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The Effect of Ownship Information and NexRad Resolution on Pilot Decision Making in the Use of a Cockpit Weather Information Display

Paul F. Novacek, Malcolm A. Burgess, Michael L. Heck, and Alan F. Stokes
RTI International, Hampton, Virginia

December 2001

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We would like to thank Mr. Brian Haynes of Honeywell for cooperation in the modification and use of a prototype Flight Information Services Data Link display system in the simulation. We would especially like to acknowledge the contributions of the pilots. They all volunteered their time and traveling expenses. Some traveled to Hampton, Virginia from as far away as Connecticut. These individuals were magnificent in the generosity of their time, patience and piloting skills.

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Reason for Experiment

Significant progress has been made in recent years toward the provision of real-time data-linked weather information to pilots. One of the most recent efforts is the broadcast Flight Information Services Data–Link (FISDL) service—a government–industry partnership created to bring near real-time weather information into the cockpit. RTI International recently completed an experiment that explored the effects of a data-linked in-flight weather display on pilot decision making. In that previous experiment, two groups of pilots were placed in a full-mission simulator, 12 without the data-linked weather display and 13 with the display. The results found that although the weather display increased the pilot's awareness of the weather situation, there were many issues that prevented the display from being used to its full capability.

This follow-on experiment explored specific issues that were uncovered in the previous experiment. The results will assist the manufacturers of weather display systems, and provide information for the FAA on certification and usability issues.

Overview of Experiment

The experiment described in this report explored the effects of adding ownship position symbology and changing the NEXRAD cell size resolution shown on the data-linked weather display.

It is anticipated that with sufficient training, careful use of the cockpit weather display, and prudent pilot procedures in instrument flight conditions, the emerging cockpit weather display products will provide substantial improvements to the safety of flight. It is important to note that this experiment, like the one that preceded it, was designed specifically to identify potential hazards in the use of cockpit weather displays.

Every aspect of the design of this experiment was undertaken with this objective in mind, including subject pilot selection, subject pilot training, and the mission scenario. Pilots were selected so as to provide as wide and representative a range as possible of the experience, knowledge of weather and risk aversion of the population of general aviation pilots who might use these emerging cockpit weather display products. The training provided the subject pilots was carefully tailored so as to provide them with sufficient familiarity with the experimental equipment to successfully accomplish the mission scenario, while at the same time creating a reasonable probability that within the population of subject pilots selected, potential hazards in the use of the equipment might become apparent. Likewise, the mission scenario incorporated in the experiment was selected to ensure that it could be accomplished by the average pilot with careful attention by the subject pilot to the instrument flight procedures, but offered sufficient opportunity for observation of human error in the use of the prototype cockpit weather display where such hazards might exist.

The experiment was conducted with twenty-four current instrument rated pilots who were divided into two equal groups and presented with a challenging but realistic flight scenario involving weather containing significant embedded convective activity. All flights were flown in a full-mission simulation facility in simulated instrument meteorological conditions. The objective of the experiment was to investigate the possible misuse of the data-linked weather information with respect to the addition of ownship position symbology and a change in NEXRAD image cell resolution. The results of the experiment identified the issues that need further investigation or consideration by the manufacturers and the FAA.

The pilots were presented with a flight scenario that involved the delivery of critical medicine to the NASA-Wallops Flight Facility. Departing from the Newport News–Williamsburg International Airport (Virginia), the pilots were told that additional medicine was to be picked up at the Richmond International Airport enroute to Wallops. The two legs of the flight were designed to encounter convective weather in order to investigate both temporal and spatial issues related to the use of a weather information display. In addition to the weather display, all the normal weather information sources were also available.

The 24 pilots were divided into two groups of 12 each. One group flew the mission with a weather display that used small NEXRAD image cells (4x4 km cells) and the second group was given a display that used large NEXRAD image cells (8x8 km cells). The weather display provided to both groups in this experiment included ownship position symbology, whereas in the previous experiment, ownship position information was not provided on the display. The small-cell (4x4 km) NEXRAD images were processed through a software filter that assigned the highest level radar return to the entire large cell. All aspects of the previous and current experiment were identical, except for the provision of ownship position and different NEXRAD image cell sizes.

Both experiments were organized around two key decision points, a decision during an approach into the Richmond airport and a decision enroute to the Wallops Island airport. Both the Richmond and Wallops Island decisions were scored on a good/poor ordinal scale. At Richmond, a good decision was deemed to be one in which the pilot decided to abandon the approach prior to the Final Approach Fix, thus avoiding the hazardous weather by at least five nautical miles. A poor decision was deemed to be one in which the pilot continued with an approach for whatever reason, placing the aircraft within five nautical miles of hazardous weather conditions. Enroute to Wallops Island a good decision was deemed to be one in which the pilot circumvented a hazardous area of convective weather by changing course, so as to avoid the hazards by at least ten nautical miles. The experiment was designed to elicit the cognitive and perceptual processes involved in making these navigation decisions.

Conclusions of Experiment

Decision Making in the Flight Environment

When compared to the use of a cockpit weather display in a previous experiment that did not contain ownship position information, the introduction of ownship information did not improve the ratio of good decisions versus poor decisions, for either the Richmond or the Wallops decisions. On the other hand, the addition of ownship position information to the display did not have a detrimental effect on the decision-making ability of the pilot. Additionally, it was found that the addition of ownship position symbology reduced the perceived pilot workload in using the weather information display.

The introduction of larger NEXRAD image cells had a positive, although not statistically significant, effect on decision making for the Richmond leg of the scenario. The introduction of larger NEXRAD image cells did not have an effect on decision making, for the Wallops decision.

Display of Ownship Position and Pilot Workload

The introduction of ownship had a markedly positive effect on reducing the perceived pilot workload. This effect was attributed in large part to the reduced cognitive load required to determine the aircraft position in relation to the hazardous weather conditions.

Pilots' use of Weather Information Sources

The display of NEXRAD mosaic images substantially increased the pilots' awareness of the general location of convective weather in their vicinity. The attractive visual display of these images, however, caused some pilots to depend too heavily on the weather display for the information they needed regarding hazardous convective weather conditions. As a result, they did not feel it was necessary to obtain additional essential and corroborating information from other available sources.

METAR Presentation Limitations

The METAR textual information was presented in typical ICAO teletype coded formats. The experiment found that the interpretation of the codes in a high workload environment is prone to errors. Many errors were observed and excessive fixation times were observed when the pilots attempted to decode the METAR information. Many of the pilots commented that the METARs would be more useful if they were displayed with their English translation, much as DUATS provides the English translation. The METARs were up to an hour old in many cases, and although the information could be current, the perception of latent information may have caused the pilots to disregard the information in favor of ATC or pilot reports.

Increased Situational Awareness

The relationship between pilot workload and situational awareness was the subject of many of the comments received from the pilots—that the weather display slightly increased their workload, but vastly improved their situational awareness. A frequent comment from the pilots' epitomizes the issue, "The weather display took some time getting used to... but was well worth the added workload."

Judging Proximity and Movement of Hazardous Weather

The age of the NEXRAD images on the weather display led to noticeable errors committed by many of the pilots in the course of determining the proximity and rate of movement of the hazardous convective weather.

Stimulus Area Effect

Analysis of the Richmond decision indicated that better decisions were made with the introduction of larger NEXRAD image cells. One explanation for this finding converges on the stimulus area effect. The stimulus area effect states that the larger the visual area of a warning stimulus, the greater importance it holds.

The larger stimulus area—presented by the larger NEXRAD image cell size—created a greater uncertainty in the exact location of the hazardous weather, which led the pilots to select a track farther away from the depicted weather.

Recommendations

The following recommendations are provided for the consideration by cockpit weather display system manufacturers:

- Consider providing ownship information
- Provide direction and rate of the movement of hazardous weather
- Provide distance determination
- Provide intuitive NEXRAD image age information
- Provide METAR code english translation

Recommended information to be added to the AIM and to Advisory Circulars include:

- That pilots become fully proficient in determining and maintaining awareness of the age of data-linked weather products
- Pilots become aware of the limitations that the age imposes

Recommendations are also provided for further research and development efforts, including:

- Improved hazardous convective weather forecast products
- Storm cell movement depiction
- Icing forecast products
- Aggressive development of means for providing training in use of cockpit weather displays

1 Introduction

Statistics indicate that there is, on average, one fatal general aviation accident per day in the United States alone (AOPA, 1999 Nall Report). Some of the reasons for these fatalities include pilot-related causes, mechanical failure, midair collisions and other problems. While mechanical failure accounts for only 14.1 percent of the total accidents, pilot-related causes account for over 73 percent of the total accidents. The primary causes of fatalities were weather, maneuvering flight and approaches. Weather-related accidents were more likely to be fatal than any of the other major causes of fatal accidents. With an overall fatality rate of 83.1 percent, weather related accidents were the deadliest of the pilot-caused fatalities. Most fatalities involving weather were the result of controlled flight into terrain or other objects, spatial disorientation leading to uncontrolled flight, or pilot-induced structural failure of the aircraft. Some accidents attributed to other causes involved weather as a contributing factor as in the cases of improper IFR approach accidents. Windshear and crosswind also caused weather-related accidents. Most troubling is that 72.2 percent of the weather-related fatalities were caused by attempted VFR flight into Instrument Meteorological Conditions (IMC).

While pilot training and certification regulations to minimize pilot error have been implemented, there have been significant advances in technology that can offer advanced weather displays in the cockpit via data link. This could provide a significant advance in aviation safety. Conventional round dial instruments accompanied by aeronautical charts, approach charts, and flight service station briefs represent a few of the many separate pieces of data that must be accessed for safe flight. The pilot is obliged to integrate these various pieces of information into a single mental model of the outside world. This represents a very appreciable cognitive workload, and, inevitably, mistakes are sometimes made.

Advances in display system design are attempting to reduce a pilot's cognitive workload by doing much of the integration behind the scenes. These designs are moving toward flat-panel displays with terrain, traffic, routing, and weather all overlaid on a single screen, thereby fostering a more intuitive mental model of "the big picture" for the pilot. By reducing the workload involved in mentally integrating multiple elements, a pilot can allocate attention elsewhere, particularly to higher level situation assessment, judgment and decision making tasks. Extra attention to these tasks should reduce the potential for error and enable the individual to make better decisions.

However, because human performance research has lagged well behind the display manufacturers, many of the performance issues are yet to be determined, and the best way to display weather information is not yet clear. Nevertheless, weather information (because of its great importance in flight safety) is a prime candidate for early implementation in the cockpit.

In 1999, the Federal Aviation Administration (FAA) entered into partnerships with industry for the development of two Flight Information Services Data Link (FISDL) systems. The FISDL systems will broadcast text and graphical weather information products via data link for reception and display in equipped aircraft. An overview of the FISDL systems is provided in Appendix A, Flight Information Services Description.

The initial FAA guidance for pilots is limited to a FISDL description included in the AIM. The guidance outlined in the AIM is provided in Appendix B. Guidance material for FISDL avionics manufacturers and service providers is available in the RTCA document DO-267, *Minimum Aviation System Performance Standards (MASPS) for Flight Information Services-Broadcast (FIS-B) Data Link,* dated March 27, 2001.

The RTI International's Center for Aerospace Technology, sponsored by the FAA and NASA, investigated pilot performance using a prototype airborne weather display in a full mission simulator developed expressly for the study of new cockpit technologies in general aviation (Yuchnovicz, Novacek, Burgess, Heck, Stokes, 2001). The initial experiment was conducted with current instrument rated pilots who were presented with a challenging but realistic flight scenario involving weather with significant embedded convective activity. The objective of the experiment was to investigate the potential for misuse of weather information, and thus provide information to the FAA for use in development of guidance to pilots and manufacturers.

1.1 Potential Issues with Datalinked Weather Displays

One potentially significant issue in the use of displayed weather is that weather products are not displayed in real time as are most other cockpit data including the data provided by on-board weather radar. In the best of circumstances, the latest graphical NEXRAD products will be broadcast to aircraft within one minute of reception from the weather service provider, but will already be five or six minutes old when received from the weather service provider for transmission to the aircraft.

This presents the pilot with complex issues of interpretation and prediction. It is not clear, for example, whether pilots will try to extrapolate, from delayed data, the current position of storm cells, and attempt to weave between areas of perceived danger (tactical use), or adopt a more conservative approach of longer-term route planning to avoid potential hazards altogether (strategic use). The term “perceived” is crucial here, as studies to date suggest that a “keep out of the red” heuristic procedure may be adopted when, for example, viewing a NEXRAD baseline reflectivity product indicating amounts of rainfall according to a color coding scheme. Of course, the cessation of red cells (indicating areas of heavy rainfall) does not imply the cessation of peril. Areas of low visibility, turbulence and windshear may not appear as coded zones in certain weather products so any such heuristic procedure is a dangerous one.

It has been anticipated by some that pilots might try to use the data-linked weather information “tactically” as though it were “real time” and definitive, instead of delayed and probabilistic, possibly getting themselves into trouble. This might lead to pilots that become overconfident in their ability to judge exactly where it is safe or unsafe to fly. It is believed that “strategic” use of the weather display (using the information to plan a route around possible danger zones) would be safer and more appropriate.

A related issue concerns the explicit provision of predicted weather (e.g., storm cell configuration, location and movement), such that the mental workload of extrapolation is not added to pilots' tasks. Manufacturers and regulatory agencies may be hesitant in providing mathematical predictions and extrapolations of weather data to pilots because there may be non-trivial liability issues involved.

1.2 Survey of Relevant Literature

Pertaining to the display of data-linked weather information, relatively little documented research has been conducted to date. The next generation of research must begin in order to catch up to rapidly emerging technology.

Past studies have primarily focused on situational awareness (Hansman, & Wanke, 1989; and Lee, 1990), and expert/novice strategic decision making, (mostly making go/no go decisions), (Driskill, Weissmuller, Quebe, Hand, Dittmar, Metrica, & Hunter, 1997; Dershowitz, Lind, Chandra, & Bussolari, 1996; Fisher, Brown, Wunschel, & Stickle, 1989; Wiggins, Connan, & Morris, 1995; and Wiggins & O'Hare, 1995). Little has been done to examine the possible "tactical" decisions made during flight, and none have looked at this issue in a full mission simulator.

One of these issues is the impact of textual versus graphical presentation of weather information on pilot decision making. A particularly relevant study was a comparison of textual presentation versus graphical presentation of weather information undertaken at the Lincoln Laboratory of MIT (Lind, et. al., 1994) that provided a valuable first step by looking at the influence of data-link provided graphical weather on pilot decision making. When compared to strictly text information, the graphical information caused pilots to become more confident in their assessment of the weather, and to make better Go/No Go decisions as well as flight path change decisions. Although very valuable, this study was performed in an office setting without a true flight simulator and, therefore, without factors that come into play in an operational setting. Decisions were made based on static images presented at selected certain points during a scripted scenario.

Spatial displays have also been found to improve accuracy over text in presenting information for an analog operation/tactical decision task (Wickens & Scott, 1983).
All these findings are consistent with the multiple resource theory of attention, and the proximity/compatibility principle. These findings suggest that if an individual is to perform a visual-spatial task (such as navigating an aircraft through the airspace), then the information needed to perform that task should be presented in a visual-spatial way (e.g. as graphics, rather than, for example, a visual-verbal way such as in teletyped weather products).

The studies performed to date represent a fraction of the studies that are needed with the introduction of new technologies to resolve issues that arise in implementation and operational use.

2 Participants

This experiment was a cooperative effort between the Federal Aviation Administration (FAA), National Aeronautics and Space Administration (NASA) and RTI International.

2.1 FAA Data Link Office

The FAA Flight Information Data Link Office (AUA-420) is a prime sponsor for this experiment. This effort was undertaken to support the development of guidance for the use of cockpit weather displays in the National Airspace System.

2.2 NASA AWIN Project

The NASA AWIN (Aviation Weather INformation) project is also a prime sponsor, and provided technical support and contract management for this experiment in partnership with the FAA. AWIN is an element of the Weather Accident Prevention Project of NASA's Aviation Safety Program.

2.3 RTI International

The experiment was performed by the Flight Systems Engineering Office of RTI located in the Hampton, Virginia, office. An RTI consultant from Rensselaer Polytechnic Institute assisted in the experiment design and analysis. Another RTI consultant provided air traffic control expertise in the design and execution of the experiment.

3 Methodology

The objective of this follow-on experiment was to investigate the effect of ownship position information and NEXRAD cell size resolution on a pilot's decision making ability.

> The hypothesis states that the introduction of ownship position information on the weather display will improve navigation decisions. Additionally, finer NEXRAD image resolution will impact navigation decisions.

3.1 Experiment Design

It is anticipated that with sufficient training, careful use of the cockpit weather display, and prudent pilot procedures in instrument flight conditions, the emerging cockpit weather display products will provide substantial improvements to the safety of flight. It is important to note that this experiment, like the one that preceded it, was designed specifically to identify potential hazards in the use of cockpit weather displays.

Every aspect of the design of this experiment was undertaken with this objective in mind, including subject pilot selection, subject pilot training, and the mission scenario. Pilots were selected so as to provide as wide and representative a range as possible of the experience, knowledge of weather and risk aversion of the population of general aviation pilots who might use these emerging cockpit weather display products. The training provided the subject pilots was tailored so as to provide them with sufficient familiarity with the experimental equipment to successfully accomplish the mission scenario, while at the same time creating a reasonable probability that within the population of subject pilots selected, potential hazards in the use of the equipment might become apparent. Likewise, the mission scenario incorporated in the experiment was selected to ensure that it could be accomplished by the average pilot with careful attention by the subject pilot to the instrument flight procedures, but offered sufficient opportunity for observation of human error in the use of the prototype cockpit weather display where such hazards might exist.

The experiment was designed to have certain desirable properties. It was moderate in length (approximately one hour depending on pilot actions) in order to eliminate fatigue-related effects. It was made up of sufficiently independent phases to test responses to discrete weather conditions. The incident density was to be plausible and would be designed to occur while crossing informational boundaries (where most decision related errors are more likely to occur). The mission scenario and cockpit simulator were to be sufficiently realistic such that the subject pilot would be immersed in the experiment.

The experiment employed a between-subjects design, whereby two groups of similar subject pilots were divided into control and treatment groups. Performance differences between the two groups could then be attributed to differences between the control and treatment conditions. A previous Aviation Weather Information (AWIN) experiment, compared a control group of 12 pilots (group A) without a weather display against a treatment group of 13 pilots (group B) that did have a weather display. The follow-on experiment, reported herein, compared a group of 12 pilots (group C) that had ownship symbology, against the 13 pilots (group B – treatment) of the previous experiment that did not have ownship symbology. Therefore, the control group and treatment group were similar except for the introduction of ownship symbology.

Within the follow-on experiment, the performance of two groups of 12 pilots each were compared. The experimental treatment consisted of the introduction of reduced-resolution NEXRAD graphic images. The first group of 12 pilots (group C) were presented with a NEXRAD image cell size of 4km (same resolution used in the previous experiment), while the second group of 12 pilots (group D) were presented with a NEXRAD image cell size of 8km. The relationship of the experimental groups can be seen in Figure 3-1.

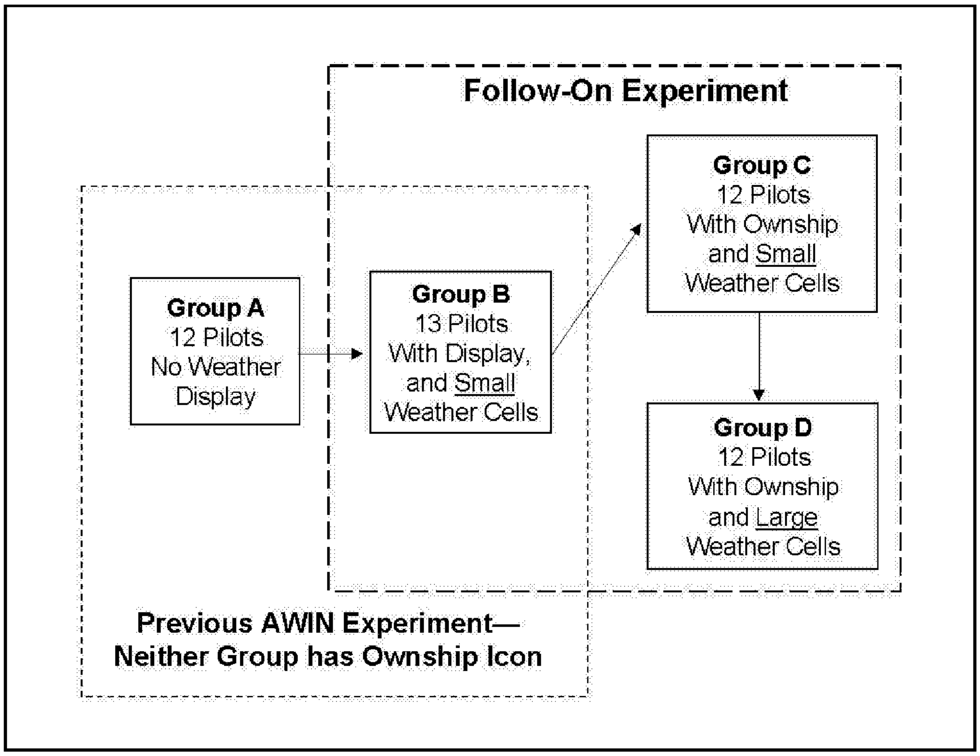


Figure 3-1. Relationship between previous and current experiment groups.

In addition to determining the impact of ownship symbology and NEXRAD display resolution on pilot decision making, several additional concerns were identified, and addressed in the course of the experiment to provide advisory information for the FAA and feedback to the avionics manufacturers. For example, it was noted how much instruction and practice was required to familiarize and operate the display. The pilots were questioned about their understanding of the data content, refresh rate, staleness, and NEXRAD image cell size resolution. Post flight questionnaires were administered to determine if the pilots were able to determine both their location and their proximity to displayed weather. They were also invited to comment on the functionality of the display and any improvements they could suggest.

A simulated flight was designed (using actual recorded weather) that originated in Newport News, Virginia, and consisted of two decision points: 1) approaching the Richmond, Virginia, airport, and 2) enroute to Wallops Island, Virginia. The actual weather consisted of two converging frontal boundaries. One frontal system included convective activity moving rapidly west to east across the vicinity of the Richmond airport. Another somewhat stationary trough of low pressure included convective activity developing along a north/south line over the Chesapeake Bay. The first decision emphasized the time-delay (temporal) aspects of the weather while the second decision emphasized the spatial aspects. Details of each scenario providing the two decision conditions are given in greater detail in the Results section of this report.

3.2 Pilot Selection Process

Due to the nature of the flight scenario, it was decided to limit subject pilot candidates to those who were instrument rated and legally current. The previous weather display experiment used risk aversion and weather knowledge as selection criteria after determining instrument currency. Risk aversion was measured using a PC-based test described in Appendix C, Risk Assessment Test. The risk aversion test provides a domain independent measure of what a subject pilot *does* in response to a risk-reward opportunity, not of what they *say* they will do.

Weather knowledge was measured with a written test, provided in Appendix D, Weather Knowledge Questionnaire and Key. The test was promoted as a general aviation questionnaire to disguise the true nature of the experiment, thereby reducing any tendency for a subject pilot to study weather interpretation before the actual simulator trials began.

The tests were administered to 57 current IFR-rated pilot candidates. By combining the risk aversion and weather test scores, the pilots were selected and organized into two groups that demonstrated either high-risk/low-weather-knowledge tendencies or low-risk/high-weather-knowledge tendencies. The approach for selecting and organizing the subject pilots was used to maximize the likelihood that navigation decision errors would be observed within the relatively small sample size of qualified pilots.

The previous weather display experiment used 25 pilots from the initial screening. The results of that previous experiment showed a slightly positive correlation between risk/weather-knowledge and eventual decisions, although the results were not statistically significant. As a result, pilots were not selected for the follow-on experiment based on their risk/weather-knowledge scores, but were instead selected at random from the pilots remaining in the initial screening pool who had not been selected for the first experiment. Due to the pilot selection method of the previous experiment—using the extremes of risk/weather knowledge scores—the remaining subjects were roughly equivalent with respect to their risk predilection/weather knowledge scores.

Twenty-four pilots were required to complete the follow-on experiment, but due to scheduling problems, seven pilots needed to be recruited beyond the initial 57 tested in the initial screening. These added pilots were given the same risk aversion and weather knowledge tests as the initial pool of pilots to permit comparative statistical analysis. Although not intentional, all of the pilots for the follow-on experiment were male.

3.3 Experimental Apparatus

The experiment was performed in a full-mission flight simulator to provide a realistic operational environment. Two major components comprise the experimental system: pre-flight planning tools and the flight simulation facility.

3.3.1 Pre-Flight Planning Tools

Each pilot was given 30 minutes to plan the flight. The following flight planning tools were provided:

- A written transcript of a telephone Flight Service Station (FSS) weather briefing (provided in Appendix E, Preflight Weather Briefing)
- Aircraft Flight Manual
- Aeronautical charts (sectional and IFR low-altitude enroute)
- Blank flight logs
- Partially completed flight plan forms (each pilot given same route).

3.3.2 Flight Simulation Facility

The flight simulation facility consisted of a full-mission simulator that provided a simulation of a complex, high-performance single-engine, single-pilot IFR-equipped airplane having the major features and performance of a Piper Malibu PA-46-310P. The key elements of the simulation facility are illustrated in Figures 3-2 and 3-3. This full-mission simulator facility consisted of three major sections as follows:

- Aircraft Cockpit Simulator – Consisted of the cockpit mockup with controls, instruments, radios and indicators. A closed-circuit television camera was mounted behind and above the pilot's left shoulder to provide live images from the cockpit to the Scenario Controller and Observer positions. The simulated cockpit instrumentation is shown in Figure 3-4. The weather information display was located between the primary and secondary instruments to maximize its visibility and probability of use.

- Simulation Facility and Scenario Controller and Observer Positions – Consisted of the master control station used for scenario generation and for selection, monitoring and recording of flight progress. It provided the operator with displays of all control positions, radio and instrument switch positions, instrument displays and the Out-the-Window scene (as presented to the subject pilot). A weather data display consisting of NEXRAD images was provided for the scenario controller, and enabled the observer to track the flight's progress relative to the weather. A video image of the cockpit from the camera was provided to enable the observer to monitor the subject pilot's actions. Live audio of all radio transmissions between the pilot and the Air Traffic Controller, Flight Watch, ATIS, etc., was available to the simulation scenario controller and to the observer. An intercom audio network was provided which permitted private conversations between the scenario controller, observers, and air traffic controller positions. The ability for the pilot and air traffic controller to communicate was also provided by the same intercom system. All intercom traffic was recorded on the audio track of the video recording.

- ATC Controller Position – Consisted of a custom ATC workstation developed for experiments of this type and a weather display that provided the latest NEXRAD images enabling the ATC controller to track the flight's progress relative to the weather. The NEXRAD images were updated every minute. A display of the current pilot-selected communication frequencies was also provided so that the ATC controller could verify that the pilot was contacting ATC on the correct frequency before responding to an initial contact.

Additional detail regarding the experimental system is provided in Appendix F, Cockpit Research Facility Description.

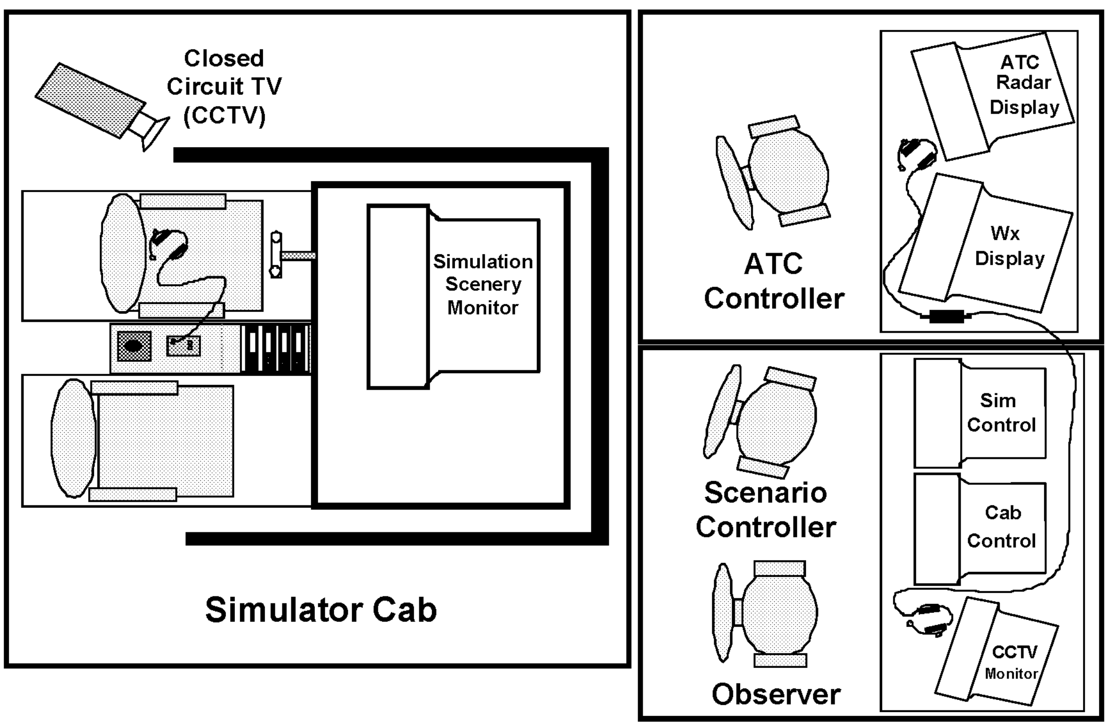


Figure 3-2. Experimental System Facility Layout

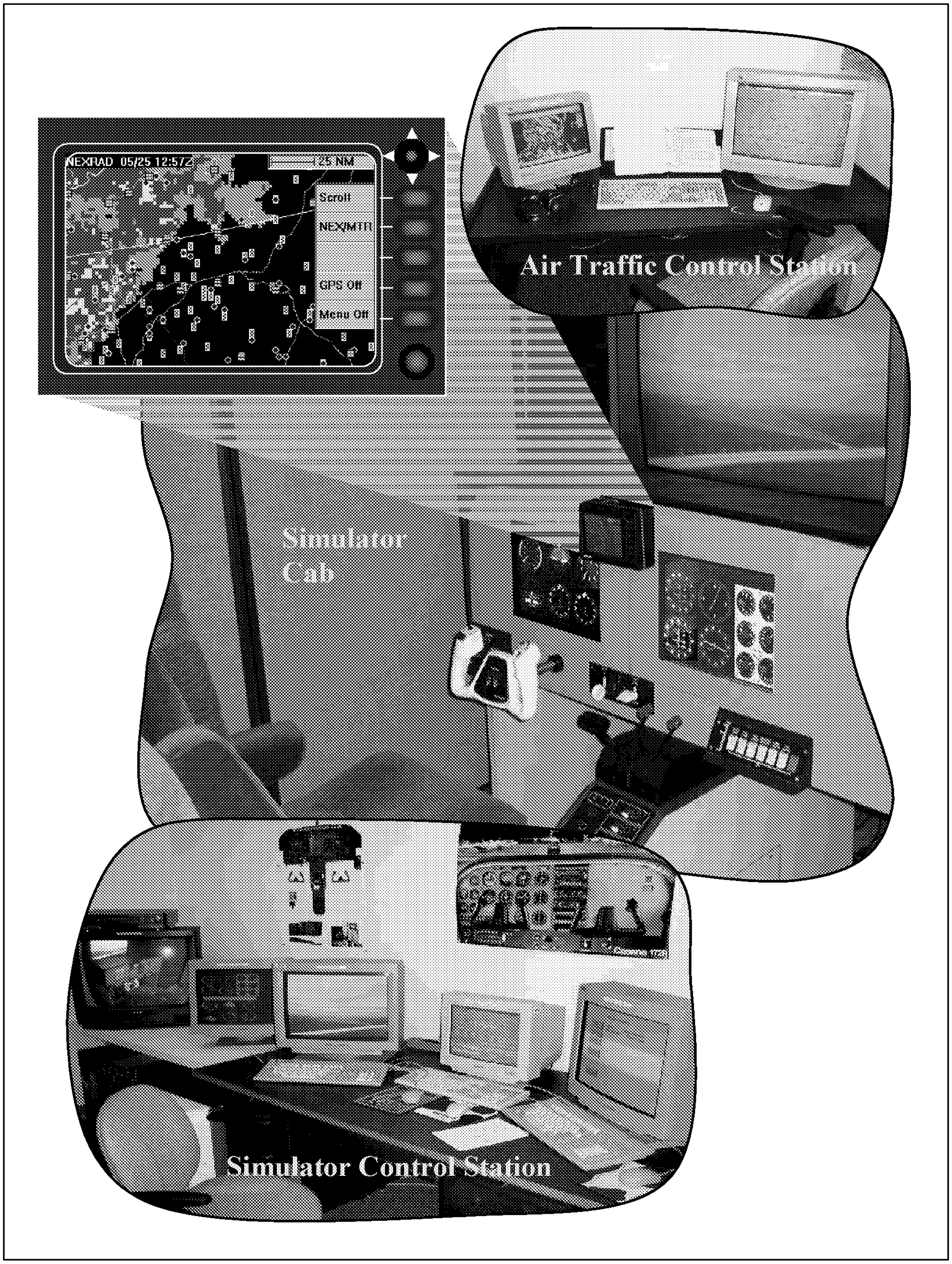


Figure 3-3. Key Simulation Facility Stations

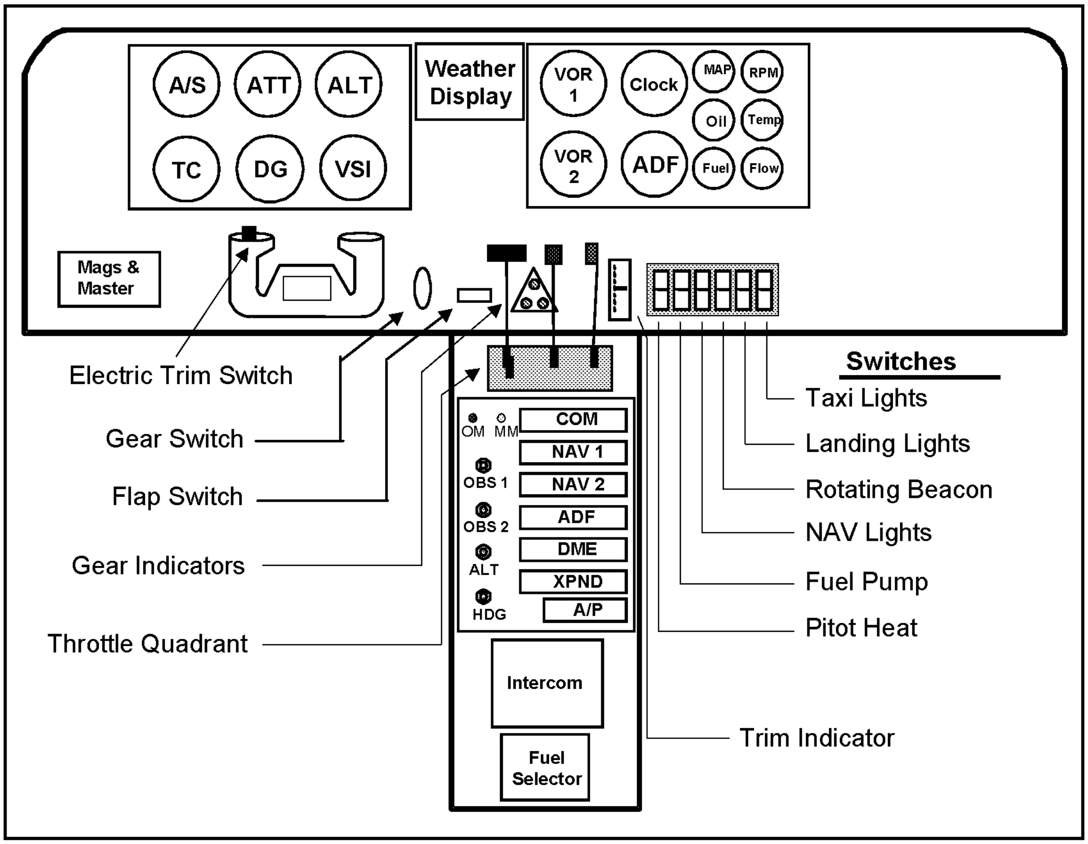


Figure 3-4. Simulator Instrument Layout

3.3.3 Cockpit Weather Information Display

The weather information display system used in this experiment consisted of two key components, a PC based computer and a display unit, both obtained from Honeywell (previously NavRadio Inc.).

The computer was a PC based workstation running Microsoft Windows NT and custom software. The PC was used to record, process and playback the NEXRAD/METAR data gained through a C-band satellite downlink receiver. Using SkyForce software, the PC sequenced through the database of previously recorded NEXRAD/METAR information and displayed the images on the SkyForce Observer. The PC also contained the software to depict the moving map, mode/scroll control, airport/navaid information and map database.

The SkyForce Observer display unit contains a flat-panel LCD display of 320 x 240 resolution, a joystick and mode select softkeys. The Observer provides only the display and control function of the system. The computational effort resides in the PC workstation.

The SkyForce Observer display enables the pilot to select the weather information and contains the following features:

- NEXRAD image depiction
- METAR text reports
- Graphic symbology of airports, navaids, major highways and state boundaries.
- Depiction of graphic METAR symbology
- Zoom and scroll capability
- Map range scale
- NEXRAD image timestamp

The placement and layout of the SkyForce Observer controls are depicted in figures 3-5 and 3-6. Details of the FISDL system, of which this display is an early prototype, are provided in Appendix A, Flight Information Services Description.

