DOT/FAA/TC-10/09

Federal Aviation Administration
William J. Hughes Technical Center
Atlantic City International Airport, NJ 08405

The AIRWOLF Tool to Support En Route Controller Weather Advisories

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October 2010

Technical Report

U.S. Department of Transportation
Federal Aviation Administration

Technical Report Documentation Page

1. Report No. DOT/FAA/TC-10/09	**2. Government Accession No.**	**3. Recipient's Catalog No.**
4. Title and Subtitle The AIRWOLF Tool to Support En Route Controller Weather Advisories		**5. Report Date** October 2010 **6. Performing Organization Code** AJP-6110
7. Author(s) Ulf Ahlstrom, Human Factors Team – Atlantic City, ATO-P John T. DiRico, Human Factors Team – Atlantic City, ZFW Kelly Stephenson, Hi-Tec Systems, Inc.		**8. Performing Organization Report No.** DOT/FAA/TC-10/09
9. Performing Organization Name and Address Federal Aviation Administration Human Factors Team – Atlantic City, ATO-P William J. Hughes Technical Center Atlantic City International Airport, NJ 08405		**10. Work Unit No. (TRAIS)** **11. Contract or Grant No.**
12. Sponsoring Agency Name and Address Federal Aviation Administration Human Factors Research and Engineering Group 800 Independence Avenue, S.W. Washington, DC 20591		**13. Type of Report and Period Covered** Technical Report **14. Sponsoring Agency Code** ATO-P
15. Supplementary Notes		

16. Abstract

In current en route operations, controllers integrate weather information and traffic data manually while providing advisories to pilots. Previously, we developed a weather support tool called Automatic Identification of Risky Weather Objects in Line of Flight (AIRWOLF) that (a) detects conflicts between aircraft and hazardous weather, (b) alerts the controller, and (c) generates automatic weather advisories. Automated weather advisories based on the AIRWOLF tool could support the controller by eliminating the need for a manual integration of traffic and weather data, thereby reducing the total time it takes a controller to provide an advisory. To test this hypothesis, we evaluated our AIRWOLF weather support tool in a part-task simulation. During the simulation, participants responded to the AIRWOLF tool alerts by providing weather advisories via radio or data link communication. The results showed that it took, on average, 27 seconds to manually compose and transmit a weather advisory by radio (currently used in Air Traffic Control). When participants used automatic weather advisories, it reduced the advisory time by approximately 7 seconds. When participants used data link communication with the AIRWOLF tool, the weather advisory times were reduced by as much as 16 seconds. These results show that the AIRWOLF tool could reduce advisory time and support controllers for the safe, efficient, and strategic efforts required to handle adverse weather conditions in the en route environment.

17. Key Words Advisory En Route Controller Weather		**18. Distribution Statement** This document is available to the public through the National Technical Information Service, Springfield, Virginia, 22161. A copy is retained for reference at the William J. Hughes Technical Center Library.	
19. Security Classification (of this report) Unclassified	**20. Security Classification (of this page)** Unclassified	**21. No. of Pages** 23	**22. Price**

Form DOT F 1700.7 (8-72) **Reproduction of completed page authorized**

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Acknowledgments

We would like to acknowledge Computer Scientist Ed Jaggard (Engility Corporation) for his development efforts and support during the data collection. We would also like to thank Subject Matter Experts Jim McGhee and Richard Ridgway (Northrop Grumman IS) for their help during this project.

Executive Summary

Adverse weather conditions are hazardous to flights and contribute to reroutes and delays. In today's en route Air Traffic Control (ATC) system there are no weather decision-support tools at the air traffic controller workstation. En route controllers integrate weather information and traffic data manually while providing advisories to pilots. This manual weather advisory process adds a cognitive load to the controller, and the procedure is time-consuming.

In previous research, we developed a weather support tool called Automatic Identification of Risky Weather Objects in Line of Flight (AIRWOLF). The AIRWOLF tool detects conflicts between aircraft and hazardous weather and alerts the controller. For aircraft-weather conflicts, the AIRWOLF tool also generates automatic weather advisories. The AIRWOLF automated weather advisories could support the controller by eliminating the need for a manual integration of traffic and weather data and by reducing the total time it takes a controller to provide an advisory.

To test this hypothesis, we evaluated our AIRWOLF weather support tool in a part-task simulation. Five ATC Subject Matter Experts (SMEs) participated in the simulation (mean ATC experience = 25.1 years). During the simulation, we used our advanced Distributed Environment for Simulation, Rapid Engineering, and Experimentation (DESIREE) simulator, which replicates the functions and user interfaces of the En Route Automation Modernization (ERAM) ATC system. Using DESIREE, we created traffic scenarios where precipitation hazards moved into an en route sector and conflicted with the routes of arriving traffic. The participants' task was to pay attention to aircraft and weather areas and to provide weather advisories to pilots when alerted by the AIRWOLF tool. We evaluated three different conditions in the simulation: today's manual weather advisory production with radio communication (*Manual*), automatic weather advisories with radio communication (*Automatic*), and automatic weather advisories with data link communication (*Data Link*). During the simulation runs, we recorded and time-stamped all AIRWOLF weather conflict alerts and communication events (i.e., radio and data-link messages).

