

The Effect of NEXRAD Image Looping and National Convective Weather Forecast Product on Pilot Decision Making in the Use of a Cockpit Weather Information Display

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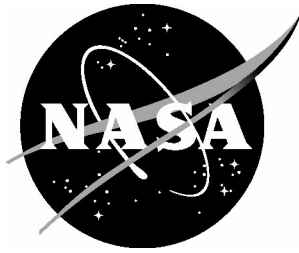
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Executive Summary

Reason for Study

The study described herein is the third in a series of cockpit weather experiments (CWE III) conducted by the RTI International's Center for Aerospace Technology, and sponsored by the FAA and NASA. The first in the series of experiments (CWE I) investigated the effect of a prototype airborne weather display on pilot performance in a full mission simulator developed expressly for the study of new cockpit technologies in general aviation. The second in the series of experiments (CWE II) further investigated the effect of weather information displays on pilot performance. While the cockpit weather information displays implemented in these two studies substantially increased the pilots' awareness of the general location of convective weather in their vicinity, they did not improve the decision making of the pilots using the display.

The study described herein was undertaken to investigate the potential of several improvements to cockpit weather displays to better support the decision making of general aviation pilots in avoiding hazardous convective weather conditions.

Two methods were identified that could provide information concerning convective cell movement: NEXRAD mosaic image looping, and the National Convective Weather Forecast (NCWF) product. The purpose of the experiment reported herein (CWE III) was to determine the effects of the use of NEXRAD looping and the use of the NCWF product on pilot workload and decision making. The experiment was also specifically designed to investigate the potential misuse of these two techniques for display of hazardous weather information as they relate to decision making in IFR flight, so as to support the development of recommendations to be provided to the FAA and to the display manufacturers for the design and use of such displays.

Overview of Study

The experiment was conducted with forty eight current instrument rated general aviation pilots who were divided into three 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. Visibility for the pilot was essentially zero from shortly after takeoff until just before landing.

The control group of 16 pilots performed the flight with access to conventional sources of pre-flight and in-flight weather products. In addition to the conventional weather sources, the two treatment groups of 16 pilots each were provided with a near real-time weather display in the cockpit that presented text and graphical weather products to be provided by datalink service. Both treatment groups were equipped with a display providing NEXRAD mosaic images, graphic depiction of METARs, and access to text METARs. The weather information display used by one of the two treatment groups incorporated a NEXRAD image looping feature permitting the pilot to select a rapid sequence replay of the NEXRAD images received in the aircraft during the flight. The weather information display used by the second of the two

treatment groups incorporated the National Convective Weather Forecast (NCWF) product overlaid on the NEXRAD display. The NEXRAD image looping display provided the pilot with a history of storm movement from which the pilot had to estimate the future movement of the storm. The NCWF display provided the pilot with a depiction of direction and speed of storm movement, and a forecast of the predicted location of the storm in one hour.

Key Conclusions of Study

- Both of the cockpit weather displays used in the experiment provided a significant increase in awareness to the pilot of his/her situation with respect to location, proximity, and direction of movement of hazardous convective weather conditions.
- Both cockpit weather displays used in the experiment provided an incomplete understanding of the information required to successfully deal with hazardous convective weather conditions, and will require substantial pilot training to permit their safe and effective use.
- Overuse of both versions of the data link NEXRAD display by the pilots, at the expense of accessing other essential sources of information such as ATC and weather service providers such as FSS, AWOS, ASOS, ATIS, etc., offset the improved situation awareness and other benefits provided to the pilots by the weather displays to the extent that the decision making performance of the pilots having the weather displays was found to be no different statistically than that of the pilots in the control group having no weather display.
- There was no significant difference in the effect of the two different types of weather displays on the likelihood that the pilots would over depend on their weather display in their navigation and decision making in dealing with hazardous weather conditions.
- A minimum level of training, and a curriculum providing this minimum level of training, is clearly required to prevent misuse of any variant of the data link NEXRAD cockpit weather display, and to permit an acceptable pilot workload.
- The safe and effective use of a cockpit weather display in actual instrument conditions requires the support of an autopilot so as to maintain an acceptable workload for most pilots.

Recommendations

Recommendations are provided for possible incorporation in the FAA Aeronautical Information Manual (AIM) and draft advisory circulars. These recommendations address the following topics:

- The requirement 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 so as to 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.

- The requirement that the pilot 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.
- The mental activity required to use the FISDL display can increase the pilot's workload in instrument conditions for some pilots. An autopilot can offset this workload increase, freeing up the mental processes to support more effective use of the display. The pilots in this study reported that an autopilot is essential to their effective use of the FISDL display.

Additional recommendations are provided for the consideration of the FISDL display system manufacturers in the areas of display content and features, provision of comprehensive user training for display users, and emphasis to users of the need for an autopilot to permit safe and effective use of the display.

Recommendations are also provided for further research, including the conduct of further evaluations of specific FISDL issues to support the implementation of FISDL standards, further development of display enhancements and concepts for information integration, and the development of training curriculum for weather information 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 and current NTSB accident statistics). 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. 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.

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 required to integrate these various pieces of information into an accurate mental model of the outside world. This information integration task often requires increases in 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 information 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. With reduced 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 pilots 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 with the first of these services becoming available in 2002. In addition to these first two industry efforts, several other vendors are nearing certification and implementation of various weather information display systems. The FISDL systems 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 current FAA Aeronautical Information Manual provides a description of FISDL and guidance for pilots in its use. See Appendix B, of the current AIM, dated February 21, 2002. 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.

1.1 Potential Issues with Datalinked Cockpit Weather Information Displays

The introduction of datalinked weather information will present pilots with new challenges of interpretation, prediction, and action. Studies to date suggest that a “keep out of the red” heuristic may be adopted when, for example, viewing a NEXRAD baseline reflectivity product that indicates amount of rainfall according to a color-coding scheme (Yuchnovicz, Novacek, Burgess, Heck, & Stokes, 2001). 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. Thus, pilot interpretations based on a faulty understanding of the weather information display, such as the red-cell avoidance heuristic, can be extremely dangerous. There is also evidence that some pilots interpret delayed data-linked weather information as though it were real time and definitive, instead of delayed and probabilistic. Inappropriate interpretations of cockpit weather information could have serious consequences for aviation safety.

1.1.1 Use of Display to Predict Location of Hazardous Weather

Pilots may use the cockpit weather information for prediction. One potentially significant issue in the use of displayed weather for prediction and forecasting is that the weather information is not real time, which is different from most other cockpit data including the data provided by on-board weather radar. In the best of circumstances, the latest graphical NEXRAD products will already be five to seven minutes old when received from the weather service provider for transmission to the aircraft and will be refreshed at a rate of 5-7 minutes. Thus, the data available to the pilot via the cockpit weather display could be as old as 14 minutes. It is not clear whether pilots will try to extrapolate, from delayed data, the current position of storm cells or adopt a more conservative approach. Also, it is not known if pilots will account for the age of the weather data in their extrapolations. If pilots do choose to use the weather information displays for prediction, their abilities to make accurate storm movement forecasts from delayed data is unknown.

Pilots may use their interpretations of the weather information to take actions. There is concern, however, that some pilots might try to use the data-linked weather information to make tactical control actions (e.g., to weave their way between areas of perceived danger). The current level of technology does not afford weather information displays enough accuracy to be used for tactical navigation or as a substitute for traditional navigation aids (e.g., VORs). The current level of technology only allows pilots to use datalinked cockpit weather information displays safely for strategic use (e.g., to plan a route around possible danger zones). Thus, pilots might become overconfident in their ability to judge accurately where it is safe or unsafe to fly and use their interpretations of

the weather information to make tactical decisions and actions, which could be extremely hazardous.

1.1.2 Mode Awareness

Mode awareness concerns the extent to which operators perform actions that are appropriate given the particular mode of system operation. Mode errors occur when operators take a particular action or interpret information in ways that are appropriate in an inactive mode of system operation, but inappropriate in the active mode of system operation. Thus, mode errors are likely to occur when the operator has failed to remember the active mode of system operation (Norman, 1988). Breakdown in mode awareness of cockpit weather information displays could have large impacts on pilot workload and performance. Failure to appreciate the scale selected on a weather information display, for example, can cause a pilot to fly too close to hazardous weather conditions to permit safe flight.

Mode awareness issues are particularly important in automated cockpits e.g., some autopilots have numerous modes of operation (Sarter & Woods, 1995). Note that cockpit weather information displays may have more modes of operation than most standard autopilots. Mode errors most often occur during automated performance or under conditions of high workload (Wickens & Hollands, 2000). System designers can aid mode awareness by making the active mode of the system salient.

1.1.3 Cognitive Tunneling

Pilots may overtrust cockpit weather information displays, which could influence their normal weather information processing strategies. For instance, pilots may over rely on cockpit weather information displays at the expense of failing to sample conventional weather information sources. Such effects are generally referred to as cognitive tunneling.

There is evidence that cognitive tunneling effects are exacerbated under times of high workload or high stress, i.e., under attentional narrowing, (Moray & Rottenberg, 1989). Also, under time stress it is known that operators attend more to information sources that are visible, readily interpretable, and directly in their forward field of view (Wickens et al, 1998). For instance, Wickens and Kramer (1997) found that novice pilots tended to cognitively tunnel on what they considered to be the most important cockpit instrument, and failed to monitor other instruments that also provided important information when performing high-workload maneuvers. Thus, pilots who overtrust cockpit weather displays may fail to sample other sources of important weather information, especially in situations characterized by high time stress or high workload. For instance, pilots who cognitively tunnel on cockpit weather information displays may be less likely to collaborate with NAS ground weather sources (AFSS, EFAS, HIWAS, ASOS, etc.) concerning hazardous weather. There may be serious implications for aviation safety if such effects are found with cockpit weather displays. There is evidence, however, that the negative effects of overtrust, high workload and stress (e.g., cognitive tunneling effects) can be attenuated through increased experience (Stokes, Kemper, & Kite, 1997; Stokes & Kite, 1994; and Mandler, 1984) and training (Johnston & Cannon-Bowers, 1996).

1.1.4 Map Orientation

Some cockpit weather information displays are fixed displays, in which the north direction is permanently aligned with the top of the display (i.e., a north-up display). In such displays the position of the ownship symbol moves in relation to the stationary map to show the aircraft's current position. Thus, north-up displays present information about ownship's location in a world-centered reference frame, that is, in terms of the ownship's position on the globe (Aretz, 1991).

Conversely, rotating displays are those in which ownship's direction of travel is constantly aligned with the top of the display (i.e., track-up displays). In track-up displays the ownship icon is stationary. To indicate change in flight path direction, the map rotates beneath the ownship symbol until the current direction of travel is depicted at the top of the display. Thus, track-up displays present information about ownship position in an ego-centered reference frame, that is, in a manner consistent with how the world is viewed through the eyes of the pilot (Aretz, 1991).

Past research has shown that different tasks benefit from different orientations. Local guidance tasks, like flight control, benefit from track-up display orientation because the pilot does not have to perform the mental rotations necessary to make the display congruent with the forward field of view (Aretz, 1991; Harwood, 1989)¹. Because track-up maps rotate, however, the positions of landmarks change as flight path changes. Thus, if it is important for the pilot to develop a global awareness (i.e., cognitive map) of the world or to identify their location relative to specific landmarks (e.g., restricted areas), then a north-up orientation is recommended (Aretz, 1991; Harwood, 1989). Also, fixed displays (i.e., north-up displays) facilitate better communications between other pilots in the airspace and air traffic controllers (Baty, 1976 as cited in Wickens et al. 1996).

It is not clear whether the optimal orientation for cockpit weather displays is track-up or north-up. Currently, most weather displays have a north-up orientation, which is probably optimal for strategic planning and collaboration with ATC concerning hazardous weather. Currently, some cockpit weather information displays allow pilots to select between track-up and north-up orientations, which could cause confusion. Thus, map orientation is an important consideration for new datalinked cockpit weather information technologies.

¹ When navigating to landmarks within an ego-centered reference frame there is a direct correlation between landmarks depicted on the track-up display and the position of those same landmarks in the pilot's forward field of view. That is, a landmark that is depicted on the map 15° to the left of ownship track will be seen 15° to the left in the pilot's forward field of view. To navigate towards this landmark, the pilot must make a 15° left turn. However, the congruence between landmark locations out-the-window and depicted on a north-up display are not quite as intuitive. This incongruence between out-the-window and north-up reference frames is exacerbated when an aircraft is flying south on a north-up display. For instance, in order to navigate towards a landmark that is depicted 15° to the left of the ownship icon, while traveling south on a north-up display, would require a 15° right turn.

1.1.5 Appropriate Use of Colors

Color is a visual cue that is incorporated into many cockpit weather information products. The great advantage of color is its strong association with population stereotypes and logic. To capitalize on population stereotypes it is suggested that red be used to denote warning, yellow be used to denote caution, and green be used to denote satisfactory status (Stokes, Wickens, & Kite, 1990; Proctor & Van Zandt, 1994). Tullis (1981) and Kopala (1979) noted that pilots prefer interacting with colored displays. Stokes et al. (1990) reported that pilots believed the use of color increased the pictorial realism of displays. Color displays have also been shown to improve pilots' abilities to detect details in simulated landings and response accuracy when access to necessary information is brief (Stokes, et al., 1990).

Although color-coding can be a useful tool, several issues must be addressed when introducing color-coding into weather information displays. Because of limits of absolute color judgments within the sensory continuum, no more than five or six distinct colors should be incorporated into cockpit weather information displays. Stokes et al. (1990) recommends yellows, greens, oranges, and reds for displays. Also, colorblindness is an important issue to consider, because approximately 10% of pilots suffer from some form of colorblindness (Sekular & Blake, 1994) with red-green confusions being the most predominant. Furthermore, pilots that are red-green colorblind are perhaps at greatest risk because most cockpit weather information displays employ red to highlight areas of hazard and green to highlight areas of non-hazard. Thus, cockpit weather displays should incorporate redundant coding schemes so older pilots and pilots with color perception impairments can discern hazard/no hazard information in ways unrelated to color. Appropriate use of color is a major human factors' consideration for cockpit weather information displays.

1.1.6 Undertrust of Cockpit Weather Information Displays

Pilots may not fully utilize cockpit weather information displays because they undertrust or even mistrust the technology. Trust in technology should be calibrated (i.e., directly proportional) to its reliability (Wickens et al., 1997). There is evidence, however, that human trust in technology is not always well calibrated (see Liu, Fuld, & Wickens, 1993). Undertrust may occur for several reasons. For instance, users may not understand the operation of the hidden components of the technology (Wickens et al., 1997). Also, new technology may be confusing to operators or operators may underestimate the accuracy of the technology, which are also conditions that invite undertrust (Parasuraman & Riley, 1999; Sorkin, 1989).

Pilot undertrust in cockpit weather information displays could be a major consideration. For instance, low-resolution weather displays "distort" the weather situation by making the weather appear more hazardous than is actually the case (Novacek et al., 2002). Thus, the information presented by the weather display may not match pilots' out-the-window view. Such false alarms are likely to lead to mistrust and abandonment of weather information displays (see Parasuraman, Maoulaoua, & Hillburn, 1999). Thus, pilots who do not understand the limitations of cockpit weather information displays or how to appropriately utilize them are likely to suffer from miscalibrated levels of trust. Methods

to prevent and remedy undertrust include training (Norman, 1988) and improved display design (Landauer, 1995, Norman, 1988, Sorkin, Kantowitz, & Kantowitz, 1988; Sorkin & Woods, 1985).

1.1.7 Usability of Cockpit Weather Information Displays

Usability assessment measures the extent to which system design optimizes the interaction between the users and the system. Usability analyses often include measures of the system's ease of learning, ease of use, ease of remembering, frequency of errors, and user subjective satisfaction (Nielson, 1993). According to Schneiderman (1992) usability analyses should consider three classes of end-users: Novice (users who know the task but have little experience with the system), Knowledgeable intermittent (users who know the task and understand the system, but use the system infrequently), and Expert frequent users (users who have intimate knowledge of the tasks and also use the system frequently). Cockpit weather information displays should be subjected to usability criteria within all three classes of users to detect information-processing bottlenecks.

There are advantages to conducting usability assessments. For instance, systems with high-usability ratings have been shown to reduce the cognitive workload of the user (Mayhew, 1999). Usability evaluation is also cost effective, as some developers report a 100-fold return on usability investments (Usability.gov, 2001). Usability assessments are necessary to optimize pilots' interactions with cockpit weather information displays.

1.1.8 Development of Decision Support Systems for Cockpit Weather Information Displays

Cockpit weather information displays are a type of decision support system. Decision support systems are defined by Zachary (1988) as any interactive system that is designed to improve decision-making by extending the operators' cognitive limitations (as cited in Wickens et al., 1997). The weather displays do not make decisions for pilots, but provide new kinds of information to pilots concerning hazardous weather. Thus, the introduction of these technologies into the cockpit forces pilots to make new kinds of interpretations, predictions, and actions.

When pilots are flying in weather, there are a number of judgments and decisions that must be made: 1) pilots must determine if there is hazardous weather, 2) pilots must determine their proximity to the hazardous weather, 3) pilots must determine if the hazardous weather is going to impact their flight path, and 4) pilots must decide on a course of action (i.e., a revision to the flight plan) to avoid flying into the hazardous weather. The current cockpit weather information products were specifically designed to support pilots in detection of potentially hazardous weather and in determining their proximity to potentially hazardous weather. Some of the current displays, however, are not explicitly designed to support the pilots' higher-level decision making. That is, the displays do not incorporate support tools to help pilots determine if hazardous weather is going to impact their current flight path. Nor do the current displays incorporate support tools to help pilots select actions (i.e., revisions to flight plan) that might be taken to avoid conflicts with hazardous weather. Thus, it would be helpful to pilots if high-level decision support tools were integrated into cockpit weather information displays.

