notion is particularly reflected in the Research, Engineering and Development Plan which is driving toward an ultimate system called "Flow Management". The message which must be stated emphatically is the need to influence the direction which system planners within and outside the FAA must take to incorporate AI efficiently into airspace management. Again, a goal of unconstrained operation to airspace users must be the rule.

ARTIFICIAL INTELLIGENCE AND OTHER ASPECTS OF AIR TRAFFIC CONTROL

Robert W. Crosby, Federal Aviation Administration

Much of the attention of the artificial intelligence (AI) workshop was focused on direct air traffic control (ATC) issues: conflict resolution, flow control, and weather prediction. This was entirely proper, and the Federal Aviation Administration (FAA) advanced automation program fully concurs with this emphasis. However, rather than reiterate the contributions of others, it would be preferable to use this opportunity as a means of establishing the potential benefit of AI in some of the less direct, but equally important, aspects of ATC. Specifically, the following three topics are suggested: software (SW) design, system repair and maintenance, and training.

Software Design

The reliability of the advanced automated system (and its successors) will be critically dependent on the SW design. Because of the extremely high reliability desired, on the one hand, and the complexity of the SW on the other, it is essential that techniques be used that: 1) minimize the number of hidden faults inadvertently designed into the system; and 2) provide fault tolerance for those that remain. Existing design methods may be enhanced substantially by incorporating AI techniques. Two such techniques come to mind immediately: the use of intelligent search techniques to explore a branching SW tree; and knowledge based systems that make use of expert techniques to solve complex SW design problems.

System Repair and Maintenance

The availability of the ATC system depends critically on rapid failure detection, isolation, and repair. As experience is accumulated on failures, it is likely that this knowledge can be incorporated into an expert system that will reduce system repair time significantly. A second area relates to the detection of incipient expert failures. Again, based upon accumulated knowledge, it should be possible to anticipate many hardware (HW) failures with aid of an expert system. As an aid to maintenance personnel, AI techniques can improve both system performance and personnel productivity.

Training

For the foreseeable future the ATC system will be operated primarily by controllers, with automation being used to aid them, particularly in performing routine tasks. The training of controllers, as well as the operating and maintenance personnel who support them, is thus a key link in the performance of the system. Computer based instruction (CBI) has been used by the FAA for over a decade in the training of these personnel. However, existing CBI, through rote learning techniques, seeks primarily to reduce the number of instructors required for training. Although rote learning may be suitable for routine tasks, the successful operation of the ATC system also requires, from time to time, innovative solutions to new or unpredictable events. As the degree of automation of the ATC system increases this need can be expected to increase. CBI based upon rote learning tends to reject those people who are good at innovation, but bored by routine. Obviously, the ATC system needs both types of people. New and more powerful CBI techniques are now being explored that make use of AI techniques to provide a more versatile learning environment. The development of such a training system for the FAA should be given high priority.

AIRPAC: ADVISOR FOR INTELLIGENT RESOLUTION OF PREDICTED AIRCRAFT CONFLICTS

Curtis A. Shively, Mitre Corporation

SUMMARY

AIRPAC is an expert system being developed to assist air traffic controllers with the planning of resolutions for predicted violations of safe separation or "conflicts" between aircraft. AIRPAC uses knowledge-based system (KBS) techniques to suggest aircraft maneuvers that will prevent a conflict. AIRPAC's choice of a resolution is based on decision rules gathered via consultations with air traffic controllers. By applying these rules to a description of the conflict, AIRPAC produces a single "best" resolution that includes detailed parameters of the recommended aircraft maneuvers. To plan resolutions, AIRPAC uses a hierarchical approach similar to the nested levels of abstraction in a human reasoning process. AIRPAC explains its operation by providing an audit trail of rules used in the search for a resolution. This explanation capability and the representation of resolution rationale in symbolic terms natural to humans are significant benefits provided by the KBS approach.

Introduction

The Federal Aviation Administration (FAA) is undertaking the development of the automated en route air traffic control (AERA) system (1). AERA is intended to automate many of the routine tasks performed by today's air traffic controllers. AERA will also provide computer-based tools for assisting controllers with the more complex planning and control functions requiring human intervention. An important purpose of the U.S. air traffic control (ATC) system is to assure that aircraft are safely separated from one another. An objective of AERA is to predict potential violations of safe separation or "conflicts" between aircraft ten to twenty minutes in advance. These predictions will be based on aircraft flight plans, wind observations, anticipated pilot or controller actions, and other information. If a conflict is predicted with sufficient lead time, AERA can suggest aircraft maneuvers to resolve it in a way that reflects desirable considerations beyond avoidance of imminent collision. The capability to predict aircraft conflicts and plan their resolutions in advance is expected to increase controller productivity and permit more airspace users to fly the routes they prefer.

