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GENERAL AVIATION PILOT ERROR
A Study of Pilot Strategies in Simulated Adverse Weather Scenarios

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I. Introduction

This report covers the first nine months of research on general aviation pilot error under Technical Task Directive #2, DTRS contract #57-85L-C-00101. It constitutes Phase I of the contract and embraces four subtasks:

1. Selection of Pilot Error Types for Modeling
2. Pilot Error Modeling
3. Model support: The design of an instrument to study response of pilots to weather scenarios.
4. Protocol analysis of pilot weather forecasting strategies.

In addition this report will discuss plans for Phase II, "Defining the Limits of General Aviation Pilots' Understanding of Weather," as identified by the CAWT (Computer Aided Weather Test) and the protocol analysis tests of high and low time pilots. Phase III, which depends upon the Phase II findings, will be concerned with developing methods for improving the pilots' understanding of weather.

II. Justification for Selected Pilot Errors For Project Focus

This research examines pilot error through the mechanism of a "model" or representation of pilot error. A model in this context begins essentially with a conceptualization of pilot error. From this conceptualization flows a requirement for specific data inputs to allow the model to be enriched and to provide construct validity. Indeed the value of a model lies both in its generality, that is its ability to account for a wide variety of known pilot error situations, and in terms of its ability to spell out specific research studies to provide data inputs for model credibility. In addition the elements of a model should lend themselves to generating specific countermeasures, that is intervention strategies to break the chain of events leading to an accident.

In the case of pilot error, a model can involve process or time based events leading up to an accident or it can address those characteristics of pilots who are overrepresented in a class of accidents. The latter models emphasize pilot attributes or personality factors such as attitudes, feelings of invincibility, risky proclivities, macho pretensions, etc. These models not only involve difficulties in measurement objectivity but also involve countermeasures which require changing of attitudes. Those same attributes, as "control one's own destiny", a "lack of fear", and "self confidence", which lead to accidents, are also essential attributes of successful pilots.

A process model focuses on events in the causal chain leading to an accident. Typically it does not assume an accident prone pilot, but rather emphasizes failures of detection, interpretation and decision making. Decisional error is a primary focus in this research. Generally as models embrace a wider scope they must of necessity become very general. The ultimate case then becomes one of arguing for such generalities as carelessness, which explains both everything and nothing and gives little hint to countermeasure design. In contrast the emphasis of this research task is on process models for specific types of common pilot errors. Models developed will be tested against several criteria:

1. Their ability to explain a large percentage of accidents of a specific type.

2. Their ability to spell out specific research to understand and to verify elements in the models.

3. Their ability to specify implementable countermeasures to reduce the probability of pilot error.

Selection of error types for this project should meet the following criteria:

1. Pilot errors involve detection, diagnosis and/or decision making

2. A high frequency of accidents with these errors

3. A high severity of accidents with these errors

4. Error countermeasures which can be implemented

Using these criteria the research team proposed to initially focus on three types of error:

1. VFR flight into IMC

2. Pilot fuel mismanagement (exhaustion or starvation)

3. Pilot response to critical inflight events, for example power plant failure

In terms of the top ten causes for general aviation accidents (NTSB, 1981) as shown in Table 1, the three proposed errors rank tenth, fourth, and third, respectively. VFR into IMC is first in accident severity. The number one cause, in Table 1 'inadequate preflight', is an essential element in all three selected errors above. In addition pilot difficulties with these three situations can lead to the second, fifth, seventh and ninth causes, that is fuel exhaustion, failure to maintain flying speed, selection of suitable terrain, and misjudgment of speed and distance. Hence, modeling the three proposed errors should account for a significant percentage of pilot accident causes.

Support for the three selected errors comes from two other sources. An inquiry with the FAA Accident/Incident Data System (AIDS) data for general aviation has revealed 1600 critical inflight events over the 1980-1985 period --almost one failure per day. A second inquiry revealed over two thousand fuel mismanagement cases based on a sample from 3380 cases over the period 1980-1985. A third inquiry from this data set revealed 1100 cases of flight into adverse weather.

Jensen & Benel (1977) report that from 1970 through 1974, 5700 fatalities were recorded of which 12.5% involved VFR into adverse weather. See Tables 2, 3, & 4. This is the largest single cause of the 54 errors reported. The next major cause is spatial disorientation (9.28%) which is often the consequence of VFR pilots in IMC. In terms of frequency, fuel mismanagement was the fourth highest reported error. [1]

An inquiry of the NASA Aviation Satety Reporting System (ASRS) data base revealed over 400 cases in the first half of 1986 involving the three related pilot errors. This suggests that these types of pilot error continue to occur today.

While accident statistics provide ample evidence for the importance of the three error types, the selection of these error types is also based upon the nature of the errors. All three could be categorized as knowledge based

[1] Jensen, R. & Benel, R. A., Judgment evaluation and instruction in civil pilot training, Springfield, VA, NTIS Final Report FAA-RD-78-24.

Table 1

Top Ten Causes
For All General Aviation Accidents - 1981

Rank	Accident Cause
1	Pilot-Inadequate preflight preparation and/or planning.
2	Pilot-Failed to obtain/maintain flying speed.
3	Powerplant-Failure for undetermined reasons.
4	Pilot-Mismanagement of fuel.
5	Fuel exhaustion.
6	Material failure.
7	Pilot-Selected unsuitable terrain.
8	Pilot-Improper leivel off.
9	Pilot-Misjudged distance and speed.
10	Pilot-Continued VFR into adverse weather conditions.

Table 2. Number of fatal and nonfatal civil aviation accidents in which the pilot in command is listed as the cause or a factor for all accidents occurring between 1970 and 1974 for skill based activities (Jensen and Benel, 1977).

Skill Based Errors

		Fatal	Nonfatal
1.	Delayed action in aborting takeoff	5	236
2.	Delayed in initiating go-around	32	380
3.	Failed to see and avoid other aircraft	128	196
4.	Failed to see and avoid object	166	75
5.	Misjudged distance, speed, altitude, clearance	351	2864
6.	Failed to maintain adequate rotor RPM	16	153
7.	Improper operation of powerplant controls	53	685
8.	Improper operation of brakes/flight controls	1	688
9.	Improper operation of flight controls	164	569
10.	Improper liftoff	10	1596
11.	Improper compensation for wind	12	550
12.	Control interference	0	1
13.	Improper recovery from bounced landing	5	811
14.	Spatial disorientation	528	60
15.	Failure to maintain directional control	13	1978
16.	Premature liftoff	11	302
17.	Failure to abort takeoff	26	257
18.	Failed to initiate go around	8	637
19.	Exceeded design stress limit of aircraft	121	16
	Total for Perceptual-Motor Activities	2496	14561
	Percent of total pilot caused accidents	43.8	56.3

Table 3. Number of fatal and nonfatal civil aviation accident in which the pilot in command is listed as the cause of a factor for all accidents occurring between 1970 and 1974 for rule based activities (Jensen and Benel, 1977).

RULE BASED ACTIVITIES (Procedural)

		Fatal	Nonfatal
1.	Failed to extend landing gear	1	255
2.	Failed to retract landing gear	4	14
3.	Incorrectly used miscellaneous equipment	14	62
4.	Improper IFR operation	110	66
5.	Improper fuel management	105	1231
6.	Improper starting procedure	1	30
7.	Failed to assure gear down and locked	1	207
8.	Misused or failed to use flaps	27	235
9.	Inadvertently retracted landing gear	0	104
10.	Retracted gear prematurely	1	2
	Total for Procedural Activities	164	2230
	Percent of total pilot caused accidents	4.6	8.6

Table 4. Number of fatal and nonfatal civil aviation accidents in which the pilot in command is listed as the cause or factor for all accidents occurring between 1970 and 1974 for knowledge based activities (Jensen and Benel, 1977).

KNOWLEDGE BASED ACTIVITIES (Decisional)

		Fatal	Nonfatal
1.	Operation of aircraft with known deficiencies	84	201
2.	Operation beyond experience/ability	170	368
3.	Continued VFR into known adverse weather	717	343
4.	Continued flight into known severe turbulence	18	7
5.	Improper inflight decisions/planning	236	597
6.	Exercised poor judgment	235	767
7.	Operated carelessly	7	38
8.	Selected unsuitable terrain	22	1230
9.	Initiated flight into adverse weather	124	61
10.	Psychological condition	11	4
11.	Selected wrong runway	11	341
12.	Failed to follow approved procedures	145	425
13.	Inadequate preflight planning or preparation	511	2341
14.	Lack of familiarity with aircraft	121	611
15.	Started without proper assistance	6	89
16.	Became lost/disoriented	68	248
17.	Taxied, parked without proper assistance	0	67
18.	Left aircraft unattended	1	8
19.	Diverted attention from operation of aircraft	111	501
20.	Inadequate supervision of flight	62	610
21.	Spontaneous improper action	15	119
22.	Misunderstood orders/instructions	3	20
23.	Inadequate training	0	5
24.	Direct entry	9	14
	Total for Decisional Activities	2940	9087
	Percent of total pilot caused accidents	51.6	35.1

pilot activities, i.e. decisional errors rather than skill or rule based errors. This is consistent with the emphasis in this research project on information and its effect on pilot decisional errors. For example, seeking, receiving, interpreting and forecasting weather is essential for minimizing VFR penetration into IMC.