There is a great deal of theory and empirical results that researchers can rely on to develop high-level decision support systems. In fact, such decision support tools exist in other domains. For instance, Schraagen (1997) described a fire-fighting decision support tool that was developed to help firefighters predict the spread of fire. Also, the fire-fighting support tool could make recommendations to firefighters regarding appropriate actions. Today's cockpit weather information tools are slightly modified versions of meteorology weather displays. There is a limit to the extent to which pilots can utilize such technologies during flight to make accurate judgments concerning hazardous weather. When flying through weather pilots, must make complex decisions concerning hazardous weather under high time stress and high workload with access to delayed information. Even expert meteorologists, when operating under similar conditions, would likely find such decisions difficult.

The upper limit of pilot processing capabilities could easily be exceeded as datalinked information is introduced into the cockpit. Information concerning weather avoidance, terrain avoidance, and conflict (with other aircraft) avoidance will soon be "pumped" into the cockpit. Pilots and controllers will be left to integrate the information to make high-level decisions. Thus, development of decision support tools to aid high-level decisions is crucial to the ultimate level of usefulness attained by datalinked cockpit information technologies (e.g., cockpit weather information displays).

1.2 Summary of Previous Cockpit Weather Experiments

The study described herein is the third in a series of cockpit weather experiments (CWE III) conducted by the RTI International's Center for Aerospace Technology, sponsored by the FAA and NASA. The first in the series of experiments (CWE I) investigated the effect of a prototype airborne weather display on pilot performance in a full mission simulator developed expressly for the study of new cockpit technologies in general aviation (Yuchnovicz, et al., 2001). The objective of the experiment was to investigate the potential for misuse of weather information, and thus provide information to the FAA for providing guidance to pilots and recommendations to manufacturers concerning the development of weather display technologies. CWE I was conducted with current instrument rated pilots who were presented with challenging but realistic flight scenarios involving weather with significant embedded convective activity. Pilots in the treatment group had access to conventional weather information sources and were provided a weather display in the cockpit that presented text (e.g., Text METAR) and graphical (e.g., NEXRAD radar) weather products. In contrast, the control group was given access only to conventional weather sources.

The results of CWE I indicated that the treatment group did not make better decisions than the control group. The pilots in the treatment group found it difficult to use the weather information display to determine their proximity to potentially hazardous convective weather, to determine if hazardous weather was going to impact their flight path, and to determine the path of hazardous weather. Furthermore, the pilots had difficulty decoding the coded text METARs. The presence of the weather information display also impacted the pilot's normal procedures as they relied less on traditionally

available weather information sources (e.g., Flight Watch). That is, the pilots cognitively tunneled on the cockpit weather information display.

The second in the series of cockpit weather experiments (CWE II) further investigated the effect of weather information displays on pilot performance. Based on the findings of CWE I, certain “improvements” were made to the weather display implemented in CWE II. For instance, an ownship symbol was added to make it easier for pilots to determine their proximity to convective weather and to assess if hazardous weather was going to impact their flight path. CWE II also investigated the effects of image-cell resolution of NEXRAD graphics (4x4 km cells vs. 8x8 km cells) on pilot decision making. All other aspects of CWE II and I were identical.

Several of the results of CWE II replicated the findings from CWE I. For instance, the pilots found it difficult to use the coded text METAR reports. They also relied too heavily (i.e., cognitively tunneled) on the weather display, as they failed to appropriately utilize conventional sources of weather information.

The introduction of ownship symbology did not improve the decision quality of the pilots. It was found, however, that ownship symbology reduced perceived pilot workload in using the weather information display. The reduction in workload associated with ownship symbology was due to the reduced cognitive load required to determine the aircraft position in relation to the hazardous weather conditions.

Furthermore, the age of the NEXRAD images on the weather display led to noticeable errors by many of the pilots in determining their proximity to convective weather and in determining the rate of movement of convective weather. Pilots who calculated the age of the NEXRAD images experienced substantially higher workload than pilots who assumed the information was real time or of constant age, as precise age calculations are cognitively taxing. Thus, it seems pilots have a difficult time extrapolating storm-cell movement from delayed data. It is unclear, however, whether the pilots’ problems with accurately forecasting storm-cell movement were due to the difficulty of determining the age (i.e., uncertainty) of the weather information or were simply limitations of their cognitive prediction processes.

Pilots also reported numerous types of mode errors. For instance, they sometimes lost-track of the range setting (i.e., mode) of the display. One pilot stated that he navigated much closer to the storm than he intended because he thought the 25 nm scale was active when in fact the active mode of the display was the 10 nm scale. Such mode-awareness breakdowns could lead to life-death consequences in real-world operation.

Surprisingly, the low-resolution display (i.e., less accurate information) led to better pilot decision making. This finding is consistent with the stimulus area effect. The stimulus area effect states that larger stimulus areas, represented by the 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. It is difficult to determine, however, if the effect would be mediated by an out-the-window view. Pilots may not use

or trust weather displays at lower resolution, because the information depicted on the display would not match their out-the-window view.

1.3 Purpose of Current Experiment

Several of the pilots in the previous two experiments expressed a desire to have information on storm cell movement. Two methods have been identified that can be used to provide information concerning convective cell movement: Looping NEXRAD and the National Convective Weather Forecast (NCWF) product. The purpose of the current experiment (CWE III) is to determine the effects of the use of NEXRAD looping and the use of the NCWF product on pilot workload and decision making. More specifically, the goal of the experiment is to investigate the potential misuse of these two sources of hazardous weather information as they relate to decision making in IFR flight.

Based on the findings of the previous experiments, CWE III implemented several improvements to the cockpit weather information display. A graphical weather depiction age indicator was added so pilots, at a glance, could determine the age of the weather information. The introduction of the age graphic should attenuate the mental effort necessary for pilots to calculate the age of the weather information. This prediction is consistent with Stone, Yates, and Parker's (1997) suggestion that the conversion of arithmetic calculation or confusing language to graphical form should attenuate strain on working memory. Also, decoded text METAR are provided so pilots do not have to spend time deciphering the coded METAR reports. While professional pilots working with METAR reports on a regular basis would prefer the coded METAR reports because they substantially reduce the time required for their assimilation, many GA pilots have limited experience with deciphering coded METARs and the decoded reports should substantially decrease pilot workload. A flight-path depiction was added to make it easier for pilots to determine if hazardous weather would impact their flight path. A 25 nm range-ring was added to aid the pilots in the determination of their proximity to hazardous weather (when using the 10 mile and 25 mile scale displays). Also, the 25 nm range-ring is invariant across display scale selection (i.e., range modes), which should attenuate mode errors associated with the display scale selection.

1.4 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 high-fidelity flight simulator and, therefore, without factors that come into play in an operational setting. The study suffered from low-cognitive fidelity as decisions were made based on static images presented at selected 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 (Wickens, Gordon, & Liu, 1998). 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-460) was 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 was also a prime sponsor, and provided technical support and contract management for this experiment in partnership with the FAA. The AWIN effort is an element of the Weather Accident Prevention Project of NASA's Aviation Safety Program.

2.3 RTI International

The experiment was designed and conducted by the Flight Systems Engineering Office of RTI International, located in the Hampton, Virginia, office. Mr. James Murray, a retired FAA air traffic controller, National Airspace System automation specialist, air traffic manager, and consultant to RTI International in many previous research efforts, provided air traffic control expertise in the design and execution of the experiment. Mr. Rickey Thomas of Kansas State University, also a consultant to RTI International, provided expertise in preparation for and analyses of the data. Consultants from Booz-Allen Inc. assisted in the conduct of the experiment.

3 Methodology

The objective of this experiment was to determine the effects of the use of NEXRAD image looping and the use of the NCWF product on pilot workload and decision making. More specifically, the experiment investigated the potential misuse of these two sources of hazardous weather information as they relate to decision making in flight in instrument meteorological conditions.

3.1 Experimental Hypotheses

The experiment was designed to answer several experimental hypotheses. The first two hypotheses concern the impact of NEXRAD looping on decision making and workload.

- 1) Pilots using a NEXRAD image looping display will make significantly better decisions with respect to convective weather than pilots without a weather information display.
- 2) Pilots using a NEXRAD image looping display will experience significantly higher workload than pilots without a weather information display.

The second two hypotheses concern the impact of the NCWF product on decision making and workload.

- 3) Pilots using the NCWF product display will make significantly better decisions with respect to convective weather than pilots without a weather information display.
- 4) Pilots using the NCWF product display will experience significantly higher workload than pilots without a weather information display.

It is expected that with sufficient training, careful use of the cockpit weather information 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 previous experiments, was designed specifically to identify potential hazards in the design and use of cockpit weather displays.

3.2 Experiment Design

Every aspect of the design of this experiment was undertaken with the objectives of the experiment in mind, including participant pilot selection, participant pilot training, and the mission scenario. Pilots were selected so as to provide a wide and representative range of the experience and knowledge of the population of general aviation pilots who might use these emerging cockpit weather display products. The training provided to the participant pilots was tailored 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 sample of pilots, 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 to the instrument flight procedures, but offered sufficient opportunity for observation of human error in the use of the cockpit weather displays 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 likely to occur). The mission scenario and cockpit simulator were to be sufficiently realistic such that the participant pilot would be immersed in the experiment.

The experiment employed a three (Display Type) by two (Decision Type) mixed design. The between factor was Display Type whereby pilots were randomly assigned into one of three groups (i.e., No Display vs. Looping NEXRAD vs. NCWF). Performance differences between the three groups could then be attributed to differences between the control (no display) and treatment conditions (NCWF and Looping NEXRAD). The within-subjects factor was Decision Type (Temporal vs. Spatial). All participants made both types of decisions.

3.3 Participant Pilot Sampling Procedure

Participant pilots were recruited for the experiment through advertisement via the Internet and through local flying organizations. A convenience sample of 48 current instrument flight rated pilots was selected for participation in the study. An additional 6 IFR and current pilots were recruited as back-up participants.

3.3.1 Random Assignment of Participant Pilots to Experimental Conditions

Forty-eight pilots were randomly assigned to the experimental conditions (i.e., NCWF, Looping NEXRAD, and Control). Random assignment of pilots to experimental conditions minimized the probability that pilot characteristics (e.g., total flight hours) and uncontrolled experimental characteristics (e.g., time of day) would systematically differ across conditions. Thus, any differences in outcome across conditions are likely due to type of display rather than differences between pilots.

The random assignment procedure was restricted to ensure an equal number of pilots were selected into each condition ($n = 16$). The procedure required that any given condition could not be run until all the other conditions were represented once (i.e., sampling without replacement). For example, the first three pilots constituted a randomized block where the first pilot was randomly assigned to one of the three experimental conditions. The second pilot was randomly assigned to one of the two remaining experimental conditions, and the third pilot was assigned to the one remaining experimental condition. This assignment completed a block of randomized conditions. The fourth pilot started the second randomized block, and was randomly assigned to one of the three conditions. The fifth pilot was randomly assigned into one of the two

remaining conditions, and the sixth pilot was assigned to the one remaining condition; and so on.

Maintaining an equal sample size across conditions had several advantages. For instance, equal sample size ensured that each display condition contributed equally to the statistical analyses, consistent with the logic of experimental design (Keppel, 1991). Moreover, equal sample size allowed for more robust statistical tests and increased statistical power (Glass, Peckham, & Sanders, 1972; Milligan, Wong, & Thompson, 1987; and Keppel, 1991).

3.4 Experiment Apparatus

The experiment was performed in a full-mission flight simulator to provide a realistic operational environment. Three major components comprised the experimental system: pre-flight planning tools, the flight simulation facility, and the weather information display.

3.4.1 Pre-Flight Planning

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 A, 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).

3.4.2 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 instrument panel, however, was substantially simplified from that of the Piper Malibu to that of a typical low-end general aviation aircraft to permit a wide population of general aviation pilots, not all who would be familiar with the more sophisticated Piper Malibu instrumentation, to participate in the experiment. The key elements of the simulation facility are illustrated below in Figures 3.4.2-1 and 3.4.2-2.

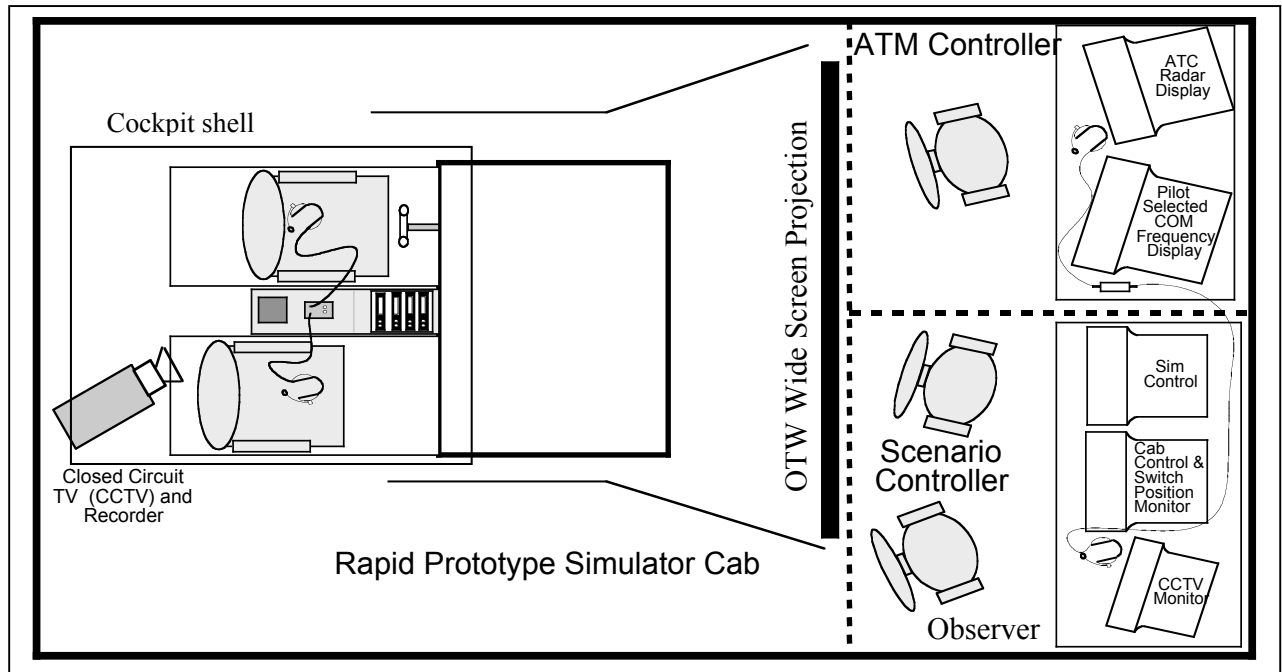


Figure 3.4.2-1. Cockpit Simulation Facility (CRF) Diagram



Figure 3.4.2-2 Cockpit Simulation Facility Instrument Panel and Controls

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. The flight control system incorporated a mechanical simulation of control forces in pitch, roll and yaw. 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 below in Figure 3.4.2-3. The refresh rate of the cockpit instrumentation displays was 30 Hertz. 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 observers to track the flight's progress relative to the weather. A video image of the cockpit from the camera was provided to enable the observers to monitor the participant 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 observers. 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.

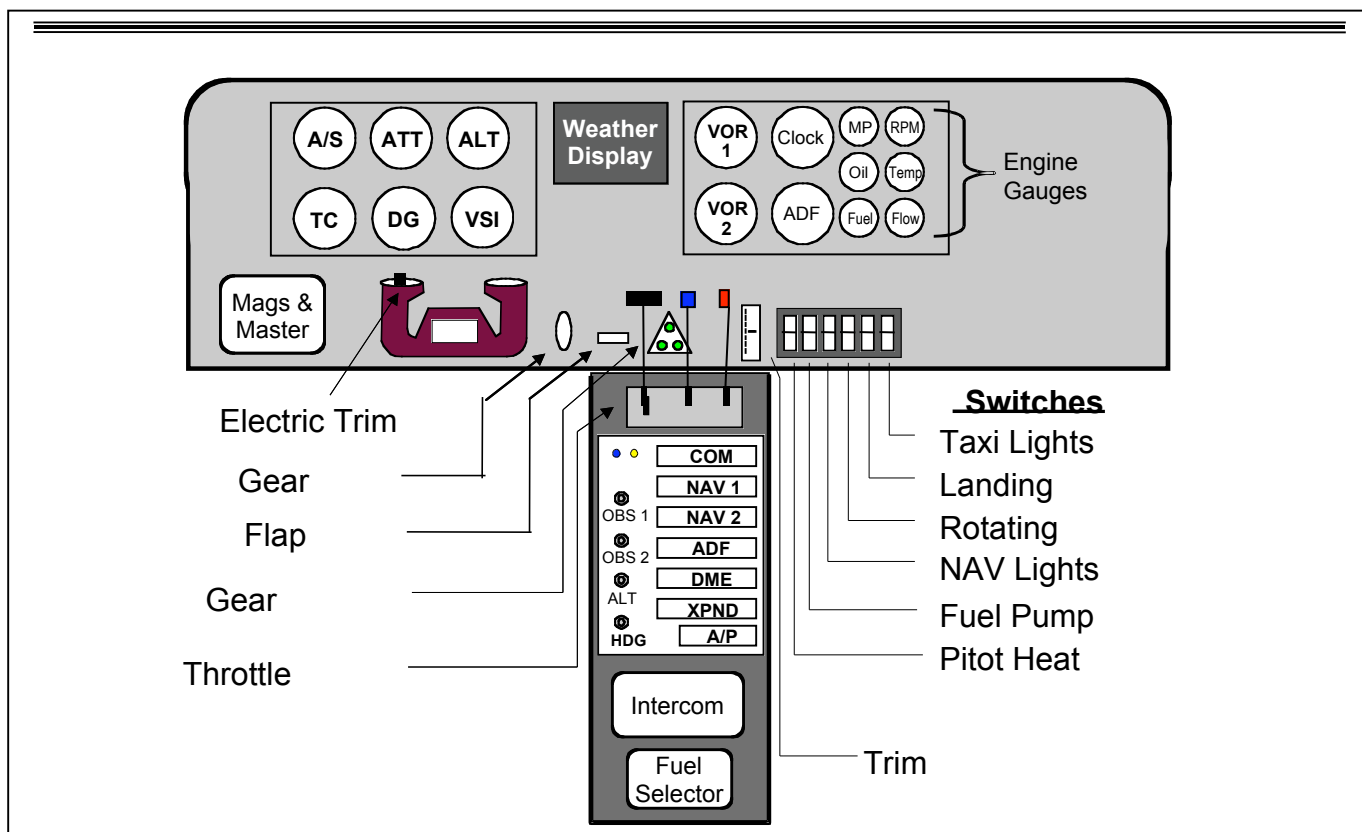


Figure 3.4.2-3. Cockpit Simulation Facility Instrument Panel and Controls

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

3.4.3 Cockpit Weather Information Display

The weather information display system used in this experiment consisted of two key components, a PC-based computer and a prototype display unit originally developed by NavRadio Inc, which was subsequently acquired by Honeywell 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 custom software, the PC sequenced through the database of previously recorded NEXRAD/METAR information and displayed the images on the weather display. The PC also contained the software to depict the moving map, mode/scroll control, airport/navaid information and map database.

