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Enhanced Weather Radar (EWxR) System

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EWXR PROGRAM (NCC1-355)

Contractor Report

Background

On October 23, 1998, as part of the NASA Weather Accident Prevention Program, Rockwell and NASA entered into a cooperative research agreement to explore the use of advanced technologies to enhance the quality of on-board weather information processing. The focus of the program, Enhanced Weather Radar (EWxR), is the on-board weather radar. The advanced radar capabilities include:

- A decision aid to assist the pilot in the operation of the on-board radar;
- Integration of strategic ground-based weather information and tactical on-board weather information;
- A decision aid to automatically characterize storm cells;
- A decision aid to assist the pilot in the interpretation of hazards relative to their flight plan.

Rockwell and NASA demonstrated the advanced radar capabilities on the NASA ARIES and Rockwell Collins Sabreliner aircraft. The EWxR demonstrations included presentation of a single display, combining tactical and strategic weather information, characterizations and classification of storm cells to provide a decision aid, and evaluation of storm hazards relative to the flight plan to provide a second decision aid. This document provides an overview of the EWxR advanced radar capabilities, display formats, system architecture, and demonstration examples from the Spring 2002 NASA ARIES flight test and September 2002 Rockwell Sabreliner flight test.

Overview

A pilot operating the on-board weather radar must have considerable experience in radar operating techniques, in order to realize maximum benefit from the weather radar system.
Initial developments under the EWxR program focused on providing guidance to pilots on how to operate the on-board weather radar and automating control of the weather radar. The guidance was in the form of suggestions to the pilot on how to effectively manage the radar tilt and range settings based upon current altitude above terrain and the current weather conditions. Automation of those tasks was further developed to provide the pilot with a "hands-free" capability to operate the on-board weather radar.

The automated or "hands-free" storm-finding feature optimizes the radar returns by automatically adjusting the tilt and range settings for the current altitude above the terrain and searching for storm cells near the atmospheric 0-degree isotherm.

Even if the operation of the on-board radar is automated, the on-board weather radar has limitations as a weather avoidance tool based upon limited range, attenuation, single-beamwidth display, etc. In order to eliminate or minimize the limitations of the radar, ground-based weather information is used to augment the on-board weather radar information.

National Weather Service (NWS) ground-based Next Generation Radar (NEXRAD) information is used by the EWxR system to augment the on-board weather radar information. The EWxR system overcomes the attenuation and range limitations of the on-board weather radar by allowing the pilot to simultaneously display NEXRAD and on-board weather radar information in a "split-view" format, as shown in Figure 3. The "split-view" format uses Composite Base Reflectivity NEXRAD imagery, which shows nearly all weather phenomena by collapsing altitude dependent information to a simple plan view and combining overlapping base reflectivity scans. At a given time, on-board weather radar provides data from a single sweep, at an operator-selected elevation. Relying solely on this information, it is possible for a pilot to miss a cell that is below or above the current radar scan. The composite NEXRAD portion of the EWxR display compensates for this limitation of the on-board radar.

A rule-based decision aid was developed to automatically characterize cells as *hazardous*, *possibly-hazardous*, or *non-hazardous* based upon attributes of that cell. Cell attributes are determined based on data from the on-board radar and from ground-based radars. An example of an attribute detected by the on-board radar is the reflectivity level. Examples of ground-based attributes detected by NWS NEXRAD radar sites are storm height, speed, and heading, hail potential, and tornadic behavior. The EWxR decision aid uses the attributes from the multiple sensors to assess whether a storm cell is hazardous. The benefit of using the information from the multiple sensors is that one sensor may detect information about a cell that will trigger a hazard where another may not due to latency, range limitations, attenuation, etc.

The flight path impact prediction algorithm is an aid for pilots that need to avoid hazardous weather along their flight plan and their mission. Pilots must continually monitor weather along their flight plan as well as at their destination. Pilots rely on their on-board weather radar for the location of hazardous weather. However, they must also use cognitive skills to predict locations of hazards in the future. To do this, they must characterize the weather as hazardous and then determine the location of hazardous weather relative to where the aircraft will be in the future. To that end, the pilot must consider the aircraft's current speed, altitude, and flight path to predict the location of the aircraft at some time in the future. The pilot must then predict where cells that are deemed hazardous will be at that same time in the future. From there, the pilot must determine if the hazardous cell is "too close" and must be circumnavigated. The flight path impact algorithm automates those tasks and provides the pilot with a unique display to denote an impact area along the flight plan.

