P12.10

DESCRIPTION OF URET ENHANCEMENTS TO SUPPORT SEVERE WEATHER AVOIDANCE

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1. INTRODUCTION

The Federal Aviation Administration (FAA), assisted by The MITRE Corporation's Center for Advanced Aviation System Development (CAASD), is working with industry representatives to develop the National Airspace System (NAS) Operational Evolution Plan (OEP) (Federal Aviation Administration, 2005) that integrates and aligns the FAA's objectives and plans with those of the aviation industry.

One of the capabilities being developed as part of OEP is the User Request Evaluation Tool (URET), which provides the en route Sector Team with automated conflict detection and trial planning capabilities, and a set of tools to assist in the management of flight data. A prototype version of URET was developed by CAASD and deployed to the Indianapolis Air Route Traffic Control Center (ARTCC) in 1996 and to the Memphis ARTCC in 1997. This prototype was used for over 1.4 million sector-hours to develop and validate requirements for the production version of URET, which was installed at those sites in January 2002. URET is currently deployed to 15 ARTCCs. Deployment to the remaining five ARTCCs is ongoing and completion is planned by the end of 2006.

Evidence from the ongoing usage of URET is that it supports a shift away from tactical operations based on radar data towards strategic Air Traffic Control (ATC) planning based on flight plans and associated trajectories. The benefits provided by this shift include less frequent and/or less severe maneuvers to resolve conflicts, more time for negotiation between controllers and pilots to develop clearances that meet the objectives of both, accommodation of pilot requests and user-preferred routing resulting in the reduction of delays and user operating costs, and the relaxation of some of the altitude and speed restrictions currently in place. (Burski et al., 2000 and Knorr, 2001)

CAASD is developing a set of automated resolution capabilities to assist controllers with aircraft and airspace problems. This set of support capabilities is termed Problem Analysis, Resolution, and Ranking (PARR). (Kirk et al., 2001a,b) One increment of PARR expands the problem detection, notification, and analysis/resolution capabilities to include support for integration of situations involving severe weather. (Kirk et al., 2003 and Love et al., 2004) The URET problem detection and notification capabilities are enhanced to indicate where controller attention may need to be focused to assist with severe weather avoidance. Analysis and resolution support for these problems is provided by enhanced URET displays, trial planning and resolution capabilities. These capabilities provide near-term benefits, while also evolving the NAS toward the Next Generation Air Transportation System (NGATS) and the needs of the year 2025. (Joint Planning & Development Office, 2005)

Severe weather is a major cause of delay in the NAS today, (Sherry et al., 2001) with en route aircraft frequently avoiding areas of severe weather. (Rhoda et al., 2002) In-flight encounters with weather are also cited as a factor in numerous aircraft accidents/incidents. (Aviation Statistical Reports, 1999) Although pilots are responsible for avoiding severe weather, controllers typically assist pilots with severe weather when requested and workload permits. Currently, controllers have few tools available to assist pilots in severe weather situations, and often rely on Pilot Reports (PIREPs) for severe weather-related information. (Celio et al., 2003)

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This paper provides a description of the severe weather enhancements as currently implemented in the CAASD En Route Research Prototype, which contains the full set of URET and PARR capabilities. The Concept of Use for these enhancements is presented, along with the methodology and results of initial laboratory evaluations and a pilot survey. Topics for future evaluations and analysis are also identified.

Because PARR is a URET enhancement and utilizes many of the URET capabilities, an overview of URET is provided in the following subsection. Further details on URET may be found in (Celio et al., 2000).

1.1 *URET Overview*

URET processes real-time flight plan and aircraft track data from the NAS Host computer. These data are combined with site adaptation, key aircraft performance parameters, and winds and temperatures from the National Weather Service (NWS) in order to build four-dimensional flight profiles, or trajectories. URET uses these trajectories to continuously detect potential aircraft separation violations for Instrument Flight Rules (IFR) flights up to twenty minutes into the future, and to notify the appropriate sector.

In addition to their application of modeling the currently planned actions of aircraft, trajectories are the basis for URET's trial planning capability. Trial planning allows the controller to check a desired flight plan amendment for potential conflicts before a clearance is issued.