The result showed that it took, on average, 27 seconds to manually compose and transmit a weather advisory by radio. When participants used radio and automatic weather advisories, it reduced the advisory time by approximately 7 seconds. When participants used automatic weather advisories and data link communication, the weather advisory times were reduced by as much as 16 seconds. These results show that the AIRWOLF tool could support controllers for the safe, efficient, and strategic efforts required to handle adverse weather conditions in the en route environment. We discuss potential enhancements to the current AIRWOLF tool and provide an analysis of benefits from different air-ground integration alternatives.

1. INTRODUCTION

Adverse weather conditions are hazardous to flights and contribute to reroutes and delays. Among the primary weather hazards are convective activity (i.e., thunderstorms), icing, turbulence, and reductions in ceiling and visibility. To mitigate the effects of weather hazards, researchers have explored ways to improve weather information for pilots during all phases of flight (Ahlstrom, 2003).

In today's Air Traffic Control (ATC) system there are no weather decision-support tools at the air traffic controller workstation. Besides a precipitation display and text-based weather advisories, controllers have no ability to display weather hazards within their airspace (Ahlstrom, 2007; Ahlstrom & Dury, 2007). Although there have been efforts to develop weather display requirements for ATC operators (Ahlstrom, 2008) that would improve today's weather-related communication and meet future needs in the National Airspace System (NAS), this capability does not exist in the current NAS. As a result, air traffic controllers must integrate weather information and traffic information manually while making decisions.

During ATC operations in adverse weather, controllers communicate with pilots and provide weather advisories on precipitation areas. However, a previous study by Ahlstrom and Dury (2007) showed that more system support is needed to optimize the controller weather advisory function. Uncertainty about weather hazards limits the usefulness of controller weather advisories to pilots and decreases safety for nonequipped aircraft. Therefore, there is a human factors requirement to develop weather information systems and air-ground integration modes that enhance controller weather avoidance actions, such as providing weather advisories and radar navigational guidance.

1.1 Background

In current en route operations, controllers integrate weather information (i.e., graphical and text-based format) and traffic data manually while providing advisories to pilots. Once the controller decides to issue a weather advisory to an aircraft, there is an initial *production* phase where parameters, such as aircraft location, distance to weather, directions, and weather area coverage, are extracted from the situation display and used in the weather advisory. This initial phase is entirely manual and cognitive in nature; the controller has no system support during this phase.

The content and phraseology for weather advisories are defined in Federal Aviation Administration (FAA) Order JO 7110.65T (FAA, 2010), Paragraph 2-6-4: Weather and Chaff Services, which mentions that the issuing of weather and chaff information is done by defining the area of coverage in terms of azimuth (by reference to the 12-hour clock) and the distance from the aircraft, or by indicating the general area width and area coverage in terms of fixes or distance and direction from fixes. One weather advisory example in FAA (2010) is made up of seven parameters:

1. intensity of the precipitation area (e.g., Moderate to Extreme),
2. area of coverage (e.g., between 11 o'clock and 3 o'clock),
3. distance from the aircraft to the precipitation area (e.g., 20 miles),
4. direction of movement (e.g., East),

5. speed (e.g., 40 knots),
6. echo top information (e.g., FL350 or Flight Level of 35,000 ft), and
7. width of the precipitation area (e.g., 30 miles in diameter).

Using ATC phraseology, the weather advisory takes the following form: *"Moderate to Extreme precipitation between 11 o'clock and 3 o'clock, 20 miles. Moving East at 40 knots, tops FL350. Precipitation area is 30 miles in diameter."*

In Ahlstrom (2008), we developed en route controller displays for severe weather avoidance. This improved controllers' weather situation awareness and allowed controllers to transmit important weather information to pilots. Another way of integrating weather information at the en route controller workstation is to let the ATC system keep track of weather hazards. Rather than provide the controller with separate weather displays, the system can use the weather data and automatically track weather hazards and sector traffic and alert the controller of impending conflicts. This could enhance weather avoidance operations even further. For example, there would be no need for controllers to manually correlate weather and traffic data (as done in current operations). Moreover, it would enhance the simultaneous tracking of multiple weather hazards.

Besides today's manual production of weather advisories, the current method of communicating weather information is via radio, which adds another constraint on the controller during high workload periods. This further emphasizes the need to explore ways to support the controller with weather advisories and to explore ways to optimize weather-related communication between the controller and the pilot. In the following section, we describe an automatic weather probe that tracks aircraft and weather hazards and alerts the controller of impending conflicts.

1.1.1 Automatic Identification of Risky Weather Objects in Line of Flight (AIRWOLF)

In Ahlstrom and Jaggard (2010), we outlined a general weather probe algorithm for ATC controllers. We named the weather probe concept after its function: Automatic Identification of Risky Weather Objects in Line of Flight (AIRWOLF). The AIRWOLF tool operates by, first, calculating a future aircraft position for an aircraft (e.g., 15 minutes along the aircraft's projected route) and then determining whether the route to the future position intersects with a known weather object (e.g., precipitation or convection polygon). If there is an intersection between an aircraft route and a weather object, the AIRWOLF probe will detect it and treat it as a conflict. The probe performs this calculation for all aircraft at their associated altitudes. This is an iterative calculation that the algorithm performs for each aircraft every time there is a flight data update in the system. The AIRWOLF tool checks the aircraft's flight plan for route information for *flat tracking* aircraft (i.e., aircraft that conform to their specified routes). If an aircraft is *free tracking* (i.e., aircraft that are not flying their routes), the AIRWOLF probe uses the aircraft's current heading to perform the future position calculation. The time parameter for the calculation of the future aircraft position can be adjusted to account for different sector needs (sector size, traffic patterns, etc.). We also implemented a function that determines whether a particular aircraft is small, large, or heavy, which is defined by the FAA based on aircraft weight. This implies that the AIRWOLF tool can be programmed to probe for one set of weather hazards for small aircraft (e.g., visibility, ceiling, precipitation, convection, icing, and turbulence) and another set of weather hazards for large and heavy aircraft (e.g., heavy and extreme precipitation, severe and extreme turbulence).