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ACCIDENT/INCIDENT REPORT DATA FOR FUEL MISMANAGEMENT AND FLIGHTS INTO WEATHER                         JUN 02, 1986          PAGE 258
FOR THOMAS H. ROCKWELL

DATE    DO  ACFT MAKE     CITY                 ST   VRST PHASE OF FLIGHT    CAUSAL        SUPPTF IFLYP FLTCP LTCON LCRT TNR   TYO   FAT
NNUM    PROD ACFT MODEL             BEECH 58  LANDING GEAR                 CAUSAL        CONTRF IFLYS FLYCS SKCON PRUF TMN90 TOTHR INJ
EVENT REMARKS

830420 SW67 BEECH       GAGE                 OK    ---  APPR-FORCE LAND    PLAN/FUELOT   CARLS  BSNS  VFR   DAY   PVT  00117 00012 000
599VK  WP01 95B55       SHATTUCK             17    DRY  CNTLD COLL                       EMLAND OTHR  NONE  CLER  OTHR 00012 01549 000
A      CRASH OCCURRED DURING EMERGENCY LANDING AFTER ENGINES QUIT FROM FUEL EXHAUSTION.

840707 SW66 BEECH       LUBBOCK              TX         APPR-FORCE LAND    PLAN/FUFLOT   UNSKL  PERS  VFR   DAY   PVT  00017 00007 000
55HT   SW66 95B55       TOWN AND COUNTRY     15    DRY  CNTLD COLL         MGT/FUEL      EMLAND PLEA  NONE  SCAT  OTHR 00007 00371 001
A      RIGHT ENGINE, FUEL EXHAUSTION ON AUX TANK, MAIN HAD 15 GALLONS. LEFT ENGINE OUT OF FUEL, MAIN AND AUX.

850412 SO67 BEECH       ORMOND BEACH         FL         CRUISE-NORMAL      PLAN/FUELOT   CARLS  PERS  VFR   DAY   COM  00050 00050 000
12285  SO67 95B55       MUNI                 08    DRY  FORCED LANDING                   EMLAND PLEA  NONE  OCST  PILT 00030 12000 000
G      PILOT CHECKED FUEL GAUGES BEFORE TAKEOFF. RAN OUT OF FUEL EN ROUTE. NO DAMAGE DUE TO AIRPORT LANDING.

850804 SO66 BEECH       MARION               SC         CRUISE-NORMAL      PLAN/FUFLOT   CARLS  PERS  VFR   DAY   COM  00250 00015 000
17726  SO66 95B55                                       FORCED LANDING     PREFLT/INSP   EMLAND PLEA  NONE  SCAT  PILT 00015 01300 000
G      POWER OFF LANDING ON HIGHWAY DUE TO FUEL EXHAUSTION. NO DAMAGE. PILOT WAS 10 MINUTES INTO FLIGHT WHEN ENGINES QUIT.

840530 NM67 BEECH       DUCHESNE             UT         CRUISE-NORMAL      ENRT/TERRAIN WXNOB PERS  UNK   NIT   PVT  00199 00020 001
67572  NM66 95B55                                       CNTLD COLL         WX/VFR        WX     PLEA  JOST  DRKN  UNKN 00020 01012 000
A      AIRCRAFT CRASHED ON MT AGASSIZ AT THE 12100 FT LEVEL. RADAR INDICATED WEATHER IN VICINITY OF CRASH.

800220 CE62 BEECH       CHESTERFIELD         MO    HAZ  TKOF-INIT CLIMB    BELOW VMC     UNOPS  PERS  VFR   DAY   PVT  00132 00023 000
2620   CE62 95B55       SPIRIT OF ST. LOU    07         CNTLD COLL         FUEL/SYS      EMLAND PLEA  NONE  CLER  OTHR 00020 00212 000
A      LOST LEFT ENGINE ON INITIAL CLIMB DUE TO FUEL STARVATION. AIRCRAFT BELOW VMC. ABORTED, CRASHED OFF SIDE OF RUNWAY.

840703 NE65 BEECH       NORTH HAVERHILL      NH         TKOF-INIT CLIMB    BELOW VMC     MISJG  BSNS  VFR   DAY   COM        00075 001
8101K  NE65 95B55       DEAN MEMORIAL        01    DRY  STALL              MGT/FUEL      MISCL  OTHR  NONE  DRKN  OTHR       01400 000
A      RIGHT ENGINE QUIT ON TAKEOFF. STRUCK THE GROUND IN A STEEP BANK. SELECTED AUX TANK WAS EMPTY.

810821 NM02 BEECH       ROSEBURG             OR         TKOF-INIT CLIMB    MGT/FUEL      UNSIT  BSNS  VFR   DAY   PVT  01736 00050 000
40213  NM64 95C55       MUNI                 34         CNTLD COLL         GRND/WIR      EMLAND OTHR  NONE  CLER  OTHR 00050 02063 000
A      BOTH ENGINES QUIT AND AIRCRAFT CRASHED SHORTLY AFTER TAKEOFF.

820621 WP08 BEECH       ONTARIO              CA    HAZ  CRUISE-FCD/PREC LD MGT/FUEL      MISTK  BSNS  VFR   NIT   PVT  00157 00022 000
7073F  WP08 95C55       ONTARIO                         CNTLD COLL         EQUIP/MGT     EMLAND OTHR  NONE        EXEC 00020 02570 002
A      AIRCRAFT CRASHED DURING EMERGENCY LANDING AFTER ONE ENGINE QUIT DUE TO FUEL STARVATION. FIRE STARTED AFTER CRASH.

810615 WP05 BEECH       LOS ALAMITOS         CA         CRUISE-NORMAL      FUEL/LOW      CALCP  PERS  VFR   DAY   PVT  00100 00100 000
6722        95C55       LOS ALAMITOS         22L   DRY  OTHER              PLAN/FUFLOT   MISCL  OTHR  NONE  CLER  UNKN 00015 01500 000
G      CG PILOT STATED TO TOWER HE HAD LOST POWER IN BOTH ENGINES. LANDED OKAY. ALL FOUR FUEL TANKS FOUND OKAY.

820210 WP04 BEECH       TWENTYNINE PALM      CA    FOG  UNKNOWN            CNTL/WX       UNOPS  BSNS  IFR   DAY   PVT  00326 00009 002
2000J  SW67 95C55                                       UNCNTLD COLL       PLAN/WX       WX     OTHR  LTNG  DRSC  OTHR 00007 01509 000
A      VFR PILOT LOST CONTROL IN FOG AND RAIN. PILOT NOT MULTI ENGINE RATED. EXPIRED MEDICAL AND NO BIENNIAL FLIGHT CHECK.

800220 GL03 BEECH       ROCK ISLAND          IL    FOG  APPR-FINAL         PLAN/FUELOT   CARLS  PERS  IFR   NIT   CPF  00003 00023 000
53KC   CE61 95C55       QUAD CITY            09         COLL-TREES         PREFLT/INSP   EMLAND PLEA  CEIL  DRSC  OTHR 00003 05010 002
A      RAN OUT OF FUEL ON IFR APPROACH. HIT TREES SHORT OF RUNWAY. FAILED TO OBTAIN FUEL EN ROUTE AS SUGGESTED.

820224 WP04 BEECH       HURON                CA         TKOF-INIT CLIMB    PLAN/FUELOT   CARLS  BSNS  VFR   DAY   PVT  01030 00030 001
491A   WP04 95C55       HURON                35         UNCNTLD COLL                     MISCL  OTHR  NONE  CLER  OTHR 00025 06050 000
A      AIRCRAFT ROLLED TO RIGHT AND CRASHED IMMEDIATELY AFTER TAKEOFF. MINIMUM FUEL FOUND IN TANKS DURING INVESTIGATION.
PREPARED BY NATIONAL SAFETY DATA BRANCH AVN120
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AIDS DATA SAMPLE OUTPUT

III. Results from Analysis of General Aviation AIDS DATA

A. Introduction

In order to develop valid conceptual models of pilot error, it is essential to examine the contribution of the accident data base. With the cooperation of the FAA office at Oklahoma City the project team was able to secure printouts of 1600 cases of critical inflight errors, 2100 cases of fuel mismanagement and 1100 cases of flight into adverse weather for the period 1980-1985. To be reportable in this data base, an incident or accident must have involved either a fatality, an injury or substantial damage.

A sample of data entries is shown, Figure 1. An explanation of the codes used in this data base is provided in Appendix A.

It is evident that the reported description of the accident is not conclusive. Often certain data are not available, e.g. pilot ratings, weather etc. Perhaps the greatest weakness of this accident data base as with most accident data bases is the lack of "why" information. We can often infer what happened in the given instant, but not the reasons behind the behavior of the pilot. Also, exposure metrics are not available, i.e. what percent of pilots in the population have less than 500 hours. This is necessary to interpret a finding that some percent of injured pilots have less than 500 hours. Nonetheless such data can be useful in understanding the nature and conditions of a class of pilot error. This is not to suggest that pilot error is always present in a given accident. Each data set will be briefly described and summarized by means of random samples of 100 cases.

B. Fuel Mismanagement Cases

In this paper fuel mismanagement is a general term which embraces fuel starvation, i.e. the plane had an emergency landing with fuel on board in one of its tanks, fuel exhaustion, i.e., all the fuel was consumed before the aircraft made an emergency landing and "low fuel" which means the pilot recognized imminent exhaustion and elected an emergency landing while power was still available.

Appendix B-1 depicts the breakdown of the fuel mismanagement data by various accident characteristics. Examination of primary causes behind the fuel mismanagement cases in the AIDS data base provides further support for relating knowledge based systems and pilot errors. Some of the major errors were:

1. poor preflight habits in fuel assessment
2. failure to note cap & vent status
3. improper fuel consumption estimation
4. improper power setting during flight
5. no schedule for tank selection
6. lack of knowledge of aircraft tank size, consumption rates, etc.
7. failure to account for weather caused route deviatons.