The URET capabilities include a controller interface for both textual and graphic information. The text-based Plans Display and Aircraft List manage the presentation of flight data (call-sign, route, altitude, etc.), Trial Plans, and conflict information for the sector. The Graphic Plan Display (GPD) provides a graphical capability to view aircraft routes and altitudes, predicted conflicts, and Trial Plan resolutions, which are color coded to reflect the conflict status of the plan.

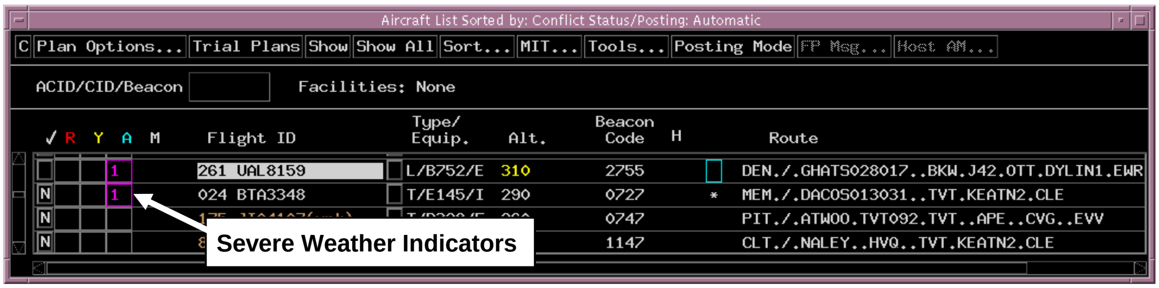

Figure 1. Severe Weather Indicators on the URET Aircraft List

2. SEVERE WEATHER AVOIDANCE

This section describes URET enhancements designed to support the controller in severe weather situations, by displaying areas of current and forecast severe weather, and identifying aircraft that are in, or predicted to enter, these areas, as well as providing trial planning and resolution tools to assist in avoiding the areas. Further details on these enhancements may be found in (Bolczak et al., 2002). An overview of a Concept of Use is also presented; additional details are given in (Celio et al., 2003).

2.1 *Severe Weather Problem Prediction*

Severe Weather Problem Prediction is currently performed using the NWS National Convective Weather Forecast (NCWF) product. (Meganhardt et al., 2000) This product is updated every five minutes and utilizes NEXRAD (NEXt generation weather RADar) radar, lightening, and coverage data. It defines detection “polygons” of current severe weather, a maximum storm “tops” altitude, and a 1-hour extrapolation forecast.

The NCWF is currently used for Traffic Flow Management (TFM) severe weather reroute applications across multiple sectors and centers, (Sherry et al., 2001 and Sud et al., 2001) using forecasts of 1 – 2 hours. This product, as used in TFM, has a minimum lateral polygonal area of 520 km^2; for the smaller scale application at the sector, this minimum has been reduced to 50 km^2. Accuracy of the current (520 km^2) NCWF product is addressed in (Megenhardt et al., 2000); research for improved products tuned to smaller scale, shorter-term applications is described in (Evans, 2001 and Megenhardt et al., 2002).

Severe weather forecast polygons are defined in URET using the NCWF detection polygon and extrapolation forecast polygon to obtain polygons at 0, 10, 20, 30 and 40 minute projections. Buffers are added to each polygon to account for uncertainty in forecasted weather, based on comparison with actual severe weather data. (Love et al., 2004) The size of each buffer is variable and is based on the height of the polygon, its direction of motion, and its projection time. In addition, buffers are added to reflect trajectory conformance bounds (2.5 nm), and pilot-preferred separation estimated from pilot surveys (7 nm). (Benson, 2003) Additional analyses and pilot surveys will be conducted to validate these buffers.

Assuming each buffered polygon is active and stationary ±5 minutes between its projection time, URET Current Plans are probed for penetrations of active polygons for 0 – 20 minutes in the future; Trial Plans are probed for an additional 20 minutes. (Celio et al., 2003)

2.2 *Severe Weather Display Capabilities*

The display modifications to support the controller in situations of severe weather were designed to integrate closely with the existing URET displays. The Aircraft List remains the primary URET display, with selectable indicators added to notify predicted problems with areas of severe weather. Since both the severe weather and Special Use Airspace (SUA) problem indicators denote airspace problems, they share the same space on the Aircraft List and are color-coded as illustrated in Figure 1 (SUA indicators take precedence over those for severe weather when both are present). As with the existing URET alert indicators, the display of corresponding graphical and textual problem information is available through selection of a severe weather problem indicator. As with other PARR enhancements to URET (Kirk et al., 2001a,b) resolutions to corresponding problems are available through indicator selection, as described below.