Once the AIRWOLF probe detects a future conflict between an aircraft and a hazardous weather object, it alerts the controller. In our current implementation, the controller was alerted by a weather conflict number in line 0 of the data block.

When the AIRWOLF tool generates a weather conflict alert, the controller can display the aircraft route and the weather hazard polygon (see Figure 1). Moreover, in the case of convection or precipitation polygons, the system automatically displays echo top and cell movement information. The National Convective Weather Forecast data (NCWF-1) generates every 5 minutes and contains polygon and echo top, speed, and direction information. Similarly, the Corridor Integrated Weather System (CIWS) can produce precipitation forecast polygons along with echo top, speed, and direction information. The AIRWOLF tool can read and probe any gridded weather data (it does not have to be polygons). In this report, we will focus on exemplifying the probing for hazardous precipitation polygons. The AIRWOLF tool alert and display functions are the same, regardless of what weather data is used for the probing; only the output information on the situation display will vary.

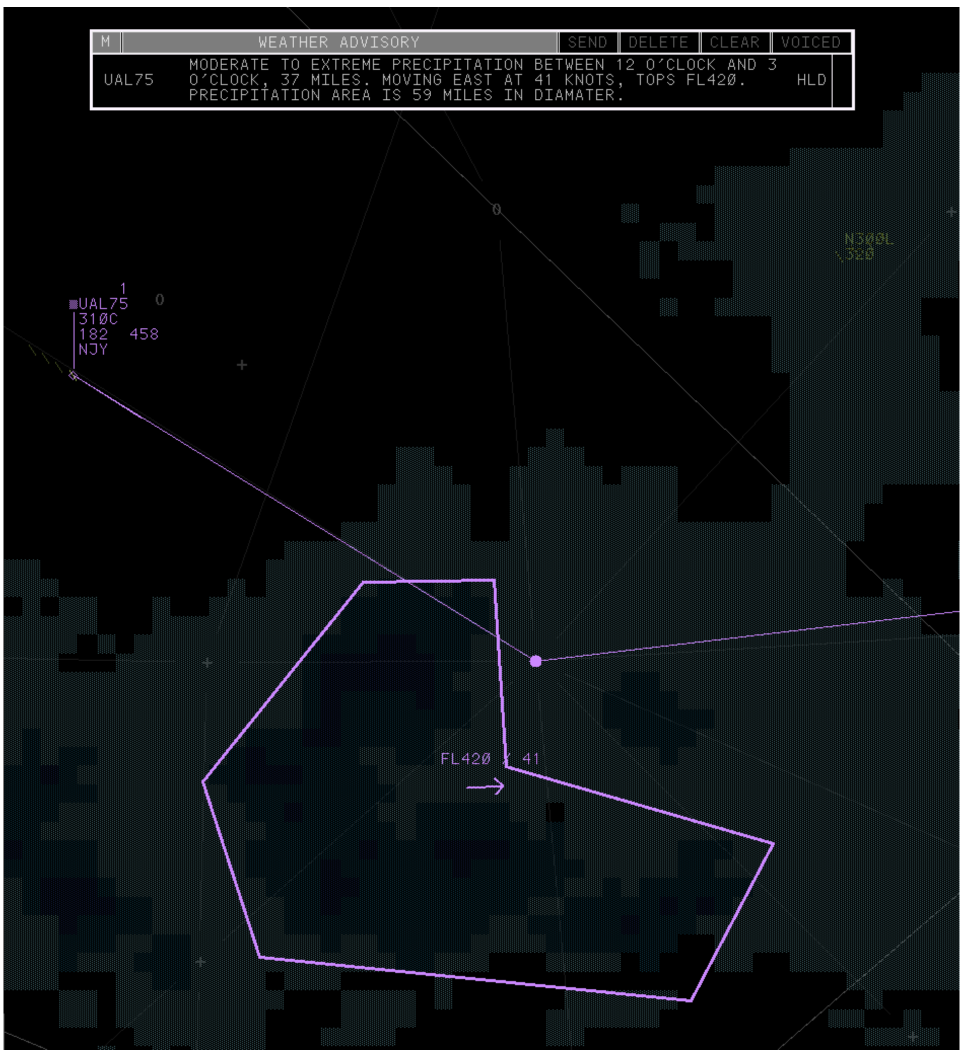

Figure 1. The AIRWOLF weather conflict alert.

1.1.2 Automatic Weather Advisories

For the AIRWOLF probe output, the system displays an aircraft that is in conflict with a precipitation hazard polygon (as we have shown in Figure 1). Because the location of the aircraft and the hazard polygon (moderate to extreme precipitation) are known to the system, the AIRWOLF algorithm can compute the distance from the aircraft to the polygon (i.e., 37 miles), polygon area coverage (between 12 o'clock and 3 o'clock), and the width of the polygon area (59 miles in diameter). The remaining parameters for the polygon direction of movement (East), polygon speed (41 knots), and polygon echo top (FL420) are given by the weather data.