Of interest is the fact that in 90% of the cases the weather was VFR and 83% took place in the daytime. Two thirds occurred in cruise conditions. Ninety five percent were nonfatals and 78% did not involve injury.

The potential for injury is considerable when one realizes there were 2200 cases over a 5 year period or 440 cases/year reported. How many unreported cases resulted in successful emergency landings can only be estimated. The incredible aspect of this pilot error is that it is completely preventable with proper preflight checks of fuel status and a reasonable calculation of fuel requirements. This is clearly the case since 53% were assigned "improper preflight." This is a good example of how "Back to Basics" should apply.

Experience does not appear to be a factor since over half the pilots involved had over 500 hours total flying time, suggesting the possibility of complacency with regard to fuel management. Fifty percent of the pilots involved had less than 100 hours in the plane's make and model which accounted for 54% of the fuel starvation cases. It appears that lack of familiarity of tank selection procedures is a causal element.

C. Critical Inflight Events (CIFE)

Examination of a random sample of 100 of the 1500 cases of inflight emergency reveals an overwhelming percentage associated with engine failure or alleged engine failure (code 7200) (≈ 75%). See Appendix B-2. Electrical failure occurred in 6% of cases and vacuum failure in about 1%.

Most failures occurred during cruise (44%), 90% were in daylight, 98% were in VFR conditions. Analysis of pilot experience levels revealed only 27% of the pilots had less than 500 hours total experience, but 41% had less than 100 hours in the plane's make and model. This suggest that CIFEs are much more common for pilots flying aircraft with which they have limited experience.

The consequence of CIFE's were that 39% involved injury and 6% resulted in fatalities.

D. Accidents & Incidents of Flight into Adverse Weather

A sample of 100 of the 1100 cases of flight into weather reveals that nearly twice as many of these accidents occurred in daylight vs. nighttime conditions (60% vs. 34%). Without exposure data this is difficult to interpret. It would seem obvious that weather is more difficult to evaluate in night flying. See Appendix B-3. The most frequent visibility restriction was fog (50%) followed by rain (19%). Almost 24% of the pilots in these cases had received a weather briefing. This suggests the possibility that either the briefing's format or content or the pilots' comprehension of the briefing was inadequate. There was no way to infer from the data the possibility of a "busted forecast."

When a second sample of 100 cases of VFR into IMC was examined, it was found that 27% involved night flying (see Appendix B-4). This appears to be a significant finding in light of the problems of weather evaluation at night. As reported above for the original data set a significant percentage of VFR into IMC cases (35%) received a weather briefing. Twenty-six percent of the cases involved mountainous terrain. Like night flying, mountainous terrain clearly complicates the VFR into IMC problem. These incidents are not experience related.

Only 27% of these accidents involved inexperienced (less than 200 hours total flying time) pilots. (Forty-three percent of these accidents were by pilots with an excess of 500 hours total flying time.) It should be noted that the data are not related to weather exposure hours.

Finally, 61% of accidents associated with flight into weather involved at least one fatality. This points out the need for effective countermeasures.

IV. Development of Pilot Error Models

For the three accident types above, conceptual "process" models were developed which encompassed a wide variety of scenarios under this pilot error type. The models emphasize pilot information acquisition and decision-making. These models were conceptualized in view of our perceptions of a typical pilot's mental processes prior to and during a flight. At the same time, the models highlight those processes which are reported as being causal in the AIDS data base. The three models are shown in Figures 2, 3, and 4. They depict the decisional process, list typical errors, contributing factors and propose needed research.

For example, in the CIFE model, Figure 2, the decision of the pilot to abort or not abort his flight following the detection of a flight emergency represents a logical consequence of inflight surveillance. Since the AIDS data reveals that 44% of CIFEs occur during cruise conditions, it suggests that better surveillance reflects a potentially key intervention point. Similarly, the model asks if the pilot considers whether or not an immediate landing is required. The data base reports that over 65% of reported flight emergencies involve engine failure or alleged engine failure which force landing decisions.

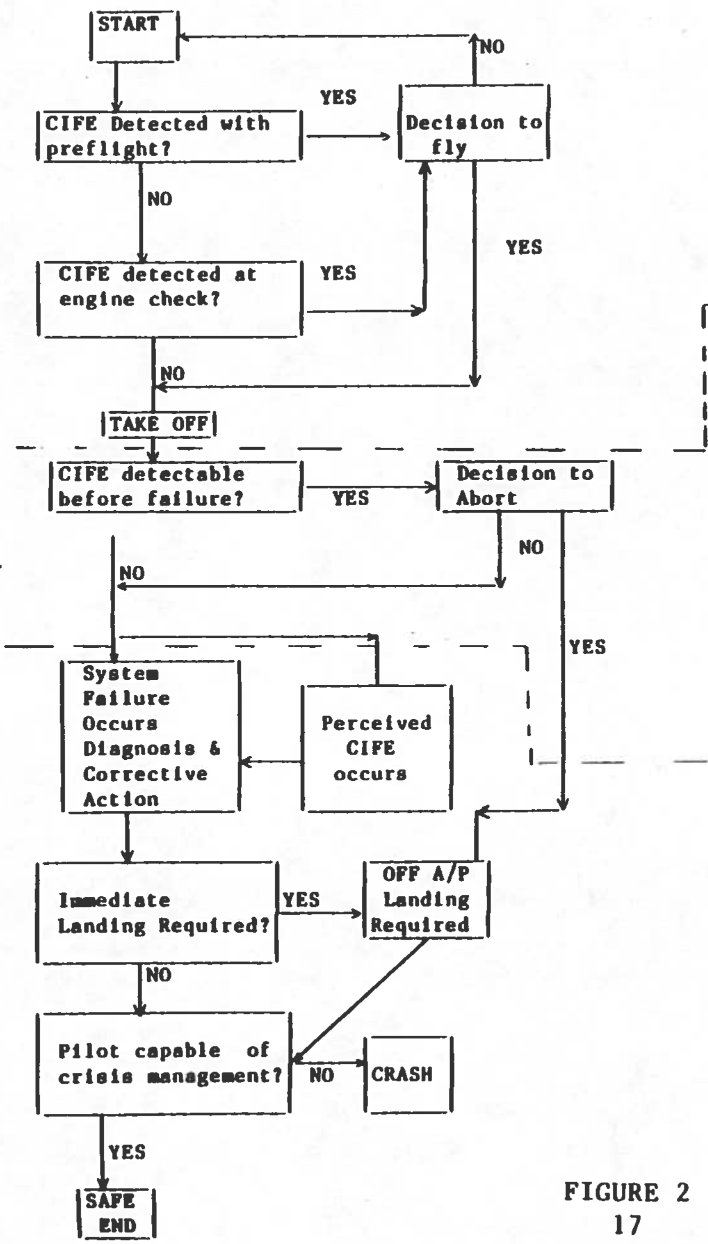
Likewise for the fuel management error model, Figure 3, the pilot errors in ascertaining the preflight fuel system status and fuel requirements are reflected in the AIDS data which reveal that 53% of the causes of fuel mismanagement were assigned the cause of "improper preflight." The model also highlights the possibility of 'inappropriate enroute fuel transfer procedures' such as tank selection, the AIDs data suggest that these errors account for 22% of accidents of this type.

In the VFR into IMC model, Figure 4, the process starts with the question of preflight weather briefing. The AIDS data demonstrate that 16% of GA pilots fail to perform this activity. The model also addresses whether or not the pilot was able to maintain aircraft control in IMC. The AIDS data indicate that 16% of GA pilots were unable to demonstrate this control. In addition to mapping our conceptualization of the logical sequence of events in these pilot error scenarios, Figure 4 also enumerates possible procedural errors which pilots might commit, such as failing to understand weather information. In this error type knowledge of enroute weather sources is a contributing factor.

There are some interesting commonalities of these three process models. In each the critical role of the preflight planning state offers an opportunity for error commission or failure to detect subsystem problems. Each error conceptualized also recognizes the value of subsystem and/or weather change detection during flight. Good monitoring performance can often provide early detection and time for safe recovery. Finally, the three models point out the need for crisis management on the part of the pilot when he has to deal with weather or subsystem changes in the face of emergency action.

Critical Inflight Event Model -- 9/15/86 Subsystem Failures RF 717989

Characterize CIFE by
1. whether warning precede failures
2. whether failure is sudden or gradual
3. whether A/C controllable after failure



