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Summary

A study of intelligent guidance and control concepts for protecting against the adverse effects of wind shear during aircraft takeoffs and landings has been begun. The principal objectives are to develop methods for assessing the likelihood of wind shear encounter, for deciding what flight path to pursue, and for using the aircraft's full potential for combating wind shear. This study requires the definition of both deterministic and statistical techniques for fusing internal and external information, for making "go/no-go" decisions, and for generating commands to the aircraft's cockpit displays and autopilot for both manually controlled and automatic flight.

The program has begun with the development of a real-time expert system for pilot aiding that is based on the results of the FAA Windshear Training Aids Program. A two-volume manual that presents an overview, pilot guide, training program, and substantiating data provides guidelines for this initial development. The Expert System to Avoid Wind Shear (ESAWS) currently contains over 140 rules and is coded in the LISP programming language for implementation on a Symbolics 3670 LISP Machine.

This six-month progress report includes a brief introduction to ESAWS, as well as numerous appendices that describe the logic and code of the program in considerable detail. This development is especially fluid, and these materials are presented as evidence of progress made to date rather than as documentation of a working system; consequently, the logic is subject to further change, and no guarantee is made that the submitted coding is "bug-free" or even representative of ESAWS's final structure. Program logic is being developed by Professor Stengel and graduate student Alexander Stratton; Mr. Stratton has been responsible for all program coding and has authored a considerable portion of this progress report.

Table of Contents

1. LISP Implementation of Wind Shear Expert System

Wind Shear Expert System software has been written in Common LISP for a Symbolics 3670 LISP machine, using elementary list operations. Execution of the system and input/output operations are carried out in the standard LISP environment, using a "LISP Listener". Currently, the user acts as both flight crew and simulation environment; additions planned for the system, including a FORTRAN aircraft simulation, will add realism for system development and demonstration and will complete the model of flight crew decision-making and control presented in the FAA Windshear Training Aid.

Software for the Wind Shear Expert System consists of parameter definitions (Appendix A), rule bases (Appendix B), and functional LISP procedures (Appendices C to F). Rule bases are defined as LISP variables using the function "*defvar*". A rule base is simply a list of related rules (see Appendix B for English translations of rules). In the code, each rule is a list containing seven elements. The first element of a rule is the rule's name. Two other elements, called the"if-part" or *premise* and the "then-part" or *consequent*, are executable LISP statements that are evaluated if the rule is tried. Two of the elements are character strings that give an English translation of the rule; these strings are typed to a LISP Listener if the premise is evaluated and does not return "*NIL*".

The two remaining elements of a rule are lists of parameters. One list consists of the variables whose values are set if the consequent is evaluated. This list is a "flag" for a goal-directed search procedure. The other parameter list consists of variables that must have values for the premise to be evaluated; this list is a "flag" for a forward-chaining procedure and is not presently used. Editing features of the Symbolics machine enable nested lists such as the rule bases to be easily entered into files in a neat format that simplifies identification and later modification. Grouping the rules into separate rule bases breaks down the expert system functions into subfunctions in a natural manner.

Expert system parameters store data for the expert system, and are objects of search procedures (see Appendix A). Parameters have been defined using "*defvar*", and are bound using "*setq*" in rules and functional procedures. Some parameters are additionally given property values, to expand them to vectors. Some parameters have been grouped to aid variable binding. With hindsight, this has worked well for internal parameters that are given values during search, but it is cumbersome for representing other parameters external to the system. Redefinition of external data, perhaps using "*defflavor*" and "*make-instance*", may have advantages and is being considered.

Functional LISP procedures retrieve rule elements, evaluate rules, conduct goal-directed searches, and bind variables. They are defined using "*defun*" and are called from a LISP Listener or from within the rule bases. The goal-directed search procedure "*get-value-of*" is currently the only search procedure being used, although other procedures have been written. "*Get-value-of*" is called with a goal parameter and a rule base as arguments. It searches the rule base for rules that have a "flag" indicating they can set the value of the goal parameter and tries them usingthe procedure "tryrule". "*Get-value-of*" is called to begin execution of the expert system and is called frequently within the rule base, resulting in backward-chaining. The development of LISP procedures is essentially complete; however, FORTRAN procedures for simulating, estimating, and controlling aircraft and systems must be implemented. The Symbolics LISP machine permits interaction of LISP and FORTRAN procedures, making the demonstration of FAA Windshear Training Aid procedures and other algorithms possible.

The expert system may be called by a LISP Listener or by a FORTRAN program; the former method has been used up until now. The expert system presently sends documentation to a LISP Listener while it is operating. It prompts the user for inputs through a LISP Listener; the user can give additional inputs by temporarily halting execution of the expert system. This interim arrangement has been adequate for development thus far, but it does not adequately demonstrate the interaction of the expert system with its operating environment.

To adequately demonstrate the system and aid further development, a simulation environment must be implemented that includes aircraft, on-board systems, ground-based information sources, and "mother nature". Modelling events outside of the system adds autonomy and realism to the simulation. To better understand the interaction of the expert system with its environment, a multi-window display must be developed that gives information about several aspects of the system and its environment simultaneously. The Symbolics machine has programs that are intended to streamline the development of multi-window displays; our intention is to quickly develop a simple means of presenting a variety of information.

2. Search Procedures for Wind Shear Expert System

The Wind Shear Expert System, in its current state, is principally a model of pilot and crew decision-making and control, as described in the FAA Windshear Training Aid. The four primary functions of the system are:

1. MONITORING -- Observe sensors, receive reports, alerts, warnings

2. ASSESSMENT -- Detect wind shear encounters, determine if there are signs of wind shear, and if it is safe to continue

3. PLANNING -- Determine what actions and precautions are taken

4. ACTION -- In automatic mode, execute standard, recovery, and go-around procedures; in semi-automatic mode, issue commands to flight directors

These functions are performed as side effects of a goal-directed search for parameter values in a set of rules. A rule, in the context of this report, is an IF-THEN statement; a list of the 141 rules implemented on a Symbolics 3670 LISP machine is enclosed (see Appendix B). A search procedure is simply a process of "trying" rules in a selective fashion. "Trying" a rule means that the premise of a rule is examined to determine its truth or falsehood, and the consequent is examined if the premise is true. Often the consequent is a direction to perform some action or procedure. Typically, the value of a parameter is set in the consequent. The search procedure is given a goal parameter, it finds rules that have consequents that set the value of the goal parameter, and it tries them sequentially, stopping when a rule is tried whose premise is true. If another parameter, whose value has not been determined, is encountered in a rule's premise, that parameter becomes the new goal parameter and a new search commences for the value of that parameter. If none of the rules capable of setting a goal parameter have premises that are true, the user is asked to give a value for the parameter in question. This enables the expert system to be tested with an incomplete rule base.

To demonstrate the actions of the search procedure, consider the following example. The expert system is invoked periodically from a simulation by directing the search procedure to get a value for the parameter "*RBC-search-complete*". Turning to the section "Parameters for Wind Shear Expert System", we find that "*RBC-search-complete*" is set in the EXECUTIVE rule base. Now turning to Appendix B, we find two rules that can set this parameter:

> "IF the mission phase is not landed,
> THEN we must complete executive procedures,
> and the rule-based controller search is not complete.
>
> IF the mission phase is landed,
> THEN the rule-based controller search is complete."

Trying the first rule, we must consider the truth or falsehood of the expression, "the mission phase is not landed". To know this, we must find out what the mission phase is. Turning to the list of parameters, we find a parameter "*mission-phase*" that is set in the MISSION PHASE rule base. The rules within the MISSION PHASE rule base are tried next. When the mission phase has been determined, we return to considering the truth or falsehood of the first premise. If, for example, we determined that the mission phase was not "*landed*", we would then consider the consequent of the first rule, "we must complete executive procedures, and the rule-based controller search is not complete." The first part of the consequent is actually a call to the search procedure (rules were translated into English to facilitate readability; regrettably, this can make it more difficult to follow the search process), to get a value for the parameter "*executive-search-complete*". Once this search is complete, the parameter "*RBC-search-complete*" is set to NIL and the top-level search is finished.

3. Plans for Improvement of Wind Shear Expert System

The Wind Shear Expert System has developed primarily from the top level downward, branching out as the number of rules increases. This approach, one of the advantages of the expert system paradigm for control system development, tends to leave open-ended parameters on the lowest level. The material enclosed does not represent a complete rule-based controller and should be viewed as an interim development. Currently, there are a few parameters that do not have any rules or procedures to give them values. Additionally, there are procedures called by the expert system that are not yet implemented as software. Briefly, a list of major items still needing attention includes:

- Simulation environment
- Improved user interface
- Improved relevance information and testing
- Control system architecture
- Target trajectory generation
- Prediction procedures for aircraft and weather
- Rules to interface with new procedures

Addition of the above items should complete an expert system model of the FAA Windshear Training Aid and provide the basis for further development of a rule-based pilot aid for wind shear survival.

Appendix A

Parameters for Wind Shear Expert System

Below is a list of the current parameters contained in the wind shear expert system. Parameters have been classified according to how they are given values. These classifications are:

INTERNAL (I) -	Parameter is internal to the expert system and gets its value from a goal-directed search procedure.
PRESET (Pr) -	Parameter is set by flight crew, through the pilot interface.
STATE VARIABLE (S) -	Parameter is a state estimate, set by a state estimator.
OUTSIDE (O) -	Parameter's value is given to the program by an outside interface.

1. Internal Parameters

PARAMETER NAME	TYPE	VALUES (INTERPRETED)
EXECUTIVE RULEBASE sets:		
RBC-search-complete	I	T (we should keep searching) NIL (we should stop searching)
executive-procedures-complete	I	T (procedures are not complete)

MISSION PHASE RULEBASE sets:

mission-phase	I	PREFLIGHT-DECISION stage TAKEOFF (pilot committed) CLIMBOUT (off the ground) CRUISE (takeoff completed) PRELANDING-DECISION stage APPROACH (pilot committed) FLARE (below flare height) LANDING (on runway) LANDED (operations completed)
current-airport	Pr/I	[any airport name] (nearest airport)
are-we-committed	Pr/I	T (flight crew committed to takeoff/land) NIL (flight crew not committed)

WINDSHEAR RULEBASE sets:

microburst-encounter	I	T (we are having a microburst encounter) NIL (no microburst encounter)

DETECTION RULEBASE sets:

detection-complete	I	T (search of detection rule base completed)

DEVIATION RULEBASE sets:

aircraft-response	I	[list] contains one or more of: MICROBURST (significant deviations): ABOVE-TARGET-AIRSPEED BELOW-TARGET-AIRSPEED ABOVE-TARGET-VERTICAL-SPEED BELOW-TARGET-VERTICAL-SPEED ABOVE-TARGET-PITCH-ATTITUDE BELOW-TARGET-PITCH-ATTITUDE ABOVE-TARGET-GLIDESLOPE-DEV. BELOW-TARGET-GLIDESLOPE-DEV. ABOVE-TARGET-THROTTLE-POS. BELOW-TARGET-THROTTLE-POS.
target-airspeed	I	[numerical] (knots)
airspeed-deviation	I	[numerical] (deviation from target, knots)
target-vertical-speed	I	[numerical] (ft/min)
vertical-speed-deviation	I	[numerical] (deviation from target, ft/min)
target-pitch-attitude	I	[numerical] (deg)
attitude-deviation	I	[numerical] (deviation from target, deg)
target-glideslope-displacement	I	[numerical] (dots)

glideslope-deviation	I	[numerical] (deviation from target, dots)
throttle-deviation	I	[numerical] (deviation from target, %)

COMMUNICATION RULEBASE sets:

new-information-received	I	T (new information is received) NIL (no new info received)
incident-reported	I	T (if there was an incident, it's reported)
tower-informed-goa	I	T (tower informed of intent to go-around) NIL (tower not yet informed of intent)
tower-informed-delay	I	T (tower informed of intent to delay) NIL (tower not yet informed)

ACTION RULEBASE sets:

actions-taken	I	T (actions have been taken)

STANDARD PROCEDURES RULEBASE sets:

standard-procedures-complete	I	T (standard procedures are now complete)
configuration-set-for-takeoff	I	T (configuration is set for takeoff) NIL (configuration not set for takeoff)
configuration-set-for-landing	I	T (configuration is set for landing) NIL (configuration is not set for landing)

glideslope-established	Pr/I	T (glideslope has been established) NIL (glideslope is not yet established)

RECOVERY PROCEDURES RULEBASE sets:

recovery-procedures-complete	I	T (recovery procedures are now complete)

GO-AROUND PROCEDURES RULEBASE sets:

go-around-procedures-complete	I	T (go-around procedures are complete)

DELAY PROCEDURES RULEBASE sets:

delay-procedures-complete	I	T (delay procedures are complete)

PLANNING RULEBASE sets:

recommended-procedures	I	T (mission plan is now updated)

RUNWAY SELECTION RULEBASE sets:

recommended-runway	I	[runway id] (new runway selection)

SPEED SELECTION RULEBASE sets:

recommended-Vr	I	[numerical] (precautionary rotation speed)
recommended-Va	I	[numerical] (precautionary approach speed)

FLAP SELECTION RULEBASE sets:

recommended-flaps	I	[numerical] (precautionary flap setting)

ASSESSMENT RULEBASE sets:

recommended-action	I	CONTINUE operations as planned CONSIDER-PRECAUTIONS DELAY-ALTER-ABORT EXECUTE-RECOVERY procedures

RISK RULEBASE sets:

risk	I	[numerical] (overall risk factor for wind shear - values correspond to: 0 - no probability of wind shear 1 - low probability of wind shear 2 - medium probability of shear 3 or greater - high probability

WEATHER RISK RULEBASE sets:

weather	I	[numerical] (risk of wind shear derived from weather reports,e.g., SIGMETs, same severity scale as "risk")
suspected-runways	I	[list of runway id's] (runways reported or observed to have conditions suggesting wind shear)

LOCALIZED WINDS RULEBASE sets:

localized-strong-winds	I	[numerical] values correspond to: 0 - no indications of wind shear 1 - indications, off the flight path 2 - indications, convecting onto path 3 - indications of wind shear on path

HEAVY PRECIPITATION RULEBASE sets:

heavy-precipitation	I	[numerical] (same scale as localized-strong winds)

RAINSHOWER RULEBASE sets:

rainshower	I	[numerical] (same scale as localized-strong winds)

LIGHTNING RULEBASE sets:

lightning	I	[numerical] (same scale as localized-strong winds)

VIRGA RULEBASE sets:

virga	I	[numerical] (same scale as localized-strong winds)

TURBULENCE RULEBASE sets:

turbulence	I	[numerical] (moderate or greater - same scale as localized-strong-winds)

2. Preset Parameters

origin-airport	Pr	[any airport name] (origin airport)
taxi-speed-limit	Pr	[numerical] (taxi speed limit, knots)
destination-airport	Pr	[any airport name] (next destination)
flare-agl	Pr	[numerical] (flare altitude, ft)
Vr	Pr	[numerical] (standard rotation speed for this configuration, knots)
Va	Pr	[numerical] (standard approach speed for this configuration, knots)
critical-agl	Pr	[numerical] (height below which ground contact is major concern, ft)
aircraft-type	Pr	[any type in PWG] (type of aircraft)
V1	Pr	[numerical] (abort groundspeed, knots)
suitable-runways	Pr	[list of runways] (suitable runways)
Vr-field-length-limit	Pr	[numerical] (field length limit rotation speed for this configuration, knots)

3. State Variables

agl	S	[numerical] (alt. above ground, ft)

airspeed	S	[numerical] (current airspeed, ft)
vertical-speed	S	[numerical] (ft/min)
pitch-attitude	S	[numerical] (deg)
glideslope-displacement	S	[numerical] (dots)
groundspeed	S	[numerical] (groundspeed, knots)
runway-remaining	S	[numerical] (current est. of available runway, ft)

4. Outside Parameters

wind shear-alert	O	T (on-board wind shear detection sys. alert) NIL (no on-board wind shear det. sys. alert)
traffic	O	T (threatening traffic ahead) NIL (no threatening traffic ahead)
pirep*	O	[numerical] (amount of speed lost/gained by some other flight crew, knots)
llwas*	O	[numerical] (amount of speed differential that triggered some llwas alert, knots)
forecast*	O	[list] (forecast of convective weather)
temp/dewpt-spread	O	[numerical] (degrees F)

ATIS*	O	TURBULENCE noted in report RAINSHOWERS noted in report LIGHTNING noted in report VIRGA noted in report HEAVY-PRECIPITATION noted LLWS (low-level wind shear noted)
ASWW*	O	TURBULENCE noted in report RAINSHOWERS noted in report LIGHTNING noted in report VIRGA noted in report HEAVY-PRECIPITATION noted LLWS (low-level wind shear noted)
SIGMET*	O	TURBULENCE noted in report RAINSHOWERS noted in report LIGHTNING noted in report VIRGA noted in report HEAVY-PRECIPITATION noted LLWS (low-level wind shear noted)
onboard-radar*	O	TURBULENCE observed HEAVY-PRECIPITATION observed
tower-report*	O	TURBULENCE noted by tower RAINSHOWERS noted by tower LIGHTNING noted by tower VIRGA noted by tower HEAVY-PRECIPITATION noted WINDSHEAR noted by tower
TDWR*	O	TURBULENCE noted by TDWR HEAVY-PRECIPITATION noted WINDSHEAR noted by TDWR
wind-profiler*	O	TURBULENCE detected by profiler WINDSHEAR detected by profiler

forward-looking*	O	TURBULENCE detected RAINSHOWERS detected LIGHTNING detected VIRGA detected HEAVY-PRECIPITATION detected WINDSHEAR detected
observation	O	[numerical] (phenomenon seen by flight crew on flight path, values correspond to: 0 - no suspicious phenomenon seen 1 - localized strong winds seen 2 - heavy precipitation seen 3 - rain showers seen 4 - lightning seen 5 - virga seen
LSS*	O	LIGHTNING detected by lightning sensor

* The parameter also has properties indicating airports and runways to which it pertains.

Appendix B

Rule Bases for Wind Shear Expert System

EXECUTIVE RULEBASE

IF the mission phase is not landed,
THEN we must complete executive procedures,
and the rule-based controller search is not complete.

IF the mission phase is landed,
THEN the rule-based controller search is complete.

IF the mission phase is preflight decision stage or prelanding decision stage,
THEN we must determine recommended procedures,
and executive procedures are complete.

IF the mission phase is takeoff,
or the mission phase is climbout,
or the mission phase is approach,
or the mission phase is flare,
or the mission phase is landing rollout,
THEN we must take control actions,
and executive procedures are complete.

IF the mission phase is takeoff complete,
THEN the current airport is now the destination airport,
and the pilot is not committed to land,
and executive procedures are complete.

MISSION PHASE RULEBASE

IF the current airport is the origin airport,
and our altitude(ft) is 0 feet,
and the pilot is not committed to takeoff,
THEN the mission phase is preflight decision stage.

IF the current airport is the origin airport,
    and our altitude (ft) is 0 feet,
    and the pilot is committed to takeoff,
THEN the mission phase is takeoff.

IF the current airport is the origin airport,
    and our altitude (ft) is 0 feet,
    and our airspeed (knots) is greater than the taxi speed limit (knots),
    and the flight crew has not committed to takeoff,
THEN the flight crew has passively committed to takeoff,
    and the mission phase is takeoff.

IF the current airport is the origin airport,
    and our altitude (ft) is greater than 0 feet,
    and our altitude (ft) is less than 1000 feet,
THEN the mission phase is climbout.

IF the current airport is the origin airport,
    and our altitude (ft) is greater than 1000 feet,
THEN the mission phase is takeoff complete.

IF the current airport is the destination airport,
    and our altitude (ft) is greater than 1000 feet,
    and the flight crew is not committed to land,
THEN the mission phase is prelanding decision stage.

IF the current airport is the destination airport,
    and our altitude (ft) is below 1000 feet.,
    and we are not flight crew is not committed to land,
THEN the flight crew has passively committed to land,
    and the mission phase is approach.

IF the current airport is the destination airport,
    and our altitude (ft) is less than 1000 feet,
    and our altitude (ft) is above flare altitude (ft),
    and the flight crew is committed to land,
THEN the mission phase is approach.

IF the current airport is the destination airport,
    and our altitude (ft) is below flare altitude (ft),
    and the flight crew is committed to land,
THEN the mission phase is flare.

IF the current airport is the destination airport,
and our altitude (ft) is 0 feet,
and our airspeed (knots) is above the taxi speed limit (knots),
THEN the mission phase is landing roll.

IF the current airport is the destination airport,
and our altitude (ft) is 0 feet,
and our airspeed (knots) is below the taxi speed limit (knots),
THEN the mission phase is landed.

WINDSHEAR RULEBASE

IF the search of the detection rulebase is complete,
and the aircraft trajectory is deviating significantly from the target trajectory,
THEN there is a microburst encounter.

IF a wind shear alert is sounded by an on-board wind shear detection system,
THEN there is a microburst encounter.

IF a microburst encounter has already begun,
and the aircraft trajectory is deviating somewhat from the target trajectory,
THEN there is a microburst encounter.

IF a microburst encounter has not begun,
and the aircraft trajectory is not deviating significantly from the target trajectory,
THEN there is no microburst encounter.

DETECTION RULEBASE

IF the mission phase is approach or prelanding decision stage,
THEN airspeed deviations must be monitored,
and vertical speed deviations must be monitored,
and pitch attitude deviations must be monitored,
and glideslope displacement deviations must be monitored,
and throttle position deviations must be monitored,
and the search of the detection rulebase is complete.

IF the mission phase is neither approach nor prelanding decision stage,
THEN airspeed deviations must be monitored,
and vertical speed deviations must be monitored,
and pitch attitude deviations must be monitored
and the search of the detection rulebase is complete.

DEVIATION RULEBASE

IF airspeed (knots) is below target airspeed (knots) by more than 15 knots,
THEN the aircraft is deviating significantly from the target trajectory.