The display unit contained a flat-panel LCD display of 320 x 240 resolution, a joystick and mode-select softkeys. The display unit provided only the display and control function of the system. The computational effort resided in the PC workstation.

The weather display enabled the pilot to select weather information and included the following features:

- NEXRAD image depiction
- Coded METAR text reports
- Decoded METAR text reports
- Depiction of graphic METAR symbology
- Graphic symbology of airports, VORs, major highways and state boundaries
- Zoom and scroll capability
- Map range scale
- 25 nm range ring
- NEXRAD image timestamp
- NEXRAD image age indicator
- Flight-path depiction.

The key features of the cockpit weather display are depicted in Figure 3.4.3-1 The placement and layout of the weather display controls are depicted in Figure 3.4.3-2 Details of the FISDL system, of which this display is an early prototype, are provided in Appendix C, Flight Information Services Description.

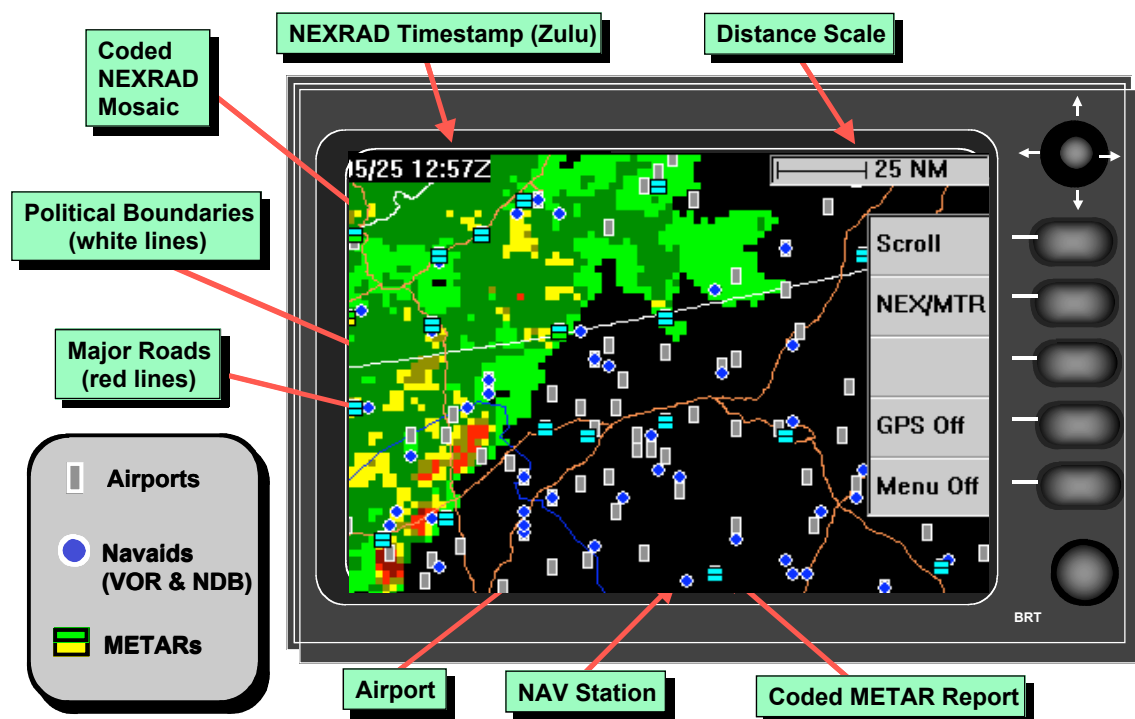


Figure 3.4.3-1. Cockpit Weather Display Features

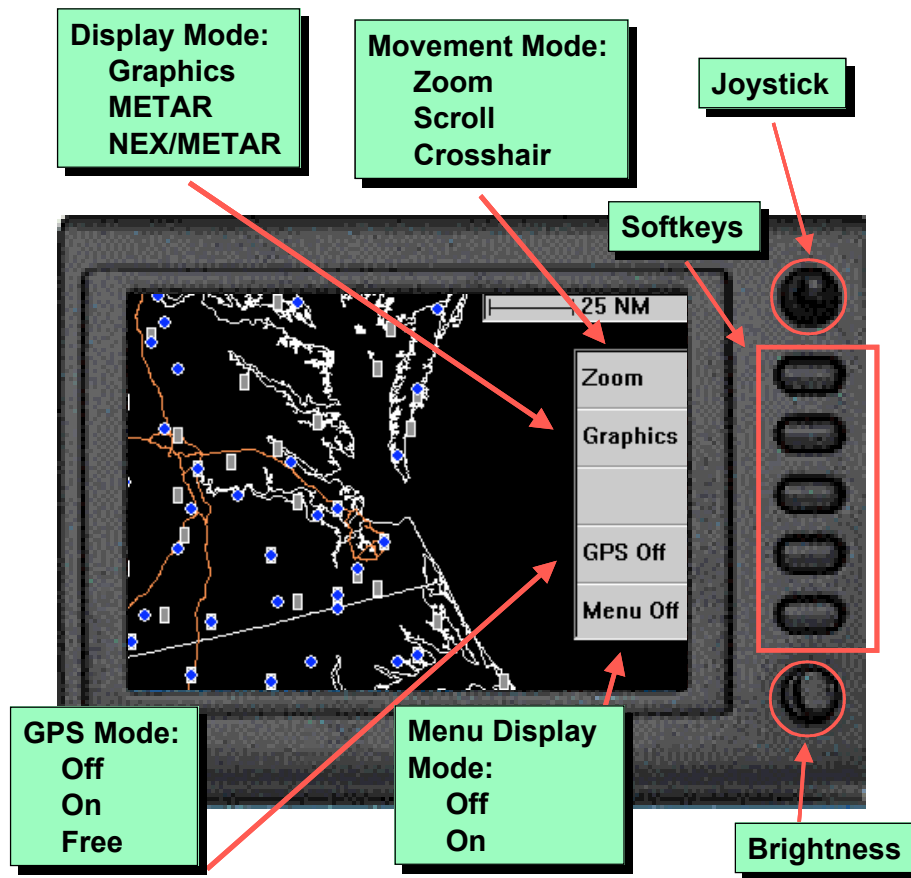


Figure 3.4.3-2. Cockpit Weather Display Controls

Two versions of the weather display were developed for the CWE-III experiment—a version incorporating NEXRAD image looping and a version incorporating the NCWF product. One of the treatment groups was given the ability to animate previous NEXRAD images (i.e., see a history of storm-cell movement) with a dedicated “LOOP” softkey selection. The second treatment group was presented with the National Convective Weather Forecast (NCWF) product that depicted a 1-hour forecast of storm-cell movement.

3.4.4 NEXRAD Image Looping Display

The NEXRAD image employed a three-color palette to depict the precipitation returns for a given area. The arrangement of the NEXRAD precipitation intensity levels used in the experiment is shown in Figure 3.4.4-1. The images were updated every seven minutes. The pilot was able to zoom and scroll around the image to the desired view. The 16 small-cell (i.e., 4 x 4 km) NEXRAD images used in the experiment are duplicated in Appendix D, NEXRAD Images Used in CWE III Experiment.

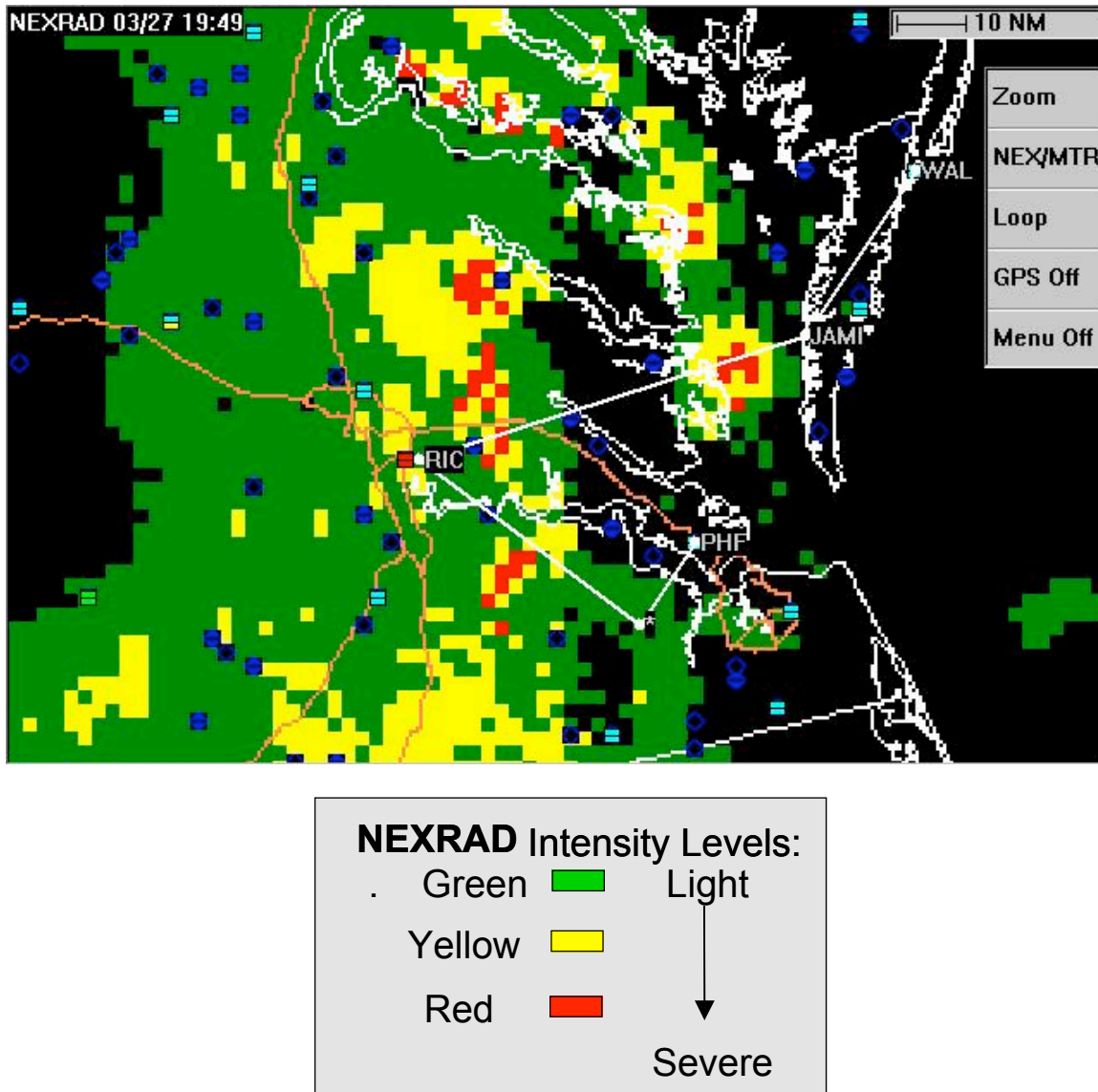


Figure 3.4.4-1. NEXRAD Mosaic Image Precipitation Intensity Key

The NEXRAD weather display employed an additional “LOOP” softkey that enabled the pilot, when the softkey was actuated, to display a replay of a series of up to seven

NEXRAD images (approximately 49 minutes) in a single cycle. Successive actuation of the “LOOP” softkey replayed the loop a single time for each actuation of the softkey.

The “LOOP” softkey resided in the third softkey position on the weather display and was only available when a NEXRAD image was currently being displayed. The position of the looping softkey is normally reserved for actuation of additional information when the crosshair mode is selected by the first softkey. Therefore, whenever the crosshair mode was selected, the third softkey provided the Text/Airports/Nav aids selection. Thus, the looping feature, and softkey annunciation, was only available when a NEXRAD image was currently displayed and the crosshair mode was not selected.

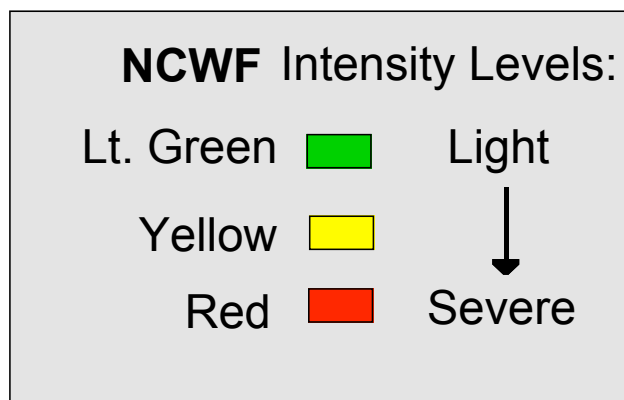
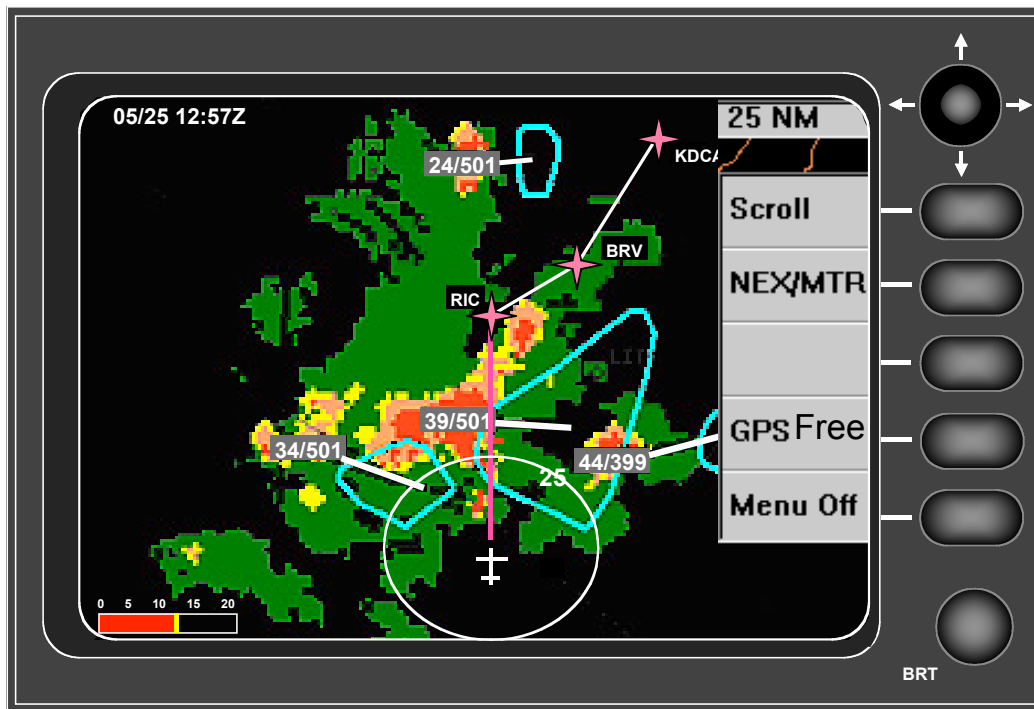
3.4.5 NCWF Product Display

The National Convective Weather Forecast (NCWF) product, developed by NCAR under the FAA Aviation Weather Research Program (AWRP) and implemented operationally by the National Weather Service Aviation Weather Center (AWC), provides current convective hazards and one-hour extrapolation forecasts of thunderstorm hazard locations. The NCWF product is currently available from the [Aviation Digital Data Service](#) (ADDS). through the Internet for flight planning purposes. While at least one weather display manufacturer is apparently studying the possibility of including the NCWF product in their cockpit weather display, no company has yet sought approval from the FAA to do so.

The information currently provided in the FAA Aeronautical Information Manual (AIM) about the NCWF product as of February 21, 2002 is provided in Appendix E.

The hazard field and forecasts in the NCWF product are updated every 5 minutes. The diagnostic analysis combines national radar and echo top mosaics, and cloud-to-ground lightning.

In the experiment the NCWF images were updated every seven minutes and the Convective Hazard Detection field was depicted using a three level intensity scale as indicated in Figure 3.4.5-1. The three levels corresponded to VIP levels as indicated in Table 3.4.5-1. The one-hour forecast locations of significant convection (NCWF hazard scale levels of 3 or greater) were depicted by cyan polygons. The direction of movement and speed of the convective cells were indicated by vectors. Also, the altitude of the storm tops and storm speed (nautical miles per hour) were presented in digital symbology adjacent to the movement vectors. The display of the NCWF storm movement vectors, one-hour forecast, storm speed, and cloud tops was available in the 10 and 25 mile range scales. When a scale of greater than 25 miles was selected, these NCWF features were not displayed to reduce clutter. The NCWF images used in the experiment are provided in Appendix F.



NCWF

Figure 3.4.5-1. NCWF Product Display Convective Hazard Intensity Levels

Table 3.4.5-1 NCWF Display Relationships to Other Sources

Hazard Field			Approximate Correlations			
	VIL (kg/m ²)	Ltg. Rate (/10 min)	Effect	Airborne Radar	Reflectivity (dBZ)	VIP
	12 +	15 +	Severe Turbulence, Lightning Hail likely	Level 4 Very Hazardous	50 +	5 - 6
	3.5 - 12.0	3 - 15	Possible Severe Turbulence, Lightning	Level 3 Hazardous	40 - 49	3-4
	0 - 3.5	NA	Light to Mod. Turbulence, Possible Lightning	Level 1-2 weak-moderate	0 - 39	1 - 2

3.4.6 Graphical METAR Reports

The graphical METARs (common to both the NEXRAD Image Looping display and the NCWF product display) were small graphic icons that depicted the ceiling and visibility for the reporting station. The coding of the graphic METARs is depicted in Figure 3.4.6-1.