We can use these parameters to generate an automated weather advisory, as illustrated at the top of Figure 1. This weather advisory contains the seven parameters and the format we defined in section 1.1, Background. In our current AIRWOLF tool implementation, the automated weather advisories (i.e., free-text message) are displayed in a Weather Advisory View (following the ERAM View concept). Using the DESIREE simulator, Data Link capabilities, the controller can send the weather advisory to the aircraft if the aircraft is equipped for data link communications. For aircraft that are not equipped with data link communications, the controller can read the automated weather advisory over the radio.

Automated weather advisories could support the controller by (a) eliminating the need for a manual integration of traffic and weather data, (b) eliminating the need to *produce* a weather advisory, (c) reducing the total time it takes a controller to provide a weather advisory to a pilot, and, in the case of data link communications, (d) eliminating voice transmissions when providing weather advisories to pilots.

1.2 Purpose

The main purpose of this study was to explore ways to improve weather information dissemination and air-ground communication modes for en route controllers as they assist pilots to avoid hazardous weather. This entailed an evaluation of weather data displays and a weather decision-support tool, as well as an evaluation of controller weather advisories.

To evaluate the potential benefits of automated weather advisories, we conducted a part-task simulation. Two questions were of particular importance for this effort. First, how long does it take, on average, to manually compose and transmit a weather advisory using radio (i.e., today's ATC)? Second, what are the time reductions on weather advisory durations, if any, from the use of automatic weather advisories?

2. METHOD

We evaluated our AIRWOLF weather support tool by means of a part-task simulation. Although there are many factors that influence how many weather advisories a controller has to issue, in the present part-task simulation, we were interested in measuring time durations for weather advisories. Therefore, we needed to create a focused test that (a) allowed us to measure a sufficiently large sample of weather advisories, (b) controlled when and how many advisories were issued, (c) measured advisory time durations that were not confounded by controller workload effects, and (d) measured advisory time durations in a comparable manner across two air-ground integration modes (voice vs. data link).

To accomplish this goal, we created two different weather and traffic scenarios using a generic en route sector. We used grid-based precipitation data from the National Weather Service (http://www.nws.noaa.gov/) and convection polygons from the National Convective Weather Forecast (NCWF-1) product (http://aviationweather.gov/products/ncwf/info.shtml). The weather hazard (moderate to extreme precipitation areas in both scenarios) was moving into the south portion of the sector (as illustrated in Figure 1), conflicting with the routes of North and West arrivals going through the sector. To control for when and how many weather advisories had to be issued in each scenario, we used the AIRWOLF probe running in two different modes. This created three different weather advisory conditions: Manual, Automatic, and Data Link.

In the first AIRWOLF mode, which simulated today's en route ATC system, called the Manual condition, we used the AIRWOLF tool alerting function (i.e., number indicator in line 0 of the data block) to indicate to the participant that a pilot was in need of a weather advisory. All other alerting functions of the AIRWOLF probe (i.e., route and hazard polygon display) were suppressed during this condition. Each participant had to manually (a) compose a weather advisory (using the parameters and format defined in section 2.4, Procedure) by extracting and integrating information about the aircraft route and weather hazard (precipitation display) and (b) transmit the weather advisory to the pilot via radio. Weather information was provided by the precipitation display, Center Weather Advisory (CWA), and the Significant Meteorological Information (SIGMET) advisory; no additional weather information was available to the participants. In this Manual condition, the participants used the echo top and weather area movement information contained in the SIGMET and CWA. In case the participants needed a quick refresher on the advisory phraseology (defined in section 2.4, Procedure), we posted an advisory *cheat-sheet* example at the workstation.

In the second AIRWOLF mode, called the Automatic condition, the AIRWOLF tool also displayed an alert in line 0 of the data block. However, simultaneously with the weather conflict alert, the system displays an automatic weather advisory in a Weather Advisory View on the situation display. The participants could also select the line 0 alert number, and display a highlighted aircraft route and weather hazard polygon, as illustrated in Figure 1. In this condition, the participant read the automatic weather advisory to the pilot over the radio.

In the third AIRWOLF mode, called the Data Link condition, the AIRWOLF weather alerting function was the same as in the Automatic condition. However, no voice transmission was necessary because the participants could send the automatic weather advisory directly to the pilot via data link. Before sending the weather advisory, the participants were instructed to verify the advisory content.

With two weather-traffic scenarios and three weather advisory conditions, each participant ran six simulation runs in a counterbalanced order. Each simulation run lasted 30 minutes, with an average of 6.5 aircraft in the sector at any given time. The AIRWOLF weather alert function was adjusted so that all weather conflicts occurred while the aircraft was inside the sector under control. The AIRWOLF tool generated 15 and 22 weather conflicts during the first and second weather-traffic scenario, respectively. We used two different weather-traffic scenarios to generate some variation in the advisory parameters (e.g., distance to weather, extent of weather area), because each weather scenario had slightly different streams of traffic due to the weather. To minimize the participants' workload, we eliminated all aircraft-to-aircraft conflicts by separating all scenario traffic streams by altitude. This allowed the participants to focus on the weather advisory task, minimizing the confounding effect of participant workload on advisory times.