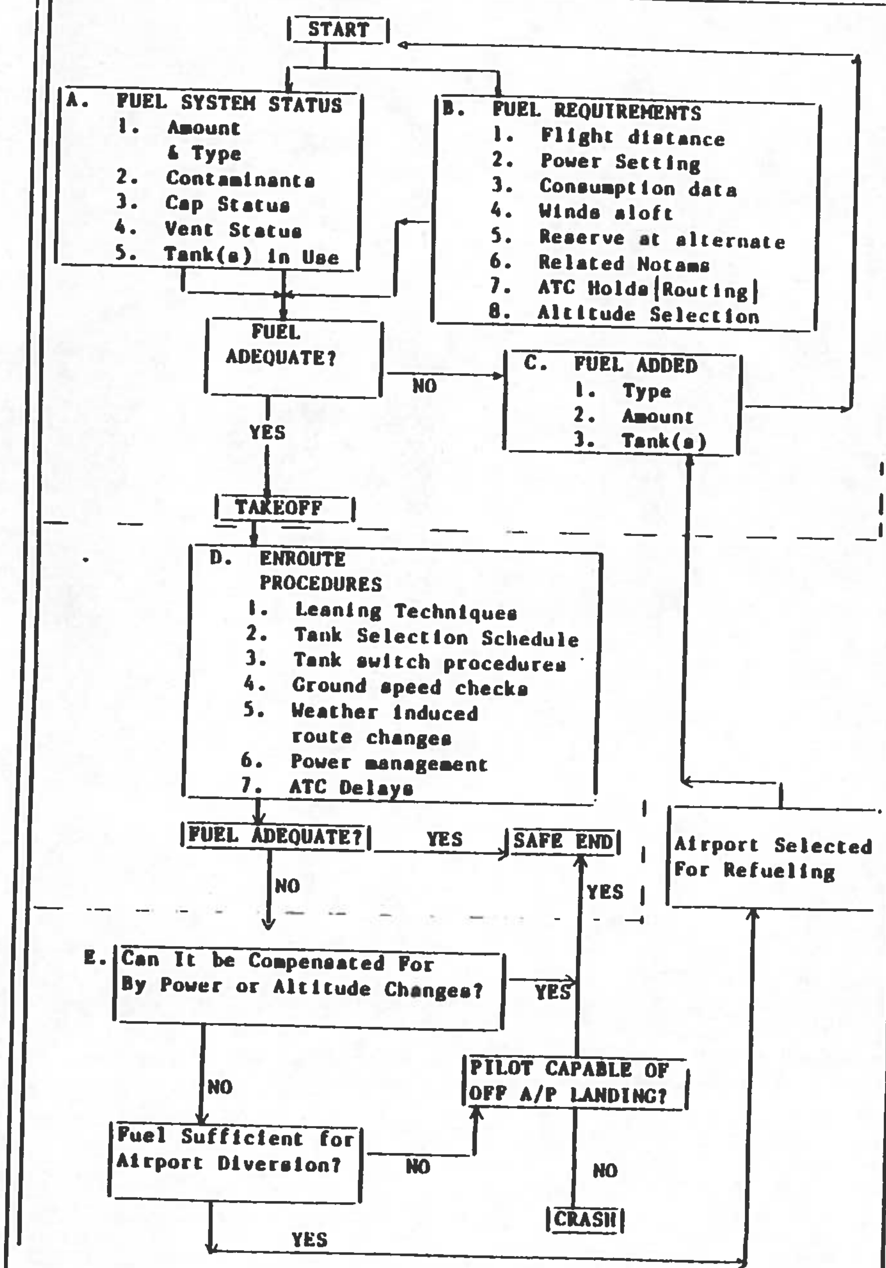
ERRORS	CONTRIBUTING FACTORS
1. Inadequate Preflight 2. Fails to recognize early warnings of problems 3. Fails to do sequence check 4. Decides to fly despite system descrepancies	1. No checklist 2. Poor preflight habits 3. In a hurry - distracted 4. Lack of knowledge of A/C system 5. Unfamiliar with A/C 6. Willing to accept risks
5. Fails to recognize early warnings 6. Fails to monitor instrument readings 7. Fails to notice small discrepancies in flight sensations 8. Fails to notice lack of agreement of related instruments 9. Diagnostic Error 10. Error in estimation of urgency 11. Improper corrective action	7. Unfamiliar with A/C 8. Overloaded with stick and rudder 9. Doesn't understand A/C system 10. Poor scanning discipline
12. Poor emergency flying skills	1. Information overload 2. Poor stick and rudder skills 3. Pilot health (fatigue) 4. No emergency checklist

RESEARCH NEEDS

1. Where are errors most likely to occur in the causal sequence?
2. Which errors are most severe?
3. How important are stick & rudder skills in earlyCIFE detection and diagnosis?
4. How to better perform preflights with CIFE's in mind?
5. How to prepare pilots for crisis management?
6. How to use available resources in flight?

FIGURE 2

PILOT FUEL MISMANAGEMENT MODEL - 9/15/86 RF 717989



ERRORS

A.
1. No visual check of fuel status
2. Failure to drain tanks
3. Failure to check caps & vents
4. Failure to select proper tank

B.
1. Miscalculate route miles
2. Miscalculate fuel consumption/ power setting
3. Failure to get winds aloft
4. Failure to plan an alternate
5. Failure to account for traffic delays

C.
1. Failure to observe refueling

D.
1. Poor leaning procedure
2. Improper tank selection schedule
3. Failure to use proper switching procedures
4. Failure to update ground speed
5. Improper power management
6. Poor selection of refueling airport
7. Failure to have notams

E.
1. Poor emergency flying skills
2. Fails to use ATC assistance.

CONTRIBUTING FACTORS

A.
1. Poor preflight habits
2. In a hurry
3. Willing to make assumptions
4. Distracted
5. Not using checklist

B.
1. Ignorance of burn rates
2. Ignorance of enroute weather
3. Ignorance of fuel calculations
4. Willing to make assumptions
5. Ignorance of potential ATC delays

C.
1. Assumptions on airport hours of operation
2. Assumptions of fuel type available

D.
1. Information overload
2. Preoccupation with aircraft control
3. Unfamiliar with aircraft
4. Lack of discipline in power management

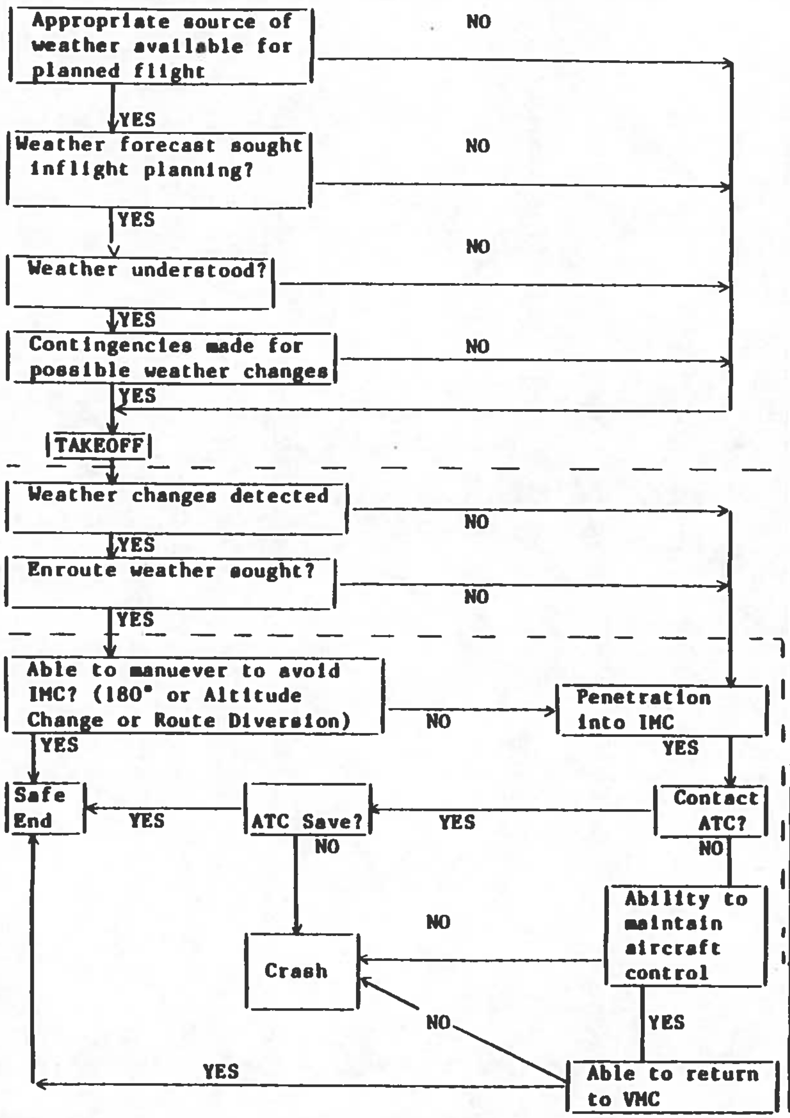
E.
1. Lack of emergency training
2. ATC assistance
3. Pilot health (fatigue)
4. No emergency checklist

NEEDED RESEARCH

1. Pilot misunderstanding of enroute weather and changes.
2. Why pilots assume fuel system status?
3. Why pilots make tank selection errors?
4. How to avoid mismatching errors in fuel type?
5. Why pilots fail to know fuel related aircraft characteristics. e. g. consumption vs. power settings?
6. Relative frequency & severity of errors
7. How to prepare pilots for crisis management.?
8. How to prepare pilots for off A/P landings.

FIGURE 3

A MODEL FOR VFR FLIGHT INTO IMC 9/15/86 RF717989



TYPICAL ERRORS

1. Failed to get NOTAMS big weather picture and weather forecast, (used wrong source).
2. Failed to understand weather.
3. Failed to use weather in flight planning.
4. Failed to prepare navigation alternatives for weather contingencies.
5. Failed to get correct weather.
6. Poor fuel management in face of weather changes.
7. Failed to note changes in weather enroute.
8. Failed to note forecast would not hold.
9. Failed to get weather updates.
10. Failed to let ATC know of pending weather induced problems.
11. Failed to consider 180° or diversion before IMC.
12. Failed to note weather trend
13. Failed to use arrival weather sources.
14. Failed to keep aircraft under control.
15. Failed to contact ATC for assistance

CONTRIBUTING FACTORS

1. Inadequate weather knowledge
2. Lack of weather experience
3. Difficulty in obtaining weather briefing?
4. In a hurry
5. Fuel status
6. Disbelieves forecast
7. Inexperience in make & model of A/C
8. Lack of recent experience
9. Operation in mountains
10. Operation at night
11. Busted forecasts
12. ATC availability
13. Knowledge of enroute weather sources
14. Presence of auto pilot
15. Stick and rudder skills
16. Poor communication skills
17. Mission or passenger induced stress
18. Radar communications limitations
19. ATC Radar

NEEDED RESEARCH

1. How to pinpoint weather interpretation confusions in pilot?
2. Why pilots scud run?
3. How to find early indicators of busted forecast?
4. How to prepare pilots for crisis management?
5. Are differing mental models of weather by FSS, meterologists and pilots the source of weather communication problems?
6. Why do pilots take chances with weather penetration?
7. How to help pilots get enroute weather?
8. How to help pilots get better pre-flight weather?
9. How to help pilots assess their weather flying capability?
10. How to improve pilot interpretation of weather observed through the windshield?
11. What are pilots perception of weather forecast accuracy?
12. How accurate is weather information given to pilots?
13. What sources of weather do pilots use to base decisions (preflight & enroute)
14. What is the process pilots use to make weather related flight decisions?
15. How are pilot weather information seeking and weather based decisions related to their knowledge of aviation weather?