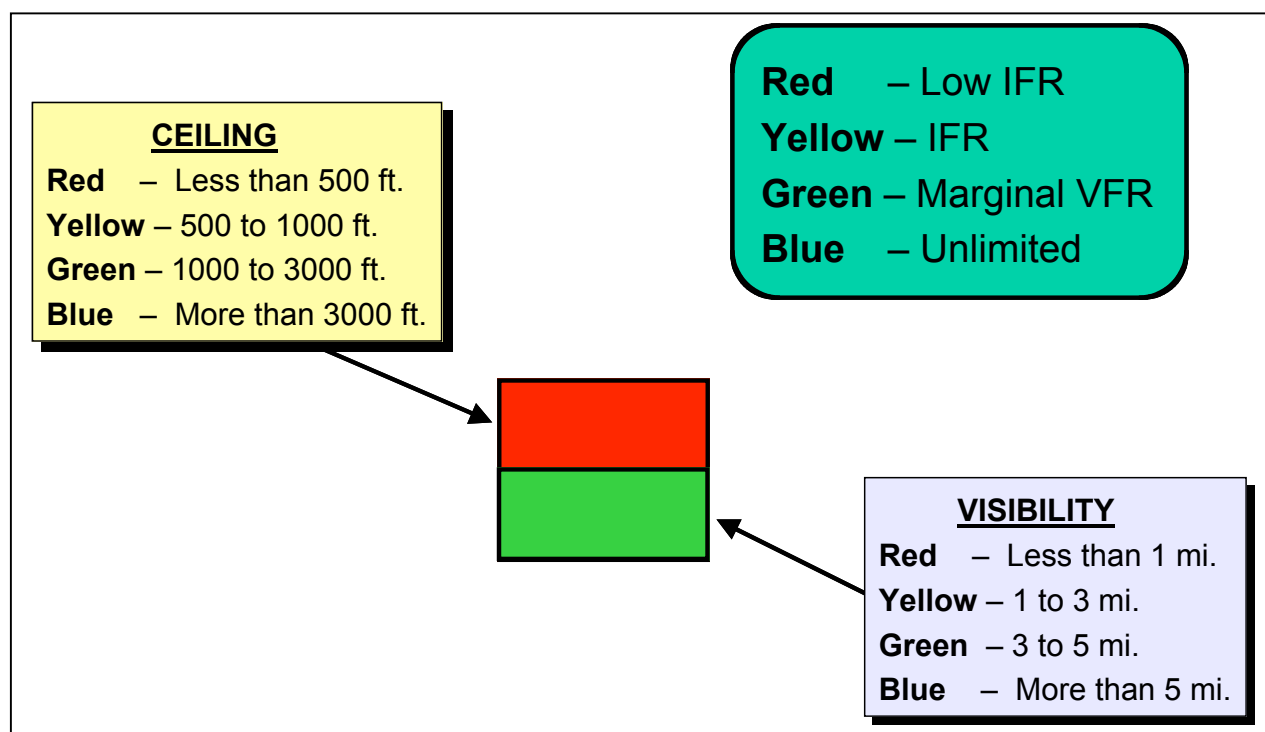


Figure 3.4.6-1 Graphic METAR Key

3.4.7 Text METAR Reports

An example of a decoded text METAR (common to both the NEXRAD Image Looping display and the NCWF product display) is given in Figure 3.4.7-1. The pilots were provided decoded text METARs instead of the traditional coded text METARs. The English translation of the text METAR was consistent with the ICAO code. By selecting either the METAR function or the NEXRAD/METAR function on the Looping NEXRAD display or the NCWF display, then selecting the crosshair function of the joystick, the subject pilot equipped with one of these displays could place the crosshairs over any METAR graphic icon and call up on the display the text description of the entire METAR report for that reporting station.

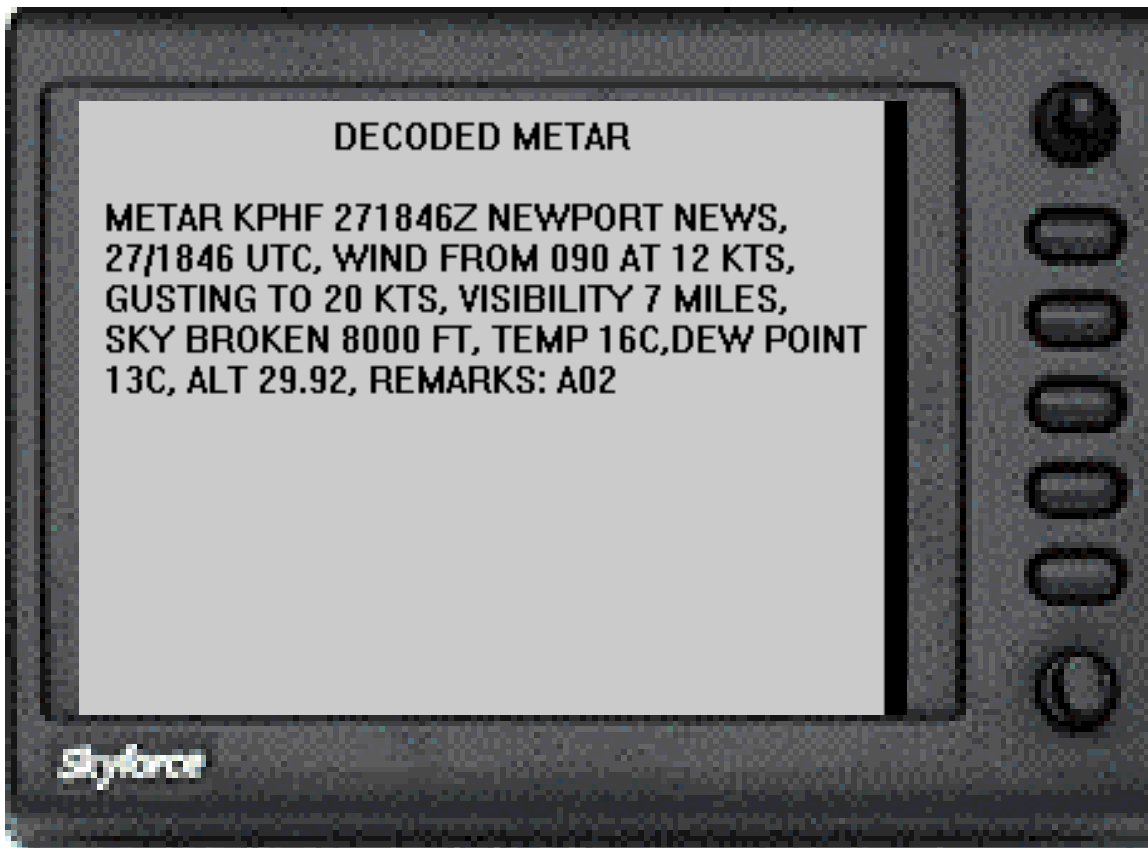


Figure 3.4.7-1 Example of Decoded METAR Text

3.4.8 NEXRAD Image Age Graphic

In the lower left corner of the display, a graphical thermometer-type icon displayed the difference between the mission system time and valid time of the weather image (common to both the NEXRAD Image Looping display and the NCWF product display). The range of the thermometer scale started at zero delay on the left side, increasing to 20 minutes on the extreme right side, in five-minute increments. The pointer was depicted in yellow, and red filled the space between the pointer and the left edge of the thermometer

graphic. See Figure 3.4.8-1. The general intent of the age graphic was to allow the pilot to discern the age of the weather information at a glance (i.e., the more red displayed the older the information).

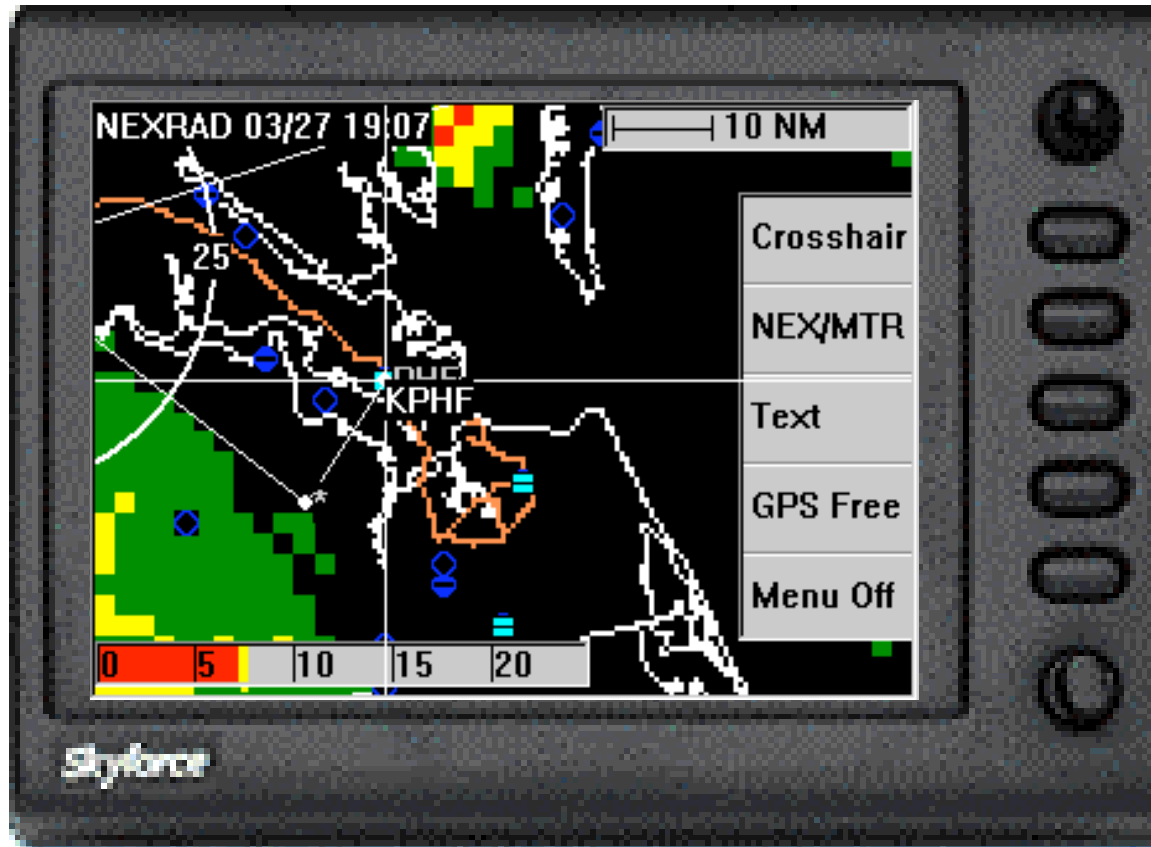


Figure 3.4.8-1. NEXRAD Image Age Graphic

3.4.9 NEXRAD Image Range Ring

The range-ring depiction (common to both the NEXRAD Image Looping display and the NCWF product display) is illustrated in Figure 3.4.9-1. A white 25 nautical mile ring was depicted around the aircraft ownship icon. The range ring was depicted when either the 10 or 25 mile map scales were selected. Superimposed over the line was a digital numeric icon of “25.”

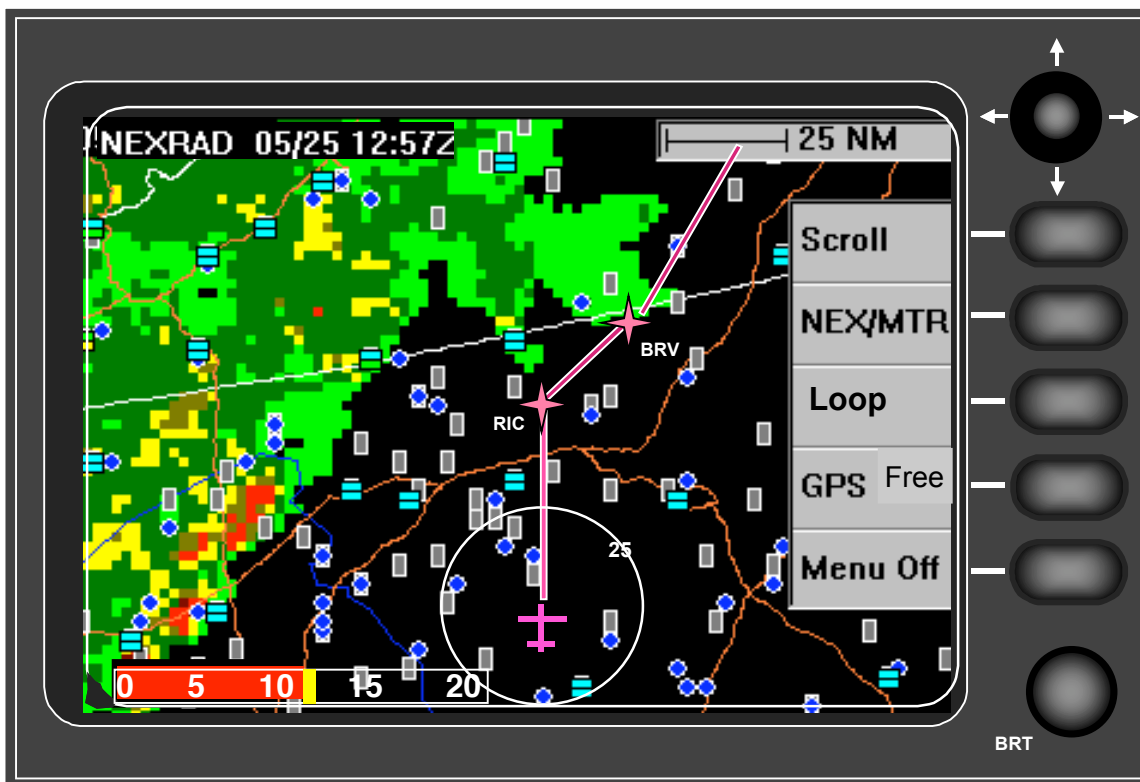


Figure 3.4.9-1. NEXRAD Image Range Ring and Flight Path Depiction

The route depiction feature (common to both the NEXRAD Image Looping display and the NCWF product display) is also illustrated in Figure 3.4.9-1. The route depiction consisted of a series of superimposed waypoints connected by a magenta line. Collocated next to the waypoint icon was the station identifier. The pilot was not able to declutter the course lines or waypoint icons, nor was the pilot able to edit the flight plan. The display of the courseline, waypoints and identifiers was available in the following map ranges: 10, 25 and 50 mile scales. When a scale of greater than 50 miles was selected, the waypoint identifiers were not displayed.

4 Experiment Procedure

The experiment procedure consisted of the following five key phases:

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

4.1 Experiment Briefing

The participant pilots were given a briefing of the mission objective, mission scenario, and an extensive overview of the simulator controls. The pilots in the treatment groups were also given a comprehensive overview of the operation of the appropriate weather display (NEXRAD Image Looping or NCWF weather forecast). The briefing scripts are provided in Appendix G, Experiment Briefing.

4.2 Simulator Familiarization

The participant 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 provided a thorough understanding of the equipment and its capabilities. To assure equal treatment to all participant 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 90 minutes and included a practice flight with at least two approaches (one VFR approach and one IFR approach). Some pilots required as many as three IFR approaches before they met the proficiency criteria. The training outline and proficiency criteria are provided in Appendix H, Simulator Training and Proficiency Criteria.

4.3 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 request a change of route upon the initial call to clearance delivery. The flight plan route is illustrated in Figure 4.3-1. They were also briefed that all the normal weather information services typically available in the National Airspace System (NAS) were also available in the simulator, including Flight Service, Flight Watch, ATIS, ASOS and ATC.

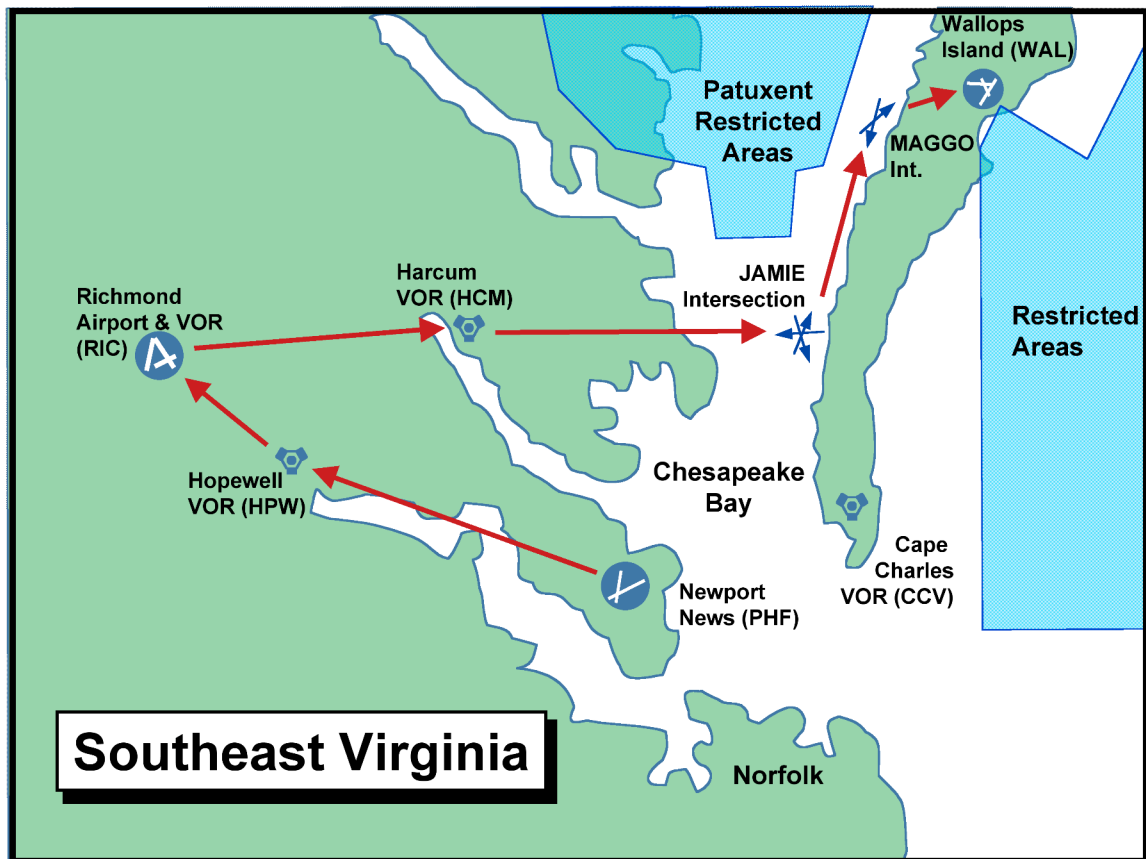


Figure 4.3-1 Flight Plan Route

4.4 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/Test Director and a second observer conducted the experiment. The Observers' primary role was to collect and record data on the Observer form (Appendix I), including the comments of the other members of the research team. Additionally, the Air Traffic Controller provided a record of his observations that were included in each participant pilot's data folder.