The graphical display of severe weather information is illustrated in Figure 2. The controller may choose to display all severe weather polygons, or only polygons currently in conflict with an aircraft. Motion vectors are included with the detection polygons and indicate direction, speed, and tops for the severe weather area. Using the existing URET Graphic Trial Planning capability, the controller may graphically create a Trial Plan around these weather polygons using trackball input. NEXRAD data (matching that available to the Radar Controller) can also be displayed on the GPD. Textual severe weather problem information is available on the URET Plans Display as illustrated in Figure 3.

2.3 *Severe Weather Problem Resolution*

The Severe Weather Problem Resolution capability utilizes Dijkstra's Algorithm (Bertsekas, 1992) to compute the shortest path around the buffered severe weather polygons. This algorithm

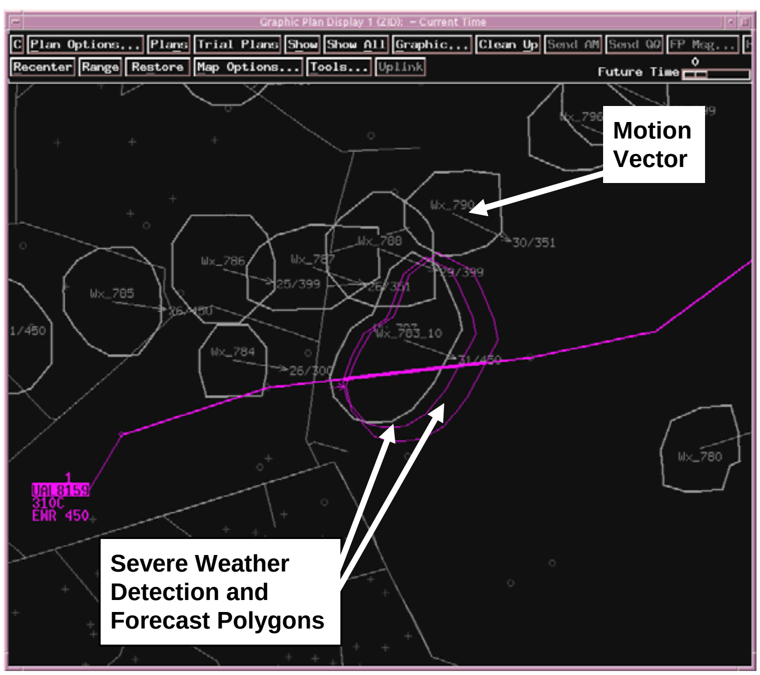

Figure 2. Severe Weather Problem

Figure 3. Textual Severe Weather Information

has been modified to search for two maneuvers, one of which initially turns to the left relative to a path proceeding direct from the aircraft's current position to the maneuver end point, and the other which turns to the right. Each maneuver ends at a fix on the current route of flight, with the fix selected to satisfy a maximum turn angle constraint. The controller is free to examine each maneuver and choose the one that is most operationally acceptable, or create an alternative resolution. Maneuver description text is provided on the URET Plans Display to support coordination with the aircraft.

Figure 2 is an example of an aircraft with a severe weather problem. The problem is with Wx_783_10 and Wx_783_20 (the 10 and 20 minute forecast polygons for Wx_783). Using the Severe Weather Problem Resolution capability, the controller is presented with two lateral resolutions. The first resolution (Figure 4) is a 20 degree turn to the right taking the aircraft around the severe weather polygons. A second resolution to the left (not shown) is also available. Both resolutions avoid all other aircraft for the next 20 minutes and all severe weather areas and SUAs for the next 40 minutes. The controller could then electronically submit one of these resolutions as an amendment to the Host computer using the existing URET capabilities, and verbally coordinate it with the aircraft using the maneuver description text.