Some previous work has been done toward automating the resolution of aircraft conflicts. FAA sponsored research on developing the AERA system has included the experimental implementation of a conventional numerical algorithm for selecting conflict resolutions based on numerical weighting factors. Some research on using KBS techniques for planning conflict resolutions has been done in the university environment (2) (3). The AIRPAC system (4) (5) described in this paper is the result of an independent research and development project conducted by the Mitre Corporation to investigate the general feasibility of applying KBS techniques to automation of ATC functions. AIRPAC includes knowledge gleaned from previous work on automating conflict resolution, as well as from new consultations with air traffic controllers who were shown the program at various stages of its development.

AIRPAC's Approach

AIRPAC assumes that other processes can model aircraft trajectories and predict future aircraft conflicts. AIRPAC focuses on the selection of aircraft maneuvers that will resolve the given problem. Some simple approximation of resolution trajectories is done by AIRPAC in order to check basic feasibility of a proposed resolution. However, it is assumed that AIRPAC's resolutions are passed through other trajectory modeling and conflict prediction processes to be certain that the given problem would be resolved and no new conflicts would be generated.

As of this writing, AIRPAC deals with the following types of conflict situations:

- one-vs-one - a single conflict between two aircraft, isolated from their other conflicts in the ATC sector
- one-vs-two - two conflicts, separated somewhat in time and space, but sharing a common aircraft
- three-at-once - three conflicts among three aircraft, each in conflict with the other two at about the same time and place.

A resolution consists of maneuvers for one or more aircraft that will prevent the predicted violation(s) of safe separation. In the en route phase of flight, two aircraft are considered to be safely separated if they are five nautical miles apart in the horizontal dimension or 1,000 feet (2,000 feet at high altitudes) apart in the vertical dimension. A conflict occurs between the two aircraft if separation criteria are violated in both dimensions at the same time. Therefore, resolution techniques are intended to assure separation in one or the other of these two dimensions.

Resolution Tactics

AIRPAC uses the following basic resolution tactics:

Horizontal

- Delay vector - turn off route, parallel, then back to route
- Delay route bend - continue original heading, delaying turn
- Vector around - turn off route, pass parallel to conflicting aircraft then back to route
- Vector both around - both aircraft, to opposite sides of route
- Vector behind - turn toward, then behind conflicting aircraft
- Vector cutting bend - turn and proceed directly to the navigation fix after a route bend.

Vertical

- Change altitude - climb (descend) to new higher (lower) cruise altitude
- Restrict climb - level off to pass below conflicting aircraft
- Restrict descent - level off to pass above conflicting aircraft
- Early descent - start descent early, to pass below conflicting aircraft.

AIRPAC can also recommend a speed change to achieve a resolution by merely altering the timing of an aircraft along its original path.

Each basic tactic shown above may imply a sequence of several maneuvers. For example, the restrict climb tactic includes a maneuver to level off followed by a maneuver to resume climbing once the conflicting aircraft has passed safely above. AIRPAC is intended to plan resolutions well in advance, before the conflicts represent imminent problems. Consequently, AIRPAC suggests a complete sequence of maneuvers to avoid the conflict and return any diverted aircraft to its originally intended route, destination, altitude or altitude transition.

Resolution Factors

AIRPAC attempts to assess the relative merits of various alternative resolutions. Each alternative represents choosing both the aircraft (one or more) to divert and the corresponding tactic to use. In AIRPAC these choices are based on factors such as the following:

- Conflict geometry - crossing, head-on, merging, overtake
- Aircraft intent - arrival, departure, overflight
- Aircraft speeds and relative positions
- Aircraft performance characteristics and limits
- Bends in aircraft route
- Intent and destination after the conflict
- Lead time before the conflict.

In considering these factors, it is desirable to recognize particular aspects of the conflict situation that might immediately suggest a good resolution. Suppose, for example, that an aircraft has a bend in its route shortly after the conflict region. An experienced human controller might immediately consider the possibility of diverting that aircraft directly to the next navigation fix after the route bend. Such a tactic would provide the double benefit of both preventing the conflict and shortening the path of the diverted aircraft to its desired destination. In this manner, the human controller has formulated a plan that considers broad, non-numeric aspects of the conflict situation and achieves multiple goals.

