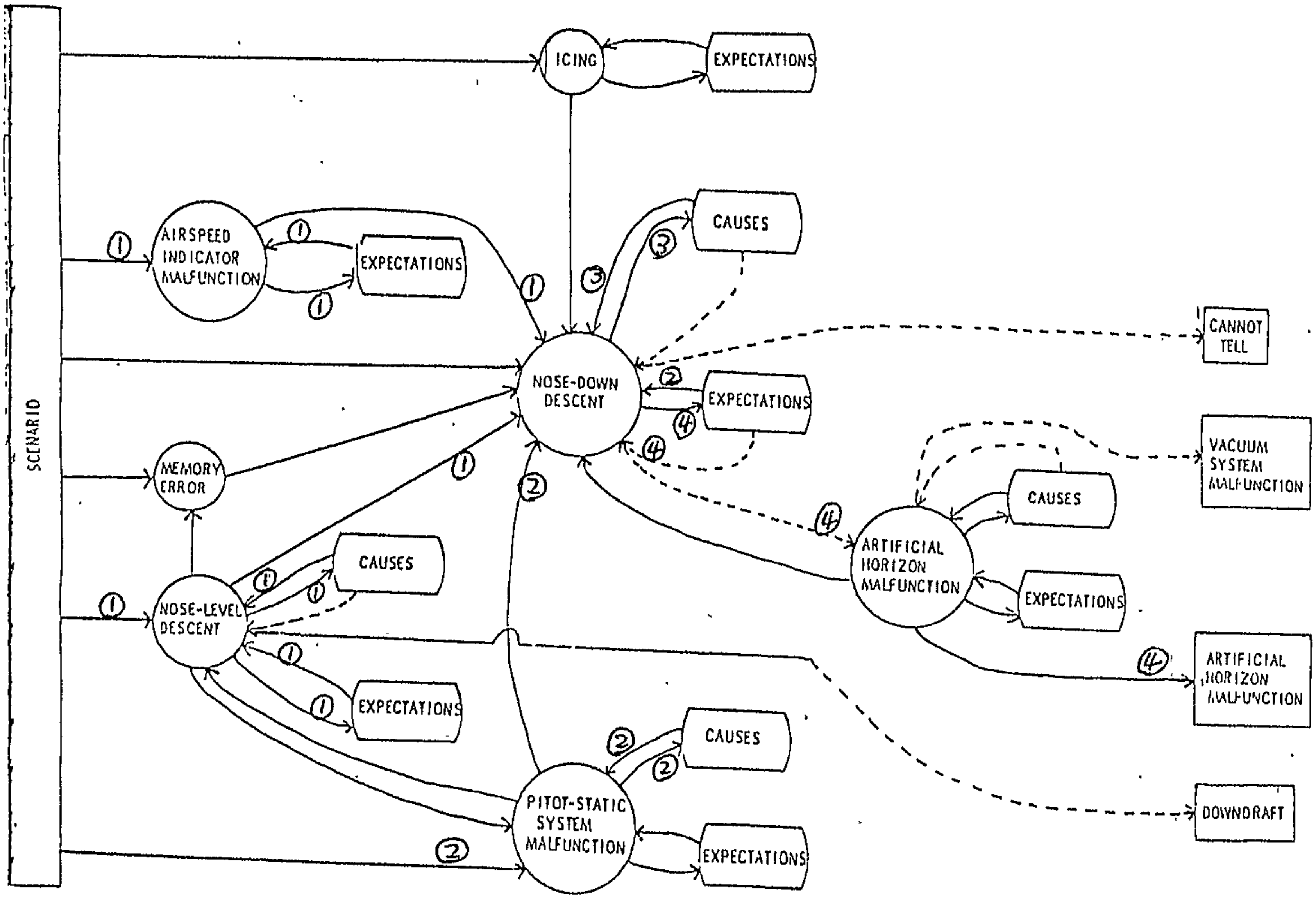


Figure 3-12. Processing by Subjects #12-15 (Group B).

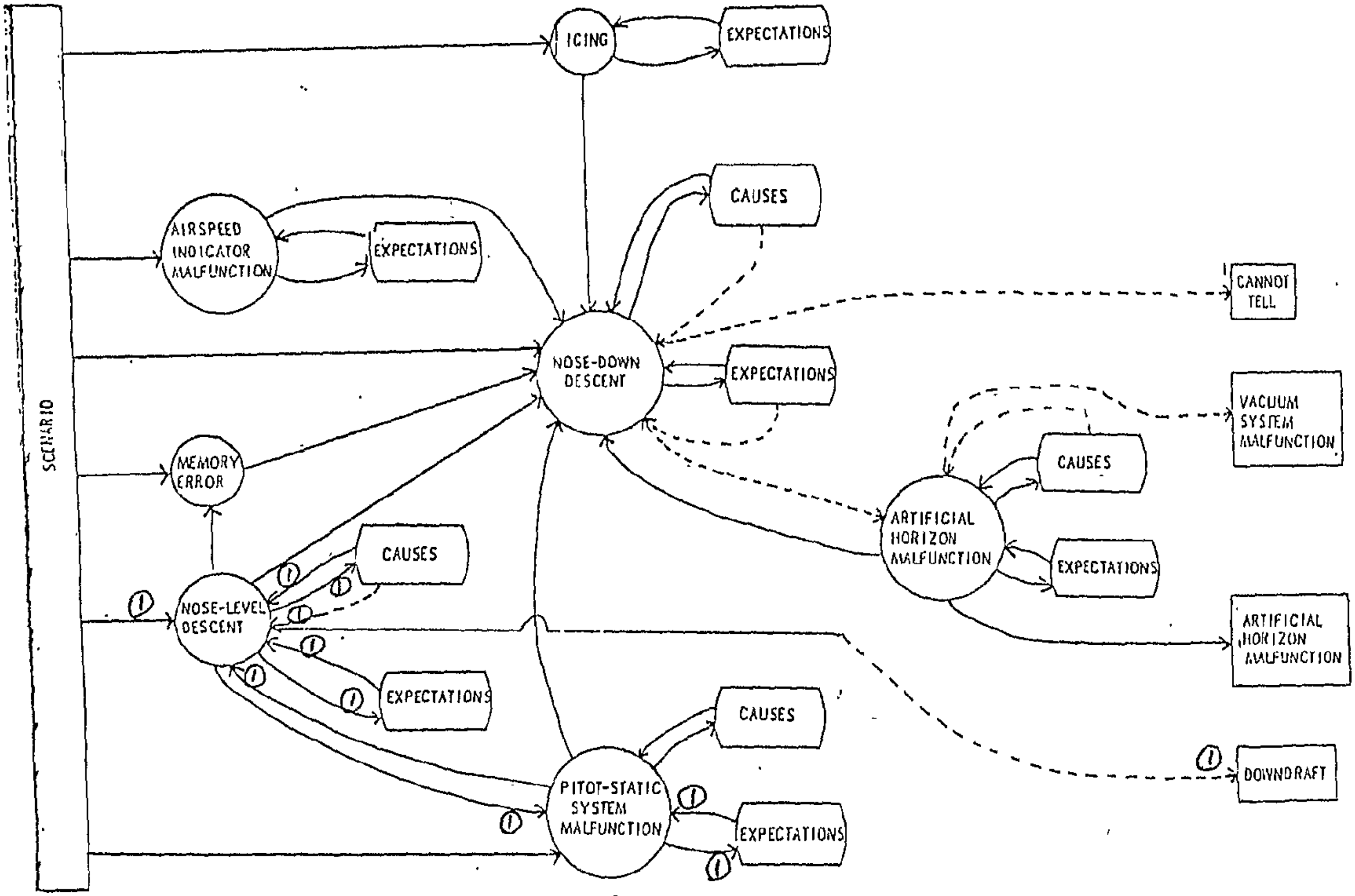


Figure 3-13. Processing by Subject #16 (Group C).

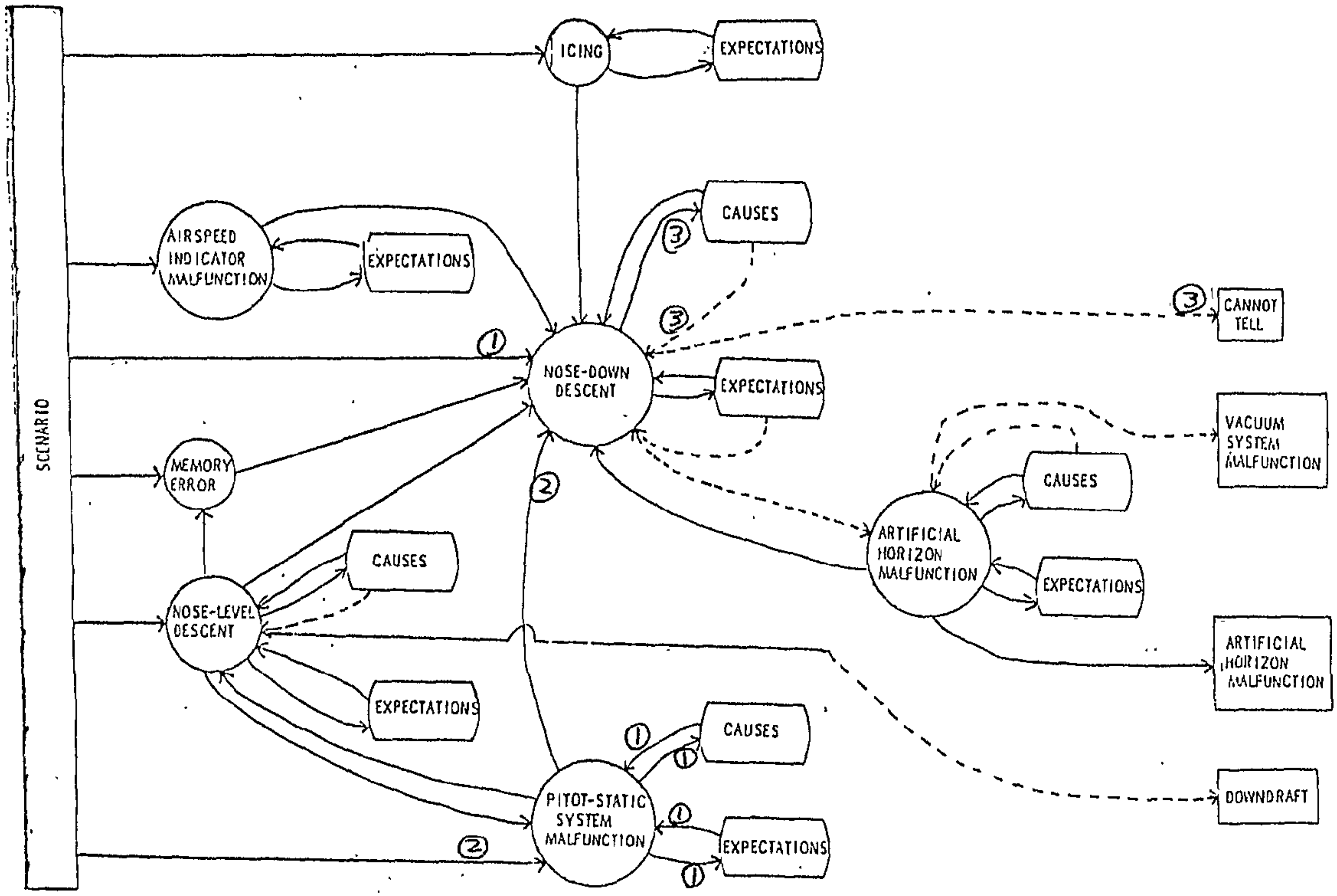


Figure 3-14. Processing by Subjects #17-19 (Group D).

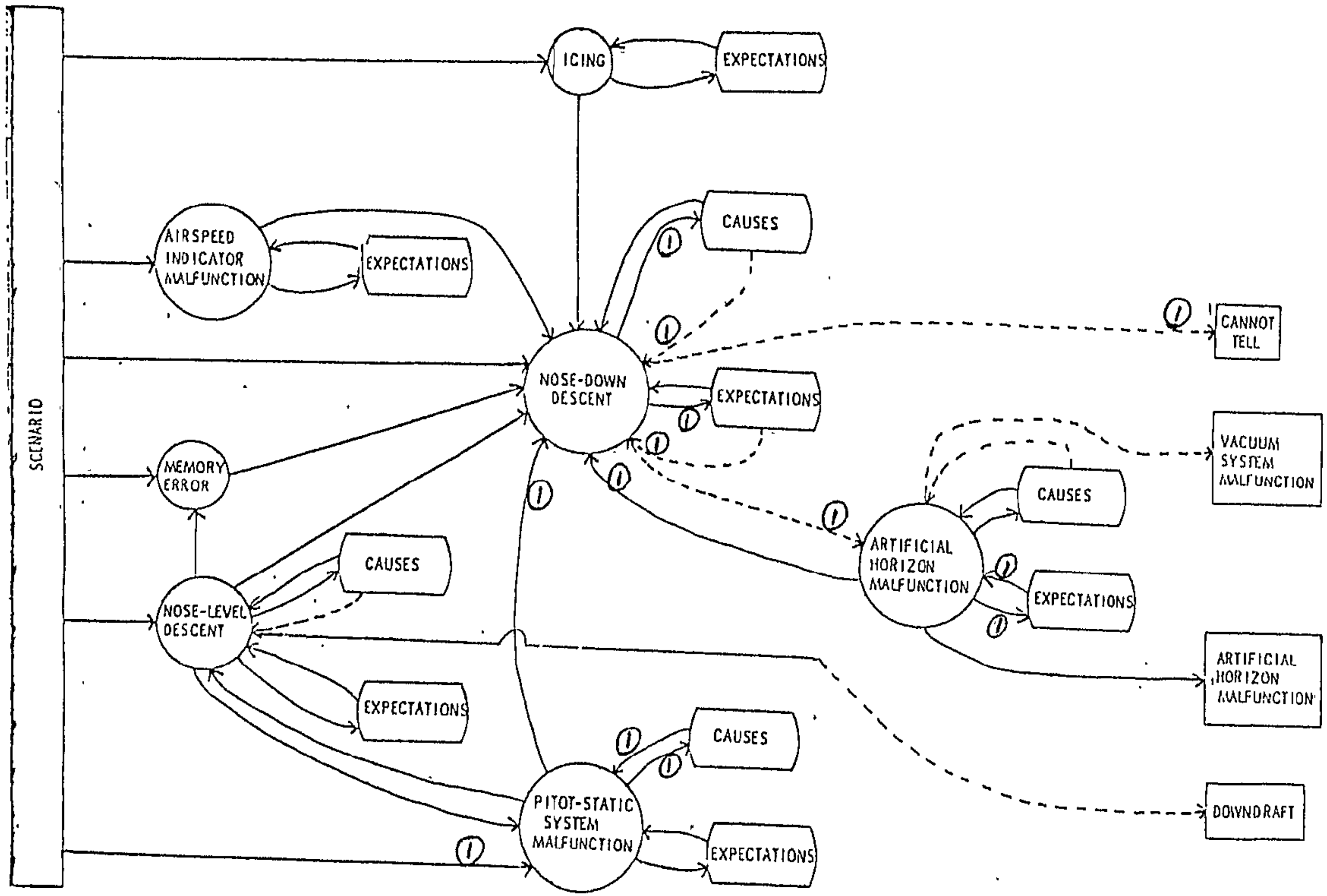


Figure 3-15. Processing by Subject #20 (Group E).

Patterns of Performance

The flow chart shown in Figures 3-11 to 3-15 is a high-level description of all the paths taken by one or more pilots. Groups A, B, C and D divide the subjects into four classes according to their final conclusions. (Group E is really a special case of Group B.)

The most apparent differences among the groups are the contexts in which the six alternative questions (check for goal state, check for causes, test expectations, look for new frame, check for memory error, or consider instrument malfunction) are addressed. Group B, for instance, differs from Group A by the failure to check for possible causes of the artificial horizon malfunction.

Cognitive Narrowing. The failure of Group B to determine whether a vacuum pump failure was causing the ARTIFICIAL HORIZON MALFUNCTION can be explained by a faulty ordering of the six questions in terms of application priority. Use of a simple rule would have almost certainly caused all the Group B pilots to discover the vacuum pump failure:

> Always check for possible causes of the state of nature represented by the currently activated frame before asking whether it is a goal-state.

(During Task 3, all of the pilots in Group B demonstrated that they had knowledge of the relationship between the vacuum system and the functioning of the artificial horizon.)

This explanation of Group B's failure to seek a deeper cause is consistent with pilots' explanations at the end of the experiment as to why they stopped without asking about the suction gauge:

"I just narrowed my vision down to one area, tunneled my vision down and stopped."

Activation of Default Values. All three pilots in Group D activated the NOSE-DOWN DESCENT frame. They then proceeded to check for possible causes of the descent. When they failed to find a cause they stopped and concluded the cause of the problem could not be determined with the available information.

Given the plane was in a nose-down descent, what accounts for this failure to find the cause? The answer lies in the activation of a default value. All three of these pilots reported that they thought the plane was in a straight nose-down descent (Task 4). Subject #18 even reported visualizing the turn and bank indicator, that the:

"Turn and bank indicator showed straight and level."

(In actuality he had been given no information about the turn and bank indicator, which showed a left bank.)

This data suggests that the pilots in Group D activated a default value for the direction of the NOSE-DOWN DESCENT, that the descent was straight ahead. They did so in the absence of any data to support this assumption. (On the other hand the plane had been cruising straight ahead, and they had not received any information clearly indicating a turn.)

The activation of this default value rules out the actual cause of the DESCENT, a BANKED PLANE. None of the subjects in Group D considered this as a possible cause of the descent.

Similarly, none of the pilots in Groups A and B considered a BANKED PLANE as a possible cause of the NOSE-DOWN DESCENT when they started looking for such a cause (see Figures 3-11 and 3-12). These pilots also assumed the plane was descending straight ahead when checking for a cause of the descent. The five subjects in Group A who ultimately concluded the plane was in a left-bank did so only after they discovered the vacuum system malfunction.

Changing Focus. Like the pilots in Group D, many of the subjects in Groups A and B checked for possible causes of a NOSE-DOWN DESCENT (see Figures 3-11, 3-12, and 3-14). They all failed to find the cause, a BANKED PLANE, because of a faulty assumption. Yet the pilots in Groups A and B continued and discovered the ARTIFICIAL HORIZON MALFUNCTION, while those in Group D stopped and concluded the cause could not be determined.

The difference in performance was that, after failing to find a cause for the NOSE-DOWN DECENT, the pilots in Groups A and B checked to see whether the "Expectations" for this frame were present. In particular, they checked to see whether the artificial horizon showed nose-down. When they found it did not, they began to investigate a possible ARTIFICIAL HORIZON MALFUNCTION.

Why did some pilots (Groups A and B) think about expected instrument readings in this context (failing to find a cause of DESCENT) while others (Group D) did not? One possible answer lies in the functions that checking expectations could serve. Addressing this question would help the pilot discover that he has:

1. Activated the NOSE-DOWN DESCENT frame based on insufficient information (such as increasing airspeed alone).

2. Activated the NOSE-DOWN DESCENT frame based on faulty information due to a recall error (memory distortion).

3. Activated this frame based on faulty information due to an instrument malfunction.

4. Activated this frame based on faulty assumptions (activation of incorrect default values).

Thus, asking this question could help the pilot discover that he is focusing his attention on the wrong frame(s).

Unlike the subjects in Groups A and B, the pilots in Group D never considered the possibility that they were addressing the wrong question. They assumed that the state of nature was a straight NOSE-DOWN DESCENT and tried to determine the cause. Subject #18 for instance, checked for:

POWER LOSS

STRUCTURAL ICING

GEAR DOWN

FLAPS DOWN

DOWNDRAFT

Upon finding that none of these causes were present, he immediately concluded that he could not diagnose the problem.

Slot-Fillers. If Subject #18 and the other pilots in Group D had switched their attention from the "Causes" slot of the NOSE-DOWN DESCENT frame to the "Expectations" slot, this could have focused their attention on the inconsistent reading on the artificial horizon and, consequently, on the ARTIFICIAL HORIZON MALFUNCTION. This assumes, of course, that the pilots looked at the right slot-filler in the "Expectations" slot.

In general the "Causes" and "Expectations" slots in a frame have multiple slot-fillers. When a question is addressed by focusing on one of these slots, it can be asked with respect to one or more of the slot-fillers. If it is not applied to the right slot-filler, critical information may be missed.

In this problem, five slot-fillers were identified for the "Expectations" slot in the NOSE-DOWN DESCENT frame. In terms of solving this particular problem the critical expectation is that of "Nose-down on artificial horizon." Two pilots in Group A activated the NOSE-DOWN DESCENT frame, and then checked the "Expectations" slot. The slot-filler they checked was "Descent shown on vertical speed indicator." When that expectation was met, they concluded that the correct frame had been activated and looked at the other slot (checked for possible causes) immediately, rather than considering all of the slot-fillers in the "Expectations" slot of the NOSE-DOWN DESCENT frame. Had they not tested additional expectations upon failing to identify a cause, they would not have solved the problem.

This suggests that another general rule should be followed:

Check all of a frame's "Expectations" slot-fillers before looking for possible "Causes". Otherwise, the pilot may fail to detect memory and activation errors, instrument malfunctions, and faulty (default) assumptions.

Cross-Checking Instruments. The proposed fault diagnosis process relies very heavily on the contents of the frames in order to achieve various goals. If those contents are inadequate, then checking all of the slot-fillers in the "Expectations" and "Causes" slots may not be sufficient to ensure detection of instrument malfunctions, incorrect assumptions, etc. Subject #16 (Figure 3-13) illustrates this point. This pilot was the only subject to consider a BANKED PLANE as a possible cause of DESCENT. He activated the NOSE-LEVEL DESCENT frame and checked for possible causes of DESCENT, including a BANKED PLANE. To check for a left bank, he asked for the indication on the artificial horizon (which showed straight and level flight). He did not check anything else to rule out a BANKED PLANE, and therefore falsely concluded that this was not the cause of the DESCENT.

This suggests that the slot-fillers for frames must be selected so as to ensure detection of instrument malfunctions. In this example, the "Expectations" slot of the BANKED PLANE frame should have directed the pilot to check both the artificial horizon and the turn and bank indicator to avoid reliance on a single instrument (system). Similar consideration is needed in selecting slot-fillers to ensure detection of activation and memory errors and incorrect activation of default values.

Selecting the Right Question. In an earlier section, the determinants of attention to certain cues were discussed. A similar issue can be raised with respect to the six fundamental questions that pilots asked:

How does a pilot decide which question to ask in a given context?

It has been suggested that these questions are addressed in order to achieve certain objectives (in which case we could ask how objectives are selected). It has been implied, for instance, that a pilot tests for the presence of a frame's expectations in order to discover:

1. Activation of the wrong frame based on incomplete information.
2. Memory distortions.
3. Instrument malfunctions.
4. Activation of incorrect (default) assumptions.

Thus, asking a question about "Expectations" represents a plan (Wilensky, 1983) for achieving an objective such as finding a new frame upon which to focus attention. This type of question selection processs can be modeled as a production system, as illustrated by the following example.

. If none of the possible causes associated with a frame are present, check to see whether the wrong frame has been activated (based on incomplete or erroneous information).

To see whether the wrong frame has been activated, check for the presence of that frame's "Expectations."

Pilots activating the PITOT-STATIC SYSTEM MALFUNCTION frame might check for two possible causes, PITOT TUBE ICING or STATIC PORT ICING, by checking the outside air temperature gauge. These would be rejected as possible causes because the temperature is too high for icing. The pilot should then check the "Expectations" associated with a PITOT-STATIC SYSTEM MALFUNCTION. Finding no inconsistencies on the airspeed indicator, altimeter and vertical speed indicator, the pilot would reject this MALFUNCTION frame.

<u>Goal-Directed vs. Data-Driven Processing</u>. The previous subsection suggested that information such as "Expectations" is used in order to achieve an objective. The implication is that the objective is selected by the pilot and that this directs the selection of an appropriate plan, which then focuses on a particular slot.

An alternative (or additional) explanation is that focusing attention on a particular slot, like the initial activation of some frame, is a data-driven process. Thus, a pilot might consider whether the reading on the artificial horizon is consistent with a NOSE DOWN DESCENT not because he feels it will help him achieve some objective, but because:

1. He remembers getting information about the plane's pitch.
2. Pitch information is relevant to one of the "Expectations" slot-fillers in the NOSE-DOWN DECENT frame.

This type of data-driven processing could be accomplished by some type of intersection search (Anderson and Bower, 1980) in which data activates both frames and slot-fillers. Questions are generated by looking at the activated slot-filler within the currently activated frame.

Such a data-driven process can still achieve objectives. Its success in doing so, however, depends upon the way in which the knowledge structures are organized and activated.

This concept of data-driven selection of questions offers an alternative explanation for the failure of the Group D pilots to discover the artificial horizon malfunction. Previously, it was suggested that these pilots failed to check the "Expectations" slot of the NOSE-DOWN DESCENT frame because they failed to identify appropriate objectives (e.g., discover instrument malfunctions or activation of incorrect default assumptions). The proposed data-driven processor, however, would account for this failure in terms of an attentional error: The pilot failed to attend to the indication of zero pitch in the scenario. As a result there was no activation of instruction to check the artifical horizon, which was contained as a slot-filler in the "Expectations" slot of the NOSE-DOWN DESCENT frame.

This explanation is consistent with the fact that none of the pilots in Group D recalled the indication of zero pitch in Task 2. (All of the other pilots in the experiment recalled this indication.)

A Normative Model.

Based on a comparison of the processing strategies of successful and unsuccessful pilots on this task, recommendations for a high-level control structure can be made. Since only one problem has been studied, however, it is impossible to determine how widely applicable these recommendations are.

This control structure must decide what questions to address in a given context. One alternative, of course, is to put explicit "Instructions for Use" in each frame as was done earlier in this paper. To the extent that the same questions are to be asked repeatedly, however, this becomes a less desirable approach.

The proposed control structure consists of an ordered list of objectives, along with a set of plans designed to attain these objectives. The plans act upon the contents of various knowledge-bases and a working memory (see Figure 3-16).