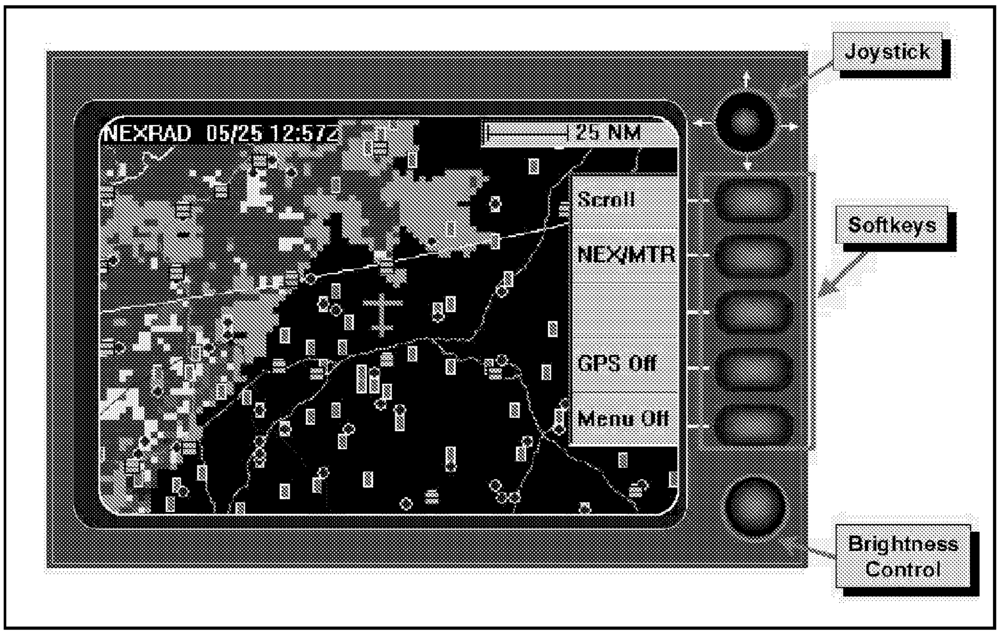


Figure 3-5. Weather Display Controls

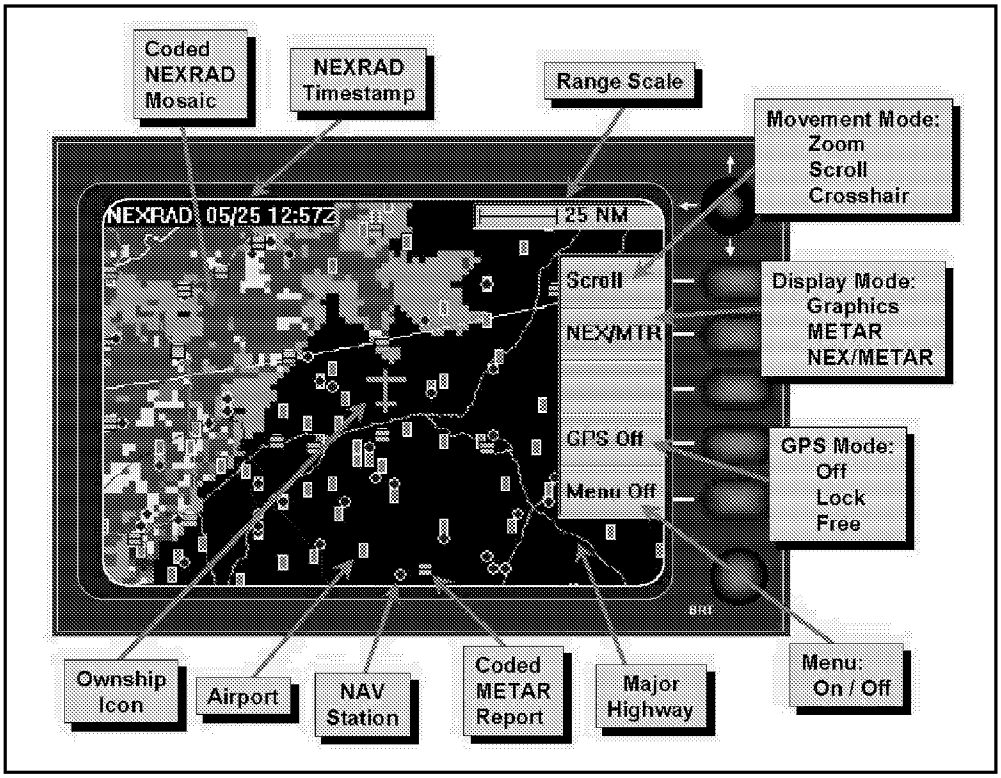


Figure 3-6. Weather Display Screen Labels

The NEXRAD image employs a six-color palette to depict the precipitation returns for a given area. The pilot was able to zoom and scroll around the image to the desired view. The arrangement of the intensity levels is shown in Figure 3-7. The six-color palette represents the NEXRAD precipitation intensities received and used in the experiment. Subsequent to the initiation of this experiment, RTCA guidance (DO-267) was published for FIS-B systems, further limiting the color palette used to depict NEXRAD images.

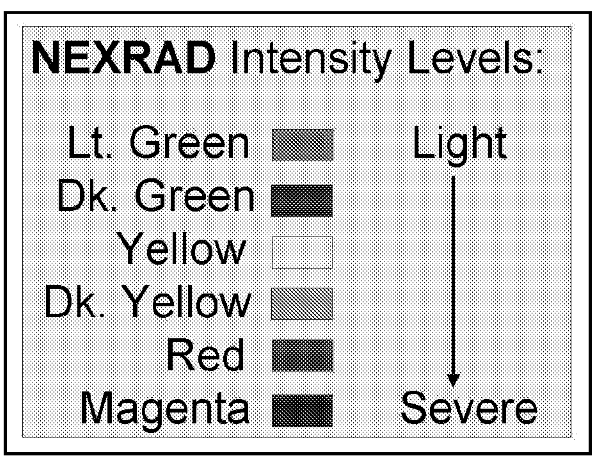


Figure 3-7. NEXRAD Mosaic Image Precipitation Intensity Key

The 10 small-cell NEXRAD images used in the experiment are duplicated in Appendix G, and the large-cell NEXRAD images used in the experiment are duplicated in Appendix H.

The graphical METARs are small graphic squares that depict the ceiling and visibility for the reporting station. The coding of the graphic METARs are shown in Figure 3-8.

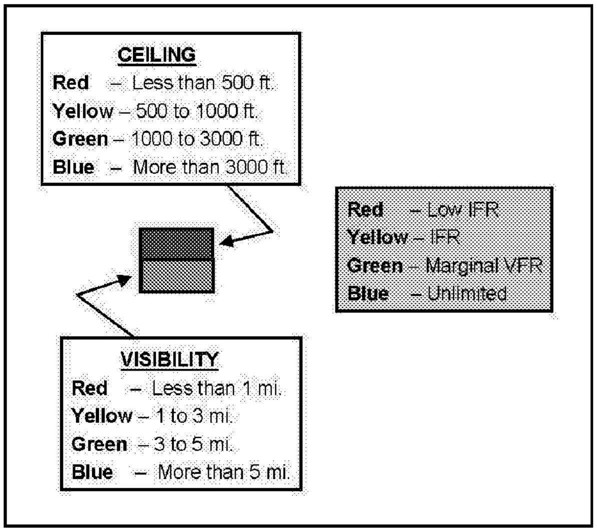


Figure 3-8. Graphic METAR Key

4 Procedure

4.1 Key Phases of Experiment Procedure

The experiment procedure consisted of the following five phases:

1. Experiment briefing
2. Simulator familiarization
3. Pre-flight planning
4. Simulator mission
5. Post-mission briefing

4.1.1 Experiment Briefing

The subject pilots were given a 45-minute briefing of the mission objective, mission scenario, and an overview of the simulator controls. The pilots were also given an overview of the weather display operation. The briefing scripts are provided in Appendix I, Experiment Briefing.

4.1.2 Simulator Familiarization

The subject pilots were provided with a familiarization session and practice flight in the simulator. Systems, controls and displays were explained and demonstrated. The simulator instructor answered any questions that the pilot had with respect to the operation of the simulator. Additionally, the pilots were given a hands-on training session on the use of the in-flight weather display system and the autopilot.

The training was provided in an interactive environment that gave a thorough understanding of the equipment and its capabilities. To assure equal treatment to all subject pilots, the training session was heavily scripted and the pilots were trained to a predetermined performance level derived from the FAA Practical Test Standards for Instrument Pilots.

The simulator training took approximately 45 minutes and included a practice flight with two approaches. The training script and proficiency criteria can be found in Appendix J, Simulator Briefing and Training.

4.1.3 Pre-Flight Planning

Each pilot was given 30 minutes to plan the mission. Weather reports and flight planning materials were provided. Additionally, a partially completed flight plan form was provided that had the route and aircraft-specific particulars completed. The pilots were told that the route given to them was already filed with Flight Service, but that they were free to change the route upon the initial call to clearance delivery. The flight plan route is illustrated in Figure 4-1. They were also told that all the normal weather information services typically available in the National Airspace System (NAS) are also available in the simulator, including Flight Service, Flight Watch, ATIS, ASOS and ATC.

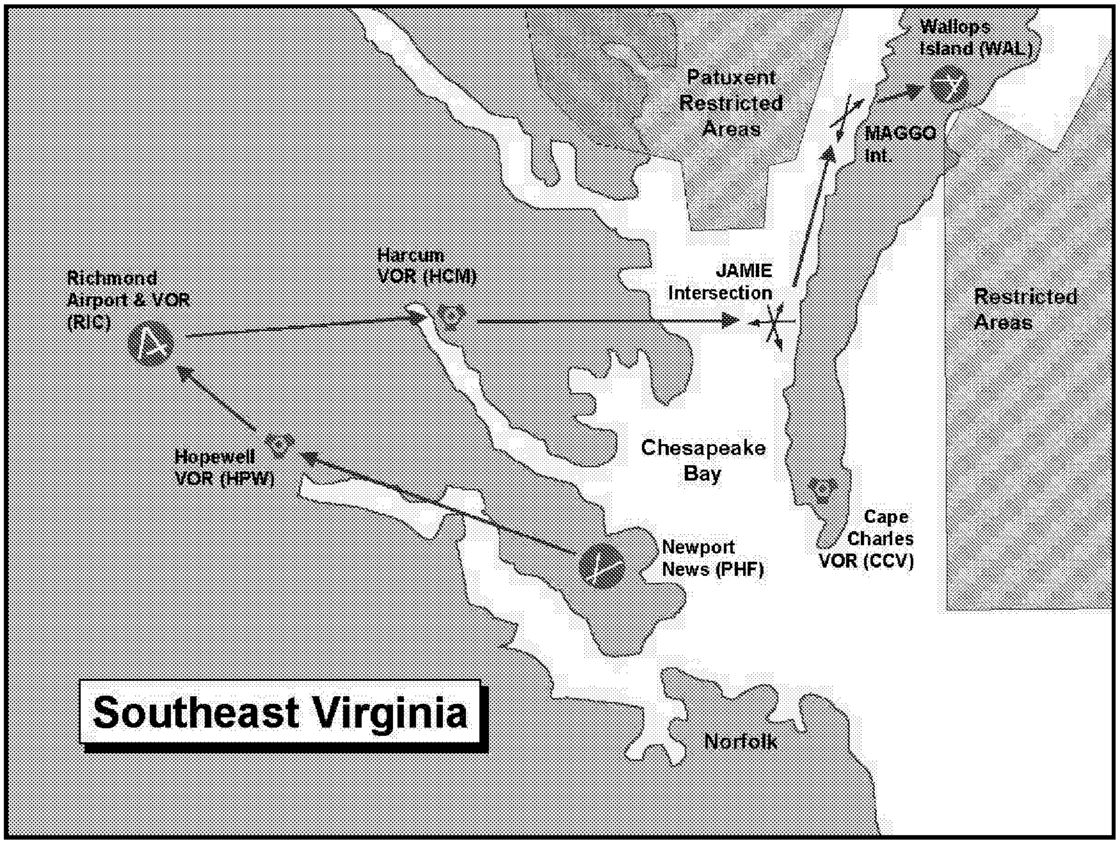


Figure 4-1. Flight plan route given to pilot.

4.1.4 Simulator Mission

The pilots were left alone in the simulator for the mission and observed remotely. The mission lasted approximately one hour, depending on the pilot and route selected around the hazardous weather conditions.

A team of four individuals, including a Simulator Operator, an Air Traffic Controller, an Observer/Director and a second observer conducted the experiment. The Observer's primary role was to collect and record data on the Observer form (Appendix K), including the comments of the other members of the research team. Additionally, the Air Traffic Controller provided a record of his observations that are included in each subject pilot's data folder.

4.1.5 Post-mission De-briefing

Upon completion of the mission, each pilot was given a questionnaire while still seated in the simulator, thus providing important subjective comments while still in the mission "mode." The questionnaire is included in Appendix L, Immediate Reactions Questionnaire.

After completing the questionnaire, the pilots were interviewed by the experiment observers using the Structured Interview Guide (Appendix M) to confirm behavioral actions and decisions.

As a final step, the pilot completed an open-ended questionnaire. The questionnaire is included in Appendix N, Weather Display Questionnaire.

4.2 Flight Procedures

The mission flown by the subject pilots consisted of two flight legs, the Richmond leg and Wallops Island leg.

4.2.1 Mission Scenario

The mission scenario consisted of a flight to deliver medication to a diabetic patient at the NASA Wallops Island facility. The NASA Wallops Island facility is located on the eastern shore of Virginia. The pilots were told that the insulin available in the Wallops area had become tainted and a new supply was to be flown to the patient. They were also told that diabetic ketoacidosis (DKA) is a common and potentially fatal complication for which one effective therapy is a special form of sodium bicarbonate. Thus, the medical rationale involved the delivery of a **vital** medication, insulin, and a **desirable** medication, sodium bicarbonate. The pilot was informed that a medical mercy mission had been coordinated and that he was to be the pilot.

The flight originated at the Newport News Virginia airport, with the insulin already onboard the aircraft. The pilot was instructed to fly to Richmond Virginia and pick-up the special sodium bicarbonate on the way to Wallops Island.

In the course of the preflight briefing, the pilot found that there was a weather front moving into Richmond, but that the forecast for the area would permit the pilot to land at the Richmond airport to pick-up the sodium bicarbonate medicine. The forecast weather for the entire flight placed the aircraft in instrument meteorological conditions, but the weather at Wallops Island airport was forecast to be above minimums.

All flights were flown in a full-mission simulation facility in simulated instrument meteorological conditions. Visibility for the pilot was essentially zero from shortly after takeoff until just before landing. The pilots were to conduct the flight in accordance with all appropriate ATC procedures in conjunction with an Air Traffic Controller (ATC), located in an adjoining room. The ATC workstation fulfilled the roles of clearance controller, ground controller, tower controller, approach/departure controller and FSS briefer as required throughout all phases of the flight. The scripts are provided in Appendix O, Air Traffic Control Scripts.

The pilot was able to access the normal in-flight weather services through the simulator radios, including:

- FSS – Flight Service Station
- ATC – Air Traffic Control (tower, departure and approach)
- FW – Flight Watch
- ATIS – Automatic Terminal Information Service
- ASOS – Automated Surface Observation System

The ATC workstation presented the Air Traffic Controller with a readout of the frequency that the subject pilot selected on the simulator communication radio. When the pilot tuned the communication radio to a frequency that corresponded to a recorded weather message (ATIS, etc.), a prerecorded report was played through the intercom. The ATIS/ASOS recorded scripts can be found in Appendix P, Enroute Weather Report Scripts.

If the pilot called either a Flight Service Station or Flight Watch briefer, the Air Traffic Controller read a scripted weather report to the pilot depending on the time of the call. These weather scripts can be found in Appendix P, Enroute Weather Report Scripts.

Actual weather data was used to assure the realism of the operational scenario. All weather information used in this experiment was recorded from actual weather conditions that existed in the geographical area of the experiment on the evening of April 25, 2000. The NEXRAD images were recorded during passage of multiple weather fronts through southeastern Virginia from a prototype satellite data gathering system provided to RTI International by Honeywell, Inc. The NEXRAD images were replayed on the weather display in the simulation facility cockpit.

All NEXRAD mosaic images used in the experiment were recorded with a cell resolution of 4 km. Half of the pilots (12) received the 4 km NEXRAD image cell sizes, while the second group of 12 received 8 km cell sizes. Special software was used to systematically reduce the resolution of the images in a consistent manner. The small-cell (4x4 km) NEXRAD images were processed through a software filter that assigned the highest level radar return to the entire large cell.

To realistically reproduce actual data-linked weather products, the subject pilot received the NEXRAD mosaic images delayed by seven minutes. The pilot's weather display of NEXRAD images were initially seven minutes old, aging to 14 minutes old before receipt of the next update (of a seven minute-old image). The pilot also had access to graphical and textual Aviation Routine Weather Report (METAR) information.

The NEXRAD weather display used by the Air Traffic Controller emulated the ASR-9 weather radar. The Air Traffic Controller received a real-time NEXRAD image that was no more that one minute old.

All the other weather data products needed to develop preflight and inflight weather reports for the experiment scenario were collected from the appropriate FAA sources for the same location, date and time captured in the NEXRAD mosaic images.

4.2.2 First Leg of Flight – Newport News to Richmond

During the course of the first leg of the flight, between Newport News and Richmond, the ceiling and visibility at the Richmond airport had descended to below minimums (200 feet) sooner than forecasted. Additionally, there was a thunderstorm approaching the Richmond airport. The only way the pilot could learn of these deteriorating conditions was to obtain an in-flight update of the weather. The pilots could gather these updates either through the weather display or by radio.

Before reaching the initial approach fix for the Richmond airport, the weather display depicted a thunderstorm cell several miles to the west of the airport but headed toward the airport (see Figure 4-2). The image on the pilot's weather display was a minimum of seven minutes old and would have aged up to 14 minutes. By the time the pilot began the approach, the actual weather cell had intensified and moved closer to the airport. [The ATC workstation weather display showed the storm to be approximately two miles northwest of the airport.]

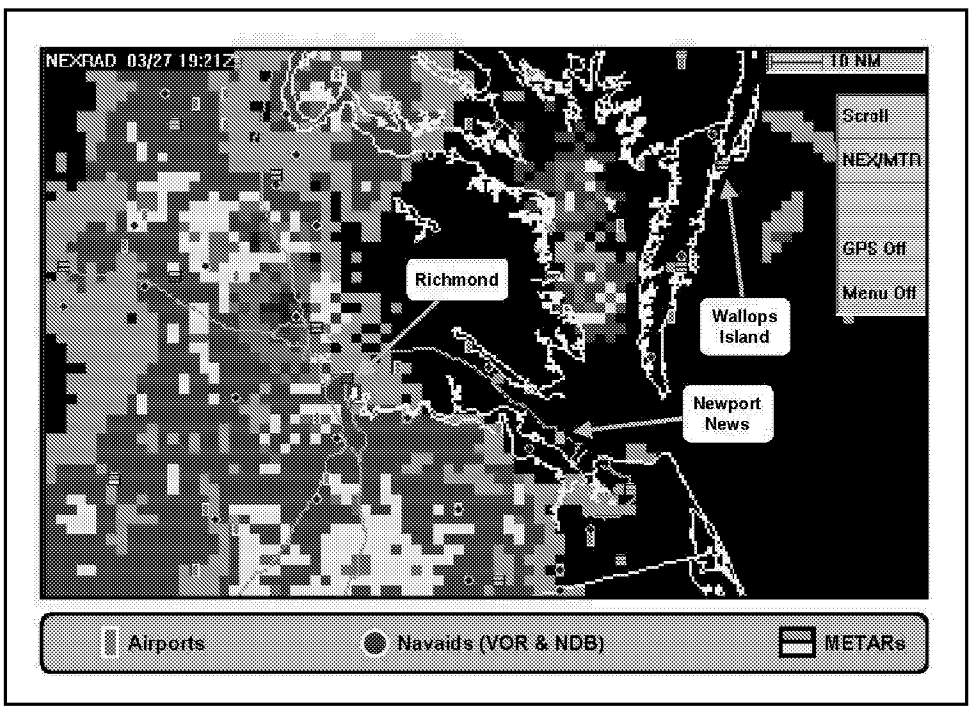


Figure 4-2. Display Image When Approaching Richmond

There were several possible responses to this scenario. The pilot could continue the approach with old data and proceed into the thunderstorm (poor decision), or, the pilot could decide to abandon the approach into Richmond and proceed directly to Wallops Island (good decision). A third option was for the pilot to ask ATC to provide a hold until updated weather information could be obtained and sorted-out before deciding to continue into the Richmond airport or proceed to Wallops Island (good or poor decision depending on proximity of flight path to thunderstorm). To preserve the timing aspects of the experiment, the pilots were told that the medicine needed to be delivered to Wallops Island within one hour.

As the aircraft traversed the various precipitation zones—as depicted on the simulator operator's NEXRAD image display—the simulator operator introduced levels of turbulence appropriate to the precipitation level. For flight in clear air, turbulence was not encountered, but when the aircraft traversed into an area depicting precipitation, a turbulence model was applied to the simulation and the turbulence was increased in proportion to the intensity level.

If the pilot gathered weather information (either via voice or from the weather display) during the leg between Newport News and Richmond, the pilot was apprised of the rapidly changing weather and had to make a decision to either divert to Wallops Island or continue the approach into Richmond. This is the decision that the experiment was designed to uncover along with the basis for the subject pilots' decisions.

If the pilot proceeded with the approach into Richmond, typical and consistent weather warnings were given to the pilot by ATC, including a windshear warning when the pilot contacted the tower. To expedite the simulator mission, if the pilot decided to proceed with a landing into Richmond, ATC informed the pilot (when crossing the final approach fix) that the Richmond airport manager had closed the airport due to windshear and heavy lightning activity. This methodology would preserve the timing essential to maintaining a consistent relationship between the aircraft position and weather movement for all the test subject flights. Therefore, all the pilots either broke off the attempt to land at Richmond at various distances from Richmond, or were waved-off at the final approach fix.

The Newport News – Richmond leg of the experiment was designed primarily to determine the pilot's judgment relative to the temporal issues in the use of the weather information display with respect to ownship position symbology and NEXRAD image cell size resolution.

4.2.3 Second Leg of Flight – Richmond to Wallops Island

During the leg between Richmond and Wallops Island, a line of storm cells materialized across the direct route to Wallops Island, with one storm cell to the north of the direct course and one to the south. The location of this convective activity can be seen in Figure 4-2.

The distance between the red cells was approximately 10-12 miles. The hole between the storms was tempting enough to create a corridor between the areas of hazardous weather. These cells did not move substantially with succeeding NEXRAD images, but slightly changed shape and size.

The METAR graphical and textual depiction showed that the Wallops Island airport was above minimums, therefore giving the pilot an incentive to proceed with the flight to Wallops Island.

The pilot was monitored as to the decision to proceed between the storm cells, or circumvent the area of thunderstorm altogether. This part of the experiment was designed primarily to determine the pilot's judgment relating to spatial issues in the use of the weather information display.

5 Results

5.1 Subject Pilots

A total of 24 pilots participated in this experiment. Of these 24 pilots, 12 flew with a NEXRAD image cell size of 4 km, and 12 flew with a NEXRAD image cell size of 8 km. Both groups had ownship position, whereas in the previous experiment the weather display had 4 km cell size without ownship position depicted. Participants were pilots qualified for and current in instrument conditions with varying levels of flight experience, as illustrated in Table 5-1.

Table 5-1. Pilot Flight Hours

Pilot #	Treatment Group (cell size)	Total Flight Hours	Est. Actual Inst. Hours	Simulated Inst. Hours (Hood)	Simulated Inst. Hours (Simulator)	Inst. Hours Proficiency (Last 90 days)	RAT Score	WX Test Score
25	Small	560	50	56	2	2	3.8	30
37	Small	2512	204	118	417	0	3.95	26
15	Small	1880	400	43	1	9	3.65	21
40	Small	5315	516	263	121	3	3	18
11	Small	307	8	58	0	15	3.55	33
27	Small	951	76	105	4	4	4.6	28
9	Small	700	150	50	0	10	4.2	26
12	Small	875	30	15	2	5	3	24
1	Small	487	13	27	20	2	4.05	28
56	Small	1159	23	91	3	2	3.35	27
22	Small	1760	106	148	3	2	4	28
4	Small	1525	75	117	8	9	3.75	30
28	Large	1750	92	105	10	6	3.55	32
46	Large	15278	1634	150	350	25	4.35	30
58	Large	1000	105	210	2	0	3.5	24
17	Large	20614	2000	20	400	150	3.4	31
13	Large	536	60	60	0	6	3.95	32
59	Large	3740	555	184	350	2	3.45	18
16	Large	5060	179	182	0	4	3.5	30
60	Large	1500	38	88	8	10	4.3	31
62	Large	3000	250	150	15	30	2.55	31
63	Large	3100	300	300	0	1	3.6	28
64	Large	180	0	56	20	7	3.75	26
65	Large	1100	100	58	22	10	4.65	30
Average:		**3120**	**290**	**110**	**73**	**13**	**3.73**	**27.6**
Standard deviation:		**4736**	**487**	**74**	**139**	**29**	**0.49**	**4.05**

RAT Scores — Higher score signifies higher risk predilection.

Weather Test Scores — 39 points possible.

5.2 Richmond and Wallops Island Decisions

The results of the experiment were organized around the two key decision points established in the experiment procedure—the "Richmond decision" and the "Wallops Island decision."

Both the Richmond and Wallops Island decisions were scored on a 1–4 ordinal scale, with a (1) being a strong "poor" decision, and a (4) being a strong "good" decision. A score of (2) was considered a "poor" decision with good elements, while a score of (3) was considered a "good" decision with poor elements. The intent was to produce definitive guidelines that can be applied to each scenario using a consistent method.

5.2.1 The Richmond Decision

A good decision—a score of (3) or (4)—was deemed to be one in which the pilot decided to divert to Wallops Island prior to the Final Approach Fix (outer marker) of the approach into the Richmond airport, thus avoiding the hazardous weather by at least five nautical miles. A poor decision—a score of (1) or (2)—was deemed to be one in which the pilot continued with an approach past the Final Approach Fix into the Richmond airport for whatever reason, placing the aircraft within five nautical miles of hazardous weather conditions. Hazardous weather was established to be a red NEXRAD mosaic image cell, a known area of hazardous turbulence, or a known area of hazardous windshear. A minimum separation of 5 miles from the most hazardous part of convective weather depicted in a NEXRAD image (red cells) was selected as the criteria for this segment of the scenario because:

a. The hazard is a rapidly moving and fairly localized thunderstorm with a well-defined leading edge.
b. The weather conditions five miles and greater to the east of the thunderstorm was known to be reasonably safe with no significant turbulence.
c. The medical scenario created a motivation to proceed to within a reasonable but safe distance.

The "Richmond decision" required the subject pilot to decide whether or not to attempt to land at the Richmond airport in the face of a fairly rapidly moving thunderstorm passing within a mile or two to the north of the airport. There were a total of 11 different NEXRAD mosaic images displayed to the pilot, updating in 7-minute intervals. Figure 5-1 depicts the NEXRAD mosaic image at 1914Z. This image was present on the weather display upon arrival in the vicinity of the Final Approach Fix to runway 34 (outer marker) to the southeast of the Richmond airport.

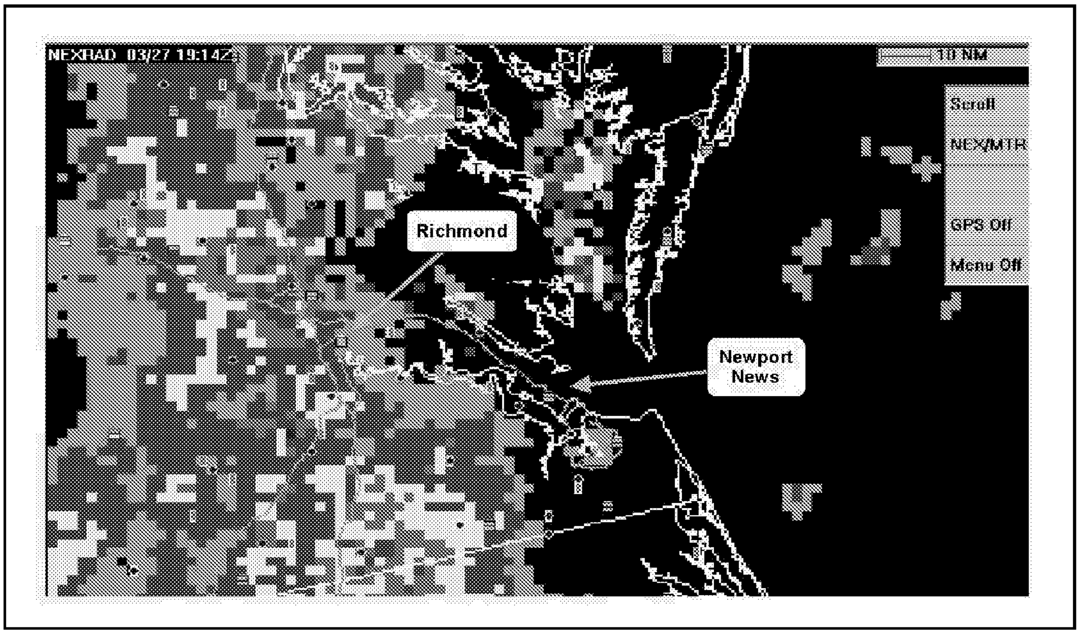


Figure 5-1. NEXRAD image at 1914Z.

Because of the delay in transmission of the image to the aircraft, the data was at least 7 minutes old. Actual conditions at the Richmond airport in the time frame of this decision can be seen in Figure 5-2 which provides the NEXRAD image for 1921Z.

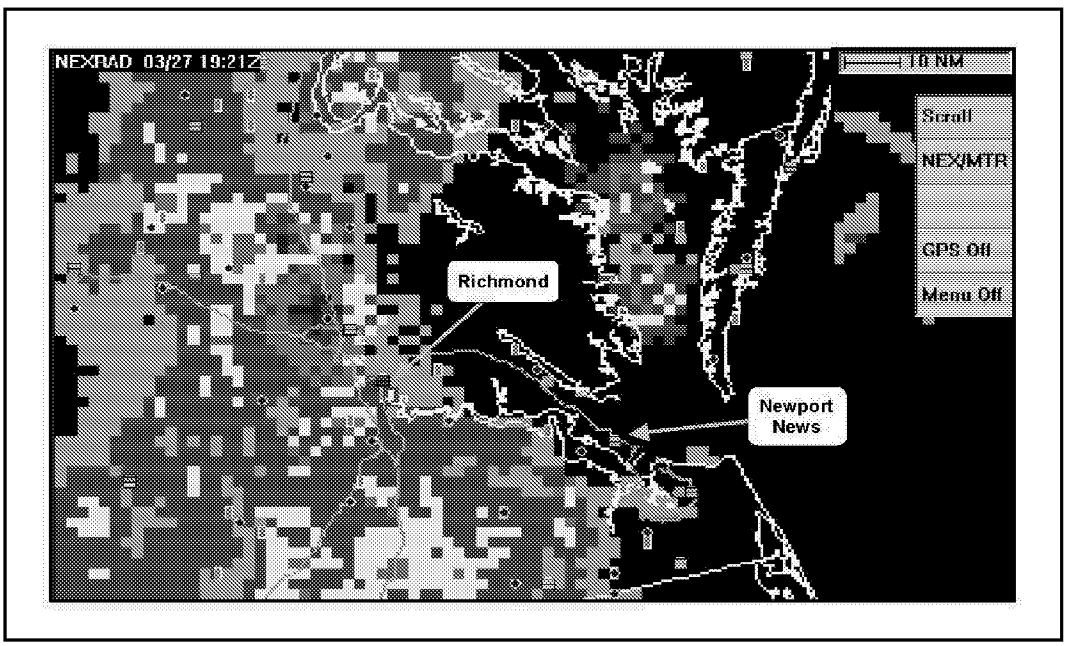


Figure 5-2. NEXRAD image at 1921Z.

The images depicted in these figures were the 4th and 5th images in the sequence of 11 images used. The thunderstorm seen to the northwest of Richmond is the storm that was designed to elicit a weather decision from the pilots. [The actual recorded storm was somewhat smaller than the one depicted to the pilot and was enlarged with photo retouching software.] This particular storm moved from west to east across the successive NEXRAD images at approximately 40 nautical miles per hour in the early images. The rate of movement of the storm diminished to less than 10 nautical miles per hour in the later images.

The four-point grading criteria of the Richmond decisions are defined as follows:

1 = The pilot continued the approach into poor weather and was waved off the approach (from the tower controller) at the Final Approach Fix (outer marker).

2 = The pilot abandoned the approach <u>less than</u> five (5) miles outside of the outer marker, but flew <u>within</u> five (5) miles of a red NEXRAD image cell, while in the Richmond area.

3 = The pilot abandoned the approach by their own decision <u>less than</u> five (5) miles outside of the outer marker, and flew <u>more than</u> five (5) miles from a red NEXRAD image cell, while in the Richmond area.

4 = The pilot abandoned the approach <u>more than</u> five (5) miles outside of the outer marker, and flew <u>more than</u> five (5) miles from a red NEXRAD image cell.

5.2.2 The Wallops Island Decision

The "Wallops Island decision" required the subject pilot to decide whether to proceed as first cleared to Wallops Island or detour around the hazardous weather. To proceed as cleared, the pilot would have flown between two thunderstorms located between Richmond and Wallops Island. Figure 5-3 provides the approximate image that the weather display depicted after the pilot departed the vicinity of the Richmond airport, enroute to Wallops Island.

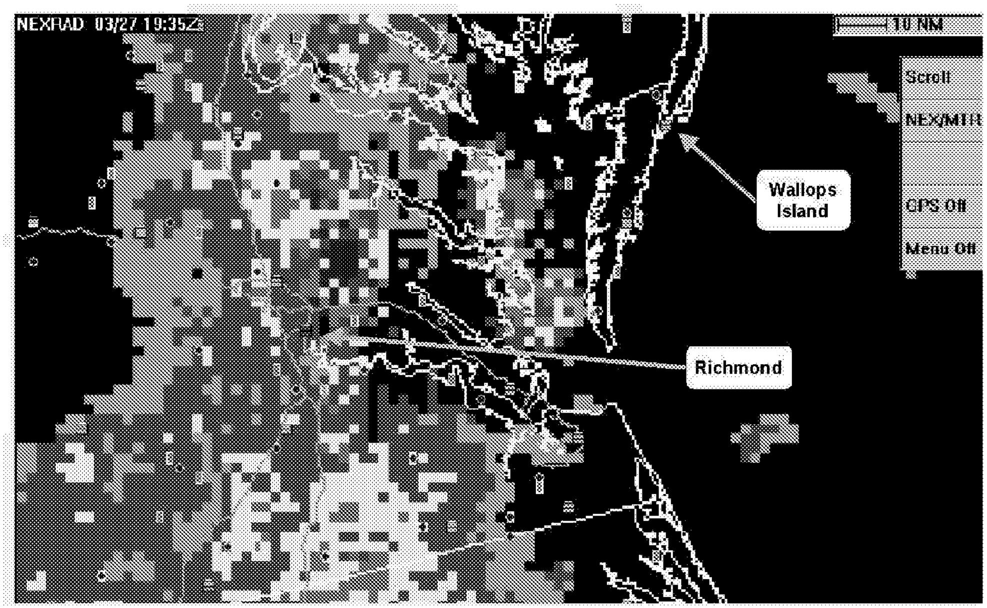


Figure 5-3. NEXRAD image at 1935Z.

In this image, there is a line of convective activity over the Chesapeake Bay, between Richmond and the Wallops Island airport. Within this line of convective activity are two thunderstorm cells that did not move significantly in position, but that changed shape and size slightly between NEXRAD images. [These two thunderstorm cells were enhanced slightly with photo retouching software to create an enticing corridor that tempted the pilots to fly between them.]

A four-point scale was again used to grade the pilot decisions relating to the thunderstorms over the Chesapeake Bay. A good decision—score of (3) or (4)—was deemed to be one in which the pilot circumvented the hazardous area entirely by changing course to the south, so as to avoid it by at least ten nautical miles. The pilot would then proceed up the coast of Virginia to the Wallops Island airport. A poor decision—score of (1) or (2)—was deemed to be one in which the pilot decided to find his way around (or through) the thunderstorms in an attempt to proceed by the most direct route to the Wallops Island airport, and for whatever reason, coming within ten nautical miles of hazardous weather.

The four-point grading criteria of the Wallops decisions are defined as follows:

1 = The pilot flew within 10 miles of a red cell while circumventing the storms over the bay using the pilot's own route planning.

2 = The pilot flew within ten miles of a red cell, but only because of a delayed turn or distraction, but the intent was to circumvent by at least 10 miles.

3 = The pilot flew within 10 miles of a red cell, but was following vectors from ATC and for whatever reason, ATC vectored the pilot to within that 10 miles.

4 = The pilot avoided a red cell by 10 miles or more.

An attempt to take a route to the north around the convective activity was also deemed to be a poor decision as the convective area continued into extensive restricted airspace that was in use and not available to the pilot.

The four-point grading scale was designed such that if a decision in the previous weather display experiment (two-point scale) were to be graded by this follow-on experiment scale (four-point scale), the outcome would be consistent. For example, if a pilot broke off the approach to Richmond within three miles of the outer marker, the two-point scale would assign a "poor" decision and the four-point scale would assign a grade of (2), which is still within the guidance of a "poor" decision.

The new scoring scheme permitted the results of this follow-on experiment (treatment group) to be compared to the results of the previous weather display experiment (control group), while still providing a graduated scale for statistical analysis in the follow-on experiment. By using this four-point grading method, more powerful analysis methods could be applied when comparing the decisions with other data such as weather scores, risk scores, and the information provided by the questionnaires.

The results of both decision points are illustrated in Table 5-2.