AIRPAC attempts to embody such reasoning abilities exhibited by human controllers. To that end AIRPAC's approach to finding resolution is based on the following principles:

- Recognize a multi-conflict situation (three-at-once or one-vs-two) and try to resolve it as a complete set.

- If this fails, try to resolve the individual one-vs-one conflicts in their order of occurrence in time.
- Whether a set is multi-conflict or one-vs-one, look first for a particular aspect of the situation that suggests a tactic achieving several goals at once.
- At each decision point, consider first the alternative which is believed a priori to be best.
- Stop the search as soon as a feasible resolution is found.

The decision to stop AIRPAC's search with the first successful resolution is somewhat arbitrary. Whether the controller should be presented only the "best resolution" or several viable alternatives remains an open question.

Hierarchical Planning

In AIRPAC the planning of resolutions proceeds according to the following steps:

- Problem decomposition
- Tactic selection
- Tactic development
- Maneuver parameter calculation.

These steps represent a hierarchy or different levels of abstraction, corresponding to refining and specifying the resolution in more and more detail.

In the problem decomposition step AIRPAC recognizes whether the given conflict set involves multiple conflicts. For a three-at-once conflict set, AIRPAC suggests a strategy for reducing the problem to a single one-vs-one conflict by maneuvering one particular aircraft away from the situation. In the case of a one-vs-one conflict set, the common aircraft is initially designated as the aircraft to be maneuvered before tactic selection begins.

During tactic selection, AIRPAC evaluates various alternatives for choice of aircraft to maneuver (unless already specified) and tactic to use. Alternatives initially considered are motivated by special factors such as aircraft route bends, if present. Otherwise tactics are proposed according to various cases of conflict situations, characterized by combinations of conflict geometry and intent of the involved aircraft.

Each resolution alternative selected for consideration is further evaluated by the tactic development process. In this phase a basic tactic such as "change altitude" may be further expanded into two possible subtactics, "go higher" and "go lower". Checks on the feasibility of the tactic are performed. For example, in the case of a go higher tactic, the intended altitude would be checked against the maximum cruise altitude of the given type of aircraft. Such checks may be done both before and after maneuver parameter calculation.

During maneuver parameter calculation parameters for the individual maneuvers in the resolution tactic are determined. These parameters include maneuver start and end times, turn angles for horizontal vectors and restrictions of target altitudes for vertical maneuvers.

Knowledge Representation and Application

Much of AIRPAC's resolution knowledge for problem decomposition, tactic selection and tactic development is represented by IF-THEN production rules. If all antecedent clauses of a rule are satisfied, THEN the rule can be "fired" and its consequent clause(s) carried out. As of this writing AIRPAC includes 98 such rules.

AIRPAC's rules operate on information stored in data structures known as frames (6). In a frame the individual piece of information about a particular entity is stored as values in "slots" accessed via reference to the frame name. AIRPAC uses frames to represent the description of the given conflict problem and the details of the resolution being planned. Static knowledge such as the performance characteristics of various types of aircraft are also stored in frames. AIRPAC's rules themselves are actually represented in frames also.

An example of an AIRPAC rule (slightly simplified) is shown below:

```
IF (in-frame CONFLICT involved -ac -a)
AND (in-frame -a route-bend-after-conflict)
THEN (try vector-cutting-bend with air-
   craft-to-maneuver -a).
```

This rule applies if an aircraft involved in the conflict has a route bend after the conflict. If such an aircraft is found, the rule consequent ("THEN" clause) recommends resolving the conflict via a "vector cutting bend" tactic supplied to that aircraft.

The operation of this rule is as follows. The first antecedent of the rule examines the frame for the conflict to be resolved, shown here as frame "CONFLICT" for simplicity. In that frame are stored the names of the two aircraft involved in the conflict. The variable "-a" is associated with one of these aircraft and its frame examined by the second antecedent. If that aircraft has a route bend after the conflict, the rule can be fired and its consequence carried out. Otherwise the test is repeated for the other aircraft in the conflict.