The first knowledge-base contains the eighteen frames identified earlier. The second contains objectives and associated plans for attaining them. The third contains the pilot's world knowledge and recall of past experiences related to aviation (episodic memory). The working memory serves to store the pilot's (episodic) memories of the scenario, the sequence of frames he has activated and objectives he has achieved, the information he has requested, the currently activated frame, etc.

The pilot's objectives, in order of priority, are:

I. Activate a frame representing the plane's physical activity and orientation (e.g., NOSE-DOWN or NOSE-LEVEL DESCENT). This is primarily a data-driven process that occurs as the pilot listens to the scenario. The control structure can influence this process by priming certain cues, as discussed earlier. This priming involves accessing general aviation knowledge concerning common problems, and then activating the relevant frames. This would be done before listening to the scenario (or possibly while listening to it).

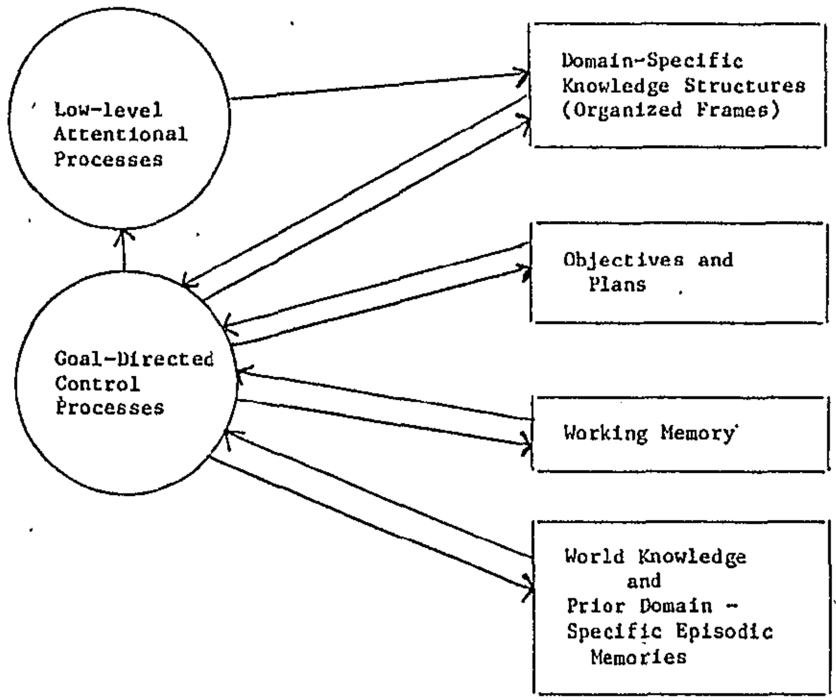


Figure 3-16. System Architecture

II. Make sure the correct frame has been activated.

A. Ensure that the frame was not activated because of attention to the wrong cues.

B. Be certain that the frame was not activated based on insufficient data.

C. Make sure the frame was not activated based on incorrect data due to:

1. a memory distortion.

2. an instrument malfunction.

D. Determine whether any default values have been activated incorrectly.

This goal can be achieved by checking all of the "Expectations" for the activated frame (assuming the right slot-fillers are present). Do not rely on the contents of working memory for these checks. It is important that the list of slot-fillers for the "Expectations" slot contain cross-checks for the various instruments in order to ensure detection of instrument malfunctions.

III. If an expectation is not met, either an instrument has malfunctioned, the wrong frame has been activated, or an incorrect default value has been activated. Check for an instrument malfunction first by activating the associated instrument malfunction frame. Objectives II and IV should be applied to use the contents of this malfunction frame.

If the instrument is malfunctioning, revise the contents of the working memory appropriately and return to Objective I. Use the contents of the working memory as cues for triggering a frame or replacing default values. Do the same thing if the instrument is not malfunctioning, since this implies the wrong frame or default value was activated originally.

IV. Once it has been established that the correct frame has been activated, try to determine what is causing this state of nature. Activate the "Causes" slot for the frame, checking all of the slot-fillers until a cause is found or the list has been exhausted. Test each possible cause, activating the associated cause frame and testing its expectations.

V. Repeat Steps II-IV in a recursive fashion, using as the activated frame the cause that has just been identified. Continue until no more causes in the chain of events can be identified.

Those pilots who failed to fully diagnose the problem appeared to have the necessary frames at their disposal. Their high-level control processes, however, deviated from this normative model in significant ways. The organization of their processes failed to reflect the objectives of:

1. Avoiding memory distortions.
2. Detecting instrument malfunctions.

3. Avoiding incorrect activation of a frame due to attentional errors and use of insufficient information.

4. Avoiding false inferences due to activation of incorrect default values.

5. Avoiding cognitive narrowing (failure to detect a causally-related chain of events).

This normative model could be realized as an expert system (Barr and Feigenbaum, 1981; Davis, 1982; Nilsson, 1980; Nau, 1983). It is not clear, however, whether it is compatible with the cognitive processes observed in these pilots. If the attainment of these objectives is normally an implicit, data-driven process in human fault diagnosis, resulting from well-designed knowledge structures and attentional processes, then familizarizing pilots with such a control structure might have little impact on performance.

Criticality of Assumptions

Certain assumptions were made in order to permit the development of a parsimonious general model of performance. The primary effect of these assumptions was to model pilots as accessing all frames through the higher-level frames. It is possible, of course, that any frame at any level in the hierarchy can be activated directly by external cues. This experiment does not permit an evaluation of this alternative.

Representation of Knowledge

A frame system using (verbal) symbol manipulations was used to model performance. It is possible that another representation using some analog process (a qualitative or quantitative simulation) as a mental model of flight could account for the same data.

Extrapolation to a General Aviation Setting

The objective of this study was to better understand the manner in which knowledge structures are used in fault diagnosis. The problem context was "similar" to a vacuum pump failure in a light plane. Can we make any inferences about performance in an actual aircraft?

The major difficulty with making such an inference is the lack of similarity between our problem setting and an actual flight in terms of information input. The visual displays normally available to pilots provide a much different form of data-gathering. Our problem setting is much closer to that of a pilot conversing with an intelligent computer that is flying the plane. We might expect much more data-driven processing with the availability of the normal visual displays. Nevertheless, the knowledge structures and cognitive processes studied in this experiment probably play some role in actual on-board fault diagnosis. Thus, some of the concepts identified may provide insights into performance in a realistic setting. Some speculations are provided below:

1. Attention is attracted to unexpected events. If, in a real flight, the vacuum pump fails and our scenario becomes reality, the pilot's attention may not be attracted to the artificial horizon. Instead, it will probably be drawn to instruments that show an unexpected change. If that instrument is the turn and bank indicator, he will probably detect the artificial horizon malfunction quickly. On the other hand, if attention is drawn to the unexpected changes on the altimeter, vertical speed indicator or airspeed indicator, the pilot may be very slow to note that it is the failure of the artificial horizon that is causing his problems. Thus, from the standpoint of detecting vacuum system failures, the artificial horizon is a poorly designed instrument. Its failure to (always) give an unexpected change in reading when the vacuum system malfunctions could contribute to slow or even unsuccessful attempts to diagnose the problem. This design problem is exacerbated by the fact that the artificial horizon sometimes does tumble when the vacuum pump fails. This could generate an expectancy that would further reduce the pilot's tendency to focus attention on the artificial horizon.

2. Pilots behave as though activated default values are based on actual data (are not assumed values). If a pilot assumes he is flying straight because he is unaware of making any yoke movements (while tracking the failing artificial horizon), he may not look at the turn indicators very quickly (or at all). He may instead attend to the instruments relevant to the perceived problem (descent). An activated default value in a frame may also influence other values in the same or other frames via some inheritance process. Thus, BANKED plane may not be considered as a possible cause of DESCENT because the pilot "knows" he's flying straight.
3. Pilots tended to assume that their instruments were functioning properly, accepting this by default rather than by cross-checking the appropriate instruments. Thus, pilots may activate a frame based on incomplete or inaccurate information (due to memory distortion or instrument malfunction). They may then assume it is the correct frame (e.g., DESCENT) and proceed to look for causes of the associated state of nature, instead of first making sure their understanding of the plane's activity is correct. This "cause chasing" may use up valuable time.

Future Issues

A general model of fault diagnosis has been proposed. This model raises a number of issues about how people perform such tasks, and about how performance can be improved. These questions can only be addressed by designing additional experiments to collect converging and supplementary evidence.

The next section describes alternative approaches to modeling fault diagnosis without benefit of verbal protocol analysis. The models discussed there are based upon PLATO® data which is nearly experimenter free. In that situation one must base all of his conclusion on observed behavior without benefit of discussion and/or rationalization about why particular information may or may not be important to a particular subject. The combination of frame models with more traditional graphical aids and stochastic process representations will hopefully provide a rich picture of how pilots respond to critical in-flight events.

IV. Modeling Instrument Scan Patterns

During the course of this research project and its predecessors, a wealth of data on information search patterns was collected for over 100 pilots. Each pilot/subject was asked to diagnose from one to five critical event scenarios. Some did this by paper and pencil techniques, some by PLATO® computer graphics displays, and some by protocol analysis. This section describes modeling attempts directed toward discerning common solution strategies among subgroups of pilots.

Order of Inquiry

Early descriptive models for paper and pencil subjects were reported by Rockwell and Giffin (1981). Subjects participating in the PLATO® experiments were discussed by Rockwell and Giffin (1982). In both cases heavy emphasis was placed upon statistical analysis of data which attempted to relate diagnostic performance to pilot experience, knowledge and biographic information. Some broad generalizations about diagnostic behavior were made from these data, but no model which could predict how a given pilot might behave when confronted with a new scenario was obtained.

One tool developed in this early research was the Pilot Information Plot (PIP). These PIP charts permitted one to see graphically how any particular subject searched for information on any given scenario. The PIP charts offered a convenient way to conjecture the hypotheses and the method of testing being pursued by a subject but were not helpful in discerning global strategies across many subjects. Each trajectory appeared to be unique for that subject and that scenario.

Figure 4-1 is a prototype PIP that one might conjecture would generated by a knowledgeable, efficient pilot. This trajectory was generated after studying the entire pool of subjects and is put forth as a subjective composite for "good" subjects. The scenario, which involves a vacuum pump failure, provided the subject with the following situational data:

1) Increasing airspeed
2) Decreasing altitude
3) Level flight attitude indication
4) Instrument meteorological conditions.

From these data, the better subjects appeared to deduce the following:

1) The instrument readings are contradictory.
2) One or more of the instrument readings is in error.
3) Two are static system instruments, one is a vacuum instrument.

A confirmation of static system performance often involved checking the VSI and alternate static source. A confirmation of vacuum system performance might include checking vacuum instruments against independent information e.g. turn and bank or magnetic compass. Finally, the key element of suction gage reading offered confirmation of the vacuum pump failure hypothesis.

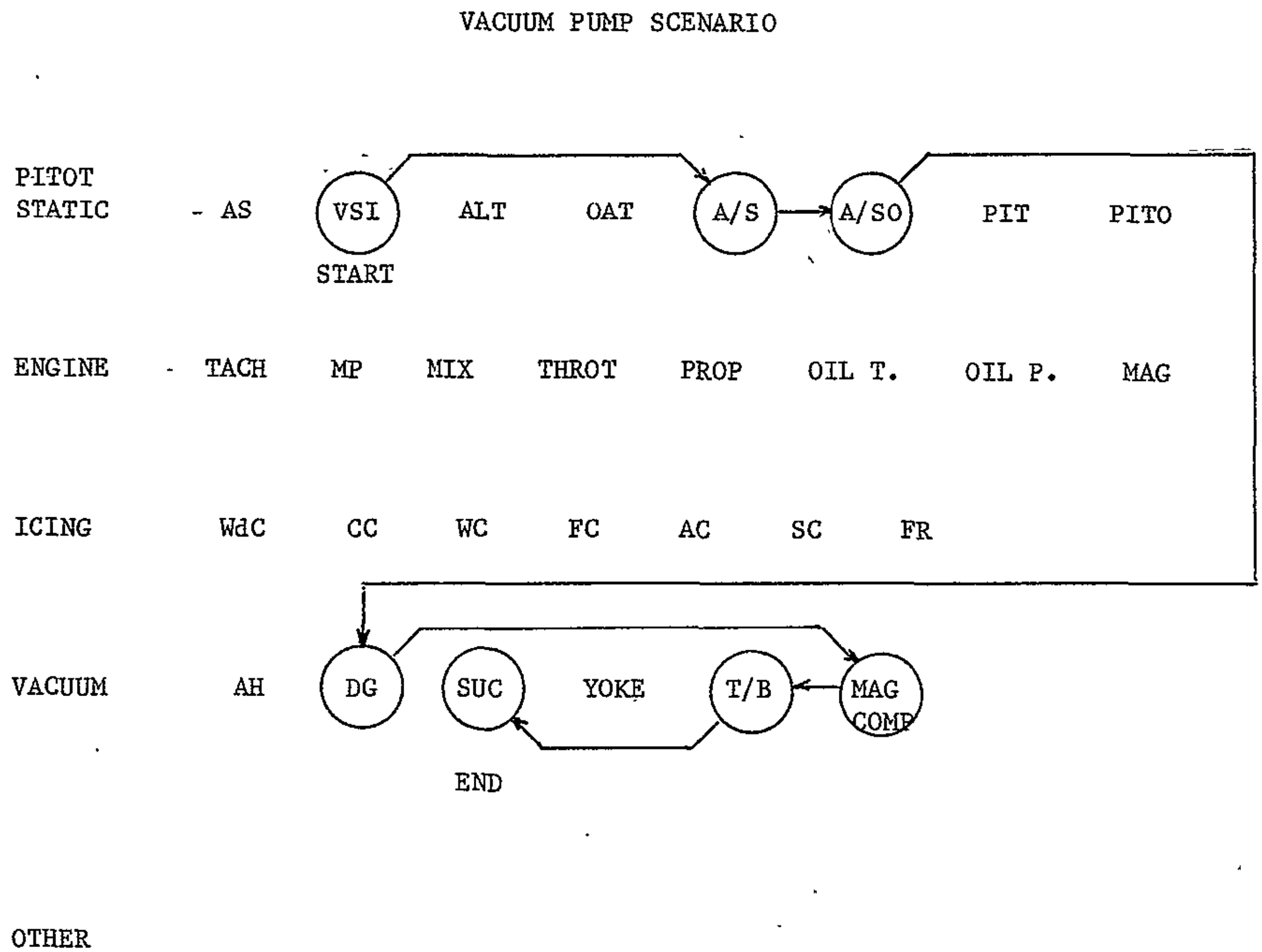


Figure 4-1. Sample PIP Chart

Frequency versus order of inquiry diagrams were also prepared for successful and unsuccessful groups of subjects in an attempt to isolate apparent hypothesis generation and preferred groupings or "tracks" of information inquiry. The clustering of inquiries looked remarkably similar across groups relative to incorrect hypotheses with the distinction between successful and unsuccessful subjects being mostly one of which group generated the proper hypothesis to test. These diagrams and their analysis appear in the 1982 report.

Script Norms

The concept of "script norms" as discussed by Bower, Black and Turner (1979) was modified for use in analyzing the entire group of PLATO subjects. Bower, Black and Turner asked subjects to write a list of actions describing what people generally do in some common situaiton e.g. attend a lecture. The question was whether people agree in the actions they mention. They tested this by examining the distributions of how many actions were mentioned by varying numbers of subjects. They designated the group's script to be those events mentioned by more than 25 percent of the subjects.

In the context of the CIFE scenarios, script norms are developed by tabulating distributions for the number of items of information requested by varying numbers of subjects. Here the pilot/subjects are being asked to recognize script relevant information from a large pool of potential information rather than being asked to generate a script from a completely unstructured environment. The resulting distributions reveal both the level of agreement among subjects about which data are important and an indication of what groups of data belong together.

Figures 4-2 through 4-6 are the script norms for the five scenarios administered to the computer aided testing (CAT) PLATO® subjects. These graphs show the explicit items of information requested by different fractions of subjects.

The general shape of the distributions is the same for all five scenarios. As was the case with Bower, Black and Turner, there appears to be a sharp difference at the 20 percent point for all scenarios except scenario five. Scenario five involved a broken muffler baffle leading to reduced power available and was considered by most subjects to be "unsolvable". This caused many subjects to search the panel without any strong hypotheses about the problem diagnosis. Consequently the script norms for that scenario show many more items requested by a large portion of subjects as compared to the simpler scenarios.

For purposes of this discussion we will arbitrarily define the group's script to be those items requested by more than 40 percent of the subjects. Since scenario five was different from the rest and was administered to only a small number of subjects, it will not be considered in the rest of this discussion.

Scenario one, an oil pressure gage leak, and scenario three, a magneto drive gear failure both concern obvious engine related symptoms. As expected, the group scripts for both scenarios are heavily laden with engine health symptoms. The triumverant of oil temperature, cylinder head temperature and oil pressure was sought by nearly every subject in both scenarios. The key elements, fluid leaks for scenario one and left magneto for scenario three, were selected by at least 60 percent of the subjects. The fact that these elements provided conclusive information for solution is reflected by the 52.4 percent and 63.6 percent of the subjects who correctly diagnosed one and three respectively.

Scenario two, the vacuum pump failure, and scenario four, the frozen static port were apparently much more perplexing. Only 23.8 percent of the subjects correctly identified the vacuum failure and only 43.2 percent identified the frozen static port. In examining the script norms for those scenarios, it appears that ice is of prime concern to both groups. Alternate static questions, pitot heat, VSI and wing condition show up in both scripts. Since suction gage reading is not in the 40 percent script cutoff for scenario two, it is obvious that the number who correctly solved that problem should be small.

It is noted that pilots as a group seem to agree on the importance of a relatively small number of information items in problem diagnosis. The script for scenario one had only 7 items of information which were requested by over 40 percent of the subjects, scenario two had 8 items, scenario three had 13 items and scenario four had 11 items. These are only small percentages of the some 110 items of information which were available to the CAT subjects.

Figure 4-2. Oil Pressure Gage
Scenario # 1
29 CAT Subjects
Script Norms

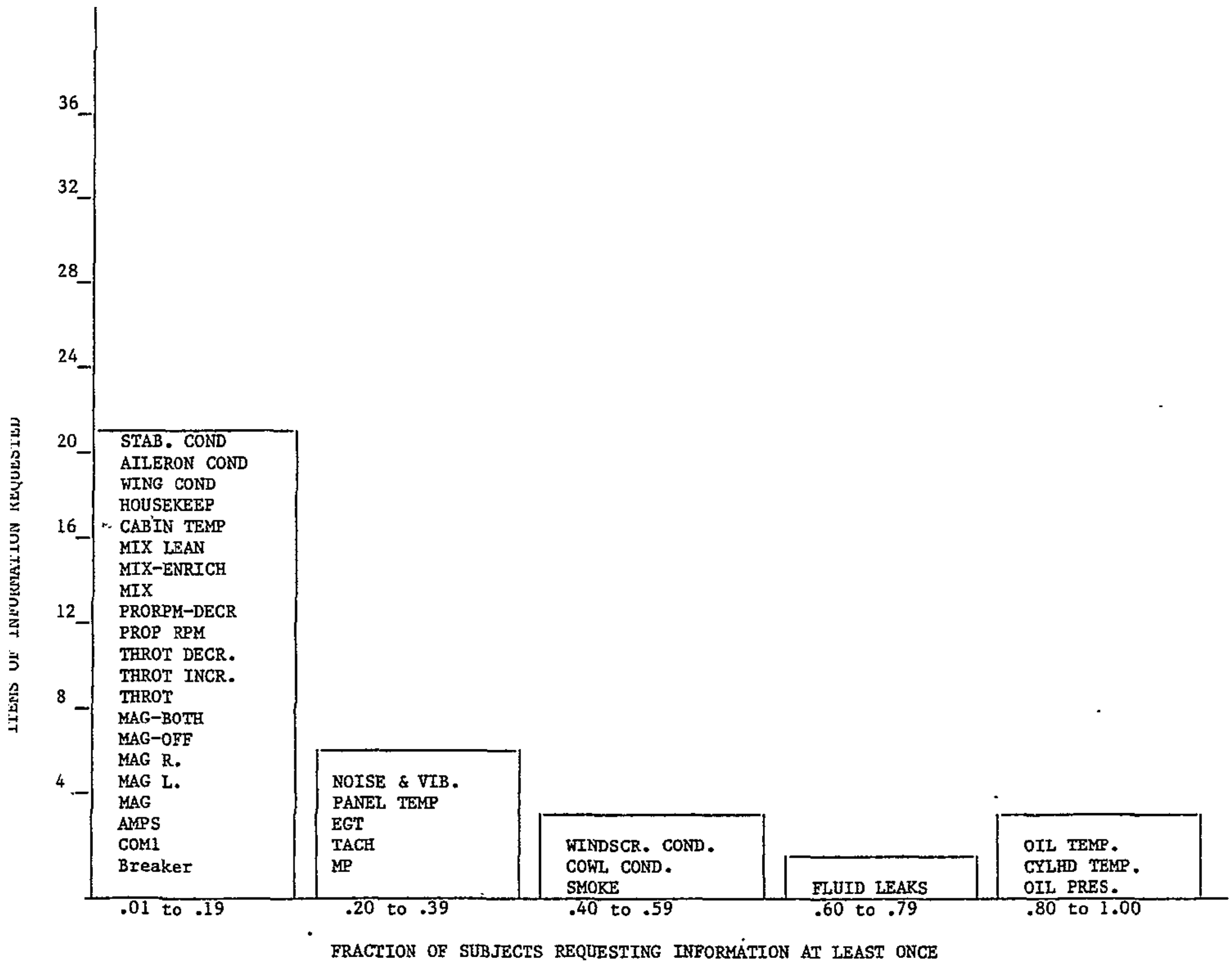


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Figure 4-3. Vacuum Pump
Scenario #2
42 CAT Subjects
Script Norms