4.5 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 separate questionnaires for the control and treatment groups are included in Appendix J, Immediate Reactions Questionnaires.

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

As a final step, the pilots in the treatment conditions were asked open-ended questions concerning the cockpit weather information displays. The questionnaire is included in Appendix L, Weather Display Questionnaire.

4.6 Mission Scenario

The mission scenario consisted of a flight to a wedding rehearsal, wedding, and dinner at Wallops Island. Wallops Island is located on the eastern shore of Virginia. The participant pilots were told that they were one of three pilots who have been close friends for many years since their military flying tours. The participant pilot was to assume the role of the friend who lives in Newport News, VA, and would be flying the aircraft to Wallops Island for the wedding of one of the other friends. The participant pilot (the friend flying the aircraft from Newport News - Williamsburg Airport) had agreed to stop at the Richmond Airport enroute to Wallops Island to pick up the third friend who had agreed to be the best man at the wedding.

The two friends who were traveling had planned their flight so as to leave around mid-day on the day of the wedding to attend the wedding rehearsal, wedding and dinner party, all of which were scheduled for the same evening. The rehearsal started at 1700 hours local. The pilot was delayed at work due to an important meeting, however, and the planned departure time from the Newport News airport was slipped to 1500 hours local. At that point, while there was more than sufficient time to fly the agreed route to Wallops Island and make it to the wedding rehearsal via the Richmond Airport, there was not sufficient time to drive from Newport News to Wallops so as to participate in the rehearsal or the wedding. Nor was there time for the pilot’s friend (the best man) to drive from Richmond in time to participate in the wedding rehearsal or wedding at Wallops Island.

The flight originated at the Newport News Virginia airport. The pilot was instructed to fly to Richmond Virginia and pick-up the other friend (best man) on the way to Wallops Island. Total flight time for the two legs of the flight was about one hour. The pilots were briefed to assume a time of about 15 minutes at Richmond to pick up the passenger, and to assume that transportation would be provided from the Wallops Island Airport to the wedding rehearsal, which would take no more than five minutes.

In the course of the preflight briefing, the pilot found that there was a weather front moving in the direction of Richmond, but that the forecast for the area would permit the

pilot to land at the Richmond airport to pick-up his friend. The forecast weather for much of the flight placed the aircraft in instrument meteorological conditions (clouds and occasional light rain), but the weather along the eastern shore of Virginia and at Wallops Island airport was forecast to be well above minimums.

All flights were flown in a full-mission simulation facility in simulated instrument meteorological conditions. The pilots were in instrument meteorological conditions with essentially zero visibility from shortly after takeoff until reaching visual meteorological conditions about 15 minutes 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 M, Air Traffic Control Scripts.

The pilot was able to access the normal in-flight weather services through VHF 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 ATC workstation presented the Air Traffic Controller with a readout of the frequency that the participant 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 N, 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 also be found in Appendix N, 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 March 27, 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. All NEXRAD mosaic images used in the experiment were recorded with a cell resolution of 4 km. NCAR was provided the NEXRAD images from the evening of March 27, 2000. An NCWF NEXRAD and NCWF forecast was then generated for each NEXRAD image by NCAR for use in the experiment. The NEXRAD images and NCWF images were replayed on the weather display in the simulation facility cockpit. The NEXRAD images used in the experiment are provided in Appendix D,

NEXRAD Images. The corresponding NCWF images are provided in Appendix F, NCWF Images.

To realistically reproduce actual data-linked weather products, the participant pilot received the NEXRAD mosaic images and NCWF weather forecast images delayed by seven minutes. The pilot's weather display of NEXRAD images and NCWF 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 text METARs were available only in a decoded format.

The NEXRAD weather display used by the Air Traffic Controller emulated the weather radar information typically provided at the various controller work stations. The Air Traffic Controller received a real-time NEXRAD image that was no more than 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.

4.7 Flight Procedures

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

4.7.1 First Leg of Flight – Newport News to Richmond

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 displays. 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/1/2 mile) 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. A typical image of the weather conditions at that time as seen on the cockpit weather display equipped with the NEXRAD images alone is depicted in Figure 4.7-1. A typical image of the weather presented on the display equipped with the NCWF product is depicted in Figure 4.7-2. The image on the pilot's weather display was a minimum of seven minutes old and could have aged up to as much as 14 minutes old. 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.]

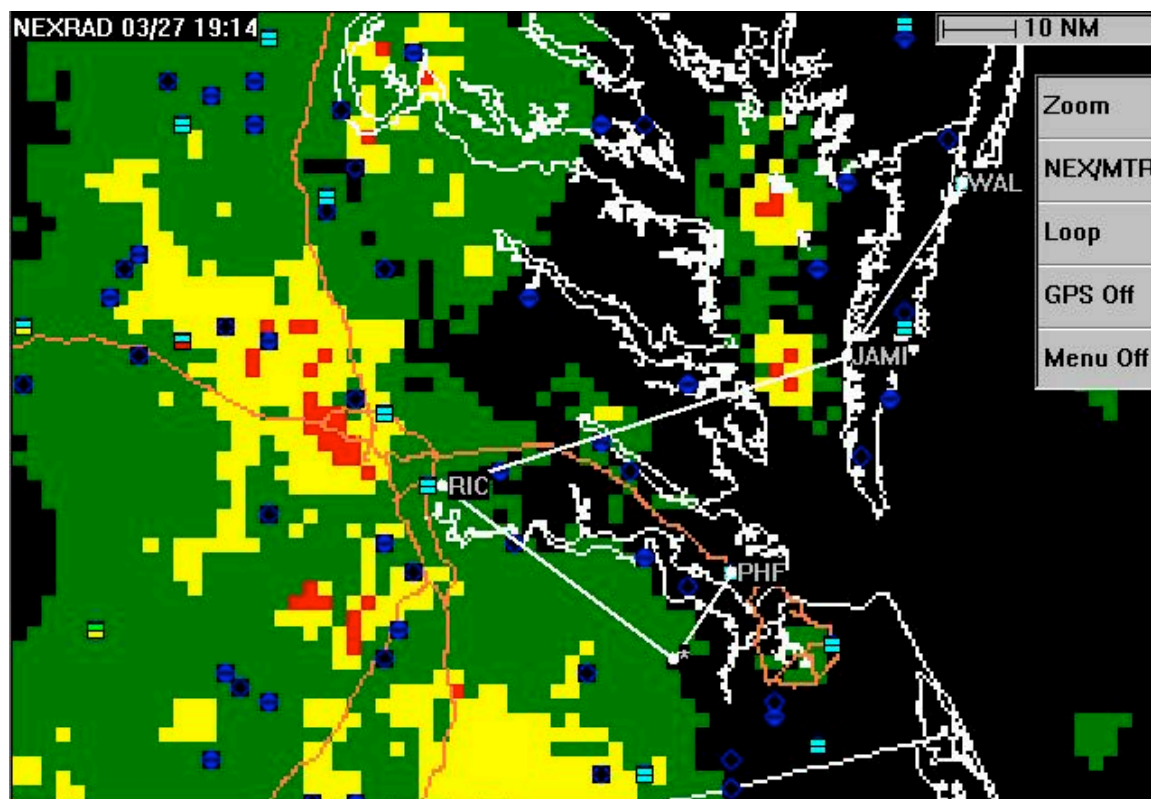


Figure 4.7-1 Typical NEXRAD Image

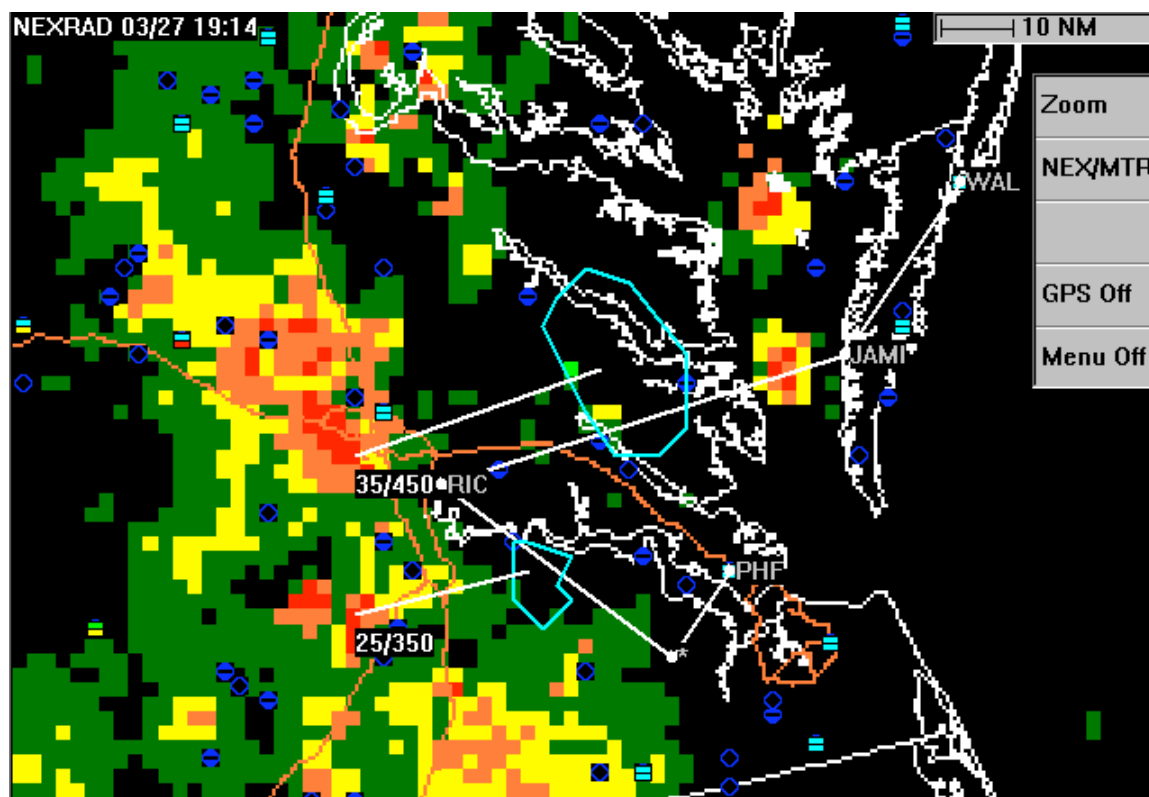


Figure 4.7-2. Typical NCWF Image

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).

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 participant pilots’ decisions.

If the pilot proceeded with the approach into Richmond, typical and consistent weather warnings were given to the pilot by ATC, including an ATIS report indicating the Richmond airport weather conditions had deteriorated to 200 feet/3/4 mile with thunderstorms in the vicinity, and a windshear warning when the pilot contacted the tower. If the pilot inquired of ATC in any way about the weather conditions, the weather conditions along the route to Richmond were described and eventually a PIREP was relayed that was provided by a Cessna 210 about ten minutes ahead who had experienced severe windshear and turbulence during the approach into the Richmond airport. To expedite the simulator mission, if the pilot decided to proceed with the approach 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 flights. Therefore, all the pilots either broke off the attempt to land at Richmond at various distances from Richmond, or were waved-off just after passing the final approach fix.

4.7.2 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 4.7-3 in a typical NEXRAD Image and in Figure 4.7-4 in a typical NCWF image.

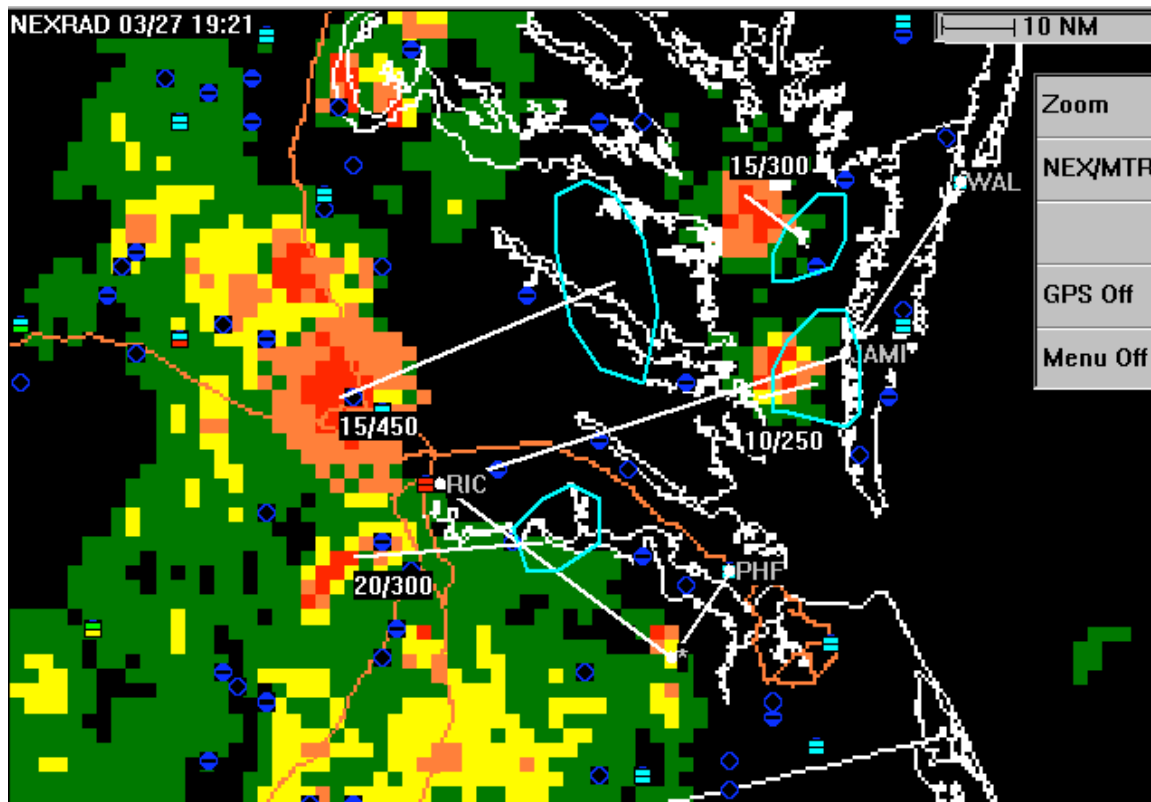


Figure 4.7-3 Typical NEXRAD Image Used In Wallops Leg Decision

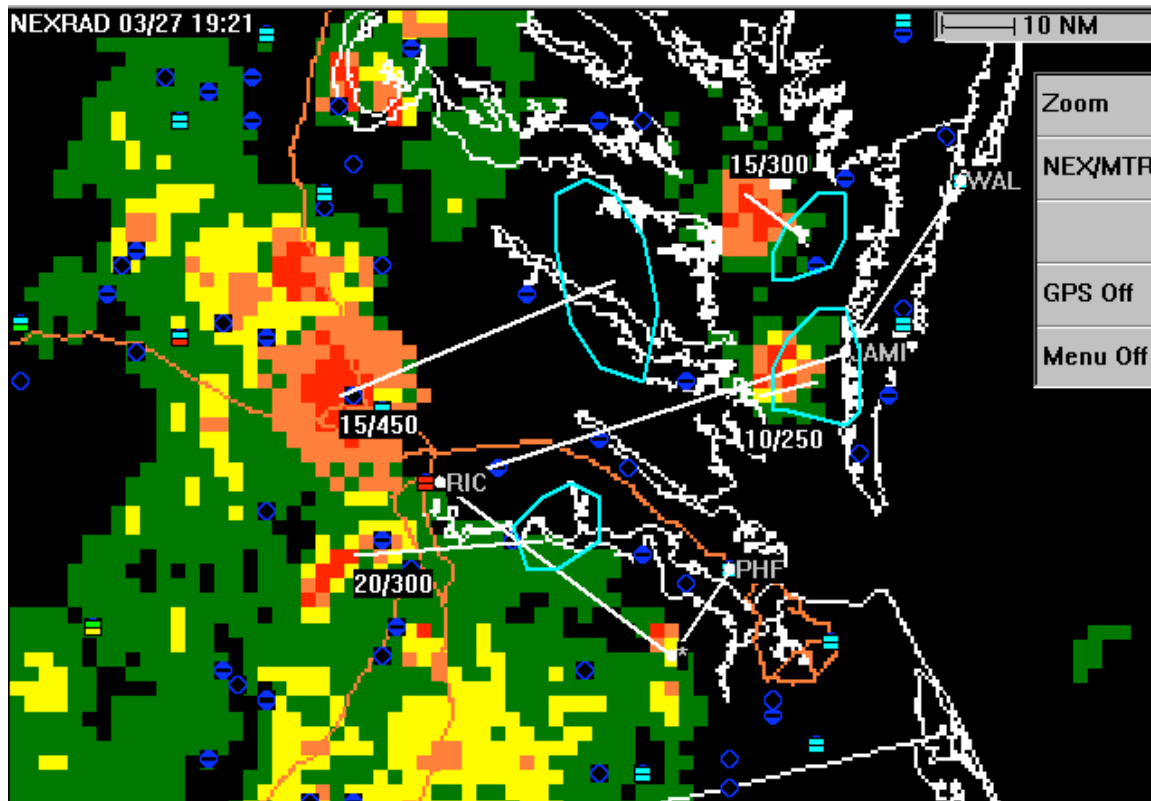


Figure 4.7-4. Typical NCWF Image Used in Wallops Leg Decision

The distance between the red cells was approximately 10-12 miles. The gap between the storms was tempting enough to suggest a corridor might exist between the areas of hazardous weather. These cells did not move substantially with succeeding weather information image updates, but slightly changed shape and size.