For convenience in focusing the scope of rule applications AIRPAC's rules are grouped into rule sets. At each step of resolution planning, AIRPAC considers rules in only a single rule set for possible firing. Since all rules in a set are not necessarily mutually exclusive, more than one rule could be eligible for firing (all antecedents are satisfied). AIRPAC prefers to fire rules in the order in which they are originally defined to be members of the rule set. Thus the relative preference desired for various resolution alternatives can be represented by the ordering of rules within AIRPAC's rule sets.

Many of AIRPAC's rules are designed to explicitly redirect the search for rules that can be fired. For example, the "try" term in the consequent of the above rule transfers the search to the "vector-cutting-bend" set of rules. The "with" clause in that rule's consequent designates the aircraft with the route bend as the "aircraft-to-maneuver" via the vector cutting bend tactic.

As of this writing AIRPAC includes 26 rule sets which are organized according to the hierarchical planning steps outlined above. AIRPAC's control mechanism begins the search for a resolution in the set of problem decomposition rules. These rules recognize whether the basic conflict situation is three-at-once, one-vs-two, or one-vs-one and direct the search to the corresponding rule set for tactic selection. A single tactic applied to a particular aircraft may be immediately proposed for evaluation, if that aircraft has a special attribute such as a route bend. Otherwise tactic selection is directed to a rule set designed for the given conflict geometry, i.e., crossing, head-on, merging or overtake.

Rules in the set for a particular conflict geometry are mutually exclusive, corresponding to different combinations of aircraft intent (e.g., arrival versus departure) and other factors. The rule that applies to the given situation suggests a list of resolution alternatives (both tactic and aircraft) in the order preferred for evaluation.

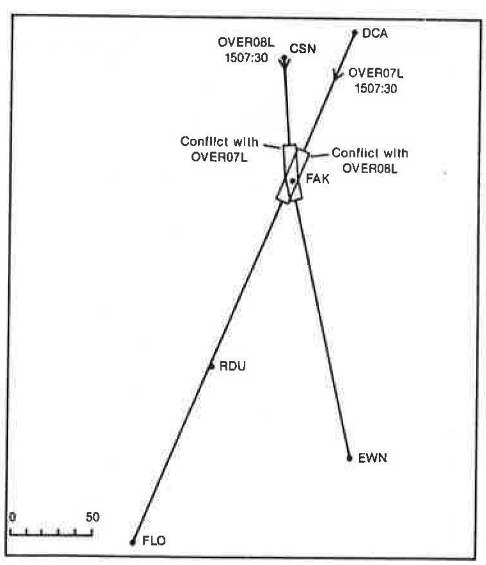
Evaluation of a resolution alternative is accomplished by rules in the development rule set for the proposed tactic. If the tactic passes all tests and parameters for its maneuvers are computed successfully, the alternative becomes the recommended resolution and the search is terminated. If necessary, each proposed alternative is evaluated in turn, until a successful one is found or all are exhausted. If this list is exhausted without success, AIRPAC terminates the search without finding a resolution to the conflict. In this manner AIRPAC employs a depth first method to search forward from the description of the conflict to details of a resolution plan.

Implementation

AIRPAC has been implemented using an integrated representation and inferencing system (IRIS) (7) developed at Mitre. Written in LISP, IRIS provides a variety of programming paradigms based on a common underlying frame representation language (FRL) (8). In addition to production rules and forward chaining IRIS also supports objects, active values and of course the usual procedural programming capabilities of LISP. AIRPAC was originally programmed in Franz Lisp (9) on a VAX 11/780 computer in Mitre's command and management information systems (CAMIS) laboratory. The software for AIRPAC has also been translated into Zetalisp (10) for execution on a special purpose LISP computer.

At no time during the development of AIRPAC have any attempts been made to optimize its run time efficiency other than executing the LISP code compiled rather than interpreted. However, it is interesting to note that for the example given later in this paper execution time on the VAX 11/780 was about 30 seconds. This was reduced to just several seconds on the LISP computer. Further execution speed improvements are likely to result from eliminating some features of IRIS, included for generality but not used by AIRPAC.