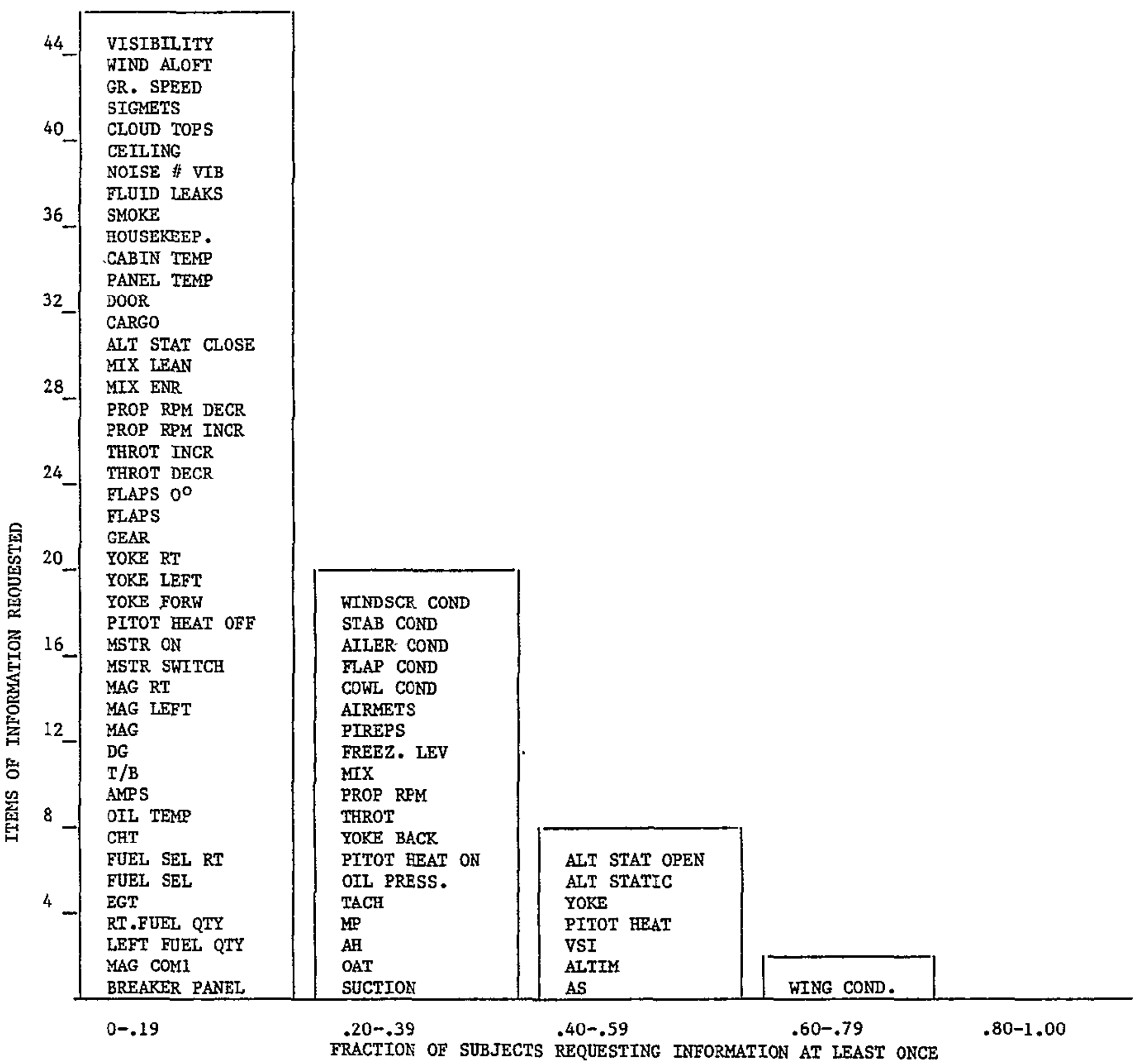

Figure 4-4. Magneto Failure
Scenario #3
36 CAT Subjects
Script Norms

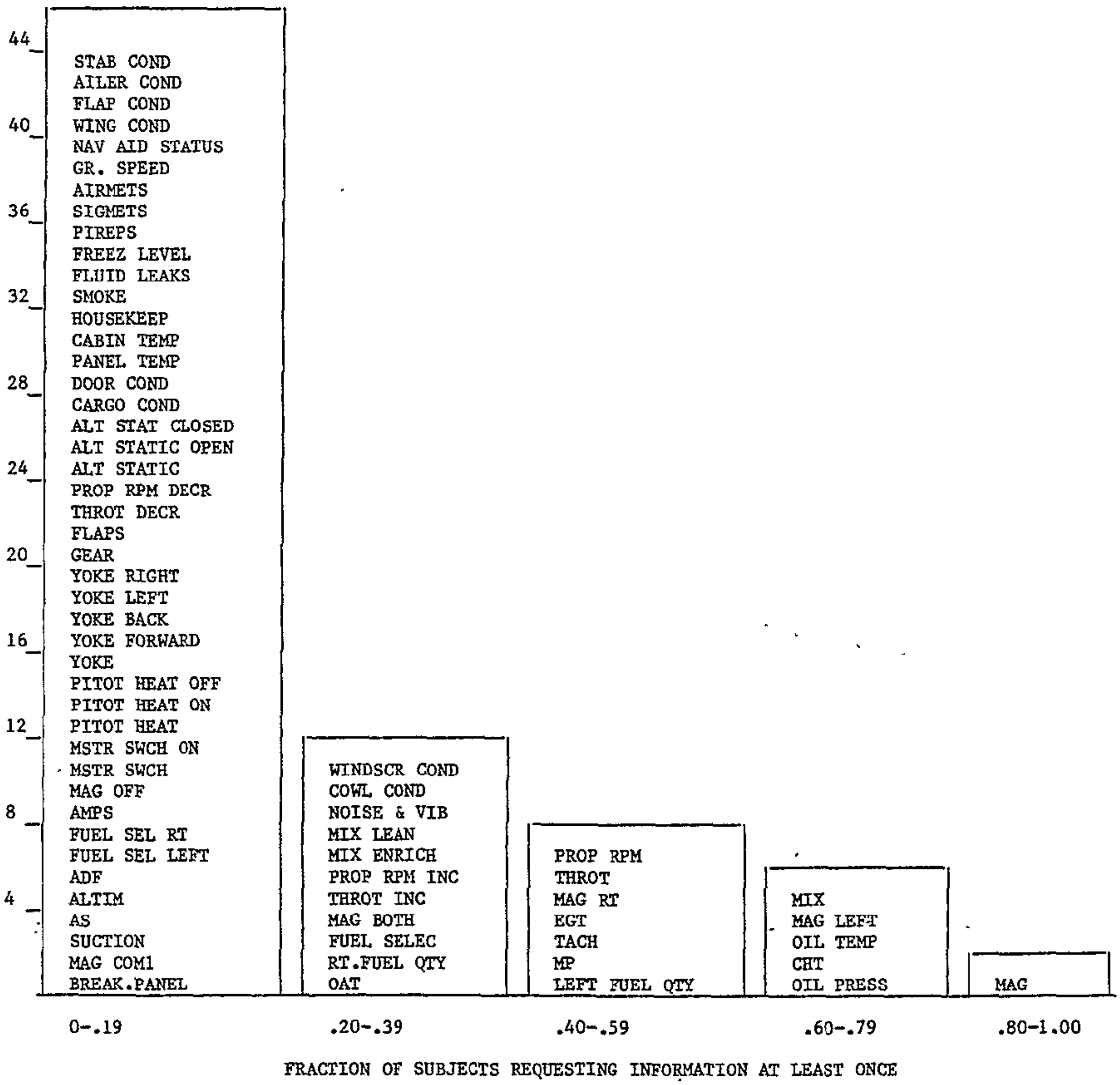

Figure 4-5. Frozen Static Port
Scenario #4
37 CAT Subjects
Script Norms

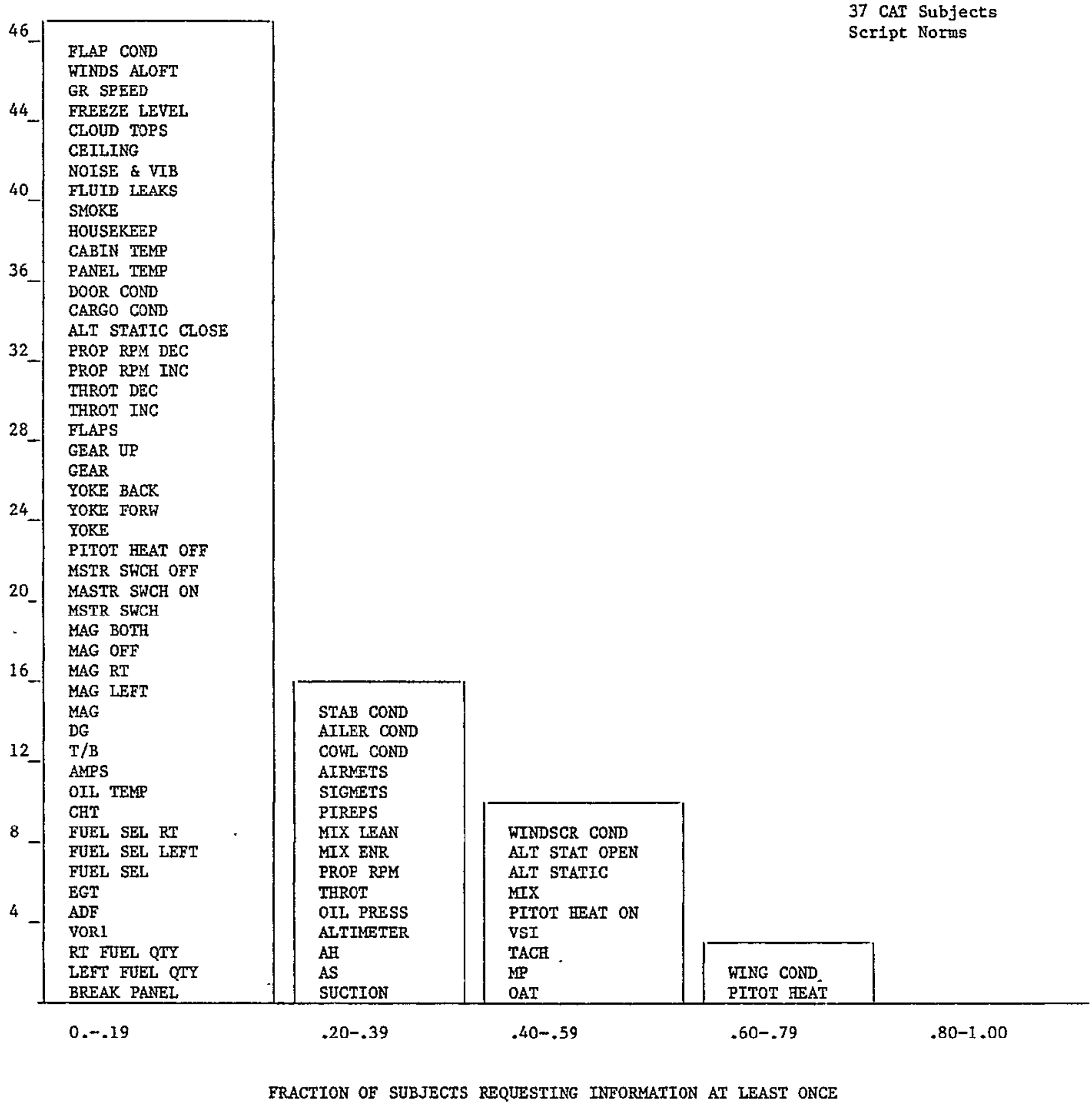

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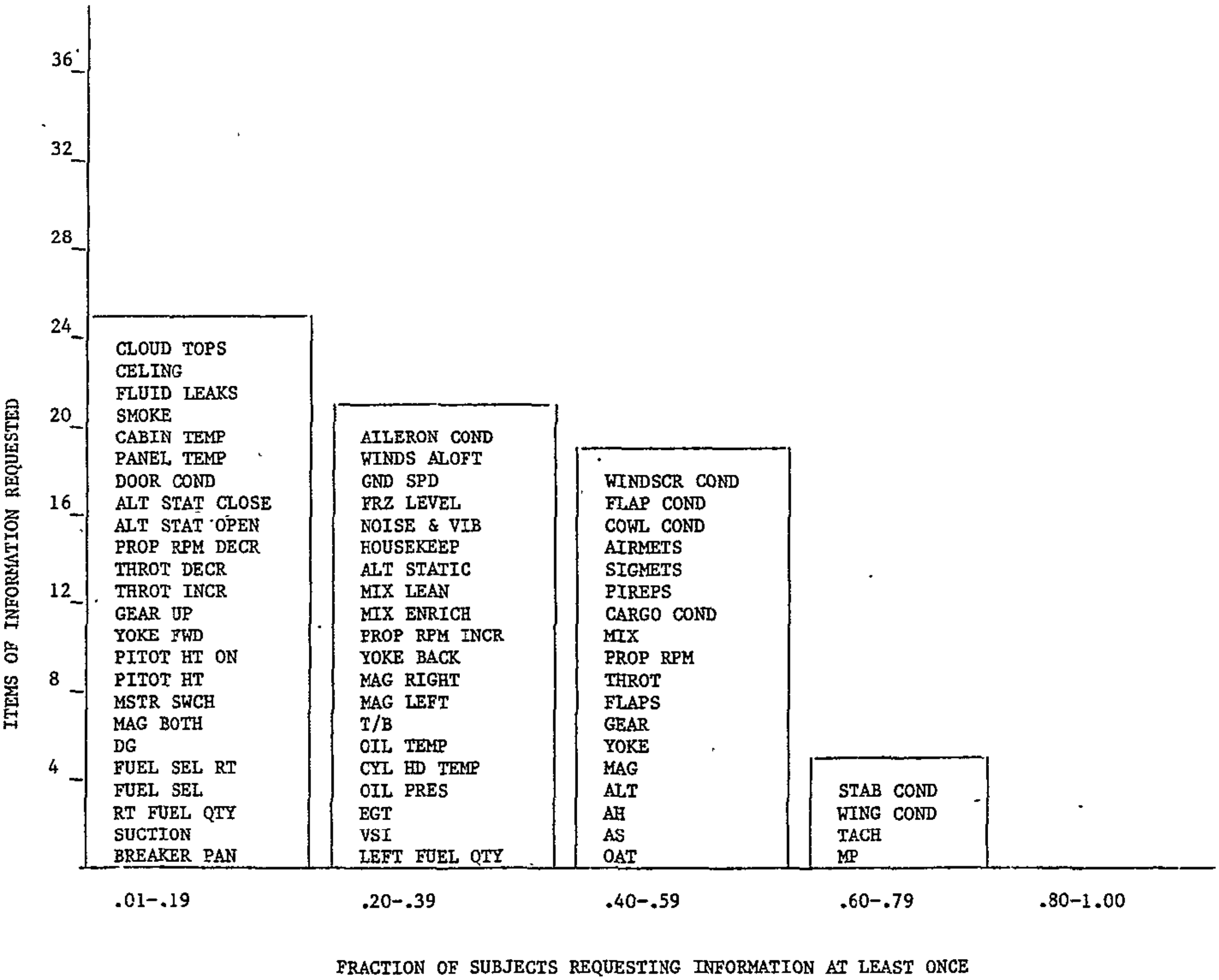
Figure 4-6. Broken Baffle
Scenario #5
14 CAT Subjects
Script Norms



Distance Measures

Another attempt to determine the existence of a common frame system for pilots involved calculation of the average distance between information items as a measure of closeness in memory structure. Clusters of information defined by short distances and high frequency of occurrences were sought as an alternative to the earlier ad hoc definitions of "tracks" used in the PIP charts. Distance is defined as the number of requests between any two items of information.

For this analysis a consolidated state list containing 34 items was generated. Here closely related requests, e.g., yoke, yoke foreward and yoke back, were combined into a single state. The resulting list of states is shown in Table 4-1.

Scenario two, vacuum pump failure, and scenario three, magneto drive gear failure, were analyzed across all computer aided testing subjects. Pairs considered significant were limited to those with an average distance measure of less than or equal to 3 as calculated from at least 3 subjects. The pairs of items meeting these requirements for scenario two are listed in Table 4-2. Similar pairs for scenario three are listed in Table 4-3.

By reading horizontally one can determine the most likely neighbors for any given information inquiry. For example, in the vacuum pump scenario a request for outside air temperature (OAT) is likely to be followed by airspeed, altimeter, vertical speed, pitot heat and yoke.

FROM \ TO	1. BKR	2. RAD	3. COM	4. SUC	5. OAT	6. FUEL	7. AS	8. AH	9. ALT	10. VOR	11. MP	12. TACH	13. VSI	14. EGT	15. TANK	16. OP	17. CHT	18. OT	19. AMM	20. TB	21. DG	22. MAG	23. MASTER	24. PH	25. YOKE	26. GEAR	27. FLAP	28. THROT	29. PROP	30. MIX	31. ALT STAT	32. CAB	33. ATC	34. EXT
1. BKR																																		
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32. CAB																																		
33. ATC																																		
34. EXT					X																											X		

Table 4-2. Vacuum Pump Scenario; Distances ≤ 3 Inquiries; Number of Observations ≥ 3 Subjects.

FROM \ TO	1. BKR	2. RAD	3. COM	4. SUC	5. OAT	6. FUEL	7. AS	8. AH	9. ALT	10. VOR	11. MP	12. TACH	13. VSI	14. EGT	15. TANK	16. OP	17. CHT	18. OT	19. AMM	20. TB	21. DG	22. MAG	23. MASTER	24. PH	25. YOKE	26. GEAR	27. FLAP	28. THROT	29. PROP	30. MIX	31. ALT.STAT.	32. CAB	33. ATC	34. EXT
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33. ATC																																		
34. EXT																X	X	X																

Table 4-3. Magneto Gear Scenario; Distance ≤ 3 Inquiries; Number of Observations ≥ 3 Subjects.

Since OAT relates closely to an icing hypothesis one might conjecture that the rest of the members of this cluster indicate how this group of subjects might continue to test that hypothesis.

By reading vertically one can determine from what elements subjects are likely to enter any given state. For example, in the vacuum pump scenario, inquiries about the altimeter may result from information about outside air temperature, airspeed, artificial horizon, manifold pressure and vertical speed.

The vacuum pump scenario had the lowest successful diagnosis rate (23.8%) of the four main scenarios tested. The clusters shown in Table 4-2 may therefore be reflecting a mix of hypotheses. Most subjects seemed to entertain an icing hypothesis at least sometime during their diagnosis, but jumped around somewhat when that could not be supported.

The magneto drive failure scenario on the other hand had the highest success rate with 63.6% of the subjects solving it. Consequently the clusters in Table 4-3 may be more indicative of the true closeness in memory structure among items. For example, oil temperature is close to oil pressure, cylinder head temperature and ammeter readings all of which related directly to engine health. Similarly, requests for cylinder head temperature are likely to follow tank selector, oil pressure, oil temperature, throttle and exterior condition inquiries. Tank selector and exterior condition inquiries leading to CHT suggest a switch in tracks. The other requests are consistent with an engine health track of inquiry.

Markov Models

The theory of Markov chains offers an intriguing model for diagnostic information gathering. It seems reasonable to ask whether or not there is a multi-stage dependence among inquiries, e.g. does the next inquiry depend upon the last 1, 2, ..., n inquiries? The model to be examined is that of an n^{th} order Markov chain in which a transition into state j on the k^{th} inquiry depends upon the states occupied on inquiries k-1, k-2, ..., k-n. When n = 1, the process is a common first order Markov chain and when n = 0 it is an independent process. A first order process has one state dependence expressed as

$$Pr[i_k | i_1, i_2, \ldots, i_{k-1}] = Pr[i_k | i_{k-1}]$$

Independent trials on the other hand carry no historical information from inquiry to inquiry, expressed as

$$Pr[i_k | i_1, i_2, \ldots, i_{k-1}] = Pr[i_k]$$

Hypotheses concerning the order of Markov chains which might be used to model information search trajectories were tested on five different groups of pilots on each of three scenarios. Scenario one was eliminated because not all subjects took it. The groups were selected from those which proved significantly different in the t-tests previously reported by Rockwell and Giffin (1982). The groups tested were

1. All CAT (PLATO) subjects - 39 pilots
2. Successful subjects with high correctness scores - 11 pilots

3. Non-private pilots - 22 pilots

4. Private pilots - 16 pilots

5. Subjects with high knowledge test scores - 10 pilots

Three different sets of state definitions, representing various consolidations of inquiries were tested. These sets of states are listed in Table 4-4.

The hope was to find a homogeneous group of pilots and a properly descriptive set of state variables so that search trajectories could be combined in order to test hypotheses. Ideally, one pilot should be subjected to repeated exposure to the same decision-making problem in order to compute the frequencies with which he would move between inquiries. However, because of the nature of the scenarios given it was not reasonable to repeat trials for the same individual once he had been exposed to the true solution. For that reason the (tenuous) assumption of homogeniety among pilots within a group was made. The relative frequency of moving from state i to state j was then calculated by pooling the number of inquiries across all pilots in a group who followed i with j and dividing by the total number of i-inquiries observed within the group.

The statistical tests performed were those suggested by Anderson and Goodman (1957). They assumed repeated observations of the same chain and based their analysis on asymptotic distributions. Their approach for an N-state chain is to:

39-STATE SET		23 STATE SET	16-STATE SET
1. Breaker Panel	21. Oil Pressure	1. Magnetic Compass	1. Airspeed
2. Com 1	22. Cylinder Head Temp.	2. Suction	2. Vertical Speed
3. Mag Compass	23. Oil Temp	3. Outside Air Temp	3. Altimeter
4. Com 2	24. Ammeter	4. Airspeed	4. Alternate Static
5. Transponder	25. Turn and Bank	5. Artificial Horizon	5. Pitot Heat
6. Suction	26. Directional Gryo	6. Altimeter	6. Outside Air Temp.
7. Outside Air Temp	27. Magnetos	7. Vertical Speed	7. Structural Ice
8. Left Fuel Quan.	28. Master Switch	8. Turn and Bank	8. Air Traffic Control
9. Right Fuel Quan.	29. Pitot heat	9. Directional Gyro	9. Engine Gages
10. Airspeed	30. Yoke	10. Pitot Heat	10. Artificial Horizon
11. Artificial Horizon	31. Gear	11. Yoke	11. Directional Gyro
12. Altimeter	32. Flaps	12. Alternate Static	12. Suction
13. VOR1	33. Throttle	13. Tachometer	13. Yoke
14. Manifold Pressure	34. Prop RPM	14. Manifold Pressure	14. Turn and Bank
15. Tachometer	35. Mixture	15. Mixture	15. Magnetic Compass
16. ADF	36. Alternate Static	16. Throttle	16. Other
17. Vertical Speed	37. Inside Cabin	17. Propeller	
18. VOR2	38. Air Traffic Control	18. Oil Temp.	
19. Exhaust gas Temp.	39. External Conditions	19. Oil Pressure	
20. Fuel Selector		20. Magneto	
		21. Structural Ice	
		22. Air Traffic Control	
		23. Other	

Table 4-4. State Definitions for Markov Tests

1) obtain 1, 2, ..., k stage transition frequencies

2) calculate transition probabilities for a total of n observations.

4) compute a likelihood ratio statistic

5) test the significance of the result.

Transition probabilities are computed as follows:

$$\hat{p}_k = \frac{n_k}{n} = \frac{\text{Total inquiries for element k}}{\text{Total inquiries}}$$

$$\hat{p}_{jk} = \frac{n_{jk}}{n_j} = \frac{\text{Number of inquiry sets (j,k)}}{\text{Total number of j inquiries}}$$

$$\hat{p}_{ijk} = \frac{n_{ijk}}{n_{ij}} = \frac{\text{Number of inquiry sets (i,j,k)}}{\text{Total number of (i,j) inquiries}}$$

The likelihood ratio is given by

$$\lambda = \prod_{i,j,\ldots k,\ell=1}^{N} \left[\frac{\hat{P}_{j,\ldots k,\ell}}{\hat{P}_{i,j,\ldots \ell}} \right]^{n_{i,j,\ldots k,\ell}}$$

The test is for a chain that is of order (r-1) against an alternative of r. That is

H_0: Chain is of order (r-1)

H_1: Chain is of order r

The test statistic $- 2\ell n\ \lambda$ can be shown to be Chi square distributed (χ^2) with $N^{r-1}(N-1)^2$ degrees of freedom under the null hypothesis.

The procedure is to begin with r=1 and continue testing with increasing order of r until H_0 cannot be rejected. At that point one can conclude that the chain is of order r.

The above tests were applied to the previously described combinations of subjects and scenarios. The results are noted in Tables 4-5 through 4-9. Summary conclusions are contained in Table 4-10.

If taken at face value these tests offer some surprising conclusions. They suggest that for the groups of pilots tested, these scenarios can evoke no stronger dependence than that of a first order Markov chain.

Table 4-5. All Pilots. Tests for Order of Chain (39 Pilots, 39 States max)

	First Test H_0: Independent Trials H_1: First Order Markov			Second Test H_0: First Order Markov H_1: Second Order Markov		
	$-2 \ell n \lambda$	$\chi^2_{.95}$	Conclusion	$-2 \ell n \lambda$	$\chi^2_{.95}$	Conclusion
Scenario 2 (33 States)	1778	1099	Reject	906	34200	Cannot Reject
Scenario 3 (30 States)	1590	909	Reject	817	25600	Cannot Reject
Scenario 4 (34 States)	1840	597	Reject	673	37474	Cannot Reject

Table 4-6. Successful Pilots. Tests for Order of Chain (11 Pilots, 16 States max)

	First Test			Second Test		
	H_0: Independent Trials			H_0: First Order markov		
	H_1: First Order Markov			H_1: Second Order Markov		
	$-2 \ell n \lambda$	$\chi^2_{.95}$	Conclusion	$-2 \ell n \lambda$	$\chi^2_{.95}$	Conclusion
Scenairo 2 (16 States)	389	261	Reject	226	3740	Cannot Reject
Scenario 3 (10 States)	182	103	Reject	60	877	Cannot Reject
Scenario 4 (15 States)	296	229	Reject	121	3067	Cannot Reject

Table 4-7. Non-Private Pilots. Tests for Order of Chain (22 Pilots, 23 States max)

	First Test			Second Test		
	H_0: Independent Trials			H_0: First Order Markov		
	H_1: First Order Markov			H_1: Second Order Markov		
	$-2 \ln \lambda$	$\chi^2_{.95}$	Conclusion	$-2 \ln \lambda$	$\chi^2_{.95}$	Conclusion
Scenario 2 (22 States)	777	491	Reject	476	9932	Cannot Reject
Scenario 3 (16 States)	456	261	Reject	233	3511	Cannot Reject
Scenario 4 (21 States)	844	447	Reject	374	8614	Cannot Reject

Table 4-8. Private Pilots. Tests for Order of Chain (16 Pilots, 23 States max)

	First Test			Second Test		
	H_0: Independent Trials			H_0: First Order Markov		
	H_1: First Order Markov			H_1: Second Order markov		
	$-2 \ln \lambda$	$\chi^2_{.95}$	Conclusion	$-2 \ln \lambda$	$\chi^2_{.95}$	Conclusion
Scenario 2 (22 States)	717	491	Reject	249	9932	Cannot Reject
Scenario 3 (16 States)	505	261	Reject	340	3511	Cannot Reject
Scenario 4 (22 States)	660	491	Reject	253	9932	Cannot Reject

Table 4-9. High Knowledge Pilots. Tests for Order of Chain (10 Pilots, 23 States max)

	First Test H_0: Independent Trials H_1: First Order Markov $-2 \ln \lambda$	 $\chi^2_{.95}$	 Conclusion	Second Test H_0: First Order H_1: Second Order $-2 \ln \lambda$	 $\chi^2_{.95}$	 Conclusion
Scenario 2 (19 States)	377	367	Reject	140	6339	Cannot Reject
Scenario 3 (14 States)	272	200	Reject	118	2480	Cannot Reject
Scenario 4 (20 States)	421	406	Reject	110	7418	Cannot Reject

Table 4-10. Summary of Search Patterns.

Scenario	39 States Max All Pilots (39)	16 States Max Successful Pilots (11)	23 States Max Non-Pvt (22)	23 States Max Pvt (16)	23 States Max High Knowl (11)
2 (Vac Pump)	1st Ord (33 States)	1st Ord (16 States)	1st Ord (22 States)	1st Ord (22 States)	1st Ord (19 States)
3 (Mag Fail)	1st Ord (30 States)	1st Ord (10 States)	1st Ord (16 States)	1st Ord (16 States)	1st Ord (14 States)
4 (Static Sys)	1st Ord (34 States)	1st Ord (15 States)	1st Ord (21 States)	1st Ord (22 States)	1st Ord (20 States)

Such a conclusion is counter-intuitive and is not supported by an analysis of PIP charts for individual pilots. The PIP charts indicate strong evidence of sequential information seeking with very few returns to previously tested states. Yet the high order Markov chain model does not appear to be appropriate for the data at hand.

In retrospect one might postulate several reasons for the failure of the Markov model to adequately describe the observed information seeking behavior of pilots.

1) Observed trajectories across many subjects cannot be combined. In spite of attempts to define homogeneous groups, one is left with the conclusion that individual differences are too great to treat observations from n subjects as though they represented n realizations of the same Markov chain.

2) Sample sizes are too small. The statistical tests used are based on limiting distributions. The sample sizes ranging from 10 to 39 in the PLATO data are simply too small to provide an adequate test of the theory.

3) The unfamiliar task of collecting individual pieces of information one at a time is inhibiting to the memory processes of expert pilots who normally "chunk" familiar patterns of stimuli from an aircraft instrument panel. Larken et al (1980) observed that experts are reduced to the level of

novices in chess playing when pieces are arranged in random order on a chess board as opposed to being in an arrangement from a game. A similar problem may exist in the form in which pilots retain knowledge in long term memory. The awkward isolated search may in fact destroy what otherwise might be a highly structured n-state process.

Table 4-11 shows one example of a first order Markov process. The frequencies (both absolute and relative) shown are for the number of observations of inquiry i followed by inquiry j tabulated for the 22 non-private pilot subjects who took scenario three. The high frequency cells are caused by combining several unique inquiries into a single state. For example, state 20, magneto, includes mag left, mag right, mag both and mag off inquiries. Hence there is a high probability that successive inquiries will return to that state.