The METAR graphical and textual depictions showed that the eastern shore of Virginia and the Wallops Island airport were well 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 thunderstorms altogether. This part of the experiment was designed primarily to determine the pilot's judgment relating to spatial interpretation issues in the use of the weather information display.

5 Results

5.1 Pilot Characteristics

A convenience sample of 48 pilots participated in the experiment. Of these 48 pilots, 16 flew with the NEXRAD image looping display, 16 flew with the NCWF product display, and 16 flew with access to only conventional weather information sources (i.e., no weather display). The pilots' experience and proficiency were examined in terms of the customary indices, such as total flight hours, actual instrument hours, hours "under the hood," flight simulation hours, and hours last 90 days. In addition, a general aviation knowledge test was given to the pilots (see Appendix L, General Aviation Questionnaire) from which a measure of experience and of their declarative knowledge concerning weather were obtained. A descriptive summary of the experience and proficiency variables is provided in Table 5.1-1. Note that the participant pilots had a wide range of experience and proficiency. Thus, the convenience sample of pilots recruited for the experiment was representative of the range of experience and proficiency found in the population of GA pilots.

Table 5.1-1. Subject Pilot Experience and Proficiency Measures

<i>Experience & Proficiency Measures</i>	Mean	Standard Error	Max	Min
<i>Mean Total Flight Hours</i>	2469.42	428.77	15000.00	220.00
<i>Mean Actual Instrument Hours</i>	314.44	105.57	4000.00	1.40
<i>Mean Hours "Under The Hood"</i>	115.25	24.52	1000.00	.00
<i>Mean Flight Simulation Hours</i>	52.07	13.00	300.00	.00
<i>Mean Hours Last 90 Days</i>	12.91	4.06	150.00	.00
<i>Weather Knowledge Scores</i>	.66	2.57E-02	1.00	.23

Although the pilots were randomly assigned to the display type conditions, it is possible that simply by chance the pilot characteristics could significantly differ across display

conditions. An analysis of variance (ANOVA) indicates there are no significant mean differences between the pilots' characteristics across the three subject pilot groups (control, looping NEXRAD, and NCWF) in total hours, actual instrument hours, hours "under the hood," flight simulation hours, hours last 90 days or weather knowledge. The groups are similar (i.e., statistically matched) in terms of their experience and proficiency as measured by the indices used in this experiment—total flight hours, instrument flight experience, currency, and weather knowledge. Thus, the level of experience and proficiency of the pilots did not confound the ability to assess the effects of display type on pilot performance (e.g., decision quality) in this experiment.

Although pilot experience did not differ significantly across experimental conditions, experience variables might be associated with pilot performance. For instance, it makes sense that more experienced pilots may make higher-quality decisions than less experienced pilots. The pilot experience and proficiency measures, however, were not significantly associated in the appropriate direction with any of the primary dependent variables of the experiment (i.e., decision quality metrics)². Feldt (1958) suggested that statistically controlling for variables that are associated with dependent measures less than $r = .20$ can actually lead to decreases in statistical power. Thus, it was deemed unnecessary to statistically control for the effects of pilot experience and proficiency as such analyses would not lead to increases in statistical power to detect the effect of display type on the primary dependent measures.

5.2 Effects of Display Type on Decision Quality

The results of the experiment are 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.

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

² The conclusion that the experience and proficiency measures were not associated with the decision quality metrics was based on Pearson correlation analyses and Spearman correlation analyses. Also, the quality of pilots' decisions was used to create post-hoc groups. ANOVA was conducted using the decision-quality groupings as the explanatory variable and the experience measures as response variables. The ANOVA supported the correlation analyses that there was no statistically significant association of decision quality with any of the experience and proficiency measures. That is, pilots who made good decisions were not significantly more experienced or proficient than pilots who made poor decisions.

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) as seen on the air traffic controller's weather radar display 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 wedding scenario created a motivation to proceed to within a reasonable but safe distance.

The "Richmond decision" required the participant pilot to decide whether or not to attempt to land at the Richmond airport in the face of a 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 subject pilots who had the NEXRAD Image Display, updating in 7-minute intervals. Figures 5.2-1a and 5.2-1b depict the NEXRAD mosaic image available on the weather display during the period 1921Z to 1925Z as the pilots approached the Final Approach Fix to runway 34 to the southeast of the Richmond airport. The weather information displayed in the same time frame to the subject pilots who had the NCWF Display is depicted in Figures 5.2-1c and 5.2-1d.

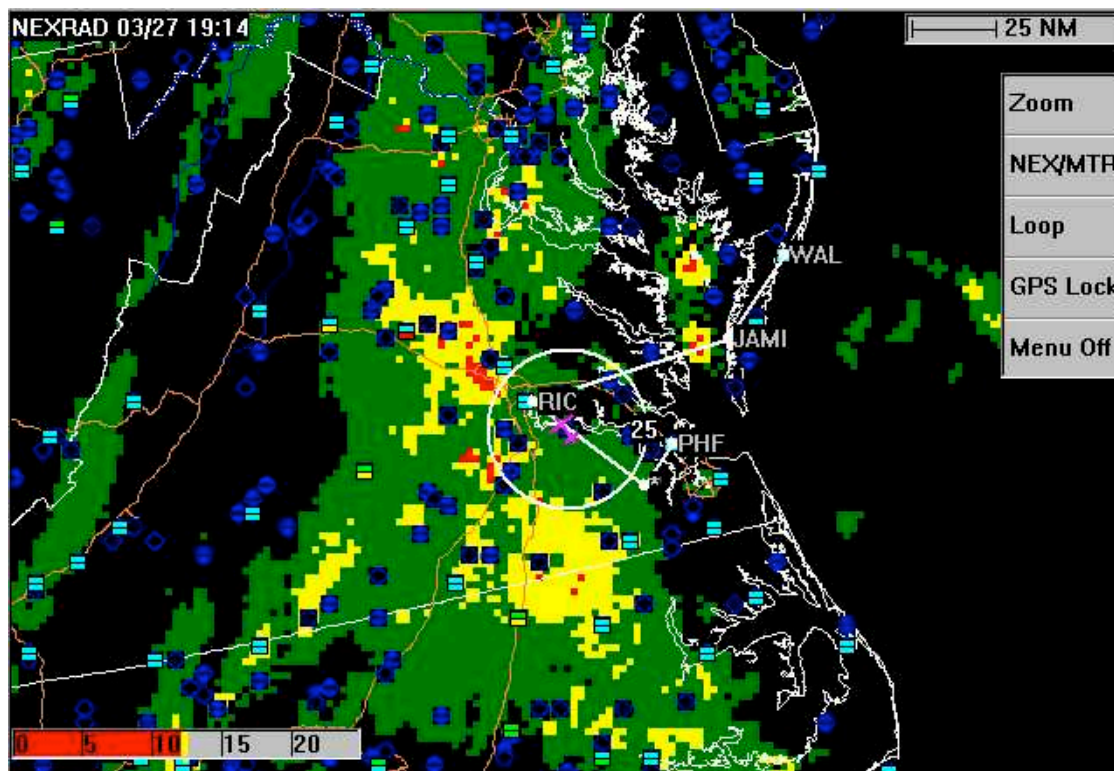


Figure 5.2-1a. NEXRAD Display (with looping) seen by subject pilots inbound to Richmond Airport IAF (25nm Scale)

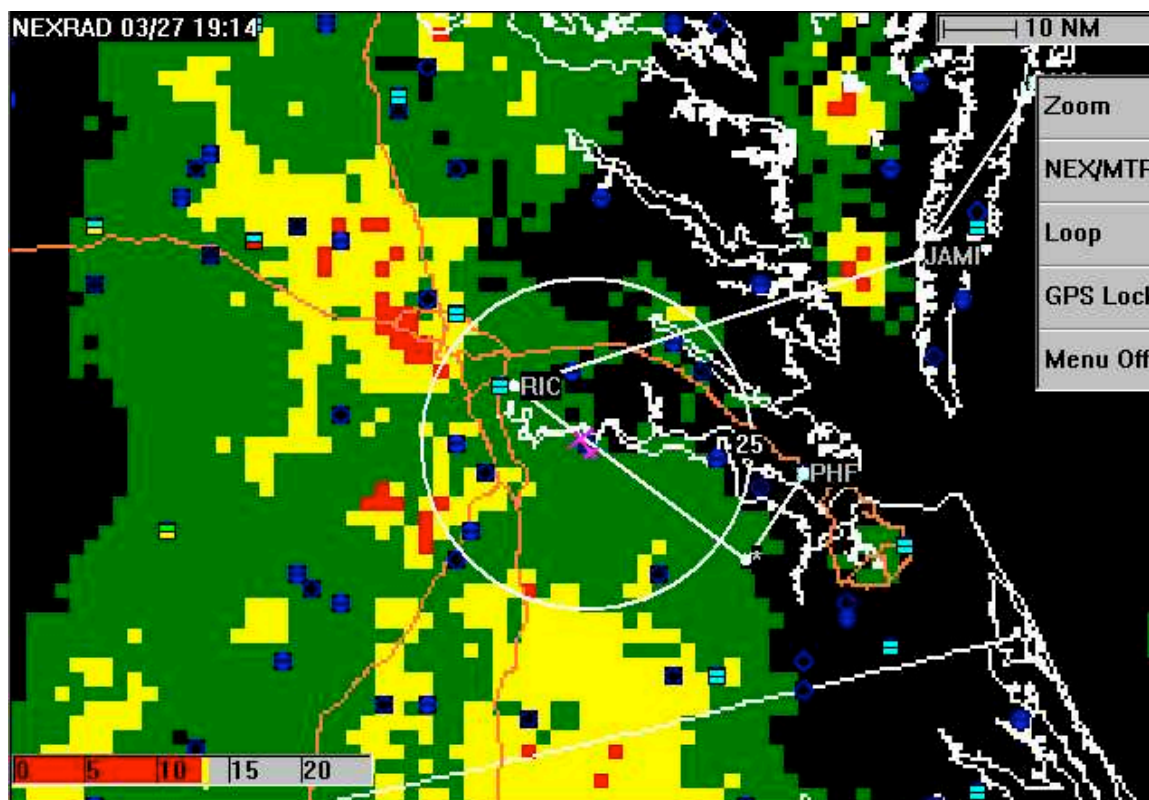


Figure 5.2-1b. NEXRAD Display (with looping) seen by subject pilots inbound to Richmond Airport IAF (10nm Scale)

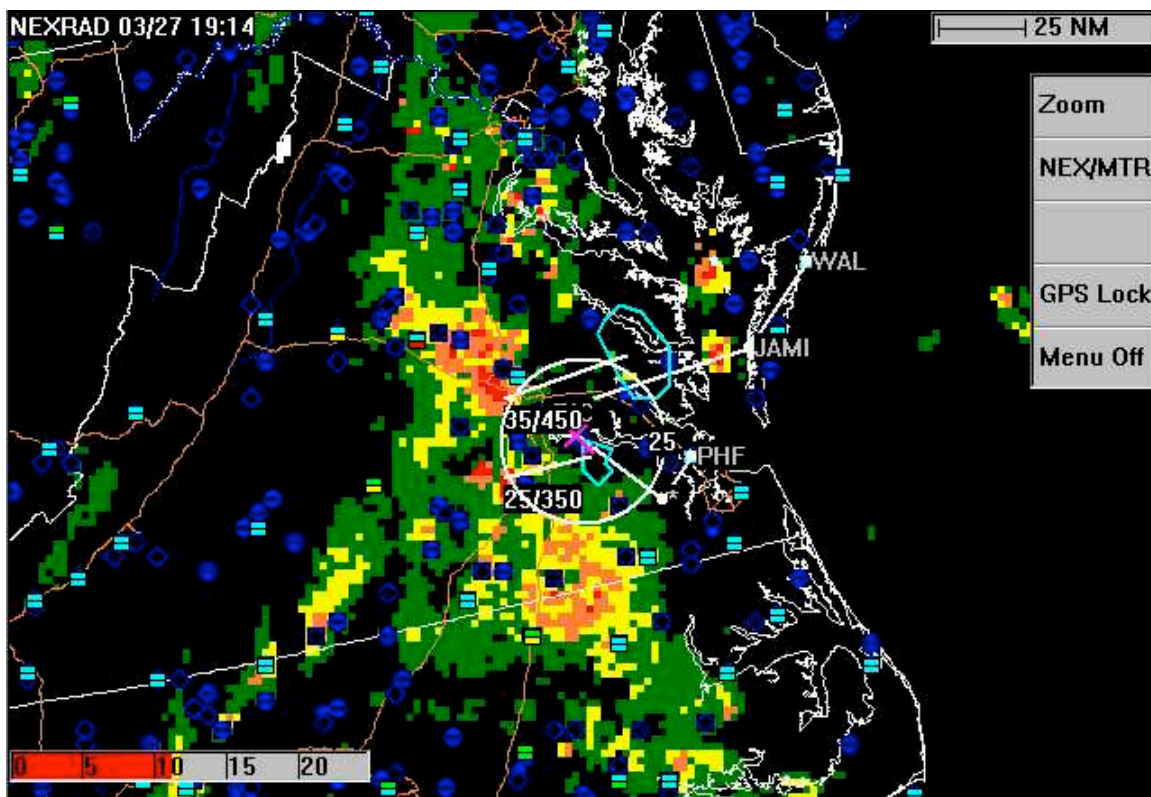


Figure 5.2-1c NCWF Display seen by subject pilots inbound to Richmond Airport IAF (25nm Scale)

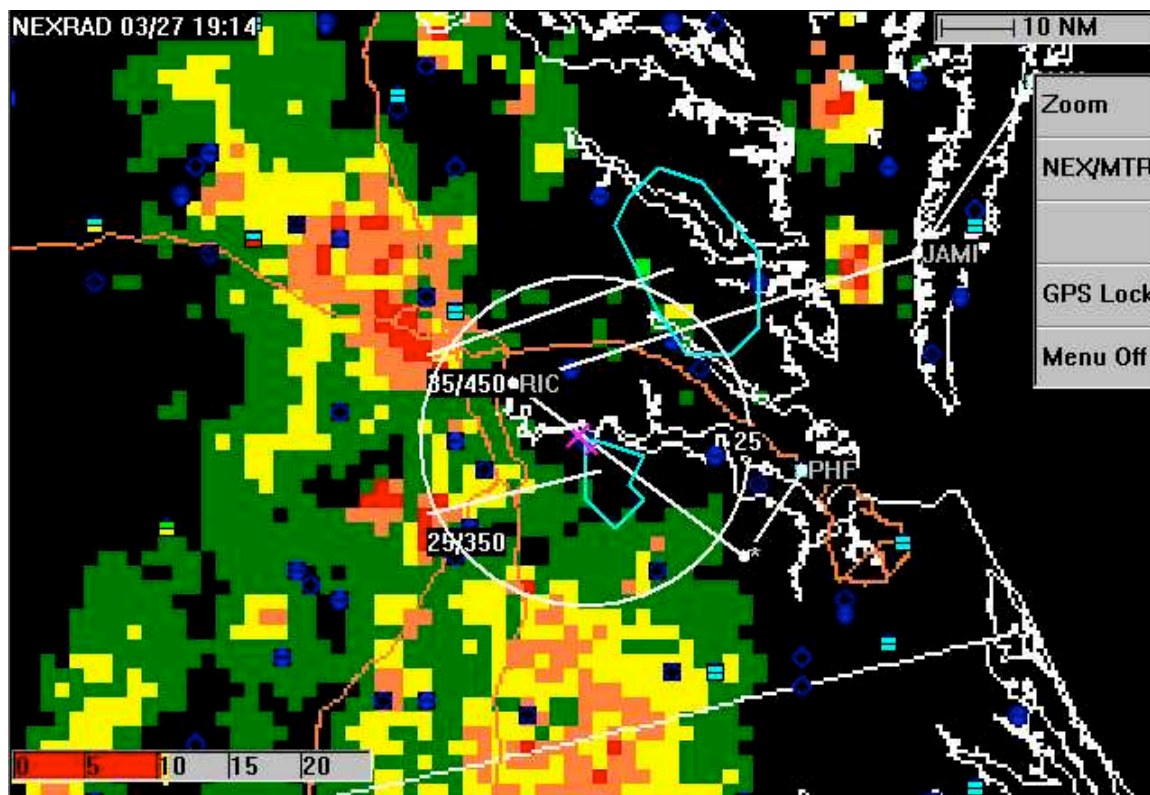


Figure 5.2-1d NCWF Display seen by subject pilots inbound to Richmond Airport IAF (10nm Scale)

Because of the delay in transmission of the image to the aircraft, the data was at least seven minutes old and could have been as many as 14 minutes old. Actual conditions at the Richmond airport in the time frame of this decision can be seen in Figures 5.2-2 and 5.2-3, which depict the NEXRAD mosaic images with the time stamps of 1921Z and 1928Z respectively.