2.4 *Concept of Use*

The Concept of Use for the Severe Weather capabilities is very similar to that for the URET Aircraft-to-Aircraft and Aircraft-to-SUA conflict probe capabilities. The Aircraft List now includes severe weather indicators. When severe weather notification is displayed, the controller can view the problem on the GPD, along with all severe weather polygons and/or NEXRAD data if desired.

Pilot requests regarding severe weather avoidance may be handled as follows:

- If a pilot requests a specific reroute to avoid severe weather (e.g. left 20 degrees for 50 miles then direct to the ABC VOR), the controller uses the URET Graphic Trial Planning capability to determine if the requested reroute is problem-free. If so, the controller issues the reroute and enters the appropriate amendment into the Host computer through URET.
- If the pilot requests support in determining a weather avoidance maneuver (e.g. the pilot asks the controller if it looks better to go right or left of the weather area at 12 o'clock and 50 miles), the controller uses the Graphic Trial Planning or Severe Weather Problem Resolution capabilities to examine alternative routings. An alternative is selected, the flight plan is amended, and the appropriate maneuver is relayed to the pilot as a reroute (using data link if available (Kirk et al., 2003)), or as heading changes as required. The controller may also use the severe weather display and trial planning capabilities to determine if the aircraft can climb over the severe weather area in a conflict-free manner.
- If the pilot requests additional weather information, such as direction, speed or maximum altitude of the severe weather area, the controller uses the severe weather polygons, motion vector, and NEXRAD displays on the GPD to provide assistance.

When an Aircraft-to-Aircraft or Aircraft-to-SUA problem is displayed on the Aircraft List, the controller uses the URET trial planning capabilities to resolve the predicted problem. If a Trial Plan has a severe weather problem associated with it, the controller may modify this Plan to avoid the severe weather area, particularly if the aircraft has previously requested a deviation for weather.

All of the enhancements for severe weather avoidance are designed with the goal of assisting

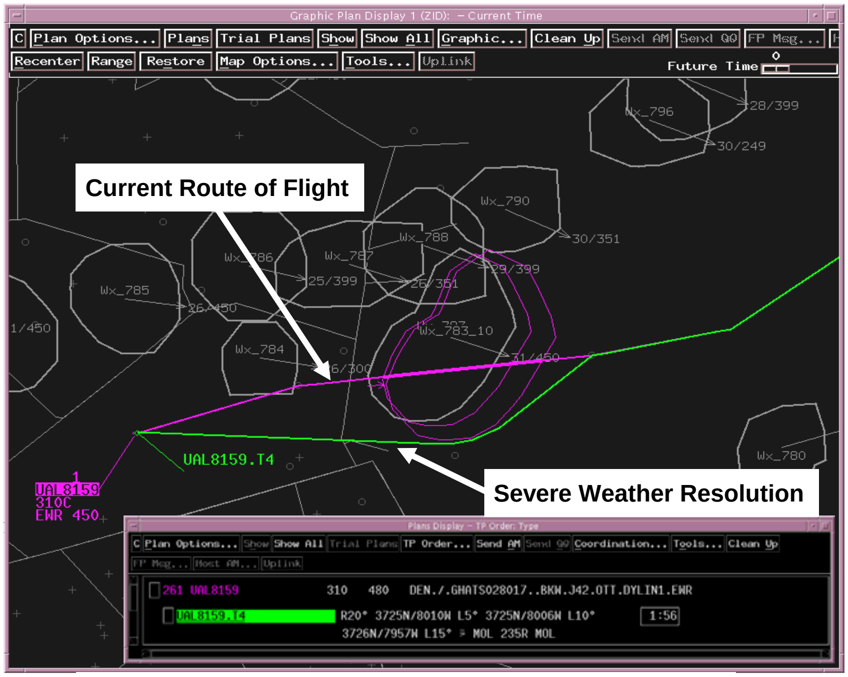

Figure 4. Severe Weather Resolution

controllers with current tasks by providing more information. These enhancements are not intended to shift the responsibility for severe weather avoidance to controllers: the Pilot In Command (PIC) remains responsible for avoiding areas of severe weather.

3. EVALUATION OVERVIEW

Operational evaluations covering severe weather detection, notification and the display of NEXRAD were held in April and July 2002 in the CAASD laboratories with (respectively) five and six former Certified Professional Controllers (CPCs). An additional evaluation focusing on the Severe Weather Problem Resolution capability was held in July 2003 in the CAASD laboratories with these six former CPCs.