FIGURE 4

V. Research Methodology for the VFR into IMC Problem

The VFR into IMC scenario constitutes a particularly important problem in general aviation safety. As previously reported, for the period 1980-1985 we estimate that 1100 such accidents occurred, making it one of the more frequent cases of GA pilot mishaps. Even more striking is that of these 1100 cases, a full 61% involved at least one fatality, making it far and away the most severe form of GA pilot accidents (see Appendix B-4). The frequency and severity of these weather related crashes are nothing new, as indicated by the Jensen and Benel study (1977).

Clearly this has been and remains a problem which requires immediate research aimed at reducing these unfortunate events. As suggested earlier, the available data collected thus far on this problem are insufficient to ascertain the true causes of this type of accident. Certainly this type of accident represents an inadequacy in pilot information seeking and decision-making behavior. But more specifically, what information are these pilots failing to acquire? Conversely, what information do they rely on and how does that relate to their subsequent flying decisions? Do they seek too little information to make good decisions? Are they confused in their understanding of weather situations? What type of understanding do GA pilots have of weather conditions?

In order to discover some answers to such questions, we initiated an effort to refine the VFR into IMC model through two weather-related experiments. The first experiment involves testing pilots through a computer-aided weather test (CAWT) scenario. A second experiment to be described in the next section utilizes protocol analysis to help understand how pilots make weather forecasts.

A. The Computer Aided Weather Test

The computer aided weather test involves three elements:

a. A simulation of a VFR flight from Greensboro, NC to Athens, OH, including inflight weather changes which call for pilot decision making.

b. A computer aided debriefing of the weather flight.

c. A computer presentation of a quiz on pilot knowledge and judgment of weather.

The weather flight route was chosen so as to require flight over mountainous terrain (which AIDS data determined to be a causal factor in 16% of weather-related crashes). See Table 5. The weather used in this scenario was actual past weather for that route during stationary frontal conditions which produced VFR and marginal VFR weather flight conditions. The pilot was allowed to seek various forms of weather-related information through the Interim Voice Reponse System (IVRS). He is requested to seek any and all information he desires in order to decide if he will make this trip. This includes aircraft characteristics, flight plan, charts and weather. The types of information he seeks, the stations from which he seeks it, the order with which he seeks the various weather relevant data, and the piloting decisions he makes are all computer recorded and available for subsequent analysis. It is anticipated that this analysis will provide a better understanding of the various approaches that pilots of different experience levels might make which engender potentially unsafe flying decisions in problematic weather conditions. The subject is then debriefed to help the experimenter understand the basis for his information seeking and decisions. Finally the subject is given a weather quiz, which includes an assessment of both weather knowledge and judgment in order to better estimate this pilot's understanding of weather related information.

TABLE 5

Crosstabulated percentages for aircraft accident causals.

WEATHER CAUSALS	PLAN/WX 37%	WX/VFR 26%	UNK 8%	GRND/WTR 3%	FUEL/LOW 3%	ENRT/TERRAIN 3%
WX/VRF 24%	2	**	5	2	1	3
ENRT/TERRAIN 23%	7	16	0	0	0	**
CNTL/WX 16%	10	6	0	0	0	0
PLAN/WX 7%	**	2	1	0	0	0
PLAN/FUELOT 5%	1	0	2	1	0	0
FUEL/LLOW 5%	1	0	0	0	**	0

Appendix C describes the experimental protocol.

Appendix D depicts the computer screens shown to the pilot.

Appendix E shows the weather quiz. Note: For the quiz the pilot can request a feedback mode which scores each question and, if wrong, provides the correct answer.

In order to provide feedback to the test subjects on what information an experienced pilot would have sought for this flight scenario, a weather savvy pilot description is provided. See Appendix F.

B. <u>The Pilot Forecasting Strategies Study (PFSS)</u>

The second experiment seeks to determine the differences in high and low time pilot understanding of weather information in a somewhat different manner. A description of the experimental method and the weather information materials the subject receives in this experiment are provided in Appendix G.

In this study the subject is also provided with a flight scenario but is asked to give his best estimate as to the weather forecast at his destination. (No forecast is available.) The weather used in this scenario was taken from IVRS in October 14, 1986. Briefly, the weather pattern that day for this chosen region consisted of a cold front moving through the Charleston, WV area in a generally west to east flow during the scenario period. This weather system produced some IFR conditions for some WV stations but only marginal VFR conditions for Charleston. The rationale for choosing this particular weather scenario was to alert the subject to the possibility that IFR flight conditions might exist for his destination. It was hoped that this weather scenario would (1) motivate him to exlore the weather information to ascertain the general quality of this weather system and (2) would provide weather that could not be easily forecasted. The subject is permitted to request weather information in an IVRS-like format, seeking as much information as he desires within available limits. However, in this experiment the subject is requested to think aloud as he reasons his way toward arriving at his subjective weather forecast. His spoken thoughts are tape recorded and subsequently analyzed.

As with the CAWT experiment, the subject's protocols are analyzed to determine the weather parameters sought and terminals used. The methodology and subsequent analysis here will hopefully allow for a more complete understanding of the reasoning behind the pilot's weather search pattern, his general weather comprehension, and the factors involved in the derivation of his ultimate weather forecast. In this way we hope to determine if similarities in procedures and comprehension of weather issues exist among those pilots who are better able to anticipate the weather forecast and who have done so in a methodical manner.

Such identified processes might be suggestive of training elements to use in teaching pilots better weather comprehension skills. Likewise, perhaps we can identify common but troubling procedures which lead pilots to miss the forecast. The identification of common cognitive errors might also lead to suggestive recommendations for corrective actions to be taken with pilots in their training in understanding weather issues.

VI. Plans for Phase II Research.

A. Research Objectives and Proposed Schedule

Phase II research which will begin in January 1987 will identify the limits in the understanding and application of aviation weather by the general aviation pilot based on the research methodology developed in Phase I described in the previous sections.

The specific objectives for these tests will be to not only identify pilot weather understanding problems but to contrast high and low time pilots in this regard. Subject populations for the the two studies are based on the AIDS data which showed low time pilots were overrepresented in VFR into IMC accidents and the spectrum of pilot experience available in the Columbus, Ohio area. The CAWT study will include 30 pilots with a total hours less than 500 hours contrasted with 30 pilots with above 500 hours of experience. The PFS study will include 15 pilots with a total of less than 400 hours experience contrasted with 15 pilots with over 900 hours experience. See Appendix H for a breakdown of relevant biographical variables of the present subject pool for the two studies. It is expected these tests will be completed by March 30, 1987. Initial data analysis (section B below) is expected to take 2 months (March and April). A preliminary experiment to test methods of improving pilot weather understanding and application will be conducted on a sample of 20 pilots of low and high time background. These tests over May and June 1987 will complete Phase II testing. The final report will be prepared in July and August 1987 leaving 30 days for sponsor review.

Data analysis complete
methods to improve pilot weather und.

B. Proposed Analysis Strategies

1. The Computer Aided Weather Test (CAWT)

The CAWT data analysis is in its initial stages. The input includes a master computer record (see Table 6) which includes

a. Subject biographical data

b. Order of weather information sought

c. Preflight and flight decisions

d. Debriefing reponses

e. Scored weather quiz responses.

A general analysis stragtegy is shown in Figure 5.

Figure 6 depicts a time-based graphical representation of weather information seeking for the preflight stage for a test subject. The three-letter codes are the station identifiers of airports from which weather information can be obtained. At each station seven pieces of information are available, and these are color coded so that trends in the weather section pattern may be more easily discerned. For example, green represents forecast weather, and the subject consistently asked for this information. Winds aloft is coded yellow, and the subject asked for this information at only two stations. Note that weather information was not available at PSU, HNN, or PUB. However, the request for information at these stations was still recorded. Also indicated is the order in which the subject asked for weather information.

The information requests were converted to weighted scores and displayed as ratios of information requested to information available at the bottom of the chart. Responses to key debrief questions and quiz questions are also presented. Subscores and components scores for weather inquires are tabulated based on proposed weighted values for weather inquiries at various stations.

A correlation analysis involving the measured variables will be conducted. (See Figure 7).

Following this analysis the CAWT results will be related to pilot response to specific quiz responses. For example; do responses on questions on "scattered clouds as a ceiling" or "clouds AGL versus clouds MSL" relate to CAWT performance?

The above analysis will allow the research team to characteristize weather seeking performance. Potential classifications might include:

a. Route tunnel vision (weather sought on route-of-flight only)

b. Testing of forecast accuracy.

c. Making use of Pireps

d. Establishing the "big weather picture".