IF airspeed (knots) is above target airspeed (knots) by more than 15 knots,
THEN the aircraft is deviating significantly from the target trajectory.

IF airspeed (knots) is below target airspeed (knots) by between 5 and 15 knots,
THEN the aircraft is deviating somewhat from the target trajectory,
and the type of deviation includes "below target airspeed".

IF airspeed (knots) is above target airspeed (knots) by between 5 and 15 knots,
THEN the aircraft is deviating somewhat from the target trajectory,
and the type of deviation includes "above target airspeed".

IF vertical speed (ft/min) is below target vertical speed (ft/min) by more than 500 ft/min,
THEN the aircraft is deviating significantly from the target trajectory.

IF vertical speed (ft/min) is above target vertical speed (ft/min) by more than 500 ft./min.,
THEN the aircraft is deviating significantly from the target trajectory.

IF vertical speed (ft/min) is below target vertical speed (ft/min) by between 200 and 500 ft./min.,
THEN the aircraft is deviating somewhat from the target trajectory,
and the type of deviation includes "below target vertical speed".

IF vertical speed (ft/min) is above target vertical speed (ft/min) by between 200 and 500 ft./min.,
THEN the aircraft is deviating somewhat from the target trajectory,
and the type of deviation includes "above target vertical speed".

IF pitch attitude (deg) is below target pitch attitude (deg) by more than 5 degrees,
THEN the aircraft is deviating significantly from the target trajectory.

IF pitch attitude (deg) is above target pitch attitude (deg) by more than 5 degrees,
THEN the aircraft is deviating significantly from the target trajectory.

IF pitch attitude (deg) is below target pitch attitude (deg) by between 2 and 5 degrees,
THEN the aircraft is deviating somewhat from the target trajectory,
and the type of deviation includes "below target pitch attitude".

IF pitch attitude (deg) is above target pitch attitude (deg) by between 2 and 5 degrees,
THEN the aircraft is deviating somewhat from the target trajectory,
and the type of deviation includes "above target pitch attitude".

IF glideslope displacement (dots) is below target glideslope displacement (dots) by more than 1 dot,
THEN the aircraft is deviating significantly from the target trajectory.

IF glideslope displacement (dots) is above target glideslope displacement (dots) by more than 1 dot,
THEN the aircraft is deviating significantly from the target trajectory.

IF glideslope displacement (dots) is below target glideslope displacement (dots) by between 0.4 and 1 dot,
THEN the aircraft is deviating somewhat from the target trajectory,
and the type of deviation includes "below target glideslope displacement".

IF glideslope displacement (dots) is above target glideslope displacement (dots) by between 0.4 and 1 dot,
THEN the aircraft is deviating somewhat from the target trajectory,
and the type of deviation includes "below target glideslope displacement".

COMMUNICATION RULEBASE

IF the outside interface indicates new information,
THEN new information has been received.

IF the outside interface does not indicate new information,
THEN no new information has been received.

IF there was a microburst encounter,
and there is no longer a microburst encounter,
THEN the incident must be recorded now.

IF the above premise is not true,
THEN there is no need to report an incident.

ACTION RULEBASE

IF we are having a microburst encounter,
and guidance mode is automatic,
THEN recovery procedures must be completed,
and control actions are taken.

IF we are not having a microburst encounter,
and guidance mode is automatic,
and recommended procedures have been determined,
and standard procedures are recommended,
THEN standard procedures must be completed,
and control actions are taken.

IF we are not having a microburst encounter,
and guidance mode is automatic,
and go-around procedures are recommended,
THEN go-around procedures must be completed,
and control actions are taken.

IF we are not having a microburst encounter,
and delaying procedures are recommended,
THEN delaying procedures must be completed,
and control actions are taken.

IF we are having a microburst encounter,
and guidance mode is semi-automatic,
THEN semi-automatic recovery procedures must be completed,
and control actions are taken.

IF we are not having a microburst encounter,
and guidance mode is semi-automatic,
and recommended procedures have been determined,
and standard procedures are recommended,
THEN semi-automatic standard procedures must be completed,
and control actions are taken.

IF we are not having a microburst encounter,
and guidance mode is semi-automatic,
and go-around procedures are recommended,
THEN semi-automatic go-around procedures must be completed,
and control actions are taken.

STANDARD PROCEDURES RULEBASE

IF the mission phase is takeoff,
and the configuration has not been set for the takeoff roll,
THEN the configuration must be set for the takeoff roll,
and standard procedures are complete.

IF the mission phase is takeoff,
and the airspeed (knots) is below Vr (knots),
THEN takeoff control laws must be executed,
and standard procedures are complete.

IF the mission phase is takeoff,
and the airspeed (knots) is above Vr (knots),
THEN rotation control laws must be executed,
and standard procedures are complete.

IF the mission phase is climbout,
THEN climbout control laws must be executed,
and standard procedures are complete.

IF the mission phase is approach,
and the configuration has not been set for landing,
THEN the configuration must be set for landing,
and standard procedures are complete.

IF the mission phase is approach,
and the glideslope has not been established,
THEN we must complete procedures to establish the glideslope,
and standard procedures are complete.

IF the mission phase is approach,
and the glideslope has been established,
THEN approach control laws must be executed,
and standard procedures are complete.

IF the mission phase is flare,
THEN flare control laws must be executed,
and standard procedures are complete.

IF the mission phase is landing roll,
THEN landing control laws must be executed,
and standard procedures are complete.

RECOVERY PROCEDURES RULEBASE

IF the altitude (ft) is above critical (ft),
and the aircraft type is an L-1011,
and the mission phase is takeoff,
THEN controls must be configured for a recovery,
and the desired thrust setting is maximum rated,
and the desired pitch attitude (deg) is 17.5 degrees,
and recovery procedures are complete.

IF the altitude is above critical,
and the aircraft is not an L-1011,
or the aircraft is an L-1011 and the mission phase is approach,
THEN controls must be configured for a recovery,
and the desired thrust setting is maximum rated,
and the desired pitch attitude (deg) is 15 degrees,
and recovery procedures are complete.

IF the altitude is below critical,
and the mission phase is not takeoff or landed,
THEN controls must be configured for a recovery,
and the desired thrust setting is overboost,
and the desired pitch attitude (deg) is 20 degrees,
and recovery procedures are complete.

IF the mission phase is takeoff,
and the groundspeed (knots) is less than V1 (knots),
THEN controls must be configured for takeoff abort,
and the desired thrust setting is reverse,
and recovery procedures are complete.

IF the mission phase is takeoff,
and the groundspeed (knots) is greater than V1 (knots),
and the airspeed (knots) is less than Vr (knots),
and the runway remaining (ft) is greater than 2000 feet,
THEN controls must be configured for takeoff,
and the desired thrust setting is maximum rated,
and recovery procedures are complete.

IF the mission phase is takeoff,
and the airspeed (knots) is greater than Vr (knots),
THEN controls must be configured for a recovery,
and the desired thrust setting is maximum rated,
and the desired pitch attitude (deg) is 15 degrees,
and recovery procedures are complete.

IF the mission phase is takeoff,
and the runway remaining (ft) is less than 2000 feet,
THEN controls must be configured for a recovery,
and the desired thrust setting is maximum rated,
and the desired pitch attitude (deg) is 15 degrees,
and recovery procedures are complete.

GO-AROUND PROCEDURES RULEBASE

IF the tower has not been informed of our intent to go-around,
and there is no traffic in our way,
THEN go-around control laws must be executed,
and the tower must be informed of our intent to go-around,
and go-around procedures are complete.

IF the tower has not been informed of our intent to go-around,
and there is traffic in our way,
and our altitude is above critical,
THEN approach control laws must be executed,
and the tower must be informed of our intent to go-around,
and go-around procedures are complete.

IF the tower has not been informed of our intent to go-around,
and there is traffic in our way,
and our altitude is below critical,
THEN go-around control laws must be executed,
and the tower must be informed of our intent to go-around,
and go-around procedures are complete.

IF the tower has been informed of our intent to go-around,
THEN go-around control laws are in effect,
and go-around procedures are complete.

DELAY PROCEDURES RULEBASE

IF the tower has not been informed of our intent to delay,
and our ETA at the airport (min) is less than 20 minutes,
THEN the tower must be informed of our intent to delay,
and delay procedures are complete.

IF the tower has been informed of our intent to delay,
THEN delay procedures are complete.

PLANNING RULEBASE

IF the recommended action is to delay, alter, or abort,
and the mission phase is preflight decision stage,
or the mission phase is prelanding decision stage,
THEN delaying procedures are recommended.

IF the recommended action is to delay, alter, or abort,
and the mission phase is takeoff,
or the mission phase is climbout,
or the mission phase is flare,
or the mission phase is landing roll,
THEN standard procedures are recommended.

IF the recommended action is to delay, alter, or abort,
and the mission phase is approach,
and the altitude (ft) is above decision height (ft),
THEN go-around procedures are recommended.

IF the recommended action is to delay, alter, or abort,
and the mission phase is approach,
and the altitude (ft) is below decision height (ft),
THEN standard procedures are recommended.

IF the recommended action is to take precautions,
and precautions have already been taken, or the flight crew has rejected precautions,
THEN standard procedures are recommended.

IF the recommended action is to take precautions,
and the mission phase is preflight decision stage,
THEN we must determine the best runway,
and we must determine the best flap setting (deg),
and we must determine the best Vr (knots),
and the precautions must be accepted or rejected by the flight crew.

IF the recommended action is to take precautions,
and the mission phase is prelanding decision stage,
THEN we must stabilize approach at 1000 feet,
and we must determine the best flap setting (deg),
and we must determine the best Va (knots),
and the precautions must be accepted or rejected by the flight crew.

IF the recommended action is to take precautions,
and the mission phase is not preflight or prelanding decision stage,
THEN standard procedures are recommended.

IF the recommended action is to continue,
and the mission phase is approach,
and altitude (ft) is below critical altitude (ft),
and the glideslope has not been established,
THEN go-around procedures are recommended.

IF the recommended action is to continue,
and the mission phase is approach,
and the altitude (ft) is above the decision altitude (ft),
and the weighted norm of the 2-sigma touchdown dispersion (ft) is greater than the dispersion tolerance (ft),
THEN go-around procedures are recommended.

IF the recommended action is to continue,
and the above premises are not true,
THEN standard procedures are recommended.

RUNWAY RULEBASE

IF some of the suitable runways are suspected of wind shear,
THEN the best runway is the longest of the suitable runways not suspected.

IF none of the suitable runways are suspected of wind shear,
THEN the best runway is the longest of the suitable runways.

SPEED RULEBASE

IF field-length-limit Vr (knots) is greater than the standard Vr (knots),
and is less than 20 knots greater than the standard Vr (knots),
THEN the best Vr (knots) is the field-length-limit Vr (knots).

IF field-length-limit Vr (knots) is more than 20 knots greater than the standard Vr (knots),
THEN the best Vr (knots) is 20 knots plus the standard Vr (knots).

IF this rule is fired,
THEN the best Va (knots) is 20 knots plus the standard Va (knots).

FLAP RULEBASE

IF the mission phase is preflight decision stage,
  and the aircraft type is a B727,
THEN the best flap setting (deg) is 15 degrees.

(12 more rules like the above, for different A/C configurations)

ASSESSMENT RULEBASE

IF there is no new information received,
  or new information has been received,
  and all of the rules in the risk rulebase have been tried,
  and the overall risk factor is 0 (none),
THEN the recommended action is to continue.

IF the overall risk factor is 3 or greater (high),
THEN the recommended action is to delay, alter, or abort.

IF the overall risk factor is 2 (medium),
THEN the recommended action is to consider precautions.

IF the overall risk factor is 1 (low),
THEN the recommended action is to continue.

RISK RULEBASE

IF this rule is fired,
THEN the overall risk factor is set to 0
  and the list of causes is set to nil.

IF there is an indication of convective weather on our flight path,
THEN all of the rules in the weather risk rulebase must be tried,
  and the weather risk factor is added to the overall risk factor,
  and weather is added to the list of causes.

IF there is a pilot report of speed loss (knots) less than 15 knots (but nonzero),
    and this report is relevant to our current flight path,
THEN the overall risk factor is increased by 2,
    and the current runway is added to the list of suspected runways,
    and the pirep is added to the list of causes.

IF there is a pilot report of speed loss (knots) greater than 15 knots,
    and this report is relevant to our current flight path,
THEN the overall risk factor is increased by 3,
    and the current runway is added to the list of suspected runways,
    and the pirep is added to the list of causes.

IF there is a LLWAS alert with a speed differential (knots) less than 20 knots,
    and this alert is relevant to our current flight path,
THEN the overall risk factor is increased by 2,
    and the current runway is added to the list of suspected runways,
    and the LLWAS alert is added to the list of causes.

IF there is a LLWAS alert with a speed differential (knots) greater than 20 knots,
    and this alert is relevant to our current flight path,
THEN the overall risk factor is increased by 3,
    and the current runway is added to the list of suspected runways,
    and the LLWAS alert is added to the list of causes.

IF there is a pilot report of speed loss (knots) less than 15 knots (but nonzero),
    and this report is near but not on our current flight path,
THEN the overall risk factor is increased by 1,
    and the current runway is added to the list of suspected runways,
    and the pirep is added to the list of causes.

IF there is a pilot report of speed loss (knots) greater than 15 knots,
    and this report is near but not on our current flight path,
THEN the overall risk factor is increased by 2,
    and the current runway is added to the list of suspected runways,
    and the pirep is added to the list of causes.

IF there is a LLWAS alert with a speed differential (knots) less than 20 knots,
    and this alert is near but not on our current flight path,
THEN the overall risk factor is increased by 1,
    and the current runway is added to the list of suspected runways,
    and the LLWAS alert is added to the list of causes.

IF there is a LLWAS alert with a speed differential (knots) greater than 20 knots,
and this alert is near but not on our current flight path,
THEN the overall risk factor is increased by 2,
and the current runway is added to the list of suspected runways,
and the LLWAS alert is added to the list of causes.

IF there is a forecast of convective weather on our flight path,
THEN the overall risk factor is increased by 1,
and forecast is added to the list of causes.

WEATHER RISK RULEBASE

IF this rule is fired,
THEN the weather risk factor is reset to zero.

IF there are indications of localized strong winds on our flight path,
THEN the weather risk factor is increased by 3,
and the affected runways are added to the list of suspected runways.

IF there are indications of heavy precipitation on our flight path,
THEN the weather risk factor is increased by 3,
and the affected runways are added to the list of suspected runways.

IF there are indications of a rain shower on our flight path,
THEN the weather risk factor is increased by 2,
and the affected runways are added to the list of suspected runways.

IF there are indications of lightning on our flight path,
THEN the weather risk factor is increased by 2,
and the affected runways are added to the list of suspected runways.

IF there are indications of virga on our flight path,
THEN the weather risk factor is increased by 2,
and the affected runways are added to the list of suspected runways.

IF there are indications of moderate or greater turbulence on our flight path,
THEN the weather risk factor is increased by 2,
and the affected runways are added to the list of suspected runways.

IF the ATIS report indicates a temperature/dew point spread (^{0} F) greater than
30 ^{0}F,
THEN the weather risk factor is increased by 2,
and the affected runways are added to the list of suspected runways.

IF there are indications of localized strong winds near but not on our flight path,
THEN the weather risk factor is increased by 2,
and the affected runways are added to the list of suspected runways.

IF there are indications of heavy precipitation near but not on our flight path,
THEN the weather risk factor is increased by 2,
and the affected runways are added to the list of suspected runways.

IF there are indications of rain showers near but not on our flight path,
THEN the weather risk factor is increased by 1,
and the affected runways are added to the list of suspected runways.

IF there are indications of lightning near but not on our flight path,
THEN the weather risk factor is increased by 1,
and the affected runways are added to the list of suspected runways.

IF there are indications of virga near but not on our flight path,
THEN the weather risk factor is increased by 1,
and the affected runways are added to the list of suspected runways.

IF there are indications of moderate or greater turbulence near our flight path,
THEN the weather risk factor is increased by 1,
and the affected runways are added to the list of suspected runways.

LOCALIZED WINDS RULEBASE

IF ATIS information indicates low-level wind shear,
and the wind shear is on our flight path,
or an Aviation Severe Weather Watch indicates low-level wind shear,
and the wind shear is on our flight path,
or a SIGMET indicates low-level wind shear,
and the wind shear is on our flight path,
or a tower report indicates low-level wind shear,
and the wind shear is on our flight path,
or a Terminal Doppler Weather Radar indicates low-level wind shear,
and the wind shear is on our flight path,

or a wind profiler indicates low-level wind shear,
and the wind shear is on our flight path,
or a forward-looking system indicates low-level wind shear,
and the wind shear is on our flight path,
or a flight crew observation indicates low-level wind shear on our flight path,
THEN there are indications of localized strong winds on our flight path.

IF ATIS information indicates low-level wind shear,
and the wind shear is near but not on on our flight path,
or an Aviation Severe Weather Watch indicates low-level wind shear,
and the wind shear is near but not on our flight path,
or a SIGMET indicates low-level wind shear,
and the wind shear is near but not on our flight path,
or a tower report indicates low-level wind shear,
and the wind shear is near but not on our flight path,
or a Terminal Doppler Weather Radar indicates low-level wind shear,
and the wind shear is near but not on our flight path,
or a wind profiler indicates low-level wind shear,
and the wind shear is near but not on our flight path,
or a forward-looking system indicates low-level wind shear,
and the wind shear is near but not on our flight path,
or a flight crew observation indicates low-level wind shear near our flight path,
THEN there are indications of localized strong winds near our flight path.

HEAVY PRECIPITATION RULEBASE

IF ATIS information indicates heavy precipitation,
and the heavy precipitation is on our flight path,
or an Aviation Severe Weather Watch indicates heavy precipitation,
and the heavy precipitation is on our flight path,
or a SIGMET indicates heavy precipitation,
and the heavy precipitation is on our flight path,
or the on-board radar indicates heavy precipitation,
and the heavy precipitation is on our flight path,
or a tower report indicates heavy precipitation,
and the heavy precipitation is on our flight path,
or a Terminal Doppler Weather Radar indicates heavy precipitation,
and the heavy precipitation is on our flight path,
or a forward-looking system indicates heavy precipitation,
and the heavy precipitation is on our flight path,
or a flight crew observation indicates heavy precipitation on our flight path,
THEN there are indications of heavy precipitation on our flight path.

IF ATIS information indicates heavy precipitation,
and the heavy precipitation is near but not on on our flight path,
or an Aviation Severe Weather Watch indicates heavy precipitation,
and the heavy precipitation is near but not on our flight path,
or a SIGMET indicates heavy precipitation,
and the heavy precipitation is near but not on our flight path,
or the on-board radar indicates heavy precipitation,
and the heavy precipitation is near but not on our flight path,
or a tower report indicates heavy precipitation,
and the heavy precipitation is near but not on our flight path,
or a Terminal Doppler Weather Radar indicates heavy precipitation,
and the heavy precipitation is near but not on our flight path,
or a forward-looking system indicates heavy precipitation,
and the heavy precipitation is near but not on our flight path,
or a flight crew observation indicates heavy precipitation near our flight path,
THEN there are indications of heavy precipitation near our flight path.

RAINSHOWER RULEBASE

IF ATIS information indicates a rain shower,
and the rain shower is on our flight path,
or an Aviation Severe Weather Watch indicates a rain shower,
and the rain shower is on our flight path,
or a SIGMET indicates a rain shower,
and the rain shower is on our flight path,
or the on-board radar indicates a rain shower,
and the rain shower is on our flight path,
or a tower report indicates a rain shower,
and the rain shower is on our flight path,
or a Terminal Doppler Weather Radar indicates a rain shower,
and the rain shower is on our flight path,
or a forward-looking system indicates a rain shower,
and the rain shower is on our flight path,
or a flight crew observation indicates a rain shower on our flight path,
THEN there are indications of a rain shower on our flight path.

IF ATIS information indicates a rain shower,
and the rain shower is near but not on on our flight path,
or an Aviation Severe Weather Watch indicates a rain shower,
and the rain shower is near but not on our flight path,
or a SIGMET indicates a rain shower,

and the rain shower is near but not on our flight path,
or the on-board radar indicates a rain shower,
and the rain shower is near but not on our flight path,
or a tower report indicates a rain shower,
and the rain shower is near but not on our flight path,
or a Terminal Doppler Weather Radar indicates a rain shower,
and the rain shower is near but not on our flight path,
or a forward-looking system indicates a rain shower,
and the rain shower is near but not on our flight path,
or a flight crew observation indicates a rain shower near our flight path,
THEN there are indications of a rain shower near our flight path.

LIGHTNING RULEBASE

IF ATIS information indicates lightning,
and the lightning is on our flight path,
or an Aviation Severe Weather Watch indicates lightning,
and the lightning is on our flight path,
or a SIGMET indicates lightning,
and the lightning is on our flight path,
or the Lightning Sensor System indicates lightning,
and the lightning is on our flight path,
or a tower report indicates lightning,
and the lightning is on our flight path,
or a forward-looking system indicates lightning,
and the lightning is on our flight path,
or a flight crew observation indicates lightning on our flight path,
THEN there are indications of lightning on our flight path.