Table 5-2. Decision Results

Subject Number	Display Condition	Richmond Decision	Wallops Decision
25	Small Cells	4	4
37	Small Cells	1	2
15	Small Cells	1	1
40	Small Cells	4	1
11	Small Cells	3	3
27	Small Cells	1	1
9	Small Cells	1	4
12	Small Cells	1	1
1	Small Cells	1	1
56	Small Cells	1	4
22	Small Cells	4	2
4	Small Cells	4	4
28	Large Cells	1	1
46	Large Cells	3	2
58	Large Cells	4	1
17	Large Cells	4	2
13	Large Cells	1	4
59	Large Cells	4	1
16	Large Cells	4	4
60	Large Cells	4	3
62	Large Cells	4	3
63	Large Cells	4	4
64	Large Cells	1	1
65	Large Cells	4	1

1 = strong **poor** decision
2 = poor decision
3 = good decision
4 = strong **good** decision

5.3 Results of Immediate Reaction Questionnaire

Upon completion of the simulator session, each subject pilot was given a questionnaire (Appendix L, Immediate Reactions Questionnaire) to obtain their immediate reactions. The pilot was given this questionnaire while still seated in the simulator, thereby reducing distraction issues and obtaining valuable subjective information while the pilot was still in the “flight mode.”

Except for questions 10 and 11, there were five possible answers on a Likert scale that ranged from **Disagree** (score of 1) through **No Opinion** to **Agree** (score of 5). This questionnaire was reviewed with the pilot during the post-flight briefing to verify that the pilot understood the questions and to clarify any ambiguous answers.

The questionnaire responses are presented here in their entirety, but correlations to relevant data are included in succeeding sections.

Question 1. This question was asked primarily to determine the extent to which the subject pilots "bought into" the medical scenario presented to the pilots.

> **I took the medical emergency scenario seriously, in the sense that I factored the emergency into my decision making.**
> *(mean score of 4.79, standard deviation of 0.41)*

A score of five (5) was indicative of an "agree." A mean score of 4.79 and standard deviation of 0.41 with this question signifies that the vast majority of the pilots "bought into" the medical scenario, thus reducing the likelihood of invalid data due to an unrealistic situation.

Question 2. This question explored the pilots' perception of the latency in the weather information, and the extent to which the weather display depicted weather in "real-time."

> **An advantage of the onboard Weather Display was showing the weather in real-time, that is, as it actually was at that moment.**
> *(mean score of 3.83, standard deviation of 1.49)*

The mean score of 3.83 indicates that the pilots were generally unaware of the latency of the weather information. The relatively large deviation around the mean (SD=1.49), indicated a wide variation of the perception of the degree of latency among the pilots.

Question 3. This question explored the pilots' perception of the degree to which they felt they were able to interpret the weather display and the extent to which the display influenced their decision making.

> **I attribute much of my decision making to my interpretation of the Weather Display.**
> *(mean score of 4.54, standard deviation of 0.88)*

The mean score of 4.54 (a 5 being "agree"), combined with a small deviation (SD=0.88), indicates that the weather display played a large part in the decision process during the flight.

Question 4. This question asked the pilots their perception of the extent to which they used all available weather information sources.

> **I tried to systematically sample all sources of weather information open to me.**
> *(mean score of 4.0, standard deviation of 1.02)*

The mean score of 4.0 indicates that the pilots thought that they did sample all the sources of weather information that was available.

Question 5. This question explored the pilots' perceptions as to their willingness to depend solely on the weather display without cross-checking with information from other sources.

> **I used the Weather Display but felt the need to cross-check or verify my conclusions from conventional weather sources (ATC, etc.)**
> *(mean score of 4.33, standard deviation of 0.92)*

The mean score of 4.33 indicates that the pilots used the weather display, but also checked it with other sources.

Questions 6 and 7. Two questions were asked of the subject pilots about their comfort with and reliance on the autopilot.

> **I felt comfortable with the autopilot, in terms of understanding its use and operation.**
> *(mean score of 4.42, standard deviation of 0.88)*

> **Without the autopilot, my completion of the flight would have been compromised.**
> *(mean score of 4.38, standard deviation of 1.13)*

Most of the pilots said they felt comfortable with the autopilot and relied on its use to reduce the workload. The autopilot was, on average, in use for 85 percent of the flight (for all pilots). Many of the pilots stated that without the autopilot, they would have succumbed to an early termination of the flight.

Question 8. When asked about the validity of the weather display, the reactions consistently held the display validity in high regard.

> **The degree of validity of the weather data appearing on-screen was a factor I felt I held in mind as I flew.**
> *(mean score of 4.58, standard deviation of 0.72)*

Question 9. The pilots were asked if they regularly referred to the timestamp of the weather information.

> **I have been monitoring the weather display time stamp very regularly in my instrument scan.**
> *(mean score of 3.79, standard deviation of 1.47)*

Question 10. The pilots were asked what they perceived the weather conditions to be near the Richmond airport.

> **At the time of my arrival at Richmond's Airport, I knew that there was a storm —** (circle one)
>
> **a. about 10 nm North West of the field.** *(5 selections)*
>
> **b. about 5 nm North West of the field.** *(1 selection)*
>
> **c. near the field.** *(10 selections)*
>
> **d. right at the field.** *(7 selections)*

Most of the pilots correctly perceived that the storms were very close to the airport.

Question 11. The pilots were asked what they perceived the weather conditions to be on the route to Wallops Island.

> **At the time I was en route to Wallops, I saw across my path of direct flight, what I took to be —**
>
> **a. a penetrable storm.** *(2 selections)*
>
> **b. a navigable opening between convective cells.** *(6 selections)*
>
> **c. a non-navigable opening between cells.** *(0 selections)*
>
> **d. a wall of convective activity requiring diversion.** *(16 selections)*

The majority of the pilots correctly perceived the storms as a hazardous area that required a diversion. This perception, however, did not necessarily contribute to a good decision.

Question 12. The pilots were asked of the positional accuracy of the ownship position on the weather display.

> **On the weather display, I found the positional accuracy of the aircraft icon to be adequate.**
> *(mean score of 4.13, standard deviation of 0.90)*

This high "agree" score correlated with the comments received from the pilots during the interview—that they welcomed the ownship icon and found it accurate and easy to use.

Question 13. The pilots were asked of the positional accuracy of the ownship position in relation to storm information.

> **In using the weather display, I felt that I generally knew the aircraft position relative to any storms.**
> *(mean score of 4.58, standard deviation of 0.72)*

A slightly higher "agree" score for this question (compared to #12) revealed that the pilots trusted the display elements to be accurate relative to each other, but were not as confident that the ownship position was an accurate representation of their track over the ground.

Question 14. The pilots were asked if they had enough sources of weather information to make a confident decision.

> **I felt that I had adequate sources of weather information to make confident decisions.**
> *(mean score of 4.75, standard deviation of 0.68)*

With a high "agree" score, the pilots felt reasonably comfortable with their decisions.

5.4 Post-flight Weather Display Questionnaire

At the conclusion of the post-flight interview, the final item for the pilots to complete was a Weather Display Questionnaire (reproduced in Appendix N). The pilots were asked open-ended questions to obtain full responses to various issues in the use of the weather information display. The following section reproduces the more significant of those comments, and also includes researcher comments that relate to the quantitative assessments.

<u>Question 13.</u> In using this weather display today, did you find the operation straightforward? If not, what operations of this weather display did you find difficult?

> "Toggling between operating modes got to be frustrating when the workload was high."
>
> "No, locating airport of choice and obtaining METAR."
>
> "I found it difficult to keep track of cells, especially movement."
>
> "Switching from airport to navaids using the crosshairs — also forgetting display is a north-up presentation."
>
> "Mostly very easy, a little trouble with crosshair info; there was different info in different modes."
>
> "Had difficulty in pulling up text of destination airport weather in high workload condition while flying single pilot autopilot IFR."
>
> "Would like fast way to pop-up airport/VOR identifiers."
>
> "waypoint identifiers..."

The responses to this question highlight the issue of mode selection and the difficulty that the pilots had in gathering information in a timely manner, especially during high workload.

<u>Question 14.</u> In using this weather display today, did you find the <u>graphical</u> METAR symbology useful? If not, what features did you find difficult?

> "No, the symbols were small and I had a hard time seeing them to the degree of discerning colors."
>
> "I was not able to follow it..."
>
> "Graphical METAR is useful, but time lag can defeat the purpose."
>
> "Glanced at it, but it was never part of my decision making."

“The METAR symbols would take some getting used to during real-world flying; I think I would like them, but they should follow airport ID’s.”

“Data too old to be useful.”

The pilots did not seem to use the graphical METARs to a great extent, either because of their limited information, difficulty in interpreting the display, or inability to present timely information.

Question 15. In using this weather display today, did you find the textual METAR presentation useful? If not, what features did you find difficult?

“Yes, more so than colors, since it gave me a more complete picture.”

“Useful in making decisions about selecting an alternate [airport].”

“It is useful — might tend to delay getting ATIS.”

“Yes, we still need to study METAR abbreviations.”

“Yes, but would like the decoded version as an option.”

“Yes, a plain english version would be nice.”

“Not too useful — too much workload.”

“...METARs are often too old.”

“No, didn’t tell me anything ATIS didn’t give me.”

The pilots found the textual METARs more useful than the graphical METAR depiction, mostly because the textual METARs contained more complete information. Additionally, there was still an issue of timely information and difficulty in interpreting the codes.

Question 16. Considering your use of the weather display today, would you like to see any additional features or change any existing features?

“Yes, motion vectors of weather systems (cells).”

“Superimpose wind information for quick check and then remove.”

“Heading-up would be more useful — GPS Nav information on the weather display with course line would be helpful.”

"I would like to see the weather display to greater detail with smaller frames; overlay of Stormscope data desirable." [this pilot was using the large NEXRAD cells]

"Possibly a wind readout via the crosshair selection — interface with a [onboard] weather radar."

"a) I usually use my GPS at a higher magnification, 30 or 50 nm full screen. The highest resolution on today's screen seemed lower. I would like higher magnification, even though it would be very 'grainy.' I think de-cluttering would help.
b) A 'loop' display of radar (at least 30, 60 or 120 minutes) would help me keep track of what cells are doing."

"As currently formatted, the radar data [NEXRAD] seemed to overwhelm both the METAR and airport/VOR data. I would wonder about: a) Make the METAR and/or navigation data points larger, b) Make the radar less prominent (i.e., each radar 'pixel' not confluent with the other)."

"I would suggest a better display of range function."

"It would be great to get recommended course deviation to avoid heavy weather."

"Some form of range information would be nice."

"An alert or flashing cursor of some type to indicate the NEXRAD is updating or has just updated."

"Looping for time — put storm cells into motion. Also speed and cell tops."

"How about 'motion' graphics so you can see trend better..."

"Adding movement by repeating the last 6 or 8 frames with a 'sequence' button is worth considering."

"I'd like to have the moving map include the route, SUA [Special Use Airspace], generally include a GPS moving map."

"Time stamp could also include how old it is."

When asked if there were any features that needed improvement, most of the comments focused on the need for better range depiction and depiction of storm movement. Some of the suggestions were wind vectors, looping, motion vectors and a digital readout of cloud speed and tops.

<u>Question 17.</u> How did the weather display affect your decisions that you made today?

"Very strongly influenced it."

"It gave me more info to base my decision making."

"Allowed me to immediately visualize alternate courses of action."

"It affected them a lot, without the display I would not have tried to hold to get better weather, and it helped determine routes around the weather."

"Was primary in decision, but I also wanted verification from another source (ATC)."

"It enabled me to continue the flight."

"Helped me in developing an alternate course of action in determining how best to complete the flight assignment."

"Very helpful as far as situation awareness to actual weather, but not good in the terminal environment as a primary source of weather."

"Greatly influenced decisions (especially useful for rapidly changing conditions)."

"Only for rough overview of the weather situation around me. Not useful for details."

"Very helpful in overall situational awareness, but somewhat misleading in time critical decision making."

It appears that the weather information display was generally useful for strategic and situational awareness and poor for tactical use.

<u>Question 18.</u> Do you feel that you needed more training on the weather display? If so, in what areas?

"Training was enough to use it — really simple to use."

"Yes, perhaps not training, but just more use (it took me a few hours of use before I felt comfortable correlating what I see on my Stormscope with what I see when flying above layers)."

"Yes, range interpretation — switching from airports to navaids using crosshairs."

> "Yes, pulling up text of ATIS."

> "I would want some real life experience with it before I felt comfortable relying on it."

The pilots generally asked for more training, but more importantly, for more time practicing with the display in the real world.

<u>Question 20.</u> Were there any features about the weather display that caused you to cast doubt as to its usefulness in normal, real world, operation?

> "Yes, the 7 minute delay."

> "No, that will only come when the unit is airborne and compared to real weather."

> "Just that the NEXRAD is at least 8 minutes old."

> "No, provided time-lagging limitations are kept in mind. One shouldn't expect anything that cannot be delivered."

> "ATC guidance about actual conditions cast some doubt as to its usefulness."

The pilots commented that the time delay is a major limitation of the system. Similar comments were received in the previous weather display experiment.

<u>Question 22.</u> How did the use of the autopilot help or hinder the use of the weather display?

> "...with the autopilot, I was able to more effectively use the weather display."

> "Reduced the workload so time could be spent with the weather display."

> "Freed up concentration so I could study the plots."

> "Autopilot allowed me to use the weather display, higher proficiency would have to exist without an autopilot."

Because of the limited experience with the weather display and in operating the simulator, the autopilot was helpful and allowed time to interact with the display. This is consistent with the finding that the autopilot was in use an average of 85% of the flight.

6 Quantitative and Qualitative Assessments

Quantitative assessments were undertaken to investigate any probable relationships between the weather information display and the pilot actions at the two key decision points. Additionally, qualitative assessments—based on the observations and expertise of the experiment team—were undertaken to explore significant issues related to the weather information display.

Although both decisions relate to processes within the same developing weather system, they are considered to be statistically independent, as considerable effort was made in the design of the scenario to limit coupling effects along the chronological axis of the scenario. The Richmond decision is considered to have been based largely on the interpretation of the relationship in time between the aircraft's expected position in the future and the possible location of the rapidly changing hazardous weather conditions in the future—a "temporal" decision. The Wallops decision is considered to have been based largely on interpretation of the relationship in distance between the aircraft's flight path and the location of the relatively stationary hazardous weather conditions—a "spatial" decision.

6.1 Subject Group Comparisons

For the purpose of examining the effects of displaying ownship position and variation of NEXRAD display resolution upon Aeronautical Decision Making (ADM), an important consideration is the degree to which the subject pilot groups were equivalent in implicit knowledge (proficiency) and explicit knowledge (weather knowledge questionnaire).

Examination of experience and proficiency in terms of the customary indices, such as total hours, actual instrument hours, hours "under the hood," and flight simulation hours, indicated there were no significant differences between the subject pilot groups. Additionally, there were no significant differences in terms of weather knowledge or risk aversion, as indexed by the Risk Assessment Task and Weather Knowledge Questionnaire; these being the key variables by which the groups were matched for functional equivalence. Therefore, the groups appear to have been statistically matched in terms of the proficiency indices used in this experiment—flight hours, instrument flight experience, currency, weather knowledge and risk aversion.

An indicator of experiment acceptability is the extent to which the subject pilots internalized the mission scenario. A strong acceptability from the pilots verified that the scenario was realistic and resultant data could be relied upon.

6.2 Quantitative Assessments

The form of some of the data points collected in the experiment, such as binary decisions, favored non-parametric tests, such as the Chi-Square test. This technique was used in testing the relationship of several variables to decision making adequacy, and provided a value for chi together with the probability (p) that a result was due purely to chance. A less than a one in twenty chance that a result was merely a random fluke ($p < 0.05$) is generally regarded as statistically significant. This report adheres to that convention. It does not, however, imply that small probability outcomes in *excess* of 0.05 are without importance or necessarily result from random chance.

Other data points were continuous numeric data, such as weather test scores, flight hours, questionnaire responses (a 1 to 5 Likert scale), etc. An SPSS Inc. software program was used to analyze the data set. Pearson Product Moment correlation coefficients were calculated to evaluate the relationships among the continuous numeric data, and a regression analysis was conducted on the data for the two decision points.

As described earlier in the Methodology section, the experiment scenario featured two critical decision points, one on the approach to the Richmond airport, and one en-route to the Wallops Island airport. These decisions were considered both independently and together as a group. Additionally, the decisions of the current experiment were compared to the previous experiment, especially with regard to the effect of including ownship position symbology.

6.2.1 Effect of Ownship Position on Pilots' Decisions

In this follow-on experiment, both subject groups had ownship position symbology, but only one group of 12 pilots flew with the same size NEXRAD image cell size (small) that was used in the previous weather display experiment. Therefore, the effect of having ownship position displayed can be examined. Figure 6-1 provides a comparison of the frequency of good and poor decisions enroute to Richmond, and figure 6-2 provides a comparison of the frequency of good and poor decisions enroute to Wallops Island.

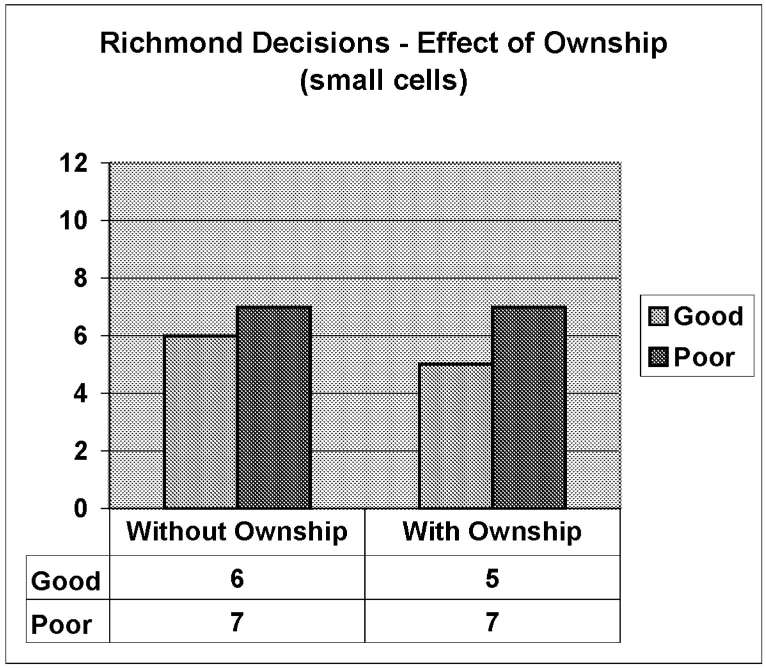


Figure 6-1. Effect of Ownship Display on Richmond Decision

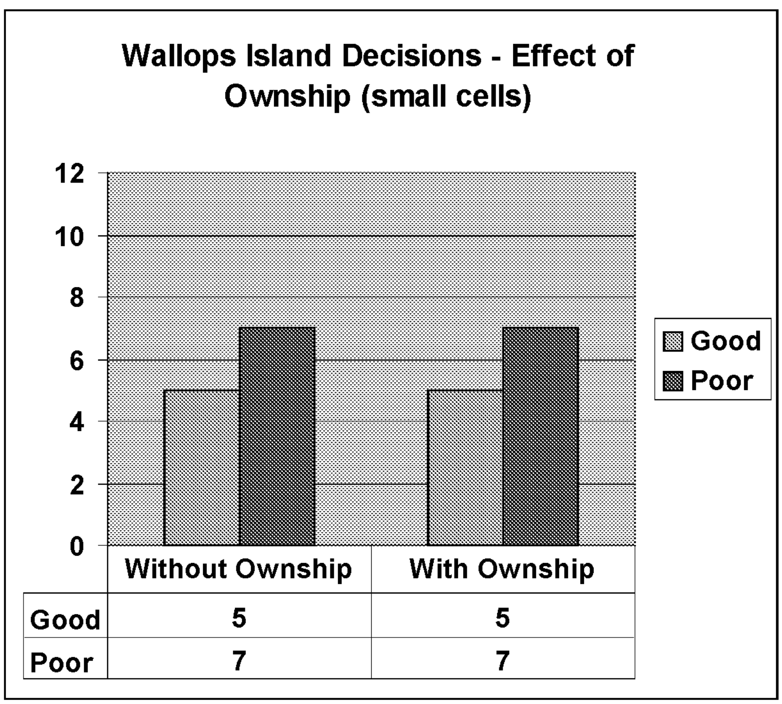


Figure 6-2. Effect of Ownship Display on Wallops Decision

As can be seen, the display of ownship position did not have a noticeable effect on the frequency of good versus poor decisions. Equally important, the finding that the addition of ownship to the display did not have a detrimental effect on the decision-making ability of the pilot. Also of interest is the indication that the addition of ownship had a noticeable effect on reducing the perceived workload of the weather information display.

6.2.2 Effect of NEXRAD Image Cell Size on Pilot Decisions

For the Richmond decision, the data indicates that pilots were more likely to make good decisions with the larger NEXRAD image cell size. Figure 6-3 provides a comparison of the frequency of good versus poor decisions for the Richmond decision.

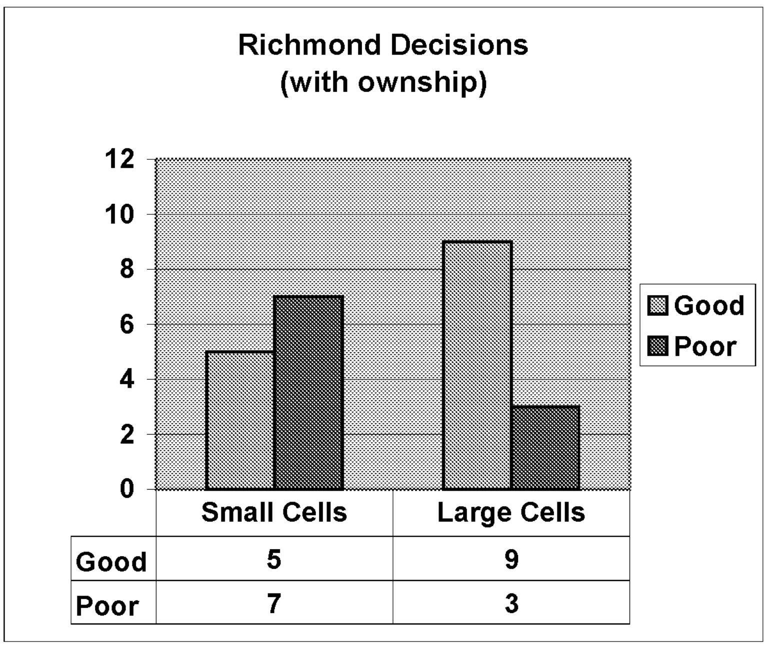
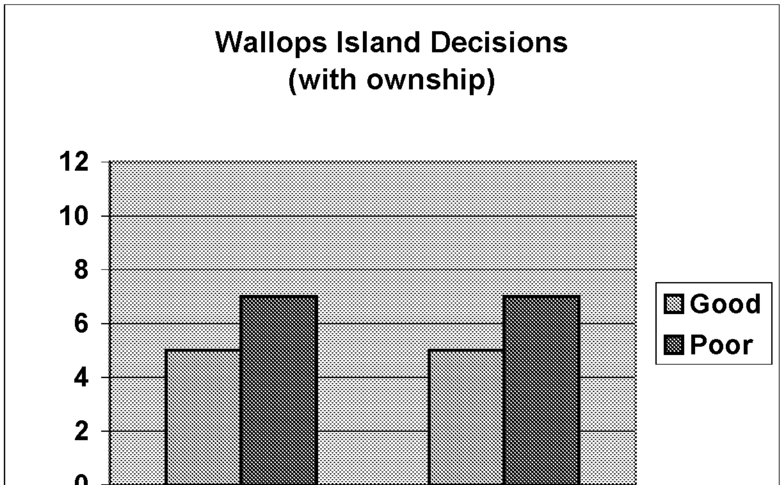


Figure 6-3. Richmond Decisions

A chi-square significance test was computed to examine differences in observed frequencies between these groups at the Richmond decision point. The chi-square with one degree of freedom was 2.73, with a p-value <0.10. Although this is not regarded as "reportably significant" using the convention that p should be less than 0.05 (i.e. less than a 1 in 20 chance of the result being a "fluke"), the experimental finding nevertheless remains unlikely to be a mere chance outcome (less than a 1 in 10 chance of this). Therefore, the chi-square does suggest that the low resolution, large cell size version of the weather display may have influenced the Richmond decision. The result is consistent with the prediction that lower resolution NEXRAD images increase uncertainty over the actual location of hazardous weather.

For the Wallops Island decision, the data shows that there was not any difference in the frequency of good versus poor decisions between the pilots that flew with the larger

NEXRAD image cells and those that flew with the small cells. Figure 6-4 provides a comparison of the frequency of good versus poor decisions for the Wallops Island decision.



	Small Cells	Large Cells
Good	5	5
Poor	7	7

Figure 6-4. Wallops Island Decisions

As would be expected from a cursory examination of the values in the table, the chi-square test was not significant. The two groups were exactly the same in terms of decision frequency as defined and analyzed in this experiment. Therefore, NEXRAD image cell size did not appear to have an effect on the decisions for the Wallops Island leg.

It should be noted that some of the poor decisions made by the pilots having the large NEXRAD image cells may have been due to pilot procedural issues rather than pilot perception or weather information issues. There were cases where the pilot made the decision to change course to avoid the storms with enough time to avoid them, but delayed the turn and drifted too close to the storm. This is reflected in the greater number of marginal decisions (coded as either a 2 or 3).

Table 6-1 provides an overview of the Richmond decisions. A comparison is made between the decision results from both experiments and the decision grading criteria. The expanded decision criteria scale is applied to the follow-on experiment only.

Table 6-1. Overview of Richmond Decisions

Grading Criteria				Decision Results With Ownship		Decision Results Without Ownship	
				Large Cells	Small Cells	Small Cells	No Display
1=	Strong Poor	Waved off approach by tower controller at OM, and	Flew within 5 miles of a red NEXRAD cell	**3**	**7**	**7**	**6**
2=	Poor	Abandoned approach less than 5 miles outside OM, but		**—**	**—**		
3=	Good	Abandoned approach less than 5 miles outside OM, and	Flew more than 5 miles from a red NEXRAD cell	**1**	**1**	**6**	**6**
4=	Strong Good	Abandoned approach more than 5 miles outside OM, and		**8**	**4**		
			Total	**12**	**12**	**13**	**12**

Table 6-2 provides an overview of the Wallops Island decisions. A comparison is made between the decision results from both experiments and the decision grading criteria. The expanded decision criteria scale is applied to the follow-on experiment only.

Table 6-2. Overview of Wallops Island Decisions

Grading Criteria				Decision Results With Ownship		Decision Results Without Ownship	
				Large Cells	Small Cells	Small Cells	No Display
1=	Strong Poor	While circumventing storms using own route planning	Flew within 10 miles of a red NEXRAD cell	**5**	**5**	**7**	**1**
2=	Poor	While circumventing storms, was distracted or delayed turn, and		**2**	**2**		
3=	Good	Pilot following ATC vectors, but		**2**	**1**	**5**	**11**
4=	Strong Good	Pilot avoided red cell, and	Flew more than 10 miles from a red NEXRAD cell	**3**	**4**		
			Total	**12**	**12**	**12**	**12**

6.2.3 Rationale for Pilots' Decisions

The post-flight interview attempted to obtain the pilots' rationale for their decisions. The responses were slightly varied, but centered around three categories and were recorded as follows:

For the Richmond decision,

- They saw deteriorating weather and decided to divert to Wallops Island.
- They would try one approach and see how far they could get, but if that first approach was not successful, they would divert to Wallops Island.
- They were concerned that if they did land at Richmond, they could not get back out.

During the interview, the same open-ended question was asked for both decisions, "What led you to make the decision to: [insert observed action at decision point]?"

The results for the Richmond decision are illustrated in Figure 6-5.

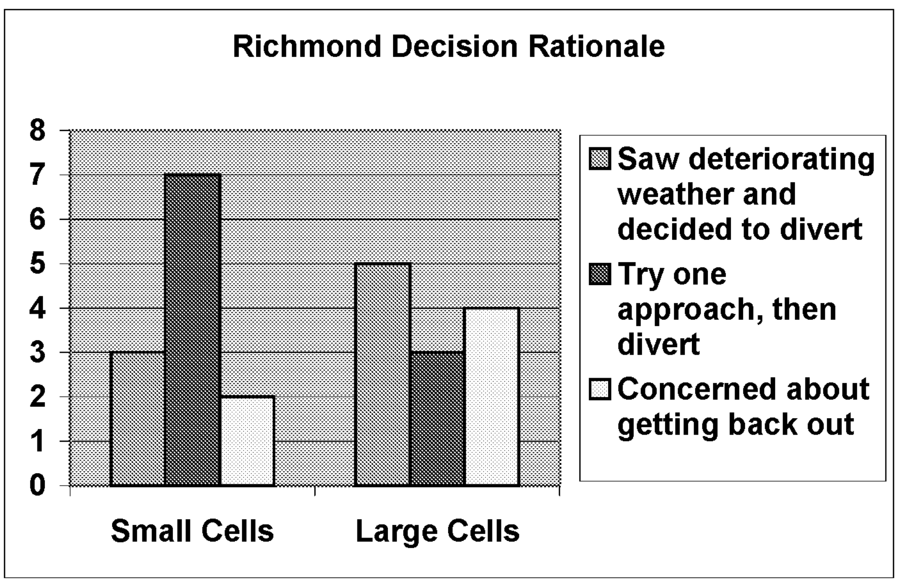


Figure 6-5. Richmond Decision Rationale

It appears that for the Richmond decision, a larger number of the subject pilots having the large NEXRAD image cells decided not to try an approach and diverted earlier. This conclusion is supported with the finding that more pilots having the large NEXRAD image cells made good decisions than those with the small NEXRAD image cell size.

For the Wallops Island decision, the same question about rationale was asked and the responses were categorized as follows:

- They saw deteriorating weather and decided to divert around the hazardous area.
- From their perception, the storms did not look exceedingly bad.
- They sought advice from ATC and asked for vectors.

The results for the Wallops Island decision are illustrated in Figure 6-6.

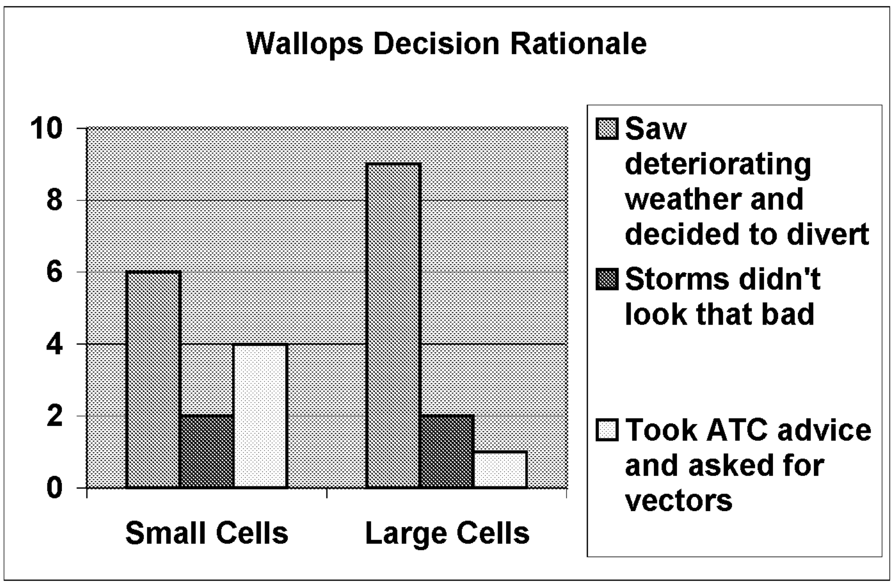
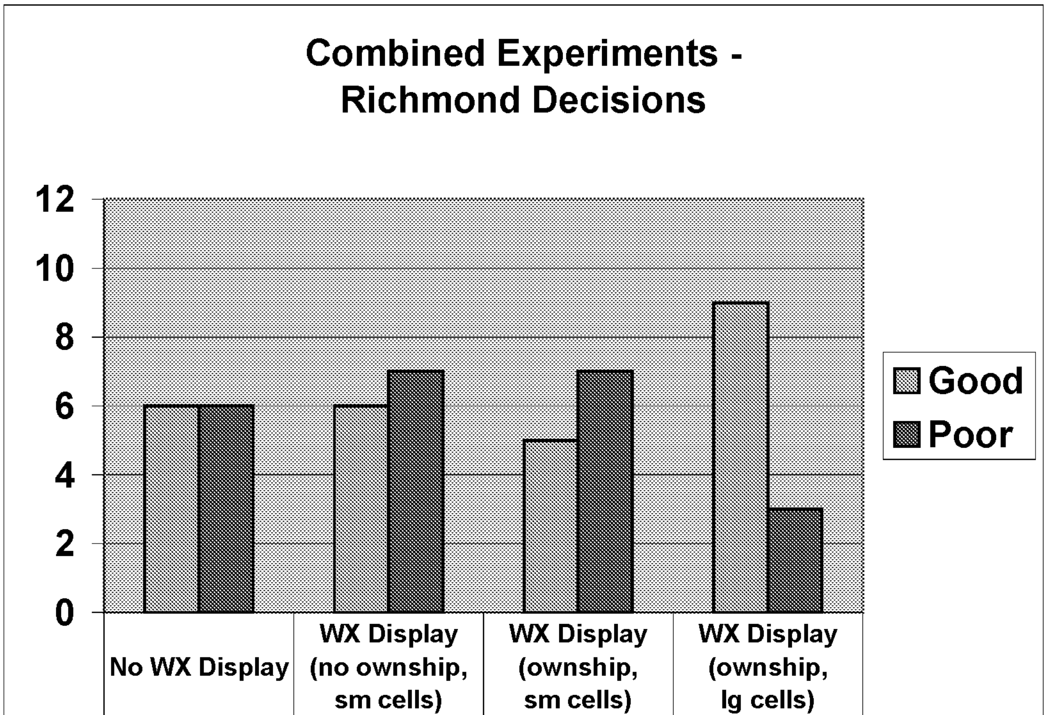


Figure 6-6. Wallops Island Decision Rationale

It appears that in making the Wallops Island decision, the subject pilots having the large NEXRAD image cells made better choices by either deciding to change course on their own or by seeking the advice of ATC and asking for vectors. Although some of the pilots made the decision to divert within plenty of time, their execution of the diversion was in some instances delayed and brought them within close proximity to the storms.

6.2.4 Combination of Decisions from Previous and Current Experiments

If the frequency of good versus poor decisions is compared across both experiments, it appears that for the Richmond decision, the pilots performed better with the weather display containing ownship position and large NEXRAD image cells. Figure 6-7 illustrates the results of the Richmond decision across both experiments.



	No WX Display	WX Display (no ownship, sm cells)	WX Display (ownship, sm cells)	WX Display (ownship, lg cells)
Good	6	6	5	9
Poor	6	7	7	3

Figure 6-7. Combined Richmond Decisions

For the Wallops Island decision, the addition of the weather display significantly reduced the ratio of good versus poor decisions.

Figure 6-8 illustrates the results of the Wallops Island decision across both experiments.

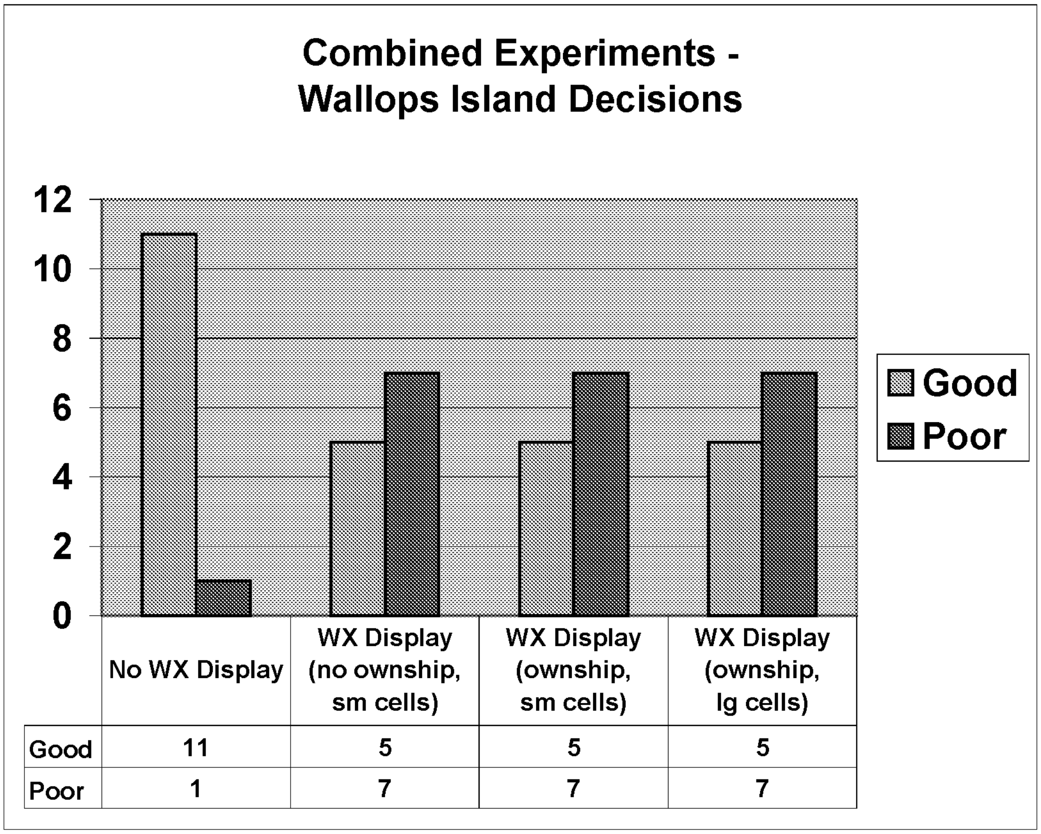


Figure 6-8. Combined Wallops Island Decisions

6.2.5 Risk Aversion, Weather Knowledge and Experience Analysis

A hierarchical regression analysis was conducted to examine the possible contribution of weather display, weather knowledge, risk aversion, and experience to decision making quality as indexed by the four point ratings. Experience was defined as total flight hours, instrument hours, and simulation hours since these three variables were very highly correlated (*Pearson Product Moment* values for *r* ranged from 0.56 to 0.85).

Hierarchical regressions were computed for the Richmond decision point, and for the Wallops Island decision point. A third was computed taking both decision points into consideration.