2. Pilot Forecasting Stategies Study (PFSS)

The PFSS data analysis is also in its initial stages. Input includes

a. Subject biographical data

b. Order of weather information sought

c. Protocol of subject's spoken thoughts during a forecasting task which may include his weather information related:

1. Subgoals

2. Stategies

3. Conceptual errors

4. Deductions

Figure 8 depicts a graphical representation of the weather information sought and basic summary statistics of the subject's information selections. The wheels represent the pool of weather information available at various IVRS reporting stations. The legend in the lower left describes the type of information at each station. The connecting legs represent various Transcribed Weather Broadcast (TWEB) routes. Weather inforrdmation not obtainable from IVRS is represented by cross-hatching on the wheels. Subject inquiries are color highlighted. A summary of the type of inquiries made by the subject is tabulated in the right hand margin as well as his estimate for the given weather forecast.

Figure 9 depicts a condensed view of a subject's information search and related cognitions. The 'order of requests' column represents the actual time-ordered weather inquiries made by the subject. These requests are assumed to be motivated by items in the 'rationale' column which summarize the subject's explanation as to why he had made such an inquiry. "Operating assumptions' are considered to represent assumptions upon which the subject relies to guide his rationale. These assumptions are themselves sometimes the product of obtained weather information. These constructs and their interplay are then mapped out in a fashion which reflects the subject's reasoning process at the forecasting task.

Results from these two types of analysis will be used to characterize weather searching strategies. Proposed questions to be addressed include:

1. How large a picture of the weather system does the pilot try to draw?
2. How does he attempt to characterize air masses?
3. Does he search for weather fronts? What parameters does he rely on to accomplish this?

4. Is the pilot concerned only with route of flight weather?

5. Does the pilot rely on assumptions to make the forecast? What are these assumptions? Does he attempt to validate these assumptions?

6. What deductions does the pilot make? Are certain sources of weather information implicated in erroneous deductions? Does the pilot seek to test deductions?

7. How specific is the pilot in determining his forecast? Does this level of specificity relate in any way to the pilot's accuracy in his forecast? Does it relate to his weather information collection procedures?

TABLE 6

ID NUMBER: 113

LAST NAME:

PILOT CERTIFICATION: PRIVATE PILOT

AIRMAN RATINGS:

TOTAL FLYING EXPERIENCE:L 51-100 HOURS

SINGLE ENGINE FLYING EXPERIENCE: 90-100%

INSTRUMENT FLYING EXPERIENCE: LESS THAN 10%

BIENNIAL FLIGHT TEST: LAST 180 DAYS

PILOT IN COMMAND HOURS: LAST 30 DAYS

CURRENT FLYING ACTIVITIES: GA (PERSONAL PLEASURE)

AGE: 20-30

PILOT RATED OR CERTIFICATION RECEIVED:L AFTER 1980

MOUNTAINOUS TERRAIN EXPERIENCE: 0-2%

% HOURS OF CROSS COUNTRY: 0-10%

DECISION MAKING:

PRE-FLIGHT: CANCEL FLY

PRE-FLIGHT: FLY WITH ALTITUDE 1500

AFTER UPDATE#1: RETURN TO GREENSBORO

TABLE 6 (continued)

WEATHER INFORMATION ASKING:

PRE-FLIGHT: GSO, CURRENT WEATHER, FORECAST WEATHER, AREA FORECAST FOR #1, A DVISORIES, WINDS ALOFT, PIREPS

PRE-FLIGHT: BKW, CURRENT WEATHER, FORECAST WEATHER, AREA FORECAST FOR #2, A DVISORIES, PIREPS

PRE-FLIGHT: PSK

PRE-FLIGHT: CRW, CURRENT WEATHER, FORECAST WEATHER

PRE-FLIGHT: HNN

PRE-FLIGHT: ROA, CURRENT WEATHER, FORECAST WEATHER, CURRENT WEATHER, FORECAST WEATHER, ADVISORIES, PIREPS, WINDS ALOFT

PRE-FLIGHT: BLF, CURRENT WEATHER, FORECAST WEATHER ADVISORIES, PIREPS

PRE-FLIGHT: HTS, CURRENT WEATHER, FORECAST WEATHER, ADVISORIES, PIREPS

PRE-FLIGHT: CMH, CURRENT WEATHER, FORECAST WEATHER, ADVISORIES, PIREPS

PRE-FLIGHT: TRI, CURRENT WEATHER, FORECAST WEATHER, ADVISORIES, PIREPS

PRE-FLIGHT: CVG, CURRENT WEATHER, FORECAST WEATHER, ADVISORIES, PIREPS

PRE-FLIGHT: PRE-FLIGHT: CVG, CURRENT WEATHER, FORECAST WEATHER, ADVISORIES, PIREPS

CANCEL FLY

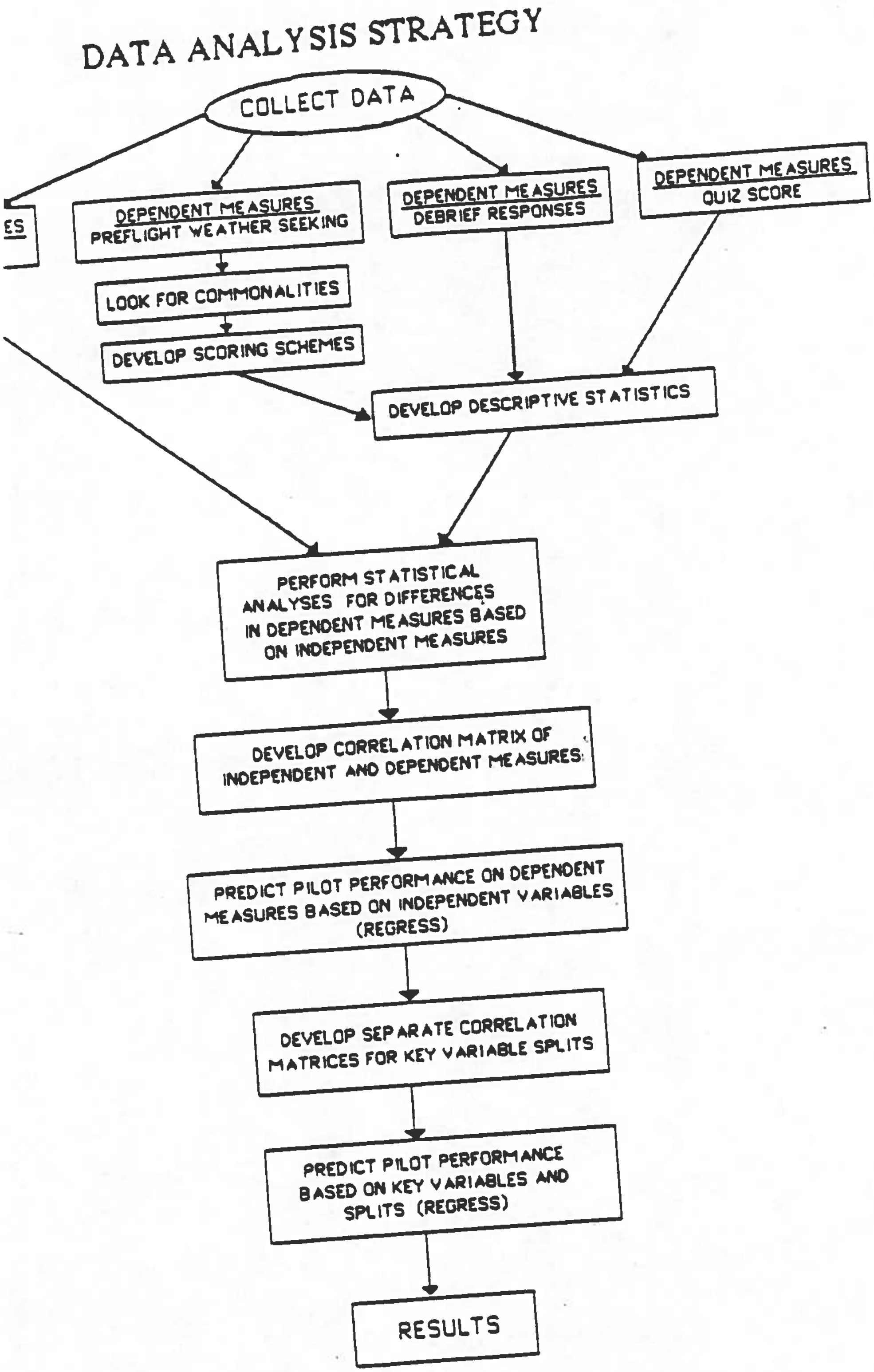


FIGURE 5 -- Proposed Data Analysis Strategy (CAWT)