The next chapter returns to analysis of individual search patterns as opposed to the aggregated descriptions of this chapter in hopes of better characterizing how "good" pilots search for information.

FROM \ TO	2	3	4	10	11	12	13	14
2-SUCTION					1 (0.5)		1 (0.5)	
3-OAT				1 (0.143)			1 (0.143)	
4-AIRSPEED								
10-PITOT HEAT				3 (0.6)			1 (0.2)	
11-YOKE						1 (1.0)		
12-ALT. STATIC						3 (0.75)		
13-TACH		1 (0.077)						4 (0.308)
14-MANIFOLD PRESSURE							3 (0.273)	
15-MIXTURE							3 (0.097)	
17-PROPELLER							1 (0.0625)	2 (0.125)
18-OIL TEMP		1 (0.111)					1 (0.111)	
19-OIL PRESS								1 (0.091)
20-MAGNETO	1 (0.016)						1 (0.016)	
21-ICE			1 (0.05)	1 (0.05)			1 (0.05)	
22-ATC								1 (0.5)
23-OTHER		2 (0.026)					2 (0.026)	2 (0.026)

Table 4-11. Absolute and Relative Frequencies of Single Stage Transitions for Non-Private Pilots in Scenario Three. (Relative frequencies representing transition probabilities are shown in parentheses.)

TO / FROM	15	17	18	19	20	21	22	23
3-SUCTION								
3-OAT	1 (0.143)				1 (0.143)	1 (0.143)		2 (0.285)
4-AIRSPEED				1 (1.0)				
10-PITOT HEAT	1 (0.2)							
11-YOKE								
12. ALT. STATIC					1 (0.25)			
13-TACH					1 (0.077)	1 (0.077)		6 (0.461)
14-MANIFOLD PRESSURE	1 (0.091)	1 (0.091)		1 (0.091)	1 (0.091)			4 (0.363)
15-MIXTURE	17 (0.548)	2 (0.064)	1 (0.032)		3 (0.097)			5 (0.161)
17-PROPELLER	2 (0.125)	7 (0.4375)		1 (0.0625)		1 (0.0625)	1 (0.0625)	1 (0.0625)
18-OIL TEMP	1 (0.111)				1 (0.111)	1 (0.111)		4 (0.444)
19-OIL PRESS	1 (0.091)		2 (0.182)		1 (0.091)			6 (0.545)
20-MAGNETO					57 (0.890)	1 (0.016)		4 (0.062)
21-ICE			1 (0.05)		2 (0.10)	12 (0.60)		2 (0.10)
22-ATC								1 (0.5)
23-OTHER	7 (0.091)	4 (0.052)	6 (0.078)	4 (0.052)	5 (0.065)	2 (0.026)	1 (0.013)	42 (0.545)

Table 4-11. (continued). Absolute and Relative Frequencies of Single Stage Transitions for Non-Private Pilots in Scenario Three. (Relative frequencies representing transition probabilities are shown in parentheses.)

V. Evaluation of Subject Information Seeking Strategies By a Panel of Expert Pilots

Recognized expert pilots were utilized in an attempt to distinguish patterns within past PLATO® and current protocol subject data. It was hoped that such an analysis would further add to the descriptive model of pilot CIFE diagnosis and validate earlier scores on diagnostic performance.

A. Purpose

Six well-known aviation experts ranked two groups of ten pilots each on the basis of the pilots' information requests. A separate scenario was used for each pilot group. The purpose was to:

a) validate a previously developed grading system that measured individual pilot performance on a scenario;

b) ascertain the basis for the expert rankings; and

c) determine if PIP templates of expert performance could be inferred which might lead to an optimum information seeking strategy.

B. Expert Selection

Experts chosen for the study included past and current chief flight instructors and department of aviation chairmen, all from The Ohio State University, as well as an FAA GADO inspector. Table 5-1 shows the total flight hours and pilot certificates of each expert. All have their CFII certificate and except for one, all have an ATP certificate.

C. Scenario/Subject Selection

Subject data from two separate scenarios were chosen for presentation to the experts. Scenarios were selected which could provide wide ranges of performance in existing subject data. The vacuum pump failure scenario was selected because of its familarity to the researchers through protocol and other analyses. The static port blockage scenario was chosen because, like the vacuum pump scenario, it also provided an instrument conflict as part of the problem.

Individual subject data were chosen for each scenario to represent a full range of pilot performance. For the static port scenario, at least one past PLATO® subject was chosen to fit into each possible combination of correct/incorrect diagnosis and low/medium/high number of total flying hours. The vacuum pump scenario subjects were selected from the protocol analysis experiment, which at that time had 12 valid subjects. Two were eliminated to allow for an even mixture of correct/incorrect diagnosis and total number of observations.

Table 5-1. Expert Characteristics

Expert	Total Flying Hours	Certificates
A	8,000	ATP, CFII
B	2,500	ATP, CFII
C	8,700	ATP, CFII, A & P
D	14,090	ATP, CFII
E	20,000	Comm., CFII, A & P
F	8,000	ATP, CFII

D. Procedure

Because the PIPs preorganized each subject's information requests into tracks, their presentation to the experts would have likely biased the rankings. To eliminate this, each PIP was converted to a list of numbered questions showing information requests as they were typically asked.

Experts were presented with a tape recorder and blank tape along with a packet (see Appendix F) containing:

a) instructions which had been presented to the subjects;

b) the vacuum pump and static port scenario descriptions;

c) one sheet of subject information requests for each subject in each of the scenarios (20 sheets total with the order in each group of ten being determined by a table of random numbers);

d) the preferred diagnosis of each scenario;

e) a complete list of responses to pilot information requests for each scenario;

f) a blank ranking sheet for each scenario numbered from one to ten; and

g) instructions for the expert.

Experts were instructed to rank the pilots within each scenario from best (1) to worst (10). "Best" referred to a pilot whose information seeking behavior most clearly resembled that of an expert. In the process of ranking, the experts were told to describe their thoughts out loud, making certain they described their reasoning for rating one pilot better than another. This entire procedure was completed at the expert's convenience without an experimenter present (but with the tape recorder running).

E. Results

Data collected from the experts consisted of:

a) a rank sheet for each scenario;

b) criteria used by experts in deciding on the rankings (as derived from the tapes);

c) the criteria used by a particular expert.

Tables 5-2 and 5-3 shows the subject rankings made by each expert for each of the scenarios. Subject 4 of the vacuum pump scenario was eliminated from analysis since the experts were uncertain whether he had made a single lucky guess.

For each of the two scenarios, a Spearman Rank Correlation was run between the ranks of each expert and each expert against the rank of scores assigned the subjects by the experimenters following the PLATO or protocol runs.

"Within expert" agreement was very high for the static port scenario. Five of the 6 experts had ranks correlated with each other at a significance level of .05 or less. Four of the six experts were significantly correlated on the vacuum pump scenario.

In terms of ranking agreement with the experimenter scores, all were correlated with the experimenter on the static port scenario and five out of six were correlated with the experimenter scores on the vacuum pump scenario.

F. Criterion Selection

Table 5-4 shows the derived criteria, which ones were utilized by a particular expert, and the proportion of experts making use of each criterion.

Table 5-2. Vacuum Pump Scenario

Subject Number Rankings

Rank \ Expert	A	B	C	D	E	F
1	1	13	13	1	13	1
2	6	1	6	13	1	7
3	13	6	1	7	6	9
4	3	9	12	6	10	12
5	12	12	7	11	9	6
6	7	7	9	12	3	13
7	10	3	11	9	12	11
8	9	10	10	3	7	10
9	11	11	3	10	11	3

Table 5-3. Static Port Scenario

Subject Number Rankings

Rank \ Expert	A	B	C	D	E	F
1	51	43	43	51	51	46
2	43	50	50	46	50	43
3	50	51	51	50	43	50
4	44	44	46	43	59	44
5	46	46	59	54	52	51
6	59	57	44	45	44	59
7	45	45	45	44	46	57
8	54	54	54	59	54	45
9	57	59	57	57	45	54
10	52	52	52	52	57	52

NOTE: The numbers in Tables 2 & 3 are subject identification numbers corresponding to the files generated during protocol and PLATO testing respectively.

From the recordings, a criterion was counted each time an expert either:

a) used a particular factor to differentiate subjects or groups of subjects from one another; or

b) explicitly stated the criterion he was or would be using to make the ranking decisions.

Even defining the criteria selection carefully as was done, the frequencies remained limited on two counts. First, experts varied considerably in levels of analysis they applied to this study. Some experts would consistently give one or more reasons for each rank assigned while others would not give any. It was a problem of getting the expert to both compare in detail the subjects' responses and to verbalize what they discovered. Second, when the criterion was not explicitly stated by the expert, it often became necessary for the researcher to be subjective and infer whether or not it was a criterion. For example, one expert while ranking subject 46 in the static port scenario supported his rank by stating, "he asked about ice, outside air temperature, pitot heat and opening the alternate static source. He suspected propeller ice when he asked about vibration and unusual noise." The problem here is determining whether these are criteria or merely summarizations to aid the expert in his recall and ranking of a particular subject. For the above reasons, the most accurate representative measure of criterion usage is the proportion of experts who made use of a specified criterion at least once. Thus, Table 5-4 lists the proportion of experts using each criterion rather than the frequency of each one.

Table 5-4. Expert Criteria Mentioned in Both Scenarios

CRITERIA: (+) = positive factor (-) = negative factor	EXPERT A	 B	 C	 D	 E	 F	PROPORTION OF EXPERTS REQUESTING THE PARTICULAR CRITERION
Suction gauge inquiry (+)	X	X	X	X	X	X	1.00
Alternate static port open inquiry (+)	X	X	X	X	X	X	1.00
Many relevant inquiries (+)	X	X	X	X	X	X	1.00
Many irrelevant inquiries (-)	X		X	X	X	X	.83
Logical sequence of inquiries (+)	X		X	X	X		.67
Exhibit lack of knowledge about aircraft systems (vacuum and static) (-)	X	X	X	X			.67
Cross-checked instruments (+)	X			X	X	X	.67
Random sequence of inquiries (-)	X		X		X	X	.67
Inquire about unknown primary flight instruments (+)		X			X	X	.5
Made too few inquiries (-)	X		X	X			.5
Did not inquire about suction gauge (-)			X		X		.33
Total number of inquiries							
Many (+)		X		X			.33
Many (-)	X	X					.33
Few (+)			X	X			.33
Engine power inquiry (+)					X	X	.33
Structural ice inquiry not made (-)	X		X				.33
Inquired about unknown primary flight instruments (-)		X					.17
Too much control testing (-)		X					.17
Too many separate paths taken (-)		X					.17
Did not cross-check instruments (-)					X		.17
Repeated inquiry (-)			X				.17
Structural ice inquiry made (+)					X		.17

As critera were selected it became useful to distinguish between positive and negative criteria. A criterion was considered positive if the expert spoke of it as a factor beneficial to the subject's rating. A negative criterion was detrimental; that is, the subject could have performed better if this factor had not appeared.

G. Analysis

From analysis of the tapes and the criteria in Table 5-4, several conclusions can be drawn:

a) Experts usually used the presence of keyword requests to make the initial broad cuts (i.e. top 5 and bottom 5) in performance. The keyword was the suction gage in the vacuum pump scenario and the alternate static source opening in the blocked static port scenario. The keyword did not necessarily lead to a high rank. Some of the experts were more concerned about how the subjects arrived at the keyword (i.e. their information seeking strategey).

b) Relevancy of a request seemed to weigh heavily in the experts' minds yet there was a great variation among experts in what constitutes relevancy.

c) Experts often categorized as "poor" those pilots who made random illogical requests.

d) An expert often used a set of personal criteria which few others even considered.

e) All experts appeared to be concerned with efficiency (making as few requests as possible and making them relevant).

f) There appeared to be some disagreement as to whether many and few inquiries are positive or negative features of the search.

Although the experts did not totally agree on a best and worst pilot for each scenario, there was considerable agreement if the top two and bottom two are considered alone. Tables 5-5 and 5-6 represent the pilot information requests of the best and worst subjects in the vacuum pump scenario while Tables 5-7 and 5-8 do the same for the static port scenario.

H. Expert Comments

Experts often provided useful commentaries after ranking the subjects. By far, the most frequent concern was the poor performance of the IFR rated pilots. One expert stated, "I must confess at how surprised I am at lack of systematic search strategy or information seeking behavior exhibited by these pilots.... It would appear we ought to do a better job in training pilots in both aircraft systems and in troubleshooting when presented with information that is inconsistent."

Table 5-5. Information Requests of Two Pilots Ranked Best By the Experts on the Vacuum Pump Scenario

Subject #1

Vacuum Pump Scenario

1. What's the manifold pressure reading?
2. Is there any ice on the wings?
3. Is there any ice on the windscreen?
4. What's the outside air temperature?
5. Can you notice any precipitation?
6. What's the suction gauge reading?
7. What's the magnetic compass reading?
8. What's the directional gyro reading?

Subject #13

Vacuum Pump Scenario

1. What are the original readings, again?
2. What's the vertical speed indicator showing?
3. What's the tachometer reading?
4. What's the manifold pressure reading?
5. What does the artificial horizon show?
6. What's the suction gauge reading?

Table 5-6. Information Requests of Two Pilots Ranked Worst By the Experts on the Vacuum Pump Scenario

Subject #10

Vacuum Pump Scenario

1. What happens when I open the alternate static source?
2. What were the original indications for the airspeed indicator and altimeter?
3. What's the outside air temperature?
4. What's the tachometer reading?
5. Is there any ice on the wings?

Subject #11

Vacuum Pump Scenario

1. What's the manifold pressure reading?
2. What's the tachometer reading?
3. What's the oil pressure reading?
4. What's the oil temperature reading?
5. What's the current weather report?
6. What is our origin and destination?
7. What is our terrain clearance?
8. How far are we from any mountain ranges?
9. What's the outside air temperature?
10. What's the surface temperature?
11. What's the vertical speed indicator showing?
12. Were any thunderstorms forecast?
13. What type of clouds are in the vicinity?
14. What do the gear indicator lights show?
15. What are the flaps set at?

Table 5-7. Information Requests of Two Pilots Ranked Best By the Experts on the Static Port Scenario.

Subject #51

Static Port Scenario

1. What's the forecast freezing level?
2. Are there any PIREPS, SIGMETS, or AIRMETS in my area?
3. Is there any ice on the wings?
4. What's the outside air temperature gauge show?
5. What happens when the alternate static source is opened?
6. What happens when the pitot heat is turned on?
7. What's the reading on the suction gauge?
8. Is there any ice on the cowling or wings?
9. What happens when the alternate static source is opened?

Subject #43

Static Port Scenario

1. What's the reading on the vertical speed indicator?
2. What's the reading on the altimeter?
3. What's the outside air temperature gauge show?
4. Is the pitot heat on?
5. What happens when the pitot heat is turned on?
6. What is the artificial horizon showing?
7. What's the tachometer reading?
8. What's the manifold pressure reading?
9. What happens when the alternate static source is opened?

Table 5-8. Information Requests of Two Pilots Ranked Worst By the Experts on the Static Port Scenario

Subject #52

Static Port Scenario

1. Is there any ice on the windscreen or wing?
2. Are there any PIREPS, AIRMETS, or SIGMETS in my area?
3. What's the forecast freezing level?
4. At what altitude are the cloud tops?

Subject #57

Static Port Scenario

1. Have any circuit breakers popped?
2. What's the suction gauge reading?
3. What's the airspeed reading?
4. What does the artificial horizon show?
5. What's the altimeter reading?
6. What's the turn and bank indicator show?
7. What's the directional gyro reading?
8. What's the vertical speed indicator show?
9. What's the manifold pressure reading?
10. What's the tachometer reading?
11. What's the exhaust gas temperature reading?
12. What tank is the fuel selector set at?
13. What's the oil pressure reading?
14. What happens when the magneto switch is changed to left, right, both, and off?
15. What happens when the pitot heat is turned on?
16. What happens when the prop RPM is advanced?
17. What happens when the prop RPM is decreased?
18. What's the mixture set at?
19. Is there any ice on the cowling, windscreen, wing, flap, aileron, or stabilizer?
20. What is the door condition?
21. What is the panel temperature?
22. What is the cargo condition?
23. What is the cabin temperature?
24. Is there any smoke in the cabin?
25. What's the housekeeping condition of the cabin?
26. Are there any noticeable fluid leaks in the cabin?
27. Is there any unusual noise or vibration in the cabin?
28. What's the vertical speed indicator show?

Another expert commented, "This indicates that pilots, in general, have an almost unlimited faith in instruments when they're flying." Commenting on the vacuum pump scenario in particular, this expert described the development of this classic situation as follows: "Even an expert pilot flying a single-engine airplane, primarily, with instruments vacuum powered,

1) Is probably not aware of the failure until the instruments have begun to lead him astray; and
2) When this situation does occur, almost in a classic sense the graveyard spiral develops and by the time a pilot recognizes what the problem is, the attempted recovery frequently results in either an unscheduled impact with the terrain or an inflight airframe failure."

As a solution to this problem he suggests, "We might need to look into the possibility of requiring a large red vacuum system failure light or some sort of an annunciator that would provide the pilot, who apparently doesn't suspect these sorts of things, with an audible or strong visual alerting system."

I. Conclusions

From the use of an expert panel we were able to conclude:

1) There was a strong consistency among experts in their ranking of pilot diagnostic performance. This was especially apparent at the high and low ends of pilot performance.

2 The experimenters previously developed grading scheme produced a ranking of subjects which correlated strongly with the expert rankings.

3) Without exception, experts were concerned with the efficiency of subject requests (i.e. requests should be relevant and few in number);

4) Ranking criteria of experts were variable except at the extremes of subject performance.

5) Experts were in general appalled that IFR rated pilots could do so poorly in diagnostic performance.

6) The expert ranking criteria confirmed earlier researcher conclusions about optimal or idealized information seeking strategies; in particular, the need to:

   a) confirm symptomatic problems,

   b) establish the orientation of the aircraft (i.e. was the aircraft in a descent?),

   c) cross check to verify instrument accuracy,

   d) use minor control inputs to check the aircraft orientation.

VI. Summary and Conclusions

The tasks set forth in the proposal for continued work "Research on Computer Aided Testing of Pilot Response to Critical In-Flight Events" (Grant NAG 2-112) have been accomplished. This project concludes a series of contracts and grants (NAS 2-10047, NAG 2-75, NAG 2-112 from NASA Ames) directed toward a fuller understanding of how pilots collect information and make decisions in the face of critical in-flight events.

The effort reported here focused on developing models of pilot decision making. 1) New data were obtained from some twenty instrument rated pilots by a lengthy protocol analysis. These data led to a frame system representation of how pilots organize a fault diagnosis task. 2) Previously collected computer data were used to describe collective behavior in terms of script norms, distance between inquiry measures and Markov processes. 3) Recognized expert pilots were used to rank both new and old subject performances and to suggest a rationale for good information seeking strategies.

By-products of this research effort over the duration of the three grants include 3 M.S. theses, 1 Ph.D. dissertation, 4 conference presentations and 3 journal articles. Additional publications are anticipated. Appendix G lists these research outputs found in the open literature.

A. Frame System Representation

A frame system has been developed which can account for the performances of twenty pilots in diagnosing a vacuum system failure in a light aircraft. Eighteen frames, all having a common structure are necessary to explain the data. These frames represent prototypical states of nature. Each frame, with the exception of the memory error frame, has an associated set of triggers, a label and two slots.

These frames are organized into a set of hierarchies with seven high-level frames. All other frames are linked to these high-level frames as slot-fillers in "Causes" slots. High level frames are activated as a pilot listens to the scenario. Activation typically uses only part of the information available in the scenario. The information selected for attention appears to be caused by 1) occurrence of unexpected events, 2) priming, or 3) frame-directed attention.

Pilots who identified the problem as an artificial horizon malfunction, but did not reach the root cause of vacuum pump failure, failed to check for possible causes at the appropriate time. Pilots who never reached a conclusion failed to ask about expected instrument readings. Those experiencing difficulty in solving the problem often suffered from memory distortions and activation of default values.

By comparing strategies of successful and unsuccessful pilots recommendations for a high-level control structure to address the vacuum pump failure problem can be made. The proposed control structure consists of an ordered list of objectives along with a set of plans designed to attain these objectives. The plans act upon the contents of three knowledge-bases and a working memory. The knowledge bases include 1) the eighteen frames identified among the test subjects, 2) a set of objectives and plans for attaining them and 3) the pilot's aviation knowledge and episodic memory of aviation experiences. The working memory stores the pilot's episodic memories of the scenario, the sequence of activated frames, the objectives achieved, the information requested and a record of the currently activated frame. Such a normative model could be realized as an expert system.

Pilots who fail to diagnose the problem appear to have the necessary frames at their disposal, but their high-level control processes deviate from the suggested normative model. Their processes failed to recognize the objectives of:

1. Avoiding memory distortions
2. Detecting instrument malfunctions
3. Avoiding incorrect activation of a frame due to inattention or use of insufficient information
4. Avoiding false inferences due to activation of incorrect default values
5. Avoiding cognitive narrowing.

B. Grouped Data

Three different approaches were investigated in the search for descriptions of how pilots as a group search for information in critical in-flight events. These included script norms, distance measures and Markov chains.

Script norms were developed by tabulating distributions for the number of items of information requested by varying number of subjects. The general shape of the distributions was the same for all five scenarios tested, with all but one showing a sharp difference at the 20 percent point. A group's script norm was arbitrarily defined as those items requested by more than 40 percent of the subjects.

From analyzing these norms it is apparent that group scripts are highly scenario dependent with traditional instrument clusters showing up as high frequency items (e.g. oil temperature, cylinder head temperature and oil pressure were all sought by nearly every subject in scenarios with engine health overtones). It is also apparent that pilots as a group agree on the importance of a relatively small number of information items in problem diagnosis. In the four principal test scenarios the number of items requested by over 40 percent of the subjects ranged from 7 to 13. These are only small percentages of the 110 items of information available to CAT subjects.

Clusters of information defined by short distances (i.e. number of inquiries separating the acquisition of two pieces of information) and high frequencies of occurrences were identified for past PLATO® subjects in both the vacuum pump and magneto malfunction scenarios. The purpose of this study was to sharpen the definition of "tracks" used in earlier flow-graph charts (PIPS) of pilot information seeking strategies.

By examining the resulting tables it is possible to identify popular hypotheses about the system failure and the information considered important to test those hypotheses. The clusters for the more difficult problem (vacuum pump failure) often contain logically disjoint information reflecting a mix of hypotheses as subjects jump around in search of supportive information. The clusters in the magneto drive gear failure scenario may be more indicative of the true closeness in memory structure among items.

Markov chain representations of several groups of pilots were attempted with limited success. Although groups were selected according to what appeared to be criteria related to homogeniety among members, the anticipated multi-stage dependence among inquiries could not be substantiated by the data. For the groups of pilots and scenarios tested, no stronger dependence than that of a first order Markov chain could be statistically identified.

The failure of the Markov model to adequately describe observed information seeking behavior is believed to be related to three possible causes. 1) Individual differences among subjects are too great to permit grouping observations as though they represented multiple realizations of the same Markov chain. 2) The unfamiliar task of collecting information one piece at a time is inhibiting to the memory processes of expert pilots who normally "chunk" familiar patterns of stimuli from an aircraft instrument panel. 3) The sample sizes are inadequate to test the model.

C. Panel of Experts

Six well-known aviation experts were used to rank two groups of ten pilots each on the basis of the pilots' information requests. A separate scenario was used for each pilot group. The groups were selected to include a mix of pilot experience levels and diagnostic performance. In addition to ranking pilot performance each expert was asked to verbalize the reasons for placing each pilot in his relative group position.

The expert rankings were highly correlated with each other as well as correlated with earlier experimenter derived performance scores. Without exception, the experts were concerned with efficiency of information requests (i.e. requests should be relevant and few in number.) The derived ranking criteria used by this group of experts confirmed earlier researcher conclusions about idealized information seeking strategy; in particular the need to

1) confirm symptomatic problems
2) establish the orientation of the aircraft
3) cross check to verify instrument accuracy
4) use minor control inputs to check aircraft orientation.

D. Epilogue

The study of pilot response to critical in-flight events has been a rewarding experience for these researchers. We feel that we have developed a better understanding of the way pilots do and should organize their information seeking tasks during problem diagnosis. Our major contributions have been to document a variety of descriptive models, develop several useful research tools and accumulate a large data base of pilot performance data for future study.

Comments by subjects and our panel of experts plus experimenter observation lead to the uneasy observation that IFR rated pilots generally do rather poorly in diagnostic performance. The subject pilots were the first to admit this. Many expressed the feeling that, although humbled by the experience, participating in any of our experiments should improve their future diagnostic skills if only by reminding them of the limits of their knowledge. None thought the exercises, beginning with paper and pencil tests, running through GAT simulations, to computer aided tests and finally protocol testing, were unrealistic. All seemed to agree that such tests were valuable learning experiences.

The nature of subject comments and their demonstrated performance point to what may well be the most useful future course for this research. The research tools which have been developed and tested could easily be adapted to the pilot training environment. Future support will be sought to accomplish that goal.

It is also apparent that many pilots have weaknesses in their diagnostic skills which could be allievated by on-board computer systems. The development of expert systems to be used in a real-time setting could greatly improve fault diagnosis performance by pilots'. Future research directed toward such an electronic co-pilot is in order. Information concerning the memory structure of pilots modeled in this research should provide a natural lead-in for that research. Support will also be sought for that effort.

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Appendix A

Illustrations of PLATO® Displays

The attached exhibit depicts a small sample of the material presented to the subject pilot by the PLATO® terminal. The displays selected for presentation here represent different facets of the program, e.g. sample biographical questions, sample knowledge test questions or a representative diagnostic scenario. The illustrations represent a sample of those presented to the subject in his response to:

1) fifteen biographical questions
2) twenty knowledge questions
3) six scenarios

CRITICAL

IN-FLIGHT

EVENTS

Developed by: The Ohio State University
Department of Industrial Engineering
under a research grant from NASA/AMES

Principal Researchers: Dr. T.H. Rockwell
Dr. W.C. Giffin

Programmer/Analyst: Jeffrey Lee

Assistant Programmer: Steve Schoenlein

PLATO Consultant: Dave Romer

(Touch the screen anywhere to begin.)