IF ATIS information indicates lightning,
and the lightning is near but not on on our flight path,
or an Aviation Severe Weather Watch indicates lightning,
and the lightning is near but not on our flight path,
or a SIGMET indicates lightning,
and the lightning is near but not on our flight path,
or the Lightning Sensor System indicates lightning,
and the lightning is near but not on our flight path,
or a tower report indicates lightning,
and the lightning is near but not on our flight path,
or a forward-looking system indicates lightning,
and the lightning is near but not on our flight path,
or a flight crew observation indicates lightning near our flight path,

```
THEN there are indications of lightning near our flight path.
```

VIRGA RULEBASE

```
IF ATIS information indicates virga,
        and the virga is on our flight path,
    or an Aviation Severe Weather Watch indicates virga,
        and the virga is on our flight path,
    or a SIGMET indicates virga,
        and the virga is on our flight path,
    or a tower report indicates virga,
        and the virga is on our flight path,
    or a forward-looking system indicates virga,
        and the virga is on our flight path,
    or a flight crew observation indicates virga on our flight path,
THEN there are indications of virga on our flight path.
```

```
IF ATIS information indicates virga,
        and the virga is near but not on on our flight path,
    or an Aviation Severe Weather Watch indicates virga,
        and the virga is near but not on our flight path,
    or a SIGMET indicates virga,
        and the virga is near but not on our flight path,
    or a tower report indicates virga,
        and the virga is near but not on our flight path,
    or a forward-looking system indicates virga,
        and the virga is near but not on our flight path,
    or a flight crew observation indicates virga near our flight path,
THEN there are indications of virga near our flight path.
```

TURBULENCE RULEBASE

```
IF ATIS information indicates moderate or greater turbulence,
        and the turbulence is on our flight path,
   or an Aviation Severe Weather Watch indicates moderate or greater turbulence,
        and the turbulence is on our flight path,
    or a SIGMET indicates moderate or greater turbulence,
        and the turbulence is on our flight path,
    or the on-board radar indicates turbulence,
        and the turbulence is on our flight path,
    or a tower report indicates turbulence,
```

and the turbulence is on our flight path,
or a Terminal Doppler Weather Radar indicates moderate or greater turbulence,
and the turbulence is on our flight path,
or a wind profiler indicates moderate or greater turbulence,
and the turbulence is on our flight path,
or a forward-looking system indicates moderate or greater turbulence,
and the turbulence is on our flight path,
or a flight crew observation indicates moderate or greater turbulence on our flight path,
THEN there are indications of moderate or greater turbulence on our flight path.

IF ATIS information indicates moderate or greater turbulence,
and the turbulence is near but not on on our flight path,
or an Aviation Severe Weather Watch indicates moderate or greater turbulence,
and the turbulence is near but not on our flight path,
or a SIGMET indicates moderate or greater turbulence,
and the turbulence is near but not on our flight path,
or the on-board radar indicates turbulence,
and the turbulence is near but not on our flight path,
or a tower report indicates turbulence,
and the turbulence is near but not on our flight path,
or a Terminal Doppler Weather Radar indicates moderate or greater turbulence,
and the turbulence is near but not on our flight path,
or a wind profiler indicates moderate or greater turbulence,
and the turbulence is near but not on our flight path,
or a forward-looking system indicates moderate or greater turbulence,
and the turbulence is near but not on our flight path,
or a flight crew observation indicates turbulence near our flight path,
THEN there are indications of moderate or greater turbulence near our flight path.

Appendix C

LISP Code for Rule Base Executive Functions

```
;;; -*- Mode: LISP; Syntax: Common-lisp; Package: USER; Base: 10; -*-
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
;;;;;                                                          ;;;;;
;;;;;                          EXEC                            ;;;;;
;;;;;         RULE BASE FOR WINDSHEAR RULE-BASED CONTROL       ;;;;;
;;;;;                                                          ;;;;;
;;;;;       Started by Alex Stratton on March 17, 1988         ;;;;;
;;;;;        Modified from EXEC4 starting July 6,1988          ;;;;;
;;;;;                                                          ;;;;;
;;;;;        This file contains rules for windshear RBC.       ;;;;;
;;;;;    simple search inference engine that determines        ;;;;;
;;;;;    values of variables.                                  ;;;;;
;;;;;                                                          ;;;;;
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
;;;
;;; define variables
;;;
;;; Variable EXEC-VARIABLES contains a list of the variables defined
;;; in this file.
;;;
(defvar exec-variables nil)
(setq exec-variables '(executive-procedures-complete windshear-alert exec-rules mphase-rules))
;;;
;;; variable RBC-FUNCTIONS-COMPLETE is T when we are landed, nil when we aren't
;;;
(defvar rbc-functions-complete)
;;;
;;; variable EXECUTIVE-PROCEDURES-COMPLETE is set when the executive functions are complete.
;;;
(defvar executive-procedures-complete nil)
;;;
;;; variable ARE-WE-COMMITTED is set to T by the pilot
;;;
(defvar are-we-committed nil)
;;;
;;; variable MICROBURST-ENCOUNTER can have values t or nil
;;;
(defvar microburst-encounter nil)
;;;
;;; variable NEW-INFORMATION-RECEIVED can be t or nil
;;;
(defvar new-information-received nil)
;;;
;;; variable RECOMMENDED-ACTION can be continue, take-precautions,
;;; avoid-windshear and execute-recovery
;;;
(defvar recommended-action 'continue)
;;;
(defvar recommended-procedures)
;;;
;;; variable INCIDENT-REPORTED can have values t and nil
;;;
(defvar incident-reported nil)
;;;
;;;   Rules to use in testing hypotheses
;;;
;;;   New format is:
;;;     (rulename if-doc
;;;               if-part   if-vars
;;;               then-doc
```

ORIGINAL PAGE IS
OF POOR QUALITY

```
;;;                 then-part then-vars)
;;;
(defvar exec-rules nil)
(setq exec-rules '(
                   (exec1 "EXECUTIVE: Terminal operations are not complete, "
                          (and (get-value-of 'mission-phase mphase-rules)
                               (neq mission-phase 'landed))          'mission-phase
                          "so we will complete executive procedures. "
                          (and (get-value-of 'executive-procedures-complete exec-rules)
                               (setq rbc-functions-complete nil))          'rbc-functions-complete)

                   (exec2 "EXECUTIVE: We have completed terminal operations, "
                          (eq mission-phase 'landed)                 'mission-phase
                          "so we should stop searching."
                          (setq rbc-functions-complete t)                 'rbc-functions-complete)

                   (exec3 "EXECUTIVE: We are approaching a decision point, and have not encountered a microburst, "
                          (or (eq mission-phase 'preflight-decision)
                              (and (eq mission-phase 'prelanding-decision)
                                   (get-value-of 'microburst-encounter windshear-rules)
                                   (neq microburst-detected t)))          'mission-phase
                          "so we must determine the recommended procedures."
                          (and (get-value-of 'recommended-procedures planning-rules)
                               (get-value-of 'incident-reported comm-rules)) 'executive-procedures-complete)

                   (exec4 "EXECUTIVE: We are completing a terminal operation, "
                          (or (eq mission-phase 'takeoff)
                              (eq mission-phase 'climbout)

                              (eq mission-phase 'approach)
                              (eq mission-phase 'flare)
                              (eq mission-phase 'landing-rollout))        'mission-phase
                          "so we must take the proper actions to complete the operation."
                          (and (get-value-of 'actions-taken action-rules)
                               (get-value-of 'incident-reported comm-rules)) 'executive-procedures-complete)

                   (exec5 "EXECUTIVE: The mission phase is takeoff complete, "
                          (eq mission-phase 'takeoff-complete)            'mission-phase
                          "so we must now consider landing operations."
                          (and (setq current-airport destination-airport)
                               (setq are-we-committed nil))               'executive-procedures-complete)
                   ))
;;;;;;;;;;;;;;;;;;;; mphase-rules ;;;;;;;;;;;;;;;;;;;;;;;;
;     These rules determine the mission-phase
;
(defvar mphase-rules)
(setq mphase-rules   '(
                       (mphase1    "          MONITOR: We are near the origin airport, on the ground, not committed to takeoff, "
                                   (and (eq current-airport origin-airport)
                                        (eq agl 0)
                                        (eq are-we-committed nil))          '(current-airport origin-airport)
                                   "          so the mission phase is preflight decision stage."
                                   (setq mission-phase 'preflight-decision)      'mission-phase)

                       (mphase2    "          MONITOR: We are near the origin airport, on the ground, committed to takeoff, "
                                   (and (eq current-airport origin-airport)
                                        (eq agl 0)
                                        (eq are-we-committed t))            '(current-airport origin-airport)
                                   "          so the mission phase is takeoff. "
                                   (setq mission-phase 'takeoff)                 'mission-phase)
```

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OF POOR QUALITY

```
(mphase3    "          MONITOR: We are near the origin airport, are above taxi speed limit, not committed, "
            (and (eq current-airport destination-airport)
                 (> airspeed taxi-speed-limit)
                 (eq are-we-committed nil))                '(current-airport destination-airport)
            "          so we are passively committed to takeoff, and the mission phase is takeoff."
            (and (setq are-we-committed t)
                 (setq mission-phase 'takeoff))           'mission-phase)

(mphase4    "          MONITOR: We are near the origin airport, and in the air,"
            (and (eq current-airport origin-airport)
                 (> agl 0)
                 (< agl 1000))                              '(current-airport origin-airport)
            "          so the mission phase is climbout. "
            (setq mission-phase 'climbout)                  'mission-phase)

(mphase5    "          MONITOR: We are above 1000 feet AGL, "
            (and (eq current-airport origin-airport)
                 (> agl 1000))                             '(current-airport origin-airport)
            "          so the mission-phase is takeoff complete."
            (and (setq mission-phase 'takeoff-complete))   'mission-phase)

(mphase6    "          MONITOR: We are above decision altitude, not committed to land, "
            (and (eq current-airport destination-airport)
                 (> agl decision-agl)
                 (eq are-we-committed nil))                '(current-airport destination-airport)
            "          so the mission-phase is the prelanding decision stage."
            (setq mission-phase 'prelanding-decision)      'mission-phase)

(mphase7    "          MONITOR: We have selected the destination, are below 1000 feet, not committed, "
            (and (eq current-airport destination-airport)
                 (< agl 1000)
                 (eq are-we-committed nil))                '(current-airport destination-airport)
            "          so we are passively committed to land, and the mission phase is approach."
            (and (setq are-we-committed t)
                 (setq mission-phase 'approach))           'mission-phase)

(mphase8    "          MONITOR: We are near the destination airport, above flare height, committed to land, "
            (and (eq current-airport destination-airport)
                 (> agl flare-agl)
                 (eq are-we-committed t))                  '(current-airport origin-airport)
            "          so the mission phase is approach."
            (setq mission-phase 'approach)                 'mission-phase)

(mphase9    "          MONITOR: We are near the destination airport, below flare height, committed to land, "
            (and (eq current-airport destination-airport)
                 (< agl flare-agl)
                 (eq are-we-committed t))                  '(current-airport origin-airport)
            "          so the mission phase is flare."
            (setq mission-phase 'flare)                    'mission-phase)

(mphase10   "          MONITOR: We are near the destination airport, on the ground, above taxi speed limit, "
            (and (eq current-airport destination-airport)
                 (> airspeed taxi-speed-limit)
                 (eq agl 0))                               '(current-airport origin-airport)
            "          so the mission phase is landing rollout."
            (setq mission-phase 'landing-roll)         'mission-phase)

(mphase11   "          MONITOR: We are near the destination airport, on the ground, below taxi speed limit, "
            (and (eq current-airport destination-airport)
```

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```
                 (eq agl 0)
                 (< airspeed taxi-speed-limit))            '(current-airport origin-airport)
            "          so the mission phase is landed."
            (setq mission-phase 'landed)                   'mission-phase)
))
```

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Appendix D

LISP Code for Rules of Rule-Based Controller

```
;;; -*- Mode: LISP; Syntax: Common-lisp; Package: USER; Base: 10; -*-
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
;;;;;                                                          ;;;;;
;;;;;                          RULES                           ;;;;;
;;;;;                 RULE BASE FOR WINDSHEAR RBC              ;;;;;
;;;;;                                                          ;;;;;
;;;;;        Started by Alex Stratton on March 17, 1988        ;;;;;
;;;;;       Modified from RULES4 starting July 6, 1988         ;;;;;
;;;;;                                                          ;;;;;
;;;;;     This file contains rules for rule-based control.     ;;;;;
;;;;;     Currently, format is consistent with RBC-FUNCTIONS.  ;;;;;
;;;;;                                                          ;;;;;
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
;;;
;;;;;;;;;;;;; variable definitions :::::::::::::
;;;
;;; define variables
;;;
;;;
(defvar airspeed 150)
(defvar target-v1)
(defvar target-vr)
(defvar target-va)
(defvar vr-field-length-limit 180)
(defvar taxi-speed-limit 50)
;;;
(defvar runway-remaining 1000)
;;;
(defvar agl 300)
(defvar critical-agl 200)
(defvar decision-agl 200)
(defvar flare-agl 200)
;;
(defvar current-airport)
(defvar current-runway 2)
(defvar always-bother-the-pilot t)
;;;
(defvar aircraft-type)
(defvar recommended-flaps)
(defvar recommended-throttle-setting)
(defvar recommended-runway)
(defvar recommended-vr)
(defvar recommended-stabilized-approach-altitude)
(defvar recommended-va)
;;;
;;;
(defvar aircraft-response nil)
;;;
;;; variable WINDSHEAR-ALERT can have values t, nil, and warning.
;;;
(defvar windshear-alert nil)
;;;
;;; Boolean variable PIREP has properties speed-change, airport
;;;
(defvar pirep nil)
;;;
;;; Boolean variable TOWER-REPORT has properties winds
;;;
(defvar tower-report nil)
;;;
```

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```
;;; Boolean variable LLWAS has properties speed, airport
;;;
(defvar llwas)
;;;
;;; Variable ONBOARD-RADAR can have values NIL, TURBULENCE, and HEAVY-PRECIPITATION
;;;
(defvar onboard-radar nil)
;;;
;;; Boolean variable OBSERVATION has properties skies, winds
;;;
(defvar observation nil)
;;;
;;; Boolean variable WEATHER-REPORT has properties turbulence, temp-sprd, dwpt-sprd
;;;
(defvar weather-report nil)
;;;
;;; Variable MISSION-PHASE can have values TAKE-OFF and APPROACH
;;;
(defvar mission-phase)
;;;
;;; Variable ORIGIN-AIRPORT
;;;
(defvar origin-airport nil)
;;;
;;; Variable DESTINATION-AIRPORT
;;;
(defvar destination-airport nil)
;;;
;;; Variable SUSPECTED-RUNWAYS
;;;
(defvar suspected-runways)
;;;
;;;   Rules to use in testing hypotheses
;;;
;;;   New format is:
;;;     (rulename if-doc
;;;               if-part   if-vars
;;;               then-doc
;;;               then-part then-vars)
;;;
;;;
;;;;;;;;;;;;;;;;;;;;; windshear-rules ;;;;;;;;;;;;;;;;;;;;;;;
;;;     these rules determine whether we are in windshear
;;;         or not.
;;;
;;; variable EXTERNAL-WINDSHEAR-VARIABLES contains a list of the variables
;;; that are assumed to have values before the windshear-rules are tried
;;;
(defvar external-windshear-variables nil)
(setq external-windshear-variables '(aircraft-response system-status))
;;;
(defvar windshear-rules nil)
(setq windshear-rules '(
                        (windshear1  "          MONITOR: Aircraft trajectory is deviating significantly from target trajectory!  "
                                     (and (get-value-of 'detection-completed detection-rules)
                                          (member 'microburst aircraft-response))       '(aircraft-response system-status)
                                     "          ******* MICROBURST ENCOUNTERED  *********"
                                     (setq microburst-encounter t)          'microburst-encounter)

                        (windshear2  "          MONITOR: Onboard windshear detection system alert! "
```

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```
                                     (and (ask-lisp-listener-about 'windshear-alert)
                                          (eq windshear-alert t))          'windshear-alert
                                     "          ******* MICROBURST ENCOUNTERED  *********"
                                     (setq microburst-encounter t)         'microburst-encounter)

                      (windshear3  "          MONITOR: A microburst encounter has begun, and there are still deviations from targets, "
                                     (and (eq microburst-encounter t)
                                          (or (member 'above-target-airspeed aircraft-response)
                                              (member 'below-target-airspeed aircraft-response)
                                              (member 'above-target-vertical-speed aircraft-response)
                                              (member 'below-target-vertical-speed aircraft-response)
                                              (member 'above-target-attitude aircraft-response)
                                              (member 'below-target-attitude aircraft-response)
                                              (member 'above-target-glideslope-displacement aircraft-response)
                                              (member 'below-target-glideslope-displacement aircraft-response)
                                              (member 'above-target-throttle aircraft-response)
                                              (member 'below-target-throttle aircraft-response))) 'aircraft-response
                                     "          ******* MICROBURST ENCOUNTERED  ********"
                                     (setq microburst-encounter t)         'microburst-encounter)

                        (windshear4  "          MONITOR: Aircraft trajectory is not deviating from target trajectory, "
                                     (and (not (member 'microburst aircraft-response))
                                          (neq microburst-encounter t))      'aircraft-response
                                     "          so there is no microburst encounter at this time."
                                     (setq microburst-encounter nil)       'microburst-encounter)
                        ))
;;;
;;;;;;;;;;;;;;;;;;;;; detection-rules ;;;;;;;;;;;;;;;;;;;;;;;;;
;;;    these rules direct a search for response deviations
;;;
(defvar detection-rules)
(setq detection-rules '(
                        (det1    "                MONITOR: The mission phase is approach or prelanding decision stage, "
                                (or (eq mission-phase 'approach)
                                    (eq mission-phase 'prelanding-decision))   'mission-phase
                                "                so we will compute deviations from all target values."
                                (and (get-value-of 'airspeed-deviation deviation-rules)
                                     (get-value-of 'vertical-speed-deviation deviation-rules)
                                     (get-value-of 'attitude-deviation deviation-rules)
                                     (get-value-of 'glideslope-deviation deviation-rules)
                                ;     (get-value-of 'throttle-deviation deviation-rules)
                                     ) 'detection-completed)

                        (det2    "                MONITOR: The mission phase is not approach or prelanding decision stage, "
                                (and (neq mission-phase 'prelanding-decision)
                                     (neq mission-phase 'approach))          'mission-phase
                                "                so we will compute deviations from target speeds and attitude only."
                                (and (get-value-of 'airspeed-deviation deviation-rules)
                                     (get-value-of 'vertical-speed-deviation deviation-rules)
                                     (get-value-of 'attitude-deviation deviation-rules)) 'detection-completed)
                        ))
;;;
;;;;;;;;;;;;;;;;;;;;; deviation-rules ;;;;;;;;;;;;;;;;;;;;;;;;;
;;;    these rules direct detection of abnormal aircraft response on an established approach
;;;
(defvar deviation-rules)
(setq deviation-rules '(
                        (dev1    "                     MONITOR: Airspeed is below target by over 15 knots, "
                                (and (> target-airspeed airspeed)
                                     (> (- target-airspeed airspeed) 15))   'target-airspeed
```

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```
        "                    and this is a strong indication of a microburst encounter."
        (setq aircraft-response '(microburst))  'airspeed-deviation)

(dev2   "                    MONITOR: Airspeed is above target by over 15 knots, "
        (and (> airspeed target-airspeed)
             (> (- airspeed target-airspeed) 15))  'target-airspeed
        "                    and this is a strong indication of a microburst encounter."
        (setq aircraft-response '(microburst))  'airspeed-deviation)

(dev3   "                    MONITOR: Airspeed is below target between 5 and 15 knots, "
        (and (> target-airspeed airspeed)
             (< (- target-airspeed airspeed) 15)
             (> (- target-airspeed airspeed) 5))   'target-airspeed
        "                    and this is an indication of a windshear encounter."
        (setq aircraft-response '(above-target-airspeed))  'airspeed-deviation)

(dev4   "                    MONITOR: Airspeed is above target between 5 and 15 knots, "
        (and (> airspeed target-airspeed)
             (< (- airspeed target-airspeed) 15)
             (> (- airspeed target-airspeed) 5))      'target-airspeed
        "                    and this is an indication of a windshear encounter."
        (setq aircraft-response '(above-target-airspeed))  'airspeed-deviation)

(dev5   "                    MONITOR: Vertical speed is under target by over 500 ft/min, "
        (and (> target-vertical-speed vertical-speed)
             (> (- target-vertical-speed vertical-speed) 500))   'target-vertical-speed
        "                    and this is an indication of a microburst encounter."
        (setq aircraft-response (cons 'microburst aircraft-response)) 'vertical-speed-deviation)

(dev6   "                    MONITOR: Vertical speed is over target by over 500 ft/min, "
        (and (> vertical-speed target-vertical-speed)
             (> (- vertical-speed target-vertical-speed) 500))   'target-vertical-speed
        "                    and this is an indication of a microburst encounter."
        (setq aircraft-response (cons 'microburst aircraft-response)) 'vertical-speed-deviation)

(dev7   "                    MONITOR: Vertical speed is under target by between 200 and 500 ft/min, "
        (and (> target-vertical-speed vertical-speed)
             (< (- target-vertical-speed vertical-speed) 500)
             (> (- target-vertical-speed vertical-speed) 200))   'target-vertical-speed
        "                    and this is an indication of a windshear encounter."
      (setq aircraft-response (cons 'below-target-vertical-speed aircraft-response)) 'vertical-speed-deviation)

(dev8   "                    MONITOR: Vertical speed is over target by betweeen 200 and 500 ft/min, "
        (and (> vertical-speed target-vertical-speed)
             (< (- vertical-speed target-vertical-speed) 500)
             (> (- vertical-speed target-vertical-speed) 200))   'target-vertical-speed
        "                    and this is an indication of a windshear encounter."
      (setq aircraft-response (cons 'above-target-vertical-speed aircraft-response)) 'vertical-speed-deviation)

(dev9   "                    MONITOR: Pitch attitude is under target by over 5 degrees, "
        (and (> target-pitch-attitude pitch-attitude)
             (> (- target-vertical-speed vertical-speed) 5))   'target-pitch-attitude
        "                    and this is an indication of a microburst encounter."
        (setq aircraft-response (cons 'microburst aircraft-response)) 'attitude-deviation)

(dev10 "                    MONITOR: Pitch attitude is over target by over 5 degrees, "
        (and (> pitch-attitude target-pitch-attitude)
             (> (- pitch-attitude target-pitch-attitude) 5))   'target-pitch-attitude
        "                    and this is an indication of a microburst encounter."
        (setq aircraft-response (cons 'microburst aircraft-response)) 'attitude-deviation)
```