EWxR Display

The EWxR system capability includes three modes for weather depiction. The first mode of operation is a weather-only (Wx) mode, which is found on all standard radar indicators. That mode displays weather radar information generated directly from the radar receiver/transmitter unit. An example of Wx mode information taken from the EWxR display is shown in Figure 1.

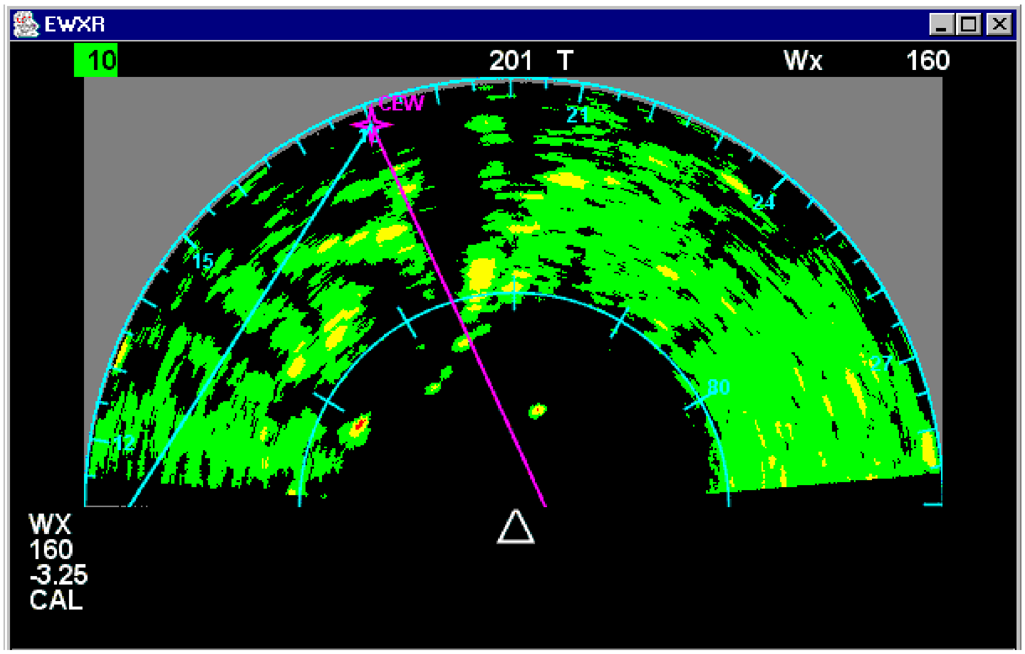

Figure 1 Wx Example

In addition to the Wx operation mode, a NEXRAD-only (Nx) mode is available to show the pilot a heading-up view of composite base reflectivity NEXRAD weather information. An example of the NEXRAD-only display is shown in Figure 2. The NEXRAD-only view of weather information provides the pilot with the capability to view weather information that is generated at 5-6 minute intervals by the National Weather Service ground-based Doppler weather radars.