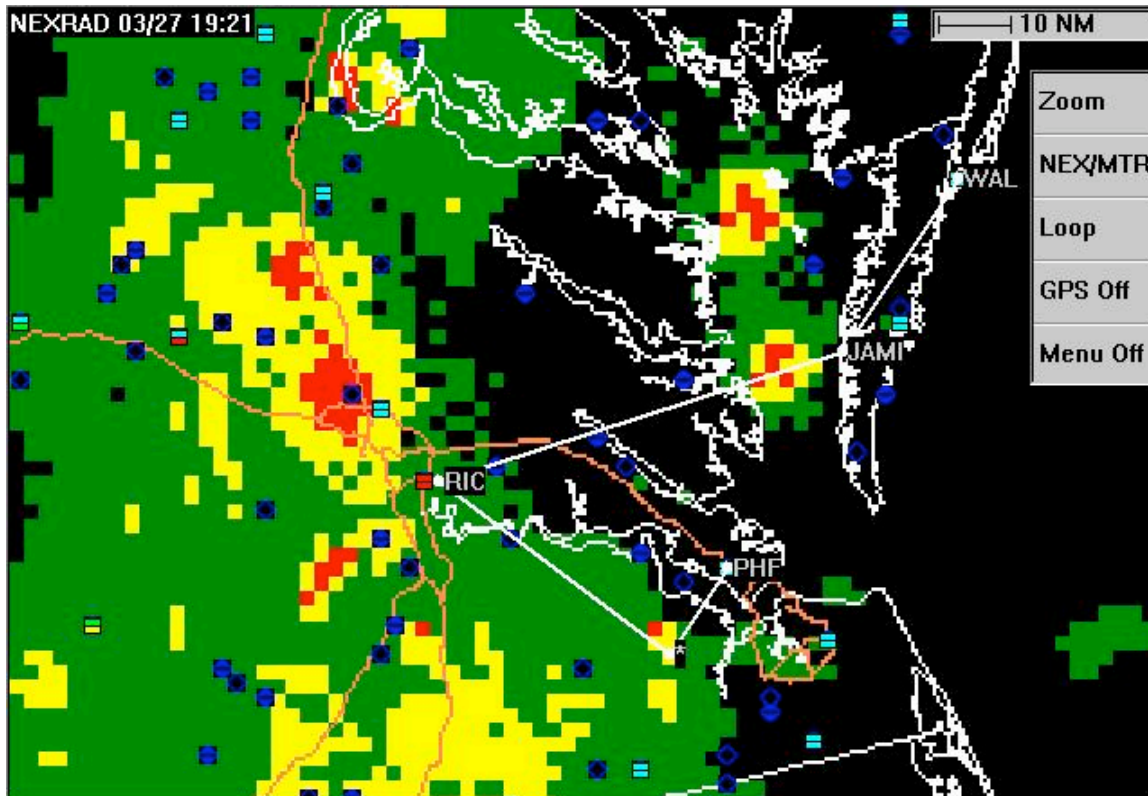


Figure 5.2-2. Actual Conditions at Richmond Airport (as seen in NEXRAD Mosaic Image with 1921Z time stamp)

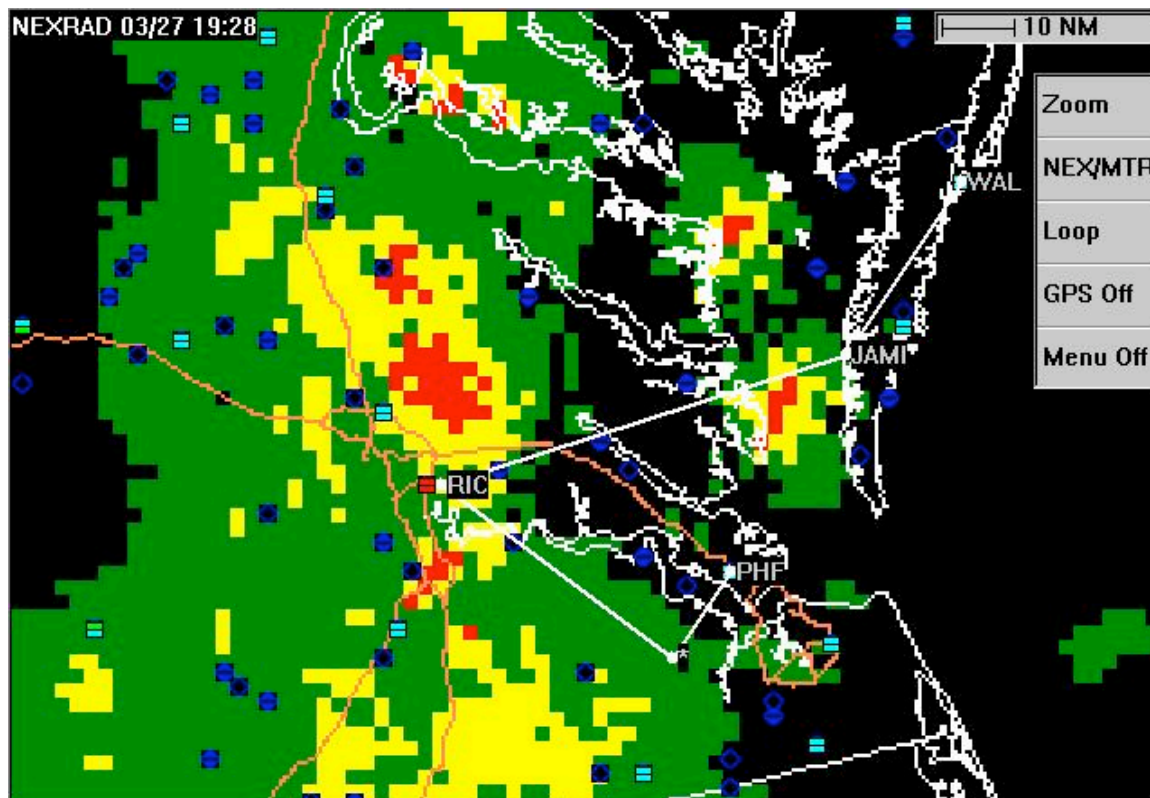


Figure 5.2-3. Actual Conditions at Richmond Airport (as seen in NEXRAD Mosaic Image with 1928Z time stamp)

The thunderstorm seen to the northwest of Richmond is the storm that was designed to elicit a weather decision from the pilots. 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 decision 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 less than five (5) miles outside of the outer marker, but flew within five (5) miles of a red NEXRAD image cell, while in the Richmond area.
- 3 = The pilot abandoned the approach by their own decision less than five (5) miles outside of the outer marker, and flew more than five (5) miles from a red NEXRAD image cell, while in the Richmond area.

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

The “Wallops Island decision” required the participant 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. Figures 5.2-4a and 5.2-4b provide the images that were available on the NEXRAD Display as the pilots departed the vicinity of the HARCUM VOR enroute to Wallops Island.

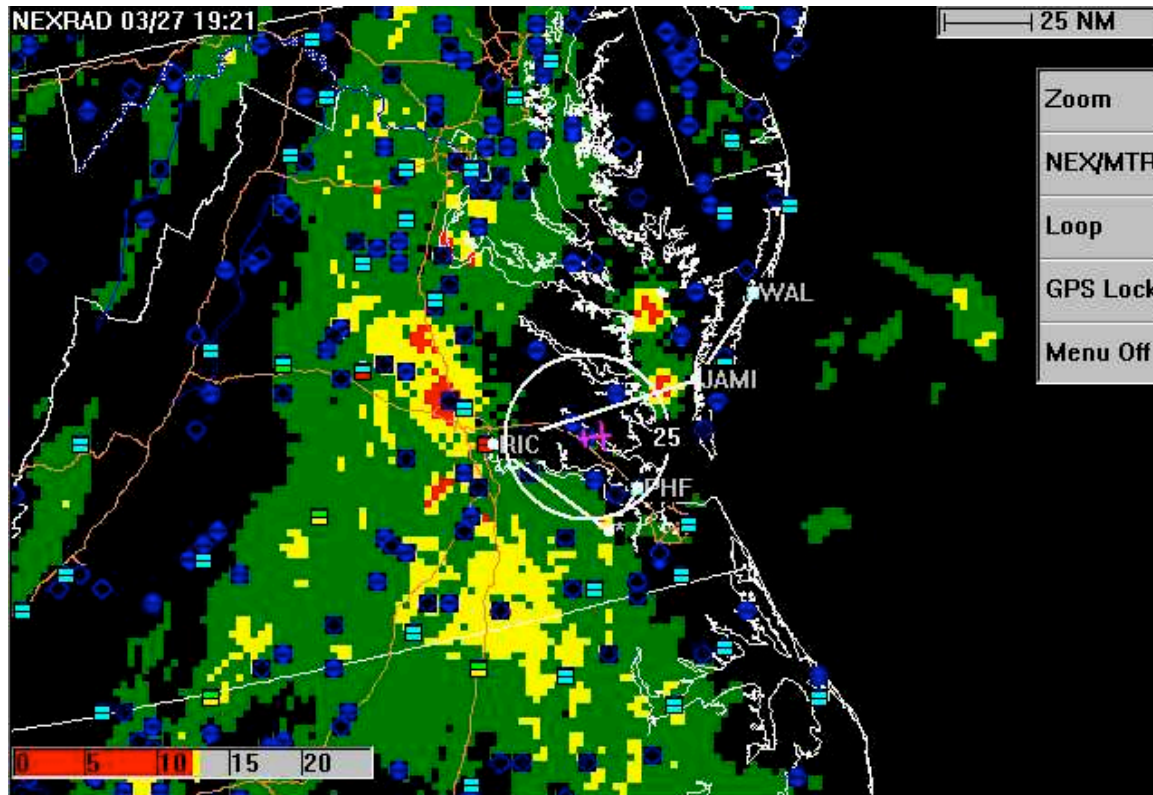


Figure 5.2-4a. NEXRAD Display (with looping) seen by subject pilots along route to Wallops at decision time (25nm Scale)

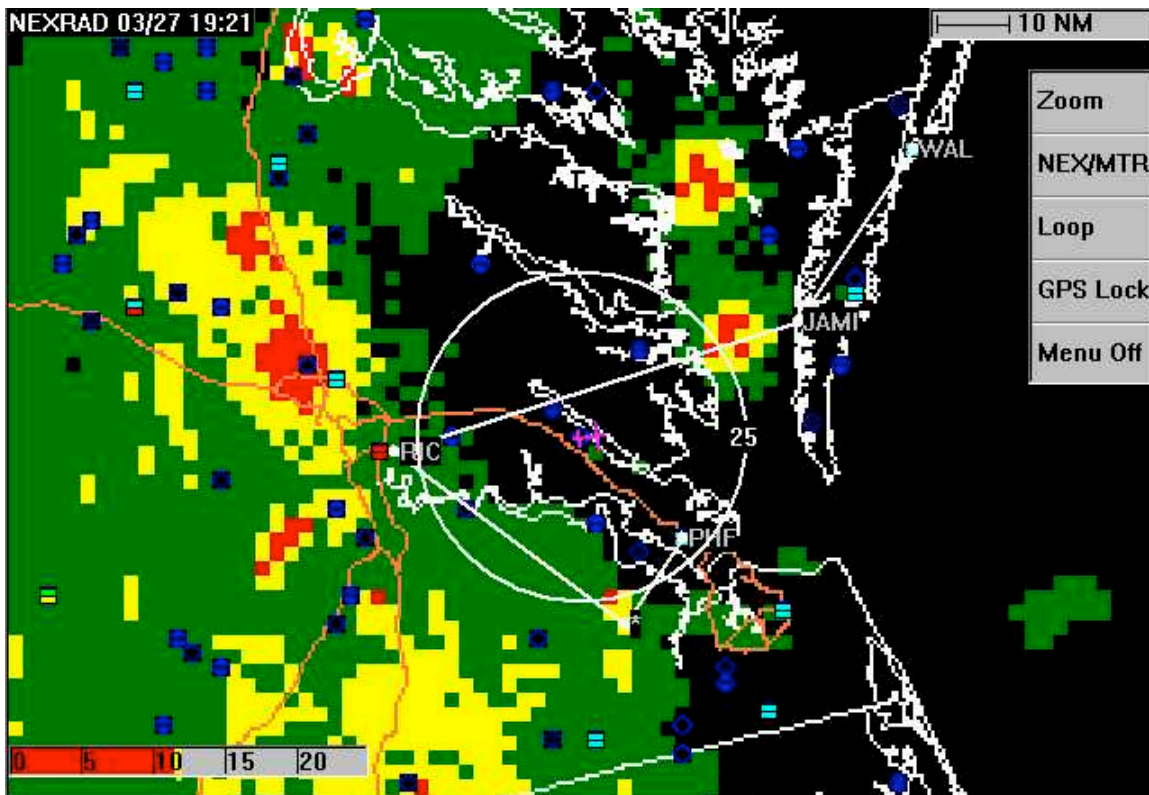


Figure 5.2-4b. NEXRAD Display (with looping) seen by subject pilots along route to Wallops at decision time (10nm Scale)

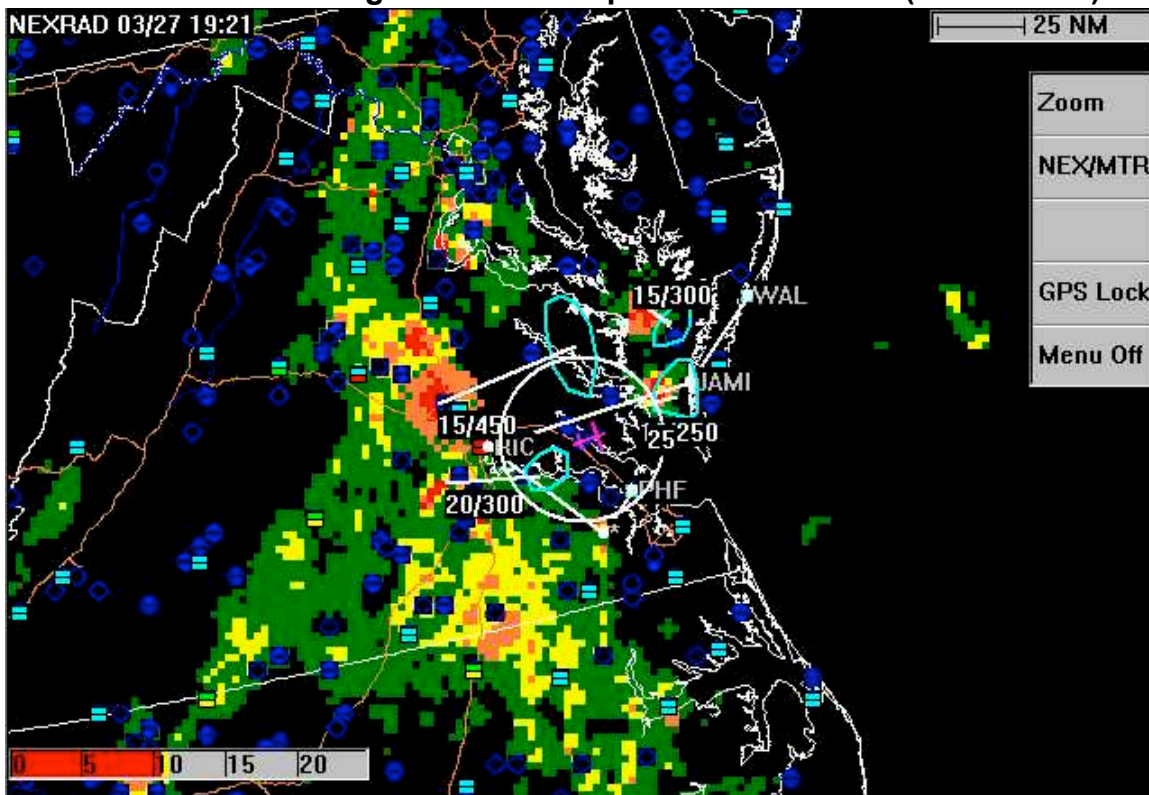


Figure 5.2-4c. NCWF Display seen by subject pilots along route to Wallops at decision time (25nm Scale)

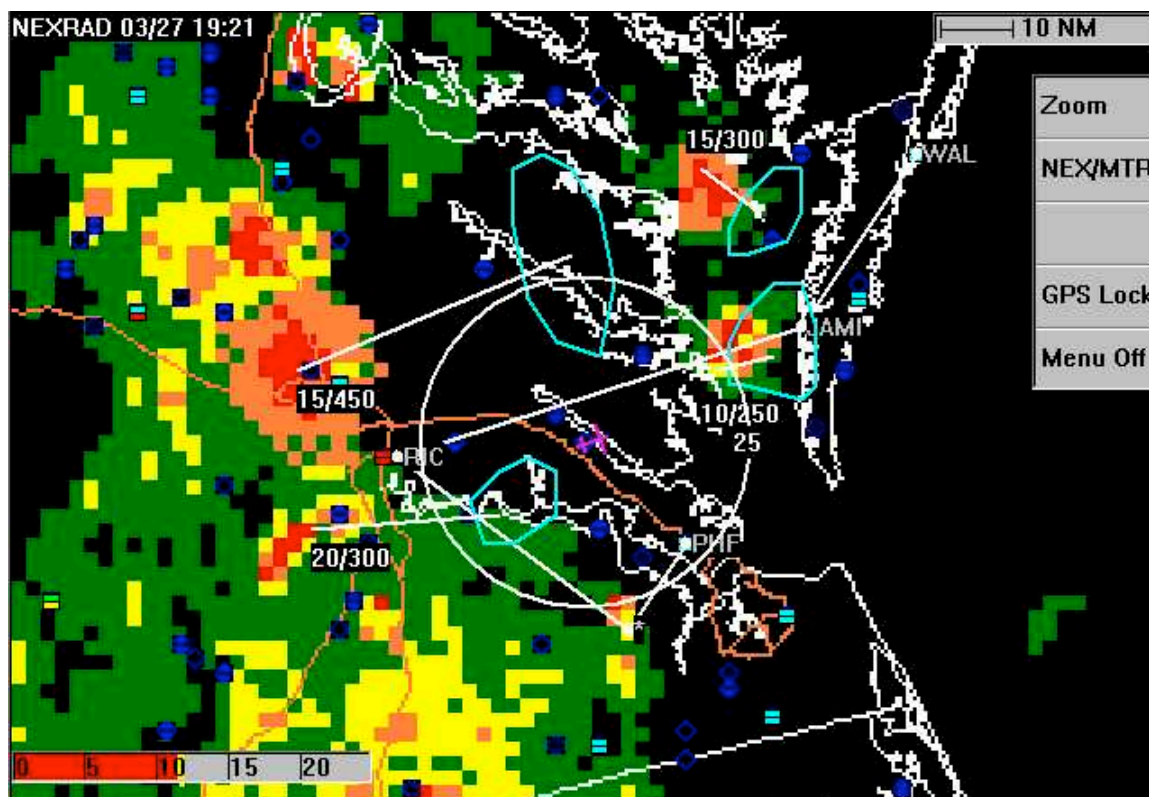


Figure 5.2-4d. NCWF Display seen by subject pilots along route to Wallops at decision time (10nm Scale)

In these images, 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.