ORIGINAL PAGE IS
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```
(dev11 "                    MONITOR: Pitch attitude is under target by between 2 and 5 degrees, "
        (and (> target-pitch-attitude pitch-attitude)
             (< (- target-pitch-attitude pitch-attitude) 5)
             (> (- target-pitch-attitude pitch-attitude) 2))   'target-pitch-attitude
        "                    and this is an indication of a windshear encounter."
        (setq aircraft-response (cons 'below-target-pitch-attitude aircraft-response)) 'attitude-deviation)

(dev12 "                    MONITOR: Pitch attitude is over target by betweeen 2 and 5 degrees, "
        (and (> pitch-attitude target-pitch-attitude)
             (< (- pitch-attitude target-pitch-attitude) 5)
             (> (- pitch-attitude target-pitch-attitude) 2))   'target-pitch-attitude
        "                    and this is an indication of a windshear encounter."
        (setq aircraft-response (cons 'above-target-pitch-attitude aircraft-response)) 'attitude-deviation)

(dev13 "                    MONITOR: Glideslope displacement is under target by over 1 dot, "
        (and (> target-glideslope-displacement glideslope-displacement)
             (> (- target-glideslope-displacement glideslope-displacement) 1)) 'target-glideslope-displacement
        "                    and this is an indication of a microburst encounter."
        (setq aircraft-response (cons 'microburst aircraft-response)) 'glideslope-deviation)

(dev14 "                    MONITOR: Glideslope displacement is over target by over 1 dot, "
        (and (> glideslope-displacement target-glideslope-displacement)
             (> (- glideslope-displacement target-glideslope-displacement) 1)) 'target-glideslope-displacement
        "                    and this is an indication of a microburst encounter."
        (setq aircraft-response (cons 'microburst aircraft-response)) 'glideslope-deviation)

(dev15 "                    MONITOR: Glideslope displacement is under target by between .4 and 1 dot, "
        (and (> target-glideslope-displacement glideslope-displacement)
             (< (- target-glideslope-displacement glideslope-displacement) 1)
             (> (- target-glideslope-displacement glideslope-displacement) .4)) 'target-glideslope-displacement
        "                    and this is an indication of a windshear encounter."
 (setq aircraft-response (cons 'below-target-glideslope-displacement aircraft-response)) 'glideslope-deviation)

(dev16 "                    MONITOR: Glideslope displacement is over target by betweeen .4 and 1 dot, "
        (and (> glideslope-displacement target-glideslope-displacement)
             (< (- glideslope-displacement target-glideslope-displacement) 1)
             (> (- glideslope-displacement target-glideslope-displacement) .4)) 'target-glideslope-displacement
        "                    and this is an indication of a windshear encounter."
 (setq aircraft-response (cons 'above-target-glideslope-displacement aircraft-response)) 'glideslope-deviation)

;
;(dev17 "                    MONITOR: Throttle setting is under target by over   percent for      , "
;        (and (> target-throttle throttle)
;             (> (- target-throttle throttle) 1)) 'target-throttle
;        "                    and this is an indication of a microburst encounter."
;        (setq aircraft-response (cons 'microburst aircraft-response)) 'throttle-deviation)
;
;(dev18 "                    MONITOR: Throttle setting is over target by over   percent for       , "
;        (and (> throttle target-throttle)
;             (> (- throttle target-throttle) 1)) 'target-throttle
;        "                    and this is an indication of a microburst encounter."
;        (setq aircraft-response (cons 'microburst aircraft-response)) 'throttle-deviation)
;
;(dev19 "                    MONITOR: Throttle setting is under target by between   and   percent for       , "
;        (and (> target-throttle throttle)
;             (< (- target-throttle throttle)  )
;             (> (- target-throttle throttle)  )) 'target-throttle
;        "                    and this is an indication of a windshear encounter."
; (setq aircraft-response (cons 'below-target-throttle aircraft-response)) 'throttle-deviation)
;
```

ORIGINAL PAGE IS
OF POOR QUALITY

```
;                       (dev20  "                    MONITOR: Throttle setting is over target by betweeen    and    percent for      , "
;                               (and (> throttle target-throttle)
;                                    (< (- throttle target-throttle)  )
;                                    (> (- throttle target-throttle)  )) 'target-glideslope-displacement
;                               "                    and this is an indication of a windshear encounter."
;                        (setq aircraft-response (cons 'above-target-throttle aircraft-response)) 'throttle-deviation)
;                       ))
;;;
;;;;;;;;;;;;;;;;;;;;;  comm-rules  ;;;;;;;;;;;;;;;;;;;;;;;;;;;;
;;;    these rules direct communications procedures
;;;
;;;
;;; variable COMM-VARIABLES contains the external variables received by communications
;;;
(defvar comm-variables nil)
(setq comm-variables '(pirep tower-report llwas onboard-radar weather-report))
;;;
;;; variable MESSAGES sets up the COMM-VARIABLES
;;;
(defvar messages)
(setq messages '((pirep 0 nil nil)
                 (tower-report nil nil)
                 (llwas 0 nil nil)
                 (onboard-radar nil nil)
                 (weather-report nil nil nil)))
;;;
;;; variable PRESET-VARIABLES contains variables preset once per situation
;;;
(defvar preset-variables)
(setq preset-variables '(always-bother-the-pilot current-airport current-runway critical-agl decision-agl flare-agl aircraft-type
                         vr-field-length-limit vr v1 origin-airport destination-airport current-runway old-action))
;;;
;;; variable PRESET-MESSAGES sets up the PRESET-VARIABLES
;;;
(defvar preset-messages)
(setq preset-messages '((always-bother-the-pilot t nil nil)
                        (current-airport Dallas nil nil)
                        (current-runway runway1 nil nil)
                        (critical-agl 200 nil nil)
                        (decision-agl 200 nil nil)
                        (flare-agl 200 nil nil)
                        (aircraft-type MD-80 nil nil)
                        (vr-field-length-limit 120 nil nil)
                        (vr 110 nil nil)
                        (v1 80 nil nil)
                        (origin-airport Dallas nil nil)
                        (destination-airport Denver nil nil)
                        (current-runway 26 nil nil)
                        (old-action continue)))
;;;
;;; variable STATE-VARIABLES contains state variables that connot be set by MONITOR rules
;;;
(defvar state-variables)
(setq state-variables '(agl aircraft-response airspeed runway-remaining))
;;;
;;; variable CONTROL-VARIABLES contains controls that the RBC can tweak
;;;
(defvar control-variables)
(setq control-variables '(elevator thrust brakes))
;;;
```

ORIGINAL PAGE IS
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```
;;; variable COMM-VARIABLE-PROPERTIES contains a list of property values that must be assigned for the COMM-VARIABLES
;;;
(setq comm-variable-properties '((pirep (airport runways))
                                 (tower-report (airport runways))
                                 (llwas (airport runways))
                                 (onboard-radar (airport runways))
                                 (weather-report (airport runways temp-dewpt-sprd))
                                 ))
;;;
;;;
;;;
;;;
(defvar comm-rules nil)
(setq comm-rules '(
                   (comm1 "               INTERFACE: An important message was received, "
                          (bind-variables comm-variables messages)     'messages
                          "               so there is new information to be assessed."
                          (setq new-information-received t)     'new-information-received)

                   (comm2 "               INTERFACE: No important messages were received, "
                          't     ()
                          "               so there is no new information to assess."
                          (setq new-information-received nil)   'new-information-received)

                   (comm3 "               INTERFACE: An assessment of weather on our intended flight path is required. "
                          't     ()
"                *********************************************
                           *      ATTENTION          ATTENTION
                           *  CONVECTIVE   WEATHER  INFORMATION  REQUEST
                           *      ATTENTION          ATTENTION
                           *
                           *  PLEASE INDICATE IF CONVECTIVE WEATHER IS
                           *  OBSERVED ON OUR INTENDED FLIGHT PATH:
                           *    0. Convective weather not observed
                           *    1. With localized strong winds - HIGH risk
                           *    2. With heavy precipitation -- HIGH risk
                           *    3. With a rainshower -- MEDIUM risk
                           *    4. With lightning -- MEDIUM risk
                           *    5. With virga -- MEDIUM risk
                           *  ENTER 0 THROUGH 5 TO INDICATE CHOICE
                           ***********************************************"
                          (bind-variables '(observation) 'lisp-listener)   'observation)

                   (comm4 "               INTERFACE: Windshear has been encountered, "
                          (and (eq (get 'microburst-encounter 'last-value) t)
                               (eq microburst-encounter nil))    'microburst-encounter
                          "               so a PIREP is being sent out."
                          (setq incident-reported t)            'incident-reported)

                   (comm5 "               INTERFACE: There are no incidents to report, "
                          't  ()
                          "               so no PIREP will be sent."
                          (setq incident-reported nil)          'incident-reported)
                   ))
;;;
;;;;;;;;;;;;;;;;;;;;; action-rules ;;;;;;;;;;;;;;;;;;;;;;;;;
;;;       these rules determine the proper top level control actions
;;;
(defvar action-rules)
(setq action-rules '(
```

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```
                     (action1    "     ACTION: We are in a microburst !!!! "
                                 (and (get-value-of 'microburst-encounter windshear-rules)
                                      (eq microburst-encounter t)
                                      (eq guidance-mode 'automatic))     'microburst-encounter
                                 "     Executing recovery procedures !!! "
                                 (get-value-of 'recovery-procedures-complete recovery-rules)  'actions-taken)

                     (action2    "     ACTION: We are not in a microburst, and standard procedures are recommended, "
                                 (and (neq microburst-encounter t)
                                      (eq guidance-mode 'automatic)
                                      (get-value-of 'recommended-procedures planning-rules)
                                      (eq recommended-procedures 'standard))        '(microburst-encounter recommended-procedures)
                                 "     so we must execute standard procedures as planned."
                                 (get-value-of 'standard-procedures-complete sop-rules)  'actions-taken)

                     (action3    "     ACTION: We are not in a microburst, but go-around procedures are recommended, "
                                 (and (neq microburst-encounter t)
                                      (eq guidance-mode 'automatic)
                                      (eq recommended-procedures 'go-around))    '(microburst-encounter recommended-procedures)
                                 "     so we must execute go-around procedures as planned."
                                 (get-value-of 'go-around-procedures-complete go-around-rules) 'actions-taken)

                     (action4    "     ACTION: We are not in a microburst, but delaying procedures are recommended, "
                                 (and (neq microburst-encounter t)
                                      (eq recommended-procedures 'delay))  '(microburst-encounter recommended-procedures)
                                 "     so we must execute delay procedures as recommended."
                                 (get-value-of 'delay-procedures-complete delay-rules) 'actions-taken)

                     (action5    "     ACTION: We are in a microburst !!!! "
                                 (and (eq microburst-encounter t)
                                      (eq guidance-mode 'semi-automatic))     'microburst-encounter
                                 "     Executing semi-automatic recovery procedures !!! "
                                 (get-value-of 'semi-recovery-procedures-complete semi-recovery-rules)  'actions-taken)

                     (action6    "     ACTION: We are not in a microburst, and standard procedures are recommended, "
                                 (and (neq microburst-encounter t)
                                      (eq guidance-mode 'semi-automatic)
                                      (get-value-of 'recommended-procedures planning-rules)
                                      (eq recommended-procedures 'standard))  'microburst-encounter
                                 "     so we must execute semi-automatic standard operations as planned."
                                 (get-value-of 'semi-standard-procedures-complete semi-sop-rules) 'actions-taken)

                     (action7    "     ACTION: We are not in a microburst, but go-around procedures are recommended, "
                                 (and (neq microburst-encounter t)
                                      (eq guidance-mode 'semi-automatic)
                                      (eq recommended-procedures 'go-around))    '(microburst-encounter recommended-procedures)
                                 "     so we must execute semi-automatic go-around procedures as planned."
                                 (get-value-of 'semi-go-around-procedures-complete semi-go-around-rules) 'actions-taken)
                     ))
;;;
;;;;;;;;;;;;;;;;;;;;;; sop-rules ;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
;;;;      these rules direct standard operating procedures
;;;
(defvar sop-rules)
(setq sop-rules '(
                  (sop1   "          ACTION: The mission phase is takeoff, and the controls have not been set for takeoff roll, "
                          (and (eq mission-phase 'takeoff)
                               (neq configuration-set-for-takeoff t))           '(mission-phase configuration-set-for-takeoff)
                          "          so the control laws must be set for takeoff roll at this time."
                          (get-value-of 'configuration-set-for-takeoff config-rules)  'standard-procedures-complete)
```

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```
                 (sop2   "          ACTION: On takeoff, groundspeed is below v1, "
                         (and (eq mission-phase 'takeoff)
                              (< groundspeed v1))             '(mission-phase v1)
                         "          so takeoff roll control laws remain in operation."
                         (f77:execute ftn-user:takeoff-cl)   'standard-procedures-complete)

                 (sop3   "          ACTION: On takeoff, groundspeed is above v1, airspeed is below vr, "
                         (and (eq mission-phase 'takeoff)
                              (> groundspeed v1)
                              (< airspeed vr))                '(mission-phase v1)
                         "          so takeoff roll control laws remain in operation."
                         (f77:execute ftn-user:takeoff-cl)   'standard-procedures-complete)

                 (sop4   "          ACTION: On takeoff, airspeed is above vr, "
                         (and (eq mission-phase 'takeoff)
                              (> airspeed vr))                '(mission-phase vr)
                         "          so rotation control laws are in effect. "
                         (f77:execute ftn-user:rotation-cl)  'standard-procedures-complete)

                 (sop5   "          ACTION: We are climbing out, "
                         (eq mission-phase 'climbout)         'mission-phase
                         "          so climbout control laws are in effect."
                         (f77:execute ftn-user:climbout-cl)  'standard-procedures-complete)

                 (sop6   "          ACTION: We are on approach, and controls are not set for landing, "
                         (and (eq mission-phase 'approach)
                              (neq configuration-set-for-landing t)) '(mission-phase configuration-set-for-landing)
                         "          so the configuration must be set for landing."
                         (get-value-of 'configuration-set-for-landing config-rules) 'standard-procedures-complete)

                 (sop7   "          ACTION: We are on approach, have not established a glideslope, and altitude is above critical, "
                         (and (eq mission-phase 'approach)
                              (neq glideslope-established t)
                              (> agl critical-agl))           'glideslope-established
                         "          so we must continue to establish the glideslope."
                         (get-value-of 'glideslope-established glideslope-rules) 'standard-procedures-complete)

                 (sop8   "          ACTION: We are on approach, and have established the proper glideslope, "
                         (and (eq mission-phase 'approach)
                              (eq glideslope-established t))     'glideslope-established
                         "          so approach control laws are in effect."
                         (f77:execute ftn-user:approach-cl)      'standard-procedures-complete)

                 (sop9   "          ACTION We are on flare, "
                         (eq mission-phase 'flare)  'mission-phase
                         "          so flare control laws are in effect."
                         (f77:execute ftn-user:flare-cl)       'standard-procedures-complete)

                 (sop10  "          ACTION: We are on landing roll, "
                         (eq mission-phase 'landing-roll)   'mission-phase
                         "          so landing control laws are in effect."
                         (f77:execute ftn-user:landing-cl)     'standard-procedures-complete)
                 ))
;;;;;;;;;;;;;;;;; recovery-rules ;;;;;;;;;;;;;;;;
;;;;;; these rules execute recovery procedures
;;;
(defvar recovery-rules)
(setq recovery-rules  '(
                      (recvry1     "          ACTION: In microburst, AGL is above critical, aircraft type is L-1011, "
```