2.1 Participants

Five ATC SMEs participated in the part-task simulation (mean ATC experience = 25.1 years). All participants had extensive knowledge of ATC weather avoidance operations and were familiar with the AIRWOLF weather probe functionality.

2.2 Apparatus

Throughout the project we used our Distributed Environment for Simulation, Rapid Engineering, and Experimentation (DESIREE) simulator for testing and development. DESIREE is a realistic and advanced simulator of en route ATC and replicates the functions and user interfaces of the En Route Automation Modernization (ERAM) system.

During the part-task simulation, the participants used a display interface that simulates the ERAM system. We used one controller workstation (R-side) equipped with a situation display (2,048 x 2,048 pixels), keyboard, auxiliary input device, and a trackball device that is the same as the equipment used in current en route field operations.

2.3 Data Collection

During the simulation runs, we recorded and time-stamped all AIRWOLF weather conflict alerts, voice alerts, and push-to-talk events (i.e., pushing down the key and releasing the key on the microphone). During the Data Link condition, we also recorded and time stamped when the participant clicked on the Weather Advisory View *send* button.

Viewed in sequence for the Manual condition, first, we presented an AIRWOLF weather alert displayed in line 0 of the data block (alert). Next, the participant manually formulated a weather advisory and subsequently pushed down on the microphone button (push) and voiced the advisory over the radio (voice). When the voice communication was completed, the participant released the microphone button (release). This completed the data recording chain for the Manual condition with alert, push, voice, and release.

For the Automatic condition, we presented an AIRWOLF weather alert displayed in line 0 of the data block (alert). Simultaneously with the *alert*, the system displayed an automatic weather advisory. Next, the participant pushed down on the microphone button (push) and read the advisory over the radio (voice), releasing the microphone button when done (release).

For the Data Link condition, we presented an AIRWOLF weather alert displayed in line 0 of the data block (alert). The participant verified the content of the weather advisory and then clicked the send button on the Weather Advisory View (send) to send the weather advisory to the pilot.

2.4 Procedure

Before the part-task simulation began, each participant was briefed on the different weather advisory tasks and, thereafter, performed three practice scenarios (Manual, Automatic, and Data Link). During both the practice and data collection runs, the participants used simulation-pilot commands to vector aircraft away from weather hazards. We used this procedure in our lab during scenario development and testing, and it was appropriate for the present part-task simulation because there was no need for actual simulation pilots. None of the practice scenarios were used during the data collection.

At the start of the simulation, each participant was given a SIGMET advisory and a CWA that described the overall weather pattern. The participant was instructed to pay special attention to aircraft and weather areas (given the known thunderstorm conditions) and to provide weather advisories as needed. Each participant ran the six simulation conditions over the course of one or two days, with all participant runs completed within one week.

3. RESULTS

As expected, the point estimates (i.e., mean time durations) and the standard deviations were nearly identical for the two weather-traffic scenarios under the three weather advisory conditions. Therefore, in the analyses, we combined the data for the two weather-traffic scenarios, and we report the results from the part-task simulation.

3.1 Weather Advisories – Total Time Durations

Figure 2 shows the mean time durations for completion of weather advisories during the Manual, Automatic (alert to release), and Data Link (alert to send) conditions. For the Manual condition, it took the participants, on average, 6.6 seconds longer to manually compose and transmit a weather advisory (using today's ATC) compared to completing a weather advisory under the Automatic condition. As expected, participants needed less time to complete the weather advisories in the Data Link condition compared to the time needed to complete the weather advisories in the Automatic condition and the Manual condition.