6.2.5.1 Richmond Hierarchical Regression Analysis

The results of the hierarchical regression for the Richmond decision point indicate that none of the variables were significant predictors of decision making. Table 6-3 illustrates the results of the regression analysis for the Richmond decision.

Table 6-3. Richmond Regression Analysis Results

Dependent Variable = Richmond Decision			
	R	**R^2**	**Significance**
1st level: low or high NEXRAD image resolution	**.34**	**.11**	**not significant**
2nd level: weather knowledge and risk aversion	**.37**	**.14**	**not significant**
3rd level: experience	**.49**	**.24**	**not significant**

6.2.5.2 Wallops Island Hierarchical Regression Analysis

The results of the hierarchical regression for the Wallops Island decision point indicate that the greatest influence on decision quality came from weather knowledge. Not surprisingly, there was no significant effect attributable to the weather display, since the pilots had exactly the same decision frequencies whether they used a low or high resolution display. Table 6-4 illustrates the results of the regression analysis for the Wallops Island decision.

Table 6-4. Wallops Island Regression Analysis Results

Dependent Variable = Wallops Decision			
	R	**R^2**	**Significance**
1st level: low or high NEXRAD image resolution	**.00**	**.00**	**not significant**
2nd level: weather knowledge and risk aversion	**.55**	**.30**	**significant p=.06**
3rd level: experience	**.64**	**.41**	**not significant**

The chi-square test suggested that better decision making may have occurred at the Richmond decision point when a low resolution (and, therefore, we posit, high uncertainty) weather display was in use. However, the regression analyses do not help to explain why such a difference might have occurred. Hierarchical regression results for Richmond included no significant predictors of rated decision making. It cannot be said that the probable difference in decision making (albeit at $p < 0.1$) was due to variability in pilots' weather knowledge, their risk aversion, or flight experience levels. The regression results for the Wallops Island decision do suggest the importance of weather knowledge and risk aversiveness.

6.2.5.3 Combined Hierarchical Regression Analysis

Considering the influence of weather display, weather knowledge, risk aversion, and experience on the combination of decisions at Richmond and Wallops Island together suggests that weather knowledge may be in part responsible for decision quality as rated in this experiment. The p-value associated with weather knowledge and risk aversion was less than 0.1, and the significant t-value associated with weather knowledge was the source of the significant effect (rather than risk aversion). This seems to suggest that weather knowledge as measured by the declarative knowledge test may have influenced decision quality at both decision points. Table 6-5 illustrates the results of the combined Richmond and Wallops regression analysis.

Table 6-5. Combined Richmond and Wallops Island Regression Results

Dependent Variable = Ratings of decision making, both locations			
	R	**R^2**	**Significance**
1st level: low or high NEXRAD image resolution	**.14**	**.02**	**not significant**
2nd level: weather knowledge and risk aversion	**.52**	**.27**	**significant p=.09**
3rd level: experience	**.58**	**.34**	**not significant**

6.3 Qualitative Assessments

The difficulties in the use of the weather information display appear to include workload problems, incorrect assumptions about the relative location and age of displayed weather data, inadequate correlation to other weather information sources, inability to interpret convective weather movement and insufficiency of training.

While it was required that all candidate subject pilots for this experiment be qualified and current as instrument pilots, the 24 pilots ultimately selected to participate demonstrated a very wide range of proficiency in instrument flight. The pilots' experience ranged from 66 hours of instrument time to over 2,000 hours of estimated actual instrument time. Their proficiency in instrument flight operations was very probably quite representative of the population of general aviation pilots having similar qualifications and levels of experience.

6.3.1 Workload Issues

This experiment was not designed to specifically measure or quantify workload in relation to the use of the weather information display. However, the observers made general observations relating to workload, and the pilots were asked a series of questions relating to their perception of the workload.

Two areas of workload were investigated including, 1) the overall workload for the entire mission, and 2) the workload specific to the use of the weather information display.

6.3.1.1 Overall Mission Workload

The observers gathered workload cues such as incorrect or inappropriate procedures, hesitation in communication, changes in voice pitch, control excursions, flight technical errors, procedural hesitation, navigation errors, haphazard search techniques, autopilot use, training transfer problems and physiological indications gained from the interview.

The subject pilots were asked to comment on the workload for the entire mission. During the post-flight interview, the pilots were asked, "Did you feel ahead of the airplane?" The results are illustrated in Figure 6-9.

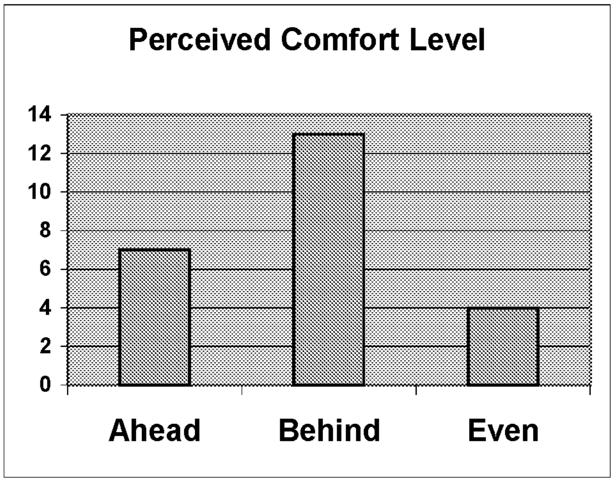


Figure 6-9. Pilots' Perceived Workload for Entire Mission

The pilots' perceived workload closely matched the observations and reflected the intended pace of the experiment—to explore the effects of the weather display in a high-workload and realistic flight environment. Another indicator of the workload is the amount of autopilot use.

The pilots had an autopilot available during the experiment and were trained on its use during the training session. During the pre-mission briefing, the pilots were instructed to use the autopilot if they felt it necessary to do so, but there was neither any requirement nor penalty in its use. Figure 6-10 illustrates the extent to which the pilots used the autopilot in the experiment.

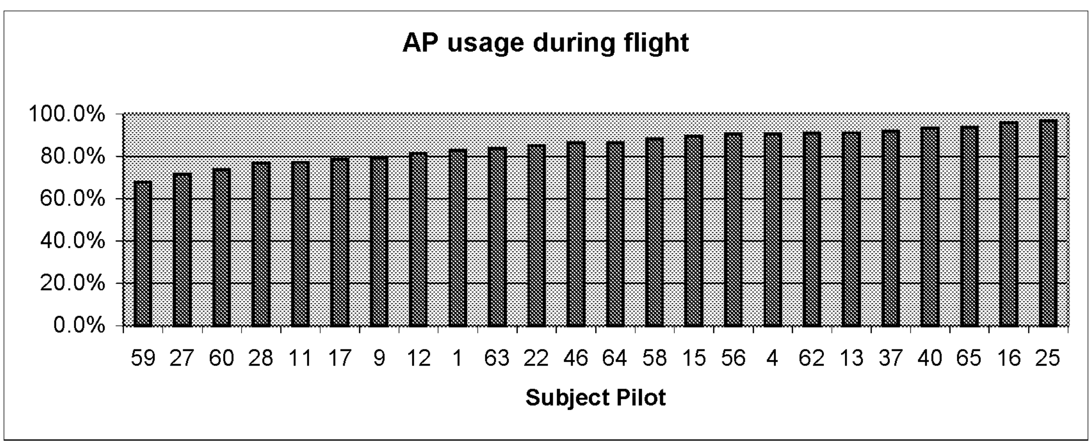


Figure 6-10. Percent of Flight Time Autopilot Used

Even though the autopilot was used for an average of 85 percent of the time in flight across all the subject pilots, some pilots were too busy to effectively integrate the use of the weather display into their procedures. Others were able to effectively use only one or two functions of the display. All of the pilots in both groups stated the autopilot was either essential to the safe accomplishment of the flight or substantially reduced the workload of flying in instrument conditions. Nearly all of the pilots stated that in reducing their workload, the autopilot made it possible for them to make more effective use of the weather information display.

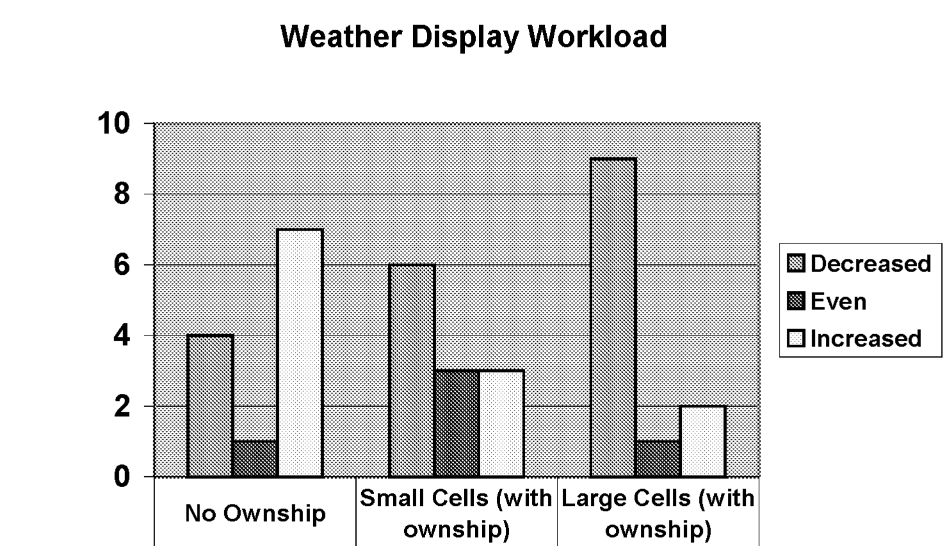
Most of the pilots said they felt comfortable with the autopilot and relied on its use to reduce the workload. The autopilot was, on average, in use for 85 percent of the flight (for all pilots). In the previous weather display experiment, the autopilot was in use 83 percent of the flight, on average. Many of the pilots stated that without the autopilot, they would have succumbed to an early termination of the flight.

Because the RTI Simulation Facility is not a full-motion/full-reactive type of simulator, the lack of a peripheral visual system, motion base and reactive flight controls more than likely contributed to the extensive use of the autopilot. Without the normal visual and tactile sensations, hand flying this simulator would be difficult in a high workload situation. Therefore, the high use rate of the autopilot is fully understandable. Additionally, from an experimentation standpoint, the consistent use of the autopilot reduced a significant variable—flight technical error.

6.3.1.2 Workload in use of Weather Display

During the course of this experiment, subjective measures were undertaken to determine the pilots' perception of their workload in using the weather display.

On the final Weather Display Questionnaire (Appendix N), the pilots were specifically asked how the weather display affected their workload. The same question was also asked of the pilots in the previous experiment that flew with the weather display without ownship position symbology. The results are illustrated in Figure 6-11.



	No Ownship	Small Cells (with ownship)	Large Cells (with ownship)
Decreased	4	6	9
Even	1	3	1
Increased	7	3	2

Figure 6-11. Pilots' Perception of Weather Display Workload

The number of pilots that felt the weather display decreased their workload steadily increased as ownship position and larger NEXRAD image cell features were added. The surprising number of pilots that felt the weather display increased their workload [in the no ownship group of the previous experiment] is most likely attributable to the lack of a display of ownship position and the resulting difficulty in determining their position on the display. Many responses to the specific workload question cited that, "... trying to find my position on the display increased my workload."

6.3.2 Use of Available Weather Data Sources

The pilots were able to access the normal in-flight weather services through the simulator radio, including:

- FSS – Flight Service Station
- ATC – Air Traffic Control (tower, departure and approach)
- FW – Flight Watch
- ATIS – Automatic Terminal Information Service
- ASOS – Automated Surface Observation System

The type and frequency of weather information sources used by the pilots were recorded on the Observer Form (Appendix K).

6.3.2.1 Richmond Area Weather Sources

A breakdown of the weather information sources used, in addition to the weather information display, by the subject pilots for the Richmond leg is illustrated in Figure 6-12.

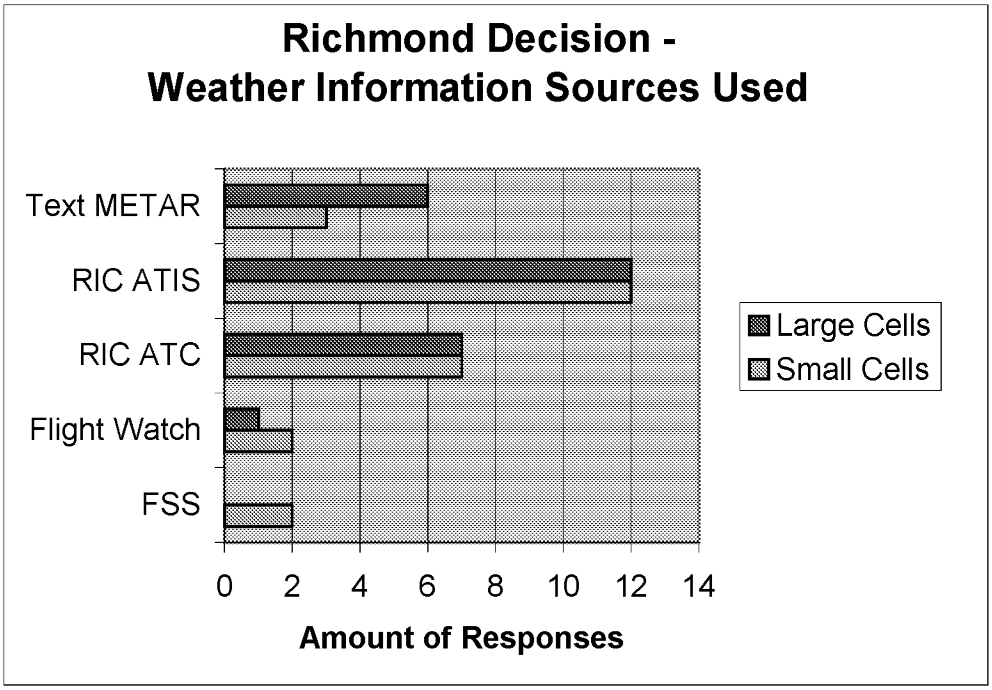


Figure 6-12. Additional Weather Sources Used for the Richmond Decision

The primary source of weather, for the Richmond decision, was reported by the pilots using the small-cell display to be the weather information display itself, and by the pilots using the large-cell display to be ATC (Figure 6-13). None of the pilots reported Flight Watch or Flight Service to be their primary weather source.

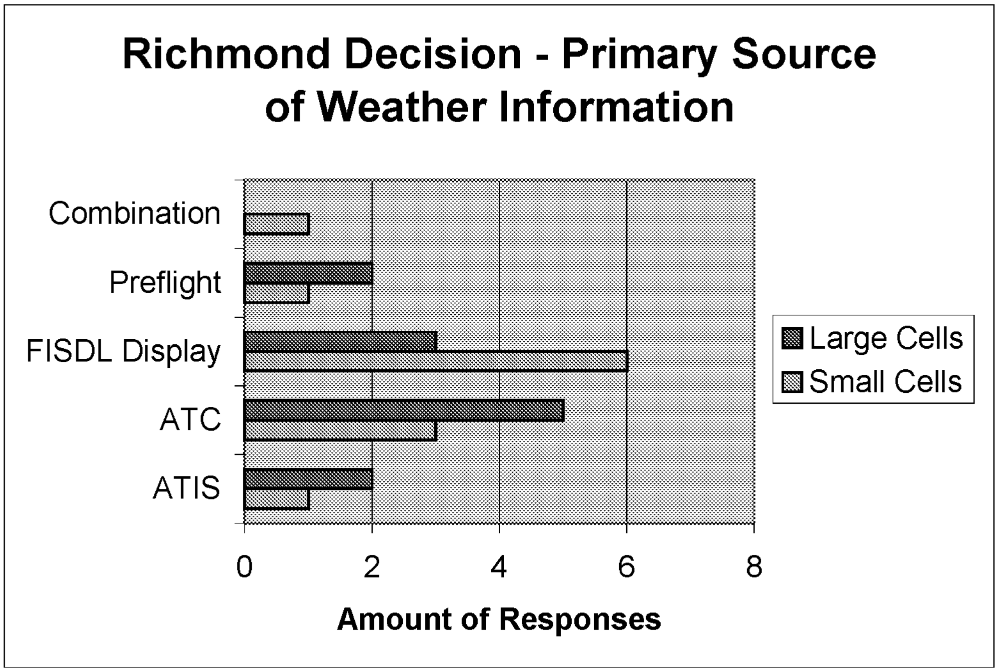


Figure 6-13. Primary Source of Weather Information for Richmond Decision

When asked in the post-flight debriefing about their use of Flight Service Stations, some pilots commented that they do not use the service much—due mostly to the difficulty in interpreting the verbal information and the excessive amount of time necessary to collect the information. Additionally, the Flight Service does not generally know their specific location and obtaining specific route information is difficult. While en-route to Richmond, 2 participants in the small-cell group contacted Flight Service before departure, and 2 contacted Flight Watch while in the air. One participant in the large-cell group contacted Flight Watch before departure.

6.3.2.2 Wallops Island Weather Sources

A breakdown of the weather information sources used, in addition to the weather information display, for the Wallops Island leg is illustrated in Figure 6-14.

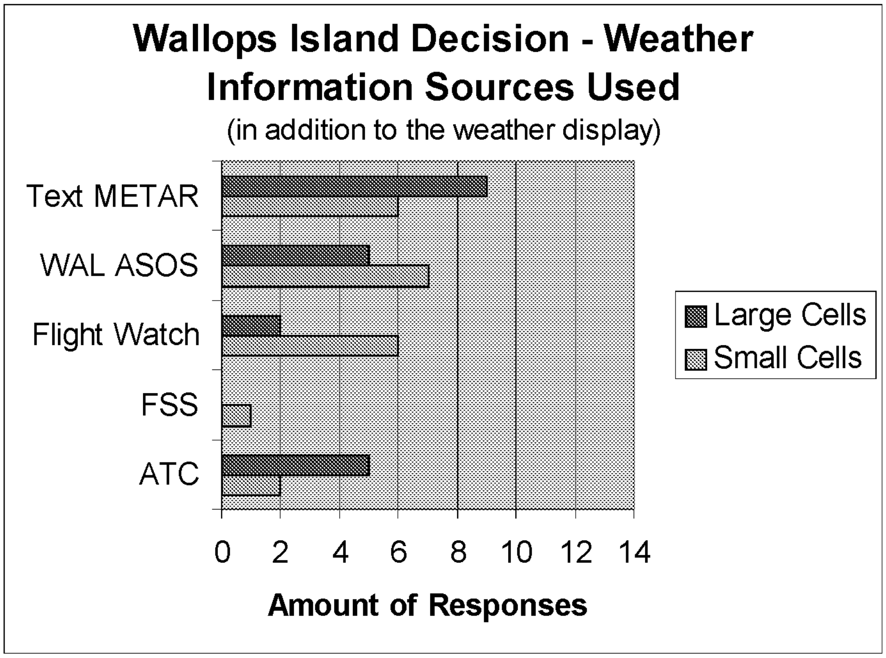


Figure 6-14. Additional Weather Sources for the Wallops Island Decision

For the Wallops Island decision, both groups reported that the weather information display was the primary source of weather information (Figure 6-15). Additionally, both groups reported ATC as the secondary source of weather. Flight Service/Flight Watch was not reported as a secondary source. While en-route to Wallops Island, 1 participant in the small-cell group contacted Flight Service and 6 participants contacted Flight Watch. In the large-cell group, 2 participants contacted Flight Watch.

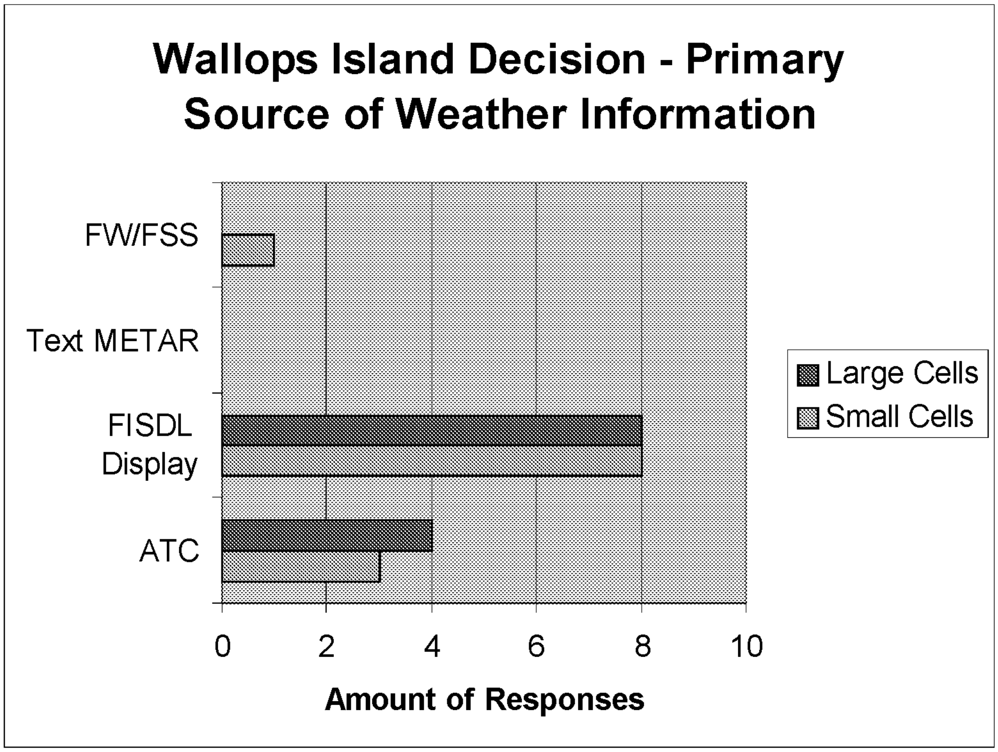


Figure 6-15. Primary Source of Weather for the Wallops Island Decision

ATC was considered to be secondary to the weather display as the source of weather information by both groups en-route to Wallops Island. Only one pilot reported Flight Service/Flight Watch to be the primary source of weather information for the Wallops Island decision. This indicates a need for pilot training in the appropriate use of FISDL weather data as an aid to collaborative decision making with appropriate weather service providers.

6.3.3 Interpretation of the Weather Information Display

Nearly all of the subject pilots were enthusiastic about the potential of the weather information display for improving their awareness of weather conditions, but many misinterpreted or did not access the information available from the display. Many of the poor weather decisions were made because the pilots were not aware of the deteriorating weather conditions and were consequently surprised that they could not get into the Richmond airport or that there were thunderstorms over the bay between Richmond and the Wallops Island airport. Nearly all recognized that a thunderstorm was in the vicinity of the Richmond airport—most failed to correctly recognize the level of the hazard this presented to them.

When those who did so were asked why they attempted to proceed with the approach past the outer marker, they said they had not recognized how close they were getting to the hazardous areas of the storm, or that it did not look that bad. Many said they had decided to proceed with one approach into the Richmond airport and "see what happens." Most of these pilots said they were looking for other clues as to the severity of the weather such as turbulence levels, lightning or rain intensity.

6.3.3.1 Judging Proximity to Hazardous Weather

Many pilots had difficulty correctly determining their position in relation to the storm cells. The weather display did not employ any type of range determination graphics around the ownship icon. The only assistance provided for range determination was a map distance scale in the upper right corner of the display window.

The difficulty in determining distance to the hazardous convective activity was reflected in the pilots' comments. Many pilots suggested that some form of range rings or other similar indication should be available to aid in estimating distances. The comments received from the pilots during the interview confirmed that they welcomed the ownship position icon and found it accurate and easy to use. The pilot comments indicated that they trusted the display elements to be accurate relative to each other, but were not as confident that the ownship position was an accurate representation of their track over the ground.

Question 13. The pilots were asked of the positional accuracy of the ownship position in relation to storm information.

> **In using the weather display, I felt that I generally knew the aircraft position relative to any storms.**
> (mean score of 4.58, standard deviation of 0.72)
> [score of 5 = agree, score of 1 = disagree]

6.3.3.2 Situational Awareness

On the final Weather Display Questionnaire (Appendix N), the pilots were asked how the weather display affected their situational awareness.

> Did you find that the weather display increased or decreased your **situational awareness**?

All of the pilots, except one, answered this question by saying that the weather display increased their situational awareness. The pilot that found the display decreasing his situational awareness was a very low time pilot that was already overloaded by the demands of the mission scenario. Many of the pilots commented that the weather display slightly increased their workload, but gave them a vast improvement in situational awareness.

6.3.3.3 Recognizing and Interpreting Effects of Delay

The pilots were briefed twice (during the introduction and again during the familiarization flight) that the NEXRAD image could be from 7 to 14 minutes old and to check the image timestamp with the onboard clock. They were also apprised that the METAR information could be as much as an hour old and to check the issue time. Due to the lack of an ocular eye tracker, empirical data for how the subject pilots used the timestamp information was not available. Insight into how they used the timestamp information was only available through the interview process.

During the post-flight interview, some of the pilots indicated that they were aware that the NEXRAD images were up to 14 minutes old, and either noted the amount of latency or just assumed a fixed delay. Others stated that 14 minutes old <u>is</u> real-time, compared to preflight weather charts that could be over an hour old.

In response to the question "How did you determine the age of the weather information?" in the Weather Display Questionnaire (Appendix N), 14 pilots responded that they used the time-stamp information to determine the age of the weather information (NEXRAD and METAR). Six (6) pilots responded that they just assumed a fixed delay of information—most likely due to the increased cognitive load required to mentally subtract the current time from the time-stamp. Three pilots did not determine the age of the weather information.

6.3.3.4 NEXRAD Image Cell Size Effects on Richmond Decision

In the analysis of the Richmond decision, the data shows that a greater number of good versus poor decisions were made with the introduction of large NEXRAD image cells. One explanation for this finding converges on the stimulus area effect. The stimulus area effect states that the larger the visual area of a warning stimulus, the greater importance it holds.

The implementation of automobile brake lights in the rear window decreased by half the rear-end accident rate (Malone, 1986). The addition of a greater amount of "warning" area contributed to the greater importance of the warning and caused drivers to brake earlier.

This extensively documented stimulus area effect is a possible explanation for the experiment results. With the larger cell sizes, fewer pilots flew near the storms. The "stimulus area" effect states that the bigger the stimulus, the more important it becomes. So a bigger red cell would be more ominous and a pilot would keep farther away. This larger stimulus area also created a greater uncertainty in the exact location of the hazardous weather, which led the pilots to select a track farther away from the depicted weather. A comparison of NEXRAD image cell sizes is illustrated in Figure 6-16.

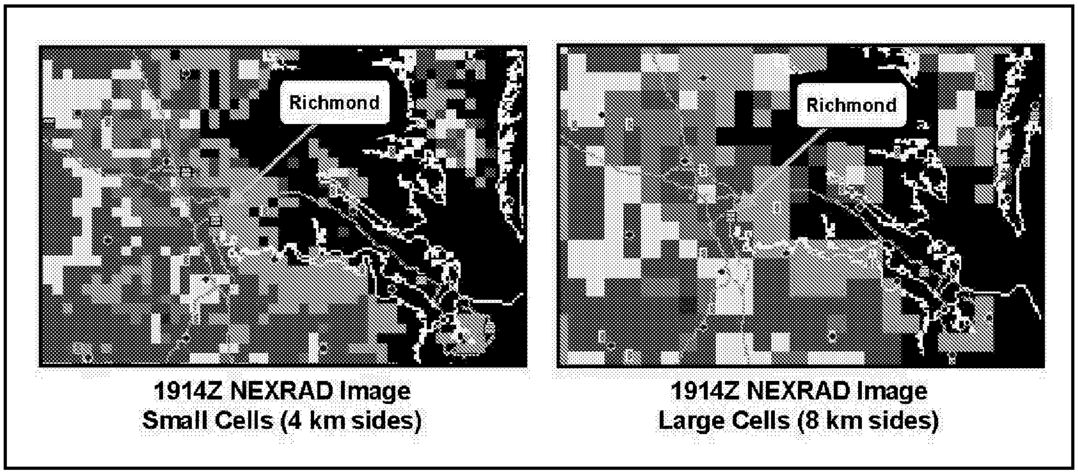


Figure 6-16. Comparison of Small versus Large NEXRAD Cells

An unlikely connection may be made between NEXRAD display cell size and U.K. traffic research. In the U.K., it was found that drivers disliked new, much smaller traffic islands (roundabouts) at multiple road junctions. Drivers were unsure of the optimal track to take across the (effectively widened) junction. Accidents, however, were significantly reduced. The drivers' uncertainty, the researchers concluded, created greater attention to clearances, tracks through the junction and the behavior of other drivers. It is instructive to note the way in which users' subjective opinions and objective performance dissociate in this case (as in many cases), and how uncertainty *can* lead to improved decision making.

The relevance of this to the present experiment flows from the analogy between weather display cell size (i.e. resolution) and traffic island size, and the role of uncertainty. There is reason to believe that lower resolution weather images must, in their nature, increase uncertainty over the "actual" location of weather boundaries and edges. If so, perhaps as in the road research case, this uncertainty translates into more data seeking and cognitive processing in this case of weather and related aspects of the flight. The lower resolution may have accomplished the goal of data-linked strategic weather avoidance, as the system was initially envisioned.

6.3.4 Retrospective Pilot Comments

In the course of the post-mission interview, the pilots were asked what their actions would have been if the weather display was not available. This was an open-ended question and purposefully placed at the end to allow the pilots to become familiar with the tone of the interview and become comfortable with the intended level of introspection. There were two parts to the questioning, the Richmond leg and the Wallops Island leg.

The pilots responded to the question, “What would you have done if you did not have the weather display...

...at Richmond?”

> “I would’ve taken longer to break off at Richmond.”
>
> “Would‘ve diverted later into Richmond, and been stuck on ground.”
>
> “Would’ve talked to ATC more and ask positional questions.”
>
> “Would rely on ATC more, but without this display, probably wouldn’t have done much different.”
>
> “Would have used Flight Watch more and probably not even attempted Richmond.”
>
> “...not even tried approach into Richmond. Would have diverted sooner.”
>
> “Would have made same decisions, but this display would be great back-up.”
>
> “Would not have even gone to Richmond.”
>
> “Would have heavily taxed ATC to help pick way through weather.”
>
> “Probably would have just returned to Newport News. ATC radar not that accurate, so would not have attempted flight with thunderstorms in the area.”
>
> “Would have treated Richmond the same.”
>
> “Would have diverted to Wallops quicker. The display led me into Richmond. Value of display increases with leg lengths. Just too quick on short flights to look at trends.”
>
> “Would not have attempted approach into Richmond and would have talked to ATC more and further out.”
>
> “Would have flown in worse conditions without knowing, and would have had to rely more on Flight Service and ATC.”
>
> “Without the display, would have gone direct to Wallops from Newport News.”

...at Wallops Island?"

> "I would've asked for more help from ATC and Flight Watch."
>
> "Would've pushed it less into Wallops."
>
> "Without display, would have asked for more vectors and let ATC help in routing."
>
> "Probably would have flown right into storms over bay. Without display, could not have made turns as soon ... but at Wallops, would have flown into storm before asking for help. Used display to slow down before penetrating weather."
>
> "Would have been more likely to go farther south around Wallops storm and avoid known weather by greater margin."
>
> "Would have been a little more nervous going around Wallops weather."
>
> "Would've probably penetrated Wallops storm, turned around, and ask for hold. Using the weather display allowed me to circumnavigate the storms—without it the flight would have been longer and at the mercy of ATC."
>
> "...more dependence on ATC and Flight Watch for vectors around weather."
>
> "Without display, would have flown into the storms at Wallops."

In review of these comments, the majority of the pilots were greatly influenced by the weather display, and without the display most would have avoided the hazardous weather by a greater margin. Although these are just subjective comments, the data from the Wallops decision supports the comments.

The following two questions were asked on the Immediate Reactions Questionnaire, and support the pilot comments as to the reliance on the weather display.

<u>Question 3</u>. This question explored the pilots' perception of the degree to which they felt they were able to interpret the weather information display and the extent to which the display influenced their decision making.

> **I attribute much of my decision making to my interpretation of the Weather Display.**
> *(mean score of 4.54, standard deviation of 0.88)*

The mean score of 4.54 (a 5 being "totally agree"), combined with a small deviation (SD=0.88), indicates that the weather information display played a large part in the decision process during the flight.

Question 8. When asked about the validity of the weather information display, the reactions consistently held the display validity in high regard.

> **The degree of validity of the weather data appearing on-screen was a factor I felt I held in mind as I flew.**
> *(mean score of 4.58, standard deviation of 0.72)*

7 Conclusions

The objective of this follow-on experiment was to investigate the effects of ownship position information and NEXRAD image cell size resolution on pilot decision making. The experiment was purposefully designed to determine how a pilot could misuse the weather information display and to identify the areas that need further design or regulatory consideration.

The first hypothesis stated that: the introduction of ownship position information on the weather display will improve navigation decisions.

For either the Richmond or Wallops decisions, the introduction of ownship position information did not improve decisions. Therefore, the hypothesis is rejected. It was noted that, 1) the addition of ownship to the display did not have a detrimental effect on the decision-making ability of the pilot, 2) that the addition of ownship symbology reduced the workload associated with use of the weather information display.

The second hypothesis stated that: NEXRAD image resolution will impact navigation decisions.

For the Richmond decision, the reduction of NEXRAD image cell size resolution had a positive, although not statistically significant, effect on decision making. For the Wallops decision, the reduction of NEXRAD image cell size resolution did not have an effect on decision making.

It is anticipated that with sufficient training, careful use of the cockpit weather display, and prudent pilot procedures in instrument flight conditions, the emerging cockpit weather display products will provide substantial improvements to the safety of flight. It is important to note that this experiment, like the one that preceded it, was designed specifically to identify potential hazards in the use of cockpit weather displays.

Every aspect of the design of this experiment was undertaken with this objective in mind, including subject pilot selection, subject pilot training, and the mission scenario. Pilots were selected so as to provide as wide and representative a range as possible of the experience, knowledge of weather and risk aversion of the population of general aviation pilots who might use these emerging cockpit weather display products. The training provided the subject pilots was tailored so as to provide them with sufficient familiarity with the experimental equipment to successfully accomplish the mission scenario, while at the same time creating a reasonable probability that within the population of subject pilots selected, potential hazards in the use of the equipment might become apparent. Likewise, the mission scenario incorporated in the experiment was selected to ensure that it could be accomplished by the average pilot with careful attention by the subject pilot to the instrument flight procedures, but offered sufficient opportunity for observation of human error in the use of the prototype cockpit weather display where such hazards might exist.

The significant issues addressed in the experiment are summarized below.

7.1 Weather Information Display Interpretation Issues

The pilots' use of the weather display did not demonstrably improve the decision outcomes, as defined in this study. A noticeable improvement in decisions on the Richmond leg was only seen when large NEXRAD cells were implemented on the weather display. For the Wallops Island decision, the use of the cockpit weather display increased the number of poor decisions independent of the NEXRAD image cell size.

Causes for these findings include difficulty in position determination, short leg duration, NEXRAD image cell resolution and workload issues.

7.1.1 Position Determination

The implementation of ownship symbology on the display did not have an outwardly noticeable effect on the frequency of good versus poor decisions. However, the introduction of ownship had a markedly positive effect on reducing the perceived workload. This was more than likely a result of the reduced cognitive workload required to determine the aircraft position in relation to the hazardous convective activity shown on the weather display.

In the previous weather display experiment, the pilots were presented with a weather display that did not include the ownship symbology. During the interview process, the pilots' primary complaint was the lack of ownship symbology. With the addition of ownship symbology in this follow-on experiment, the pilots welcomed the ownship symbology and felt comfortable with its use. The experiment did not show any drawbacks to the implementation of ownship symbology on the display.

7.1.2 NEXRAD Image Cell Resolution

The introduction of larger NEXRAD image cells had a positive, although not statistically significant, effect on decision making for the Richmond leg of the scenario.

The introduction of larger NEXRAD image cells did not have an effect on decision making for the Wallops Island decision. The difference may be due to procedural issues rather than perceptual issues. There were many cases en-route to Wallops Island where the pilot made the decision to change course to avoid the storms with enough time to avoid them, but delayed the turn and drifted too close to the storm. The data suggests that the higher fidelity of the NEXRAD image caused more workload as pilots tried to cut corners more closely to circumnavigate the weather hazards, and then had to adjust course due to the latency of the image.

The nature of the Richmond decision was more procedure-based, i.e. in an instrument approach, whereas specific decisions are made at specific points. The display using larger NEXRAD image cells contributed in a positive way to those decisions.

The nature of the Wallops Island decision was not so much a procedure-based decision. Even though the AIM specifies a 20-mile separation from convective weather, actual operations do not treat this buffer as an absolute. There are just too many variables with convective weather activity to make a strictly procedure-based decision. Some of those variables are, thunderstorm lifecycle stage, wind direction, altitude, aircraft capabilities and passenger comfort.

7.1.3 Workload Reduction

The number of pilots that felt the weather display reduced their workload increased as ownship symbology was implemented, and increased further when larger NEXRAD image cells were implemented.

In the previous weather display experiment (without ownship symbology), a large number of pilots felt that the weather display increased their workload. This is most likely attributable to difficulty in determining their position on the display and the relationship of their aircraft to hazardous weather. The inclusion of ownship symbology decreased perceived—as well as observed—workload, which allowed more time for the pilots to attend to other flight duties.

7.2 Weather Source Information Issues

The display of NEXRAD mosaic images substantially increased the pilots' awareness of the general location of convective weather in their vicinity. The attractive visual display of these images, however, caused some pilots to depend too heavily on the weather information display for their information regarding hazardous convective weather. As a result, they did not feel it was necessary to obtain additional and corroborating information from other available sources. This indicates a need for pilot training in the appropriate use of a cockpit weather display as an aid to collaborative decision making with appropriate weather service providers (Flight Service/Flight Watch).

7.3 METAR Issues

Three METAR issues were observed during the experiment, including, latency, coding and graphical METAR use.