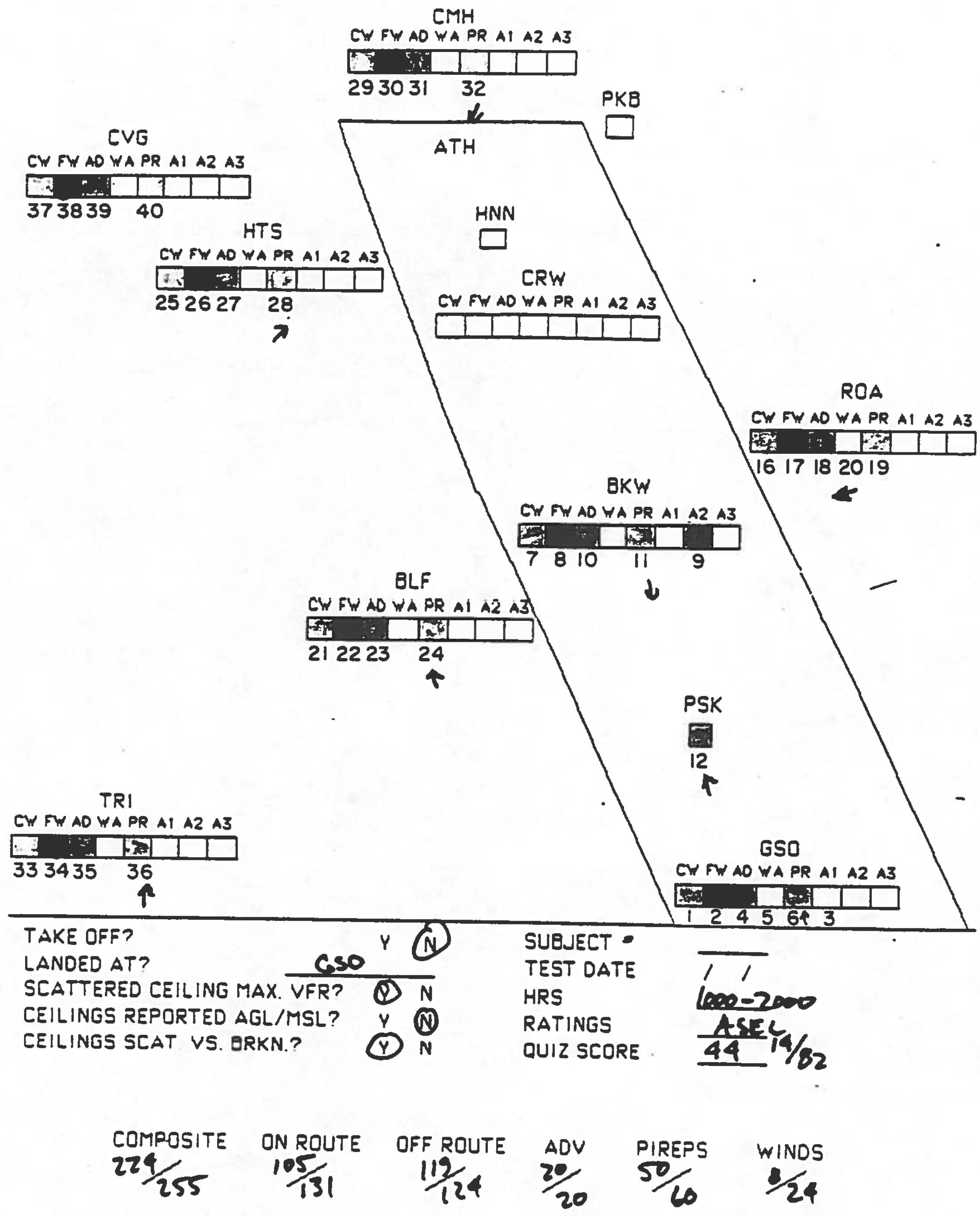


FIGURE 6. Time-based graphical representation of weather information seeking for the preflight stage of a CAWT subject.

Legend:
CW=Current Weather
FW=Forecast Weather
AD=Advisories
WA=Winds Aloft
PR=Pilot Reports (Pirups)
A1=Area Forecast #1
A2=Area Forecast #2
A3=Area Forecast #3

Quiz Score is presented in two forms:

1. Total Score
2. Ratio of Knowledge Score to Judgment Score

Variable for Correlation Analysis (CAWT)

1. Total Hours

2. Quiz Score

3. composite Weather Score

4. On-Route Score

5. Off-Route Score

6. Advisory Score

7. Pirep Score

8. Winds Aloft Score

9. Pilot Chronological Age

10. Pilot Years Since First Lesson

11. Total Number of Weather Inquiries

Figure 7: A listing of the CAWT variables for the proposed correlation analysis.

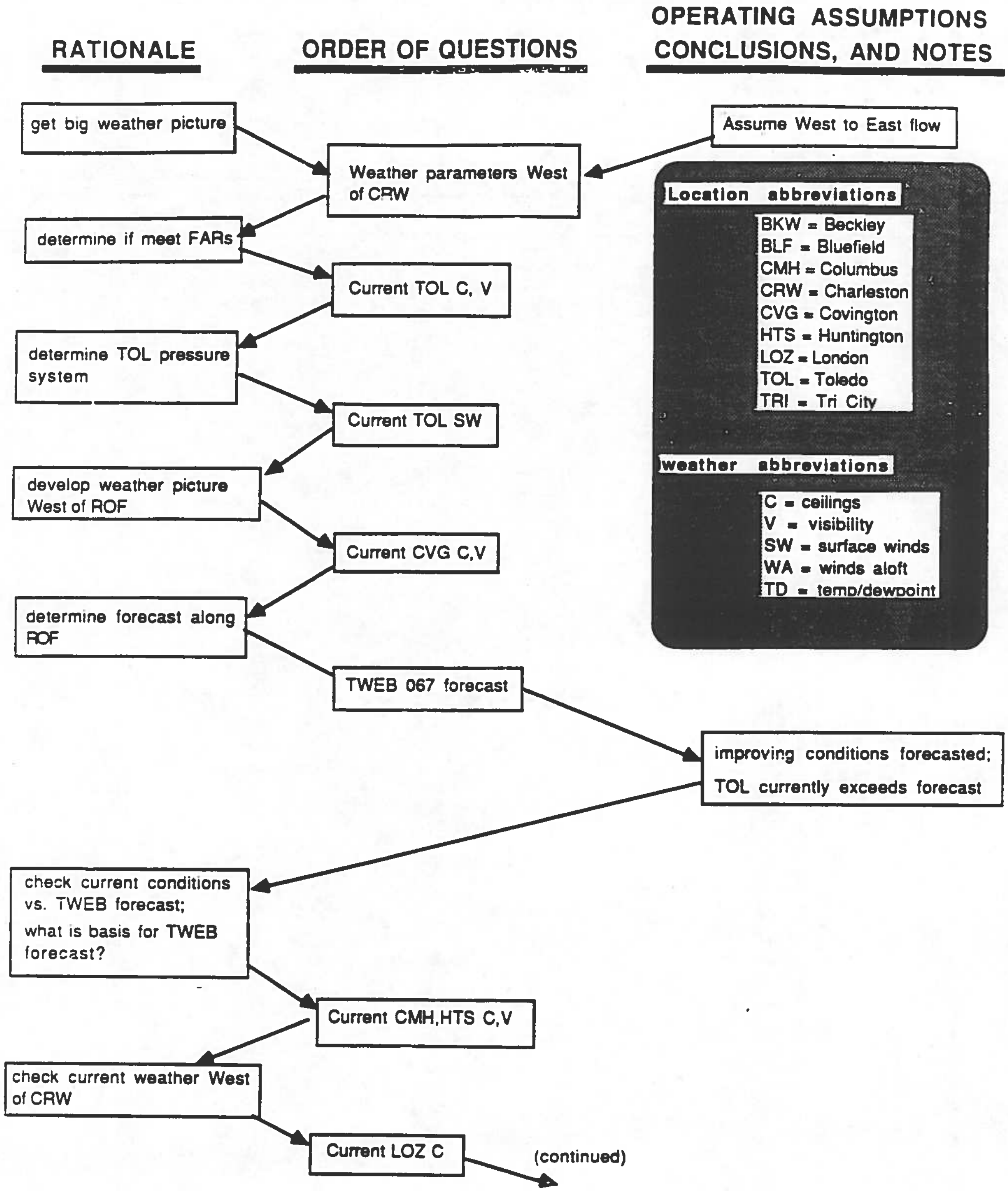
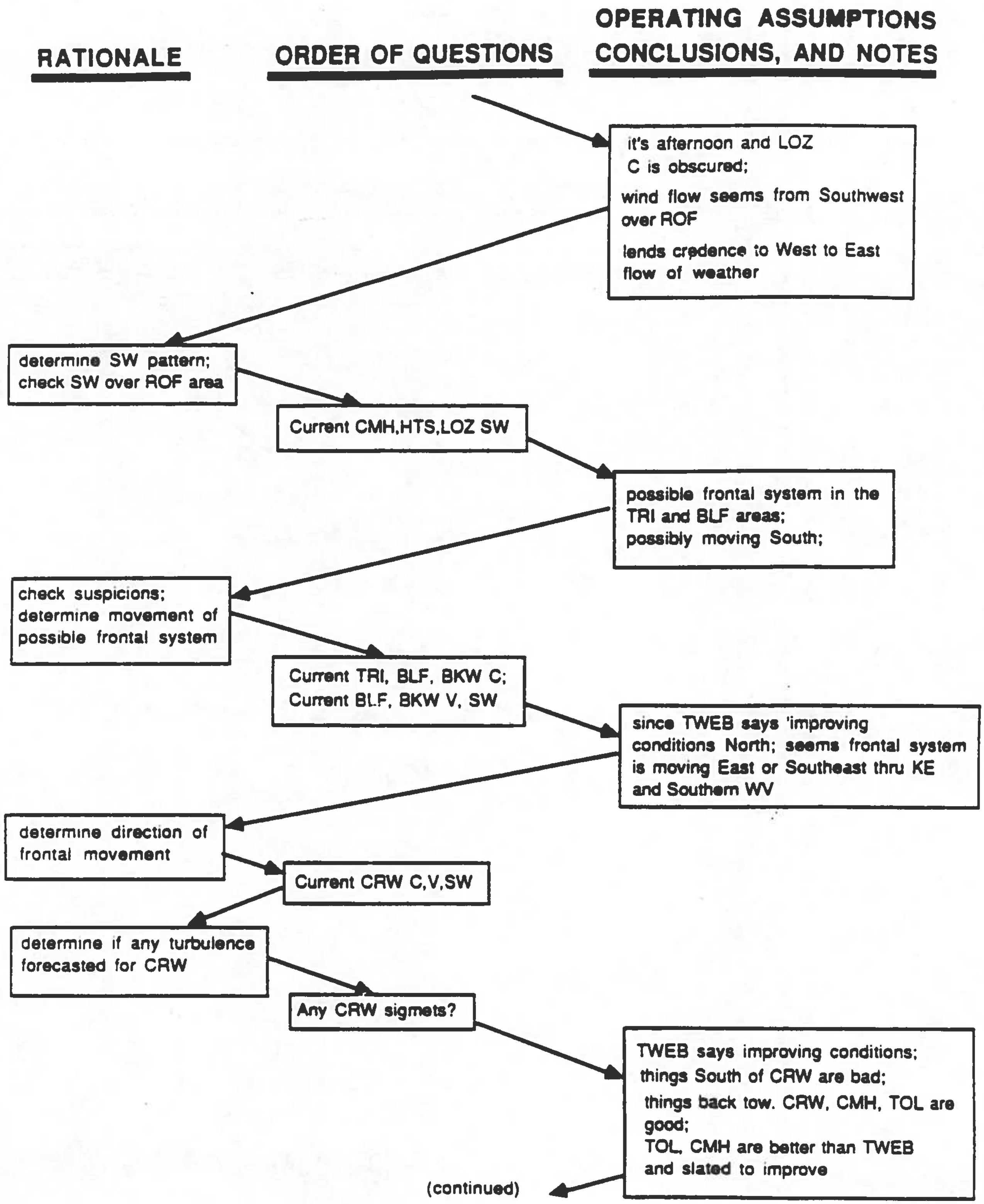
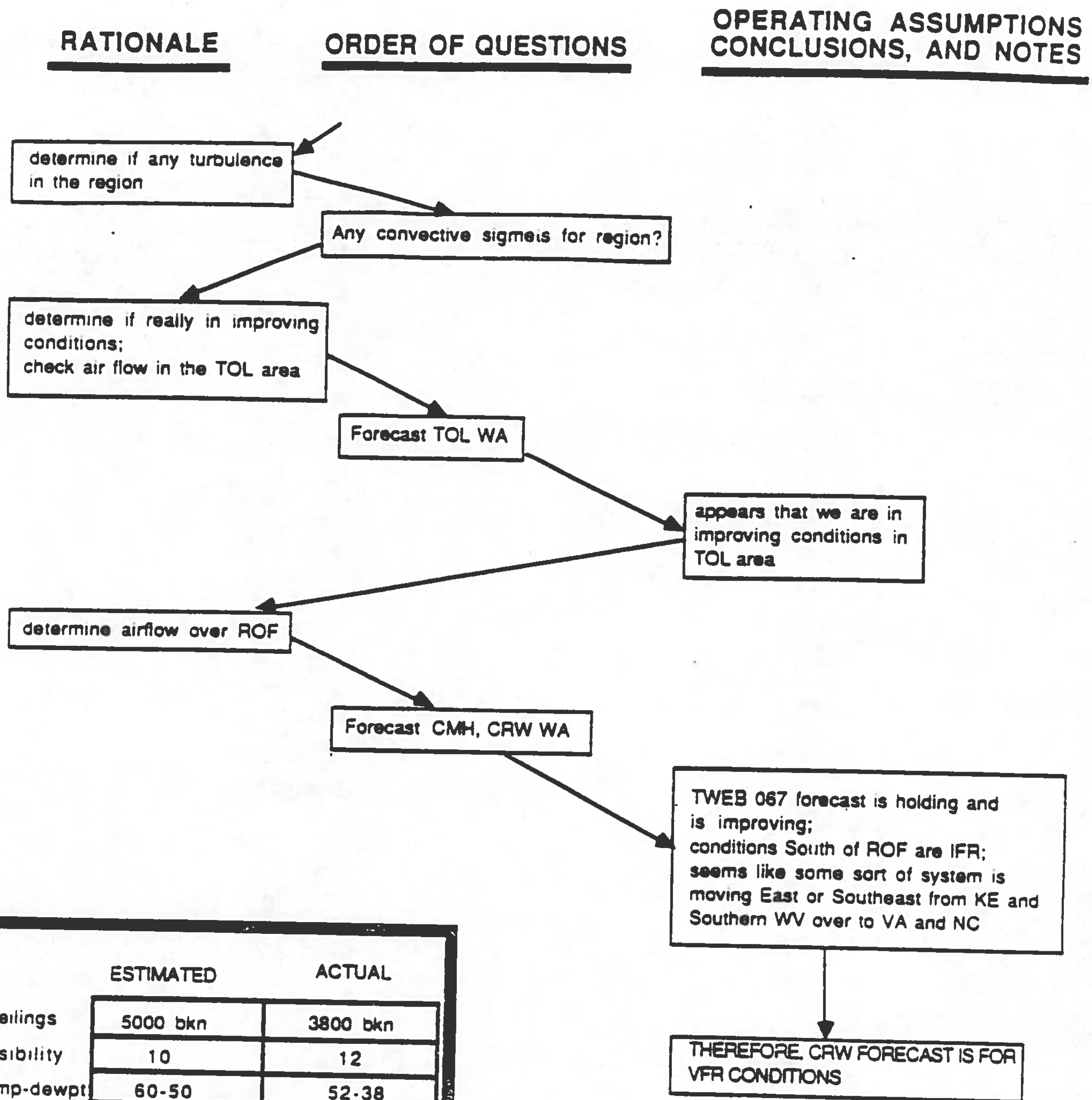