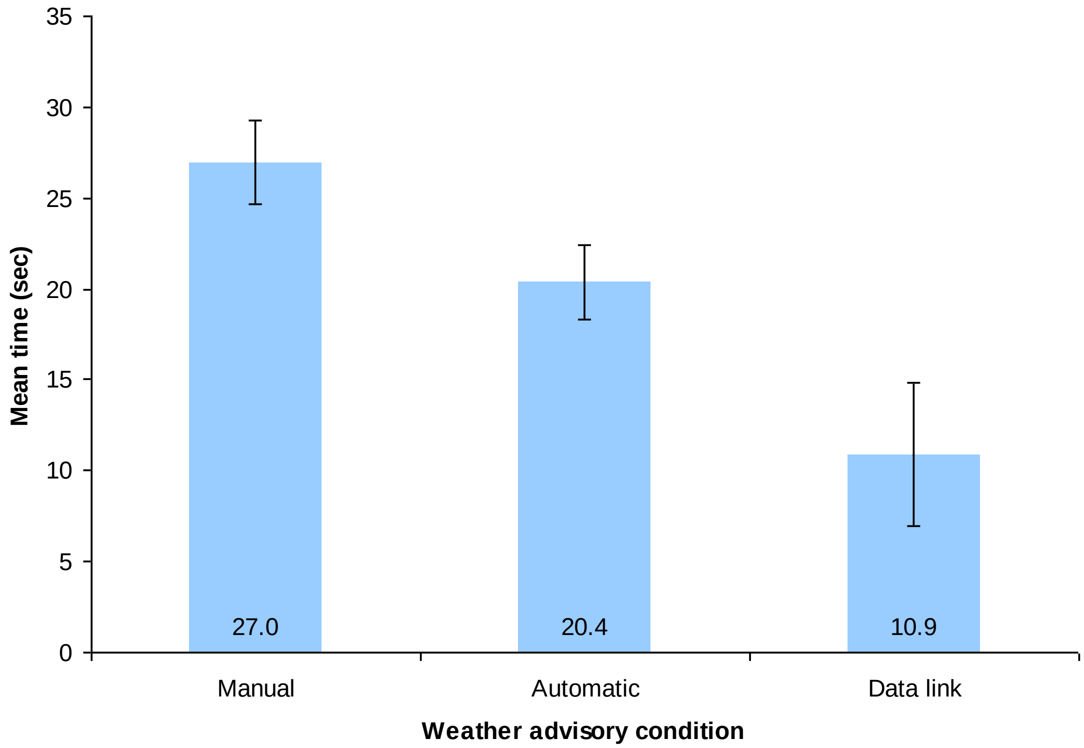

Figure 2. Mean time durations from AIRWOLF alert to advisory completion for the Manual, Automatic, and Data Link conditions. The error bars are 95% within-subjects confidence intervals.

3.2 Weather Advisories – Production Time

To compose a weather advisory in the Manual condition, the participants went through an initial production phase in which traffic and weather parameters were manually extracted from the display (mental integration). In the Automatic condition, no such production phase was needed because the participants were provided an automatic weather advisory. By comparing the time difference between alert and push for the Manual and Automatic conditions, we can evaluate the effect of automatic weather advisories.

Figure 3 shows the mean time durations from alert to push for the Manual and Automatic conditions. Figure 3 shows that the mean time duration for the Manual condition is virtually twice that of the Automatic condition. Evidently, providing participants with automatic weather advisories reduced the time duration from the AIRWOLF alert to the start of the advisory transmission by 45%.

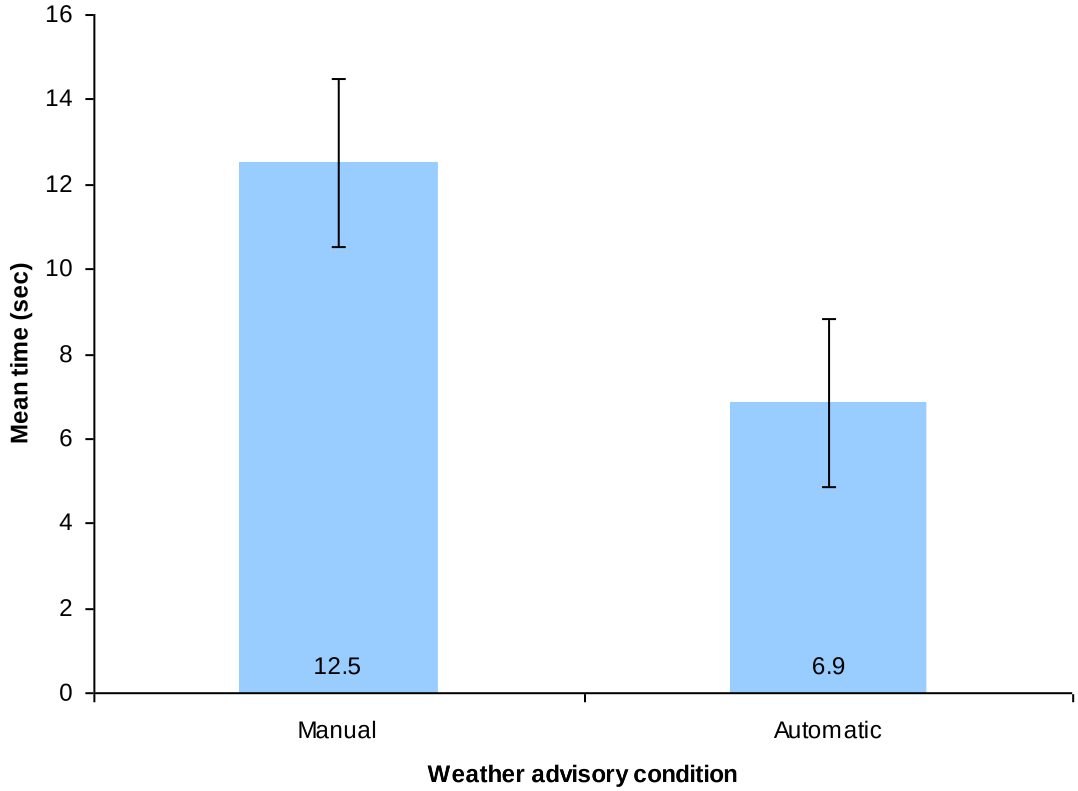

Figure 3. Mean time durations from the AIRWOLF alert to push for the Manual and Automatic conditions. The error bars are 95% within-subjects confidence intervals.

3.3 Weather Advisories – Voice Durations

Figure 4 shows the mean time durations for voice for the Manual and Automatic conditions. As expected, the time durations are nearly identical, with the voiced advisory approximately one second longer for the Manual condition.