7.3.1 METAR Coding

The METAR textual information was presented in typical ICAO teletype codes, and the experiment found that the interpretation of the codes in a high workload environment is prone to errors. In this experiment, many of the pilots had difficulty interpreting the codes. Many errors were observed and excessive fixation times were observed when the pilots attempted to decode the METAR information.

It was noted in this experiment, and in the previous experiment that the airline pilots who participated did not have as much difficulty in interpreting the reports as the general aviation pilots did. This was undoubtedly due to the increased use of coded reports by airline pilots. Many of the pilots commented that the METARs would be more useful if they were displayed with their English translation, much as DUATS provides the English translation.

7.3.2 METAR Latency

In many cases the METAR report timestamps indicated that they were up to an hour old, even if the conditions were unchanged and the data was still current. This apparent latency caused many of the pilots to disregard the information in favor of ATC or pilot reports. Some of the pilots even kept the METAR display page selected during the approach into Richmond while waiting for an update that reflected the current conditions. The perceived latency of METAR data caused many pilots to disregard the information.

7.3.3 Graphical METARs

The pilots did not use the graphical METARs to a great extent, either because of their limited information or inability to present timely information. Many of the pilots reported that the information contained in the graphical METAR symbology was not complete and required that the textual METARs also be consulted. The graphical METARs were intended to present a general synopsis of surface conditions, but because of their latency and limited information, they fall short of their intended purpose.

7.4 Judging Proximity and Movement of Hazardous Weather

The age of the NEXRAD images on the weather display led to noticeable errors committed by many of the pilots in the course of determining the proximity and rate of movement of the hazardous convective weather.

7.5 Stimulus Area Effect

Analysis of the Richmond decision indicated that better decisions were made with the introduction of larger NEXRAD image cells. An explanation for this finding converges on the stimulus area effect. The stimulus area effect states that the larger the visual area of a warning stimulus, the greater importance it holds.

The larger stimulus area—presented by the larger NEXRAD image cell size—created a greater uncertainty in the exact location of the hazardous weather, which led the pilots to select a track farther away from the depicted weather.

8 Recommendations

8.1 AIM and Advisory Circular Recommendations

The following passage is repeated from the previous weather information display experiment. The findings of the investigation of ownship and NEXRAD image cell size issues undertaken in this experiment do not change the recommendations of the previous experiment for the AIM and Advisory Circulars.

> The depiction of weather information in the cockpit, including NEXRAD and METAR products, will be delayed due to the time required for the collection and distribution of vast amounts of weather information available.
>
> The time required producing the NEXRAD mosaic image on the display includes a six-minute cycle for the individual NEXRAD radars to scan and observe the data. An additional interval is required for the automated processing of the NEXRAD data necessary to merge all the individual NEXRAD radar images. A further delay is introduced into all the FISDL products by a broadcast transmission cycle delay. The communication architecture of the FISDL broadcast will determine the magnitude of that delay for any specific FISDL product.
>
> It is essential that the pilot become fully proficient in determining and maintaining a comprehensive awareness of the age of each of the FISDL display weather information products. Thus, the pilot would be able to effectively and accurately integrate this information (NEXRAD image time stamps, METAR text time data, etc.) with the information gathered from the other sources.
>
> Because of the inherent production delays, the weather information provided by the FISDL display should not be used for avoiding hazardous weather in a tactical manner, such as finding one's way through a line of thunderstorms. In the time that it takes for a NEXRAD image to be produced and transmitted, a storm cell could have moved a significant distance. Storm cells can also sometimes develop very quickly to hazardous levels within the update time of NEXRAD images. Therefore, NEXRAD images should be used in the more strategic sense to avoid areas of convective activity by a wide margin.
>
> Weather information provided by the FISDL display in text form (METAR, TAF, etc.) could be up to an hour old, and should only be used for gathering an understanding of weather conditions over a large geographical area. Other independent sources of information (ATIS, ASOS, FSS, Flight Watch, ATC) must also be used in conjunction with the FISDL display to assure a complete understanding of the weather condition.

Pilots should be fully aware that the FISDL display does not contain sufficient information to support navigation, and it should not be used as a replacement for any aspect of approved navigation procedures and equipment. While the FISDL display can increase the pilot's situational awareness, particularly with respect to weather conditions, the display cannot be successfully used to determine headings, direction, or distances with the accuracies and reliability that are required for navigation.

8.2 Recommendations for Weather Display Manufacturers

Additional recommendations are provided for the consideration of the cockpit weather display system manufacturers and certification authorities.

8.2.1 Provide Ownship Position

The inclusion of ownship position symbology on a weather information display had a marked improvement in lowering workload and did not have a detrimental effect on decision making. With the proliferation of moving map displays in modern cockpits, pilots are becoming accustomed to seeing ownship symbology that they use to determine their position on the map display.

The benefits of ownship symbology appear to outweigh the concerns associated with the display of real-time position information and old information (7-minute-old NEXRAD image) on the same display.

8.2.2 Provide Direction and Rate of Weather Motion

Many of the pilots in this experiment had difficulty determining the movement of the convective weather and asked for either a "looping" capability (playback of preceding images) or vector arrows showing speed and direction (similar to the National Weather Service radar depiction charts). "Looping," however, may cause an increase in workload while a pilot attempts to predict the future track of a storm from past data. Further investigations need to be undertaken to determine the effects of looping on pilot performance and workload.

8.2.3 Provide for Intuitive Distance Determination

Many of the pilots in this experiment made poor estimations of the distance between the aircraft and the convective weather. This misperception was a significant contributor to the inability of many of the pilots to effectively use the weather information display. This indicates that there is a need to provide an intuitive method to determine range information on a weather display.

8.2.4 Provide for Intuitive NEXRAD Image Age

There is a concern that the display of stale weather information in the cockpit may cause interpretation difficulties and lead to use of stale weather information. This rationale was due to the difficulty and cognitive processes required in subtracting the current time from the NEXRAD image timestamp and predicting the weather movement. The problem will only be exacerbated should manufacturers choose to offer NEXRAD images on a "pay-for-view" basis with an even greater interval, for some users, between images. A more intuitive method needs to be implemented that alleviates the mental calculations necessary in correctly determining the age of NEXRAD/METAR data.

8.2.5 Provide METAR Code Translation

In this experiment, the pilots' commented that the METAR reports were difficult to interpret, took too much time and were not of much use because they were old. Currently, the textual METAR information is presented in typical teletype codes and although this is the information that will be broadcast at no charge to the user, the interpretation of those codes in a high workload environment causes many errors. In this experiment, many errors were observed and excessive time was devoted to decoding the METAR information. Similar findings were found in the previous weather display experiment. This indicates a necessity for METAR code translation.

Additionally, what pilots need prior to commencing an approach is the current official observation (via data-link) for the airport (METAR or SPECI). Rapidly changing controlling elements such as RVR are best provided (in the near term) directly from the TRACON or tower controller who has direct readouts of the current conditions. In the future, consideration should be given to the provision (via data link) of direct readouts of current conditions, such as ASOS, to the pilot.

9 Recommendations for Further Research

Proposed research topics fall into four broad categories: evaluation of cell movement depictions, integration and display of new weather products, optimum NEXRAD image cell size and development of a training system for aircraft cockpit weather information management.

9.1 Conduct Evaluations of Cell Movement Depictions

Many of the weather display issues are centered around the lack of NEXRAD image cell movement depiction. Many pilot comments confirmed this experimental finding and suggested two methods to depict cell movement, including looping and vector arrow icons.

A follow-on experiment would investigate the effects on pilot performance of adding alternative concepts for depicting movement of hazardous convective weather.

9.2 Develop Concepts for Display of Predictive Weather Products

Comments of the pilots in this experiment identified concern about the lack of lightning data, and lack of accurate information about the movement of storms. The combination of NEXRAD data and lightning data already exists in the National Convective Weather Forecast (NCWF) product created by the Aviation Digital Data Service. This image contains precipitation data that is filtered, processed and combined with lightning data to provide a near real-time depiction of the predicted movement of thunderstorms.

An experiment could be developed to investigate the effects on pilot performance of this combined forecast, and techniques for implementation could be developed.

9.3 Determine Optimum NEXRAD Image Cell Resolution

This experiment observed that the increase of NEXRAD image cell size from 4km to 8km had a positive effect on the decision making ability of the pilot, but increasing the size of NEXRAD image data even further can not guarantee further improvement in pilot decision making. A point of diminishing returns may be reached if cell size is further increased. If the NEXRAD image cells become too large, a pilot would not trust the weather depiction when the cockpit display does not correlate with the view out the window. An experiment could be developed to explore the relationship of increasing NEXRAD image cell size with decision making and to determine the point of diminishing returns.

9.4 Develop Training for Weather Information Displays

A training curriculum should be developed to support the implementation and proper use of weather displays in the cockpit. The curriculum needs to include appropriate manuals and modern interactive multi-media training techniques that would highlight common mistakes and improper usage of the weather display information, and develop appropriate operational procedures for the use of weather display systems.

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Appendix A. Flight Information Services Description

System Overview

The Flight Information Services (FIS) Data Link Display will provide pilots with the display of certain aeronautical weather and flight operational information. This information will be displayed using both text and graphic formats. Service providers will provide a broadcast FIS system using VHF data link. This system will provide coverage throughout the Continental United States from 5000 feet AGL to 17,500 feet MSL, except in those areas where this is unfeasible due to mountainous terrain. Aircraft equipment will include at least an appropriate receiver and display unit. This system will provide, free of charge, the following Basic Products:

- Aviation Routine Weather Reports (METARs),
- Special Aviation Reports (SPECIs),
- Terminal Area Forecasts (TAFs), and their amendments,
- Significant Meteorological Information (SIGMETs),
- Convective SIGMETs,
- Airman's Meteorological Information (AIRMETs),
- Pilot Reports (both urgent and routine) (PIREPs), and
- Severe Weather Forecast Alerts (AWWs) issued by the FAA or NWS.

Additional products, called Value Added Products, will be available from the FIS providers on a paid subscription basis. Most of the value-added products are expected to be graphical in nature and may include but are not limited to:

- National, Regional and Local NEXRAD mosaics
- Icing forecasts
- Turbulence forecasts
- Graphical METARs
- Winds
- Cloud Tops

The FIS products will be required to conform to FAA/NWS standards. Specifically, the FIS weather information must meet the following criteria:

1. The products are either FAA/NWS accepted aviation weather products, or based on FAA/NWS accepted weather products.
2. In the case of a product which is the result of the application of a process which alters the form, function or content of the base FAA/NWS accepted weather product(s), that process must be:
   a) An established, conventional aviation weather process used in standard U.S. aviation weather information systems, and,
   b) Managed by a qualified aviation meteorologist.

3. National Airspace System (NAS) status products (such as NOTAMs, Special Use Airspace Status, etc.) will include verbatim transmissions of FAA products. If graphics are used to describe NAS status, the basic text product will be readily available to the pilot for reference.

Operations

To receive FIS broadcasts, an aircraft must have a data link radio and appropriate display. Both of the initial FIS service providers were awarded frequencies between 136.425 MHz and 136.500 MHz for broadcast of FIS weather products. The aircraft's data link radio must be tuned to one of the two frequencies to receive weather information from the appropriate provider.

Weather information will be broadcast from each ground station at established intervals. Upon full deployment, each FIS provider will provide coverage throughout the National Airspace System (NAS).

Appendix B. Aeronautical Information Manual FISDL Guidance

Issue: 2/24/00

7-1-10. FLIGHT INFORMATION SERVICES DATA LINK (FISDL)

a. FISDL. Aeronautical weather and operational information may be displayed in the cockpit through the use of FISDL. FISDL systems are comprised of two basic types: broadcast systems and two-way systems. Broadcast system components include a terrestrial or pace-based transmitter, an aircraft receiver, and a cockpit display device. Two-way systems utilize transmitter/receivers at both the terrestrial or space-based site and the aircraft.

1. Broadcast FISDL allows the pilot to passively collect weather and operational data and to call up that data for review at the appropriate time. In addition to text weather products, such as METAR's and TAF's, graphical weather products, such as radar composite/mosaic images may be provided to the cockpit. Two-way FISDL services permit the pilot to make specific weather and operational information requests for cockpit display.

2. FISDL services are available from three types of service providers.

(a) Through vendors operating under a service agreement with the FAA using broadcast data link on VHF aeronautical spectrum (products and services are defined under subparagraph c).

(b) Through vendors operating under customer contract on aeronautical spectrum.

(c) Through vendors operating under customer contract on other than aeronautical spectrum.

3. FISDL is a method of disseminating aeronautical weather and operational data which augments pilot voice communication with Flight Service Stations (FSS's), other Air Traffic Control (ATC) facilities or Airline Operations Control Centers (AOCC's). FISDL does not replace pilot and controller/flight service specialist/aircraft dispatcher voice communication for critical weather or operational information interpretation. FISDL, however, can provide the background information that can abbreviate and greatly improve the usefulness of such communications. As such, FISDL serves to enhance pilot situational awareness and improve safety.

b. Operational Use of FISDL. Regardless of the type of FISDL system being used, either under FAA service agreement or by an independent provider, several factors must be considered when using FISDL.

1. Before using FISDL in flight operations, pilots and other flight crew members should become completely familiar with the operation of the FISDL system to be used, airborne equipment to be used, including system architecture, airborne system components, service volume and other limitations of the particular system, modes of operation and the indications of various system failures. Users should also be familiar with the content and format of the services available from the FISDL provider(s). Sources of information that may provide this guidance include manufacturer's manuals, training programs and reference guides.

2. FISDL does not serve as the sole source of aeronautical weather and operational information. ATC, FSS, and, if applicable, AOCC VHF/HF voice is the basic method of communicating aeronautical weather, special use airspace, NOTAM and other operational information to aircraft in flight. FISDL augments ATC/FSS/AOCC services, and, in some applications, offers the advantage of graphical data. By using FISDL for orientation, the usefulness of any information received from conventional voice sources may be greatly enhanced. FISDL may alert the pilot to specific areas of concern, which will more accurately focus requests made to FSS or AOCC for inflight briefings or queries made to ATC.

3. The aeronautical environment is constantly changing; often these changes occur quickly, and without warning. It is important that critical decisions be based on the most timely and appropriate data available. Consequently, when differences exist between FISDL and information obtained by voice communication with ATC, FSS, and/or AOCC (if applicable), pilots are cautioned to use the most recent data from the most authoritative source.

4. FISDL products, such as ground-based radar precipitation maps, are not appropriate for use in tactical severe weather avoidance, such as negotiating a path through a weather hazard area (an area where a pilot cannot reliably divert around hazardous weather, such as a broken line of thunderstorms). FISDL supports strategic weather decision making such as route selection to avoid a weather hazard area in its entirety. The misuse of information beyond its applicability may place the pilot and his/her aircraft in great jeopardy. In addition, FISDL should never be used in lieu of an individual pre-flight weather and flight planning briefing.

5. FISDL supports better pilot decision making by increasing situational awareness. The best decision making is based on using information from a variety of sources. In addition to FISDL, pilots should take advantage of other weather/NAS status sources, including, but not limited to, Flight Service Stations, Flight Watch, other air traffic control facilities, airline operation control centers, pilot reports, and their own personal observations.

c. FAA FISDL. The FAA's FISDL system provides flight crews of properly equipped aircraft with a cockpit display of certain aeronautical weather and flight operational information. This information is displayed using both text and graphic format. This system is scheduled for initial operational capability (IOC) in the first quarter of calendar year 2000. The system is operated by vendors under a service agreement with the FAA, using broadcast data link on aeronautical spectrum on four 25 kHz spaced frequencies from 136.425 through 136.500 MHz. FISDL is designed to provide coverage throughout the continental U.S. from 5,000 feet AGL to 17,500 feet MSL, except in those areas where this is unfeasible due to mountainous terrain. Aircraft operating near transmitter sites will receive useable FISDL signals at altitudes lower than 5000 feet AGL, including on the surface in some locations, depending on transmitter/aircraft line of sight geometry. Aircraft operating above 17,500 MSL may also receive useable FISDL signals under certain circumstances.

1. FAA FISDL provides, free of charge, the following basic products:

(a) Aviation Routine Weather Reports (METAR's).
(b) Special Aviation Reports (SPECI's).
(c) Terminal Area Forecasts (TAF's), and their amendments.
(d) Significant Meteorological Information (SIGMET's).
(e) Convective SIGMET's.
(f) Airman's Meteorological Information (AIRMET's).
(g) Pilot Reports (both urgent and routine) (PIREP's); and,
(h) Severe Weather Forecast Alerts (AWW's) issued by the FAA or NWS.

2. The format and coding of these products are described in Advisory Circular AC-00-45, Aviation Weather Services, and paragraph 7-1-28. Key to Aviation Routine Weather Report (METAR) and Aerodrome Forecasts (TAF).

3. Additional products, called Value-Added Products, are available from the vendors on a paid subscription basis. Details concerning the content, format, symbology and cost of these products may be obtained from the following vendors:

(a) BENDIX/KING WxSIGHT
Allied Signal, Inc.
One Technology Center
23500 West 105th Street
Olathe, KS 66061
(913) 712-2613
www.bendixking.com

(b) ARNAV Systems, Inc.
16923 Meridian East
P. O. Box 73730
Puyallup, WA 98373
(253) 848-6060
www.arnav.com

d. Non-FAA FISDL Systems. In addition to FAA FISDL, several commercial vendors provide customers with FISDL on both the aeronautical spectrum and other frequencies using a variety of data link protocols. In some cases, the vendors provide only the communications system which carries customer messages, such as the Aircraft Communications Addressing and Reporting System (ACARS) used by many air carrier and other operators.

1. Operators using non-FAA FISDL for inflight weather and operational information should ensure that the products used conform to the FAA/NWS standards. Specifically, aviation weather information should meet the following criteria:

(a) The products should be either FAA/NWS accepted aviation weather reports or products, or based on FAA/NWS accepted aviation weather reports or products. If products are used which do not meet this criteria, they should be so identified. The operator must determine the applicability of such products to flight operations.

(b) In the case of a weather product which is the result of the application of a process which alters the form, function or content of the base FAA/NWS accepted weather product(s), that process, and any limitations to the application of the resultant product should be described in the vendor's user guidance material.

2. An example would be a NEXRAD radar composite/mosaic map, which has been modified by changing the scaling resolution. The methodology of assigning reflectivity values to the resultant image components should be described in the vendor's guidance material to ensure that the user can accurately interpret the displayed data.

3. To ensure airman compliance with Federal Aviation Regulations, National Airspace System (NAS) status products (such as NOTAM's, Special Use Airspace Status, etc.) and other government flight information should include verbatim transmissions of FAA products. If these products are modified, the modification process, and any limitations of the resultant product should be described in the vendor's user guidance.

Appendix C. The Risk Assessment Task (RAT)

(Index of Risk Taking Predilection)

In the previous AWIN experiment, pilots were allocated to experimental groups in part based on their scores on a risk assessment task (RAT). This appendix briefly describes the history, pedigree, and rationale for employing the risk assessment task.

Rationale

Behaviors such as the dangerous misuse of weather displays need only take place once every few hundred hours of flight to have a significant adverse impact on flight safety and the incident/accident statistics. However, such a behavior is unlikely to be spotted in an hour or two of flight simulation, even if other realistic features of the operational environment are faithfully reproduced. Purely random sampling of the pilot population, therefore, may not expose potentially unsafe behavior.

The challenge, therefore, has been to utilize expert knowledge of flying, accident causation and aviation psychology to recreate the kind of environment and circumstances that could be expected to increase the probability of detecting misuse of the new weather display technologies. The experiment is not designed to calculate the prevalence of these "misuse behaviors", but rather to evaluate and assess whether and how such misuse could occur, thus providing guidance for pilots and display manufacturers.

With this in mind the team elected to proceed with a stratified random sample of pilots taken from populations that might be identified as higher risk and lower risk pilots. If weather display misuse accidents are going to occur, then pilots low in weather knowledge sophistication, high in risk acceptance, and motivated to continue a flight seem likely to be over-represented in the incident/accident statistics. Therefore, the subjects were pre-screened for weather knowledge and risk aversion. The purpose of the RAT task is to increase the probability of including subject pilots who might exhibit behaviors that would otherwise only emerge in the operational environment. The RAT task is not advertised as a definitive biographical variable or as a definitive measure or predictor of pilots' decision-making prowess. The RAT does, however, have a well-documented history as a psychometric instrument, and, indeed, in a range of applied psychological studies including aviation, as outlined below.

Given the risk construct used in the task, the research evidence to date, and the absence of alternative screening methods for our purpose, use of the RAT is a rational and low-risk option. The subject experiment is not designed to address questions relating to the relationship between risk scores and decisions made in simulated flight. The experiment seeks to reproduce and characterize misuses of the weather display in an operational environment. The absence of significant relationships observed between risk, as measured by the RAT, and other elements in the experiment, will not adversely impact the experimental outcome.

Origins of the RAT

The RAT task is one sub-task from a version of a multiple task computerized battery of cognitive tasks that was explicitly designed to evaluate aviators (Banich, Stokes & Elledge, 1989). The original research began with an information-processing task analysis of aviation and initially identified six primary areas of aviator cognitive proficiency that the battery should cover: working memory, attention (divided and focussed), spatial ability, logical reasoning, perceptual-motor abilities, and processing flexibility (or prioritizing). Risk taking predilection or aversion, that is, risk judgment, was subsequently added, as this was clearly a source of pilot variance not captured under the original six headings.

Task sensitivity testing, reporting, and reliability

All of the subtasks were tested against each other empirically in a series of discriminatory analyses (Stokes, et al., 1991a). The sensitivity, specificity and positive predictive value for each subtask in all seven areas of cognitive proficiency were compared, and thus an objective basis for comparison in standard epidemiological terms was determined. Stokes (1999) showed that the tests in the battery are reliable, do not suffer from undue practice effects, and factor load on the appropriate constructs. The risk task is particularly strong in these respects, exhibiting no practice effect and, whereas certain tasks (e.g. maze tracing, hidden figure recognition and spatial memory) all factor load onto one construct (e.g. spatial ability), only the RAT factor loaded on the risk construct.

Applications of the RAT

The original and updated versions of the battery have been utilized extensively in a range of applied studies. (Stokes et al., 1991b, 1994, 1995, 1997). Several studies have resulted in findings that involve the risk construct.

For example, risk assessment appears to be a specific ability or cognitive dimension that can be directly impaired by neurological deficit. In a clinical study, (Stokes et. al., 1991a) showed that pilots' evidenced less propensity for risk taking than members of a group of subjects did with known neuropsychological diagnoses (Stokes, 1991a, p.785). Moreover, the range of conditions in these diagnoses was broad, including as it did cerebro-vascular conditions, trauma, neurodegenerative disease and sequelae of alcoholism.

An effect often observed and commented on in the engineering psychology literature (see, for example, Wickens, 1992), is the apparent conservatism associated with age. The clinical study also scrutinized the extent to which older subjects become more risk averse. Generally speaking, risk taking did indeed decrease with age in pilots, while it increased with age in the clinical group. The mechanism underlying the latter, clinical finding is not well understood, but the RAT findings for pilots are consistent with the wider literature on risk and risk aversion, increasing confidence in the utility of the measure.

The RAT task has also been used in a series of double-blind clinical studies of the cognitive effects of aspartame (in the artificial sweetener 'NutraSweet') and of alcohol upon pilots. Aspartame was not found to affect cognition in either acute or chronic dosing, but alcohol, as anticipated, did. However, a number of new effects of alcohol were identified, including an increased variability in risk taking. Mean RAT scores were the same in the alcohol and non-alcohol conditions, but this conceals a significantly greater variance around the mean in the alcohol condition. Scrutiny of the data showed that this was not a group level effect, but indeed did arise from greater capriciousness in trial to trial responses of individuals as they worked through the RAT. Reproduced in the operational environment such swings from conservative, risk averse responding to high risk gambling could be expected to have a negative impact on safety.

The RAT and Flight Training

In a 1995 study, the effect upon flight training success of a number of information processing variables, including risk predilection, was examined in the context of university flight training (Stokes & Bohan, 1995b). This study also evaluated the predictive utility of anxiety scores and academic grades. A major influence upon the outcomes of such studies is the nature of the criterion of success. In the 1995 study, several criteria were examined, including a checkride score, hours to solo, landings to solo, and ground school grade. The first three of these are closely associated with psychomotor skill, as the criteria involve maneuvering flight, rather than primarily cognitive skills such as those involved in cross-country flight management. The criteria used are reflected in the results - dual-task tracking tasks best predict success where maneuvering flight is the criterion. An unanticipated finding was that the risk task was predictive of ground school performance (which presumably includes a more "cerebral" element and little psychomotor control). The effect, however, was weak. In this study, important additional criteria were examined. Results were compiled for checkride "passers" and "failers", as one might expect, but also for individuals who had not been permitted to take the checkride.

The significance of this may not be immediately obvious. It is necessary to know that instructors were required to "sign off" a student as being ready for the checkride. Moreover, the sign off required that the student fly solo prior to the checkride. Understandably, instructors do not wish to be the agent of someone's demise, and will not permit those at risk to fly solo. Therefore, they are dropped from the flightcheck pool.

Given this, it can be argued that the real dichotomy is not between checkride "passers" and "failers." A bigger performance gap presumably exists between those students signed off and those not signed off for the checkride, than between persons passing and failing the ride (all of whom had been adjudged fit to fly unaccompanied). In this light, the RAT scores were revisited. In fact, the highest risk scores were seen among the "not recommended" group (significantly higher than "failers"). "Passers" and "failers" did not differ significantly on the risk dimension. A compelling explanation for these results (and one supported by instructor comment) is that during flight training instructors had observed, among other defects such as poor psychomotor control, unsafe ("risky") behaviors in certain students and had declined to sign them off for solo or for the checkride. Although unknown to the instructors, these students indeed did have elevated risk task scores in the battery administered three months earlier, before the student had commenced flight training at all.

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Appendix D. Weather Knowledge Questionnaire and Key

The weather knowledge test presented here is the key used to grade the test. All graded answers are shown in gray highlight. All other questions were not graded, as they were not relevant to weather knowledge and were just used as distracters.

General Aviation Questionnaire

Thank you for participating in our Research Triangle Institute/NASA/FAA evaluation of advanced aviation technologies. We would like to learn a little more about your aviation knowledge before you participate in our study. Please take a couple of minutes to answer a few questions. Your answers are strictly confidential and will not be released.

Name: ________________________________ Date: ____________

Phone number: __________________ E-Mail: _________________________

1. How many years have you been a pilot? ______________________________

2. What is your level of pilot certification (circle one)?

   Recreational   Private   Commercial   Airline Transport

3. What is your approximate number of total flight hours? ______________

4. Are you an instrument rated pilot? ___________________________________

   If so, are you current to fly instruments? __________________________

5. What does a narrow temperature/dewpoint spread mean?

   Possible Fog____

6. How many feet are there in a statute mile? ____________________________

7. What does RVR stand for, and what does it mean?

   Runway Visual Range, Visibility down Specific Runway__________

8. What COMM frequency can you use to contact Flight Watch? 122.2, 122.0____

9. Briefly, describe class C and class G airspace.

   Class C: ____

   Class G: ____

10. How much does 20 gallons of 100 LL fuel weigh? ________________________

11. What instrument indications would you notice, on take-off, if the static ports were blocked?

    ____

12. What are the altitude limits of class A airspace, and what flight rules apply when flying in that airspace?

    ____

13. If you are flying eastbound, and you have a tailwind, would you typically be north or south of a low-pressure zone?

    South ______________________

14. On a surface analysis weather chart, what do closely spaced isobars mean?

    High Winds ________________

15. What are you likely to see on the instruments if a pitot tube becomes blocked during the enroute phase of flight? Describe each phase.

    Level (accelerating):____

    Climb:____

    Descent:____

16. In what weather products can you find icing information?

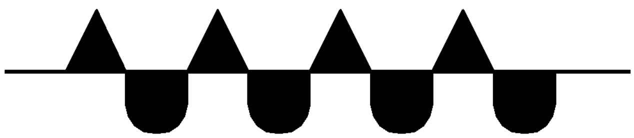
    PIREPs, SIGMETs, TAFs, AIRMETs, Area Forecasts, Prognosis Charts, Composite Moisture Charts, Wind Aloft Tables ________________

17. What do boundary layer air, and surface winds near the ground have in common?

    ___ Both are slower than surrounding air, due to friction of the surface. ______

18. On a weather chart, what do the following symbols stand for?

A. Occluded Front



B. Stationary Front

19. What type of information is found in an FDC NOTAM?

Regulatory Notices, Charting Changes

20. If a thunderstorm is identified as being severe, or giving an intense radar echo, what does the AIM say about how far you should avoid the storm?

20 miles

21. What do the following METAR/TAF weather codes stand for?

RA = Rain
SQ = Squall
BR = Mist
FZ = Freezing
FC = Tornado
DZ = Drizzle
SH = Showers
FU = Smoke
FG = Fog
GR = Hail
SN = Snow
IC = Ice Crystals
HZ = Haze
TS = Thunderstorm

22. What is a void time clearance?

23. On a radar summary chart, what does the notation "NA" mean?

Not available ____________________

24. During a night time IFR flight, what clues suggest airframe icing?

____

25. Please translate the following METAR weather report:

METAR KDCA 291554Z 26012G18KT 10SM SCT040 BKN100 15/05 A2985

Regan National, 29th day, 1554 Zulu time, wind 260 degrees at 12 knots – gusting to 18 knots, visibility 10 statute miles, scattered clouds at 4000 feet, broken clouds at 10,000 feet, temperature 15 degrees Celsius, dewpoint 5 degrees Celsius, altimeter 29.85 inches of Mercury.

Thank you for taking the time to complete our questionnaire, we appreciate your help. If we select you for our simulator study of advanced technologies, we will contact you by phone or E-mail.

Appendix E. Pre-Flight Weather Briefing

Pre-Flight Weather Briefing
As part of the mission preflight briefing materials, each pilot was given a paper copy of a standard weather briefing that would have been received by a call to a Flight Service Station telephone briefer. Both the teletype coded reports were given as well as an English translation.

Adverse Conditions:

AIRMET (WA) TANGO FOR TURB VALID UNTIL 272100Z
AIRMET TURB…MD VA NC
FROM EMI TO SBY TO RDU TO PSK TO EMI
AFT 18Z OCNL MOD TURB BLW 060 DUE TO INCRG SWLY FLOW AHD OF CDFNT. CONDS SPRDG EWD AND CONTG BYD 21Z THRU 03Z.

AIRMET (WA) TANGO for turbulence valid until twenty-one hundred universal coordinated time for Maryland, Virginia, and North Carolina.

From Westminster (EMI), Virginia to Salisbury (SBY), Maryland, to Raleigh-Durham (RDU), North Carolina to Pulaski (PSK), Virginia to Westminster (EMI), Virginia.
After one, eight, zero, zero, universal coordinated time, occasional moderate turbulence below six thousand feet due to increasing southwesterly flow ahead of cold front. Conditions spreading eastward and continuing beyond twenty-one hundred universal coordinated time, and through zero, three, zero, zero universal coordinated time.

Synopsis:

At one, seven, zero, zero universal coordinate time, a Cold Front extending from southwest Pennsylvania along the Appalachians through Central West Virginia, Western Virginia, and Eastern Tennessee, northwest Georgia and Central Alabama will continue to move Eastward.

A warm front extending from southwest Pennsylvania Eastward to Atlantic City, NJ. will continue to move Northeastward, and a Trough of Low Pressure extending from northwest West Virginia southward into Central South Carolina will continue moving Eastward.

Current Conditions:

PHF SA 1800Z M 8 BKN 07 14/12/0910/992
Newport News, Williamsburg International Airport weather report, one, eight, zero, zero universal coordinated time. Measured ceiling eight hundred broken, visibility seven, temperature one, four, dew point one, two, wind zero niner, zero at ten, altimeter two, niner, niner, two.

RIC SA 1800Z 50 SCT M70 BKN 05 14/12/3010/992
Richmond International Airport weather report, one, eight, zero, zero universal coordinated time. Five thousand scattered, measured ceiling seven thousand broken, visibility 5, temperature one, four, dew point one, two, wind three, zero, zero at one zero, altimeter two, niner, niner, two.

OFP SA 1747Z E50 BKN 150 OVC 10 18/12/2015/960
Richmond, Hanover County Airport weather report, one, seven, four, seven universal coordinated time. Estimated ceiling five thousand broken, one, five thousand overcast, visibility one, zero, temperature one, eight, dew point one, two, wind two, zero, zero, at one, five, altimeter two, niner, six, zero.

LKU SA 1750Z 20 SCT E40 BKN 100 OVC 10 17/12/2415G20/955
Louisa County, Freeman Airport weather report, one, seven, five, zero universal coordinated time. Two thousand scattered, estimated ceiling four thousand broken, one, zero thousand overcast, visibility one, zero, temperature one, seven, dew point one, two, wind two, four, zero at one, five gusting two, zero, altimeter two, niner, five, five.

WAL SA 1749Z CLR BLO 120 10 16/10/1810/969
NASA, Wallops Airport weather report, one, seven, four, niner universal coordinated time. Clear of clouds below one, two thousand, visibility one, zero, temperature one, six, dew point one, zero, wind one, eight, zero at one, zero, altimeter two, niner, six, niner.

MFV SA 1753Z CLR BLO 120 10 18/11/1806/968
Accomack County Airport, Virginia weather report one, seven, five, three universal coordinated time. Clear of clouds below one, two thousand, visibility one, zero, temperature one, eight, dew point one, one, wind one, eight, zero at six, altimeter two, niner, six, eight.

SBY SA 1750Z CLR BLO 120 10 16/10/1810/969
Salisbury, Maryland weather report one, seven, five, zero universal coordinated time. Clear of clouds below one, two thousand, visibility one, zero, temperature one, six, dew point one, zero, wind one, eight zero at one, zero, altimeter two, niner, six, niner.

UA: /OV RIC150015 /TM 1720Z /FL 040/TP C180 /SK SCT150 /TB LGT
Pilot report one-five miles southeast of Richmond, Virginia. At one, seven, two, zero universal coordinated time. At four thousand feet, a Cessna one, eighty reported in clouds with light turbulence.

UA: /OV SBY /TM 1715Z /FL 030 /TP MO20 /SK SCT150 /TB NEG
Pilot report over Salisbury, Maryland at one, seven, one, five universal coordinated time. At three thousand feet, a Mooney reported clouds at one five thousand scattered, and negative turbulence.

UA: /OV RIC045025 /TM 1710Z /FL 040 /TP C172 /TB LGT-MOD
Pilot report two-five miles northeast of Richmond, Virginia at one, seven, one, zero universal coordinated time. At four thousand feet, a Cessna one, seven, two reported light to moderate turbulence.

Satellite Imagery indicates several Cumulus clouds beginning to develop throughout central Virginia, including the Richmond area, over the past hour.

Weather Radar at one, seven, one, zero universal coordinated time indicates scattered areas of light to moderate rain showers in Central Virginia, but no precipitation in the Eastern sections of the state.

<u>En-Route Forecast:</u>

TAF KPHF 271729Z 271818 16014G24KT P6SM SCT100 BKN200 BECMG 2022 16017G27KT SCT060 OVC120
FM0000 1618G25KT P6SM SCT030 OVC060 TEMPO 5SM –SHRA OVC030
PROB40 0103 VRB20G40KT 2SM TSRA OVC020 CB

Terminal area forecast for Newport News-Williamsburg International Airport. Valid from one seven, two nine, to one eight, one eight, universal coordinated time, wind one, six, zero at one, four gusting two, four, visibility unrestricted, scattered clouds at one, zero thousand, broken clouds at two, zero thousand. Conditions becoming between two, zero, zero universal coordinated time and two, two, zero, zero universal coordinated time, wind one, six, zero at one, seven gusting two, seven, scattered clouds at six thousand, overcast at one, two thousand until zero, zero, zero, zero universal coordinated time.

Central and Eastern Virginia Area Forecast:

271800Z SCT-BKN050 OVC120 TOP 200, OTLK VFR TSRA
The area forecast for Central and Eastern Virginia after one, eight, zero, zero universal coordinated time: scattered to broken clouds at five thousand, overcast at one, two thousand, tops at two, zero thousand, outlook VFR with thunderstorms and rain.

TAF KRIC 271729Z 271818 18018G20KT P6SM SCT060 OVC120 BCMG2022 OCNL –SHRA OVC030 PROB40 2302 VRB20G40KT 2SM TSRA OVC020CB
Terminal area forecast for Richmond International Airport. Valid from one seven, two nine, to one eight, one eight, universal coordinated time, wind one, eight, zero at one, eight gusting two, zero, visibility unrestricted, scattered clouds at six thousand, overcast at one, two thousand. Conditions becoming between two, zero, zero, zero universal coordinated time and two, two, zero, zero universal coordinated time, occasional light rain showers, overcast at three thousand, with a chance of thunderstorms after two, three, zero, zero universal coordinated time.

TAF KSBY 271729Z 18018 1820G30KT SCT100 BKN200
Terminal area forecast for Salisbury, Maryland after one seven, two nine, universal coordinated time. Wind one, eight, zero at two, zero gusting three, zero, scattered clouds at one, zero thousand, broken clouds at two zero thousand, visibility unrestricted.

Winds Aloft Forecast:

	030	060	090
ORF	1920	2025+5	2130+2
RIC	2020	2125+4	2130+1

Winds aloft forecast for the Norfolk, and Richmond, Virginia areas after one, seven, zero, zero universal coordinated time.Norfolk at three thousand: wind one, niner, zero at two, zero. At six thousand: wind two, zero, zero at two, five, temperature plus five. At niner thousand: wind two, one, zero at three, zero, temperature plus two. Richmond at three thousand: wind two, zero, zero at two, zero. At six thousand: wind two, one zero at two, five, temperature plus four. At niner thousand: wind two, one, zero at three, zero, temperature plus one.

NOTAMS:
No Current NOTAMS Listed.

ATC Delays:
NONE

ATC request PIREPS for turbulence or other conditions along your route of flight. Contact Flight Watch or Flight Service. Washington Flight Watch is available with En-route Flight Advisory Service to update your weather briefing on 122.0MHz. Leesburg Flight Service station is available on 122.2 MHz for weather briefings and other in-flight services.