Each evaluation included the following:

- An introductory training briefing including a description of the functionality, CHI, Concept of Use and evaluation focus areas.
- A set of facilitated hands-on exercises to demonstrate the functionality and CHI.
- Hands-on practice and evaluation at individual workstations.
- A group discussion using a questionnaire as a guide.
- Operational acceptability of the Concept of Use.
- Operational acceptability of the severe weather problem detection and notification.
- Operational acceptability of the severe weather functionality and CHI to support the Concept of Use.
- Potential benefits for controllers, airspace users and overall traffic flow.

In addition, the operational acceptability of the Severe Weather Problem Resolution capability was discussed during the July 2003 evaluation.

The April and July 2002 evaluation scenario used recorded Indianapolis (ZID) data from Sept. 7, 2001. The July 2003 evaluation scenario used recorded ZID data from July 9, 2002. Details of the evaluation components and questionnaires are available in (Worden, 2002 and Benson, 2003).

4. EVALUATION RESULTS

Participants indicated that the functionality and CHI for the severe weather enhancements are operationally acceptable and could provide benefits for controllers, airspace users and overall traffic flow. Specifically, they indicated that it is operationally acceptable and useful to provide severe weather notification for Current Plans and Trial Plans. Generally, the participants agreed that the severe weather look-ahead times implemented for Current and Trial Plans (20 and 40 minutes, respectively) are appropriate.

Participants agreed that providing notification for penetration of severe weather that is classified as Level three and above is appropriate, and providing polygons at ten minute increments is useful for depicting polygon speed and direction. Participants said that the severe weather polygon and NEXRAD displays are useful and do not provide redundant information. Some participants suggested severe weather notification should not share space with SUA alerts on the Aircraft List. In addition, it was suggested that certain kinds of notification should be suppressed (e.g., an aircraft landing inside an area of severe weather).

Participants indicated that the Severe Weather Problem Resolution capability is operationally acceptable and useful. They suggested that lateral resolutions utilizing Very High Frequency Omnidirectional Range (VOR) navigational aids be made available. By providing routes only between VORs, this type of maneuver can simplify coordination of the clearance between the controller and the pilot by reducing the number of legs required to complete a weather resolution. The participants also indicated that altitude resolutions (to go above the severe weather) would be useful when they are within the aircraft's operational performance envelope.

With regard to resolution maneuver description language, the participants indicated that only the first part of a complex maneuver description (i.e. turn left 20 degrees) would be verbally issued, with the controller and pilot negotiating the remaining portion of the resolution at the appropriate time. To support this, they indicated that a revised format for maneuver description language using angles, distances, and intercepts would be useful.

The participants cited the following controller benefits from the severe weather enhancements:

- Current Plan severe weather notification allows controllers to anticipate pilot requests for weather-related reroutes. This allows more time to formulate solutions for those requests, and support improved workload management.
- Severe weather displays assist with creating routes that do not penetrate severe weather, decreasing subsequent pilot requests for reroutes due to weather.
- In some cases (e.g., when leading aircraft have requested reroutes for weather), severe weather notification on the Aircraft List allows controllers to deal with severe weather situations in a more timely way rather than waiting until pilot requests are received before taking action.
- Less negotiation with pilots is required to navigate aircraft through severe weather areas.
- The display of NEXRAD data on the D-side allows the Radar Associate Controller to collaborate more effectively with the Radar Controller, as the same severe weather information is available to both.
- Earlier awareness of problems is provided, leading to more timely planning and better anticipation of workload.
- Weather related problems that are missed during Traffic Flow Management (TFM) reroutes can be handled with these capabilities.

Participants cited the following airspace user and traffic flow benefits:

- Severe weather displays in conjunction with Graphic Trial Planning allow controllers to generate more effective and efficient routes for navigating around severe weather.
- Severe weather notification in Trial Plans warns controllers when route changes send aircraft into severe weather, decreasing the likelihood that aircraft will receive routes that encounter severe weather.
- Severe weather displays used in conjunction with Graphic Trial Planning allow controllers to enter vector maneuvers for severe weather avoidance into the Host, improving the quality of URET trajectories and increasing the likelihood that aircraft will receive the most efficient routes possible in severe weather situations.
- Severe weather displays allow controllers to provide useful weather information when requested by pilots, thus enhancing system safety. (Participants discussed weather related accidents/incidents where

severe weather capabilities would have been useful.)