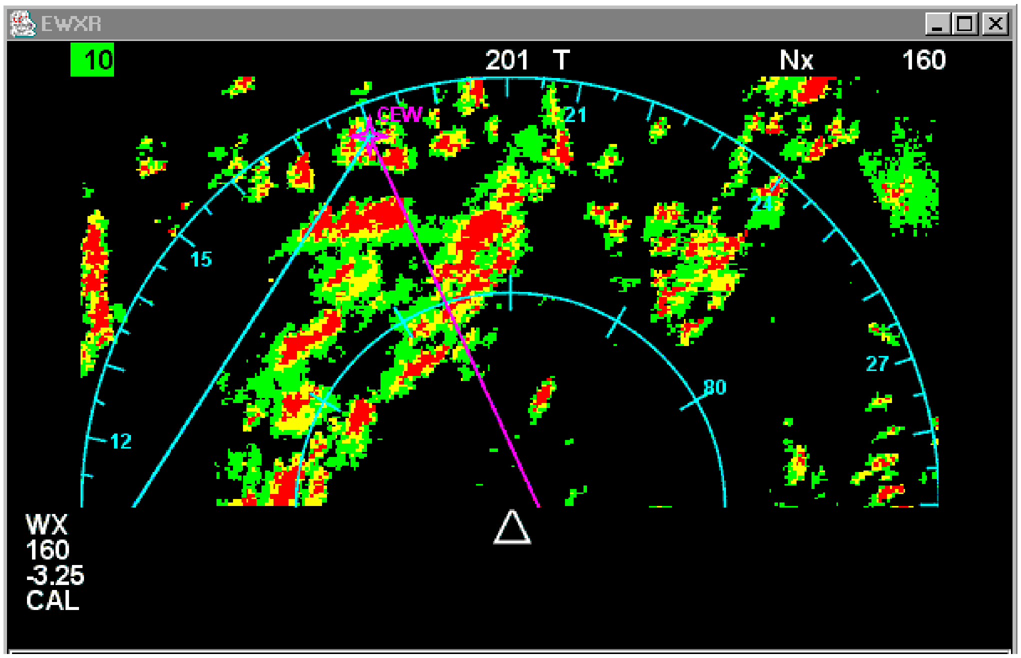

Figure 2 Nx Example

A third mode (Wx+Nx) of operation developed by the EWxR team provides the pilot with a "split-view" capability of tactical on-board weather radar information and strategic ground-based weather information. EWxR currently uses composite base-reflectivity NEXRAD information as the ground-based data source in its Wx+Nx (split-view) and Nx modes. An example of the Wx+Nx mode is shown in Figure 3. The dashed, white demarcation line separates the tactical on-board weather radar information near the aircraft from the ground-based weather information.

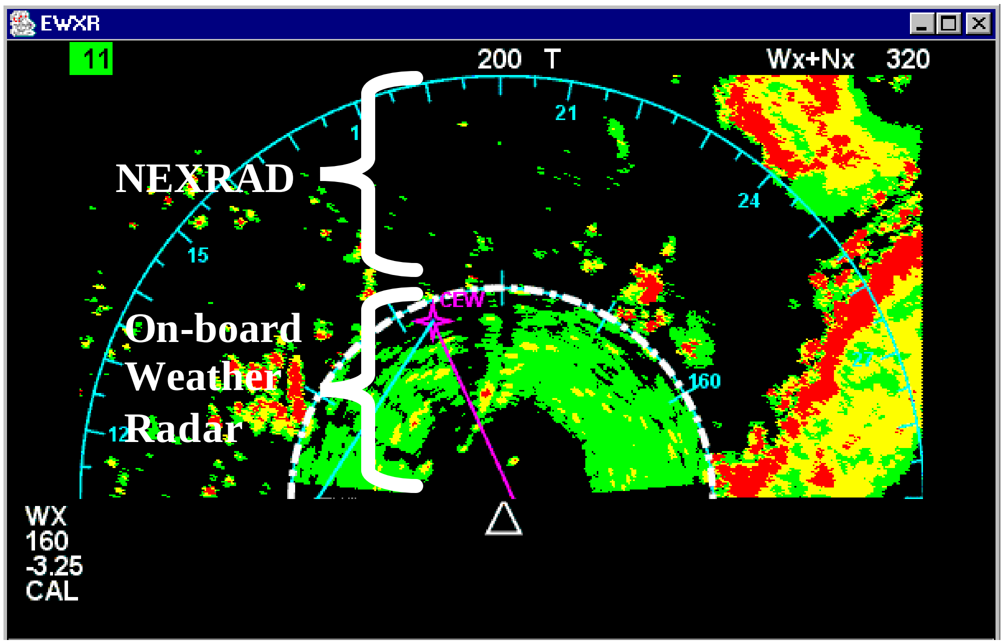

Figure 3 Wx+Nx Example

System Architecture

The EWxR system architecture supports the uplink of ground-based weather information through multiple datalink options, including Skyphone™ and a satellite communication (SATCOM) data link developed under the NASA Weather Accident Prevention Program. The EWxR ground station uplinks NEXRAD composite radar imagery and NEXRAD storm cell attribute data to the aircraft.