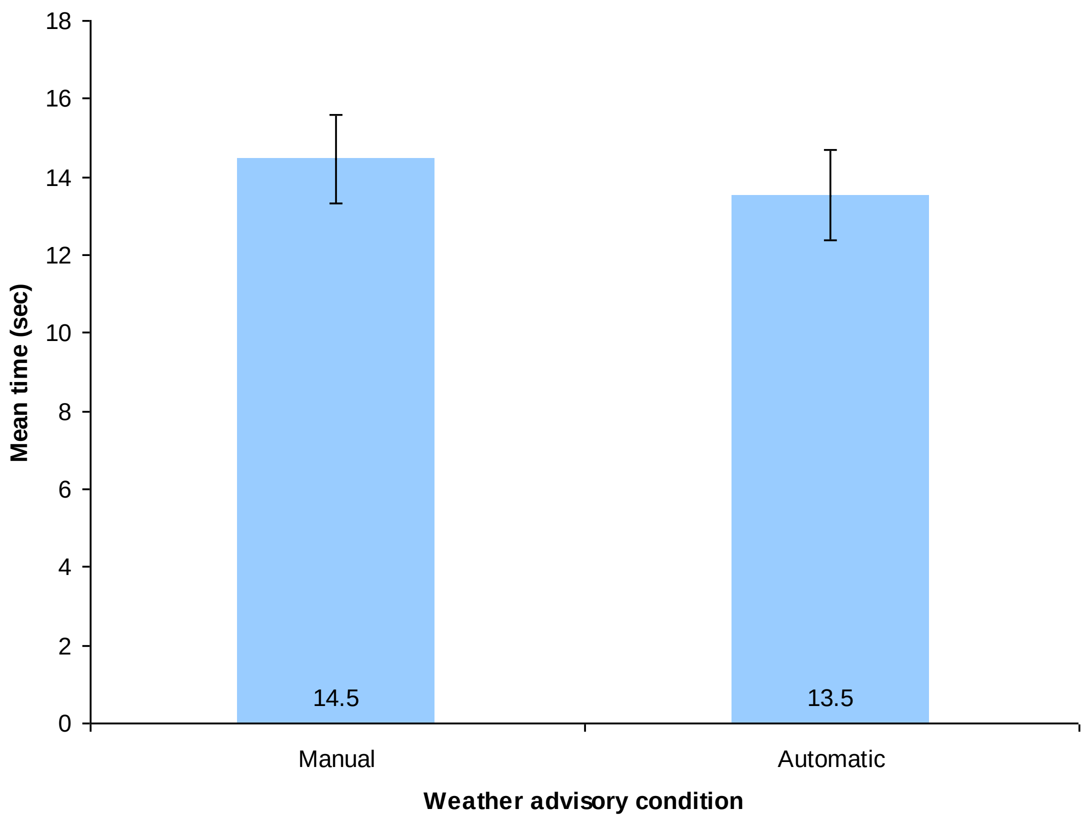

Figure 4. Mean time durations for the Manual and Automatic voice transmissions. The error bars are 95% within-subjects confidence intervals.

4. AIRWOLF INTEGRATION ALTERNATIVES

The result of the part-task simulation reveals an operationally important effect of automatic weather advisories provided by the AIRWOLF tool. Not only do automatic advisories eliminate the cognitive load inherent in manual advisory production, but using automatic advisories also reduces the overall advisory time by 24%. For data link integration, we see an even greater reduction of advisory times. Using data link communication for weather advisories reduces the total advisory time by 47% compared to the Automatic condition and by 60% compared to the Manual condition.

Apart from the benefit of automated weather advisories on controller workload, the AIRWOLF tool capability could, potentially, add additional support for en route controllers. For example, by providing a graphical display of many weather hazards, the AIRWOLF capability could further increase controller weather situation awareness. Also, in a future ATC environment with data link communication, the roles and responsibilities with regards to providing weather advisories could be more flexible compared to today's en route ATC, in which the Radar (R)-side is the sole advisory provider via radio.

In Table 1, we evaluate the impact of the AIRWOLF tool integration on en route R-side and Data (D)-side, with respect to workload, weather situation awareness, weather advisory function, and air-ground communication. Three potential integration modes are considered and compared to today's R- and D-side operations: R-side AIRWOLF integration using radio, D-side AIRWOLF integration using radio, and a future R-side and D-side AIRWOLF integration using data link communication. In Table 1, we describe the most noteworthy effects for each combination and emphasize the positive effects (see shaded areas in Table 1).

Table 1. Effects of AIRWOLF Integration on En Route R-side and D-side Workload, Weather Situation Awareness, Weather Advisory Function, and Air-Ground Communication

AIRWOLF Integration Mode	Controller Workload	Controller Weather Situation Awareness	Controller Weather Advisory Function	Air-ground Communication
Today's R-side and D-side No weather advisory support *Radio communication*	- Manual integration of weather and traffic data. Increases R-side and D-side workload. - The ability to provide weather advisories is contingent upon the R-side workload (traffic separation has priority).	- Both the R-side and D-side weather situation awareness is limited by today's weather information. - No graphical depiction of weather hazards, except precipitation intensities.	- The weather advisory function in today's operations is limited to voice communication. Only one controller can be on the frequency at a given time. - All weather advisories to pilots are provided via R-side radio.	- Limited air-ground communication, only the R-side provides weather advisories via radio.
R-side only Automatic weather advisories are displayed in the Weather Advisory View *Radio communication*	- Automatic weather advisories reduce R-side workload. - No manual integration of weather and traffic data.	- Increased R-side weather situation awareness. - A graphical display of weather hazards on the situation display.	- Supports the R-side controller. Weather advisories are displayed automatically and can be read over the radio.	- Limited air-ground communication; only the R-side provides weather advisories via radio.
D-side only Automatic weather advisories are displayed in the Weather Advisory View *Radio communication*	- Increased workload because D-side must coordinate and relay weather information to the R-side.	- Increased D-side weather situation awareness.	- The D-side is only monitoring the radio frequency. Only the R-side provides weather advisories via radio.	- Limited air-ground communication; only the R-side provides weather advisories via radio.
R- and D-sides Automatic weather advisories are displayed in the Weather Advisory View *Data link communication*	- Reduced R-side and D-side workload because weather advisories can be uplinked to pilot via data link. - Eliminates the need to provide advisories via radio to data-link equipped aircraft.	- Increased R-side and D-side weather situation awareness. - The same weather information is available at both workstations.	- Supports both the R- and D-sides; advisories can be uplinked to pilots via data link. - D-side can offload the R-side workload by taking care of the weather advisory function.	- Weather advisories can be uplinked to pilots via data link by both the R- and D-sides (for equipped aircraft). - Voice communication only necessary for unequipped aircraft.