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INTRODUCTION

Thank you for being a subject in this NASA supported research project.

The scenarios you are about to see were developed not as a device to test your flying expertise, but rather as a mechanism for us to better understand how pilots might react to certain situations.

For many of the flying situations presented (just as in real life), there are no obvious answers. What we want to find out is how you approach problem solving. These are not games in the sense that you compete with the computer or anyone else. We hope you will find the scenarios to be realistic situations a pilot must occasionally confront. For the most part, the scenarios are not dynamic ie. the instrument panel does not reflect changes over time. In effect the terminal acts not like a flight simulator, but rather as a device to present information so we can understand pilot diagnostic and decision making behavior.

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CIFE Router

Biographical Survey

Diagnostic Scenario #Ø1

Destination Diversion Test

Knowledge Survey

Diagnostic Scenario #Ø2

Airport Ranking Test

VOR-Autopilot

Diagnostic Scenario #Ø3

Diagnostic Scenario #Ø4

Diagnostic Scenario #Ø5

Diagnostic Scenario #Ø6

[illegible]

Data Display

BIOGRAPHICAL DATA

Touch the screen anywhere to begin the biographical survey.

Question No. 1

Enter Pilot Certificate by Touch Panel

a) Student Pilot

b) Private Pilot

c) Commercial Pilot

d) Air Transport Pilot

When you have made your final SELECTION:

ENTER

Question No. 2

Enter Airman Ratings Held by Touch Panel

a) Repairman

b) Airframe Mechanic

c) Powerplant Mechanic

d) Flight Engineer

e) Instrument Rating

f) Certified Flight Instructor

g) ASEL

h) AMEL

i) Rotary Wing

j) Inspection Authorization

k) None of the above

FINAL finalizes above entries.

ERASE removes last entry.

FINAL

ERASE

KNOWLEDGE SURVEY

Touch the screen anywhere to begin the knowledge survey.

Question No. 1

What is the standard adiabatic lapse rate?

a) 2°F per 1000 feet.

b) 2.5°F per 1000 feet.

c) 3°F per 1000 feet.

d) 3.5°F per 1000 feet.

e) 4°F per 1000 feet.

When you have made your final SELECTION:

ENTER

Question No. 2

Do the indications of a normally operating alternator system change during the course of a flight? (Assume charge-discharge ammeter)

a) Yes: Ammeter shows more charge when electrical equipment turned on.

b) Yes: Ammeter shows less charge when electrical equipment turned on.

c) After engine start, the ammeter shows a higher than normal rate of charge and gradually declines to normal rate.

d) No, does not change.

When you have made your final SELECTION:

ENTER

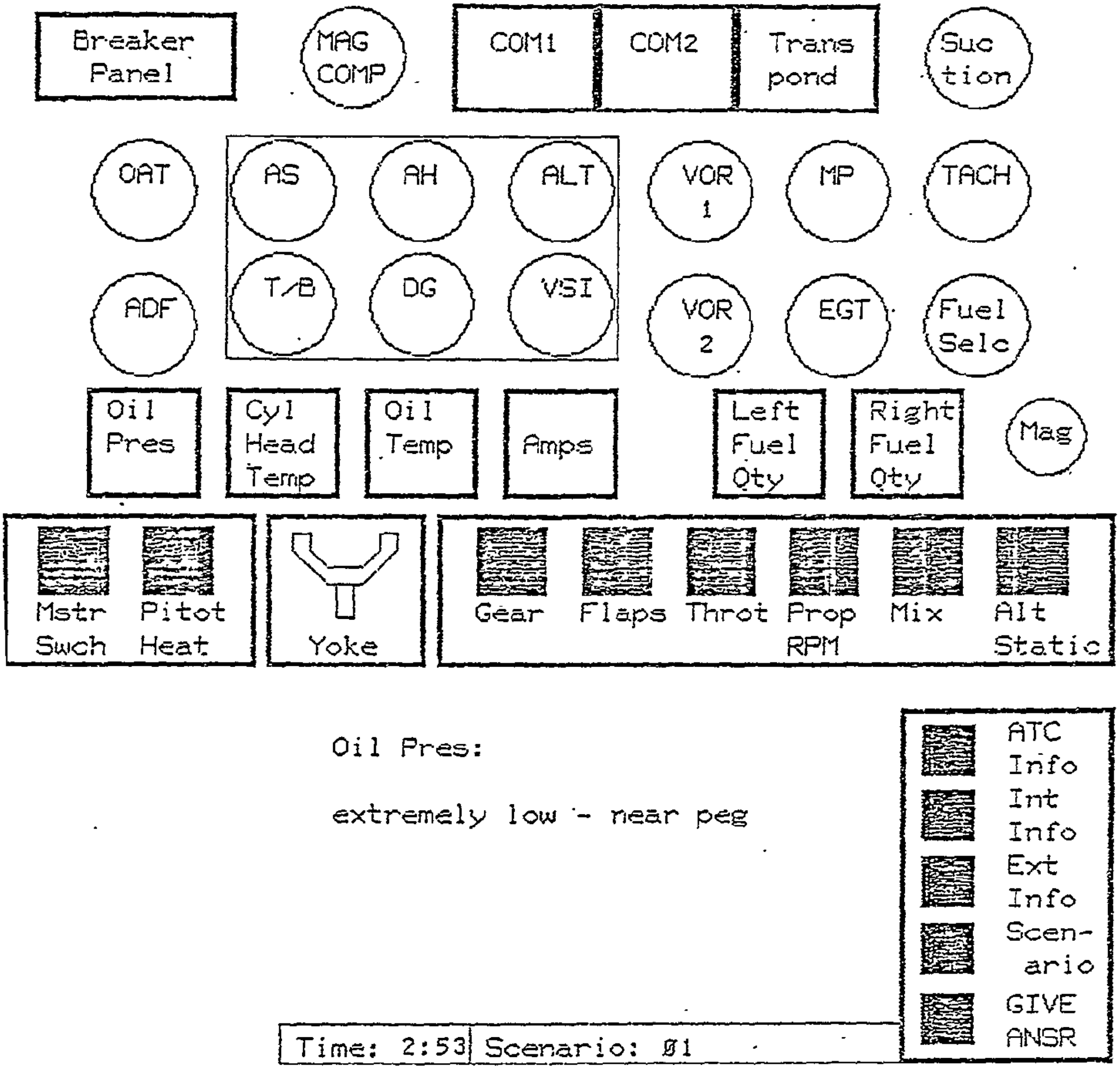
DIAGNOSTIC SCENARIO TEST

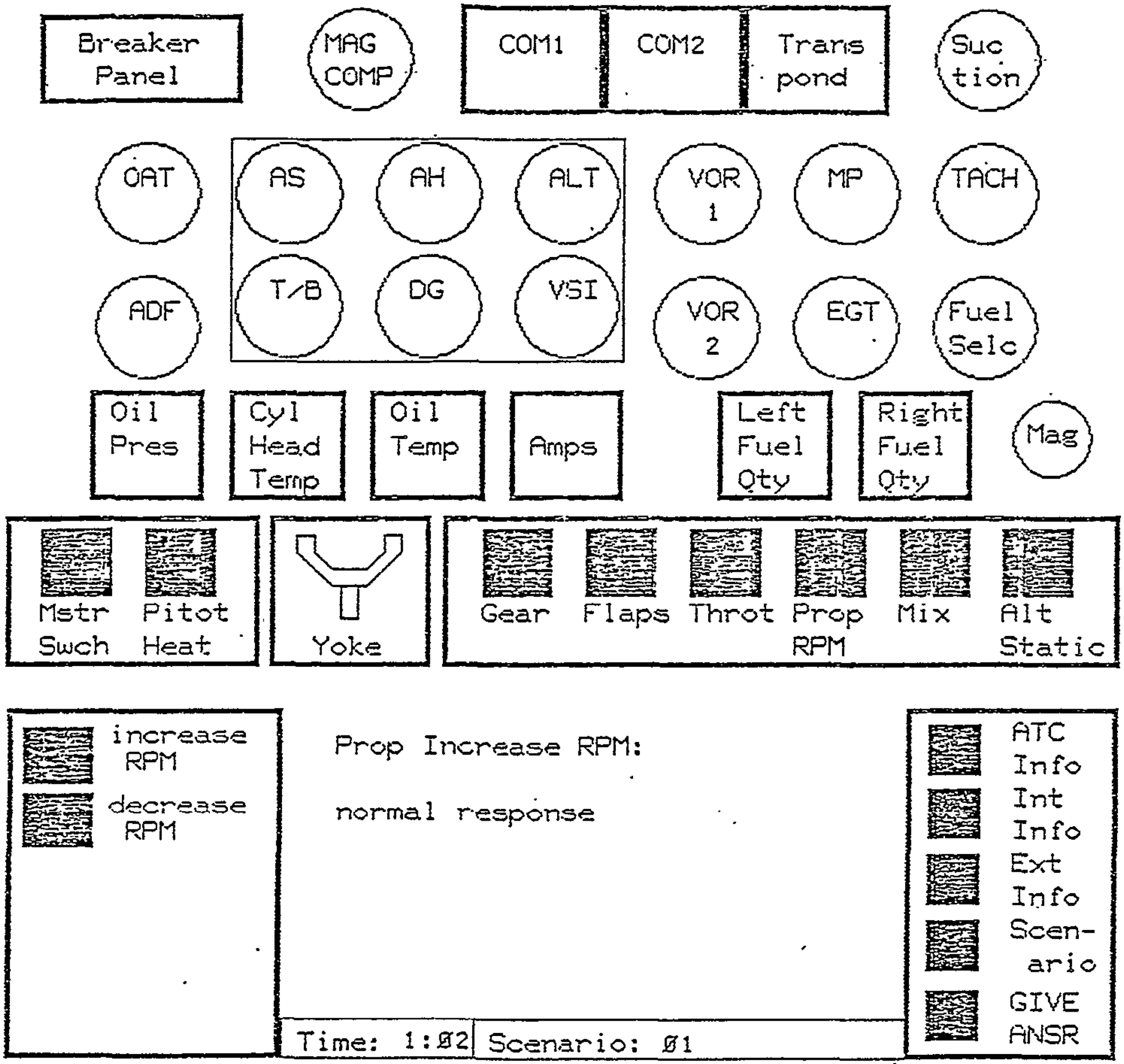
Instructions:

You have a maximum of 4 minutes for each diagnostic scenario. Since these are potential emergency situations, please answer the question as soon as you feel that you have a solution.

Please press CONTINUE when you are ready to start the test.

CONTINUE


Breaker Panel
MAG COMP
COM1
COM2
Trans pond
Suc tion
OAT
AS
AH
ALT
VOR 1
MP
TACH
ADF
T/B
DG
VSI
VOR 2
EGT
Fuel Selc
Oil Pres
Cyl Head Temp
Oil Temp
Amps
Left Fuel Qty
Right Fuel Qty
Mag
Mstr Swch
Pitot Heat
Yoke
Gear
Flaps
Throt
Prop RPM
Mix
Alt Static
Oil Pres:
extremely low - near peg
ATC Info
Int Info
Ext Info
Scen- ario
GIVE ANSR
Time: 2:53
Scenario: Ø1


Breaker Panel
MAG COMP
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VOR 1
MP
TACH
ADF
T/B
DG
VSI
VOR 2
EGT
Fuel Selc
Oil Pres
Cyl Head Temp
Oil Temp
Amps
Left Fuel Qty
Right Fuel Qty
Mag
Mstr Swch
Pitot Heat
Yoke
Gear
Flaps
Throt
Prop RPM
Mix
Alt Static
increase RPM
decrease RPM
Prop Increase RPM:
normal response
ATC Info
Int Info
Ext Info
Scen-ario
GIVE ANSR
Time: 1:Ø2
Scenario: Ø1

Information for External Conditions

Cowling Condition

Windscreen Condition

Wing Condition

Flap Condition

Aileron Condition

Stabilizer Condition

Cowling Condition:

clean and secure

ATC Info

Int Info

Instr Panel

Scen-ario

GIVE ANSR

Time: Ø:15	Scenario: Ø1

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Information for Inside Cabin Conditions

Cargo Condition | Door Condition | Panel Temp Condition

Cabin Temp Condition | Housekeeping Condition

Smoke | Fluid Leaks | Noise & Vibration

Fluid Leaks:

oil droplets on floor

Instr Panel

ATC Info

Ext Info

Scen-ario

GIVE ANSR

Time: 3:1Ø | Scenario: Ø1

ATC Information for Diagnostic Purposes

Ceiling

Visibility

Cloud Tops

Winds Aloft

Freezing Level

PIREPS

SIGMETS

AIRMETS

Ground Speed

NAV AID Status

Freezing Level:

area forecast-
8ØØØ

Instr Panel

Int Info

Ext Info

Scen-ario

GIVE ANSR

Time: 2:13 | Scenario: Ø1

▒	Instr Panel	▒	ATC Info	▒	Int Info
▒	Ext Info	▒	Scen-ario	▒	GIVE ANSR

You have chosen GIVE ANSWER.
If you are ready to give your diagnosis of the scenario, please touch the GIVE ANSR button; else touch an alternate button to continue the test.

Time: 1:57	Scenario: Ø1

1	aileron	26	elevator	51	landing	76	rudder
2	alternator	27	engine	52	latch	77	screen
3	altimeter	28	exhaust	53	leaking	78	screw
4	baffle	29	failure	54	left	79	seal
5	battery	3Ø	filter	55	line	8Ø	seizure
6	belt	31	fire	56	loose	81	smoke
7	blocked	32	flap	57	loss	82	starter
8	bottom	33	flow	58	lost	83	starvation
9	broken	34	fouled	59	magneto	84	static
1Ø	burst	35	frozen	6Ø	mixture	85	stuck
11	cable	36	fuel	61	motor	86	suction
12	cap	37	gasket	62	oil	87	switch
13	carburetor	38	gauge	63	partial	88	tank
14	C/B fuse	39	gear	64	pedal	89	temp.
15	cock	4Ø	govenor	65	piston	9Ø	throttle
16	complete	41	gyro	66	pitot	91	tip
17	condenser	42	heat	67	plugs	92	top
18	control	43	hot	68	points	93	vacuum
19	cold	44	hydraulic	69	popped	94	valve
2Ø	cowling	45	ice	7Ø	port	95	vapor
21	crankshaft	46	ignition	71	pressure	96	vibration
22	cylinder	47	induced	72	prop		
23	door	48	induction	73	pump		
24	drive	49	instrument	74	right		
25	electrical	5Ø	jets	75	ring		

oil gauge line
leaking

1	2	3		enter
4	5	6	Ø	
7	8	9		clear

STORE ANSWER

ERASE WORD

Question No. 2

How long do you think the airplane would fly?

a) Ø - 5 minutes

b) 5 - 3Ø minutes

c) as long as fuel permits

When you have made your final SELECTION:

ENTER

Question No. 3

How critical do you judge this problem to be?
(1 is the least critical and 7 is the most critical)

a) 1

b) 2

c) 3

d) 4

e) 5

f) 6

g) 7

When you have made your final SELECTION:

ENTER

Question No. 4

How confident are you about your diagnosis?
(1 is the least confident and 10 is the most confident)

a) 1

b) 2

c) 3

d) 4

e) 5

f) 6

g) 7

h) 8

i) 9

j) 10

When you have made your final SELECTION:

ENTER

Appendix B

Description of Diagnostic Scenarios and Their Answers for Scenarios 1, 2, 3, 4, and 6*

*Scenario #5 is found in Figure 7

C-3

Scenario

You are making a day trip from Albany, NY to Burlington, VT. You fly out of Albany at 9:00am, cleared Victor-91, Burlington. You climb to a cruising altitude of 7000ft. After 20 minutes of routine IMC flying you notice the smell of engine oil.

How would you diagnose the problem?

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Instr Panel

Int Info

Ext Info

ATC Info

GIVE ANSR

Time:	Scenario: 01

Our diagnosis of the problem was the following:

A small crack developed in the oil line feeding the oil pressure gauge. This crack reduced the oil pressure reading drastically, but did not seriously affect the actual lubrication of the engine. A small pool of oil began to form on the floor of the cabin, pilot's side. Assuming that the cracked line would not deteriorate quickly into a complete break, you were in no immediate danger of engine seizure.

CONTINUE

Scenario

You are making a day trip from Augusta,ME to Lebanon,NH. You fly out of Augusta at 9:00 am, cleared Victor 39 to Neets intersection, Victor 496 to Lebanon. You climb to a cruising altitude of 6000 ft. After 15 minutes of routine IMC flying in instrument conditions, your instruments indicate an increase in airspeed and steadily decreasing altitude while maintaining level flight attitude.

How would you diagnose the problem?

Instr Panel

Int Info

Ext Info

ATC Info

GIVE ANSR

Time:	Scenario: 02

Our diagnosis of the problem was the following:

Your vacuum pump failed as indicated by the low reading of the suction gauge. The vacuum pump drives the attitude and directional gyros. As the artificial horizon lost its drive it started to sag to the right and you compensated by turning left, leveling the artificial horizon and putting the plane in a slow, descending left bank. The airspeed increase was due to the slight nose-down attitude.

CONTINUE

Scenario

You are making a day trip from Keene, NH to Montpelier, VT. You fly out of Keene at 10:30 am, cleared Victor-151 to Montpelier. You climb to a cruising altitude of 5000 ft. After 20 minutes of routine cruise in IMC your engine suddenly starts running extremely rough, shaking the whole plane and losing about 20% of its cruise power.

How would you diagnose the problem?

Instr Panel

Int Info

Ext Info

ATC Info

GIVE ANSR

Time: | Scenario: 03

Our diagnosis of the problem was the following:

Your engine suffered a broken drive gear in the right magneto. The resultant untimed ignition conflicted with the remaining good ignition and caused the extremely rough engine and backfiring. Switching from 'both' to the left magneto would have resulted in a smooth running engine with slightly less power than normal cruise.

CONTINUE

Scenario

You are making a day trip from Sanford, ME to Messena, NY. You fly out of Sanford at 8:30am, cleared Victor-496 to Lebanon, Victor-141 to Messena. You climb to a cruise altitude of 6000. After 20 min IMC flying, Boston Center instructs you to climb and maintain 10,000ft. You acknowledge and begin your climb between layers. After 2 min of climb, you notice your indicated airspeed dropping off steadily from 100kts, maintaining constant pitch attitude.

How would you diagnose the problem?

Instr Panel
Int Info
Ext Info
ATC Info
GIVE ANSR

Time:	Scenario: 04

Our diagnosis of the problem was the following:

As you climbed through 6500ft, the static port froze over as the outside air temperature dropped below 32°F. This caused the airspeed indicator to decrease as altitude increased and the VSI and altimeter to read low. Several corrective actions were possible: return to your previous altitude of 6000ft; open the alternate static source; break the VSI glass.

CONTINUE

Scenario

You are making a day trip from Montpelier,VT to Bangor,ME with two passengers on board. You fly out of Montpelier at 1:00pm, cleared radar vectors to Wylie intersection, direct Augusta, Victor 3 to Bangor. You climb to a cruising altitude of 9000ft. After 30 minutes of routine flying in instrument conditions with light to moderate turbulence, one of your passengers reports smelling a faint burning odor. You are unable to detect the odor because you have a head cold.

What is the first thing you would do?

Instr
Panel
Int
Info
Ext
Info
ATC
Info
GIVE
ANSR

Time: Scenario: 06

C O N T I N U E

Our diagnosis of the problem was the following:

Rear seat carpeting was smoldering.
The rear seat passenger lit a
cigarette shortly after takeoff. When
he disposed of it in the ashtray, it was
not completely extinguished. The
cigarette fell down from the ashtray
and was beginning to char upholstery
material. The fire was easily
extinguished, once recognized and posed
no immediate danger to the flight.

Appendix C

A Sample of Subject Data

PRECEDING PAGE BLANK NOT FILMED

DATA DISPLAY

This program reports the data collected by the CRITICAL IN-FLIGHT EVENT program.

Each display is a record of responses given by a student for each phase of the CRITICAL IN-FLIGHT EVENT program.

Function keys provided:

CONTINUE will advance to the next display

REVIEW will return to the previous display

MENU will access the main menu display

RESTART will start the program again

Please enter the student that you wish to view.
(For example: student041)

> student075

Press NEXT when entered.

DATA DISPLAY
**cifel

Biographical Survey

NAME: studentØ75
DATE: Ø6/Ø9/82

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QUESTION	ANSR
1	c (3)
2	e (5)
2	h (8)
2	g (7)
3	f (6)
4	b (2)
5	d (4)
6	f (6)
7	f (6)
8	f (6)
9	f (6)
1Ø	a (1)
11	b (2)
12	b (2)
13	b (2)
14	c (3)

QUESTION	ANSR
15	g (7)

CONTINUE

MENU

REVIEW

DATA DISPLAY
**cife2

Knowledge Survey

NAME:	student075
DATE:	06/09/82

QUESTION (x=incorrect)		ANSR	AREA
x	1	c	3
	2	c	2
x	3	b	2
	4	b	2
x	5	b	1
x	6	c	2
x	7	a	1
	8	a	3
	9	b	2
	10	a	2

QUESTION (x=incorrect)		ANSR	AREA
x	11	b	1
	12	b	3
x	13	a	1
x	14	e	3
x	15	a	2
x	16	b	3
x	17	b	1
x	18	c	3
x	19	d	1
x	20	d	1

SCORE = 30%

AREA	TOTAL MISSED	TOTAL IN AREA
1) Engine and fuel systems	7	7
2) Electrical systems and cockpit instrumentation	3	7
3) Weather and IFR operations	4	6

CONTINUE | MENU | REVIEW

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DATA DISPLAY
**cife3
**scene02

Diagnostic Scenario #02

NAME: student075
DATE: 06/09/82

TIME (sec)	ΔTIME (sec)	DISPLAY	ITEM	CURRENT VALUE
6	4	Ext info	aileron	
10	5	Ext info	flap	
15	2	Ext info	cowling	
17	3	Ext info	windscreen	
20	2	Ext info	wing	
22	22	Ext info	stabilizer	
44	18	Int info	panel temp	
62	19	instr pan	OAT	
81	8	instr pan	breaker panel	
89	7	instr pan	alt static	
96	5	instr pan	alt static open	
101	7	instr pan	alt static closed	
108	9	instr pan	pitot heat	
117	6	instr pan	pitot heat on	
123	27	instr pan	pitot heat off	
150	7	ATC info	freezing level	
157	5	ATC info	cloud tops	
162	12	ATC info	ceiling	
174	6	ATC info	visibility	
180	3	ATC info	PIREPS	
183	2	ATC info	SIGMETS	
185	45	ATC info	AIRMETS	

CONTINUE

MENU

REVIEW

DATA DISPLAY **cife3 **scene02	Diagnostic Scenario #02	NAME: student075 DATE: 06/09/82

1) LEXICON RESPONSE: static
   ice

2) FLYING TIME LEFT: as long as fuel permits

3) HOW CRITICAL PROB (1-7): 5

4) HOW CONFIDENT OF OWN DIAG (1-10): 5

5) FLYING TIME LEFT (with our diag): 5-30 minutes

6) HOW CRITICAL PROB (with our diag): 5

CONTINUE MENU REVIEW

DATA DISPLAY **cife4	Destination Diversion Test	NAME: studentØ75 DATE: Ø6/Ø9/82

Based on the information you have received so far, would you normally attempt this flight?

YES

CONTINUE	MENU	REVIEW

DATA DISPLAY
**cife4

Destination Diversion Test

NAME: studentØ75
DATE: Ø6/Ø9/82

TIME (sec)	ΔTIME (sec)	AIRPORT	INFO QUERIED
12	12	5	
2Ø	8	5	approach aids (4)
26	6	5	ATC services (5)
41	15	1	
44	3	1	approach aids (4)
46	2	1	ATC services (5)
5Ø	4	1	ceiling (2)
53	3	1	visibility (3)

TIME (sec)	ΔTIME (sec)	AIRPORT	INFO QUERIED

CONTINUE | MENU | REVIEW

ORIGINAL PAGE IS
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DATA DISPLAY **cife4	Destination Diversion Test	NAME: student075 DATE: 06/09/82

" student075" has chosen airport" #1 "

CONTINUE MENU REVIEW

DATA DISPLAY
cife
question

Previous CIFE Question

NAME: studentØ75
DATE: Ø6/Ø9/82

Have you ever had a CIFE in any of the areas?

Electrical

Ice

CONTINUE MENU REVIEW

Appendix D

Combined Destination Diversion and Diagnostic Scenario
A Sample of Computer Displays

TEST version

DIAGNOSTIC SCENARIO TEST

We are now going to present to you some Critical In-Flight Events requiring your diagnosis of the problem.

Assume that you are flying a fuel-injected Cherokee Arrow (N123B) with the following performance specifications:

Cruise Speed = 135 KTAS (65% pwr. @ 7000 ft.)

Fuel Flow (65% pwr.) = 10 GPH

Usable Fuel Capacity = 48 gallons

Endurance = 4.8 hours (no reserve)

Range = 648 nautical miles (no wind, no reserve)

Press CONTINUE when finished reading.

CONTINUE

Consult attached simplified low altitude chart.

You are on an IFR flight from Utah Municipal Airport to Haven County Airport. You depart on V-110 at 6000ft in your Cherokee Arrow (N123B) which is equipped with a 3-axis autopilot. There is a NOTAM out which reports that Colorado VOR is out of service during the period you plan to navigate. Navigate using Ohigh and California VORs. You have been enroute 60 minutes from Utah Municipal Airport. You are on the gauges but the ride is smooth. Weather briefing indicated that winds at 6000 were expected to be light and variable.