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OF POOR QUALITY

```
                                   (and (> agl critical-agl)
                                        (eq aircraft-type 'L-1011)
                                        (eq mission-phase 'climbout))            'agl
"                                 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
                                    !!!   APPLY  FULL  THRUST IMMEDIATELY  !!!
                                    !!!PULL TO 17.5 DEGREES PITCH ATTITUDE !!!
                                    !!!        RESPECT STICK SHAKER        !!!
                                    !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!"
                                   (f77:execute ftn-user:recover)                 'recovery-procedures-complete)

                      (recvry2     "          ACTION: In micorburst, AGL is above critical, "
                                   (and (> agl critical-agl)
                                        (or (neq aircraft-type 'L-1011)
                                            (and (eq aircraft-type 'L-1011)
                                                 (or (eq mission-phase 'approach)
                                                     (eq mission-phase 'flare))))) 'agl
"                                 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
                                    !!!   APPLY  FULL  THRUST IMMEDIATELY  !!!
                                    !!! PULL TO 15 DEGREES PITCH ATTITUDE  !!!
                                    !!!        RESPECT STICK SHAKER        !!!
                                    !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!"
                                   (f77:execute ftn-user:recover)               'recovery-procedures-complete)

                     (recvry3      "          ACTION:  IN MICROBURST! AGL IS BELOW CRITICAL !!!!!!!!"
                                   (and (neq mission-phase 'takeoff)
                                        (neq mission-phase 'landing-roll)
                                        (< agl critical-agl))                   'agl
"                                 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
                                    !!!   APPLY OVERBOOST IMMEDIATELY      !!!
                                    !!! PULL TO 20 DEGREES PITCH ATTITUDE  !!!
                                    !!!       AVOID GROUND CONTACT         !!!
                                    !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!"
                                   (f77:execute ftn-user:recover)              'recovery-procedures-complete)

                     (recvry4      "          ACTION: In microburst, on takeoff, below V1 "
                                   (and (eq mission-phase 'takeoff)
                                        (< airspeed v1))         'agl
"                                 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
                                    !!!      AIRSPEED IS BELOW V1          !!!
                                    '!!     ABORT TAKEOFF IMMEDIATELY      !!!
                                    !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!"
                                   (f77:execute ftn-user:abortto)             'recovery-procedures-complete)

                     (recvry5      "          ACTION: In microburst, on takeoff, too fast to abort and too slow to rotate "
                                   (and (eq mission-phase 'takeoff)
                                        (> airspeed v1)
                                        (< airspeed vr)
                                        (> runway-remaining 2000))            'agl
"                                 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
                                    !!!     AIRSPEED IS ABOVE V1           !!!
                                    !!!   OVER 2000 FT RUNWAY REMAINING    !!!
                                    !!!   APPLY FULL THRUST IMMEDIATELY    !!!
                                    !!!      DO NOT ABORT TAKEOFF          !!!
                                    !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!"
                                   (f77:execute ftn-user:emgyto)             'recovery-procedures-complete)

                     (recvry6      "          ACTION: In microburst, on takeoff, fast enough to rotate "
                                   (and (or (eq mission-phase 'takeoff)
                                            (eq mission-phase 'climbout))
                                        (> airspeed vr))                     'agl
```

```
"                                !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
                                    !!!     AIRSPEED IS ABOVE VR           !!!
                                    !!!  APPLY FULL THRUST IMMEDIATELY     !!!
                                    !!!  PULL TO 15 DEGREES PITCH ATTITUDE !!!
                                    !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!"
                                   (f77:execute ftn-user:emgyto)            'recovery-procedures-complete)

                     (recvry7      "          ACTION: In microburst, on takeoff with less than 2000 ft of runway remaining "
                                   (and (eq microburst-encounter t)
                                        (eq mission-phase 'takeoff)
                                        (< runway-remaining 2000))          'agl
"                                !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
                                    !!! LESS THAN 2000 FEET OF RUNWAY LEFT !!!
                                    !!!  APPLY FULL THRUST IMMEDIATELY     !!!
                                    !!!  PULL TO 15 DEGREES PITCH ATTITUDE !!!
                                    !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!"
                                   (f77:execute ftn-user:emgyto)            'recovery-procedures-complete)
                     ))
;;;
;;;;;;;;;;;;;;;;;;;;; go-around-rules ;;;;;;;;;;;;;;;;;;;;;;;;;;
;;;      these rules execute go-around procedures
;;;
(defvar go-around-rules)
(setq go-around-rules '(
                        (goar1  "          ACTION: Tower not informed of our intent to go-around, no traffic in the way, "
                                (and (eq tower-informed-goa nil)
                                     (eq traffic nil))       '(tower-informed-goa traffic)
                                "          so we must request clearance for a go-around while executing go-around control laws."
                                (and (f77:execute ftn-user:go-around-cl)
                                     (get-value-of 'tower-informed-goa comm-rules))  'go-around-procedures-complete)

                        (goar2  "          ACTION: Tower not informed of our intentions, traffic in the way, altitude above critical, "
                                (and (eq tower-informed-goa nil)
                                     (eq traffic t)
                                     (> agl critical-agl))       '(tower-informed-goa traffic)
                                "          so we must request clearance for a go-around while executing approach control laws."
                                (and (f77:execute ftn-user:approach-cl)
                                     (get-value-of 'tower-informed-goa comm-rules))  'go-around-procedures-complete)

                        (goar3  "          ACTION: Tower not informed of our intentions, traffic in the way, ALTITUDE BELOW CRITICAL! "
                                (and (eq tower-informed-goa nil)
                                     (eq traffic t)
                                     (< agl critical-agl))       '(tower-informed-goa traffic)
                                "          so we must request clearance for a go-around while executing go-around control laws."
                                (and (f77:execute ftn-user:go-around-cl)
                                     (get-value-of 'tower-informed-goa comm-rules))  'go-around-procedures-complete)

                        (goar4  "          ACTION: Tower has been informed we are going-around, "
                                (eq tower-informed-goa t)  'tower-informed-goa
                                "          so go-around control laws are in effect."
                                (f77:execute ftn-user:go-around-cl)      'go-around-procedures-complete)
                        ))
;;;
;;;;;;;;;;;;;;;;;;;;; delay-rules ;;;;;;;;;;;;;;;;;;;;;;;;;;;
;;;      these rules execute delay procedures
;;;
(defvar delay-rules)
(setq delay-rules '(
                    (delay1  "          ACTION: Decision stage, tower has not been informed of our intention to delay, "
                             (eq tower-informed-delay nil)  'tower-informed-delay
                             "          so the tower will be informed of our intent to delay takeoff."
                             (get-value-of 'tower-informed-delay comm-rules) 'delay-procedures-complete)

                    (delay2  "          ACTION: Prelanding decision stage, tower is informed of our intent to delay, "
                             (eq tower-informed-delay t)    'tower-informed-delay
                             "          so delay procedures are complete."
                             't                                              'delay-procedures-complete)
                    ))
;;;
;;;;;;;;;;;;;;;;;;;;; planning-rules  ;;;;;;;;;;;;;;;;;;;;;;;;;
;;;      these rules determine the recommended procedures
;;;
;;;
(defvar planning-rules nil)
(setq planning-rules '(
                     (mission1     "     PLANNING: Recommended action is delay, alter, abort, and we are in a decision stage, "
                                   (and (get-value-of 'recommended-action assessment-rules)
                                        (eq recommended-action 'delay-alter-abort)
                                        (or (eq mission-phase 'preflight-decision)
                                            (eq mission-phase 'prelanding-decision)))  'recommended-action
                                   "     so delaying procedures are recommended."
                                   (setq recommended-procedures 'delay)          'recommended-procedures)

                     (mission2     "     PLANNING: Recommended action is delay, alter, abort, but we are taking off or landing, "
                                   (and (eq recommended-action 'delay-alter-abort)
                                        (or (eq mission-phase 'takeoff)
                                            (eq mission-phase 'climbout)
                                            (eq mission-phase 'flare)
                                            (eq mission-phase 'landing-roll)))          'recommended-action
                                   "      so standard procedures are recommended."
                                   (setq recommended-procedures 'standard)              'recommended-procedures)

                     (mission3     "     PLANNING: Recommended action is delay, alter, abort, on approach, above decision height, "
                                   (and (eq recommended-action 'delay-alter-abort)
                                        (eq mission-phase 'approach)
                                        (> agl decision-agl))                           'recommended-action
                                   "     so go-around procedures are recommended."
                                   (setq recommended-procedures 'go-around)             'recommended-procedures)

                     (mission4     "     PLANNING: Recommended action is delay, alter, abort, on approach, below decision-height, "
                                   (and (eq recommended-action 'delay-alter-abort)
                                        (eq mission-phase 'approach)
                                        (< agl decision-agl))                           'recommended-action
                                   "     so standard procedures are recommended."
                                   (setq recommended-procedures 'standard)              'recommended-procedures)

                     (mission5     "     PLANNING: Recommended action take precautions, but precautions were accepted or refused,"
                                   (and (eq recommended-action 'consider-precautions)
                                        (eq precautions-taken t))                       '(recommended-action precautions-taken)
                                   "     so standard procedures are recommended."
                                   (setq recommended-procedures 'standard)          'recommended-procedures)

                     (mission6     "     PLANNING: We should consider takeoff precautions "
                                   (and (eq recommended-action 'consider-precautions)
                                        (eq mission-phase 'preflight-decision))       'recommended-action
                                   "     so the the recommended runway, flap setting, and rotation speed will be found."
                                   (and (setq recommended-throttle-setting 'max-rated)
                                        (get-value-of 'recommended-runway runway-rules)
                                        (get-value-of 'recommended-flaps flap-rules)
                                        (get-value-of 'recommended-vr speed-rules)
                                        (get-value-of 'precautions-taken 'precaution-rules))    'recommended-procedures)

                     (mission7     "     PLANNING: We should consider approach precautions "
                                   (and (eq recommended-action 'consider-precautions)
                                        (eq mission-phase 'prelanding-decision))      'recommended-action
                                   "     so the recommended runway, flap setting, and approach speed will be found."
                                   (and (setq 'recommended-stabilized-approach-altitude 1000)
                                        (get-value-of 'recommended-runway runway-rules)
                                        (get-value-of 'recommended-flaps flap-rules)
                                        (get-value-of 'recommended-va speed-rules)
                                        (get-value-of 'precautions-taken precaution-rules))    'recommended-procedures)

                     (mission8     "     PLANNING: Recommended action is take precautions, but we are not in a decision stage, "
                                   (and (eq recommended-action 'consider-rpecautions)
                                        (neq mission-phase 'preflight-decision))     'recommended-action
                                   "     so standard procedures are recommended."
                                   (setq recommended-procedures 'standard)       'recommended-procedures)

                     (mission9     "     PLANNING: We have not established glideslope and ALTITUDE IS BELOW CRITICAL!  "
                                   (and (eq mission-phase 'approach)
                                        (< agl critical agl)
                                        (neq glideslope-established t))    '(recommended-action glideslope-established)
                                   "     so go-around procedures are recommended."
                                   (setq recommended-procedures 'go-around)   'recommended-procedures)

                     (mission10    "     PLANNING: Uncertainty in touchdown point is High! Still enough altitude to go-around, "
                                   (and (eq mission-phase 'approach)
                                        (> agl decision-agl)
                                        (> touchdown-uncertainty uncertainty-tolerance)) '(touchdown-uncertainty uncertainty-tolerance)
                                   "     so go-around procedures are recommended."
                                   (setq recommended-procedures 'go-around)   'recommended-procedures)

                     (mission11    "     PLANNING: It is safe to continue at this time, "
                                   (eq recommended-action 'continue)       'recommended-action
                                   "     so standard operating procedures are now in effect."
                                   't            'recommended-procedures)
                     ))
;
;;;;;;;;;;;;;;;;;;;; runway-rules ;;;;;;;;;;;;;;;;;;;;;;;;;;
;     These rules set the recommended runway and suspected runway. Need to write rules to determine suspected runways.
;
(defvar runway-rules)
(setq runway-rules '(
                     (run1    "          PLANNING: Some runways are suspected, "
                             (neq suspected-runways nil)      'suspected-runways
                             "           so the recommended runway is the longest of the other suitable runways."
                             (setq recommended-runway 'longest-suitable-not-suspected) 'recommended-runway)

                     (run2    "          PLANNING: No runways are suspected, "
                             (eq suspected-runways nil)       'suspected-runways
                             "           so the recommended runway is the longest suitable runway."
                             (setq recommended-runway 'longest-suitable)      'recommended-runway)
                     ))
;;;;;;;;;;;;;;;;;;;; speed-rules ;;;;;;;;;;;;;;;;;;;;;;;;;;
;     These rules set recommended approach and rotation speed.
;
(defvar speed-rules)
(setq speed-rules '(
                    (speed1  "          PLANNING: Field length limit Vr is 0 to 20 knots greater than actual gross weight Vr, "
                             (and (> vr-field-length-limit target-vr)
                                   (< (- vr-field-length-limit target-vr) 20))   '(standard-vr vr-field-length-limit)
                              "         so the recommended Vr is now the field length limit Vr. Don't reset speed bugs, however."
                              (setq recommended-vr vr-field-length-limit)        'recommended-vr)

                    (speed2   "        PLANNING: Field length limit Vr is over 20 knots greater than the actual gross wieght Vr, "
                              (> (- vr-field-length-limit vr) 20)     '(standard-vr vr-field-length-limit)
                              "         so the recommended Vr is now the standard Vr + 20 knots. Don't reset speed bugs, however."
                              (setq recommended-vr (+ 20 target-vr))    'recommended-vr)

                    (speed3   "        PLANNING: Increased approach speed could be desireable, "
                              't    ()
                              "         if available landing field length permits, approach speed could be increased up to 20 knots."
                              (setq recommended-va '0-to-20-over-standard) 'recommended-approach-speed)
                    ))
;;;;;;;;;;;;;;;;;;;; flap-rules ;;;;;;;;;;;;;;;;;;;;;;;;;;;
;     These rules set RECOMMENDED-FLAPS to the value given in
;     the FAA guidelines, for takeoff or approach.
;
(defvar flap-rules)
(setq flap-rules '(
                   (flap1     "         PLANNING: Mission phase is preflight, "
                              (and (eq mission-phase 'preflight-decision)
                                   (eq aircraft-type 'B727))                'aircraft-type
                              "         so the recommended flap setting is 15 degrees."
                              (setq recommended-flaps 15)         'recommended-flaps)

                   (flap2     "         PLANNING: Mission phase is preflight, "
                              (and (eq mission-phase 'preflight-decision)
                                   (or (eq aircraft-type 'MD-80)
                                       (eq aircraft-type 'B737)))     'aircraft-type
                              "         so the recommended flap setting is 5 to 15 degrees. "
                              (setq recommended-flaps '5-to-15)    'recommended-flaps)

                   (flap3     "         PLANNING: Mission phase is preflight, "
                              (and (eq mission-phase 'preflight-decision)
                                   (or (eq aircraft-type 'B747)
                                       (eq aircraft-type 'B757)
                                       (eq aircraft-type 'B767)))     'aircraft-type
                              "         so the recommended flap setting is 20 degrees. "
                              (setq recommended-flaps 20)        'recommended-flaps)

                   (flap4     "         PLANNING: Mission phase is preflight, "
                              (and (eq mission-phase 'preflight-decision)
                                   (eq aircraft-type 'DC-9-10))      'aircraft-type
                              "         so the recommended flap setting is 10 or 20 degrees."
                              (setq recommended-flaps '10-or-20)     'recommended-flaps)

                  (flap5      "         PLANNING: Mission phase is preflight, "
                              (and (eq mission-phase 'preflight-decision)
                                   (or (eq aircraft-type 'DC-9-20)
                                       (eq aircraft-type 'DC-9-30)
                                       (eq aircraft-type 'DC-9-40)
                                       (eq aircraft-type 'DC-9-50)))    'aircraft-type
                              "         so the recommended flap setting is 5 or 15 degrees. "
                              (setq recommended-flaps '5-or-15)        'recommended-flaps)

                  (flap6      "         PLANNING: Mission phase is preflight, "
                              (and (eq mission-phase 'preflight-decision)
                                   (eq aircraft-type 'DC-10))        'aircraft-type
                              "         so the recommended flap setting is 5 to 20 degrees."
```

```
           (setq recommended-flaps '5-to-20)    'recommended-flaps)

(flap7     "          PLANNING: Mission phase is preflight, "
           (and (eq mission-phase 'preflight-decision)
                (eq aircraft-type 'L-1011))        'aircraft-type
           "          so the recommended flap setting is 10 to 22 degrees."
           (setq recommended-flaps '10-to-22)    'recommended-flaps)

(flap8     "          PLANNING: Mission phase is prelanding, "
           (and (eq mission-phase 'preflight-decision)
                (or (eq aircraft-type 'B727)
                    (eq aircraft-type 'B737)
                    (eq aircraft-type 'B757)
                    (eq aircraft-type 'B767)))         'aircraft-type
           "          so the recommended flap setting is 30 degrees."
           (setq recommended-flaps 30)    'recommended-flaps)

(flap9     "          PLANNING: Mission phase is prelanding, "
           (and (eq mission-phase 'prelanding-decision)
                (eq aircraft-type 'B747))          'aircraft-type
           "          so the recommended flap setting is 25 or 30 degrees."
           (setq recommended-flaps '25-or-30)    'recommended-flaps)

(flap10     "          PLANNING: Mission phase is prelanding, "
           (and (eq mission-phase 'prelanding-decision)
                (eq aircraft-type 'MD-80))            'aircraft-type
           "          so the recommended flap setting is 28 degrees."
           (setq recommended-flaps 28)    'recommended-flaps)

(flap11    "           PLANNING: Mission phase is prelanding, "
           (and (eq mission-phase 'landing-decision)
                (or (eq aircraft-type 'DC-9-10)
                    (eq aircraft-type 'DC-9-20)
                    (eq aircraft-type 'DC-9-30)
                    (eq aircraft-type 'DC-9-40)
                    (eq aircraft-type 'DC-9-50)))            'aircraft-type
           "          so the recommended flap setting is the minimum authorized flap setting for this model."
           (setq recommended-flaps 'minimum-authorized-for-this-model)    'recommended-flaps)

(flap12    "          PLANNING: Mission phase is prelanding, "
           (and (eq mission-phase 'prelanding-decision)
                (eq aircraft-type 'DC-10))       'aircraft-type
           "          so the recommended flap setting is 35 degrees."
           (setq recommended-flaps 35)          'recommended-flaps)

(flap13    "          PLANNING: Mission phase is prelanding, "
           (and (eq mission-phase 'prelanding-decision)
                (eq aircraft-type 'L-1011))       'aircraft-type
           "          so the recommended flap setting is 33 degrees."
           (setq recommended-flaps 33)          'recommended-flaps)
))
```

Appendix E

LISP Code for Rules of Wind Shear Assessment

```
;;; -*- Mode: LISP; Syntax: Common-lisp; Package: USER; Base: 10; -*-
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
;;;;;                                                          ;;;;;
;;;;;                       ASSESSMENT                         ;;;;;
;;;;;         RULE BASE FOR WINDSHEAR RISK ASSESSMENT          ;;;;;
;;;;;                                                          ;;;;;
;;;;;       Started by Alex Stratton on March 12, 1988         ;;;;;
;;;;;   Modified from ASSESSMENT4 beginning July 6, 1988       ;;;;;
;;;;;                                                          ;;;;;
;;;;;        This file contains windshear avoidance rules.     ;;;;;
;;;;;    Currently, format is consistent with the functions    ;;;;;
;;;;;    in file RBC-FUNCTIONS.LISP.                           ;;;;;
;;;;;                                                          ;;;;;
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
;;;
;;; define variables
;;;
;;; Variable ASSESSMENT-VARIABLES contains a list of the variables defined
;;; in this file.
;;;
(defvar assessment-variables nil)
(setq assessment-variables '(weather risk obs-risk external-assessment-variables
                             weather-rules assessment-rules risk-rules observation-rules))
;;;
;;; variable EXTERNAL-ASSESSMENT-VARIABLES contains a list of the variables which
;;;  are assumed to be already set when the ASSESSMENT-RULES are evaluated.
;;;
(defvar external-assessment-variables nil)
(setq external-assessment-variables '(windshear-rules comm-rules pirep current-airport llwas onboard-radar tower-report
                                      current-runway weather-report))
;;;
;;; Variable RISK is a numerical risk factor. Its values correspond to
;;;              0 - no risk
;;;              1 - low risk
;;;              2 - medium risk
;;;      3 or more - high risk
;;;
;;; RISK has the properties: cause
;;;
(defvar risk nil)
(setq risk 'unknown)
;;;
;;; Variables WEATHER and OBS-RISK are numerical severity factors. Their values correspond to
;;;              0 - clear weather
;;;              1 - some indication of a microburst
;;;      2 or more - high indication of a microburst
;;;
(defvar weather nil)
(setq weather 'unknown)
(defvar obs-risk 'unknown)
;;;
;;;   Rules to use in testing hypotheses
;;;
;;;   New format is:
;;;     (rulename if-doc
;;;               if-part   if-vars
;;;               then-doc
;;;               then-part then-vars)
;;;
(defvar weather-rules nil)
```

```
(setq weather-rules '(
                  (weather1  "               ASSESSMENT: Resetting weather to 0 "
                             't                 ()
                             "                 ... "
                             (setq weather 0)    'weather)

                  (weather2  "               ASSESSMENT: The onboard radar indicates moderate turbulence on our current flight path, "
                             (and (eq onboard-radar 'turbulence)
                                  (neq (is-it-relevant 'onboard-radar current-runway) nil))  'onboard-radar
                             "               and turbulence is an indication of a microburst."
                             (and (setq weather (+ 2 weather))
                                  (setq suspected-runways (append (get 'onboard-radar 'runways) suspected-runways)))   'weather)

                  (weather3  "               ASSESSMENT: A weather report indicates moderate turbulence on our current flight path, "
                             (and (eq weather-report 'turbulence)
                                  (neq (is-it-relevant 'weather-report current-runway) nil))  'weather-report
                             "               and turbulence is an indication of a microburst."
                             (and (setq weather (+ 2 weather))
                                  (setq suspected-runways (append (get 'weather-report 'runways) suspected-runways)))   'weather)

                  (weather4  "               ASSESSMENT: A weather report indicates a rainshower on our current flight path, "
                             (and (eq weather-report 'rainshower)
                                  (neq (is-it-relevant 'weather-report current-runway) nil))  'weather-report
                             "               and turbulence is an indication of a microburst."
                             (and (setq weather (+ 2 weather))
                                  (setq suspected-runways (append (get 'weather-report 'runways) suspected-runways)))   'weather)

                  (weather5  "               ASSESSMENT: A weather report indicates heavy precipitation on our current flight path, "
                             (and (eq weather-report 'heavy-precipitation)
                                  (neq (is-it-relevant 'weather-report current-runway) nil))  'weather-report
                             "               and turbulence is a significant indication of a microburst."
                             (and (setq weather (+ 3 weather))
                                  (setq suspected-runways (append (get 'weather-report 'runways) suspected-runways)))   'weather)

                  (weather6  "               ASSESSMENT: A weather report indicates loow-level windshear on our current flight path, "
                             (and (eq weather-report 'llws)
                                  (neq (is-it-relevant 'weather-report current-runway) nil))  'weather-report
                             "               and turbulence is a significant indication of a microburst."
                             (and (setq weather (+ 3 weather))
                                  (setq suspected-runways (append (get 'weather-report 'runways) suspected-runways)))   'weather)

                  (weather7  "               ASSESSMENT: There is a relevant tower report of turbulence, "
                             (and (eq tower-report 'turbulence)
                                  (neq (is-it-relevant 'tower-report current-runway) nil))    'tower-report
                             "               and this is an indication of a microburst."
                             (and (setq weather (+ 2 weather))
                                  (setq suspected-runways (append (get 'tower-report 'runways) suspected-runways)))  'weather)

                  (weather8  "               ASSESSMENT: There is a relevant tower report of a rainshower, "
                             (and (eq tower-report 'rainshower)
                                  (neq (is-it-relevant 'tower-report current-runway) nil))    'tower-report
                             "               and this is an indication of a microburst."
                             (and (setq weather (+ 2 weather))
                                  (setq suspected-runways (append (get 'tower-report 'runways) suspected-runways)))  'weather)

                  (weather9  "               ASSESSMENT: There is a relevant tower report of heavy precipitation, "
                             (and (eq tower-report 'blowing-dust)
                                  (neq (is-it-relevant 'tower-report current-runway) nil))    'tower-report
                             "               and this is a significant indication of a microburst."
                             (and (setq weather (+ 3 weather))
                                   (setq suspected-runways (append (get 'tower-report 'runways) suspected-runways)))  'weather)

                  (weather10 "               ASSESSMENT: There is a relevant tower report of localized strong winds, "
                             (and (eq tower-report 'blowing-dust)
                                  (neq (is-it-relevant 'tower-report current-runway) nil))    'tower-report
                             "               and this is a significant indication of a microburst."
                             (and (setq weather (+ 3 weather))
                                  (setq suspected-runways (append (get 'tower-report 'runways) suspected-runways)))  'weather)

                  (weather11 "               ASSESSMENT: There is a relevant tower report of localized strong winds, "
                             (and (eq tower-report 'rings-of-dust)
                                  (neq (is-it-relevant 'tower-report current-runway) nil))    'tower-report
                             "               and this is a significant indication of a microburst."
                             (and (setq weather (+ 3 weather))
                                  (setq suspected-runways (append (get 'tower-report 'runways) suspected-runways)))  'weather)

                  (weather12 "               ASSESSMENT: There is a relevant tower report of localized strong winds, "
                             (and (eq tower-report 'tornado-like-features)
                                  (neq (is-it-relevant 'tower-report current-runway) nil))    'tower-report
                             "               and this is a significant indication of a microburst."
                             (and (setq weather (+ 3 weather))
                                  (setq suspected-runways (append (get 'tower-report 'runways) suspected-runways)))  'weather)

                  (weather13 "               ASSESSMENT: The onboard radar indicates heavy precipitation on our current flight path, "
                             (and (eq onboard-radar 'heavy-precipitation)
                                  (neq (is-it-relevant 'onboard-radar current-runway) nil))   'onboard-radar
                             "               and this is a significant indication of a microburst."
                             (and (setq weather (+ 3 weather))
                                  (setq suspected-runways (append (get 'onboard-radar 'runways) suspected-runways)))  'weather)

                  (weather14 "ASSESSMENT: The temperature/dewpoint spread is between 30 and 50 degrees F, "
                             (and (> temp-dewpt-sprd 30)
                                  (< temp-dewpt-sprd 50))            'weather-report
                             "and this is an indication of a microburst."
                             (setq weather (+ 2 weather))          'weather)
                  ))
;
(setq assessment-rules '(
                  (action1   "     ASSESSMENT: There is no computed risk of windshear, "
                             (or (and (get-value-of 'new-information-received comm-rules) (eq new-information-recieved nil))
                                 (and (setq risk 'unknown) (eq (return-value-of 'risk risk-rules) 0))) 'new-information-received
                             "     so IT IS SAFE TO CONTINUE."
                             (setq recommended-action 'continue)             'recommended-action)

                  (action2   "     ASSESSMENT: Risk level is now high!  "
                             (> (return-value-of 'risk risk-rules) 2)        ()
                             "     WE SHOULD ALTER OUR MISSION PLAN IMMEDIATELY."
                             (setq recommended-action 'delay-alter-abort)          'recommended-action)

                  (action3   "     ASSESSMENT: Risk level is now medium, "
                             (eq risk 2)                                     'risk
                             "     so WE SHOULD CONSIDER PRECAUTIONS."
                             (setq recommended-action 'consider-precautions) 'recommended-action)

                  (action4   "     ASSESSMENT: Risk level is now low, "
                             (eq risk 1)                                     'risk
                             "     so we should continue, with caution."
                             (setq recommended-action 'continue) 'recommended-action)
                  ))
;
```

```
; variable RISK-RULES contains rules about windshear
;
(defvar risk-rules nil)
(setq risk-rules '(
                  (risk1  "          ASSESSMENT: Setting value of risk to 0 "
                          't                                  ()
                          "          ... "
                          (and (setq risk '0)
                               (putt 'risk () 'cause)
                               (setq suspected-runways '())
                               (setq weather 'unknown))                'risk)

                  (risk2  "          ASSESSMENT: There is a relevant pilot report that indicates moderate airspeed change, "
                          (and (> pirep 0)
                               (< pirep 15)
                               (neq (is-it-relevant 'pirep current-runway) nil))  'pirep
                          "          so the risk level is now increased."
                          (and (setq risk (+ 1 risk))
                               (put 'risk '(pirep) 'cause)
                               (setq suspected-runways (append (get 'pirep 'runways) suspected-runways)))    'risk)

                  (risk3  "          ASSESSMENT: There is a relevant LLWAS alert that indicates moderate wind shifts, "
                          (and (> llwas 0)
                               (< llwas 20)
                               (neq (is-it-relevant 'llwas current-runway) nil))  'llwas
                          "          so the risk level is now increased."
                          (and (setq risk (+ 1 risk))
                               (put 'risk (cons 'llwas (get 'risk 'cause)) 'cause)
                               (setq suspected-runways (append (get 'llwas 'runways) suspected-runways)))        'risk)

                  (risk4  "          ASSESSMENT: There is a relevant pilot report that indicates significant airspeed change, "
                          (and (> pirep 15)
                               (neq (is-it-relevant 'pirep current-runway) nil))  'pirep
                          "          so the risk level is now significantly increased."
                          (and (setq risk (+ 2 risk))
                               (put 'risk (cons 'pirep (get 'risk 'cause)) 'cause)
                               (setq suspected-runways (append (get 'llwas 'runways) suspected-runways)))        'risk)

                  (risk5  "          ASSESSMENT: There is a relevant LLWAS alert that indicates significant wind shifts, "
                          (and (> llwas 20)
                               (neq (is-it-relevant 'llwas current-runway) nil))  'llwas
                          "          so the risk level is now significantly increased."
                          (and (setq risk (+ 2 risk))
                               (put 'risk (cons 'llwas (get 'risk 'cause)) 'cause)
                               (setq suspected-runways (append (get 'llwas 'runways) suspected-runways)))        'risk)

                  (risk6  "          ASSESSMENT: There is a relevant indication of hazardous weather, "
                          (neq (return-value-of 'weather weather-rules) 0)  'weather
                          "          so the risk level is now increased."
                          (and (setq risk (+ weather risk))
                               (put 'risk (cons 'weather (get 'risk 'cause)) 'cause))       'risk)

                  (risk7  "          ASSESSMENT: There is an observation of hazardous weather on our current flight path, "
                          (and (or (neq risk 0) (eq always-bother-the-pilot t))
                               (setq obs-risk 'unknown)
                               (neq (return-value-of 'obs-risk observation-rules) 0))  'weather
                          "          so the risk level is now increased."
                          (and (setq risk (+ obs-risk risk))
                               (put 'risk (cons 'observation (get 'risk 'cause)) 'cause))       'risk)
                  ))
```

```
;
; variable observation-rules contains rules relevant to onboard observation
;
(defvar observation-rules)
(setq observation-rules '(
                          (obs1  "              ASSESSMENT: Resetting obs-risk to 0 "
                                 't                  ()
                                 "                  ... "
                                 (and (setq obs-risk 0)
                                      (setq observation 'unknown))      'obs-risk)


                          (obs2  "              ASSESSMENT: There is an observation of localized strong winds on our flight path, "
                                 (eq (return-value-of 'observation comm-rules) 1)            'observation
                                 "              and this is a significant indication of a microburst."
                                 (and (setq obs-risk (+ 2 obs-risk))
                                      (setq suspected-runways (cons current-runway suspected-runways)))   'obs-risk)

                          (obs3  "              ASSESSMENT: There is an observation of heavy precipitation on our flight path, "
                                 (eq (return-value-of 'observation comm-rules) 2)         'observation
                                 "              and this is a significant indication of a microburst."
                                 (and (setq obs-risk (+ 2 obs-risk))
                                      (setq suspected-runways (cons current-runway suspected-runways)))   'obs-risk)

                          (obs4  "              ASSESSMENT: There is an observation of a rainshower on our flight path, "
                                 (eq (return-value-of 'observation comm-rules) 3)          'observation
                                 "              and virga is an indication of a microburst."
                                 (and (setq obs-risk (+ 1 obs-risk))
                                      (setq suspected-runways (cons current-runway suspected-runways)))   'obs-risk)

                          (obs5  "              ASSESSMENT: There is an observation of lightning on our flight path, "
                                 (eq (return-value-of 'observation comm-rules) 4)            'observation
                                 "              and this is a indication of a microburst."
                                 (and (setq obs-risk (+ 1 obs-risk))
                                      (setq suspected-runways (cons current-runway suspected-runways)))   'obs-risk)

                          (obs6  "              ASSESSMENT: There is an observation of virga on our flight path, "
                                 (eq (return-value-of 'observation comm-rules) 5)            'observation
                                 "              and this is a significant indication of a microburst."
                                 (and (setq obs-risk (+ 1 obs-risk))
                                      (setq suspected-runways (cons current-runway suspected-runways)))   'obs-risk)
                          ))
;
```