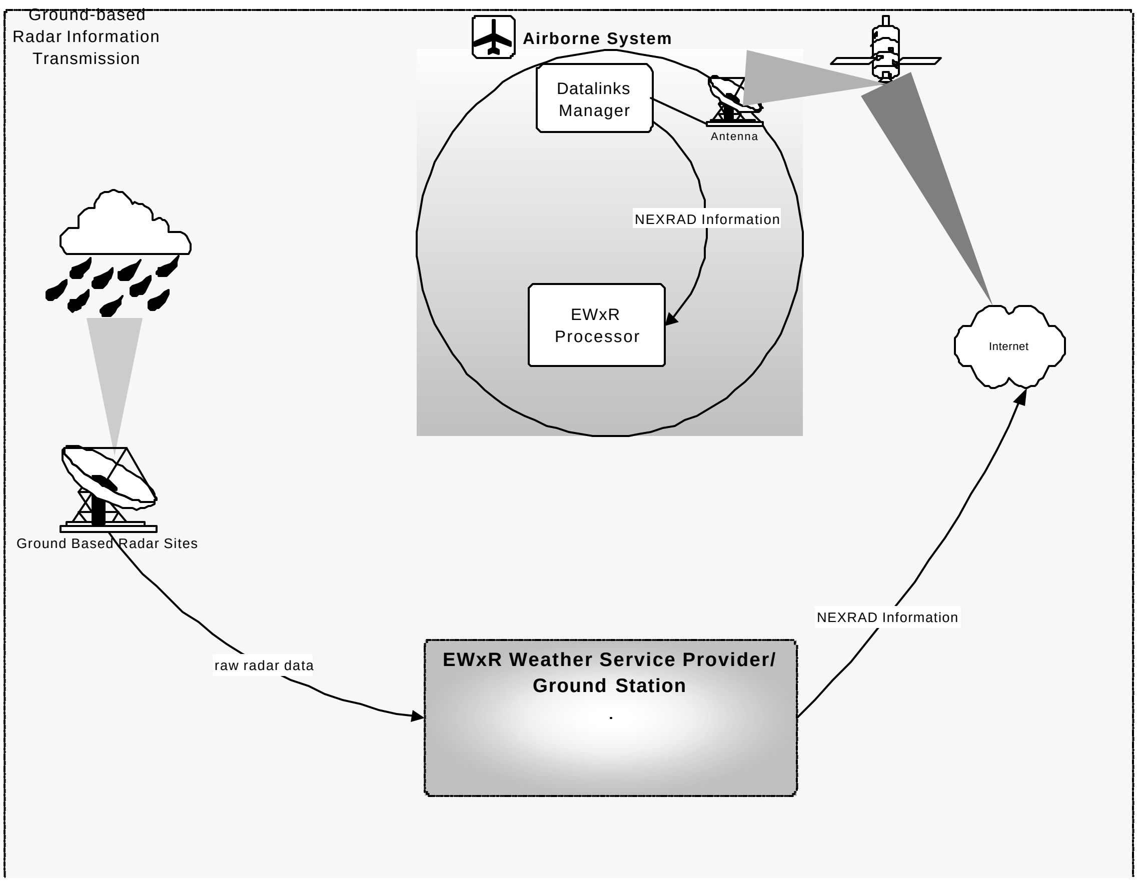

Figure 4 EWxR System Architecture

In Figure 4, the datalinks manager receives the ground-based weather information on the aircraft and passes it on to the EWxR processor. EWxR receives on-board weather radar data over the aircraft's ARINC 453 bus. Aircraft and flight plan information arrives via the aircraft's ARINC 429 bus.

Demonstration of EWxR System on NASA ARIES Aircraft

The EWxR integrated system demonstration was successfully flown on the NASA ARIES during the months of March, April, and May of 2002. The EWxR system included NWS NEXRAD Attribute Information associated with NEXRAD cells and on-board weather radar cells. Rockwell Collins demonstrated the ability of the EWxR system to assess whether a storm cell is hazardous based upon NEXRAD information. Further, the system was able to determine whether (and where) each hazardous cell would impact the aircraft flight plan. Ground-based weather information was datalinked to the EWxR system using the SATCOM datalink.

Researchers from NASA Langley Research Center and Rockwell Collins used the ARIES aircraft to demonstrate the EWxR integrated system, collect weather radar data on storm cells of interest, and verify the accuracy of the EWxR algorithms. The following figures are results from the April 3, 2002 and May 17, 2002 flight tests on the NASA ARIES aircraft. Figure 5 is a track-up view of NEXRAD imagery and NEXRAD Attribute information from the April 3, 2002 flight test.