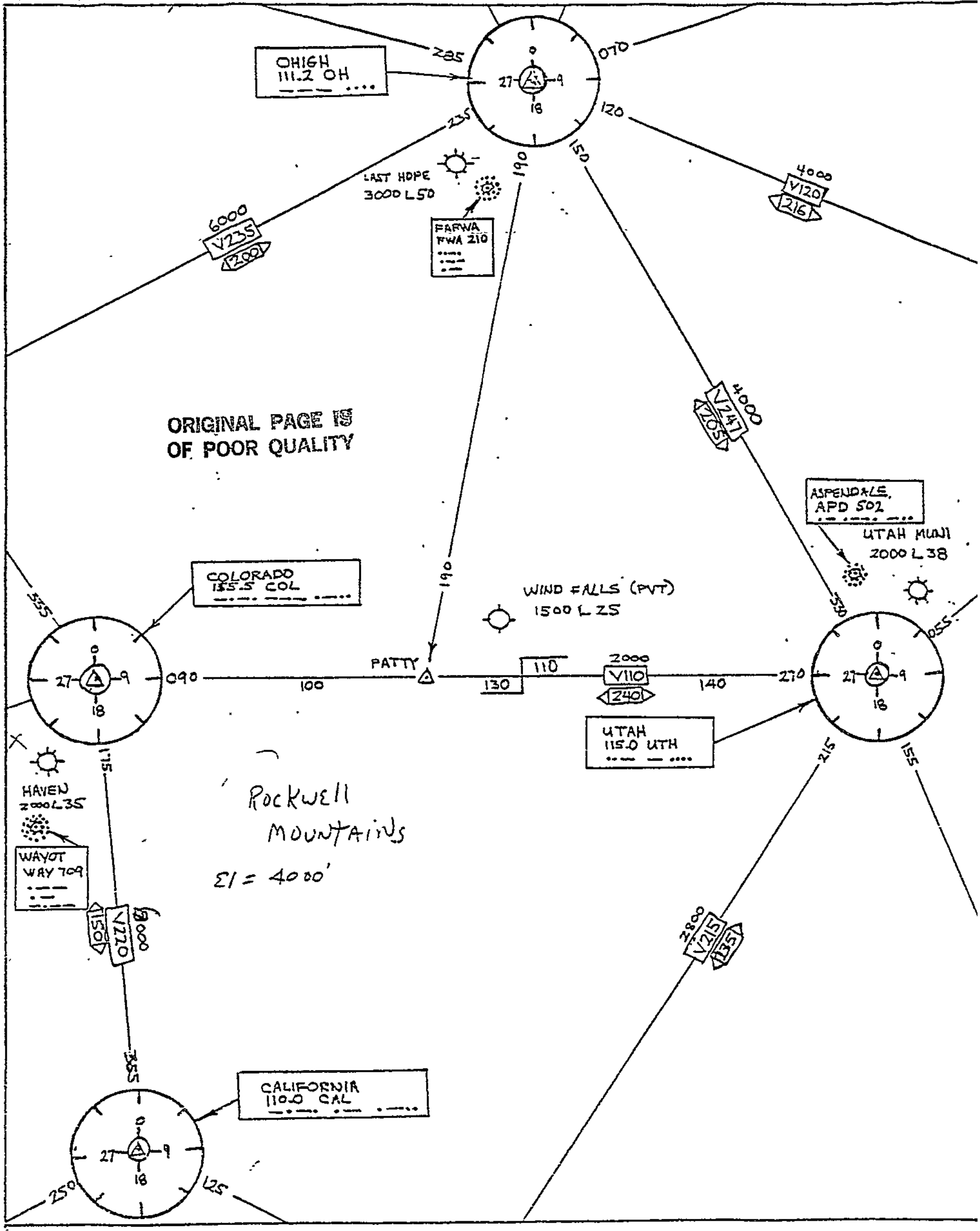
You have one passenger aboard.

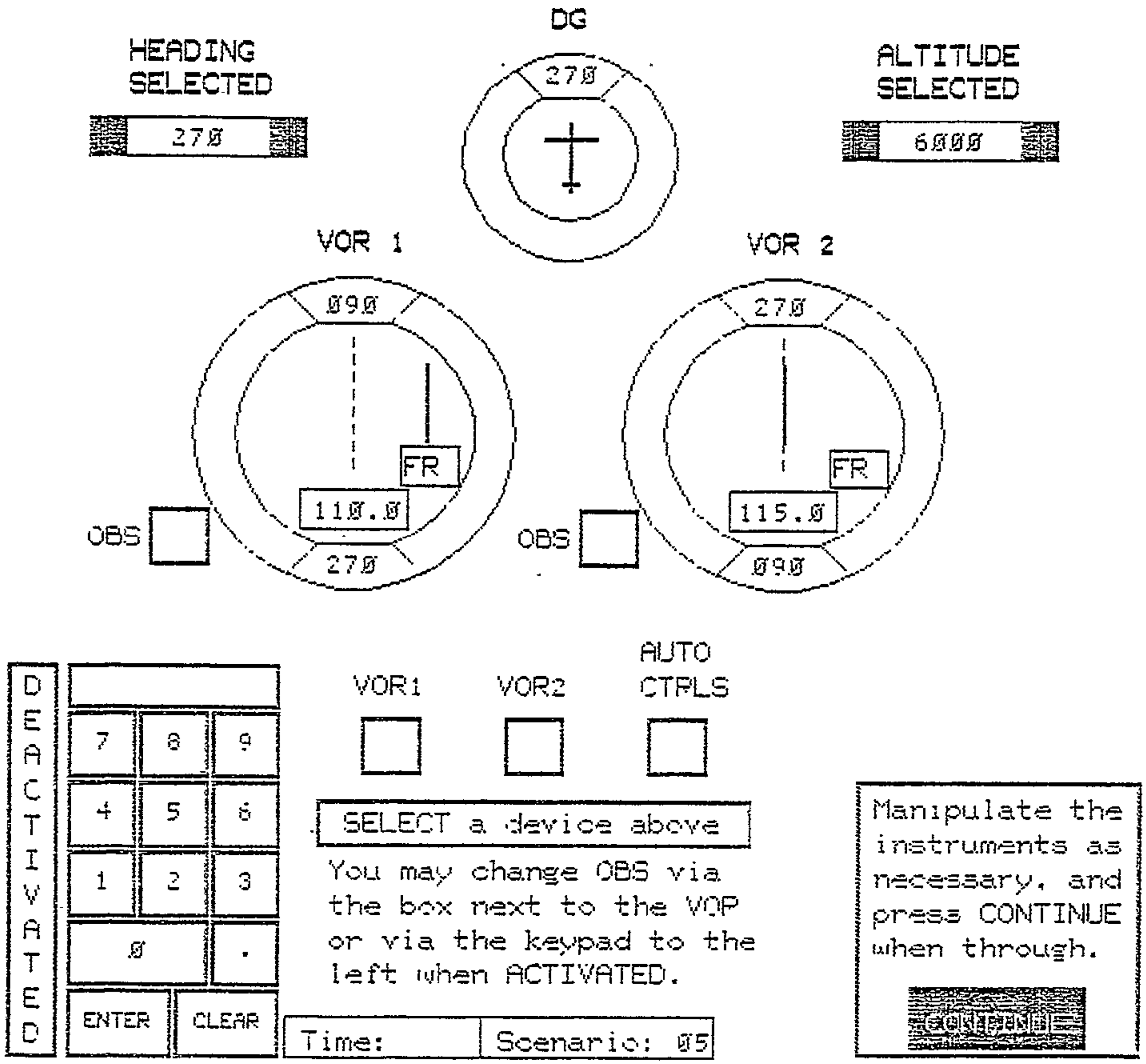
Weather at:

Haven County Airport= 2000 & 5
Ohigh= 1000 & 3
Wind Falls= 1000 & 3 by a C-172
(10 minutes ago)

Cleve Center calls and reports radar contact is lost. Please report present position.

CONTINUE	When ready, press the CONTINUE button to go to the VOR display to establish position.


OHIGH
111.2 OH
285
070
120
235
190
150
LAST HOPE
3000 L 50
FARWA
FWA 210
6000
V235
200
4000
V120
216
4000
V247
205
ASPENDALE
APD 502
UTAH MUNI
2000 L 38
COLORADO
135.5 COL
335
090
100
PATTY
WIND FALLS (PVT)
1500 L 25
130
110
2000
V110
240
140
270
330
055
UTAH
115.0 UTH
215
155
175
HAVEN
2000 L 35
WAYOT
WAY 709
150
V220
3000
Rockwell
Mountains
El = 4000'
2800
V215
135
355
CALIFORNIA
110.0 CAL
250
125


DG
27Ø
HEADING SELECTED
27Ø
ALTITUDE SELECTED
6ØØØ
VOR 1
Ø9Ø
FR
11Ø.Ø
27Ø
OBS
VOR 2
27Ø
FR
115.Ø
Ø9Ø
OBS
DEACTIVATED
7 8 9
4 5 6
1 2 3
Ø .
ENTER
CLEAR
VOR1
VOR2
AUTO CTRLS
SELECT a device above
You may change OBS via the box next to the VOR or via the keypad to the left when ACTIVATED.
Time:
Scenario: Ø5
Manipulate the instruments as necessary, and press CONTINUE when through.

POSITION REPORT

Please report your position by pressing the TO or FR buttons for the VOR of your choice. (Choose at least two VORs).

Type in your position via the keyboard at the given arrow, then press the NEXT key to enter it.

California VOR	TO	40 ok	FR	
Utah MunAir VOR	TO		FR	260 ok
Ohigh VOR	TO		FR	

Press CONTINUE after you have made your report

CONTINUE

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Last Clearance

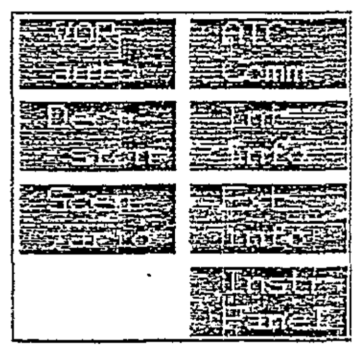
ATC Response:

N123B, thanks for the position report.
Here is your new clearance:
proceed direct California VOR direct
Haven County Airport at 6000.

There will be opposite traffic
at 5000...maintain 6000.

Please confirm your new heading
and altitude after your turn.

Time: 7:3I	Scenario: 05

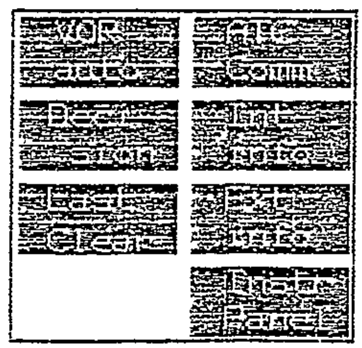


SCENARIO CHANGE

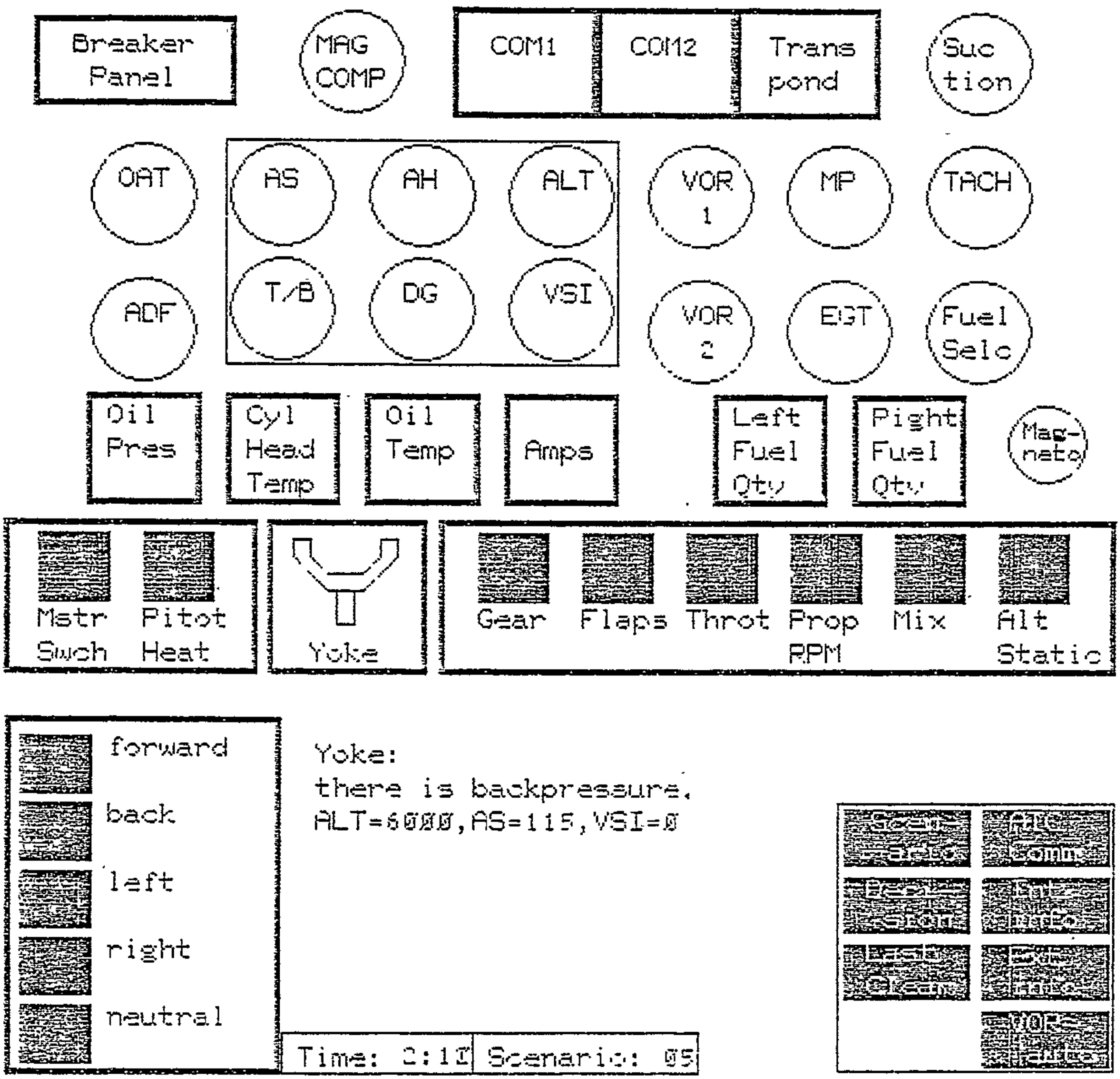
While practicing hand flying with your autopilot disengaged, you notice that increased nose-up trim is required to maintain a constant indicated altitude and that your IAS has decreased 2Økts. from normal cruise.

Your passenger notes this problem, and suggests that you turn back to Utah Municipal.

Determine the nature of the problem, and your destination decision.



Time:	Scenario: Ø5


Breaker Panel
MAG COMP
COM1
COM2
Trans pond
Suc tion
OAT
AS
AH
ALT
VOR 1
MP
TACH
ADF
T/B
DG
VSI
VOR 2
EGT
Fuel Selc
Oil Pres
Cyl Head Temp
Oil Temp
Amps
Left Fuel Qty
Right Fuel Qty
Mag-neto
Mstr Swch
Pitot Heat
Yoke
Gear
Flaps
Throt
Prop RPM
Mix
Alt Static
forward
back
left
right
neutral
Yoke:
there is backpressure.
ALT=6000,AS=115,VSI=0
Time:
Scenario: 05

Information for Inside Cabin Conditions

Cargo Condition

Door Condition

Panel Temp Condition

Cabin Temp Condition

Housekeeping Condition

Smoke

Fluid Leaks

Noise & Vibration

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Housekeeping Condition:

no loose items

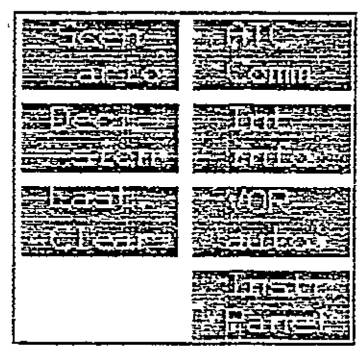
Time: 4:00	Scenario: 05

Information for External Conditions

Cowling Condition	Windscreen Condition	Wing Condition
Flap Condition	Aileron Condition	Stabilator Condition

Cowling Condition:

clean and secure



Time: 4:46	Scenario: Ø5

REQUEST OF ATC INFO

Ceiling	Visibility	Cloud Tops	Winds Aloft
PIREPS	SIGMETS	AIRMETS	
Ground Speed	NAV AID Status	Freezing Level	

COMMUNICATION WITH ATC

Pilot requests

- heading change deg
- altitude change ft

Pilot is

- declaring an emergency
- changing heading 4Ø ok deg
- changing altitude 55ØØ ok ft

Confirm new heading and altitude after your turn. Heading: Ø deg Altitude: Ø ft

Pilot would like to advise ATC of a problem and may need to make heading and altitude changes.

ATC response:
Understand declaring
emergency enter heading
or altitude change

CONTINUE

ORIGINAL PAGE IS OF POOR QUALITY

Instr Panel	ATC Comm	Int Info
Ext Info	Scen-ario	VOR-autopilot
Last Clear	Deci-sion	

You have come to a decision

If you are ready to declare your aircraft destination and diagnosis:

then touch the Decision button above

else touch an alternative button to continue the test.

Time: 7:55	Scenario: Ø5

Please enter your destination decision
via the keyboard. _

home port ok

Please enter the estimated time to your destination

| a) | Ø - 3Ø minutes |

b) 3Ø - 6Ø minutes

c) 6Ø - 9Ø minutes

d) greater than 9Ø minutes

When you have made your final SELECTION:

| ENTER |

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1	aileron	26	elevator	51	landing	76	ring
2	alternator	27	engine	52	leaking	77	rudder
3	altimeter	28	exhaust	53	lean	78	screen
4	baffle	29	failure	54	left	79	screw
5	battery	30	filter	55	line	80	seal
6	belt	31	fire	56	loose	81	seizure
7	blocked	32	flap	57	lost	82	smoke
8	bottom	33	flow	58	low	83	starter
9	broken	34	fouled	59	magneto	84	starvation
10	burst	35	frozen	60	mixture	85	static
11	cabin	36	fuel	61	motor	86	structural
12	cap	37	gasket	62	none	87	stuck
13	carburetor	38	gauge	63	oil	88	suction
14	C/B fuse	39	gear	64	partial	89	switch
15	complete	40	governor	65	pedal	90	tank
16	condenser	41	gyro	66	piston	91	temp.
17	control	42	heat	67	pitot	92	throttle
18	cold	43	high	68	plugs	93	tip
19	cowling	44	hot	69	points	94	top
20	crankshaft	45	hydraulic	70	popped	95	vacuum
21	cylinder	46	ice	71	power	96	valve
22	don't know	47	ignition	72	pressure	97	vapor
23	door	48	induction	73	prop	98	vibration
24	drive	49	instrument	74	pump	99	wing
25	electrical	50	jets	75	right		

don't know

STORE ANSWER

ERASE WORD

1	2	3		enter
4	5	6	0	
7	8	9		clear

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Appendix E

Destination Diversion Test: A Sample of Computer Displays

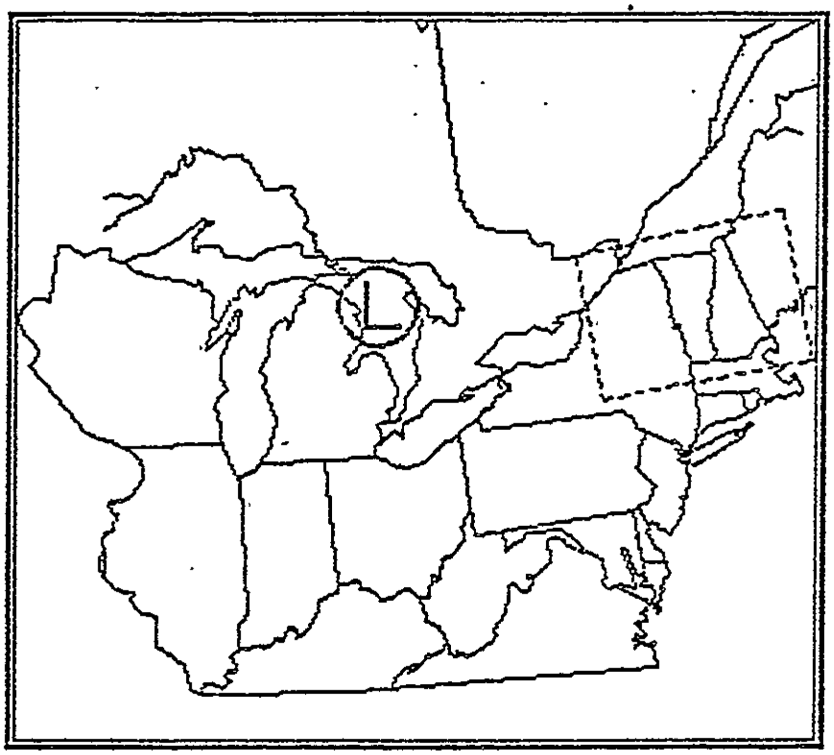


Exhibit 1

Exhibit 1 is a simplified weather chart of the Northeastern and Northcentral United States, and Southeastern and Southcentral Canada. The hypothetical flight we will consider will take place in the area surrounded by the dashed lines. You can see this area includes Vermont, New Hampshire, and parts of Maine, Massachusetts, New York, and Quebec.

CONTINUE

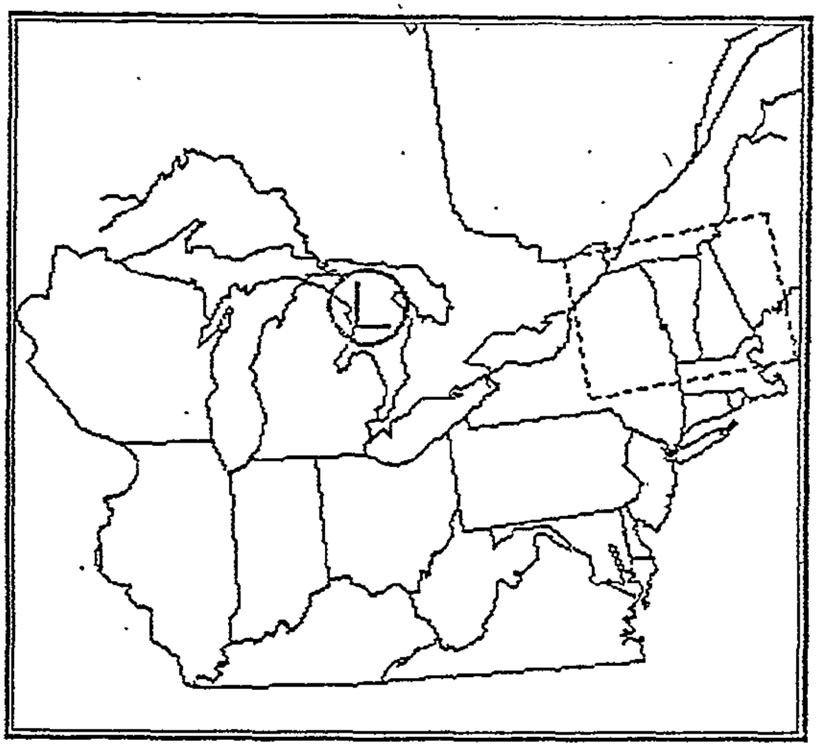


Exhibit 1

IFR conditions prevail over most of our area of concern, except over northeastern New York, where conditions are slightly better. More detailed weather information will be provided when appropriate.

CONTINUE

REVIEW

SCENARIO

You are at the Bangor International Airport in Bangor, Maine, and desire to fly to Glens Falls, New York, for a 1:00 p.m. business meeting (shown in Fig. I). The current time is 9:00 a.m. and you feel you can be ready for departure by 10:00 a.m. after you conduct all necessary preflight activities.
The plane you will be flying today is your company's Cherokee Arrow (N8086W). You have flown this particular plane several times before and regard it as a reliable airplane. A brief list of the important performance figures and IFR equipment on board is shown in Table I.

CONTINUE

REVIEW

TABLE I

Important Specs. and Performance Figures

Cruise Speed = 135 KTAS (65% pwr. @ 7000 ft.)

Fuel Flow (65% pwr.) = 10 GPH

Usable Fuel Capacity = 48 gallons

Endurance = 4.8 hours (no reserve)

Range = 648 nautical miles (no wind, no reserve)

IFR Equipment on Board

2 NAV/COMMs

2 VOR/ILS indicators

1 ADF

1 Three-light marker beacon receiver

1 Transponder (not encoding)

1 Single axis autopilot

CONTINUE

REVIEW

The aircraft's fuel tanks are full, and after a very thorough preflight inspection, you conclude that it is operationally and legally ready for the flight.

Now your attention turns to the weather and filing a flight plan. You call the nearest Flight Service Station on the telephone and obtain the weather information in Table II.

CONTINUE REVIEW

TABLE II

for Glenn Falls (New York): The weather is currently "1000 feet overcast and 3 miles visibility in rain." It is forecast to stay that way until 1:00 p.m., local time, when it should improve to 1500 overcast and 5 miles visibility.

for Bangor (Maine): The weather is currently "1000 feet overcast and 3 miles visibility in rain and fog." It is forecast to remain unchanged except for a chance of 500 feet overcast and 1 mile visibility in rain, drizzle, and fog.

for Albany (New York): The weather is currently "1000 feet overcast and 4 miles visibility in light rain." It is forecast to remain the same until 1:00 p.m., at which time it should improve to "1500 feet overcast and 4 miles.

Winds aloft: from the southwest (200°) at 30 knots at all altitudes up to 9000 feet.