- A more system-wide perspective of severe weather situations is made available to the controller-, leading to more strategic decision making. This supports a more orderly and expeditious flow of traffic during periods of severe weather.

The participants noted that the above benefits were based on the assumption that the accuracy of the severe weather detection and prediction was operationally acceptable, with appropriate buffers applied to account for predictive uncertainty. Initial measurements of this accuracy are reported in (Love et al., 2004).

5. PILOT SURVEY OVERVIEW AND RESULTS

In order to gain operational feedback into how pilots handle severe weather problems, an online survey consisting of 44 questions was created. (Benson, 2003) The survey was conducted over a one month period during July and August of 2003. The participants consisted of pilots from a major U.S. airline union organization. Pilot experience and background varied; however, all participants had experience with severe weather conditions and the use of airborne weather radar. Participation in the survey was strictly voluntary. The response rate was approximately 1.3%.

A full list of survey questions is provided in (Benson, 2003). Select questions and an overview of results are provided in the following sections. Additional survey questions related to flying over the top of severe weather, lateral separation from severe weather, and en route convective weather encounter thresholds were also asked. Responses to these questions will be used in the design of new types of resolutions, enhancements to the Concept of Use, and refined operational polygon buffers.

5.1 *Pilot's Use of Severe Weather Information*

The following three questions explored willingness, by participants, to use severe weather information provided by a controller with a tool such as that described in this paper.

Question	Response	
I would feel comfortable with a controller using a product as described above to assist me with routing my aircraft through severe weather.	Strongly Agree	36 %
	Agree	55 %
	No Opinion	2 %
	Disagree	4 %
	Strongly Disagree	3 %
I believe that this type of product would provide information about severe weather that would be useful to my flight.	Strongly Agree	50 %
	Agree	42 %
	No Opinion	2 %
	Disagree	3 %
	Strongly Disagree	3 %
I would be willing to navigate between predicted areas of severe weather with guidance from a controller who is using this tool.	Strongly Agree	18 %
	Agree	59 %
	No Opinion	11 %
	Disagree	8 %
	Strongly Disagree	4 %

The following were some comments made by participants related to willingness to navigating between areas of severe weather with guidance from a controller who is using this tool:

- "Agree, but would also use onboard radar to verify. If I didn't like what I see from onboard radar, I wouldn't accept the clearance."
- "I would never put my aircraft exclusively in the hands of a controller with or without such weather information. But the more information he can give me, the better able I am to make decisions. What does the new information show him about a proposed route? What PIREPS is he receiving from pilots attempting to use the route? Are they successfully getting through? etc."
- "Having a controller alone determine our route is not acceptable. It is a team effort with the cockpit crew, ATC and dispatch."
- "My level of comfort in following controller guidance would be directly proportional to my FAITH in the accuracy of the data provided to the controller. The better the "picture" I have of what the controller is trying to do, the more likely I would be to eagerly follow his guidance."
- "Provided controllers do not use the information to require an aircraft to penetrate an area that has been identified by airborne weather radar as unsuitable for flight"
- "It would be a long time before I would be comfortable relying on a controller for weather navigation unless I was suddenly faced with airborne radar failure."

- "As long as I can determine (from analyzing airborne wx radar) that the suggested routing would provide acceptable clearance between my aircraft and the wx as a double check"
- "Using my onboard radar for "fine tuning" the route."
- "Would like access to similar info in the cockpit to verify controller's guidance."

5.2 *ATC Assistance with Severe Weather Problems*

As indicated by the responses to the following four questions, most pilots are open to the idea of ATC "warning" or "advising" them of severe weather conditions.