Figure 9: Schematic of a PFSS subject's information search and related cognitions.



(Figure 9 continued)



	ESTIMATED	ACTUAL
ceilings	5000 bkn	3800 bkn
visibility	10	12
temp-dewpt	60-50	52-38
winds	290 @ 10	310 @ 8

(Figure 9 continued)

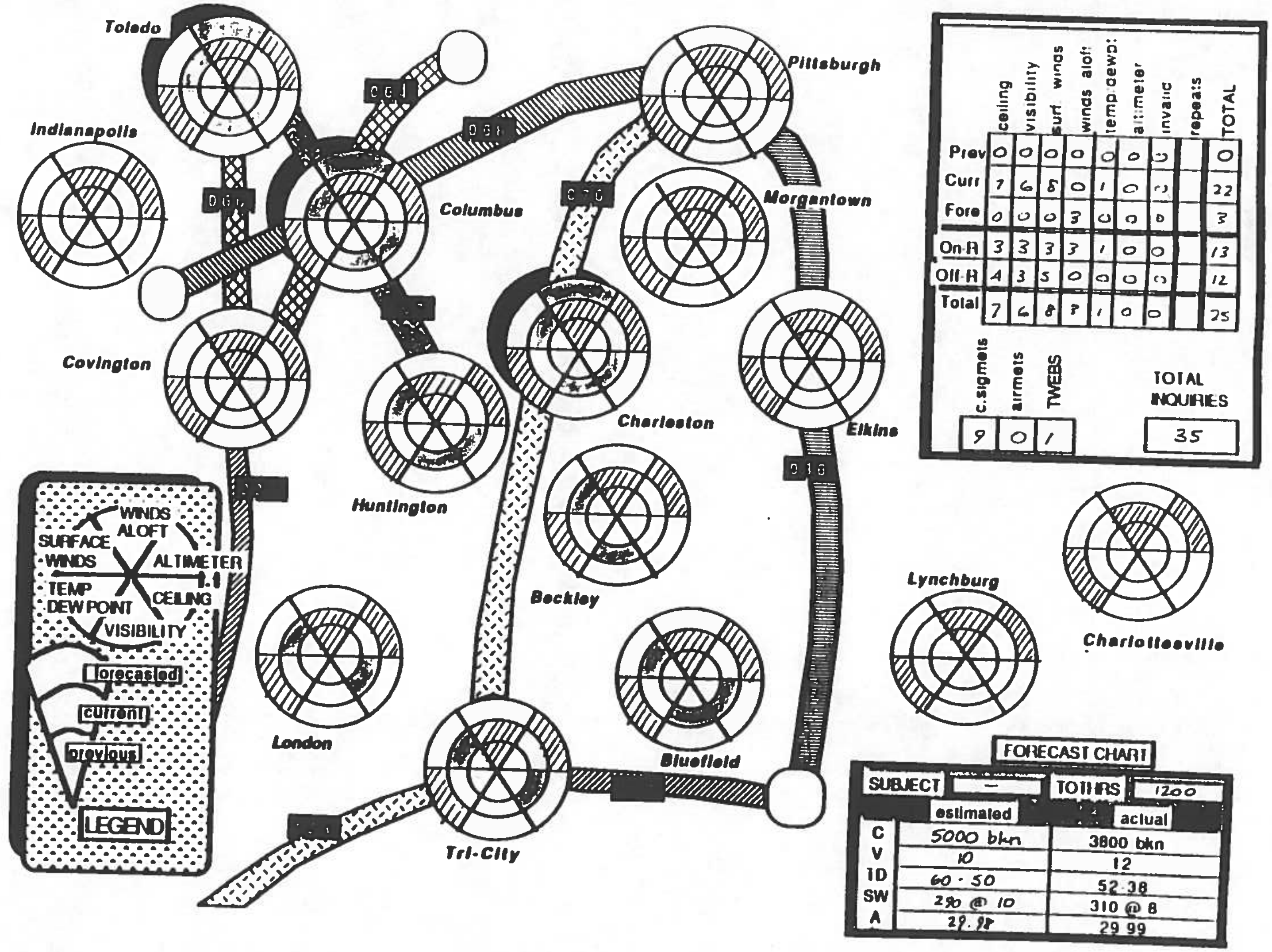


Figure 8: Graphical representation and descriptive statistical summary of a PFSS subject's weather information inquiries.