Appendix F

LISP Code for Rule Base Control Functions

```
;;; -*- Mode: LISP; Syntax: Common-lisp; Package: USER; Base: 10; -*-
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
;;;;;                                                              ;;;;;
;;;;;                    RBC FUNCTIONS                             ;;;;;
;;;;;       FUNCTIONS FOR RULE-BASED CONTROL                       ;;;;;
;;;;;                                                              ;;;;;
;;;;;             Coded 1988   by A. Stratton                      ;;;;;
;;;;;                                                              ;;;;;
;;;;;                                                              ;;;;;
;;;;;      This program contains functions that will aid in       ;;;;;
;;;;;    the evaluation of variables using a rule base and given   ;;;;;
;;;;;    facts. The user is prompted for information by the        ;;;;;
;;;;;    program, which attempts by backward chaining to find      ;;;;;
;;;;;    the value of the key variable. Rules are fired as side    ;;;;;
;;;;;    effects of the search for a value for the variable.       ;;;;;
;;;;;                                                              ;;;;;
;;;;; (tryrule rule) -- rule firing                                ;;;;;
;;;;;    This function evaluates a rule's premise, printing        ;;;;;
;;;;;    the rule's documentation and evaluating the consequent    ;;;;;
;;;;;    if the premise evaluates non-NIL.                         ;;;;;
;;;;;                                                              ;;;;;
;;;;; (get-value-of 'key-variable-name rules) -- simple search     ;;;;;
;;;;;    This function searches a set of rules, trying to set the  ;;;;;
;;;;;    value of the key variable using function TRYRULE.         ;;;;;
;;;;;                                                              ;;;;;
;;;;; (ask-lisp-listener-about var) -- interactive variable bind   ;;;;;
;;;;;    This function queries the lisp listener to give a value   ;;;;;
;;;;;    for VAR. Properties can also be set.                      ;;;;;
;;;;;                                                              ;;;;;
;;;;; (set-variables variables rules) -- search on a variable set  ;;;;;
;;;;;    This function involkes GET-VALUE-OF on a set of variables ;;;;;
;;;;;    to set their value. If a GET-VALUE-OF is unsuccessful,    ;;;;;
;;;;;    SET-VARIABLES prints out a warning message.               ;;;;;
;;;;;                                                              ;;;;;
;;;;; (fire-rules rules) -- multiple rule firing                    ;;;;;
;;;;;    This function fires the rules in the rulelist using       ;;;;;
;;;;;    TRYRULE. If any of the rules fire, FIRE-RULES returns T.  ;;;;;
;;;;;                                                              ;;;;;
;;;;; (fire-relevant-rules 'variable rules) -- all relevant rules  ;;;;;
;;;;;    This function, a cross between GET-VALUE-OF and FIRE-     ;;;;;
;;;;;    RULES, fires all rules that could set the value of the    ;;;;;
;;;;;    VARIABLE that are contained in RULES.                     ;;;;;
;;;;;                                                              ;;;;;
;;;;; (return-value-of 'variable rules) -- fire rules, return value;;;;;
;;;;;    If the value of the variable is not UNKNOWN, this         ;;;;;
;;;;;    function returns the variable's value. If the value of    ;;;;;
;;;;;    the variable is equal to UNKNOWN, RETURN-VALUE-OF gets    ;;;;;
;;;;;    the value of the variable by applying FIRE-RELEVANT-RULES ;;;;;
;;;;;    to the rules RULES. In any case, RETURN-VALUE-OF          ;;;;;
;;;;;    returns the value of the variable upon exit.              ;;;;;
;;;;;                                                              ;;;;;
;;;;; (get-value-return 'variable rules) -- get and return a value ;;;;;
;;;;;    If the value of the variable is not UNKNOWN, this         ;;;;;
;;;;;    function returns the variable's value. If the value of    ;;;;;
;;;;;    the variable is UNKNOWN, GET-VALUE-RETURN get the value   ;;;;;
;;;;;    of the variable by applying GET-VALUE-OF to the rules. It ;;;;;
;;;;;    returns the value of the variable on exit.                ;;;;;
;;;;;                                                              ;;;;;
;;;;; ($eq 'key-variable-name 'value rules) -- get-value-return+EQ ;;;;;
;;;;;    This function combines the normal LISP function EQ with   ;;;;;
```

```
;;;;;    the function GET-VALUE-RETURN described above.            ;;;;;
;;;;;                                                              ;;;;;
;;;;; (bind-variables) -- setup function for comm-rules            ;;;;;
;;;;;    This function binds variables for the rulebase.           ;;;;;
;;;;;                                                              ;;;;;
;;;;; (set-up) -- sets up the current rulebase (as of 7/88)        ;;;;;
;;;;;    This function sets up the rulebase and fires it once.     ;;;;;
;;;;;    The inputs to the simulation are set by SEARCH-MESSAGES   ;;;;;
;;;;;    and the rulebase is searched for completion of executive  ;;;;;
;;;;;    tasks.                                                    ;;;;;
;;;;;                                                              ;;;;;
;;;;; (run-rules) -- fires the current rule-base                   ;;;;;
;;;;;    This function calls the rule-base for a single search.    ;;;;;
;;;;;    This is to be used primarily from a FORTRAN simulation.   ;;;;;
;;;;;                                                              ;;;;;
;;;;; (simulate) -- execute the FORTRAN simulation                 ;;;;;
;;;;;                                                              ;;;;;
;;;;; (fetch 'property a-list) -- returns a-list values            ;;;;;
;;;;;    This function takes an A-LIST, which looks like:          ;;;;;
;;;;;       ((property1 value1) .... (propertyn valuen))           ;;;;;
;;;;;    It searches the A-LIST for the key PROPERTY. It returns   ;;;;;
;;;;;    the value of the A-LIST associated with the PROPERTY. If  ;;;;;
;;;;;    it can't find the PROPERTY, it returns NIL.               ;;;;;
;;;;;                                                              ;;;;;
;;;;; (put 'vname 'pvalue 'pname) -- Z-LISP function PUTPROP       ;;;;;
;;;;;    This makes it a bit easier to call putrop, that's all.    ;;;;;
;;;;;                                                              ;;;;;
;;;;; (make-rulesprop)                                             ;;;;;
;;;;;                                                              ;;;;;
;;;;; (is-it-relevant 'alert 'runway 'flight-path) -- relevance    ;;;;;
;;;;;    This function is called to determine the relevance of the ;;;;;
;;;;;    ALERT given to the windshear expert system. Relevance is  ;;;;;
;;;;;    assessed by first comparing the AIRPORT property of ALERT ;;;;;
;;;;;    to CURRENT-AIRPORT, and comparing the RUNWAYS property of ;;;;;
;;;;;    ALERT to RUNWAY, or examining the AREA property           ;;;;;
;;;;;    of ALERT. IS-IT-RELEVANT returns T if FLIGHT-PATH passes  ;;;;;
;;;;;    through AREA (as determined by FLIGHT-PATH-IN below), or  ;;;;;
;;;;;    if the RUNWAYS property contains RUNWAY. If quantities    ;;;;;
;;;;;    needed to assess relevance aren't known, IS-IT-RELEVANT   ;;;;;
;;;;;    returns UNKNOWN. IS-IT-RELEVANT only returns NIL if the   ;;;;;
;;;;;    alert is definitely not relevant.                         ;;;;;
;;;;;                                                              ;;;;;
;;;;; (flight-path-in 'area) -- determine if FLIGHT-PATH is in AREA;;;;;
;;;;;         not yet written                                      ;;;;;
;;;;;                                                              ;;;;;
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
;;;
;;;
;;;
;;;  define variables
;;;
(defvar flag nil)
;;;
;;;
;;;   Define the rule base using a RULES variable.
;;;
;;;   Curent format is:
;;;    (defvar myrules nil)
;;;    (setq myrules '((rulename if-doc if-part if-vars then-doc then-part then-vars)
;;;                                           :
```

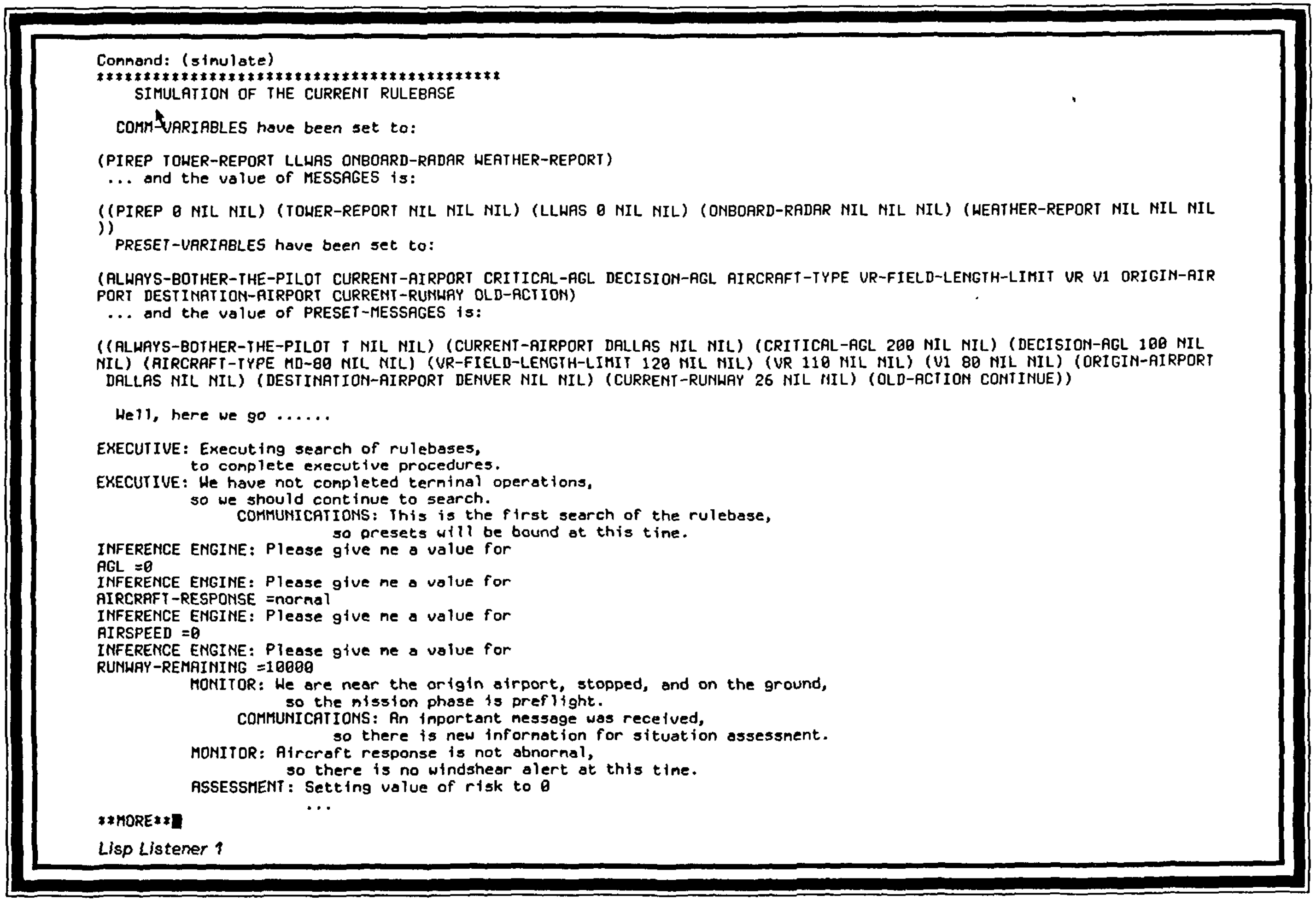
```
;;;                    (lastrule if-doc if-part if-vars then-doc then-part then-vars)))
;;;
;;;      Now, 'ifpart' and 'thenpart' must be valid LISP expressions.
;;;   'Ifpart' must be an expression that evaluates to something or NIL. The 'thenpart'
;;;   cannot be a nested expression; its second element is expected to be a
;;;   variable. If the 'ifpart' is evaluated non-NIL (this actually happens in function
;;;   TRYRULE), then the 'thenpart' is evaulated. The presumption of this
;;;   program is that variables (or at least one of them) are given
;;;   values in the 'thenpart' of a rule if their values are unknown. Otherwise,
;;;   the program will query the user for the values of some of the variables.
;;;      'If-doc' and 'then-doc' are documentation lines - they should be character
;;;   strings, suitable for printing, and set in double quotes. As they are printed
;;;   only when the if-part evaluates to non-NIL, the statements should reflect the
;;;   fact that the rule has successfully fired.
;;;      'If-vars' should contain a list of INTERNAL variables that must have values in order for
;;;   the rule to fire (if-part to evaluate non-NIL). 'Then-vars' should list the variable,
;;;   if any, that will be set if the then-part is evaluated. If-vars is not being used yet.
;
;
;
;  Functions IF-PART and THEN-PART return the if-part and the then-part,
;  respectively, of the argument RULE.
;
(defun if-part (rule)
       (third rule))
(defun then-part (rule)
       (sixth rule))
;
; Functions IF-DOC and THEN-DOC return the comments for the if and
; then conditions, which are then printed out by TRYRULE.
;
(defun if-doc (rule)
       (second rule))
(defun then-doc (rule)
       (fifth rule))
;
;  Function IF-VARS returns the internal variable that must have values
;  if the if-part of the rule is to fire.
;  Function THEN-VARS returns the variables set by RULE.
;
(defun if-vars (rule)
       (fourth rule))
(defun then-vars (rule)
       (seventh rule))
;
; Function TRYRULE evaluates its argument RULE. It tests the 'ifpart'
; of the rule; if it is true, the 'thenpart' is evaluated, and the
; documentation is printed out to the user. If the
; 'ifpart' is not true, TRYRULE returns NIL.
;
(defun tryrule (rule)
       (prog (flag)
       (setq flag nil)
       (cond ((eval (if-part rule)) (setq flag t)))
       (cond ((eq flag t) (and (zl:cursorpos 'a)
                               (princ (if-doc rule))
                               (zl:cursorpos 'a)
                               (zl:cursorpos 'f)
                               (zl:cursorpos 'f)
                               (zl:cursorpos 'f)
                               (zl:cursorpos 'f)
                               (zl:cursorpos 'f)
                               (zl:cursorpos 'f)
                               (zl:cursorpos 'f)
                               (zl:cursorpos 'f)
                               (zl:cursorpos 'f)
                               (zl:cursorpos 'f)
                               (princ (then-doc rule))
                               (eval (then-part rule)))))
       (cond ((eq flag t) (return t)))))
;
; Function GET-VALUE-OF does a simple goal-directed search. The strategy used by
; GET-VALUE-OF is as follows:
;           -search each rule's then-vars to see if they can update
;            VAR's value.
;           -call TRYRULE to try to fire the relevant rules. If a
;            rule fires (TRYRULE returns T), GET-VALUE-OF returns T.
;            If none of the rules fire, GET-VALUE-OF returns NIL.
;
(defun get-value-of (var rules)
       (prog (oldval)
             (setq oldval (eval var))
             (cond ((null rules) (and (ask-lisp-listener-about var) (go endpt)))
                   ((and (member var (then-vars (car rules)))
                         (tryrule (car rules))) (go endpt))
                   (t (get-value-of var (cdr rules))))
             endpt
;            (print oldval)
;            (print (eval var))
             (cond ((neq (eval var) oldval) (put var oldval 'last-value))))
       't)
;
; Function ASK-LISP-LISTENER-ABOUT queries the lisp listener to get
; a value for VAR
;
(defun ask-lisp-listener-about (var)
       (zl:cursorpos 'a)
       (princ "INFERENCE ENGINE: Please give me a value for")
       (print var)
       (princ "=")
       (set var (read))
       't)
;
; Function SET-VARIABLES involkes GET-VALUE-OF for a set of variables.
; If GET-VALUE-OF is unsuccessful, SET-VARIABLES prints out a warning
; message.
;
(defun set-variables (vars rules)
       (cond ((null vars) t)
             ((get-value-of (car vars) rules) (set-variables (cdr vars) rules))
             (t (and (zl:cursorpos 'a)
                     (princ "couldn't get any value of ")
                     (princ (car vars))
                     (set-variables (cdr vars) rules)))))
;
; Function FIRE-RULES fires several rules as described above.
;
(defun fire-rules (rules)
       (do ((remaining-rules rules) (flag nil)) ((null remaining-rules) flag)
           (cond ((tryrule (car remaining-rules)) (setq flag t)))
           (setq remaining-rules (cdr remaining-rules))))
;
; Function FIRE-RELEVANT-RULES fires rules that can set VARIABLE as described above.
;
(defun fire-relevant-rules (var rules)
       (cond ((null rules) nil)
             ((and (member var (then-vars (car rules))) (tryrule (car rules)))
              (fire-relevant-rules var (cdr rules)))
             (t (fire-relevant-rules var (cdr rules)))))


;
; Function RETURN-VALUE-OF returns the value of VARIABLE, as written above.
; If the FIRE-RELEVANT-RULES is unsuccessful,
; RETURN-VALUE-OF still returns the variable's value (i.e., UNKNOWN)
;
(defun return-value-of (variable rules)
       (cond ((neq (eval variable) 'unknown) (eval variable))
             ((fire-relevant-rules variable rules) (eval variable))
             (t (eval variable))))    ; this line fires if FIRE-RELEVANT-RULES fails
;
; Function GET-VALUE-RETURN returns the value of a variable, getting
; a value for it if it is UNKNOWN using GET-VALUE-OF. If GET-VALUE-OF
; is unsuccessful, GET-VALUE-RETURN still returns the variables value.
;
 (defun get-value-return (variable rules)
       (cond ((neq (eval variable) 'unknown) (eval variable))
             ((get-value-of variable rules) (eval variable))
             (t (eval variable))))    ;this line fires if GET-VALUE-OF fails
;
; Function $EQ combines GET-VALUE-RETURN and EQ
;
(defun $eq (var val rules)
       (get-value-return var rules)
       (eq var val))
;
; Function BIND-VARIABLES searches a list of MESSAGES
;  to set values for VARIABLES
;
; Format for defining the MESSAGES is:
;      (setq my-messages '((varnamel varvall)
;                                  :
;                        (varnamel varvall)))
; BIND-VARIABLES binds the value 'varvali' to the variable 'varnamei'
;
(defun bind-variables (variables messages)
       (do ((var (car variables) (car variables)) (messwipe) (flag)) ((null variables) flag)
           (setq variables (cdr variables))
           (setq messwipe messages)
           (cond ((eq messages 'lisp-listener) (and (ask-lisp-listener-about var) (go loop))))
           (do ((message (car messwipe) (car messwipe))) ((null messwipe))
               (setq messwipe (cdr messwipe))
;              (print var)
;              (print message)
;              (print variables)
;              (print variables)
               (cond ((eq (car message) var) (setq flag t)
                                             (set var (second message))
                                             (putt var (third message) 'airport)
                                             (putt var (fourth message) 'runways)
                                             (go loop))
```

```
                    ((null messwipe) (ask-lisp-listener-about var))))
;
;interactive variable bind, doesn't seem to give the right result here
;
;           (zl:cursorpos 'a)
;           (princ "COMMUNICATIONS: Please give me a value for")
;           (print var)
;           (princ "=")
;           (set var (read))
            loop))
;
;  Function SET-UP sets up a simulation of the current rulebase
;
(defun set-up ()
       (zl:cursorpos 'a)
       (princ "********************************************")
       (zl:cursorpos 'a)
       (princ "    SIMULATION OF THE CURRENT RULEBASE      ")
       (zl:cursorpos 'a)
       (princ " ")
       (zl:cursorpos 'a)
       (princ "  COMM-VARIABLES have been set to:")
       (zl:cursorpos 'a)
       (print comm-variables)
       (zl:cursorpos 'a)
       (princ " ... and the value of MESSAGES is:")
       (zl:cursorpos 'a)
       (print messages)
       (zl:cursorpos 'a)
       (princ "  PRESET-VARIABLES have been set to:")
       (zl:cursorpos 'a)
       (print preset-variables)
       (zl:cursorpos 'a)
       (princ " ... and the value of PRESET-MESSAGES is:")
       (zl:cursorpos 'a)
       (print preset-messages)
       (zl:cursorpos 'a)
       (princ " ")
       (zl:cursorpos 'a)
       (princ "  Well, here we go .....  ")
       (zl:cursorpos 'a)
       (princ " ")
       (zl:cursorpos 'a)
       (setq ksearch 0)
       (get-value-of 'executive-procedures-complete exec-rules))

;
; Function RUN-RULES runs the current rulebase
;
(defun run-rules ()
       (get-value-of 'executive-procedures-complete exec-rules))
;
; Function SIMULATE runs the simulation program ACRAFT.FORTRAN
;
(defun simulate ()
       (f77:execute ftn-user:acraft :units ((7 "ISAAC:>alex>out1.data") (8 "ISAAC:>alex>out2.data") (9 "ISAAC:>alex>out3.data")
                            (10 "ISAAC:>alex>out4.data"))))
;
; Function FETCH reutrns a property value of an A-LIST
;
```

```
(defun fetch (keyprop alist)
       (second (assoc keyprop alist)))
;
; Function PUT is just the zeta-lisp function PUTPROP
;
; syntax is : (put 'name-of-variable 'value-of-the-property 'name-of-the-property
;
; To get properties, use the C-LISP function GET
; syntax is : (get 'name-of-variable 'name-of-the-property)
;
(defun put (varname pval prop)
       (zl:putprop varname pval prop))
;
; Function PUTT is the smae as PUT except that it always returns T.
(defun putt (varname pval prop)
       (zl:putprop varname pval prop)
       't)
;
; Function WRITE-RULEDOC writes out the documentation for a rule base
;
(defun write-ruledoc (rules)
       (cond ((null rules) nil)
             ('t (and (zl:cursorpos 'a)
                      (princ " ")
                      (zl:cursorpos 'a)
                      (princ (if-doc (car rules)))
                      (zl:cursorpos 'a)
                      (princ (then-doc (car rules)))
                      (write-ruledoc (cdr rules))))))
;
;
;  Function MAKE-RULESPROP takes RULES and finds all rules that could
;  set the value of VAR (i.e. finds rules that have VAR as a member of their THEN-VARS).
;  It puts them into the 'RULES property of VAR.
;
(defun make-rulesprop (var rules)
       (cond ((null rules) nil)
             ((member var (then-vars (car rules))) (put var (cons (car rules) (get var 'rules)) 'rules)))
       (cond ((neq rules nil) (make-rulesprop var (cdr rules)))))
;
; Function MAKE-RULEBASE could be written now
;  would want to make new versions of g-v-o, g-v-r, r-v-o, etc.
;  I'll wait for now
;
;
; Function IS-IT-RELEVANT determines the relevance of an ALERT to
;  CURRENT-AIRPORT and RUNWAYS (and eventually FLIGHT-PATH)
;
(defun is-it-relevant (alert runway)
        (prog (flag)
        (cond ((eq (get alert 'airport) current-airport) (setq flag t))
              (t (return nil)))
        (cond ((member runway (get alert 'runways)) (return t))
              ((eq '(unknown) (get alert 'runways)) (return 'unknown))
              (t (return nil)))))
```