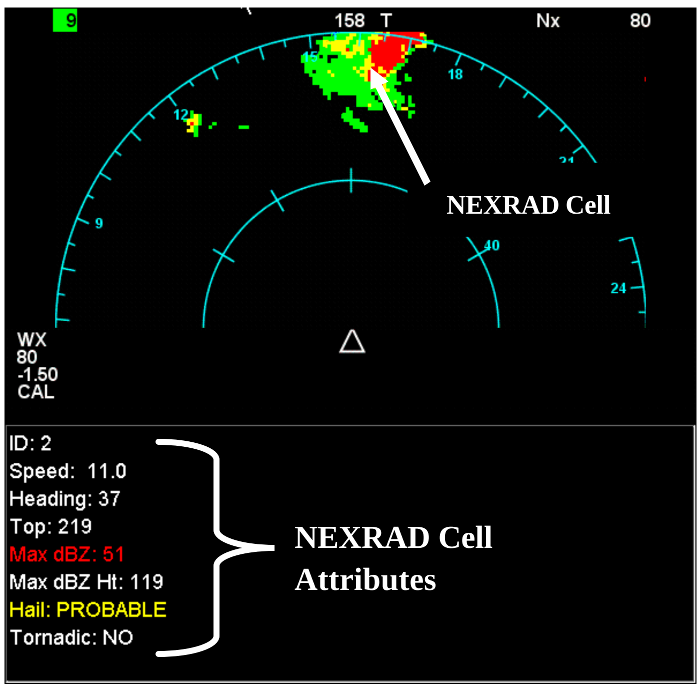

Figure 5 NEXRAD Imagery and NEXRAD Attribute Data – April 3, 2002

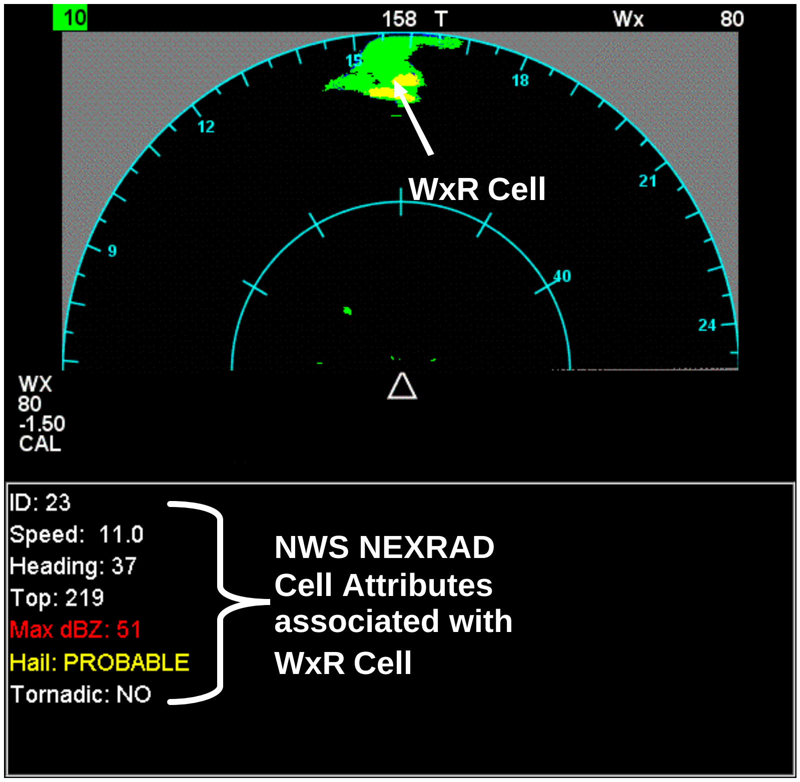

Figure 6 WxR Cell with NEXRAD Attribute Data – April 3, 2002

Figure 6 is an example of datalinked NEXRAD information associated (fused) with on-board WxR imagery on the April 3, 2002 NASA flight test demonstration. The upper-half of the display shows a cell depicted by the on-board weather radar. The lower half of the display shows the ground-based attributes that have been associated with the on-board radar cell. A decision aid is used on the attributes to assess whether the cell is hazardous. Note the high reflectivity level (51dBZ) and the PROBABLE indication of hail by the NWS attribute data. Without the additional NWS NEXRAD attribute information, the cell depicted by the on-board weather radar on April 3, 2002, could be easily mistaken as being benign, rather than hazardous.