5. DISCUSSION

In this report, we examined weather information and weather advisory procedures for en route controllers. In today's operations, R-side controllers manually integrate weather information to compose a weather advisory that is transmitted to pilots via radio. This is not optimal from a human factors perspective and not efficient from an operational perspective. The manual weather advisory process adds a cognitive load on the controller, and the procedure is time-consuming. Radio communications also have a capacity limitation in the ATC system. Often, radio communications, such as controller instructions, controller weather advisories, and pilot deviation requests, compete for bandwidth and create radio-frequency congestion. Adverse weather conditions also add complexity for the controller because pilots will either request deviations or inquire about alternate routings around weather. These deviation requests must be evaluated by the controller to verify that new headings and routes do not create additional weather and traffic conflicts, which result in increased workload for the controller. If the controller workload is too high, the controller may not be able to provide the weather advisory function at all.

In our part-task simulation, we found that weather advisories created by the AIRWOLF tool support the controller weather advisory function and also reduce controller workload. When study participants used the automatic weather advisory function, the participants reduced the total advisory time (i.e., from alert to release) by approximately 7 seconds. When participants could send weather advisories by data link communication, the participants reduced weather advisory times even further. However, AIRWOLF and data link integration at the en route controller workstation could also provide additional benefits. For example, in today's operations the weather advisory function is solely provided by the R-side controller. With an integrated AIRWOLF tool and data link capability, the D-side controller could take responsibility for the weather advisory function. This would off-load the weather advisory requirement from the R-side controller, allowing the R-side to focus on the sector traffic.

In an ATC environment where data link communications are standard, there is an even greater opportunity to enhance weather advisories and to reduce controller workload. The AIRWOLF tool could automatically generate and transfer weather advisories to pilots upon initial contact. As soon as a pilot switches frequency upon entering a new sector, the AIRWOLF tool could automatically send weather advisories to the pilot. This would eliminate the controller's responsibility of providing weather advisories, resulting in a reduced workload and allowing controllers to focus on traffic separation.

Additional AIRWOLF tool benefits (not evaluated in this study) include an increased capability to probe for multiple weather hazards. In today's ATC operations, controllers only have a graphical display of precipitation information at the workstation. All other weather information sources, except direct Pilot Reports (PIREPs), are provided to controllers in a text-based format. Because controllers are forced to manually integrate traffic and weather information, any additional weather advisory requirements (e.g., adding icing, turbulence, ceiling, and visibility information) would only make the weather advisory task more difficult and increase the advisory production time. This would further increase the cognitive load on the controllers and lengthen the duration of radio communications. However, because the AIRWOLF tool has the capability to probe for multiple weather hazards and to provide automatic weather advisories, the AIRWOLF tool could accomplish this task without increasing controller workload or the number of communications.

In a future version of AIRWOLF, we see an opportunity to create a more efficient controller tool for enhanced weather avoidance operations. The current AIRWOLF tool certainly enhances controller weather situation awareness and advisory function by providing immediate access to enhanced weather information. However, to see additional benefits, such as increased traffic throughput and weather avoidance efficiency, we need to enhance the AIRWOLF algorithm with an aircraft-to-aircraft conflict probe. Controllers need tactical weather decision-support tools to make safe and efficient decisions that support the hands-on, moment-to-moment management of traffic within their airspace. Making sure that pilots are aware of, and can avoid, hazardous weather (such as provided by the current version of AIRWOLF) is one part of the equation. Another part that is equally important is to make sure that deviation requests and reroutes are free of potential traffic conflicts. By combining the probing for weather and traffic, the AIRWOLF tool could provide conflict free alternatives for dealing with weather to the controller. These alternatives could be transmitted to the pilot or used for traffic control decisions by the controller. This is the optimal way to support en route controllers for the safe, efficient, and strategic efforts required to handle adverse weather conditions in the future NAS.

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Acronyms

AIRWOLF	Automatic Identification of Risky Weather Objects in Line of Flight
ATC	Air Traffic Control
CIWS	Corridor Integrated Weather System
CWA	Center Weather Advisory
DESIREE	Distributed Environment for Simulation, Rapid Engineering, and Experimentation
ERAM	En Route Automation Modernization
FAA	Federal Aviation Administration
NAS	National Airspace System
NCWF	National Convective Weather Forecast
PIREP	Pilot Report
SIGMET	Significant Meteorological Information
SME	Subject Matter Expert