Icing Level: 10,000 feet

No PIREPs reported

CONTINUE

REVIEW

TABLE III

FLIGHT PLAN

1. TYPE	2. AIRCRAFT ID.	3. AIRCRAFT TYPE/ SPECIAL EQUIP.	4. TRUE AIRSPEED	5. DEPARTURE PT.	6. DEPARTURE TIME Prop.	Act.
VFR	N8Ø86W	PA 28R-2ØØ/T	135 KTS.	BGR	1Ø:ØØ	
X IFR						
DVFR						

8. ROUTE OF FLIGHT
V3 to Augusta VOR V39 to Neets intersection V496 to Glenn Falls

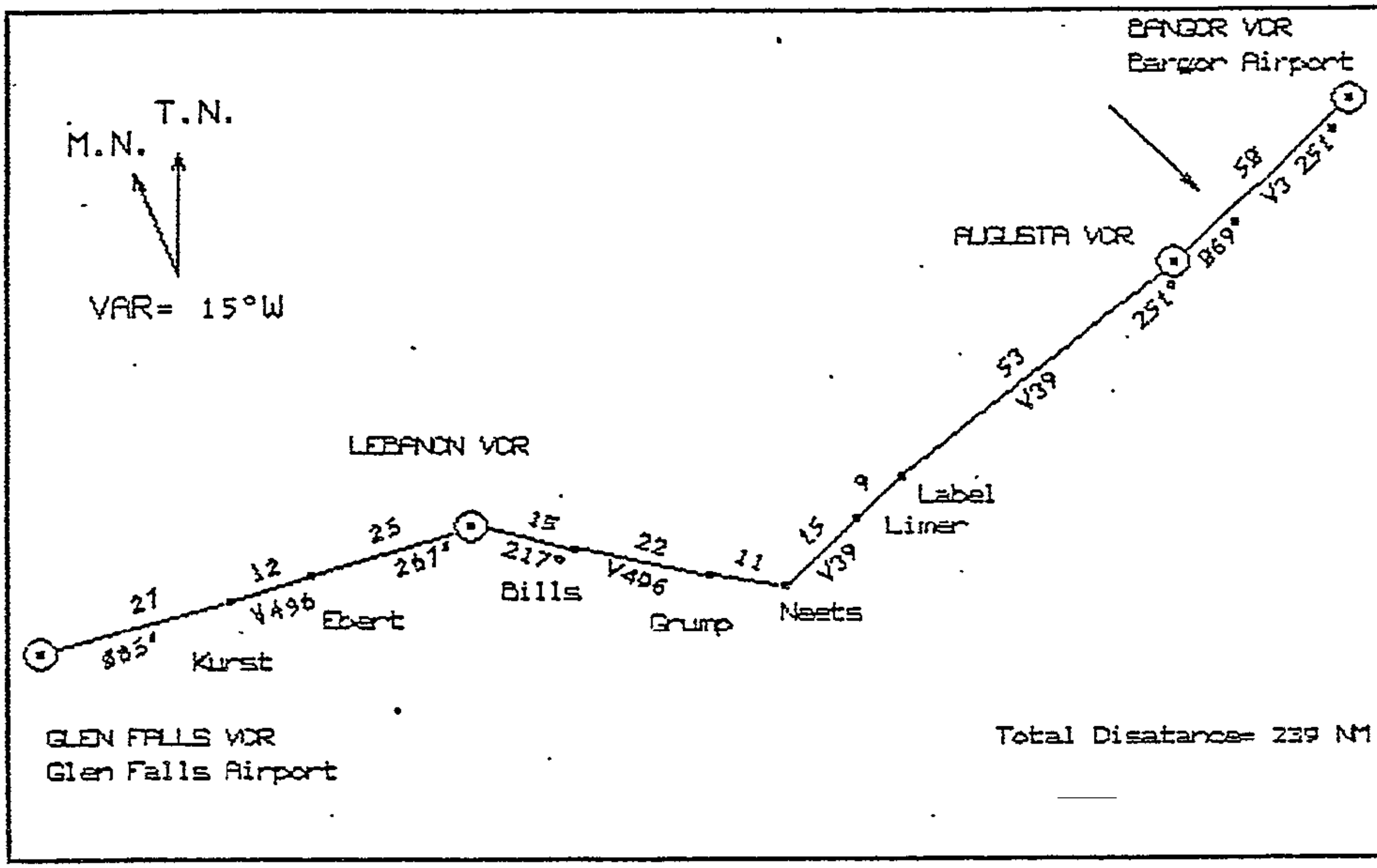
9. DESTINATION	10. EST. TIME ENROUTE HOURS	MINUTES	11. REMARKS
GFA (Glenn Falls)	2	15	

12. FUEL ON BOARD HOURS	MINUTES	13. ALTERNATE AIRPORT (S)	14. PILOT'S NAME	15. NUMBER ABOARD
4	5Ø	Albany		1

16. COLOR OF AIRCRAFT	
Red on White	CLOSE VFR FLIGHT WITH ______ FSS ON ARRIVAL

CONTINUE

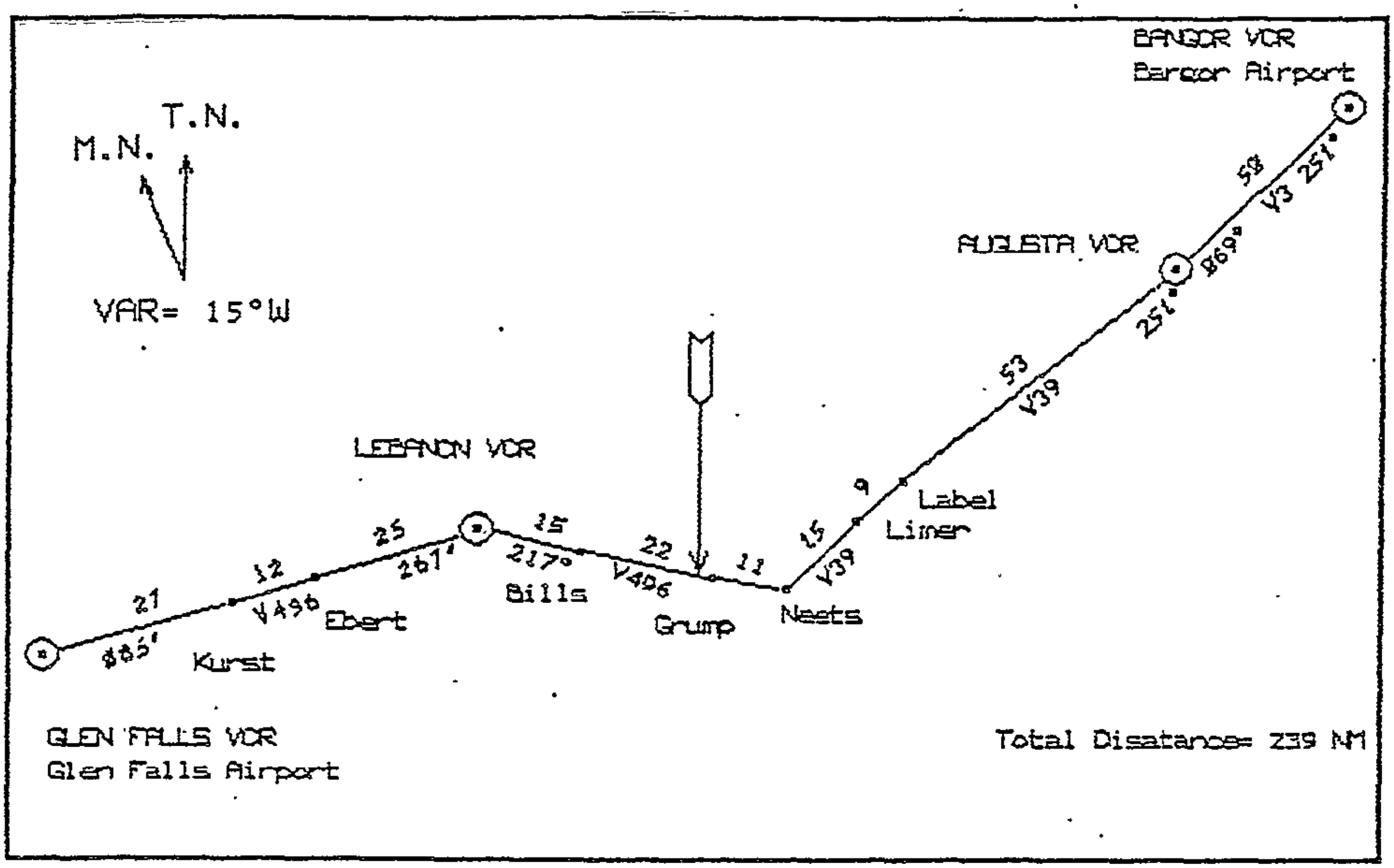
REVIEW



DESCRIPTION OF THE FLIGHT:

You were cleared to the Glen Falls airport "as filed". You lifted off from Bangor at 1Ø:ØØ a.m., and your departure was routine. At 1Ø:14 (14 minutes after departure) you reached your cruising level of 8ØØØ feet and were established on V3 northeast of the Augusta VOR.

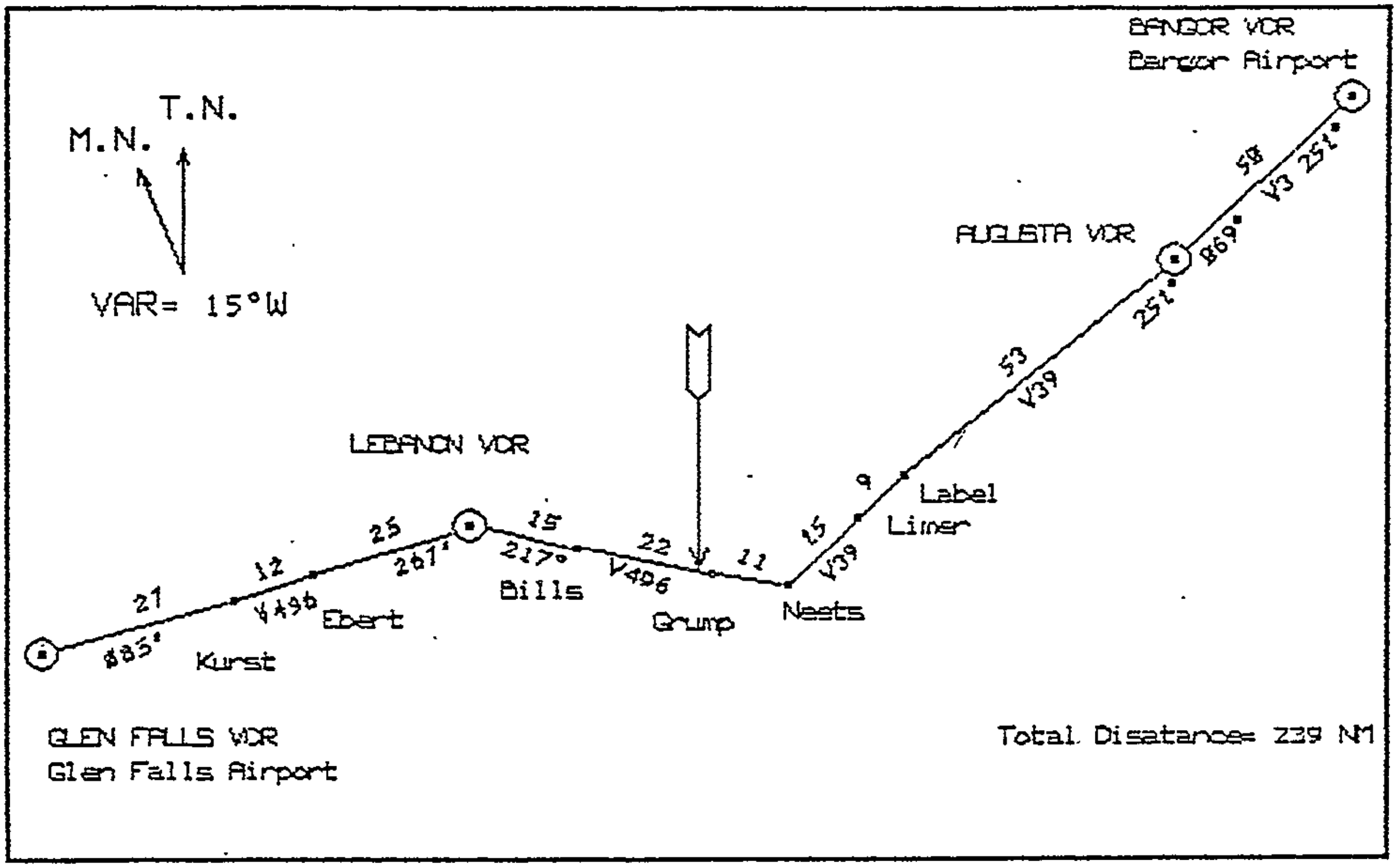
CONTINUE



At 11:21 (1 hour 21 minutes after departure) you cross Grump intersection. One minute later you hear a short static noise over your radio speakers. At the same time you notice you VOR needles and their "on-off" flags flicker unsteadily and return to normal indications.

CONTINUE

REVIEW



Curious to know what caused these events, you glance over the instrument panel and find a "zero" reading on the ammeter. You actuate the landing light and notice no change in ammeter indications. From this information you conclude the alternator has failed.

CONTINUE

REVIEW

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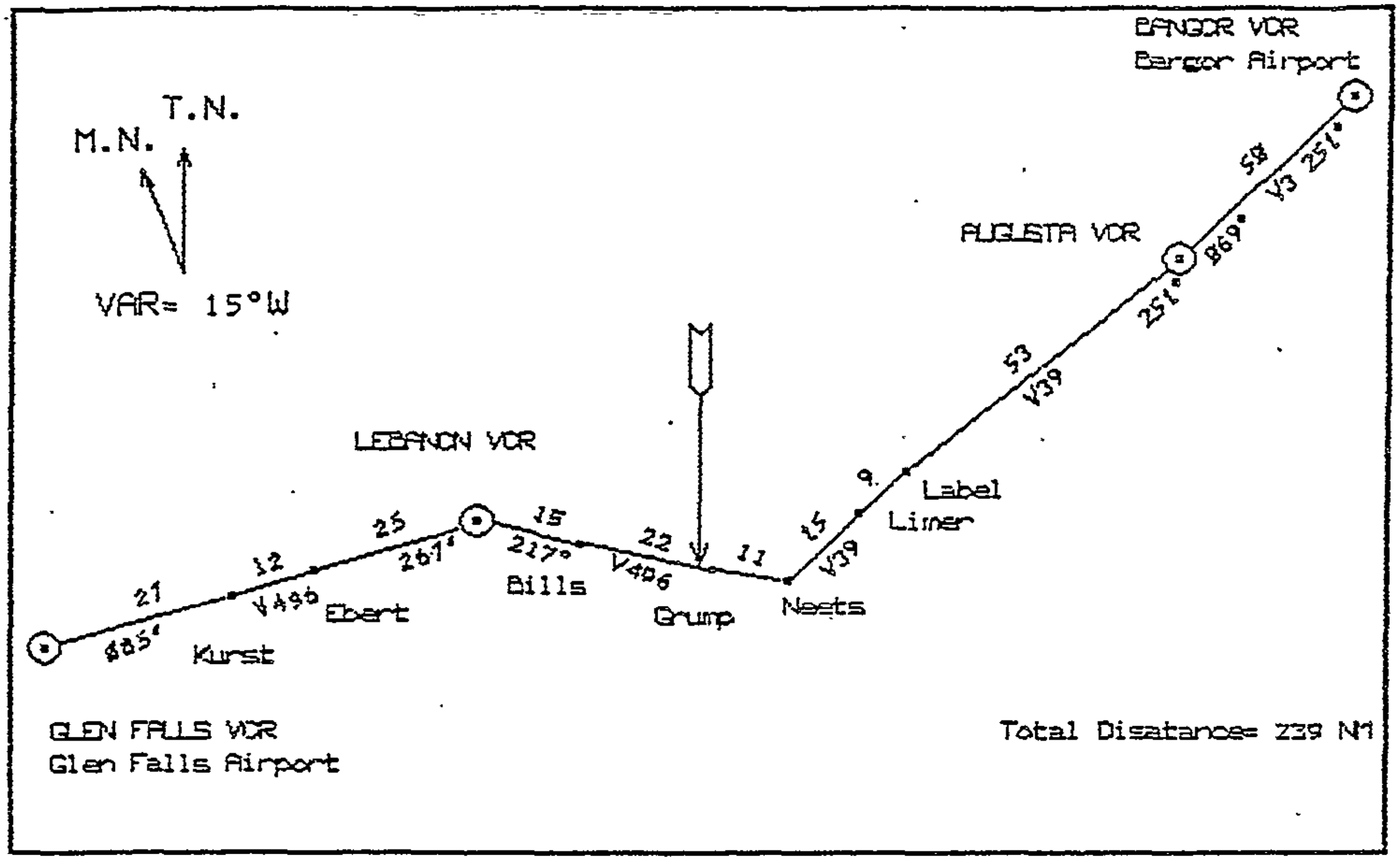
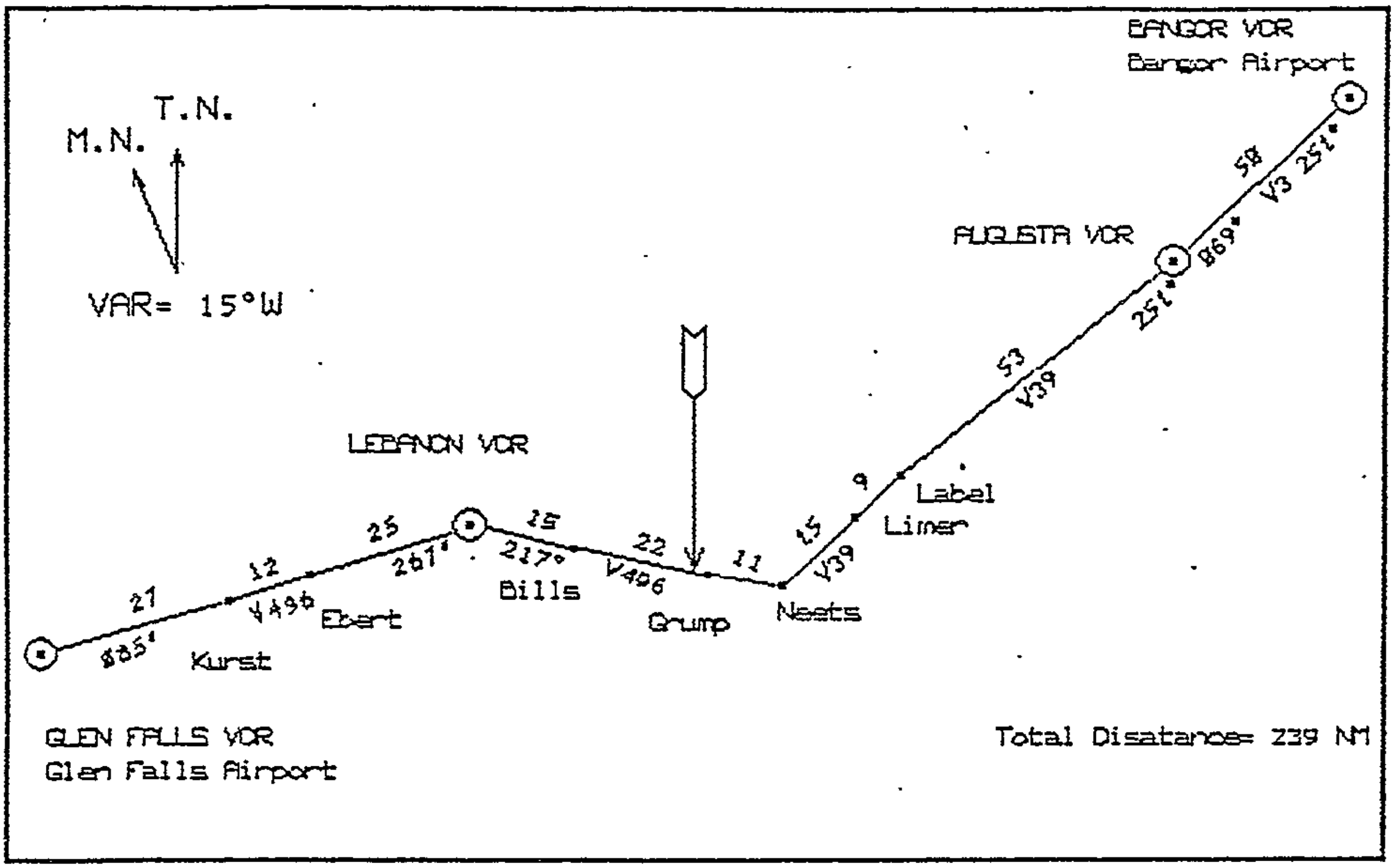


You follow the procedures in the manual but your attempts to bring the alternator back into service are unsuccessful. Therefore, you turn off the alternator, minimize the electrical load, and operate solely on <u>battery power</u>.

CONTINUE

REVIEW



The battery, by itself, can supply the required power to operate your radios for only a limited time. The amount of time you have depends on the size and condition of the battery, and the power requirements of the essential electrical equipment you use. Even under ideal conditions battery power is not expected to last longer than <u>5Ø</u> <u>minutes</u>.

CONTINUE

REVIEW

ORIGINAL PAGE IS
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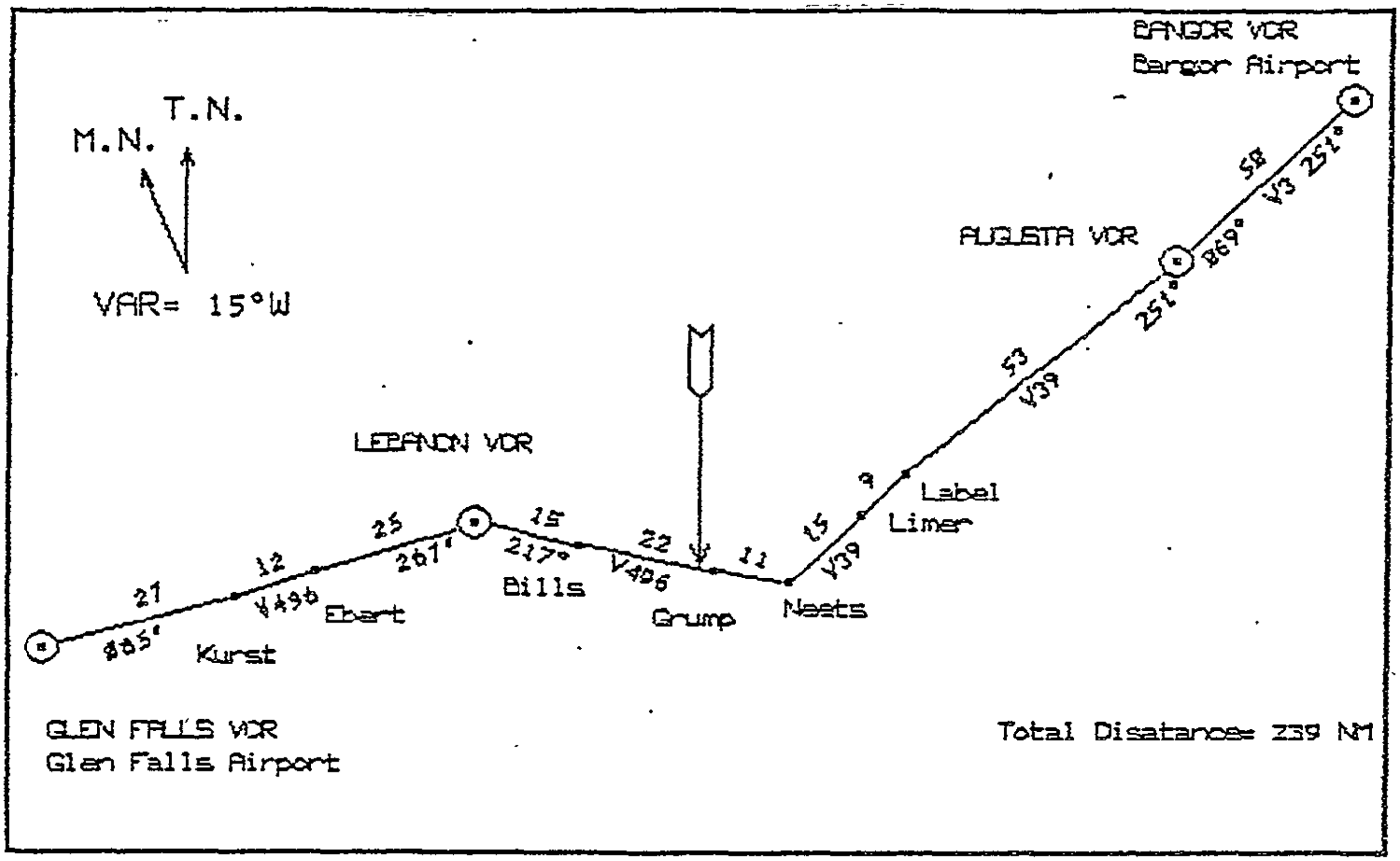
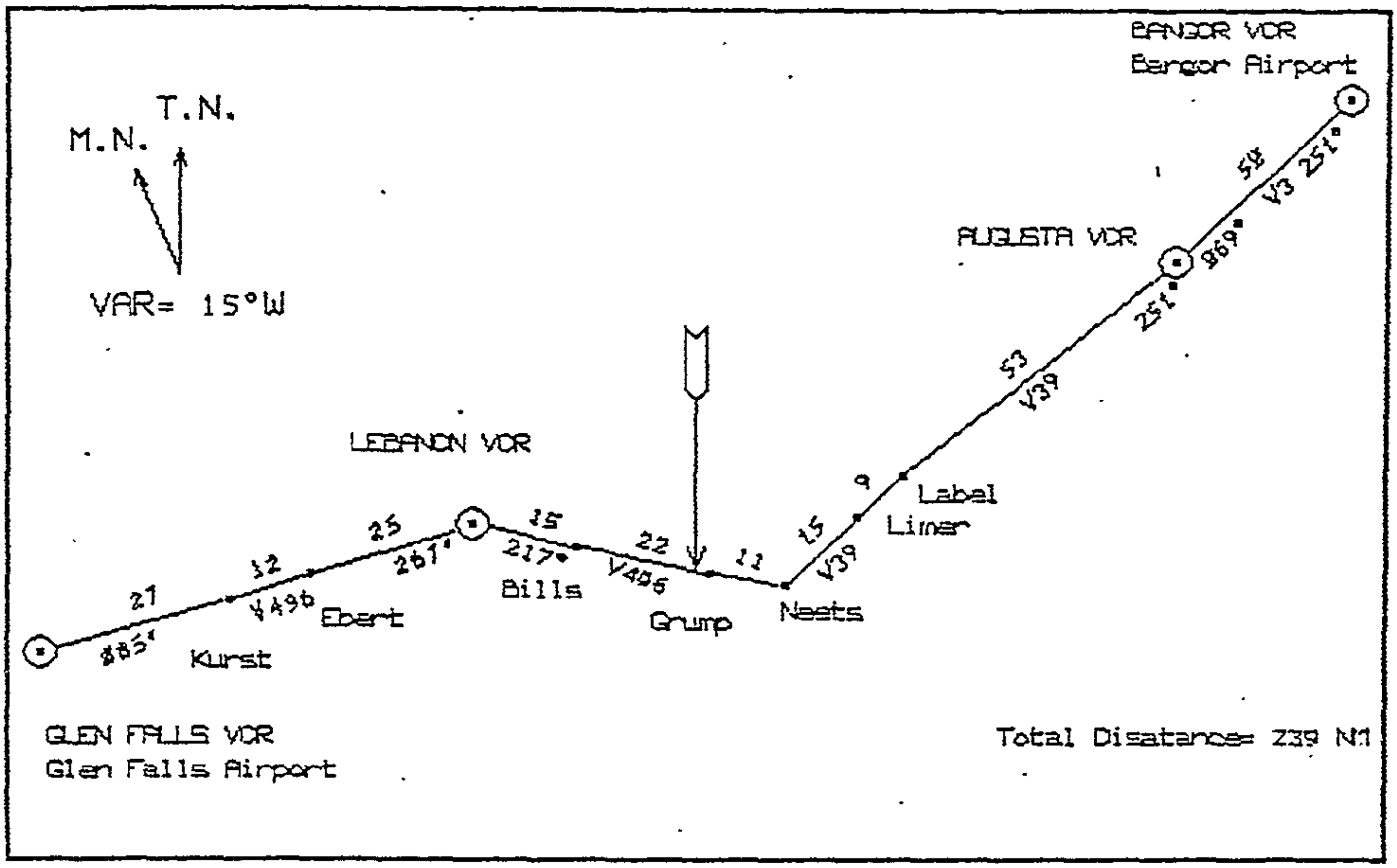


You are at an altitude of 8ØØØ feet, just west of Grump intersection. The time is now 11:23 and you have been airbourne for 1 hour and 23 minutes. Winds are out of the southwest at 3Ø knots.