Once a storm cell has been assessed as being hazardous, the flight path impact prediction algorithm automatically determines if the hazardous cell is predicted to affect the pilot's mission. Figure 7 and Figure 8 illustrate the results from the May 17, 2002 flight test on the NASA ARIES aircraft. The time associated with Figure 7 is 17:36GMT. The time associated with the two displays in Figure 8 is 17:38GMT and 17:41GMT, respectively. The aircraft's altitude was 30,340ft and its ground speed was 433 knots during that time period.

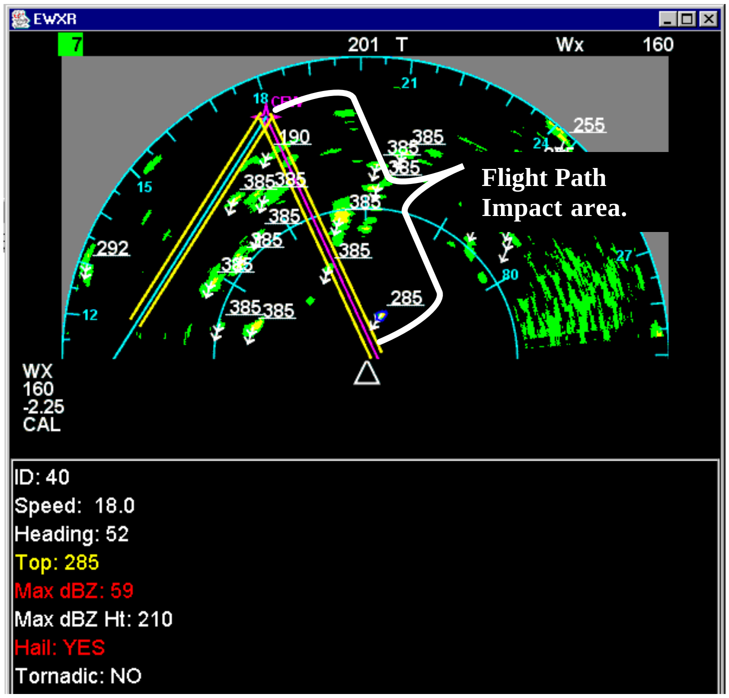

Figure 7 Flight Path Impact - May 17, 2002, 17:36GMT

In Figure 7, a large portion of the flight plan has been "flagged" as being hazardous based upon the predicted location of several hazardous storm cells along the aircraft's flight plan. The yellow bars flanking the flight plan denote the flight path impact area. The large flight path impact area occurred because the aircraft's flight plan intersects several storm cell hazards. In the display of Figure 7, the cell that is closest to the aircraft, which has a top at 28,500ft (285), has been selected by the pilot, and NEXRAD attributes associated with that cell are displayed in the lower half of the graphic. That cell has also been assessed as being hazardous because of its high reflectivity level (59dBZ) and the positive indication of hail. Reflectivity greater than 40dBZ is generally a hazard because of potential severe turbulence associated with that cell. Note the velocity vector associated with the cell (white arrow) indicating that the cell is moving towards the flight plan and is an impending hazard. A hazardous cell is considered a threat to the aircraft and its mission only if the cell will pass within a specified distance from the aircraft's flight plan. The distance to be considered hazardous is set by the operational rules of the airline. It is most commonly 20 nautical miles. This particular cell's current position and predicted positions fall within 20 nautical miles of the aircraft's current and predicted positions, so the cell is considered an immediate and future hazard to the aircraft.