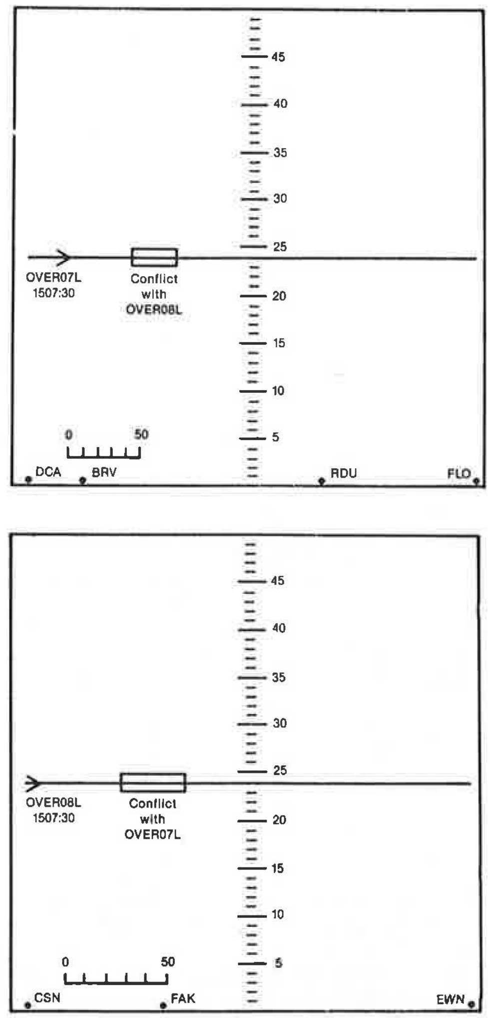
Figure 1. Horizontal plan view of aircraft trajectories in a conflict scenario.



OVER07L
DCA BRV RDU FLO 24000 240
OVER08L
CSN FAK EWN 24000 240

The Facts:
Conflict-Type Crossing OVER07L OVER08L
Intent Overflight OVER07L
Intent Overflight OVER08L
Time-to-Conflict 10.0
Start-of-Conflict 15 17 29
End-of-Conflict 15 24 50
Time-at-Crossing OVER07L 15 21 25
Time-at-Crossing OVER08L 15 21 44

Figure 2. Vertical profile view of a conflict scenario.



Examples of Conflict Resolution

An example of a one-versus-one conflict situation is shown in Figures 1 and 2. Figure 1 shows a horizontal plan view of the aircraft trajectories and Figure 2 shows altitude versus distance along route for each aircraft. On the horizontal view a "conflict box" encloses that part of each aircraft's route wherein a violation of safe horizontal separation from the other aircraft is predicted to occur. On the profile view of each aircraft the conflict box illustrates a vertical protection buffer around the altitude of the other aircraft while the two will be violating the horizontal separation standard. Arrows in both figures show the position of each aircraft at the time (15:07:30) when the resolution planning is being done.

Figure 3. Example of AIRPAC solution tree.

0.	solution	
	1. solve-conflict-set	success
	2. one-versus-one	success
	3. ovo-crossing	success
	4. vector-behind OVERO8L	success
	4. delay-vector OVERO8L	success
	5. right OVERO8L	success
	5. parallel OVERO8L	success
	5. left OVERO8L	success

Salient facts describing the conflict situation are shown at the bottom of Figure 1. Two overflight aircraft, OVERO7L and OVERO8L, are involved in a crossing conflict where their routes interact near the navigation fix at FAK. Route information indicates that both aircraft are level at 24,000 feet and traveling at 240 knots. The starting time of the conflict is indicated as 15:17:30, giving a lead time of about 10 minutes to plan and execute a resolution. Note from the "time-at-crossing" facts that OVERO8L is predicted to reach the route intersection point about 19 seconds later than OVERO71,

Figure 3 shows AIRPAC's resolution to this conflict in nested levels corresponding to the steps in hierarchical planning. From the figure it can be seen that the search progressed through rules in the "solve-conflict-set", "one-versus-one" and "ovo-crossing" rule sets. AIRPAC first evaluated a vector behind tactic whereby aircraft OVERO8L would turn to its left just prior to the conflict region and pass behind OVERO71. This tactic was declared to be a failure.

However, the second alternative, a delay vector for OVERO8L, passed all tests and thus the search terminated with success at all levels of the planning. A complete trace of the rules triggered (omitted here for brevity) would reveal that AIRPAC gave preference to maneuvers for OVERO8L because it was predicted to be later at the route intersection than aircraft OVERO7L.

The delay vector tactic includes a turn right, turn parallel, followed by a turn left to rejoin the original route. Figure 4 shows a horizontal plan view of the conflict situation with these resolution maneuvers included. Parameters for the resolution have been selected so that aircraft OVERO81 will reach the route intersection at the revised time of 15:23:55, 2.5 minutes later than OVERO71. At aircraft speeds of 240 knots, this amount of delay corresponds to a distance of 10.0 nautical miles.