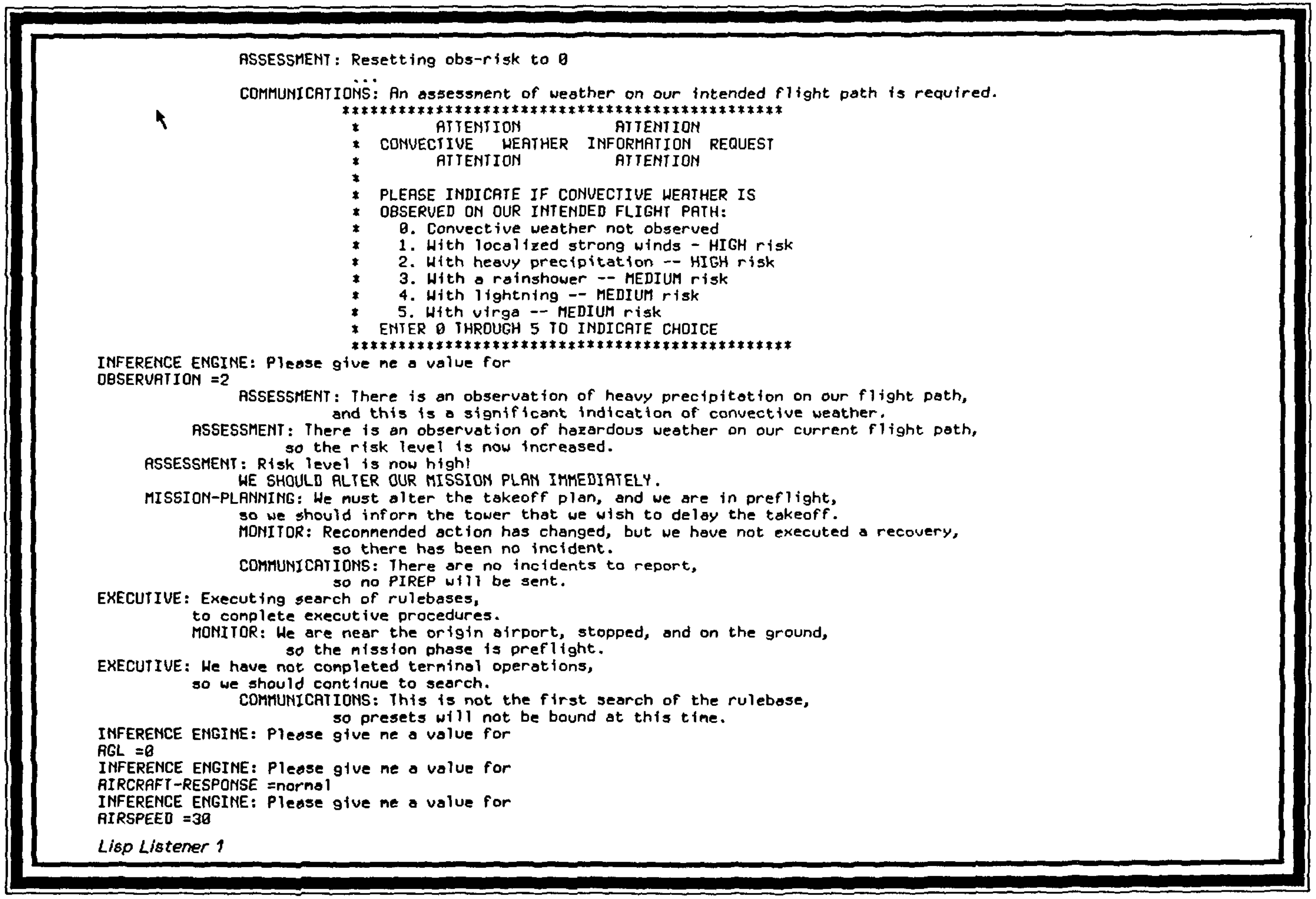
Appendix G

Typical Screen Displays from Wind Shear Expert System



```
Command: (simulate)
********************************************
    SIMULATION OF THE CURRENT RULEBASE

  COMM-VARIABLES have been set to:

(PIREP TOWER-REPORT LLWAS ONBOARD-RADAR WEATHER-REPORT)
 ... and the value of MESSAGES is:

((PIREP 0 NIL NIL) (TOWER-REPORT NIL NIL NIL) (LLWAS 0 NIL NIL) (ONBOARD-RADAR NIL NIL NIL) (WEATHER-REPORT NIL NIL NIL
))
  PRESET-VARIABLES have been set to:

(ALWAYS-BOTHER-THE-PILOT CURRENT-AIRPORT CRITICAL-AGL DECISION-AGL AIRCRAFT-TYPE VR-FIELD-LENGTH-LIMIT VR V1 ORIGIN-AIR
PORT DESTINATION-AIRPORT CURRENT-RUNWAY OLD-ACTION)
 ... and the value of PRESET-MESSAGES is:

((ALWAYS-BOTHER-THE-PILOT T NIL NIL) (CURRENT-AIRPORT DALLAS NIL NIL) (CRITICAL-AGL 200 NIL NIL) (DECISION-AGL 100 NIL
NIL) (AIRCRAFT-TYPE MD-80 NIL NIL) (VR-FIELD-LENGTH-LIMIT 120 NIL NIL) (VR 110 NIL NIL) (V1 80 NIL NIL) (ORIGIN-AIRPORT
 DALLAS NIL NIL) (DESTINATION-AIRPORT DENVER NIL NIL) (CURRENT-RUNWAY 26 NIL NIL) (OLD-ACTION CONTINUE))

  Well, here we go ......

EXECUTIVE: Executing search of rulebases,
          to complete executive procedures.
EXECUTIVE: We have not completed terminal operations,
          so we should continue to search.
               COMMUNICATIONS: This is the first search of the rulebase,
                         so presets will be bound at this time.
INFERENCE ENGINE: Please give me a value for
AGL =0
INFERENCE ENGINE: Please give me a value for
AIRCRAFT-RESPONSE =normal
INFERENCE ENGINE: Please give me a value for
AIRSPEED =0
INFERENCE ENGINE: Please give me a value for
RUNWAY-REMAINING =10000
          MONITOR: We are near the origin airport, stopped, and on the ground,
                    so the mission phase is preflight.
               COMMUNICATIONS: An important message was received,
                         so there is new information for situation assessment.
          MONITOR: Aircraft response is not abnormal,
                    so there is no windshear alert at this time.
          ASSESSMENT: Setting value of risk to 0
                      ...
**MORE**█
Lisp Listener 1
```

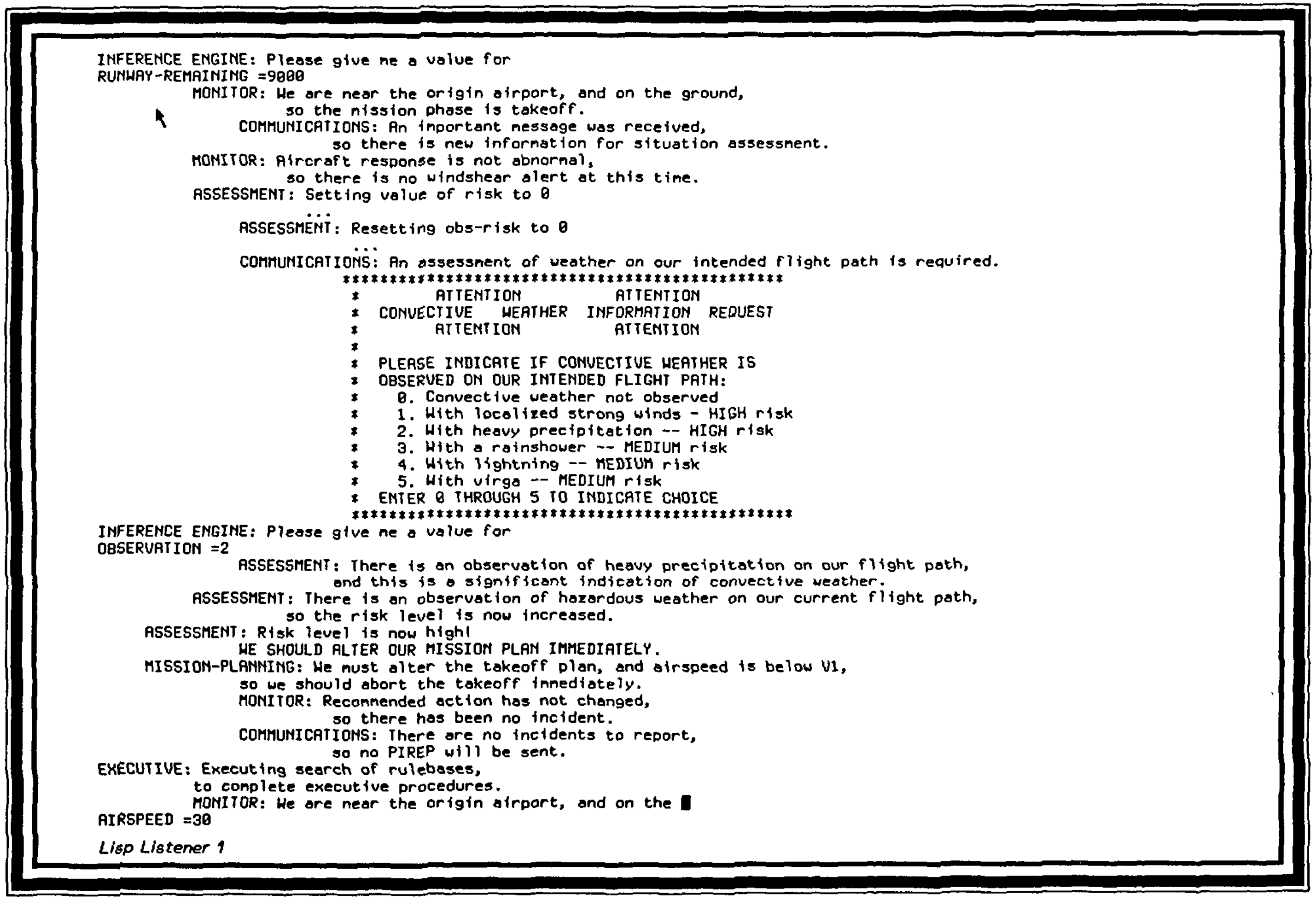
ORIGINAL PAGE IS
OF POOR QUALITY



```
               ASSESSMENT: Resetting obs-risk to 0
                           ...
               COMMUNICATIONS: An assessment of weather on our intended flight path is required.
                          ***********************************************
                           *        ATTENTION          ATTENTION
                           *  CONVECTIVE   WEATHER  INFORMATION  REQUEST
                           *        ATTENTION          ATTENTION
                           *
                           *  PLEASE INDICATE IF CONVECTIVE WEATHER IS
                           *  OBSERVED ON OUR INTENDED FLIGHT PATH:
                           *    0. Convective weather not observed
                           *    1. With localized strong winds - HIGH risk
                           *    2. With heavy precipitation -- HIGH risk
                           *    3. With a rainshower -- MEDIUM risk
                           *    4. With lightning -- MEDIUM risk
                           *    5. With virga -- MEDIUM risk
                           *  ENTER 0 THROUGH 5 TO INDICATE CHOICE
                           ***********************************************
INFERENCE ENGINE: Please give me a value for
OBSERVATION =2
               ASSESSMENT: There is an observation of heavy precipitation on our flight path,
                         and this is a significant indication of convective weather.
          ASSESSMENT: There is an observation of hazardous weather on our current flight path,
                    so the risk level is now increased.
     ASSESSMENT: Risk level is now high!
               WE SHOULD ALTER OUR MISSION PLAN IMMEDIATELY.
     MISSION-PLANNING: We must alter the takeoff plan, and we are in preflight,
               so we should inform the tower that we wish to delay the takeoff.
               MONITOR: Recommended action has changed, but we have not executed a recovery,
                         so there has been no incident.
               COMMUNICATIONS: There are no incidents to report,
                         so no PIREP will be sent.
EXECUTIVE: Executing search of rulebases,
          to complete executive procedures.
          MONITOR: We are near the origin airport, stopped, and on the ground,
                    so the mission phase is preflight.
EXECUTIVE: We have not completed terminal operations,
          so we should continue to search.
               COMMUNICATIONS: This is not the first search of the rulebase,
                         so presets will not be bound at this time.
INFERENCE ENGINE: Please give me a value for
AGL =0
INFERENCE ENGINE: Please give me a value for
AIRCRAFT-RESPONSE =normal
INFERENCE ENGINE: Please give me a value for
AIRSPEED =30
```

Lisp Listener 1

ORIGINAL PAGE IS
OF POOR QUALITY



```
INFERENCE ENGINE: Please give me a value for
RUNWAY-REMAINING =9000
          MONITOR: We are near the origin airport, and on the ground,
                    so the mission phase is takeoff.
               COMMUNICATIONS: An important message was received,
                         so there is new information for situation assessment.
          MONITOR: Aircraft response is not abnormal,
                    so there is no windshear alert at this time.
          ASSESSMENT: Setting value of risk to 0
                      ...
               ASSESSMENT: Resetting obs-risk to 0
                           ...
               COMMUNICATIONS: An assessment of weather on our intended flight path is required.
                          ***********************************************
                           *        ATTENTION          ATTENTION
                           *  CONVECTIVE   WEATHER  INFORMATION  REQUEST
                           *        ATTENTION          ATTENTION
                           *
                           *  PLEASE INDICATE IF CONVECTIVE WEATHER IS
                           *  OBSERVED ON OUR INTENDED FLIGHT PATH:
                           *    0. Convective weather not observed
                           *    1. With localized strong winds - HIGH risk
                           *    2. With heavy precipitation -- HIGH risk
                           *    3. With a rainshower -- MEDIUM risk
                           *    4. With lightning -- MEDIUM risk
                           *    5. With virga -- MEDIUM risk
                           *  ENTER 0 THROUGH 5 TO INDICATE CHOICE
                           ***********************************************
INFERENCE ENGINE: Please give me a value for
OBSERVATION =2
               ASSESSMENT: There is an observation of heavy precipitation on our flight path,
                         and this is a significant indication of convective weather.
          ASSESSMENT: There is an observation of hazardous weather on our current flight path,
                    so the risk level is now increased.
     ASSESSMENT: Risk level is now high!
               WE SHOULD ALTER OUR MISSION PLAN IMMEDIATELY.
     MISSION-PLANNING: We must alter the takeoff plan, and airspeed is below V1,
               so we should abort the takeoff immediately.
               MONITOR: Recommended action has not changed,
                         so there has been no incident.
               COMMUNICATIONS: There are no incidents to report,
                         so no PIREP will be sent.
EXECUTIVE: Executing search of rulebases,
          to complete executive procedures.
          MONITOR: We are near the origin airport, and on the
AIRSPEED =30
```

Appendix H

Charts for Program Status Report, June, 1988

INTELLIGENT GUIDANCE AND CONTROL FOR WINDSHEAR ENCOUNTERS

INTRODUCTION AND PROGRESS REPORT

Alex Stratton
Princeton University
June 23-24, 1988

Overview

- Introduction
- Expert System Development
- Plans for Future Work

Motivation for the Study

- Strong windshears, especially microbursts, can cause fatal accidents

- Pilot proficiency in coping with microburst windshear is difficult given rarity of phenomenon

- Proper decision making and control strategy can enhance the possibility of avoidance and survival