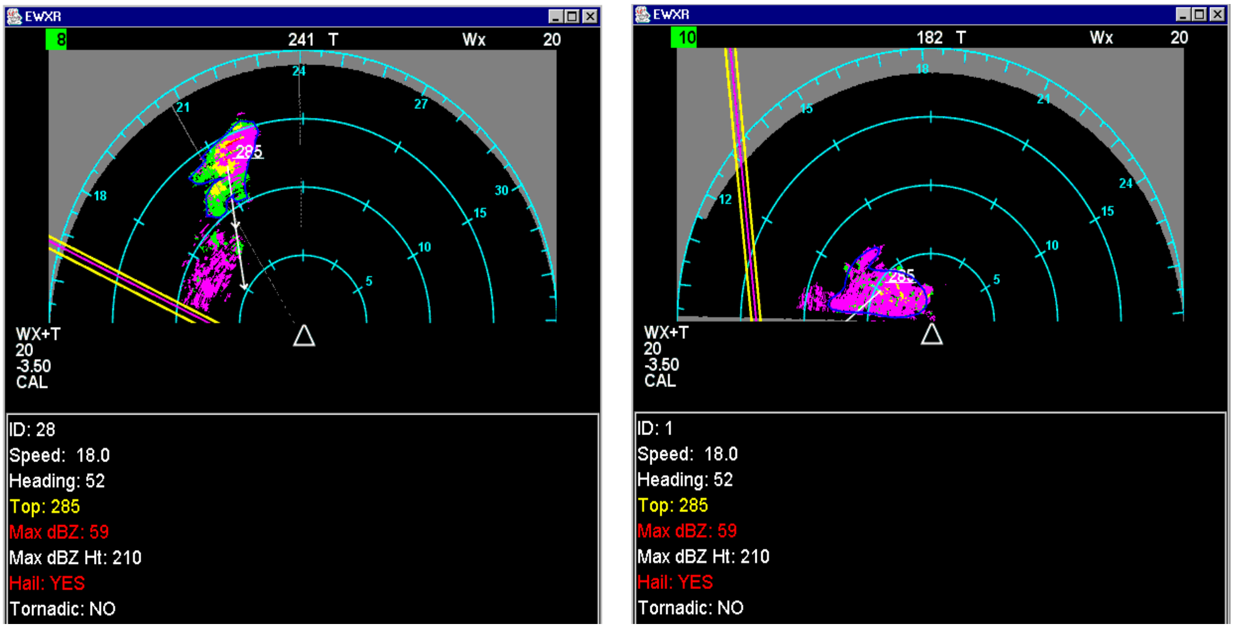

Figure 8 Confirmation of Flight Path Impact - May 17, 2002

Figure 8 shows views of the same cell later in the flight (17:38GMT and 17:41GMT). The image sequence illustrates the aircraft circumnavigating the cell. In the left image, note the turbulence associated with the cell, as detected by the on-board weather radar and indicated by magenta. The right image shows the same cell two-minutes later in the circumnavigation procedure. At the time the right image was taken, the aircraft experienced turbulence with a downward force of 2 G's, which confirmed that the cell was hazardous, as previously indicated by the decision aiding logic and flight path impact prediction.

Demonstration of EWxR System on Rockwell Collins Sabreliner Aircraft

On September 5 and September 6, 2002, Rockwell Collins and NASA Langley researchers successfully demonstrated the EWxR system on the Rockwell Collins Sabreliner aircraft. A Rockwell Collins SATCOM datalink was installed on the Sabreliner aircraft. Weather Services International (WSI) provided ground-based weather data to the aircraft.

Over the two-day period, researchers worked a storm system that extended from northern Minnesota to northern Wisconsin. Eleven cells from that system were characterized using the EWxR system. Figure 9 was taken at 20:04GMT on September 5, 2002 and shows a cell depicted by the on-board weather radar that has datalinked NEXRAD information associated with it. The inset picture shows the pilot's view of the same cell through the cockpit window.