Several additional features of AIRPAC's user interface are illustrated in Figure 5. The "form-clearance" command displays maneuver parameters in terminology similar to that found in ATC clearances. The "why not" command may be used to obtain clarification for the reason AIRPAC rejected a resolution alternative. For the conflict just illustrated this command displays the "because" command attached to the failure by the inferencing process and the name of the specific rule, "vb-too-shallow" that caused the rejection. The user could then give the "print-rule" command to examine the form of this rule. After studying the rule and realizing its effect for crossing conflicts, the user may decide that a threshold value other than 90.0 degrees may be desirable. A rule editor has been implemented to permit altering the form of AIRPAC rules without leaving the LISP environment.

Observations

Although the development of AIRPAC is not complete, the following potential benefits of using

Figure 4. Horizontal plan view of conflict situation with AIRPAC's resolution trajectory.

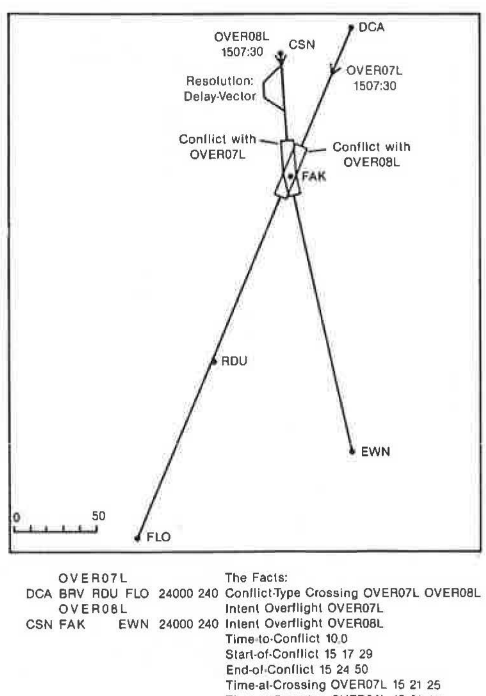


Figure 5. Examples of AIRPAC explanation Commands.

```
1.   (form-clearance)

For aircraft OVER08L:

  ( (at (15 7 30) turn right to heading 220
      for 3 minutes)

    (parallel original route heading 175
      for 1 minute)

    (at (15 12 6) turn left to heading 130
      for 3 minutes) )

2.  (why-not 'vector-behind')

vector-behind failed because -31 is too
   shallow an angle to vector behind.
This failure was caused by rule vb-too-
   shallow.

3.  (print-rule 'vb-too-shallow)

(if (encounter-angle -a)
    (not (greater (abs -a) 90.0) )
       then
    (failure because -a is too shallow an
       angle to vector behind) )
```

KBS techniques for automation of aircraft conflict resolution have already been observed:

- KBS methods allow decision rationale to be expressed in symbolic rules rather than being limited to purely numeric expressions. Consequently, AIRPAC's rules relate the selection of resolutions to factors like type-of-conflict (crossing, head-on, merging, overtake) that humans can readily understand.

- User-readable symbolic rules have facilitated the gathering of expert knowledge about conflict resolution. Air traffic controllers not familiar with KBS technology have been able to suggest changes to AIRPAC's decision rationale and confirm the desired results in an on-line computer laboratory environment.

- KBS methods inherently provide a separation of conflict resolution domain knowledge from the inference mechanism used to apply the rules to a given conflict. Thus, it would be possible to tailor resolution strategy to particular ATC jurisdictions after field introduction of the AERA system, by minor changes to the rules, rather than extensive changes to the software.

- AIRPAC supplies a trace of what rules were triggered to give the result for a particular conflict. Such an explanation capability may help air traffic controllers to understand and accept recommendations provided by an automated conflict resolution function.

Further Work

As of this writing AIRPAC can select resolutions and compute details of maneuver parameters for a variety of conflicts involving only two aircraft. AIRPAC also handles some multi-aircraft, multi-conflict situations by decomposing them into similar conflicts to which the two-aircraft techniques can be extended. AIRPAC needs to include more methods for providing a comprehensive resolution to a multi-conflict situation treated as a single problem. Where this approach fails, AIRPAC must coordinate the search for resolutions to conflicts that are related. This coordination might be accomplished by global consideration of constraints that resolutions to the individual conflicts impose on each other.