CONTINUE

REVIEW

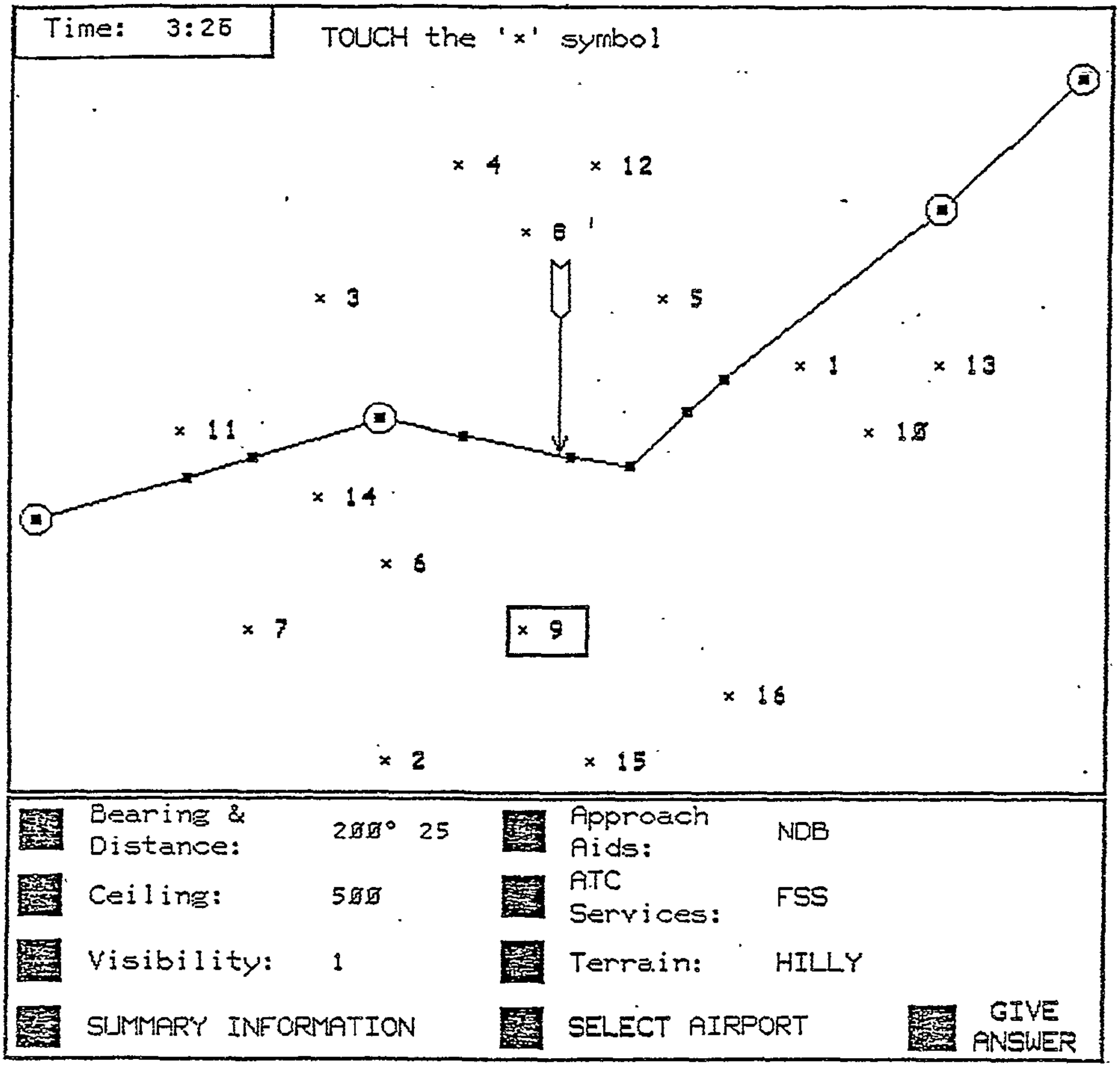


The following information is available from air traffic control one piece at a time:

1) Bearing & Distance	4) Approach Aids
2) Ceiling	5) ATC Services
3) Visibility	6) Terrain

CONTINUE

REVIEW


Time: 3:26
TOUCH the 'x' symbol
× 4
× 12
× 8
× 3
× 5
× 1
× 13
× 11
× 10
× 14
× 6
× 7
× 9
× 16
× 2
× 15
Bearing & Distance: 200° 25
Approach Aids: NDB
Ceiling: 500
ATC Services: FSS
Visibility: 1
Terrain: HILLY
SUMMARY INFORMATION
SELECT AIRPORT
GIVE ANSWER

Time: Ø:12 You have requested the following information:

Air-port	Bearing; Distance	Ceil	Visi	Approach Aids	ATC Services	Terrain
1						
2		7ØØ	1			
3	33Ø° 6Ø	1ØØØ	3	VOR	TWR (R)	HILLY
4						
5						
6						
7		5ØØ	2			
8						
9	2ØØ° 25	5ØØ	1	NDB	FSS	HILLY
1Ø		5ØØ	1			
11						
12						
13	Ø4Ø° 7Ø	1ØØØ	2	ILS	TWR (R)	LEVEL
14						
15						
16						

AIRPORT

1	2	3	4
5	6	7	8
9	1Ø	11	12
13	14	15	16

SELECT an airport then touch ENTER.

You will be able to fly to that airport and shoot one approach only.

AIRPORT: "3"

ENTER

RANKING EXERCISE INSTRUCTIONS

You have just finished choosing an airport to divert to in the face of a serious problem. Now we would like you to consider yourself to be in that same situation again. The next display will present a table of airports and descriptions in terms of ATC services, weather, the flight time from your present position to the airport, and the approach facilities there.

We would like you to rank these airports from your "most preferable" ("1") to "least preferable" ("16"), given the same situation. Recall that you have, at the very most, 50 minutes of battery time left.

You will use the touch screen to input your airport selection and assign it a rank. You will be able to edit your ranking at any time. When you have ranked all 16 airports ("x1 thru x16") you will be asked if you want to submit the list or continue editing it.

CONTINUE

Port	ATC Services	Ceil	Visi	Time (min)	Approach Aids	Port	RANK
x1	TWR (R)	1000	3	15	ILS	x1	1
x2	TWR	1000	3	15	ILS	x2	2
x3	TWR (R)	500	1	15	ILS	x3	
x4	TWR	500	1	15	ILS	x4	
x5	TWR (R)	1000	3	30	ILS	x5	
x6	TWR	1000	3	30	ILS	x6	
x7	TWR (R)	500	1	30	ILS	x7	6
x8	TWR	500	1	30	ILS	x8	
x9	TWR	1000	3	15	NDB	x9	
x10	TWR	1000	3	15	NDB	x10	
x11	TWR (R)	500	1	15	NDB	x11	
x12	TWR	500	1	15	NDB	x12	
x13	TWR (R)	1000	3	30	NDB	x13	
x14	TWR	1000	3	30	NDB	x14	
x15	TWR (R)	500	1	30	NDB	x15	
x16	TWR	500	1	30	NDB	x16	

If you knew airport "x2" had maintenance facilities, would you "pass up" airport "x1" for airport "x2"?

YES   NO

Appendix F

Expert Pilot Experiment

Pilot Response to Critical-In-Flight Events

Performance Ranking

Thank you for taking the time to rank the problem diagnosis strategies of our test subjects. You will have the opportunity to rank order the performance of ten subjects on each of two different problem scenarios. Descriptions of the information provided to the subjects, problem scenarios and our analysis of the problems are given below. Your ranking of subject performance will be based on the items of information each subject requested to solve his problem. An ordered list of inquiries for each subject on each scenario is attached. An Appendix which lists our responses to each subject query is included for your reference.

Please rank order these 10 performances from best to worst. By "best" we mean the pilot whose infomration seeking behavior most closely resembles that which an expert pilot should exhibit. Give the "best" pilot rank 1 and the worst rank 10.

As you are rank ordering these performances, please describe your thoughts out loud (with the tape recorder on). Be sure to describe the reasons for rating one pilot better than another.

Please do not write on this booklet. Score sheets for each scenario which you may use as support documents to accompany your tape recording will be provided.

Subjects (IFR Pilots) have been given the following instructions:

What we are going to do is have you describe what you think you as a pilot should do to determine the cause of a problem that has developed while flying a Cherokee Arrow, which is a 200 h.p. fuel-injected Lycoming. This particular plane is not supercharged and does not have an autopilot.

Your purpose is to describe how a person should go about diagnosing the problem, not to describe what remedial actions he should take. Do not tell us how to correct the problem. Simply try to determine what is causing it. We do not want you to fly the plane, we simply want you to try to diagnose the problem.

If you think the pilot should gather some particular information, you can ask for it and we will give you that information. For example, if you were to ask whether communications radio number one is operating okay, we might tell you that it is operating normally. You can ask for any information that might normally be available when you are up in a Cherokee Arrow. That includes such things as instrument readings, information that you could obtain visually outside, or information you could obtain over the radio.

A few things to keep in mind: First we are going to give you a scenario and then we will be giving you any information you request. The conditions or instrument indications supplied all refer to a fixed point in time. Even if you ask a question 10 minutes after we have started, it still refers to the same point in time as when the scenario was read. The plane is not continuing to fly.

Second, you are allowed to make control movements but we will only give you the immediate response to that movement. You will not be allowed to fly the plane. You cannot ask

"If I make this change, what will it indicate 5 minutes from now?"

We will simply tell you the immediate response of the instruments to that particular movement.

Third, another constraint is that you cannot ask about the effect of combining 2 control movements. You will only be allowed to adjust one control at a time and see the response to it. You cannot adjust 2 controls at once.

Finally, we do not want you to try to correct the problem. Instead, we want you to simply concentrate on determining what the cause of the problem is.

Remember, what you want to do is tell us what a pilot should do in order to determine the cause of a problem that has developed while flying a fuel-injected Cherokee Arrow. This particular plane is not supercharged and does not have an autopilot. Once we start, it is important that you not stop until you either diagnose the problem or decide that with the available information you cannot determine the cause. So there are essentially 2 endpoints. Either you say "I believe the problem is such and such," or "given the available information, I don't think it is possible to determine the cause."

Here is the scenario:

Imagine that this pilot is making a day trip from Augusta, ME to Lebanon, NH. He flies out of Augusta at 9:00 a.m., cleared Victor 39 to Neets intersection, Victor 496 to Lebanon. He climbs to a cruising altitude of 6000 feet.

After 15 minutes of routine flying in instrument conditions in the clouds, the instruments indicate an increase in airspeed, a steadily decreasing altitude and zero pitch.

So, the instruments indicate an increase in airspeed, a steadily decreasing altitude and zero pitch.

How should this pilot go about identifying his problem?

Our Diagnosis of the Problem for the First Scenario Was the Following:

Your vacuum pump failed as indicated by the low reading of the suction gauge. The vacuum pump drives the attitude and directional gyros. As the artificial horizon lost its drive it started to sag to the right and the pilot compensated by turning left, leveling the artificial horizon and putting the plane in a descending left bank. The airspeed increase was due to the slight nose-down attitude.

Subject Response to First Scenario

The information requests made by 10 IFR pilots after hearing this vacuum pump scenario are enclosed. After each such request sequence, the pilot stated his conclusion.

Please rank order the performances for the vacuum pump scenario now. Be sure to comment on your reasons for rating one pilot better than another.

Here is our second scenario:

You are making a day trip from Sanford, ME to Messena, NY. You fly out of Sanford at 8:30 a.m., cleared Victor - 496 to Lebanon, Victor - 141 to Messena. You climb to a cruise altitude of 6000. After 20 minutes IMC flying, Boston Center instructs you to climb and maintain 10,000 feet. You acknowledge and begin your climb between layers. After 2 minutes of climb, you notice your indicated airspeed dropping off steadily from 100 Kts., maintaining constant pitch attitude.

How would you diagnose the problem?

Our diagnosis of the second problem was the following:

As you climbed through 6500 ft., the static port froze over as the outside air temperature dropped below 32°F. This caused the airspeed indicator to decrease as altitude increased and the VSI and altimeter to read low. Several corrective actions were possible: return to your previous altitude of 6000 ft.; open the alternate static source; break the VSI glass.

Subject response to the second scenario:

Information requests made by 10 pilots after hearing this scenario are enclosed. After each such request sequence, the pilot stated his conclusion.

Please rank order the performances for the static port problem now. Be sure to comment on your reasons for rating one pilot better than another.

Scenario: ____________________

Work Sheet for Ranking Subjects

(To accompany remarks on tape recording)

RANK	SUBJECT #	COMMENTS
		(Be sure to think out loud as you are trying to rate the subjects.)
1. ("best")		
2.		
3.		
4.		
5.		
6.		
7.		
8.		
9.		
10. ("worst")		

Appendix F-1

Vacuum Pump Scenario

Responses given to subjects when

an item of information was requested

Vacuum Pump Scenario Responses

ADF: 368 MHZ
260° RB
Test normal

Aileron conditon: Clear of ice

AIRMETS: None

Airspeed: 145 Kts. and increasing, cruise is about 135 Kts.

Alternate Static: Closed
If opened no change in any instrument readings

Altimeter (non-encoding): 5600 ft. and decreasing

Ammeter: +2 amps (normal)

Artificial horizon: Level, no movement

Cabin temperature: 70°F

Cargo condition: secure

Circuit Breaker Panel: All Breakers closed

Cloud tops: Area forecast 14,000 Ft.

COM1: Normal

COM2: Normal

Cowling Condition: Clean and Secure

Cylinder Head Temperature: 375°F (Normal)

DG: 250° and Steady

Door Condition: Secure

EGT: 1300°F and Steady (normal)
Flap condition: Clear of ice
Flap position: 0°

	0°;		0°
	10°;		10°
if reset to	20°;	then	20°
	30°;		30°

Vacuum Pump Scenario Responses

Freezing level: Area forecast 7,000 ft.

Fuel Flow: 8 gal./hour (normal)

Fuel Quantity
  Left; nearly full
  Right; full

Fuel Selector: Left Tank
  Change to left or right: no change in instrument readings

Gear: gear up lights on
If lowered down; gear down lights, airspeed decays

Groundspeed (ATC): 120 Kts.

Magnetic Compass: Rotating through 230°

Magneto: Both
  left; 50 RPM drop
  right; 75 RPM drop
  off; engine quits
  both; normal operation

Manifold pressure: 20.5 inches (normal)

Master switch: ON

Mixture Control: Leaned for cruise
  if enrich; EGT drop, engine rough
  if lean; EGT rise, engine rough

Noise and Vibration (cabin): Normal

Oil pressure: 40 p.s.i. (Normal)

Oil temperature: 140°F (Normal)

Outside air temperature gauge: 37°F

PIREPS: None

Pitot Heat: Off
  If turned on: surge in ammeter discharge then back to normal; no effect other instruments

Vacuum Pump Scenario Responses

Prop RPM: 2300 RPM (nromal cruise setting)
  if increase; 2700 RPM, MP decreases
  if decrease: 1900 RPM, MP increases

Season: Fall

SIGMENTS: None

Smoke: None

Stabilizer condition: clear of ice

Strobe: Off

Suction gauge: Extremely low, near the peg

Tachometer: 2300 RPM and constant (normal cruise reading, constant speed prop)

Throttle: Cruise power
  If increase; increase in manifold pressure and airspeed reading, little change in altimeter reading
  If decrease; decrease in manifold pressure and airspeed reading, little change in altimeter reading.

  Note: If requested, artificial horizon remains level, turn/bank shows left turn

Transponder: Code 4320, normal operation

Trim: Trimmed for level cruise

Turbulence: None

Turn/Bank indicator: left turn

Vertical Speed inidcator: 600 fpm down

VOR1: 111.4 Mhz, Flag On

VOR2: 111.6 MHz, Flag On

Winds aloft forecast: 3000, 6000, 9000 westerly at 10 Kts.

Windscreen: clear of ice

Wing: clear of ice

Vacuum Pump Scenario Responses

Yoke: Neutral position

If back pressure applied: Airspeed indicator shows decrease, altimeter continues to decrease but at a reduced rate. If requested, artificial horizon remains level and turn/bank shows left turn.

If forward pressure applied: Airspeed indicator shows increase, altimeter continues to decrease but at a faster rate. If requested, artifical horizon remains level and turn/bank shows left turn.

If left pressure applied: Turn to left on turn/bank before turn, steeper after turn. If requested, artificial horizon remains level

If right pressure applied: Turn to left on turn/bank before turn, turn to right after turn. If requested, artificial horizon remains level.

Appendix F-2

Static Port Scenario

Responses given to subjects when

an item of information was requested.

Static Port Scenario Responses

ADF: Normal
- Off; Off
- On; normal
- Check circuit breaker; normal response
- test; normal response

Aileron condition: normal

Airspeed: Slowly decreasing from 100 Kts.

Alternate Static: Closed
- open; airspeed suddenly increases
- closed; VSI reads correctly but sluggish

Altimeter: Low, only 6300 ft.

Ammeter: Normal

Artificial Horizon: Normal climb

Cabin Temperature: Normal

Cargo condition: Secure

Circuit breaker panel: All breakers closed

Cloud Tops: Area forecast 14,000 ft.

COM1: Normal
- off; normal response
- on; normal
- check circuit breaker; normal response

COM2: Normal
- off; normal response
- on; normal
- check circuit breaker; normal response

Static Port Scenario Responses

Cowling condition: clean and secure

Cylinder Head Temperature: Normal

DG: N-300°

Door Condition: Secure

EGT: Normal response
Flap Condition: Normal
Flaps: 0°
0°; 0°
10°; 10°
20°; 20°
30°; 30°

Fluid Leaks: None

Freezing Level: Area Forecast 7000 ft.

Fuel Quantity:
Left; 3/4 full
Right; 3/4 full

Fuel Selector: Left
Left; no change
Right; no change
Off; engine quits

Gear: Up
Up; Up
Down; Normal response

Ground Speed (ATC): 100 Kts

Housekeeping condition: No Loose items

Magnetic compass: N-300°

Magneto: Both
Left; Normal RPM drop
Right; Normal RPM drop
Off; engine quites
Both; Normal

Manifold Pressure: Normal

Static Port Scenario Responses

Master Switch: On
- On; on
- Off; electrical power lost

Mixture Control: Normal
- Enrigh; Normal response
- Lean; Normal response

Noise and Vibration: Normal
Oil pressure: Normal

Oil temperature: Normal

Outside air temperature: 30°F
PIREPS: None
Pitot heat; no change
- on; no chnage
- off; no chnage

Prop RPM: Normal
- Increase RPM; Normal response
- Decrease RPM; Normal response

Signmets: None

Smoke: None

Stabilizer Condition: Normal

Suction gauge: Normal

Tachometer: Normal

Throttle: Normal
- Increase; Normal response
- Decrease; Normal response

Transponder: Normal
- Off; Normal
- On; normal
- Check circuit breaker; normal response
- Change; normal response

Turn/Bank Indicator: Normal level

Vertical Speed Indicator; Sluggish, low (100 ft./min.)

Static Port Scenario Responses

VOR1: Normal
off; off
on; normal
check circuit breaker; normal response
test; normal response

Windscreen condition: clear

Wing condition: Light rime ice

Yoke: Normal

up;	airspeed decreases faster
down;	airspeed stabilizes
left;	normal response
right;	normal response

Enclosed are the information requests made by 10 IFR pilots after hearing this scenario. After each such request sequence, the pilots stated his conclusion.

The actual problem used to generate this scenario (and the responses given to pilots after particular information requests) is given below.

<u>Our Diagnosis of the Problem was the Following:</u>

Your vacuum pump failed as indicated by the low reading of the suction gauge. The vacuum pump drives the attitude and directional gyros. As the artificial horizon lost its drive it stated to sag to the right and the pilot compensated by turning left, leveling the artificial horizon and putting the plane in a desceding left bank. The airspeed increase was due to the slight nose-down attitude.

Please rank order these 10 performances from best to worst. By "best" we mean the pilot whose information seeking behavior most closely resembles that which an expert pilot should exhibit. Give the "best" pilot rank 1 and the worst rank 10.

<u>As you are rank ordering</u> these performances, please describe your thoughts out loud (with the tape recorder on). Be sure to describe the reasons for rating one pilot better than another.

Subject # 1

Vacuum Pump Scenario

1. What's the manifold presssure reading?
2. Is there any ice on the wings?
3. Is there any ice on the windscreen?
4. What's the outside air temperature?
5. Can you notice any precipitation?
6. What's the suction gauge reading?
7. What's the magnetic compass reading?
8. What's the directional gyro reading?

A Sample Response

to the Static Port Scenario

Scenario 4

Subject 45

1. What happens when the pitot heat is turned on?
2. What's the outside air temperature gauge show?
3. Is there any ice on the windscreen?
4. What's the airspeed reading?
5. What's the altimeter reading?
6. What's the throttle set at?
7. What happens when I advance the throttle?
8. What's the prop control set at?
9. What happens when I advance the prop control?
10. What's the altimeter reading?
11. What's the airspeed reading?
12. What's the mixture set at?
13. What happens when I lean the mixture?
14. What's the throttle set at?
15. What happens when I advance the throttle?
16. What's the prop control set at?
17. What happens when I advance the prop control?
18. What happens when the pitot heat is turned on?
19. What happens if back pressure is applied to the yoke?
20. What happens if forward pressure is applied to the yoke?
21. What's the throttle set at?
22. What happens if I advance the throttle?

Appendix G

List of Publications and Proceedings Resulting from This Research

M.S. Theses:

Flathers, George W., Jr. A Study of Decision-Making Behavior of Aircraft Pilots Deviating From a Planned Flight, The Ohio State University, MS Thesis, 1980.

Lee, Jeffrey A., A Decision Support System For In-Flight Emergencies: ACE, The Ohio State University, MS Thesis, 1982.

Thomas, Mark E., The Effect of Preparation on Pilot Diagnosis of Critical In-Flight Events, The Ohio State University, MS Thesis, 1984.

Ph.D. Dissertations:

Schofield, Jeffrey E. Aircrew Compliance with Standard Operating Procedures as a Component of Airline Safety, The Ohio State University, Ph.D. Dissertation, 1980.

Journals:

Giffin, Walter C. and Thomas H. Rockwell. "Computer-Aided Testing of Pilot Response to Critical In-Flight Events," Accepted for Publication by Human Factors.

Flathers, George W., Jr., Walter C. Giffin and Thomas H. Rockwell. "A Study of Decision Making Behavior of Pilots Deviating From a Planned Flight," Aviation, Space, and Environmental Medicine, October, 1982, V. 53, No. 10, p. 958-963.

Schofield, Jeffrey E. and Walter C. Giffin, "An Analysis of Aircrew Procedural Compliance," Aviation, Space, and Environmental Medicine, October, 1982, V. 53, No. 10, p. 964-696.

Proceedings:

Two papers appearing in:

Jensen, R. S. (Editor), Proceedings of the Symposium on Aviation Psychology, April 21 and 22, 1981, Technical Report: APL-1-81, The Aviation Psychology Laboratory, The Ohio State University, Columbus, Ohio.

i) Flathers, G. W. II, W. C. Giffin and T. H. Rockwell. "A Study of Decision-Making Behavior of Aircraft Pilots Deviating from a Planned Flight."

ii) Schofield, J. E. and W. C. Giffin, "An Analysis of Aircrew Procedural Compliance."

Two papers appearing in:

Jensen, R. S. (Editor), Proceedings of the Second Symposium on Aviation Psychology, April 25 - 28, 1983, The Aviation Psychology Laboratory, The Ohio State University, Columbus, Ohio.

i) Giffin, W. C. and T. H. Rockwell. "Computer Aided Testing of Pilot Response to Critical In-Flight Events."

ii) Rockwell, T. H. and W. C. Giffin, "Combining Destination Diversion, Decisions and Critical In-Flight Event Diagnosis in Computer Aided Testing of Pilots."