- F.A.A. Pilot Windshear Guide establishes such a strategy

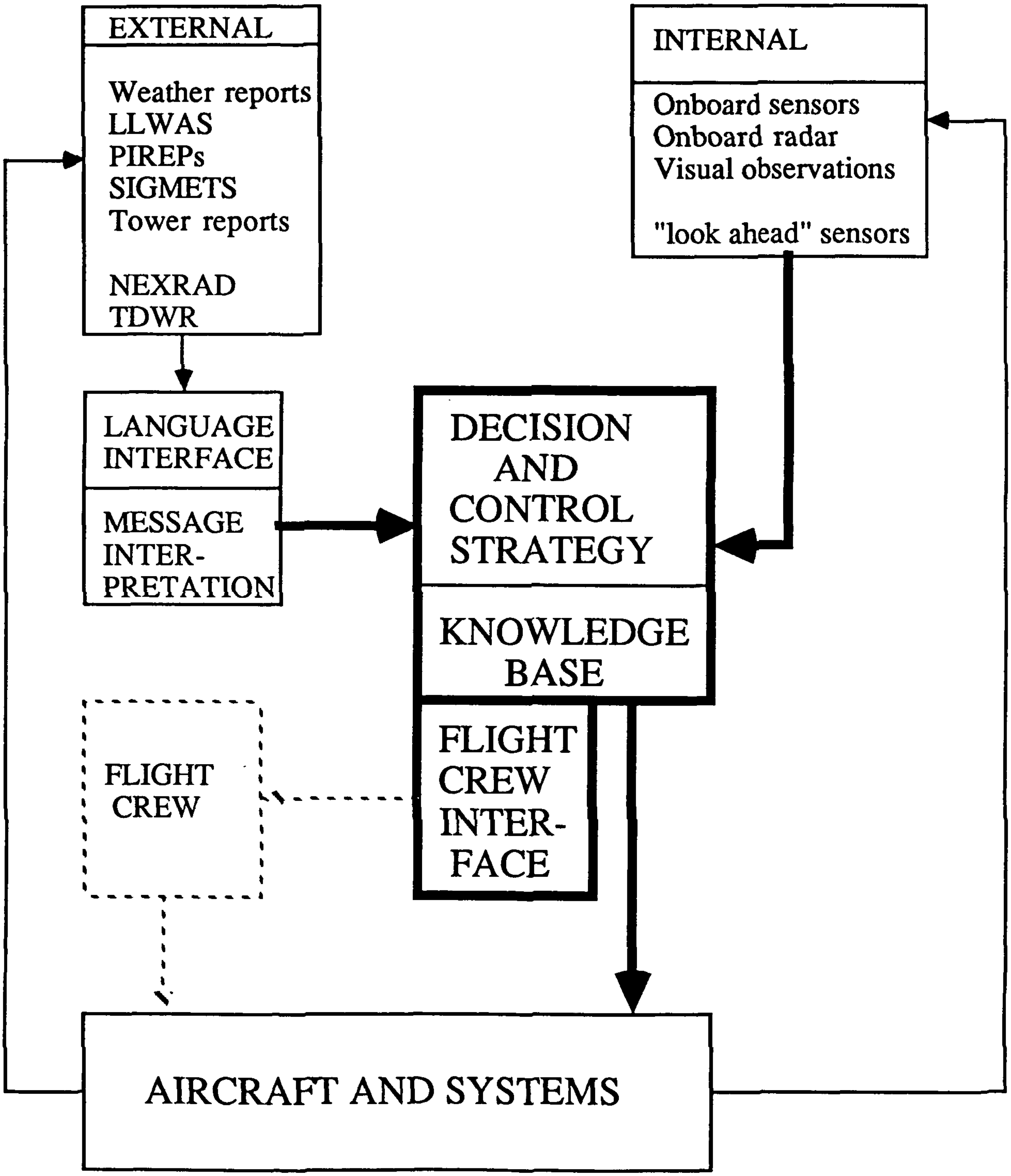
Intelligent G&C Research Goals

- Implement the Pilot Windshear Guide pilot and crew model as a rule-based (intelligent) controller

- Investigate guidance and control concepts applied to windshear encounters

- Develop a rule-based pilot aid for windshear survival

Rule-based Pilot Aid - Schematic



EXTERNAL

Weather reports
LLWAS
PIREPs
SIGMETS
Tower reports

NEXRAD
TDWR

INTERNAL

Onboard sensors
Onboard radar
Visual observations

"look ahead" sensors

LANGUAGE INTERFACE

MESSAGE INTER-PRETATION

DECISION AND CONTROL STRATEGY

KNOWLEDGE BASE

FLIGHT CREW INTER-FACE

FLIGHT CREW

AIRCRAFT AND SYSTEMS

Sources of Decision and Control Knowledge

- Prior knowledge of windfield - Optimal control laws
- No knowledge of windfield - Strategy based on current knowledge in cockpit - Pilot Windshear Guide

Pilot Windshear Guide

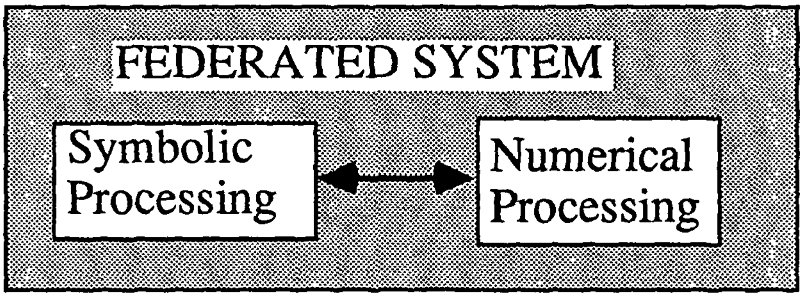
- Completed as part of the FAA's Windshear Training Aid

- Reference guide for flight crews detailing windshear avoidance, recognition, and recovery techniques

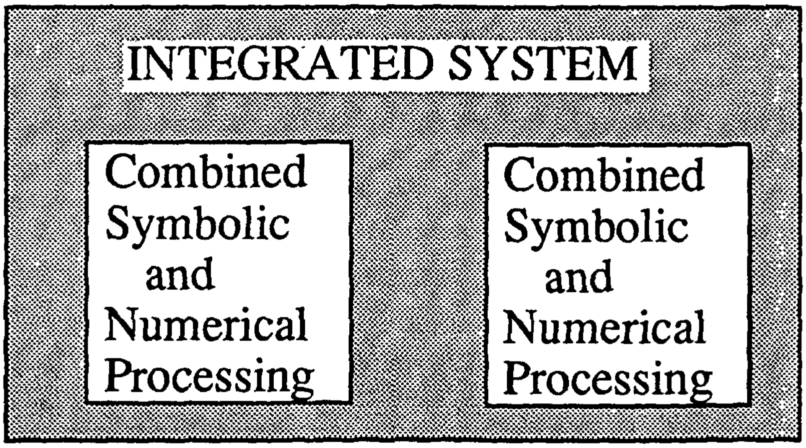
- Provides a model of pilot and crew decision-making that increases flight safety

Rule-based Systems for Control

- Federated systems - Symbolic supervisory control
  Separate numeric processing



- Integrated systems - Combined symbolic and numeric control


INTEGRATED SYSTEM
Combined Symbolic and Numerical Processing
Combined Symbolic and Numerical Processing

Expert System Control Functions

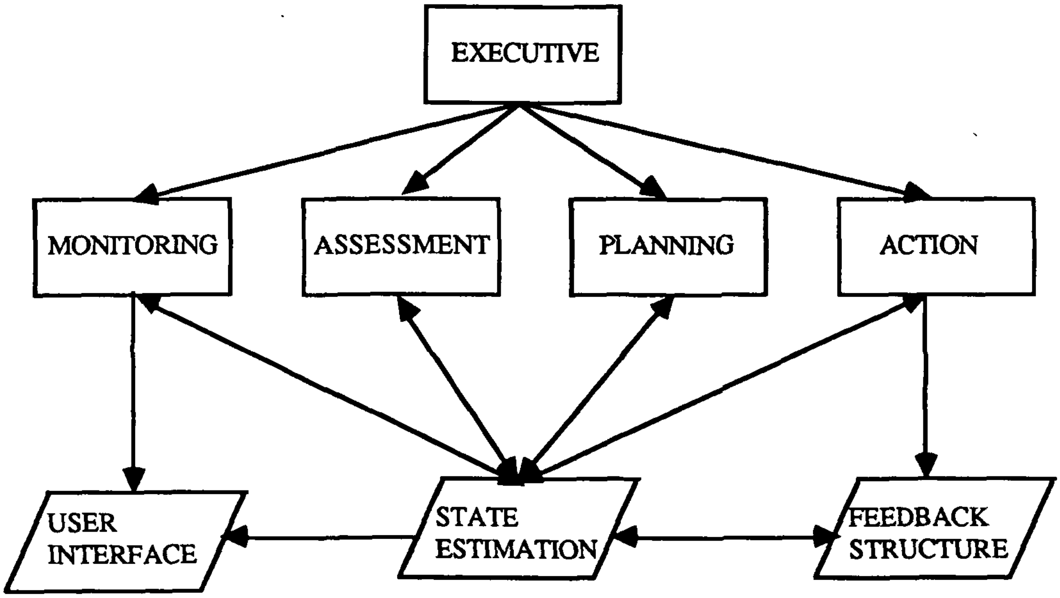
- MONITORING

- ASSESSMENT -- INTERPRETATION -- DIAGNOSIS

- PREDICTION -- PLANNING

- ACTION -- CONTROL

Expert System General Structure



Monitoring and Assessment

- MONITORING -
  Observe onboard sensors
  Receive reports, alerts, warnings
  Send reports, communicate with flight crew

- ASSESSMENT -
  Determine the risk of continuing
  Decide if the flight plan should be altered
  Decide if windshear has been encountered

Planning and Action

- PLANNING -
  Delay or abort terminal operations if necessary
  Take additional safety precautions

- ACTION -
  Select and implement guidance and control laws
  Send commands to control surfaces and throttle

Expert System Implementation

- LISP -- Knowledge representation, symbolic processing

- FORTRAN -- Numerical procedures, algorithms

- Symbolics 3670 LISP Machine

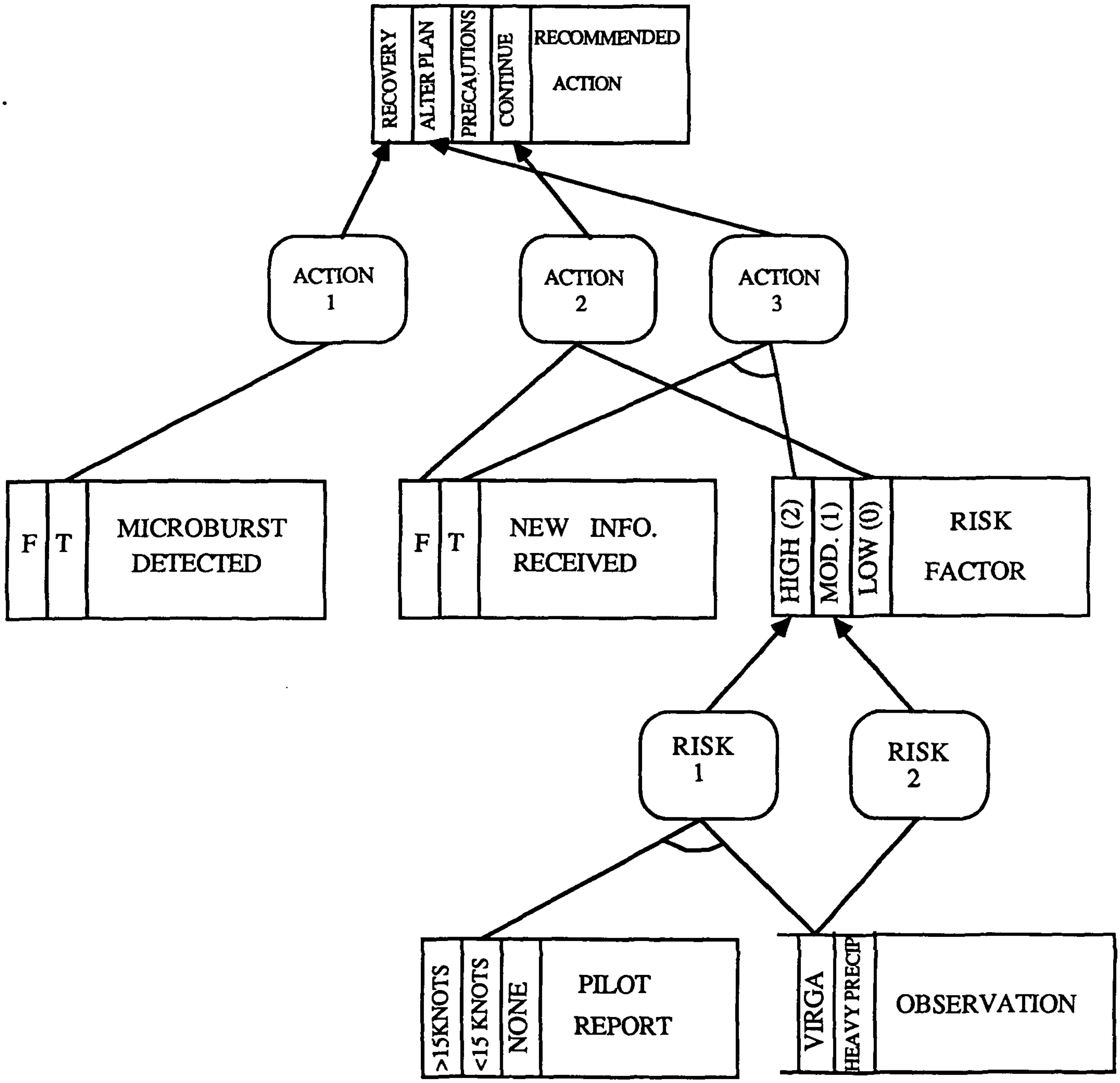
Flow of Control Driven By Goal-Directed Search Procedure

- Basic search procedure evaluates rules to set the value of a goal parameter

- Search procedure is often involked in the premise of a rule, resulting in backward-chaining

- More complicated search procedures are built with the basic procedure

Graphical Representation of Search



Example of Knowledge Acquisition

PILOT WINDSHEAR GUIDE STATEMENT:

"The choice of takeofff flap selection is dependant on the airplane type. The following should be considered unless limited by obstacle clearance and/or climb gradient:

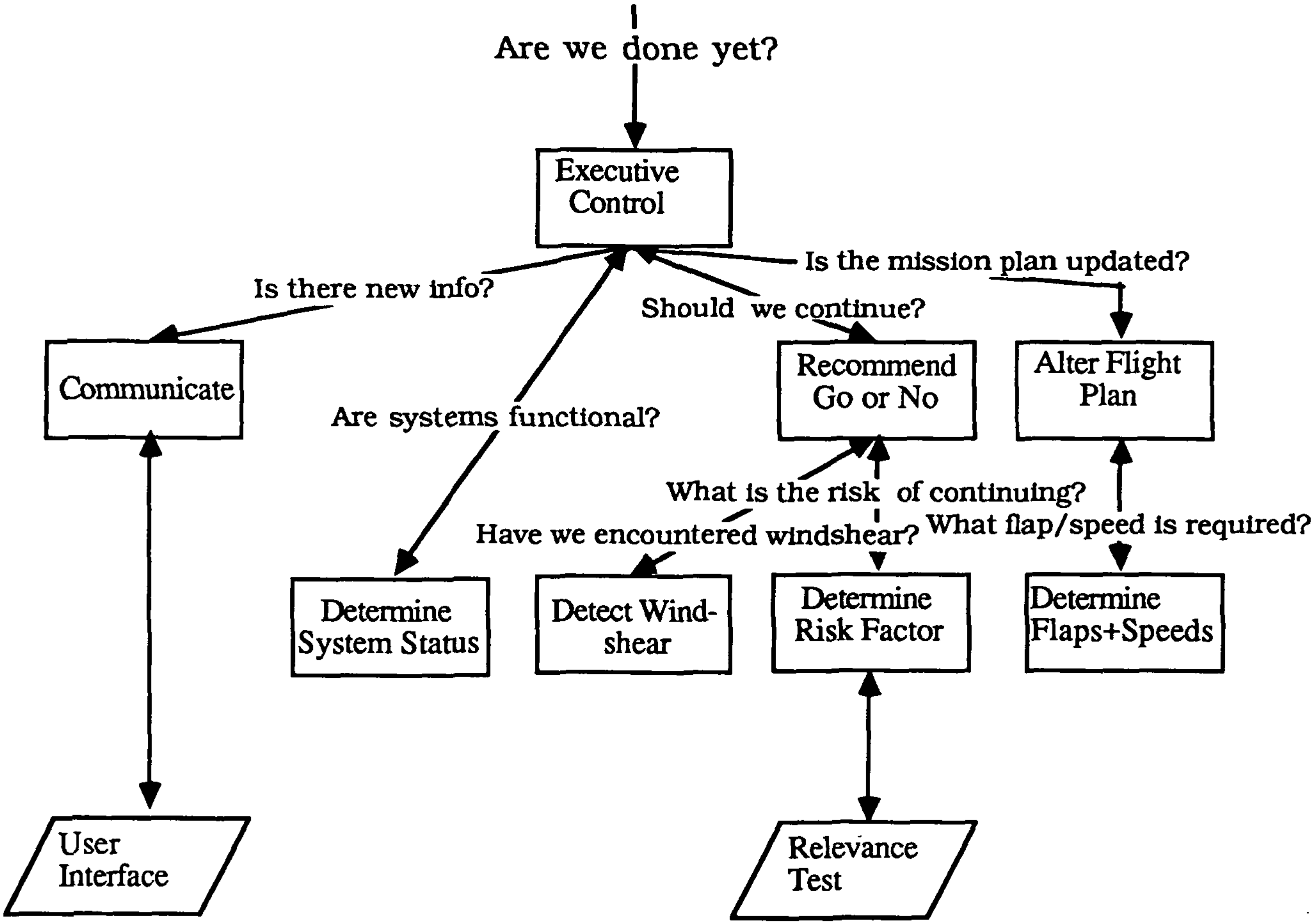
Airplane Type	Takeoff Flap Setting
B727	15
B737	5 to 15
:	:

"

PSEUDO-LISP TRANSLATION:

```
IF recommended-action equals "take-precautions"
   AND aircraft-type equals "B727"

THEN set recommended-flap-setting to "15"
```

Expert System Detailed Structure



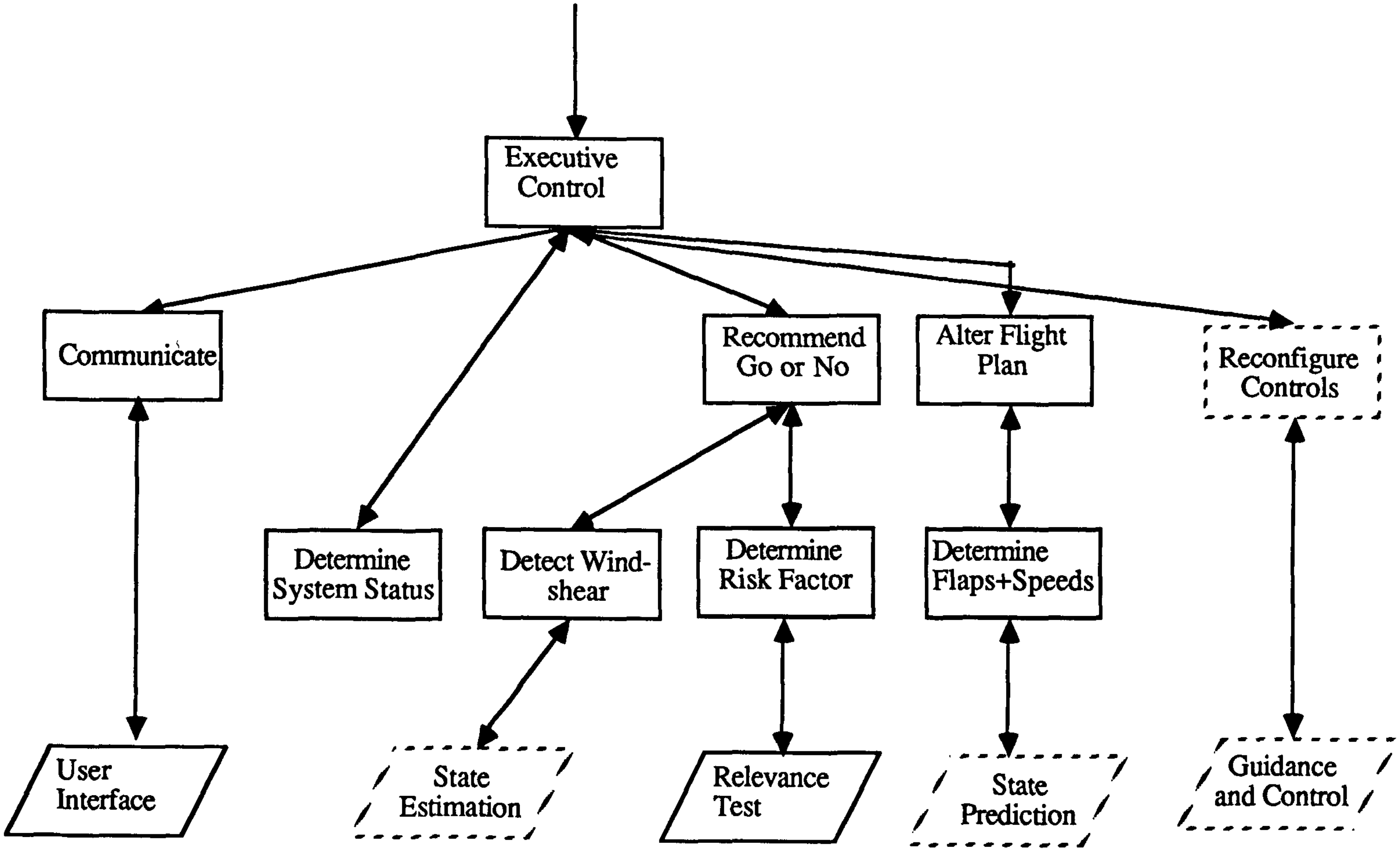
Next Additions to Expert System

- FORTRAN procedures and simulation environment will be completed next

- Low-level rules to interface FORTRAN procedures will complete knowledge base for Pilot Windshear Guide

- Improved user interface will aid the understanding and further development of expert system pilot aid

Next Additions to Expert System



Plans for Future Work

- Consider impact of next-generation sensors and ATC
- Real-time implementation of RBC
- Consider pilot/RBC interface