Appendix F. Cockpit Research Facility Description

The RTI/NASA Cockpit Research Facility (CRF) was configured for the experiment as a conventionally equipped aircraft with the addition of a display of FIS-B information. The CRF consists of three major subsystems (as illustrated in Figure F-1):

- Rapid Prototype Simulator Cab – Consists of the cockpit mockup with controls, instruments, radios and indicators. A Closed Circuit Television (CCTV) camera is mounted behind and above the pilots' left shoulder to provide live images from the cockpit to the Scenario Controller and Observer Position.

- Scenario Controller and Observer Position – Consists of the master control station, which is used for scenario generation, selection, monitoring and recording of flight progress. Provides the operator and experiment observer with displays of all control positions, radio and instrument switch positions, instrument displays and the Out-the-Window (OTW) (as presented to the subject pilot). A weather data display of NEXRAD images is provided for the scenario controller and for the observer to track the flight's progress relative to the weather. A video image of the cockpit from the CCTV camera is provided for the observer to monitor the subject pilot's actions. Live audio of all radio transmissions between the pilot and the NAS (controller, Flight Watch, ATIS, etc.) are available to the scenario controller and the observer. An intercom audio network is provided which allows private conversations between the scenario controller, observer and air traffic controller positions. Simulated radio transmissions between the pilot and air traffic controller are also enabled over the same intercom system. All intercom traffic is recorded on the audio track that accompanies the video recording made from the CCTV camera.

- ATC Controller Position – Consists of a custom ATC station developed for performing experiments of this type and a weather display that shows the latest NEXRAD images to track the flight's progress relative to the weather. Current pilot-selected COM frequencies are displayed so that the ATC controller can verify that the pilot is contacting ATC on the correct frequency before responding to an initial contact.

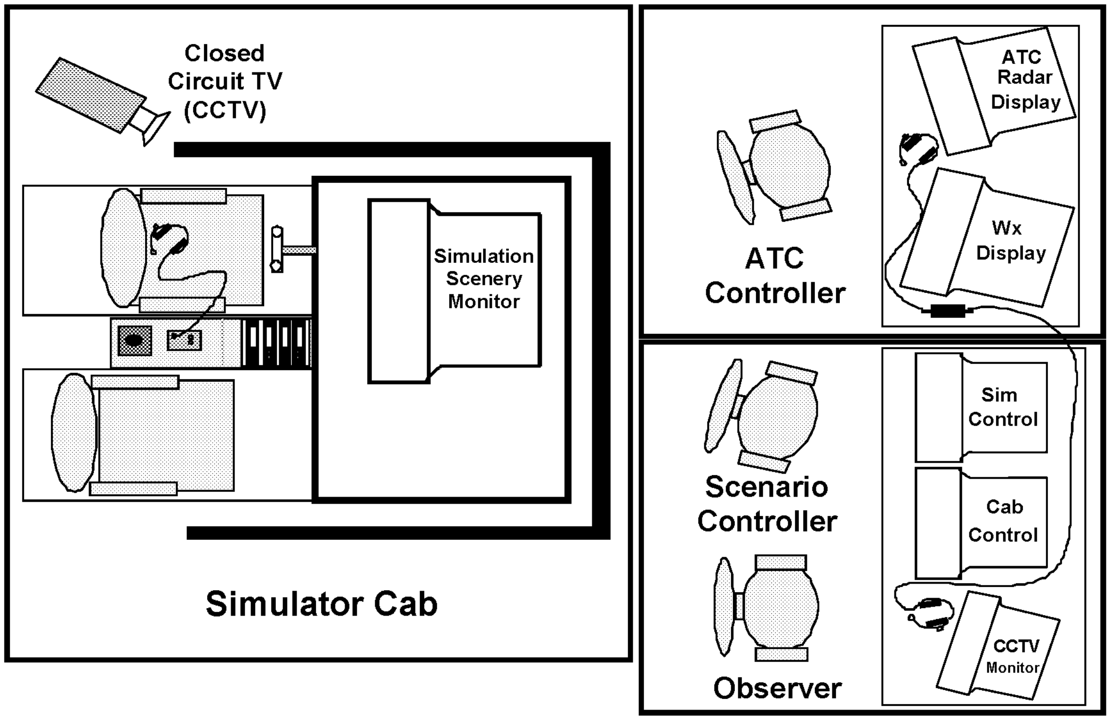


Figure F-1. Cockpit Research Facility

Simulator Cab Description

The simulator cab is a two-seat cockpit mockup designed for single-pilot IFR operations. The basic ergonomic structure of the mock-up is patterned after a generic GA airplane in terms of the relative placement and types of controls and instruments, instrument panel width and height, and seat placement. The pilot's position is outfitted with complete controls including a yoke, rudder pedals, instruments, switches and indicators as described in the paragraphs below.

The center console holds the radios and throttle quadrant. Both cockpit positions are outfitted with headsets and an intercom system that allows the pilot to communicate with a passenger and with simulated Air Traffic Control. A 37-inch monitor mounted directly in front of the pilot, approximately at the position of the aircraft nose provides the primary out-the-window view.

Controls, Instruments and Indicators Description

The controls, instruments and indicator configurations available are typical of those found in an IFR-equipped aircraft as shown in Figure F-2.

All instrument panel round dial indicators are rendered on flat panel liquid crystal displays (LCDs). The 14-inch diagonal LCDs provide enough display area to fully render the standard instrument "T" configuration with other supplemental indicators as well. A second 14-inch diagonal LCD provides display area for navigation instruments and engine parameter indicators. Table F-1 lists the types of instruments rendered in the cockpit.

All instruments provide the operational performance required by the Federal Aviation Administration Federal Aviation Regulations, Society of Automotive Engineers Aerospace Standards and RTCA, Inc. performance specifications as applicable to simulation.

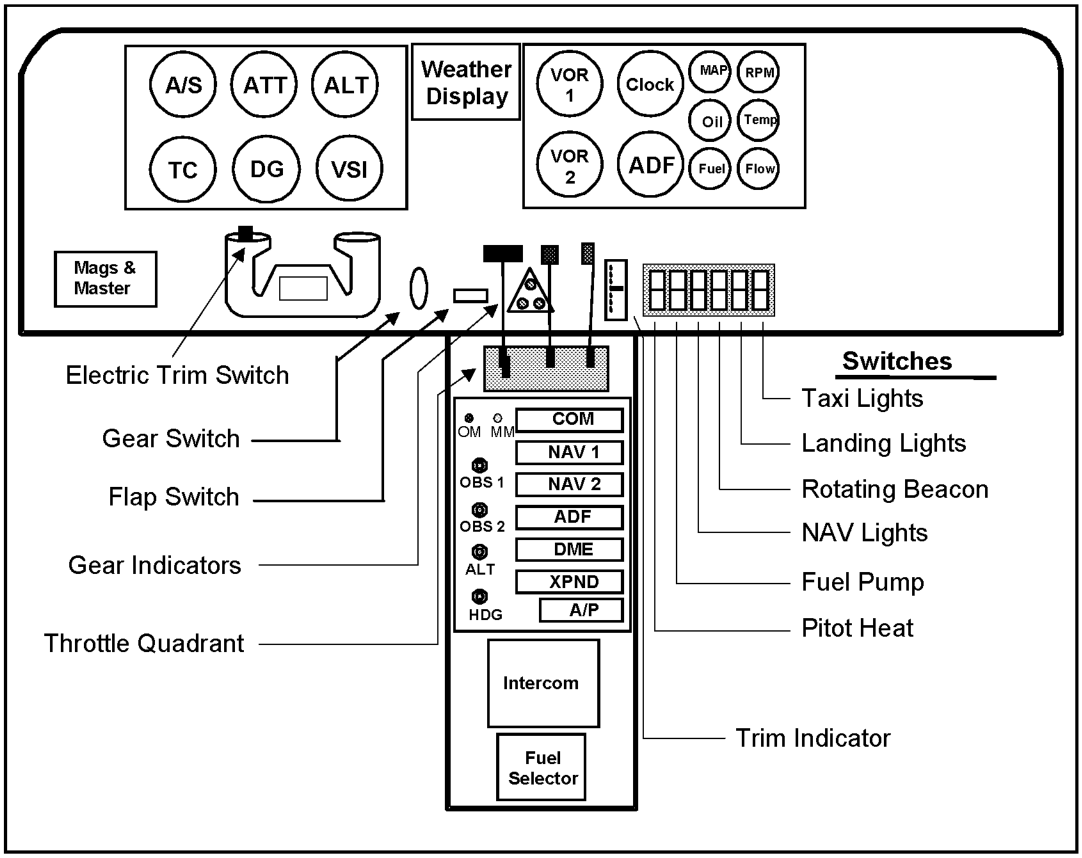


Figure F-2. Instrument Panel, Controls and Indicators

Table F-1. Instruments and Indicators in the Instrument Panel

Flight Control Instruments	Navigation / Communications Instruments	Engine Monitoring Instruments	Indicators
• Attitude • Airspeed • Altitude • Turn Coordinator • Compass Slaved Directional Gyro • Vertical Speed	• VOR / DME Display #1 with ILS Localizer & Glideslope • VOR / DME Display #2 with ILS Localizer & Glideslope • NAV Radio #1 • NAV Radio #2 • COM Radio #1 • ADF • Transponder	• Manifold Pressure (MAP) • Engine RPM • Fuel Quantity • Fuel Flow • Oil Pressure • Exhaust Gas Temperature (EGT) • Cylinder Head Temperature (CHT)	• Trim Position • Flap Position • Marker Beacon • Gear Position • Autopilot Mode

The control yoke provides the pilot with an electric trim button, push-to-talk switch for the intercom system, chronometer for time calculations as well as a full range of control movement for controlling the flight path of the airplane. Activation of the electric trim button moves the yoke in or out to relieve the control forces. The current trim position is displayed on a trim indicator in the instrument panel. A display indicator on the PFD notifies the pilot that the autopilot is engaged and if it needs additional trimming.

Visual System and Displays Description

A Silicon Graphics Onyx 10000 is used to generate the instrument panel gages and the Out-the-Window scene for the pilot. A rapid prototyping tool is used to develop and render the regulation-compliant gages in appearance and performance. Round dial instruments are rendered on two 14-inch diagonal active matrix Liquid Crystal Displays (AMLCDs), each having an addressable resolution of 1024 pixels by 768 lines.

The OTW scene is a photo-textured presentation rendered at a 40 degree horizontal by 30 degree vertical field-of-view and displayed on a 37-inch monitor at an addressable resolution of 1280 pixels by 1024 lines. The monitor is positioned so that active display area subtends approximately 40 degrees horizontal to the pilot's eye point. Both instrument displays and OTW scene are rendered at a 30 Hz frame rate with a 70 Hz display refresh rate.

A visual terrain database for the state of Virginia contains six major airports at which takeoffs and landings can be made. Another 24 airports are rendered at photographic quality to facilitate pilotage along several routes between NASA Langley, Newport

News/Williamsburg, Blacksburg, Richmond, Manassas, Washington National and NASA Wallops Island runways. The environmental conditions be varied to achieve any meteorological conditions required, i.e. overcast, low RVR, cloud decks, etc.

Data Acquisition System Description

The data acquisition system is used to collect information about the pilot's control inputs and switch actions, format the data, and transfer the data to the SGI Onyx for processing in the simulation models.

A data acquisition controller system is hosted in a Pentium 60-based PC. The data acquisition controller contains a microcontroller that performs all input / output (I/O) operations with the hardware in the simulator cab. Operations performed by the controller include:

- Acquiring analog control position information
- Performing the analog to digital conversions on control position information
- Acquiring switch position discretes
- Driving indicators in the cab (e.g. Gear Position Indicators, Outer Marker , Middle Marker)
- Acquiring frequency selections set in the COM, NAV 1, NAV 2, ADF, Transponder and autopilot interfaces in the radio stack located in the cockpit center console
- Acquiring the OBS 1 & 2, HDG select and baro Altimeter knob settings
- Updating the frequency displays in the COM, NAV 1, NAV 2 and ADF radios

Simulation Control, Monitoring and Recording

The simulation control and flight path monitoring process running in the Silicon Graphics Indigo controls all aspects of the simulation. The simulation control process initializes the simulation models in the SGI Onyx, performs real time data display and data collection capture of various flight parameters for later analysis, and presents a plan view of the aircraft's position during operation of the simulation, similar to an ATC console. The system operator uses the simulation control to select various scenarios, position / reposition aircraft model and monitor scenario progress.

Table F-2 lists the real-time parameters displayed at the operator's station during system operation. Table F-3 lists the data dictionary of parameters available for collection and reduction.

Table F-2. Real-time Parameters Displayed During Operations

Parameter	Parameter	Parameter	Parameter
Airspeed (A/S) • Calculated A/S • Indicated A/S • True A/S	**Aerodynamic Coefficients** • CL Total Lift • CD Total Drag • CY Total Side Force • CM Total Pitching Moment • CR Total Rolling Moment • CN Total Yawing Moment	**Control Surface Deflection** • Elevator • Rudder • Aileron • Aileron Trim • Rudder Trim • Trailing Edge Flaps	**Ground Contact Conditions (Landing)** • Rate of Decent • Bank Angle • Side & Vertical Forces on Nose Gear • Side & Vertical Forces on Left Gear • Side & Vertical Forces on Right Gear
• Ground Speed	**Altitude** • Pressure • AGL	**Position** • Latitude • Longitude • Heading	
Aircraft Body Angles • Pitch • Roll • Yaw • Angle of Attack α • Sideslip β	**Atmospheric** • OAT • Air Pressure • Baro Pressure	**Weight & Balance** • Gross Weight • Payload • Total Fuel • CG relative to 35% Mean Aerodynamic Chord (MAC)	
• Z-Load (# Gs through the polar axis)	• Engine Thrust	• Rate of Climb	

Table F-3. Dictionary of Recordable Parameters and Inducible Faults

Parameters			
Aerodynamic Model			
Altitude	Altitude Pressure	Aileron Position	Column Force
Elevator Position	Elevator Trim position	Rudder Position	Stall Buffet
Wheel Force	Indicated Airspeed	Altimeter Setting	Indicated Rate of Climb
Roll Attitude	On Ground Status	Weight on Gear	Weight on Nose Wheel
Weight on Left Gear	Weight on Right Gear	Angle of Attack	Side Slip Angle
Pitch Angle	Pitch Acceleration	Actual Rate of Climb	Roll Angle
Calculated Airspeed	Ground Speed	True Airspeed	
Atmosphere			
Atmospheric Pressure	OAT degrees C	OAT degrees F	Ambient Air Pressure
Autopilot - 22 Parameters		Circuit Breakers - 20 Breakers	
ICE - Induced, Pitot Head, etc - 19 Parameters		Gear - True Gear Positions, Nose, Left, Right	
NAV			
ADF Indicator	DME Distance	DME Speed	DME Time
DME Mode Switch	OBS 1, OBS 2	CDI 1, CDI 2	Glide Slope 1, Glide Slope 2
Magnetic Heading	Outer Marker	Middle Marker	
Induced Faults			
Runaway trim	Autopilot Pitch Axis Failure	Autopilot Hard Roll	Autopilot Soft Roll
Autopilot Circuit Breaker	Dead Battery	Fuel Pump Failure	NAV 1 Failure
Nav 2 Failure		**Vacuum System**	
Position		Standby Vacuum On	Vacuum Hg
Latitude	Longitude	Vacuum Enunciator	Pump Switch
Controls			
Throttle Position	Prop Position	Mixture Position	
Weight and Balance			
Center of Gravity	Long Load Force	CG % MAC	Total Weight
Passenger & Baggage Weight	Fuel Weight		

Air Traffic Management Console

The Air Traffic Management (ATM) console is used during the conduct of research projects to provide a more realistic environment for the subject pilot involved in the research. During investigations, an experienced Air Traffic Controller operates the station. The ATM station receives data from the simulator and presents it on the ATM Station monitor in a manner sufficient to support the ATM functions required of the Air Traffic Controller.

The screen consists of "radar image data" and associated mapping features, Figure F-3. System controls and informational data are presented on the side and top of the display. The operator may zoom in to a 1-mile scale (used for ground control) to a 100-mile scale (approach, departure, and enroute functions). Features that can be displayed during the operation of the ATM Station include: intersections (with and without names), airports (with and without names), runways (utilized during approaches), taxiways (utilized for ground control), VORs (with and without names), and special use airspace. The display is centered upon the selected airport (currently PHF, RIC, LFI, or WAL). Future implementations include the display and manipulation of the flight paths of multiple aircraft.

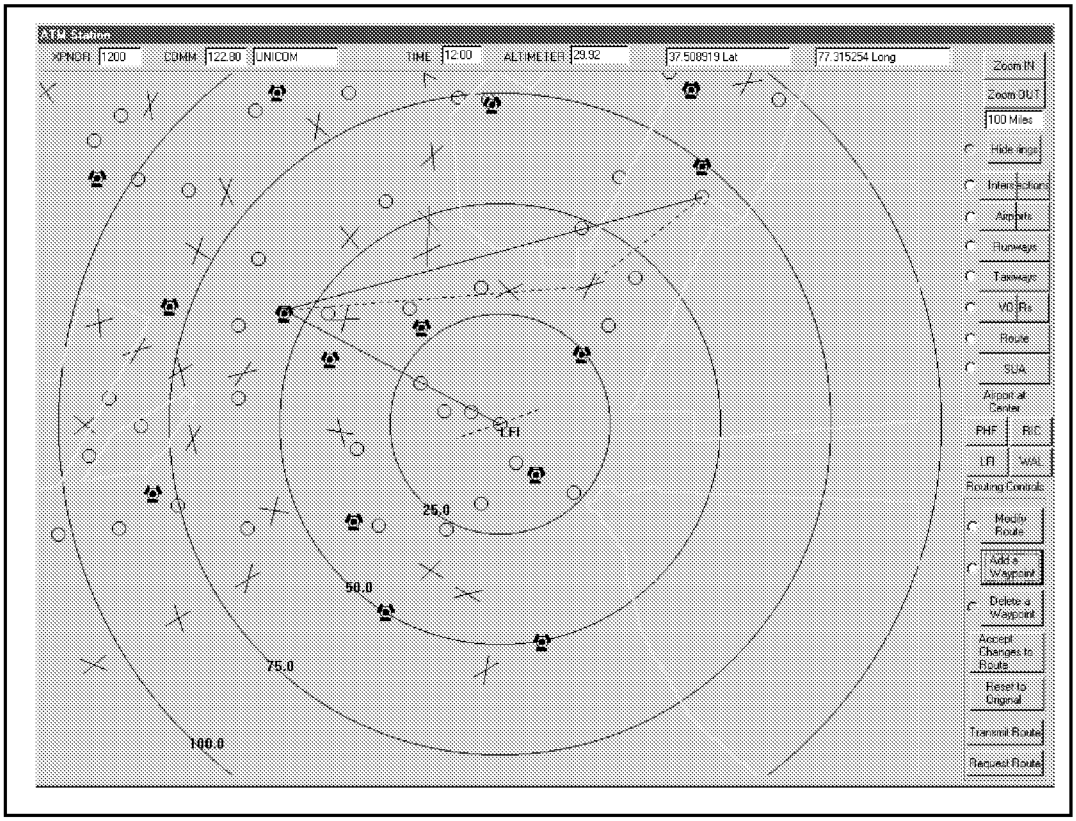


Figure F-3. Air Traffic Management Console Display

Aerodynamic Simulation Model

The simulation model is a 6 Degree of Freedom (DOF) aerodynamic model that is table driven to provide the performance characteristics for the Piper Malibu PA46-310P. The Piper Malibu represents a high performance single engine GA with a cruising speed of 170 knots. The simulation model is executed in the SGI Onyx, based on the pilot inputs collected through the data acquisition system. It is computed in 3 parts: fast rate (30 Hertz) coefficients, medium rate (15 Hertz) coefficients and slow rate coefficients (7.5 Hertz).

The aerodynamic coefficients in the simulation model incorporate the non-linear characteristics of an operational airplane. These adjustments give the simulation model more realistic longitudinal handling characteristics and make it possible, for example, to flare the airplane to a maximum lift stall at the touchdown point if desired.

Crosswind Model

A crosswind model is available that can direct a cross wind over a large range from any direction.

Turbulence Model

A basic turbulence weather model is included in the simulation. As the aircraft approaches a weather system, the level of turbulence can be increased based on the overall level of convective weather and distance from the weather.

Four levels of turbulence are calculated, from mild (level 1) to heavy (level 4). For each level, a random turbulence factor is added into the wind velocity for each of the respective axis wind velocities. All instruments react to the turbulence in a manner reflecting the movement of the airframe through the airmass, i.e. rapid fluctuations in airspeed, vertical speed, attitude, heading, etc.

The autopilot is programmed to disengage when the aircraft flies into areas of level three turbulence or higher. Attempts to reengage the autopilot while in this level of turbulence will result in an automatic disengagement within 10 seconds.