Question	Response	
Approximately how often do you request assistance from air traffic control to avoid severe weather when severe weather is present?	Always	21 %
	Frequently	34 %
	Sometimes	28 %
	Rarely	15 %
	Never	3 %
Would it be useful to you for air traffic control to advise you of severe weather along your route of flight?	Always	76 %
	Frequently	13 %
	Sometimes	10 %
	Rarely	2 %
	Never	0 %
If you request a reroute around a severe weather area on your weather display, would you like to be warned if your requested reroute is projected to penetrate other areas of severe weather identified to air traffic control (that may not be visible on your display)?	Always	92 %
	Frequently	5 %
	Sometimes	3 %
	Rarely	0 %
	Never	0 %
Would it be useful to you for air traffic control to offer possible reroutes for severe weather avoidance, without you specifically requesting a reroute?	Always	44 %
	Frequently	29 %
	Sometimes	24 %
	Rarely	3 %
	Never	1 %

Overall, the results of the online survey were favorable and indicate willingness on the part of participants to accept guidance and assistance from controllers using the kind of severe weather capabilities described in this paper.

6. TOPICS FOR FUTURE EVALUATION AND ANALYSIS

Future evaluation and analysis is planned for each component of the URET enhancements to support severe weather avoidance: Severe Weather Problem Prediction, display enhancements, and Severe Weather Problem Resolution. Specific topics for each of these components are presented below.

6.1 *Severe Weather Problem Prediction*

Accuracy analysis related to NCWF polygon buffering is ongoing. (Love et al., 2004) Additional severe weather and aircraft track scenario data, along with operational feedback, will be combined to refine the size and shape of the polygon buffers.

The accuracy of severe weather problem prediction for new, probabilistic weather products is being studied, as is the suitability of these products for use in problem resolution. These products are currently under development, and include...

- Refinements to the existing NCWF product being researched by NCAR, (Megenhardt et al., 2002) including storm growth and decay information, and reduced delay in product generation.
- MIT Lincoln Labs' Corridor Integrated Weather System (CIWS). (Evans, 2001)

as well as additional weather products -

- Improved products providing more accurate tops information, such as the MIT/LL Echo Tops product. (Evans, 2001)
- Additional types of severe weather information, including turbulence (National Center for Atmospheric Research, 2003) and icing (National Center for Atmospheric Research, 2003) products. Notification and resolution functionality for these products would be similar to current severe weather capabilities.

While severe weather requirements are heavily derived based on technical weather product capabilities, operational requirements play an equal role in how severe weather requirements evolve. Lab and field evaluations with subject matter experts help to answers questions such as how good, precise, and robust must weather products be to support operational concepts.

6.2 *Severe Weather Display Enhancements*

Future work related to display enhancements includes the mechanism for severe weather problem notification, and the resolution maneuver description language presented to the controller. With regard to problem notification, alternatives for the shared space between SUA and Severe Weather problem indicators on the Aircraft List will be examined. Conditions for the suppression of notification (e.g., an aircraft landing inside an area of severe weather) will also be examined.

With regard to resolution maneuver description language, a revised format for maneuver description language will be investigated during future evaluation. This format will include the use of angles, distances, and intercepts.

6.3 *Severe Weather Problem Resolution*

Additional evaluations are planned to assess the operational acceptability of the Severe Weather Problem Resolution capability from both a controller's and a pilot's perspective. Specific topics arise from the evaluation results presented above, and include altitude resolutions, and lateral resolutions that use VORs. Additionally, resolutions which avoid the severe weather, but encounter Aircraft-to-Aircraft conflicts will be examined. In these cases, the controller may supplement the lateral reroute (for severe weather avoidance) with an altitude maneuver to avoid the aircraft conflict, or may maneuver the other involved aircraft.

7. CONCLUSIONS

To date, evaluation results have been highly favorable. Specifically, participants indicated that the Concept of Use, functionality, and CHI for the Severe Weather enhancements are operationally acceptable and useful. Future evaluations will further refine these capabilities. Additional feedback on Concept of Use, CHI, and resolution acceptability will be sought from pilot groups, dispatchers, and other aviation weather experts.

Accuracy analysis related to application of the NCWF polygon product for severe weather problem prediction is ongoing. The accuracy of severe weather problem prediction for new, probabilistic weather products will also be studied, as will the suitability of these products for use in problem resolution. To obtain these products, CAASD has been in collaboration with weather research laboratories including Forecast Systems Laboratory (FSL), MIT Lincoln Labs (MIT/LL), and the National Center for Atmospheric Research (NCAR). A close relationship between Air Traffic Management (ATM) and weather research communities helps to manage expectations on both sides.

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