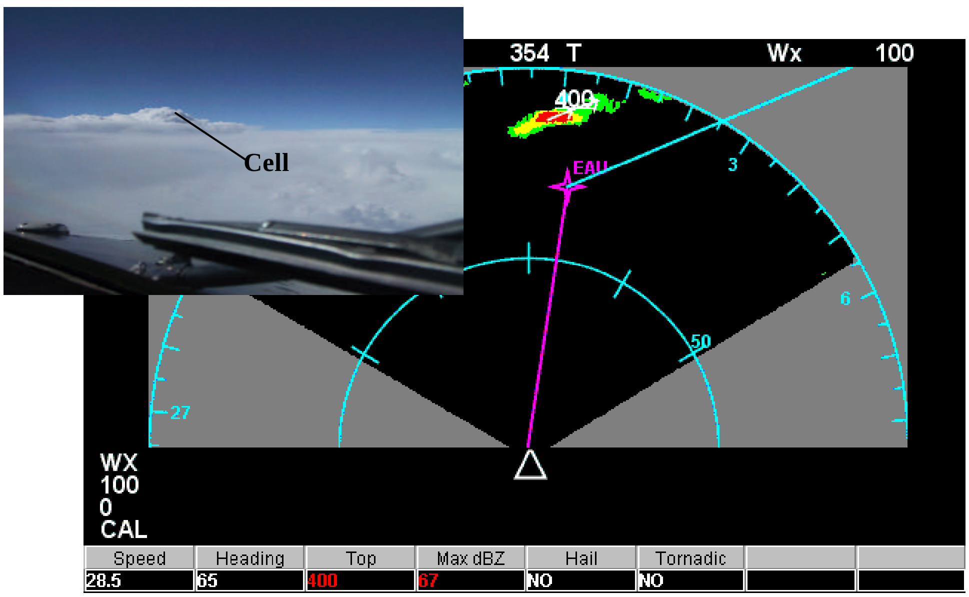

Figure 9 EWxR Hazard Assessment, September 5, 2002

The EWxR decision aid has assessed the cell as hazardous based upon the attributes associated with the cell. The 40,000 ft. storm top and very high reflectivity level (67dBZ) associated with the cell are indicators that the cell is hazardous. In this instance, without the benefit of EWxR, had the pilot been operating the radar at a different antenna tilt and range combination, the on-board radar might not have detected the high reflectivity level. That would result in a situation, similar to that depicted in Figure 6, where the unaided radar display of a hazardous storm would appear benign.

Figure 10 was taken at 20:08GMT and is another look at the hazardous cell from Figure 9. Figure 10 shows a flight path impact prediction with that cell. Note the cell is moving in the direction the aircraft will be traveling during the next leg of the flight plan and will be within 20 nautical miles of the aircraft, so it will be a potential hazard when the aircraft begins the next leg of the flight plan.

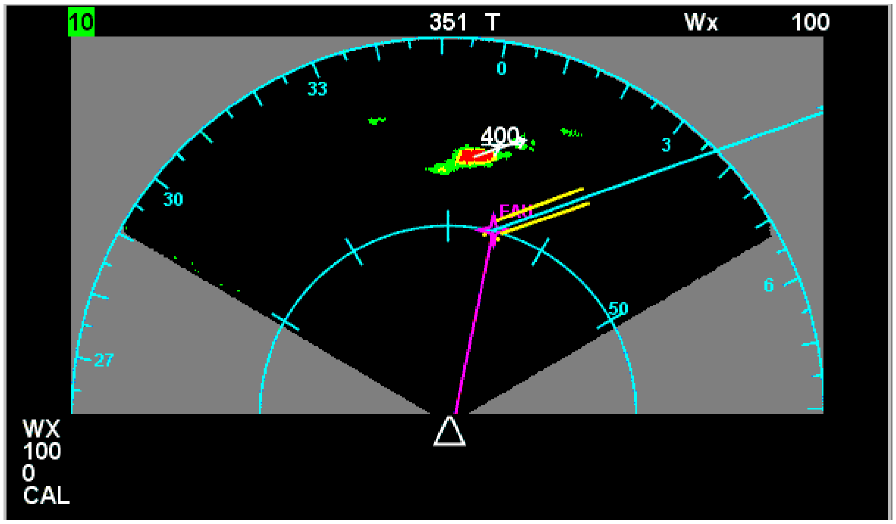

Figure 10 EWxR Flight Path Impact Prediction September 5, 2002

Summary

The successful flight tests on the NASA ARIES and Rockwell Collins Sabreliner demonstrated the utility of augmenting on-board weather radar information with ground-based weather information. The weather information allowed the NASA and Rockwell Collins EWxR system to assess not only whether storm cells are hazardous, but also whether they will affect the mission.

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14. ABSTRACT

An airborne weather radar system, the Enhanced Weather Radar (EWxR), with enhanced on-board weather radar data processing was developed and tested. The system features additional weather data that is uplinked from ground-based sources, specialized data processing, and limited automatic radar control to search for hazardous weather. National Weather Service (NWS) ground-based Next Generation Radar (NEXRAD) information is used by the EWxR system to augment the on-board weather radar information. The system will simultaneously display NEXRAD and on-board weather radar information in a "split-view" format. The on-board weather radar includes an automated or "hands-free" storm-finding feature that optimizes the radar returns by automatically adjusting the tilt and range settings for the current altitude above the terrain and searches for storm cells near the atmospheric 0-degree isotherm. A rule-based decision aid was developed to automatically characterize cells as *hazardous*, *possibly-hazardous*, or *non-hazardous* based upon attributes of that cell. Cell attributes are determined based on data from the on-board radar and from ground-based radars. A flight path impact prediction algorithm was developed to help pilots to avoid hazardous weather along their flight plan and their mission. During development the system was tested on the NASA B757 aircraft and final tests were conducted on the Rockwell Collins Sabreliner.

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