Appendix G. NEXRAD Mosaic Images – 4km Cells

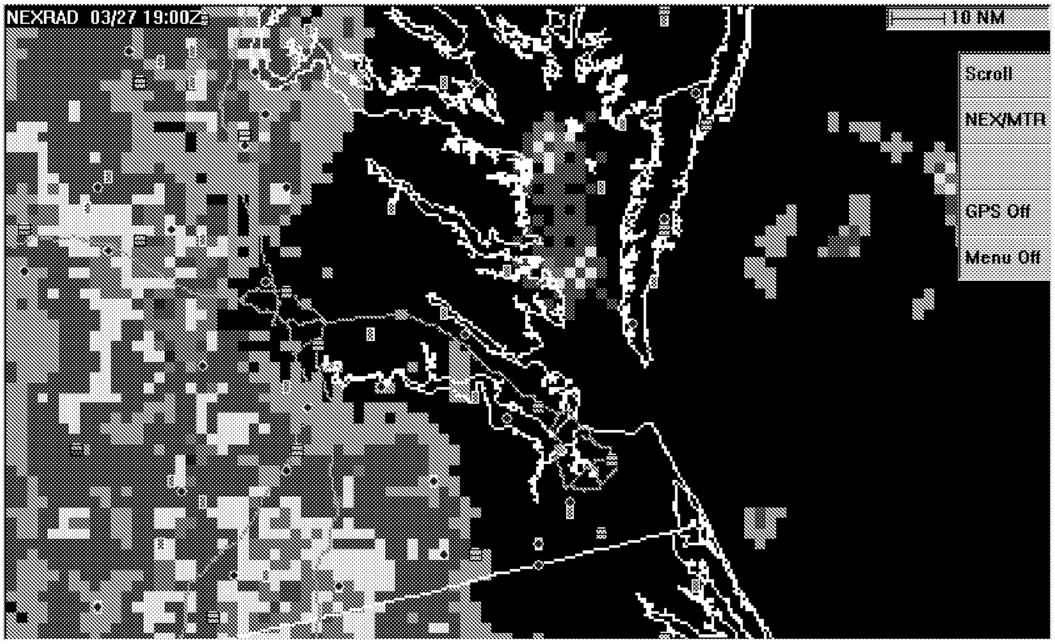


Figure G-1. 1900Z NEXRAD Mosaic Image — 4 km Cells

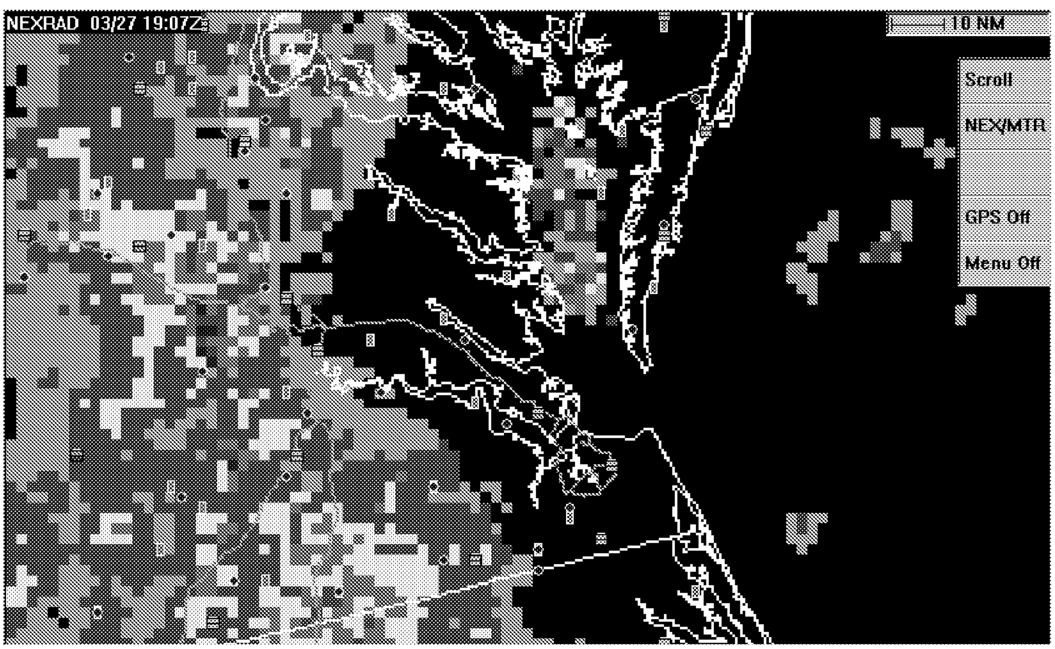


Figure G-2. 1907Z NEXRAD Mosaic Image — 4 km Cells

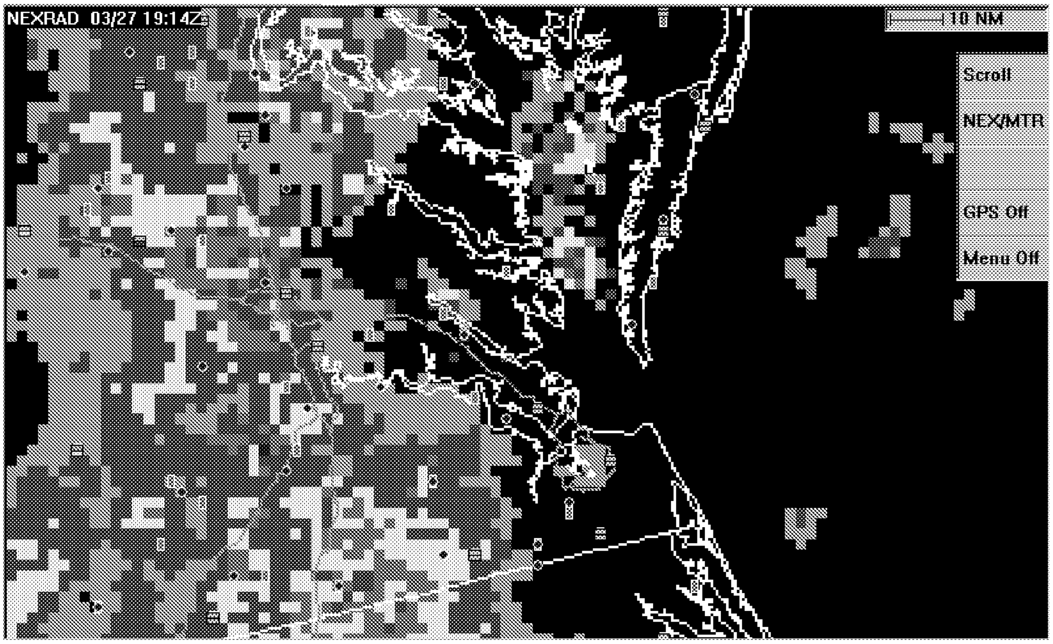


Figure G-3. 1914Z NEXRAD Mosaic Image — 4 km Cells

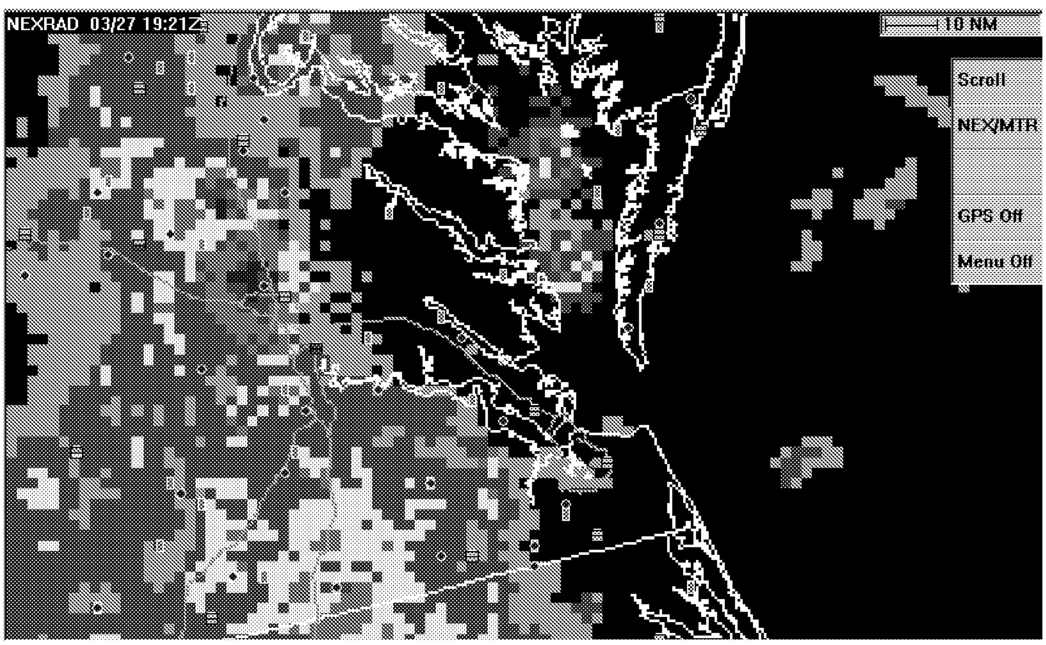


Figure G-4. 1921Z NEXRAD Mosaic Image — 4 km Cells

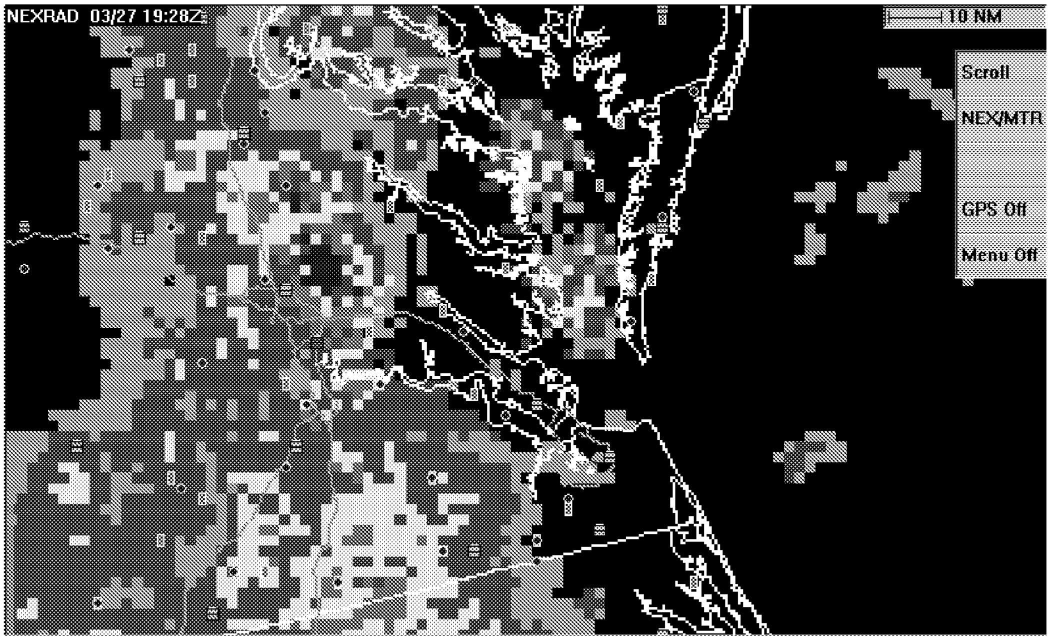


Figure G-5. 1928Z NEXRAD Mosaic Image — 4 km Cells

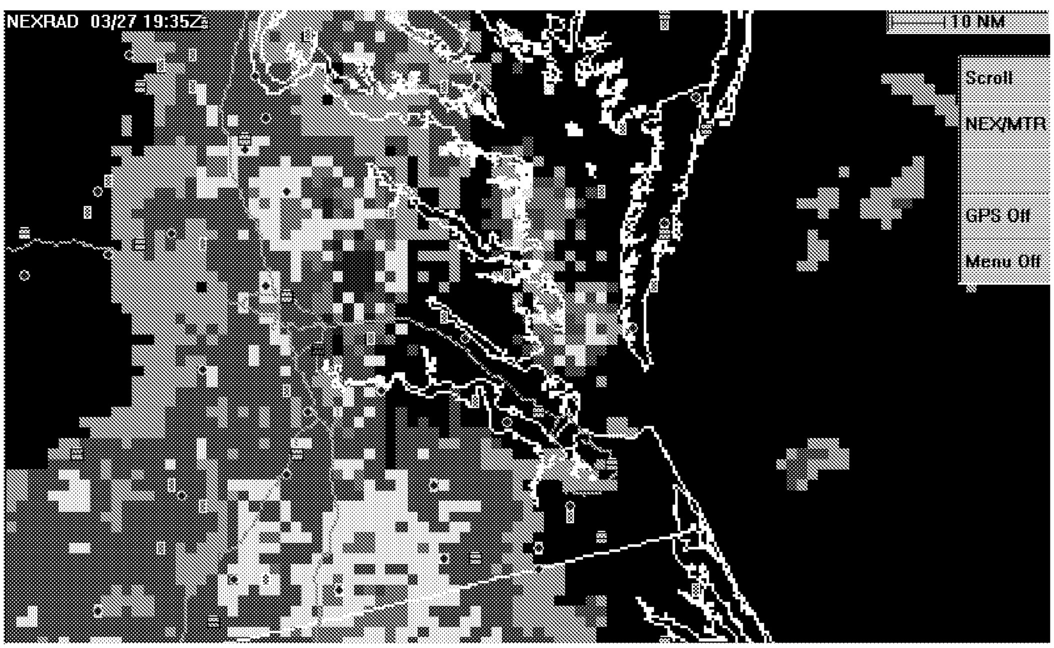


Figure G-6. 1935Z NEXRAD Mosaic Image — 4 km Cells

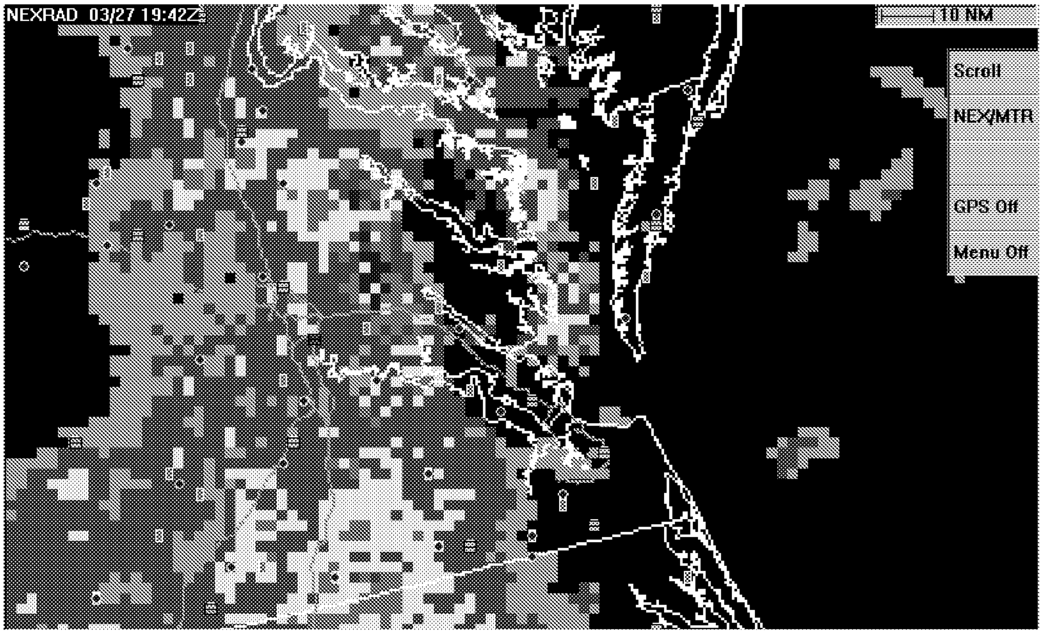


Figure G-7. 1942Z NEXRAD Mosaic Image — 4 km Cells

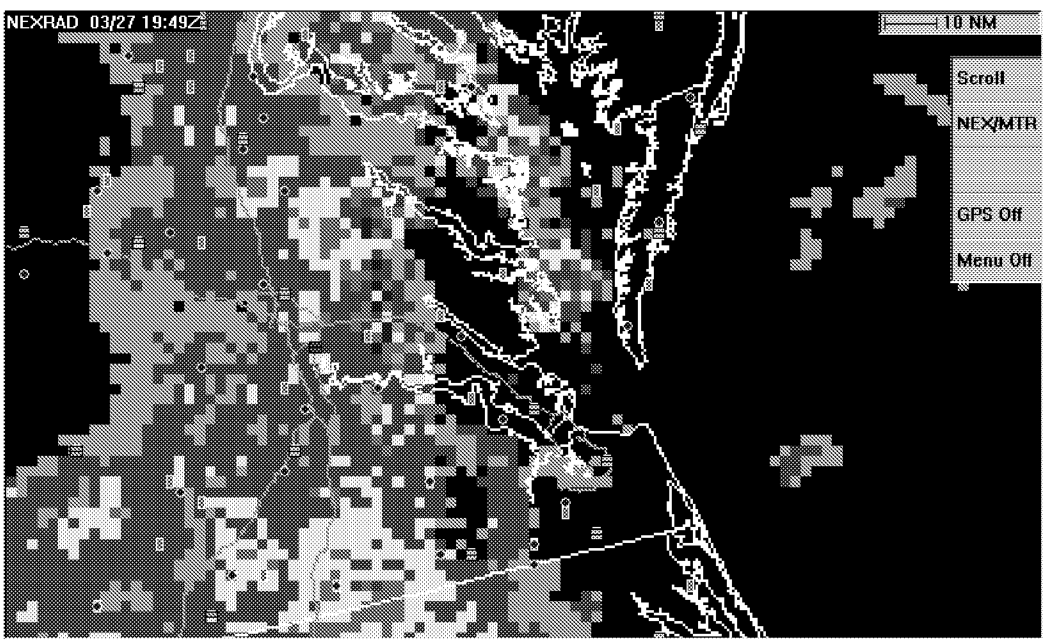


Figure G-8. 1949Z NEXRAD Mosaic Image — 4 km Cells

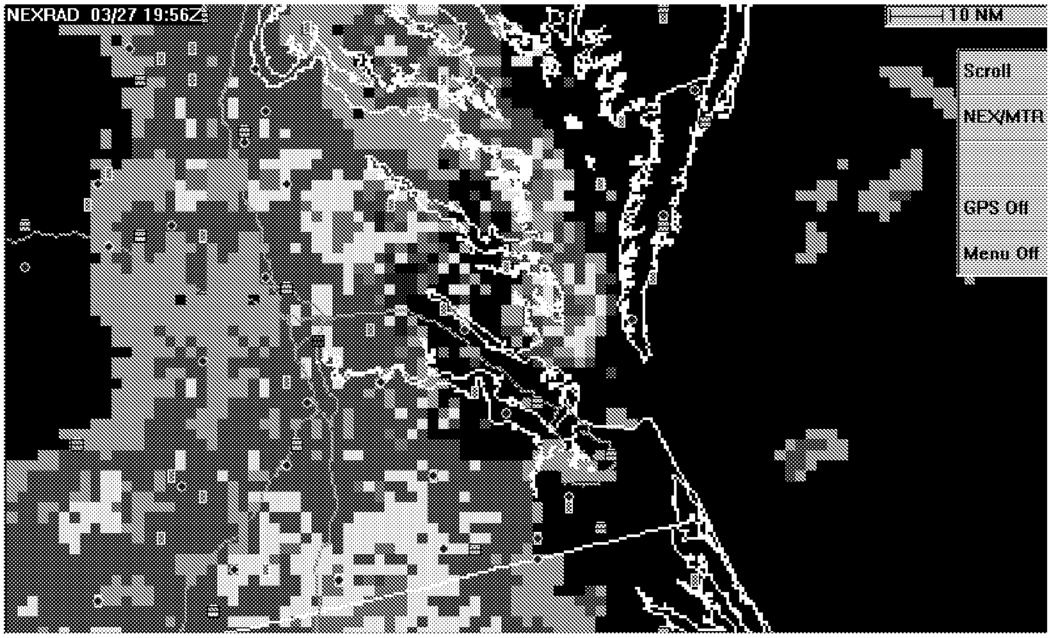


Figure G-9. 1956Z NEXRAD Mosaic Image — 4 km Cells

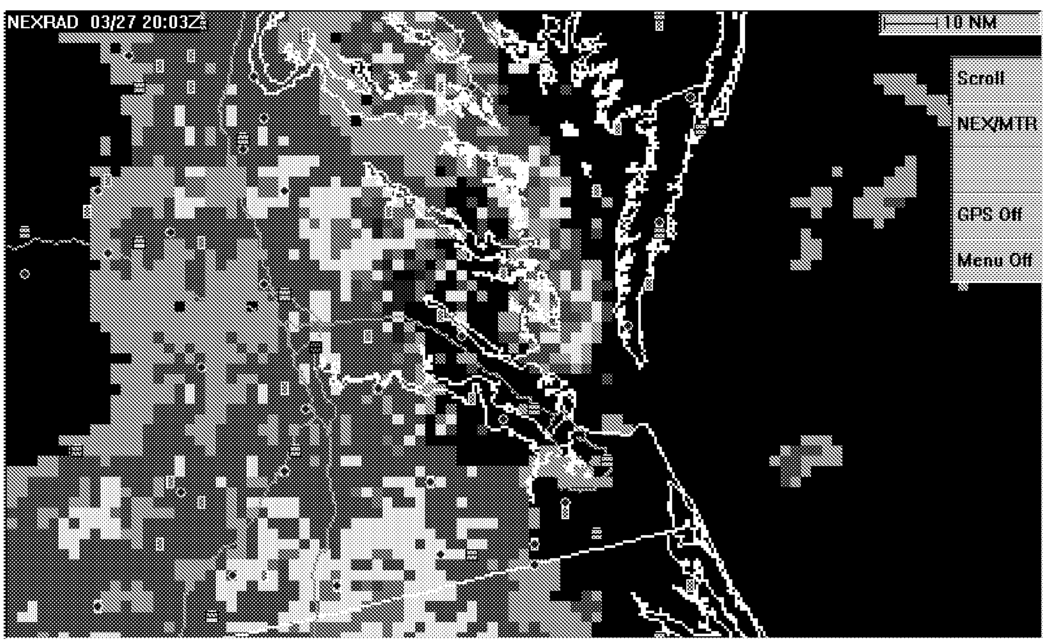


Figure G-10. 2003Z NEXRAD Mosaic Image — 4 km Cells

Appendix H. NEXRAD Mosaic Images – 8km Cells

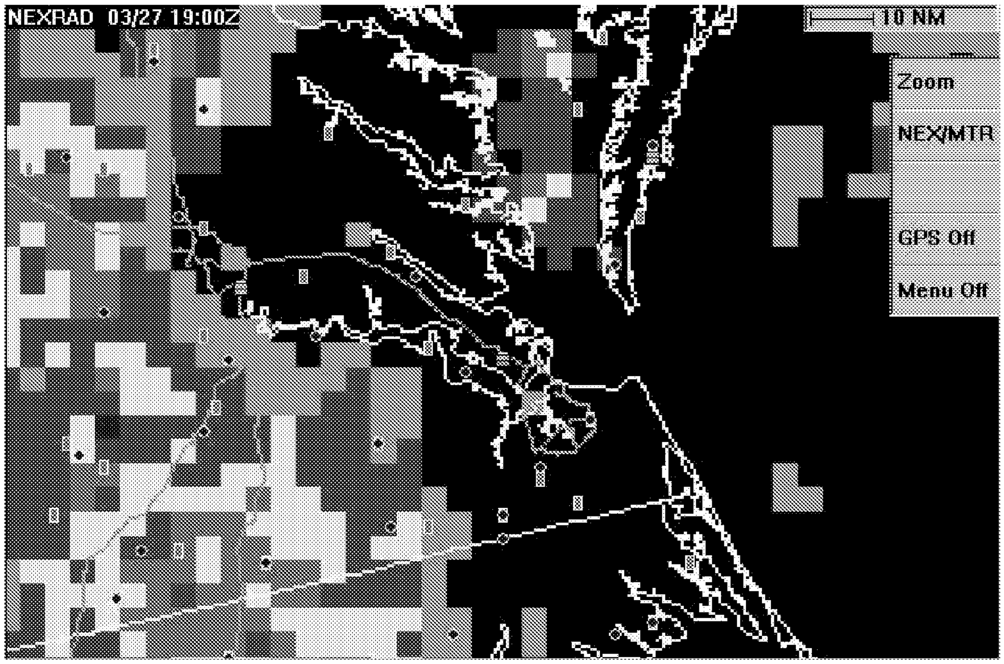


Figure H-1. 1900Z NEXRAD Mosaic Image — 8 km Cells

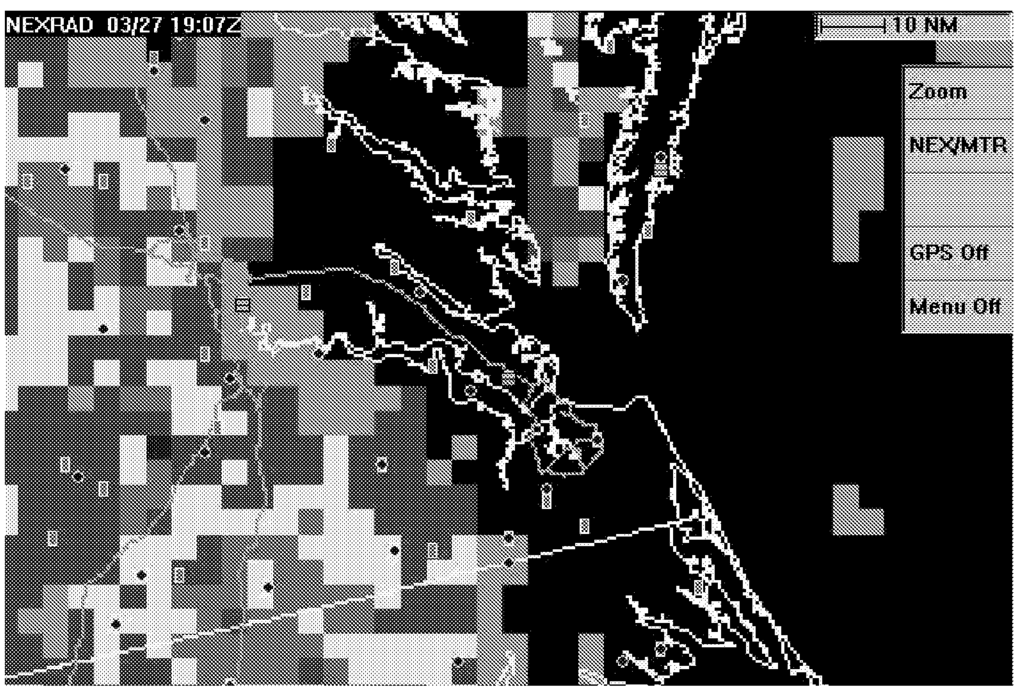


Figure H-2. 1907Z NEXRAD Mosaic Image — 8 km Cells

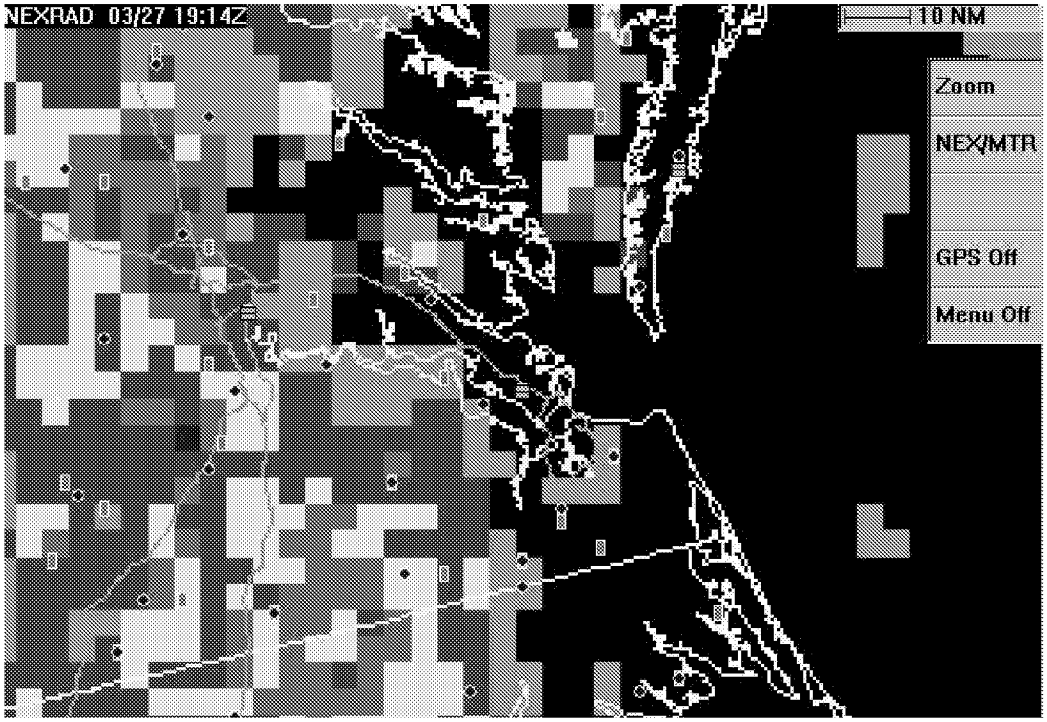


Figure H-3. 1914Z NEXRAD Mosaic Image — 8 km Cells

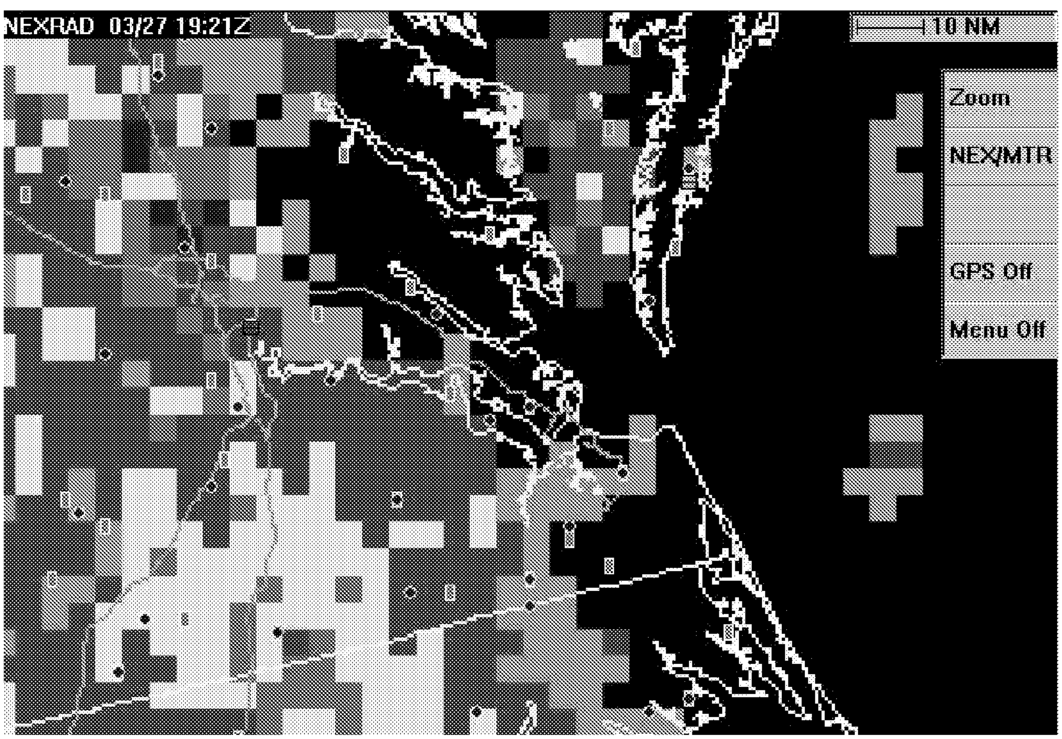


Figure H-4. 1921Z NEXRAD Mosaic Image — 8 km Cells

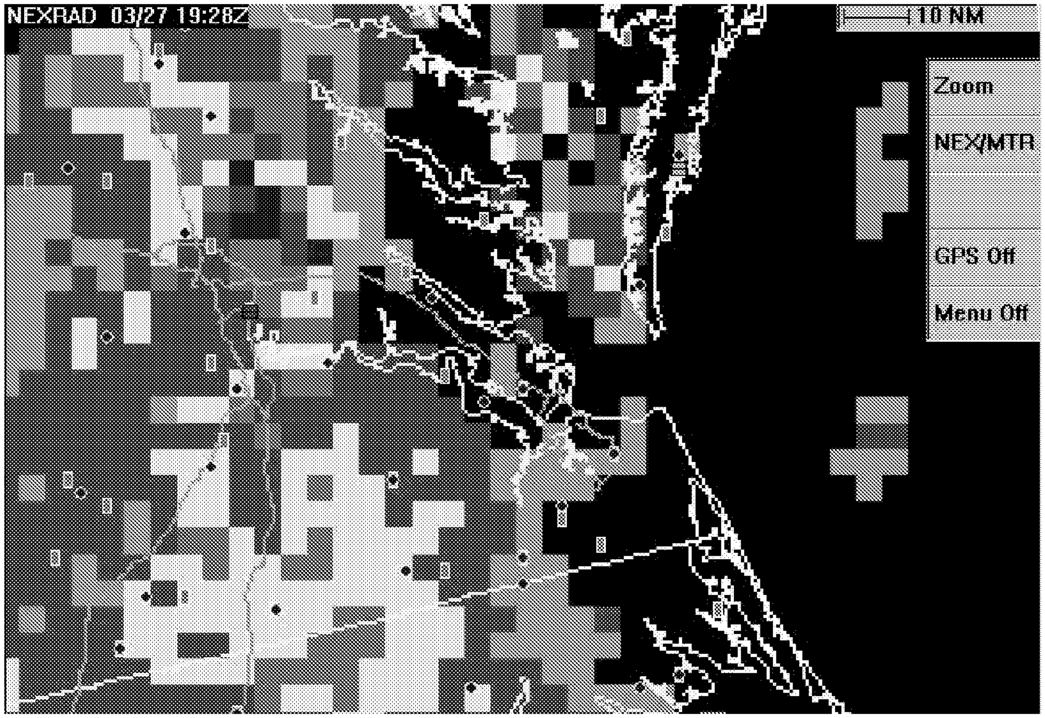


Figure H-5. 1928Z NEXRAD Mosaic Image — 8 km Cells

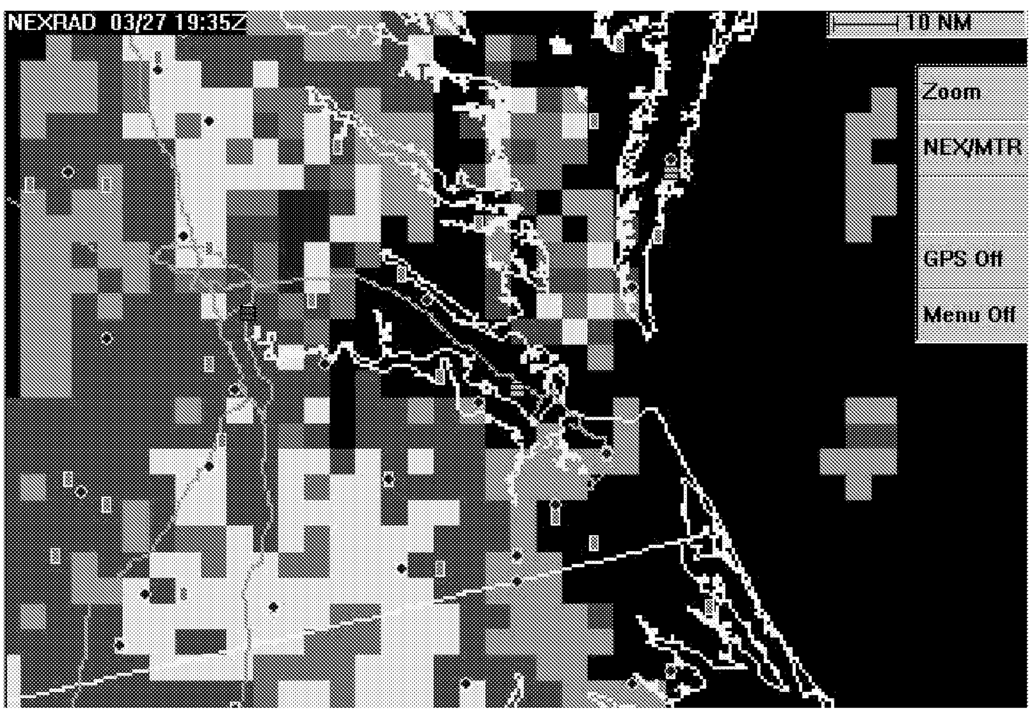


Figure H-6. 1935Z NEXRAD Mosaic Image — 8 km Cells

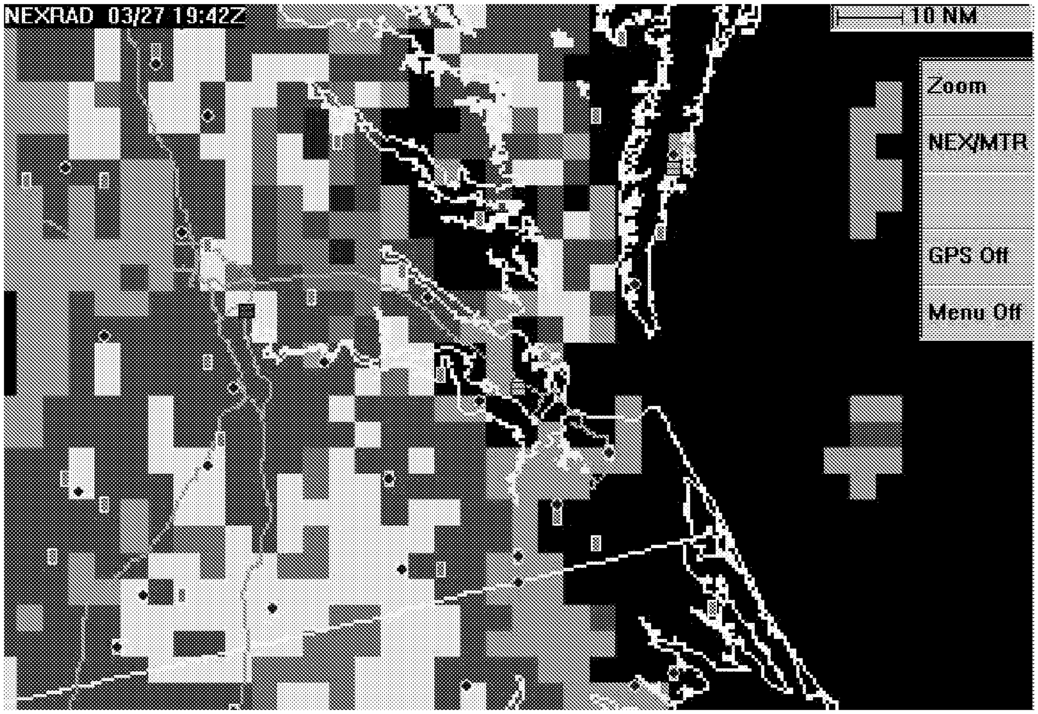


Figure H-7. 1942Z NEXRAD Mosaic Image — 8 km Cells

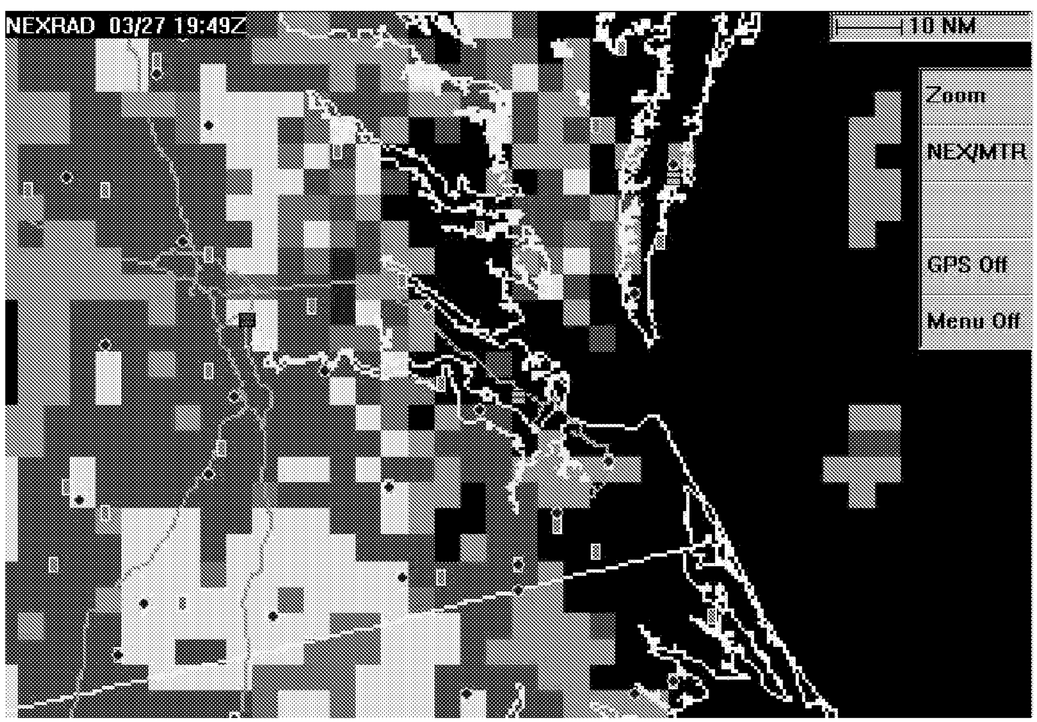


Figure H-8. 1949Z NEXRAD Mosaic Image — 8 km Cells

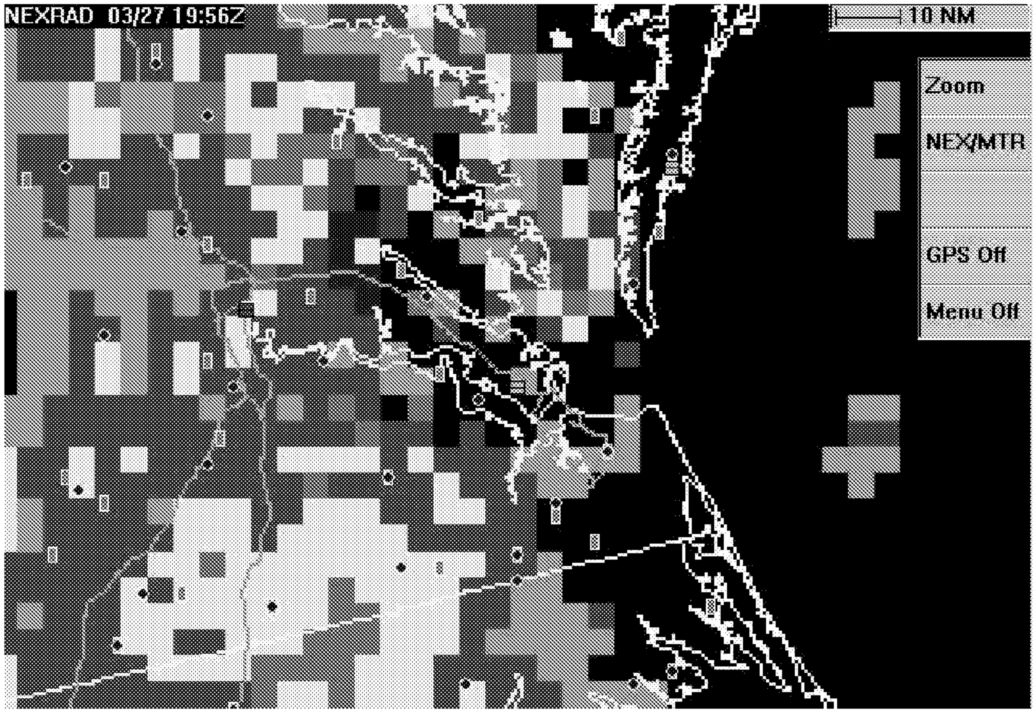


Figure H-9. 1956Z NEXRAD Mosaic Image — 8 km Cells

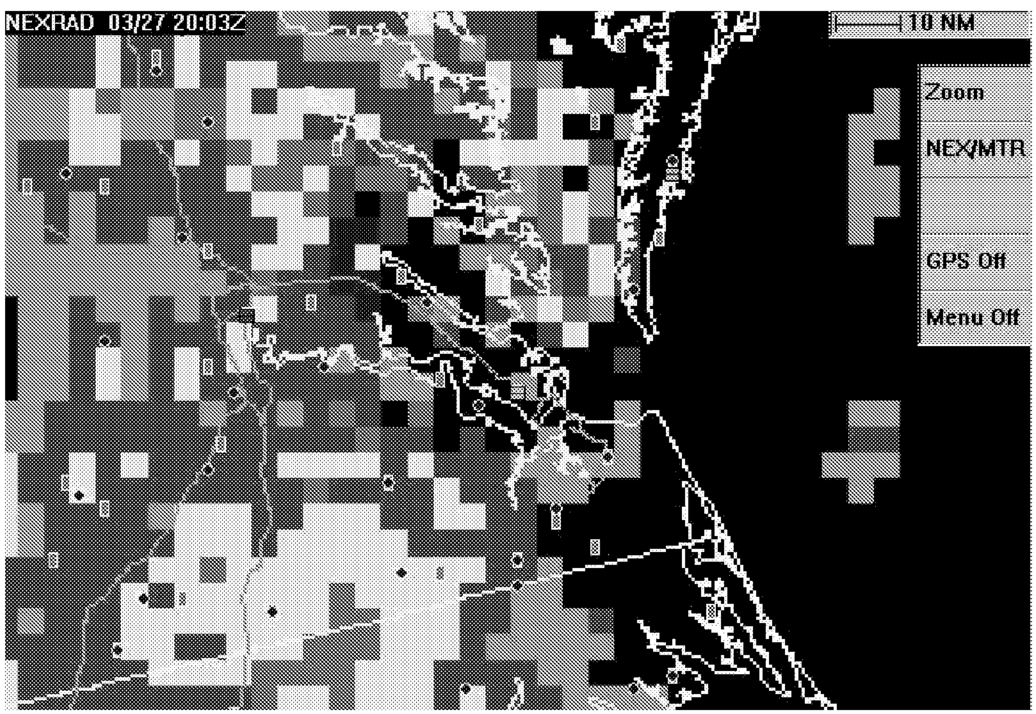


Figure H-10. 2003Z NEXRAD Mosaic Image — 8 km Cells

Appendix I. Experiment Briefing

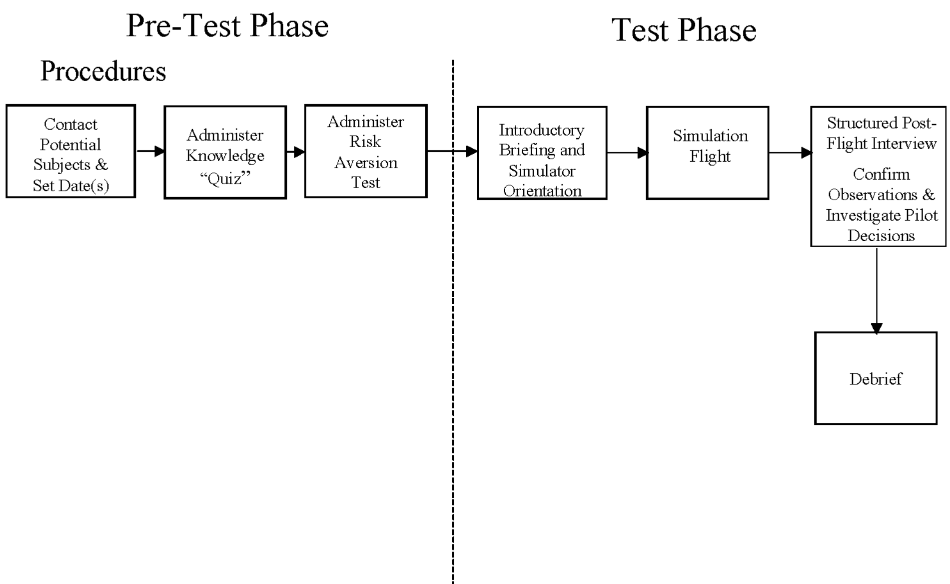
This appendix shows the briefing given to the pilots upon first entering the simulation facility. It explains the overall structure, schedule, equipment and mission of the experiment. An explanation of the weather display is also given at this point.

RTI

FAA/NASA/RTI
Flight Information Services
Data Link (FISDL)
Experiment

June, 2000

Experiment Procedure



Subject Pilot Schedule

Time	Activity
0:20	Introduction
1:30	Simulator Familiarization
0:10	Break
0:30	Flight Planning
1:30	Flight Experiment
0:30	Debriefing

Today's Flight Mission

Situation

- A diabetic patient is in urgent need of insulin at Wallops Island on eastern shore of Virginia.
- The insulin is vital to survival of the patient. The longer the delay, the greater the likelihood that patient will not survive, or at best, suffer serious complications
- Potentially fatal complications include Diabatic Ketoacidosis (DKA). One therapy for DKA includes treatment with sodium bicarbonate.

Today's Mission

(Continued)

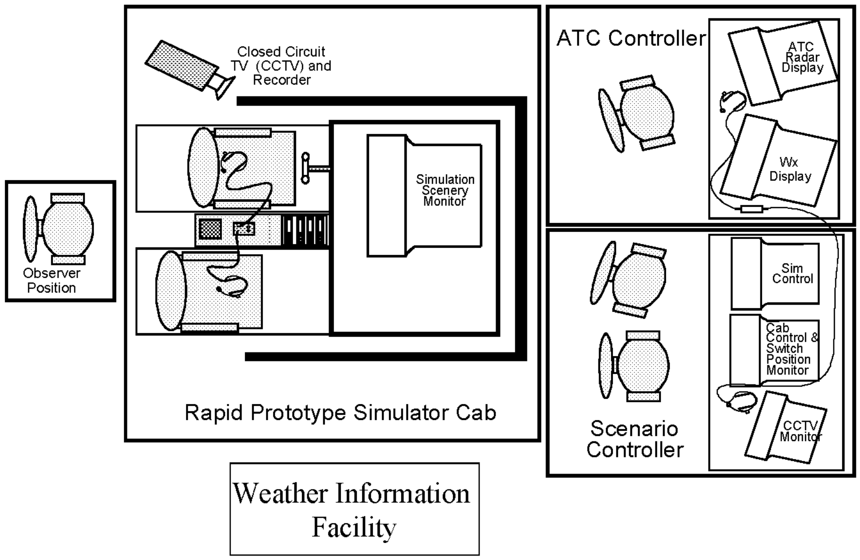
- RTI Medical Services, Inc. is to deliver insulin to the Wallops Island airport from NNWB airport, stopping enroute to pick up sodium bicarbonate at Richmond, Va airport.

(The sodium bicarbonate medicine will be driven out to A/C at end of runway)

- Departure of the RTI Medical Services flight is 1900 hours this evening.