Other factors represent more localized constraints on the resolution maneuvers of individual aircraft. AIRPAC does presently consider the limitations of aircraft performance characteristics. However, AIRPAC should be expanded to deal with constraints imposed by winds, severe weather, aircraft traffic flows, ATC sector boundaries and procedural restrictions.

In the ATC operational environment, it is often desirable for conflict resolutions to be consistent with objectives for metering the flow of aircraft to airports. Integrated metering and conflict resolution might be viewed as planning the satisfaction of multiple goals. The resolution of multi-conflict situations might also be structured as a multiple goal problem. Therefore AIRPAC ought to exert more explicit control over the formulation, coordination and satisfaction of goals.

As its development continues AIRPAC will be used as a tool for gathering conflict resolution expertise from air traffic controllers. A greater understanding of the conflict resolution decision process is needed to help the FAA identify the compability required of an automated resolution function for the AERA system. It has also been suggested that a knowledge-based system similar to AIRPAC might be developed for off-line training of new controllers in the use of standardized techniques for resolving conflicts and other ATC problems. A knowledge-based training system could represent decision rules-of-thumb in a form readable by controllers and could provide explanation for its decision. Such a system would provide many benefits for controller training, irrespective of whether a knowledge-based decision aid is available in the ATC operational environment.

Acknowledgment

The author wishes to acknowledge the significant controbution of Karl B. Schwamb as co-developer of the AIRPAC system. While the author focused on understanding and formulating the problem domain expertise, Mr. Schwamb was primarily responsible for creating, designing and successfully implementing the hierarchical approach to planning conflict resolutions.

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POTENTIAL APPLICATIONS OF ARTIFICIAL INTELLIGENCE TO THE AIR TRAFFIC CONTROL SYSTEM

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These comments concern the potential applications of artificial intelligence (AI) to the Federal Aviation Administration's (FAA) air traffic control (ATC) system. Artificial intelligence and expert systems technology are clearly a "leading edge" in advanced computer science and must be thoroughly examined for possible benefits for the FAA and, by extension, system users.

A logical approach would be to avoid concentrating great amounts of time, money, or energy on exploring generic or high-level abstract concepts but rather to attempt to demonstrate the operational feasibility of simple, straightforward, and/or "intuitively obvious" applications. While this may not be fully satisfying to enthusiastic theorists, exotic theories remain pure fantasy until the soundness of fundamental capabilities can be shown. The following is a listing of areas that the FAA should explore.

Severe Weather Detection/Prediction

The eventual implementation of terminal Doppler weather radar systems is not an invalid assumption. Research into expert system analysis of Doppler radar data has shown that gust front and microburst activity can be automatically detected. Additional work should be done to determine the feasibility of: (a) reducing the data processing time; (b) having a capability to project the above wind shear conditions; and (c) developing a scheme for providing that wind shear data to appropriate control personnel.

Traffic Flow Management

National flow management is largely a data management and non-tactical ATC process, utilizing a relatively stable set of logical cause and effect rules. The pure enormity of the national flow management process, due to the large number of destination points, departure points, congestion points, and shifting (yet inter-related) demand levels, would appear to make an expert system application "intuitively obvious". Given the economic benefits available through a more efficient national flow management process, the FAA should explore this area as soon as possible.

System Maintenance Analysis

The FAA will be capable of collecting and storing great amounts of data pertaining to equipment performance and patterns through the remote maintenance monitoring system (RMMS). An expert system capability that could aid the system monitoring and maintenance personnel in analyzing the data to reduce the out-of-service time or the project system failures would be of significant benefit to FAA technicians, controllers, and system users. This is another area that should be explored.

Air Traffic Controller Training Aid

An expert system that could monitor controller training problem simulations (radar) and automatically interrupt the simulation when a "system error" occurred, explain why it happened, and provide a reasonable set of control instructions that would have prevented the error, would enhance the productivity of training personnel by providing a "self-study" practice capability for students. It could also enhance training quality by providing opportunities for more practice exercises. If sufficiently sophisticated, this same principle could be applied to teaching efficient control techniques. The benefits here also appear to be "intuitively obvious".

Tactical Air Traffic Control

In order to achieve significant controller productivity gains, a relatively high level of control responsibility will have to be transferred from the controller to the automation system. It would seem that expert system technology will be required to do that. This is certainly a long term activity, but the FAA must begin now to determine the likelihood that such a transfer is possible.

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