RTI

Simulation Hardware Configuration



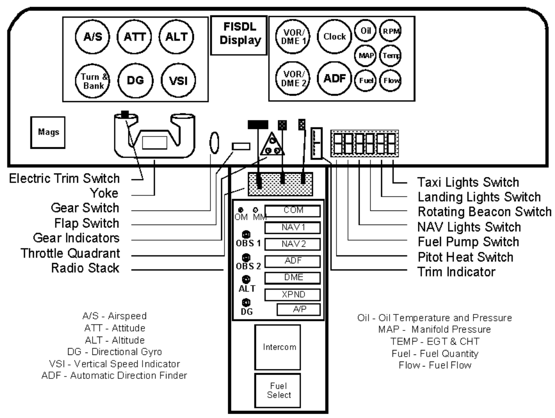
RTI

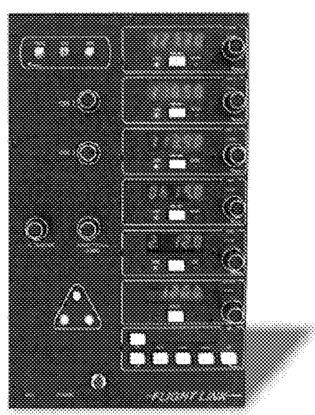
Simulation Cockpit Configuration

Weather Information Sources

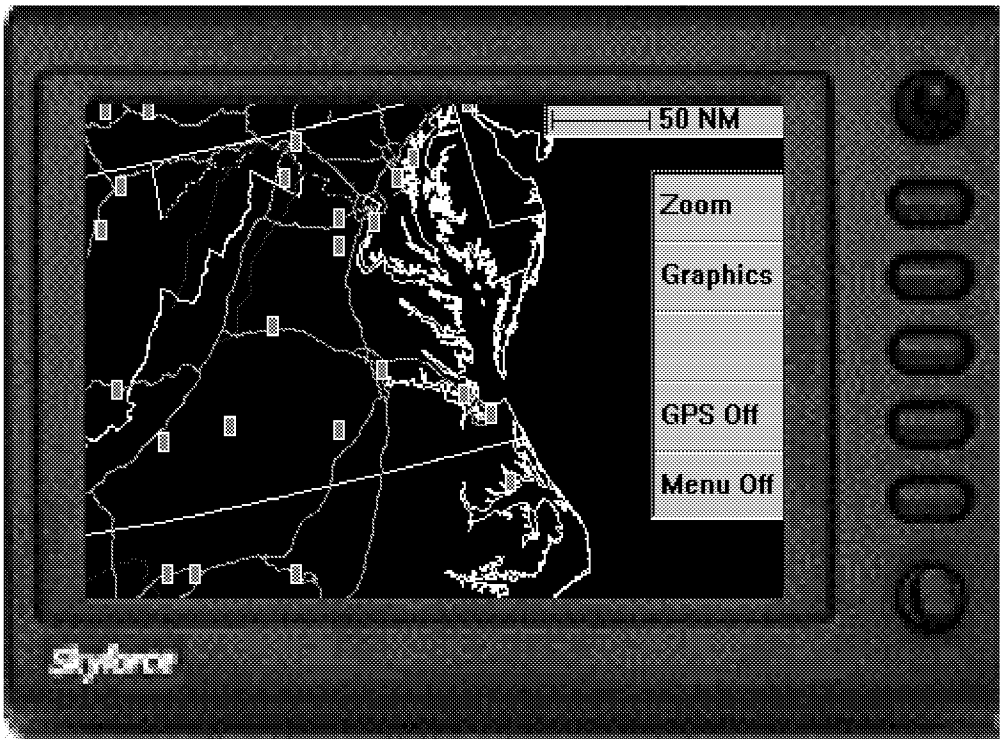
- ATIS
- Flight Service Station
- Flight Watch
- Virginia AWOS/ASOS Reports via radio
- Air Traffic Control (IAW normal NAS procedures)
  - Tower
  - Departure
  - Enroute
  - Approach
- Data Link Flight Information Services (FISDL) Display

Simulation Cockpit Configuration



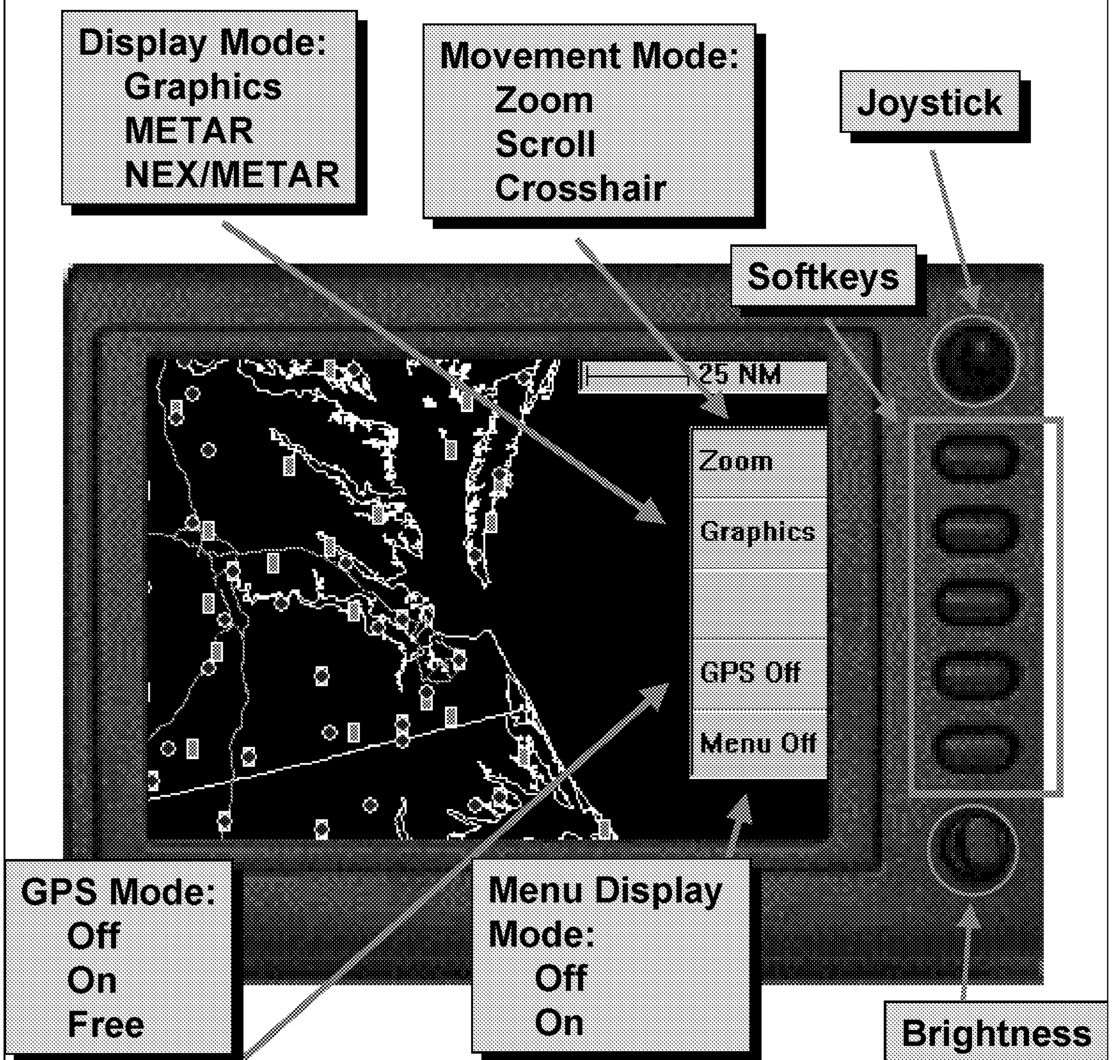


Simulation Cockpit Radio Stack

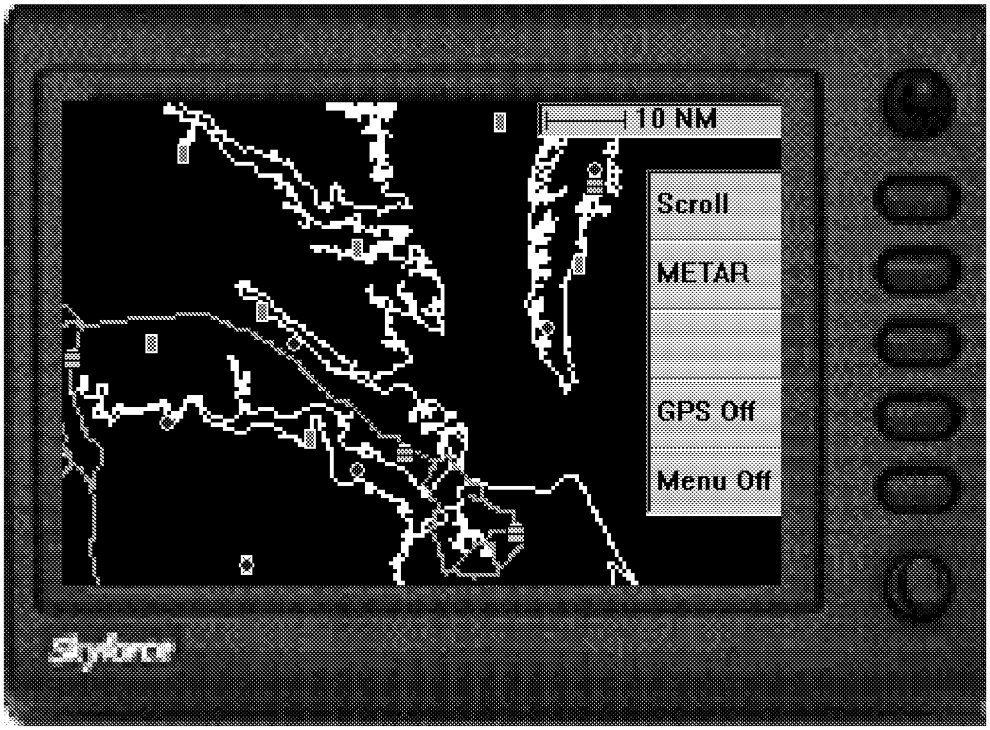


50 mile scale, graphics only mode
just showing airports in gray boxes

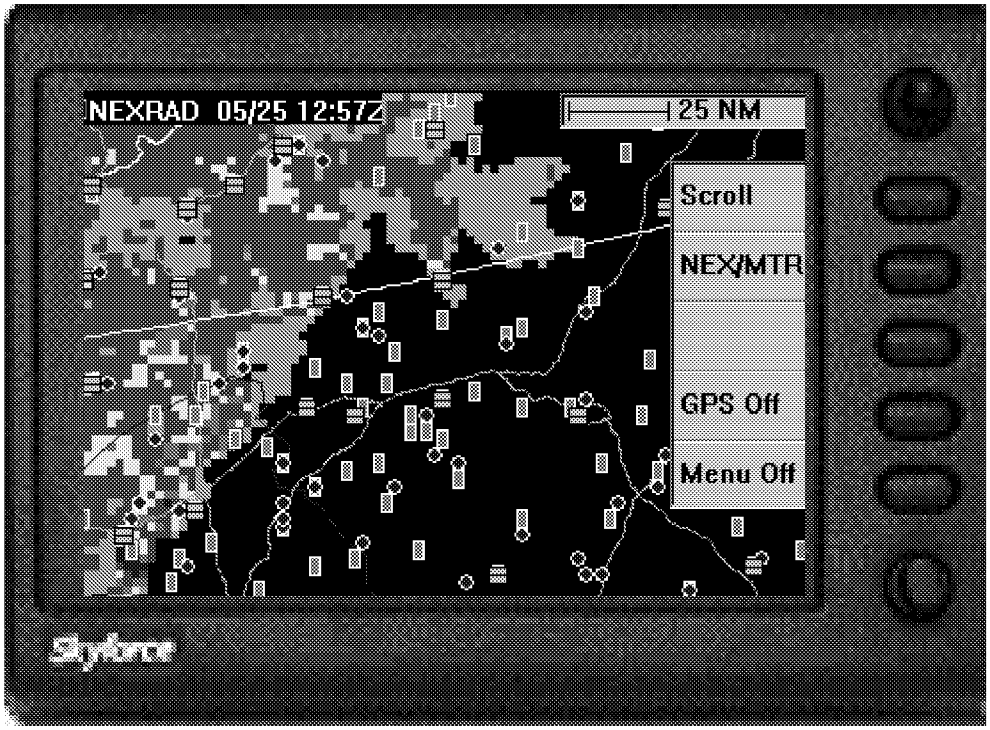
Modes



25 mile scale, graphics only mode. Showing airports in gray boxes, and NavAids in blue circles (navaids only shown in scales of 25 miles or less)



10 mile scale, METAR mode. Showing airports in gray boxes, NavAids in blue circles, and graphical METARs

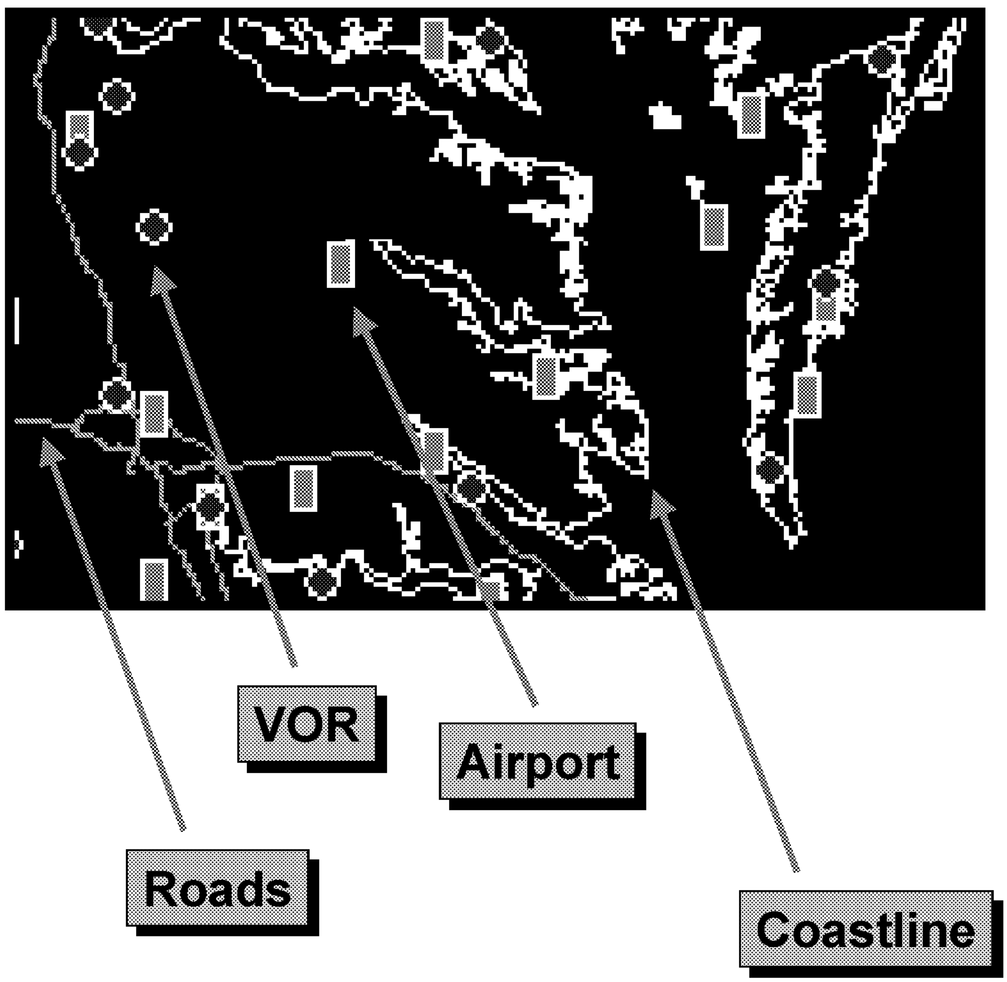


NEXRAD Intensity Levels:

Lt. Green	Light
Dk. Green	
Yellow	
Dk. Yellow	
Red	
Magenta	Severe

25 mile scale, NEXRAD/METAR mode.
Showing airports in gray boxes,
NavAids in blue circles, graphical
METARs and NEXRAD image with time stamp.

Graphic Symbols



Appendix J. Simulator Briefing and Training

All the pilots were provided the opportunity to complete a practice flight in the simulator. The researcher/trainer guided the subject pilot through maneuvers to acquaint them with the operation and performance of the simulator. Additional instruction was given to the pilots on the weather display.

Weather Display Experiment Simulator Familiarization Flight Syllabus

1. General explanation of cockpit layout:
   - Primary flight instruments
   - Secondary instruments
   - Sub panel controls and systems
   - Yoke controls
   - Radios, Autopilot, Intercom
   - Charts

2. Checklist explanation

3. Engine start and taxi

4. Run-up and system check

5. Normal takeoff and climb

6. Level off at 3000 feet (± 100 feet)

7. Shallow and steep banked turns to a heading (± 10 degrees)

8. Autopilot:
   - Engage/disengage
   - Pitch modifier
   - Altitude hold
   - Altitude modifier
   - Heading hold

9. VOR operation (on AP)

10. Use of weather display (on AP)

11. Vectors to normal VFR landing, touch-and-go (± 10 kts)

12. Go-around (± 10 kts)

13. Vectors to IFR approach and landing (second landing if required)

Appendix K. Observer Form

Pilot Name: ______________________ Subject # ________________

Condition: Ownship Only/Large Cells — Risk Score: _____ WX Score: _____

Richmond Decision

Actions	**Weather Information**
Take Off: ________________	**Radio Inquiry** (times)
Divert to Wallops: time ____ plate ____	Newport News Departure: ___________
Position: ___________________________	Flight Service: _____________________
Hold at: _____________	Flight Watch: ______________________
Time Began: ____________ Time End: _______________ Then:_______________________________	Richmond Approach: _______________
	Richmond Tower: ________________
	Other: ____________________________
Commence Richmond Approach	
OM time: ______________ Self Abort: _____________ Waved Off: _____________	**Automated Services** (times)
Abort Mission	Newport News ATIS: _______________ Richmond ATIS: ___________________ Other: ____________________________
Time: _______________ Place: __________________________	**Weather Display**
Distance to Red Cell at Break: _____	Textual METAR:
	Station: ________________ Time: __________________
Other Action: ___________________________________	**Other:** ___________________________________

All flight data confirmed: initial ________

Wallops Decision

Actions	Weather Information
Given Weather Warning at: _______	**Radio Inquiry** (times)
Penetrated Storms: _____Time	Richmond Departure: ____________
Position: ___________________	Flight Service: __________________
	Flight Watch: ___________________
Hold at: ____________	Norfolk Approach: _______________
Time Began: ___________ Time End: ______________ Then:_____________________	PAX River Approach: _____________ Wallops Tower: _________________ Other: _________________________
Diverted Around Storms: _________	**Automated Services** (times)
North: ________ South: ________	Richmond ATIS: _________________ Wallops ASOS: __________________ Other: __________________________
Closest Distance to Red Cell: ______	
Abort Mission	**Weather Display**
Time: ______________ Place: ___________________	Textual METAR: Station: _______________ Time: _________________
Other Action	**Other:**
______________________________	______________________________

All flight data confirmed: initial _______

Appendix L. Immediate Reactions Questionnaire

IMMEDIATE REACTIONS QUESTIONNAIRE

Please use the following scales to rate how much you agree or disagree with the statements offered. If some items appear to overlap, do not be concerned, but attempt to answer each on its own terms. There are no “right” or “wrong” answers, nor any agenda of preferred responses being sought by the researchers.

1. I took the medical emergency scenario seriously, in the sense that I factored the emergency into my decision making.

Disagree	**Disagree Somewhat**	**No Opinion**	**Agree Somewhat**	**Agree**

2. An advantage of the onboard Weather Display was showing the weather in real-time, that is, as it actually was at that moment?

Disagree	**Disagree Somewhat**	**No Opinion**	**Agree Somewhat**	**Agree**

3. I attribute much of my decision making to my interpretation of the Weather Display.

Disagree	**Disagree Somewhat**	**No Opinion**	**Agree Somewhat**	**Agree**

4. I tried to systematically sample all sources of weather information open to me.

Disagree	**Disagree Somewhat**	**No Opinion**	**Agree Somewhat**	**Agree**

5. I used the weather display, but felt the need to cross-check or verify my conclusions from conventional weather data sources (ATC, etc.).

Disagree	**Disagree Somewhat**	**No Opinion**	**Agree Somewhat**	**Agree**

6. I felt comfortable with the autopilot, in terms of understanding its use and operation.

Disagree	**Disagree Somewhat**	**No Opinion**	**Agree Somewhat**	**Agree**

7. Without the autopilot, my completion of the flight would have been compromised**.**

Disagree	**Disagree Somewhat**	**No Opinion**	**Agree Somewhat**	**Agree**

8. The degree of validity of the weather data appearing on the display was a factor I felt that I held in mind as I flew.

Disagree	**Disagree Somewhat**	**No Opinion**	**Agree Somewhat**	**Agree**

9. I have been monitoring the weather display time-stamp regularly in my instrument scan.

Disagree	**Disagree Somewhat**	**No Opinion**	**Agree Somewhat**	**Agree**

10. At the time of my arrival to the Richmond airport, I knew that there was a storm — (circle one)

a. about 10 nm northwest of the airport
b. about 5 nm northwest of the airport
c. near the airport
d. right at the airport

11. At the time I was en-route to Wallops Island, I saw across my path of direct flight, what I took to be —

a. a penetrable storm
b. a navigable opening between convective cells
c. a non-navigable opening between cells
d. a wall of convective activity requiring diversion.

12. On the weather display, I found the positional accuracy of the aircraft icon to be adequate.

Disagree	**Disagree Somewhat**	**No Opinion**	**Agree Somewhat**	**Agree**

13. In using the weather display, I felt that I generally knew the aircraft position relative to any storms.

Disagree	**Disagree Somewhat**	**No Opinion**	**Agree Somewhat**	**Agree**

14. I felt that I had adequate sources of weather information to make confident decisions.

Disagree	**Disagree Somewhat**	**No Opinion**	**Agree Somewhat**	**Agree**

Thank you for your help.

Appendix M. Structured Interview Guide

Richmond Decision Interview

The following questions refer to only the leg between Newport News and Richmond.

Decision Rationale

1. What led you to make the decision to:

____

2. What information did you use to make that decision?

____

3. Do you feel that you had enough information to make a sound and confident judgement of the situation?

____

4. What were your primary and secondary sources of weather information?

Primary: ____
Secondary: ____

5. Was there any information that you lacked and would have liked to have?

____

6a. Was there information that was available, but that you didn't use?

____

6b. Why didn't you obtain that information?

____

7. Do you feel that you had enough <u>time</u> to gather all the information that you wanted?

____

8. Did you ever consider holding?

____

Wallops Decision Interview

The following questions refer to only the leg between Richmond and Wallops Island.

Decision Rationale

9. What led you to make the decision to:

____

10. What information did you use to make that decision?

____

11. Do you feel that you had enough information to make a sound and confident judgement of the situation?

____

12. What were your primary and secondary sources of weather information?

Primary: ____
Secondary: ____

13. Was there any information that you lacked and would have liked to have?

____

14a. Was there information that was available, but that you didn't use?

____

14b. Why didn't you obtain that information?

____

15. Do you feel that you had enough <u>time</u> to gather all the information that you wanted?

____

The following questions apply to the entire flight.

Weather Interpretation

17a. How close are you willing to fly near hazardous weather conditions, and what do you consider hazardous conditions?

____

18. How close do you think that you flew to a red cell?

Richmond — ____
Wallops — ____

Routing

19. Did ATC help or hinder your route planning? ______________________________

20. At any time, did you consider totally aborting the mission? ____________________

21. If you had a chance to do the flight again, would you do anything different?

____

Weather Display

22. How would you compare the weather display information to other sources of weather information (ATIS, Flight Watch, etc.)?

____

23. Did you use the weather display to help you navigate?

____

24. Do you feel that the weather display increased or decreased your workload?

____

25. Did you trust the weather display to give you correct information?

____

26. Was there any confusion with the ownship symbology?

____

27. How did you determine your distance to the weather cells?

____

Comfort Zone

28a. Did you feel ahead of the airplane? ___________________________________

28b. If not, at what times did you feel behind the airplane, and what was the biggest contributor?

____

Appendix N. Weather Display Questionnaire

Subject Pilot #: ___________________ Date: ______________________

1. Approximately how many total hours do you have? _________________

2. Approximately how many actual instrument hours do you have? _____________

3. Approximately how many hours do you have under the hood in flight? _________

4. Approximately how many hours do you have in a simulator? _________________

5. Approximately how many instrument hours do you have in the last 90 days? ____

6. What ratings do you have? (circle as many as apply)

Private	Commercial		ATP	Glider	Airship	Sea
Instrument	CFI	CFII	MEI	Helicopter	A&P IA	

7. What type of aircraft do you have most of your experience in?

____

8. Have you ever used a datalinked inflight weather display system in a flight? _____
(not including onboard radar or Stormscope)

If yes, how many flights do you have with it? ___________________

9. If you answered yes to the last question, how many times have you used that data-linked inflight weather display system to make actual weather judgements? (Instead of just experimenting with the display).

____

10. Have you had any training in weather interpretation other than basic pilot training (for example, courses in meteorology)? If so, what?

____

11. What is your usual method of obtaining a pre-flight weather briefing?
(DUATS, FSS phone, etc.)

____

12. Have you tried other alternate methods of weather briefings, and what was your experience?

____

13. In using this weather display today, did you find the operation straightforward? If not, what operations of this weather display did you find difficult?

____

14. In using this weather display today, did you find the graphical METAR symbology useful? If not, what features did you find difficult?

____

15. In using this weather display today, did you find the textual METAR presentation useful? If not, what features did you find difficult?

____

16. Considering your use of the weather display today, would you like to see any additional features or change any existing features?

____

17. How did the weather display affect your decisions that you made today?

____

18. Do you feel that you needed more training on the weather display?

____

If so, in what areas?

____

19. How did you determine the age of the weather information?

____

20. Were there any features about the weather display that caused you to cast doubt as to its usefulness in normal, real world, operation?

____

21. Did you find that the weather display <u>increased</u> or <u>decreased</u> your **workload**?

____

22. <u>How</u> did the use of the autopilot help or hinder the use of the weather display?

____

23. Did you find that the weather display <u>increased</u> or <u>decreased</u> your **situational awareness**?

____

Thank you very much for participating in our study, we appreciate your help.

Appendix O. Air Traffic Control Scripts

Communication Exchanges Between Pilot and ATC

The following is a typical communication exchange for the mission. Each pilot deviated from this typical exchange, some more than others, but only to the extent of clarifying radio calls, routing changes and exchanges to gather weather information.

FIRST LEG

SUMMARY: INSTRUMENT FLIGHT FROM NEWPORT NEWS/ WILLIAMSBURG (PHF) AIRPORT TO RICHMOND INTERNATIONAL (RIC) AIRPORT VIA DIRECT HOPEWELL V260 RICHMOND. SEVERE THUNDERSTORM APPROACHING RIC. PILOT TO DECIDE WHETHER TO CONTINUE APPROACH AND ATTEMPT LANDING AT RIC, HOLD AWAITING WEATHER IMPROVEMENT, OR BY-PASS RIC AND REQUEST CLEARANCE TO WALLOPS, VA (WAL) FLIGHT FACILITY.

N73Y: (Tunes 128.65 for ATIS)

ATIS: THIS IS NEWPORT NEWS WILLIAMSBURG INTERNATIONAL TOWER INFORMATION BRAVO. 1800 ZULU MEASURED CEILING 1000 OVERCAST VISIBILITY 3 MILES. TEMPERATURE14 DEWPOINT 12 WIND 090 AT 10 ALTIMETER 29.92. LANDING AND DEPARTING RUNWAY 7. ILS RUNWAY 7 APPROACH IN USE. ADVISE YOU HAVE BRAVO.

N73Y: Newport News clearance delivery, Malibu 2573Y ready for clearance. (121.65)

ATC: MALIBU 2573Y CLEARED TO RICHMOND VOR VIA DIRECT HOPEWELL V260 RICHMOND MAINTAIN 5000. SQUAWK 1424.

N73Y: Roger, cleared to Richmond via direct Hopewell V260 Richmond maintain 5000.

(Tunes 121.9)

N73Y: Newport News ground control, N73Y ready to taxi, have information Bravo.

ATC: N73Y, GROUND CONTROL, TAXI STRAIGHT AHEAD THEN LEFT TO RUNWAY 7. WHEN READY FOR TAKEOFF, CONTACT TOWER ON 118.7.

N73Y: Malibu 73Y, Roger.

(Tunes 118.7)

N73Y: Tower, N73Y ready for takeoff.

ATC: N73Y MAINTAIN RUNWAY HEADING FOR RADAR VECTORS HOPEWELL MAINTAIN 2000, EXPECT CLEARANCE TO 5000 WITHIN 5 MINUTES AFTER DEPARTURE. CLEARED FOR TAKEOFF RUNWAY 7.

N73Y: Malibu 73Y Roger, cleared for takeoff.

(Departs)

ATC: MALIBU 73Y CONTACT NORFOLK DEPARTURE CONTROL ON 124.9.

(Tunes 124.9)

N73Y: Norfolk departure control, this is N73Y climbing to 2000 on runway heading.

ATC: N73Y ROGER, IN RADAR CONTACT. TURN LEFT PROCEED DIRECT HOPEWELL, CLIMB AND MAINTAIN 5000.

N73Y: Malibu 73Y Roger, Proceeding direct Hopewell.

N73Y: Norfolk departure control, request permission to leave frequency for Richmond ATIS.

ATC: N73Y FREQUENCY CHANGE APPROVED. ADVISE WHEN BACK ON MY FREQUENCY.

(N73Y tunes 119.15 for RIC ATIS)

ATIS: THIS IS RICHMOND TOWER INFORMATION DELTA. 1910 ZULU MEASURED CEILING 200 OVERCAST VISIBILITY THREE QUARTERS THUNDERSTORMS MODERATE RAIN SHOWERS TEMPERATURE 14 DEWPOINT 12 WIND 300 AT 10 ALTIMETER 29.92. ILS RUNWAY 34 APPROACH IN USE. LANDING AND DEPARTING ON RUNWAY 34. ADVISE YOU HAVE DELTA.

(Tunes 124.9)

N73Y: Departure control, N73Y back on your frequency.

ATC: MALIBU 73Y ROGER.

ATC: MALIBU 73Y CONTACT RICHMOND APPROACH CONTROL ON 134.7.

(Tunes 134.7)

N73Y: Richmond approach control, this is Malibu 73Y. Have information Delta.

ATC: N73Y, RICHMOND APPROACH CONTROL, ROGER, DESCEND AND MAINTAIN 2000. EXPECT VECTORS TO ILS RUNWAY 34 APPROACH.

N73Y: N73Y, Roger, descending to 2000.

ATC: N73Y DEPART HOPEWELL VOR HEADING 300 FOR A VECTOR TO ILS RUNWAY 34 FINAL APPROACH COURSE.

N73Y: N73Y, Roger, depart Hopewell heading 300 for vector to ILS runway 34 approach course.

ATC: MALIBU 73Y, 4 MILES SOUTHEAST OF KAFKA, MAINTAIN 2000 UNTIL ESTABLISHED ON THE LOCALIZER, CLEARED FOR ILS RUNWAY 34 APPROACH. CONTACT TOWER ON 121.1 PASSING KAFKA.

N73Y: Malibu 73Y, Roger, cleared for approach, tower 121.1 at KAFKA.

(Tunes 121.1)

ATC BROADCAST: ATTENTION ALL AIRCRAFT IN RICHMOND AREA. LOW LEVEL WINDSHEAR ADVISORIES IN EFFECT FOR RICHMOND INTERNATIONAL AIRPORT.

(ATC TO IMPROVISE HOLDING, CLEARANCE TO WALLOPS, OR MISSED APPROACH DEPENDING ON PILOTS DECISION/REQUEST WITH WEATHER ENCOUNTERED.)

2ND LEG

SUMMARY: INSTRUMENT FLIGHT FROM RICHMOND (RIC) TO WALLOPS FLIGHT FACILITY (WAL) VIA RICHMOND DIRECT HARCUM DIRECT JAMIE V1 MAGGO. AT PILOT'S REQUEST AFTER HOLDING OR EXECUTING A MISSED APPROACH AT RICHMOND.

ATC: MALIBU 73Y CLEARED TO THE MAGGO INTERSECTION VIA DIRECT HARCUM DIRECT JAMIE V1 MAGGO. CLIMB AND MAINTAIN 5000 CONTACT RICHMOND DEPARTURE CONTROL ON 126.4.

N73Y: Malibu 73Y, Roger, proceeding direct Harcum climbing to 5000, changing to 126.4.

(Tunes 126.4)

N73Y: Richmond departure control Malibu 73Y proceeding direct Harcum climbing to 5000.

ATC: N73Y, ROGER, IN RADAR CONTACT.

N73Y: Departure control, N73Y, request permission to leave frequency for Wallops ASOS information.

ATC: N73Y FREQUENCY CHANGE APPROVED. ADVISE WHEN BACK ON MY FREQUENCY.

(Tunes 119.175)

WALLOPS AUTOMATED SURFACE OBSERVATION WIND 170 AT 6 VISIBILITY 3 MILES. MEASURED CEILING 1000 BROKEN TEMPERATURE 23 DEWPOINT 16 ALTIMETER 29.92.

(Tunes 126.4)

N73Y: Richmond departure control, Malibu 73Y back on your frequency.

ATC: MALIBU 73Y, ROGER.

ATC: (When N73Y is approximately 10-15 nm from weather cells depicted.) N73Y, I SHOW WEATHER AHEAD. ADVISE INTENTIONS.

(Possible requests from N73Y as weather is encountered.)

N73Y: 1) Request deviation to south/north to avoid weather.
2) What do you show for weather on my route of flight?
3) Request vector around weather.
4) Request a new route/altitude to avoid weather.
5) Request frequency change for Flight Watch or FSS.

ATC: RESPOND TO SPECIFIC REQUEST, I. E:

1) ***UNABLE TO APPROVE DEVIATION TO THE NORTH. RESTRICTED AREA 6609 IN USE.***
2) ***DEVIATION TO THE SOUTH APPROVED.***
3) ***I SHOW HEAVY WEATHER ON YOUR PROJECTED FLIGHT PATH.***
4) ***ROGER, TURN RIGHT HEADING ___FOR A VECTOR SOUTH OF WEATHER.***
5) ***FREQUENCY CHANGE APPROVED. ADVISE WHEN BACK ON MY FREQUENCY.***

ATC: N73Y CLEAR OF WEATHER FLY HEADING___ FOR VECTOR TO V1.

N73Y: N73Y, Roger, turning to heading___.

ATC: N73Y CONTACT PATUXENT APPROACH CONTROL ON 127.95.

N73Y: N73Y Roger changing to 127.95

(Tunes to 127.95)

N73Y: Patuxent approach control, this is Malibu 73Y.

ATC: N73Y THIS IS PATUXENT APPROACH CONTROL, EXPECT VOR/DME RUNWAY 10 APPROACH TO WALLOPS. ALTIMETER 29.92.

N73Y: N73Y, Roger.

ATC: N73Y, DESCEND AND MAINTAIN 2000.

N73Y: N73Y, Roger, leaving 5000 for 2000.

ATC: (5Miles south of MAGGO) TURN RIGHT HEADING 060 INTERCEPT THE SALISBURY 24.1 MILE ARC CLEARED FOR VOR/DME RUNWAY 10 APPROACH.

N73Y: N73Y, Roger, heading 060 to the arc, cleared for VOR/DME Runway 10 approach.

ATC: MALIBU 73Y CONTACT WALLOPS TOWER ON 126.5.

N73Y: Malibu 73Y , Roger changing to tower.

(Tunes 126.5)

N73Y: Wallops Tower, this is Malibu 73Y on approach to runway 10.

ATC: MALIBU 73Y, WALLOPS TOWER, WIND 170 AT 6, CLEARED TO LAND RUNWAY 10.

Appendix P. Enroute Weather Report Scripts

The following weather report script was available to the Air Traffic Controller to be used as updated weather information. The reports were available while the mission was in progress, but the information was only given to the pilot if requested. These reports were available through the Flight Service Station radio, Enroute Flight Advisory Service (Flight Watch) and Air Traffic Control frequencies. Also included in this Appendix are the scripts used in the pre-recorded weather broadcasts of: Newport News ATIS, Richmond ATIS and Wallops Island ASOS.

En-route Abbreviated Weather Reports

AIRMET (WA) TANGO FOR OCNL MOD TURB BLO 060 for MD, VA and NC is current.

ZDC CWA01 1855Z Valid Until 2100Z
FROM CSN TO RIC TO DAN TO LYH TO CSN

BKN AREA OF TSRA INCRG IN INTENSITY AND COVERAGE MOV EAST
Washington Center Weather Advisory zero, one valid until two, one, zero, zero universal coordinated time. From Casanova, Virginia to Richmond, Virginia, to Danville, Virginia, to Lynchburg, Virginia, to Casanova, Virginia. Broken area of thunderstorms and rain increasing in intensity and coverage, moving east.

ZDC CWA02 1855Z VALID UNTIL 2100Z
FROM SBY225025 TO RIC090050

BKN LINE OF TSRA INCRG IN INTENSITY AND COVERAGE MOV LITTLE
Washington Center Weather Advisory zero, two valid until two, one, zero, zero universal coordinated time. From two, five miles Southwest of Salisbury, Maryland to Five, zero miles East of Richmond, Virginia. Broken line of thunderstorms and rain increasing in intensity and coverage, moving little.

RIC SP 1910Z M002 OVC 3/4TRW 58/55/9012G16/992/TSTM OVHD OCNL LGTCCCG
Richmond International Airport special weather report one, niner, one, zero universal coordinated time. Measured ceiling, two hundred, overcast, visibility ¾, thunderstorm, moderate rain showers, temperature five, eight, dew point five, five, wind zero, nine, zero, at one two, gusting one six, altimeter two niner nine two, thunderstorm overhead, occasional lightning cloud to cloud, and cloud to ground.

LKU SP 1905Z M005 OVC 1/2TRW+FG 57/57/2615G25/950/TSTM OVHD MOV E <u>OCNL LGTCCCG</u>
Louisa County, Freeman Airport special weather report one, niner, zero, five universal coordinated time. Measured ceiling five hundred overcast, visibility one half, thunderstorm, heavy rain showers, fog, temperature five, seven, dew point five, seven, wind two, six, zero at one, five gusting two, five, altimeter two, niner, five, zero, thunderstorm overhead moving East, occasional lightning cloud to cloud, and cloud to ground.

WAL SA 1846Z (Current)
MVP SA 1846Z (Current)
SBY SA 1845Z (Current)

UA: /OV RIC /TM 1900Z /FL 010-SFC /TP C210 /TB SVR /RM LLWS FA
Urgent pilot report over Richmond, Virginia at one, niner, zero, zero universal coordinated time. From one thousand feet to the surface, a Cessna two, one, zero reported severe turbulence and low-level wind shear on final approach.

UA: /OV SBY /TM 1905Z /FL 060 /TP BE55 /TB NEG /RM MANY BLD-UPS OVR <u>BAY SW</u>
Pilot report over Salisbury, Maryland at one, niner, zero, five universal coordinated time. At six thousand feet, a Beech five, five reported negative turbulence, and many build-ups over the bay Southwest.

<u>UA: /OV RIC090050 /TM 1900Z /FL080 /TP PA46 /TB NEG /RM BLD-UPS OVR BAY N</u>
Pilot report five, zero miles East of Richmond, Virginia at one, niner, zero, zero universal coordinated time. At eight thousand feet, a Piper four, six reported negative turbulence and build-ups over the bay North.

Satellite Imagery indicates solid Build-Ups forming throughout Central Virginia.

Weather Radar indicates solid light to moderate precipitation with increasing areas of Heavy precipitation developing throughout Central Virginia moving eastward into the Richmond (RIC), and Mecklenburg-Brunswick (AVC) areas.

Newport News ATIS

this is Newport News-Williamsburg International tower information bravo, eighteen hundred zulu
measured ceiling one thousand overcast
visibility three miles
temperature one-four
dew point one-two
wind, zero-niner-zero at one-zero
altimeter, two-niner-niner-two
landing and departing runway seven
ILS runway seven approach in use
advise you have bravo

Richmond ATIS

this is Richmond tower information delta, nineteen-ten zulu
measured ceiling two-hundred, overcast
visibility three-quarters
thunderstorms, moderate rain showers
temperature one-four
dewpoint one-two
wind, three-zero-zero at one-zero
altimeter, two-niner-niner-two
ILS runway three-four approach in use
landing and departing runway three-four
advise you have delta

Wallops Island ASOS

Wallops automated surface observation
wind, one-seven-zero at six
visibility, three miles
measured ceiling one-thousand, broken
temperature, two-three
dewpoint, one-six
altimeter, two-niner-niner-two

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13. ABSTRACT (*Maximum 200 words*)
A two-phase experiment was conducted to explore the effects of data-link weather displays upon pilot decision performance. The experiment was conducted with 49 instrument rated pilots who were divided into four groups and placed in a simulator with a realistic flight scenario involving weather containing convective activity. The inflight weather display depicted NEXRAD images, with graphical and textual METARs over a moving map display.

The experiment explored the effect of weather information, ownship position symbology and NEXRAD cell size resolution. The phase-two experiment compared two groups using the data-linked weather display with ownship position symbology. These groups were compared to the phase-one group that did not have ownship position symbology. The phase-two pilots were presented with either large NEXRAD cell size (8 km) or small cell size (4 km). Observations noted that the introduction of ownship symbology did not appear to significantly impact the decision making process, however, the introduction of ownship did reduce workload. Additionally, NEXRAD cell size resolution did appear to influence the tactical decision making process.

14. SUBJECT TERMS
Aviation Weather, DataLink Weather, Flight Information Services, Cockpit Weather NexRad Display, METAR Display, Weather Display, Weather Decision Making

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