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 as determined from the air traffic controller's weather radar display which displayed the weather returns in near real time. 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, flew 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.

In the following subsections, each figure is followed by the data and relevant analysis that led to the diagrams.

5.2.1 Decision Quality: Observer Ratings

Average decision quality for each type of display (i.e., NCWF, Looping NEXRAD, and Control) is plotted by decision type (i.e., Richmond or Wallops) in Figure 5.2.1-1. A repeated measures ANOVA was conducted on the 4-point decision quality metrics. The ANOVA indicates that there is a significant main effect of decision type, $F(1,43) = 15.75$, $p < .001$. Pilots made significantly poorer quality decisions at Richmond than at Wallops. There was no effect of type of display on decision quality, $F(2,43) = .06$, $p < .95$. That is, pilots with weather displays did not make significantly higher-quality decisions than pilots without weather displays. Although the interaction between decision type and type of display is not statistically significant, $F(2,43) = 1.22$, $p < .31$, Figure 5.2.1-1 reveals some monotone interaction. For example, NCWF led to the highest-quality decisions in the Richmond leg (i.e., temporal decision), but the poorest-quality decisions in the Wallops leg (i.e., spatial decision) when compared to the other displays. Moreover, pilots with looping NEXRAD made the highest-quality decisions at Wallops, but the poorest-quality decisions at Richmond when compared to the other displays.

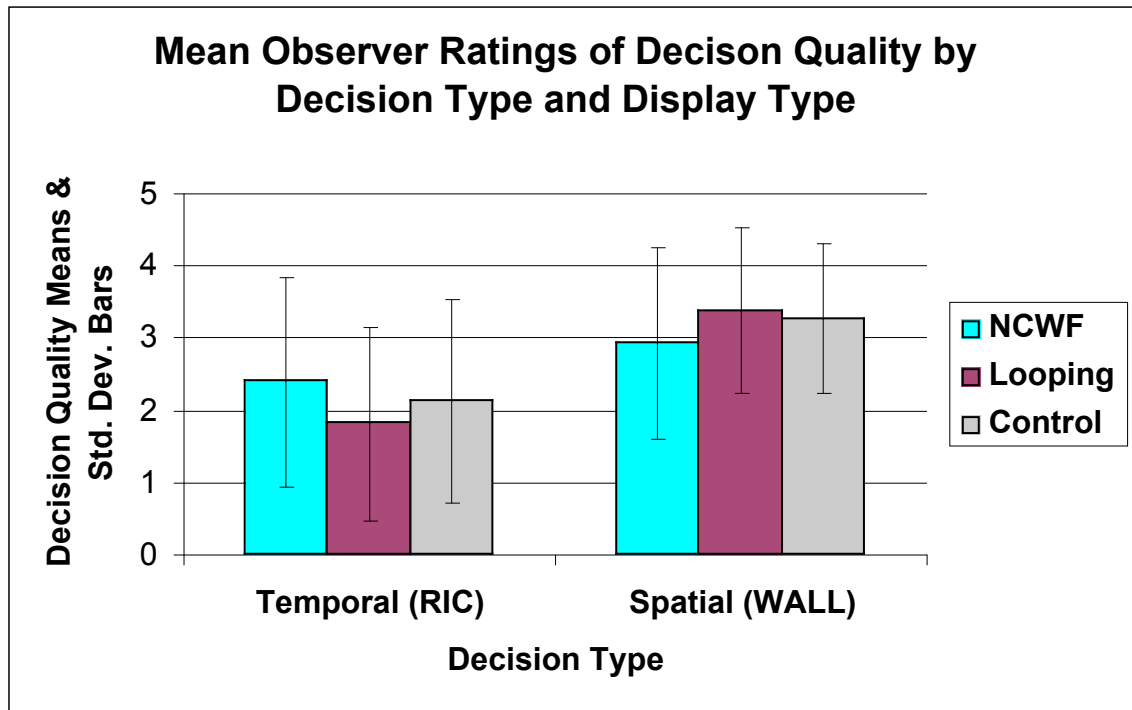


Figure 5.2.1-1. Observer Ratings of Decision Quality by Decision Type and Display Type

General Linear Model

Within-Subjects Factors

Measure: MEASURE_1	
DTYPE	Dependent Variable
1	RICDQ
2	WALDQ

Between-Subjects Factors

CONDITIO	N
Control	15
Looping	16
NCWF	15

Descriptive Statistics

	CONDITIO	Mean	Std. Deviation	N
RICDQ	Control	2.13	1.41	15
	Looping	1.81	1.33	16
	NCWF	2.40	1.45	15
	Total	2.11	1.39	46
WALDQ	Control	3.27	1.03	15
	Looping	3.37	1.15	16
	NCWF	2.93	1.33	15
	Total	3.20	1.17	46

5.2.2 Decision Quality: Minimum Distance from Red Cell

The air traffic controller and experiment observers recorded the minimum distance that each pilot flew from a red cell on both the Richmond leg and the Wallops leg. The minimum distance from red cell metric provides another measure of decision quality. Average minimum distance from red cell for each type of display (i.e., NCWF, Looping NEXRAD, and Control) is plotted by decision type (i.e., Richmond or Wallops) in Figure 5.2.2-1. A repeated measures ANOVA was conducted on the minimum distance from red cell metric. The ANOVA indicates that there is no significant main effect for either decision type, $F(1,34) = 00.17$, $p > .68$, or type of display, $F(2,34) = 00.03$, $p > .97$, on the minimum distance from red cell. Although the interaction between decision type and type of display is marginally statistically significant, $F(2,34)=1.82$, $p<.10$., Figure 5.2.2-1 clearly reveals some non-monotone interaction. The interaction implies that a particular type of display (e.g., NCWF) had differential effects on minimum red cell distance depending on the type of decision being made by the pilots. For example, pilots with NCWF had longer minimum distances from red cell on the Richmond leg (i.e., temporal decision) than on the Wallops leg (i.e., spatial decision). Pilots with Looping NEXRAD and pilots without a weather display had longer minimum distances from red cell on the Wallops leg than on the Richmond leg.

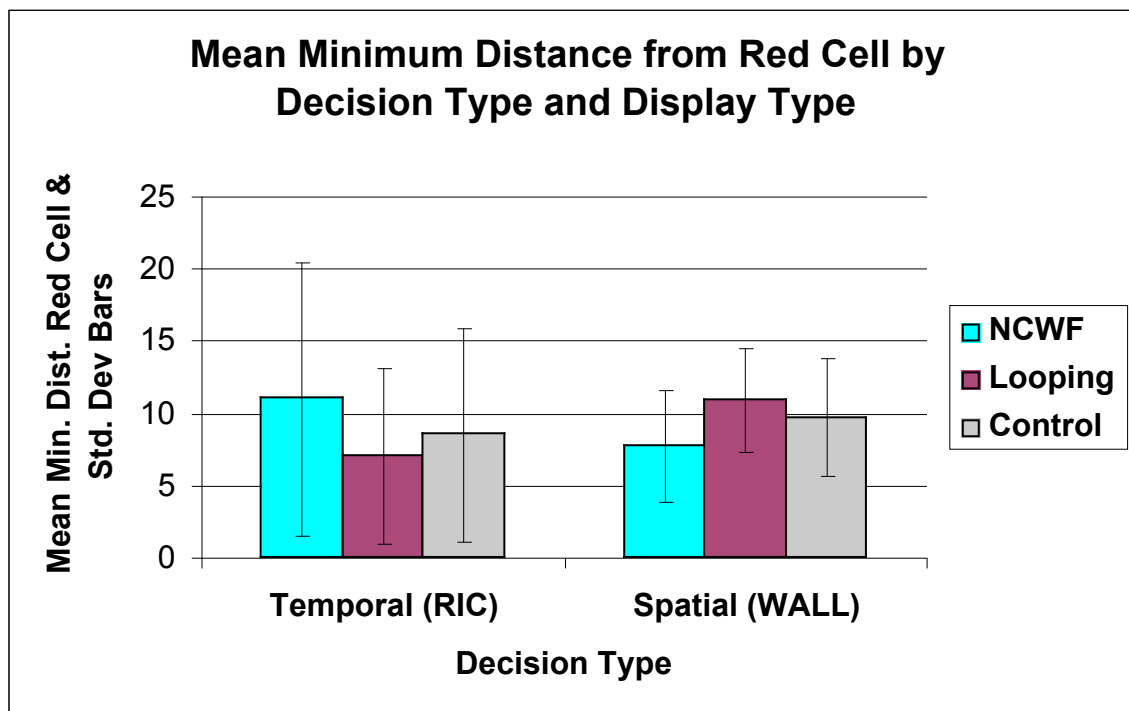


Figure 5.2.2-1. Minimum Distance from Red Cell by Decision Type and Display Type

General Linear Model

Within-Subjects Factors

Measure: MEASURE_1

DECTYPE	Dependent Variable
1	REDRIC
2	REDWALL

Between-Subjects Factors

	N
DISPLAYS Control	14
Looping	12
NCWF	11

Descriptive Statistics

	DISPLAYS	Mean	Std. Deviation	N
REDRIC	Control	8.500	7.367	14
	Looping	7.000	6.075	12
	NCWF	11.000	9.455	11
	Total	8.757	7.635	37
REDWALL	Control	9.714	4.065	14
	Looping	10.917	3.630	12
	NCWF	7.727	3.849	11
	Total	9.514	3.969	37

5.3 Findings from the Immediate Reactions Questionnaire

Upon completion of the simulator session, each participant pilot was given a questionnaire (Appendix J, Immediate Reactions Questionnaire) to obtain his or her immediate reactions. The pilot was given the 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) to **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 to determine the extent to which the participant pilots “bought into” the wedding scenario. All pilots were asked this question. Also, there were no significant differences between pilots’ responses to this question across the display conditions.

I took the wedding scenario as a serious personal commitment, in the sense that I factored the time pressure into my decision-making.

(mean score of 4.04, standard deviation of 1.17)

A score of four (4) was indicative of an “agree somewhat.” A mean score of 4.04 and standard deviation of 1.17 with this question signifies that the majority of pilots somewhat “bought into” the wedding scenario, thus the scenario was sufficiently realistic to engage the pilots in the situation.

Question 2. This question explored the extent to which the pilots perceived the weather information display as an aid to make better decisions. Only participant pilots who flew with a weather display received this question. There was not a significant difference in response to the question between pilots who flew with the NCWF display and pilots who flew with NEXRAD Image Looping display.

An advantage of the onboard Weather Display was showing the graphical depiction of the weather to aid in my decision-making.
(mean score of 4.61, standard deviation of .56)

A score of five (5) was indicative of an “agree.” A mean score of 4.61 and standard deviation of .56 with this question signifies that the majority of pilots perceived the NCWF display and NEXRAD image Looping display as an advantage to their decision making.

Question 3. This question explored the extent to which the pilots perceived the weather information display as increasing their situational awareness. Only participant pilots who flew with a weather display received this question. There was not a significant difference in the average response to the question between pilots who flew with the NCWF display and pilots who flew with the NEXRAD Image Looping display.

The weather display increased my situational awareness during the decision-making process.
(mean score of 4.44, standard deviation of .91)

A mean score of 4.44 and standard deviation of .91 on this question indicates that the pilots generally perceived the weather display as increasing their situational awareness.

Question 4. This question explored the extent to which the pilots perceived themselves as attempting to use all the sources of weather information available to them. This question was asked of all pilots. There were no significant differences in the average response to the question across the three display conditions.

I tried to systematically sample all sources of weather information open to me.
(mean score of 3.37, standard deviation of 1.35)

The mean score of 3.37 indicates that the perceived strategy of the pilots was not to systematically sample all possible sources of weather information. However, the

relatively large standard deviation of 1.35 suggests a wide variation in the pilot's perceived strategies of sampling all possible sources of weather information.

Question 5. This question explored the extent to which pilots believed it was necessary to crosscheck their inferences from the cockpit weather information display with conventional weather data sources. Only participant pilots who flew with a weather display received this question. There was not a significant difference in the average response to the question between pilots who flew with the NCWF display and pilots who flew with the NEXRAD Image Looping display.

I used the weather display, but felt the need to crosscheck or verify my conclusions from conventional weather data sources (ATC, etc.).
(mean score of 4.03, standard deviation of 1.15)

The mean score of 4.03 indicates that pilots generally perceived a need to crosscheck their inferences when those inferences were based on information from the weather display.

Question 6. This question explored the extent to which the pilots perceived themselves as understanding and appropriately operating the autopilot. The question was given to all pilots. Also, there were no significant differences in the average response to the question across the three display conditions.

I felt comfortable with the autopilot, in terms of understanding its use and operation.
(mean score of 4.17, standard deviation of 1.15)

The mean score of 4.17 indicates that pilots generally perceived themselves as being somewhat comfortable with the autopilot.

Question 7. This question explored the pilots' perceived ability to successfully complete the flight without the aid of the autopilot. The question was given to all pilots. There were significant differences in the average response to the question across the three display conditions, $F(2,44)=4.49$, $p = .02$.

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

Table 5.3-1. Pilots' Perception of Their Ability To Complete Mission Without Autopilot

Condition	Mean Score	Standard Deviation
Control	4.13	1.31
NCWF Display	3.47	1.55
NEXRAD Looping Display	4.75	.45
Total	4.13	1.28

The mean scores indicate that pilots in the Control and NEXRAD Image Looping conditions considered the autopilot necessary to the safe completion of the flight. The autopilot may have decreased workload and allowed the pilots more time to sample weather information sources. Pilots who flew with the NCWF display, however, believed the autopilot was less necessary for the safe completion of the flight than pilots in the other conditions. Pilots with the NCWF display may have been less compelled to search for conventional sources of weather information because the NCWF product is an integrative tool, which includes multiple weather products. For this reason pilots with the NCWF display may have perceived reductions in workload provided by the autopilot as less essential for the safe completion of the flight than pilots in the other display conditions.

Question 8. This question explored the extent to which pilots' perceived themselves as attending to the latency and accuracy of the weather information. Only participant pilots who flew with a weather display received this question. There was not a significant difference in the mean response to the question between pilots who flew with the NCWF display and pilots who flew with the NEXRAD Image Looping display.

The degree of validity and timeliness of the weather data appearing on the display was a factor I felt that I held in mind as I flew.
(mean score of 4.39, standard deviation of 1.05)

The mean score of 4.39 indicated that the pilots believed they were aware of the age of the information depicted on the cockpit weather display.

Question 9. This question explored the pilots' perceptions of whether they attended to the age display, which provides a graphical representation of the age of the weather information, in their instrument scans. Only participant pilots who flew with a weather display received this question. There was not a significant difference in the mean response to the question between pilots who flew with the NCWF display and pilots who flew with the NEXRAD Image Looping display.

I have been monitoring the weather age display regularly in my instrument scan.
(mean score of 4.28, standard deviation of 1.17)

The mean score of 4.28 indicated that the pilots believed they were including the age display in their instrument scan. Thus, the ratings of Questions 9 and 10 suggest that the pilots were both aware and regularly sampled (i.e., utilized) the age display.

Question 10. The pilots were asked what they perceived the weather conditions to be near the Richmond airport. The question was given to all pilots. Also, there were no significant differences in the number of response selections to the question across the three display conditions.

At the time of my arrival to the Richmond airport, I knew that there was a storm--

- a. About 10 nm northwest of the airport. (7 selections)**
- b. About 5 nm northwest of the airport. (6 selections)**
- c. Near the airport. (19 selections)**
- d. Right at the airport. (16 selections)**

Most of the pilots correctly perceived that the storms were very close to the airport. This perception, however, did not necessarily contribute to good-quality decisions.

Question 11. The pilots were asked what they perceived the weather conditions to be enroute to Wallops Island. The question was given to all pilots. Also, there were no significant differences in the number of response selections to the question across the three display conditions.

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. (1 selection)**
- b. A navigable opening between convective cells. (14 selection)**
- c. A non-navigable opening between cells. (5 selection)**
- d. A wall of convective activity requiring diversion. (18 selection)**

Although the most pilots (18) correctly perceived the storms as requiring diversion, there were several pilots (15) who perceived the storm as navigable or penetrable. It is important to note that the participant pilots who perceived the storm as requiring diversion did not necessarily make good-quality decisions.

Question 12. The question assessed the extent to which the pilot perceived that the ownship icon provided an accurate representation of aircraft position. Only participant pilots who flew with a weather display received this question. There was a marginally statistically significant difference in the mean response to the question between pilots who flew with the NCWF display and pilots who flew with the NEXRAD Image Looping display, $F(1,30)=2.90$, $p=.06$.

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

Table 5.3-2. Pilots' Perception that the Ownship Icon Provided an Accurate Representation of Aircraft Position

Condition	Mean Score	Standard Deviation
NEXRAD Looping Display	4.27	.96
NCWF Display	3.25	1.77
Total	3.74	1.50

The mean scores indicate that pilots with the NEXRAD Looping display considered the positional accuracy of the ownship icon to be adequate. The mean score of NCWF pilots indicate they had no opinion as to the positional accuracy of the ownship icon. The relatively large standard deviation of the NCWF condition, however, suggest that the pilots who flew with the NCWF display had varying opinions as to the positional accuracy of the ownship icon.

Question 13. This question assessed the extent to which the pilots perceived the weather display as helping them to identify their aircraft position relative to any storms. Only participant pilots who flew with a weather display received this question. There was not a significant difference in the mean response to the question between pilots who flew with the NCWF display and pilots who flew with the NEXRAD Image Looping display.

In using the weather display, I felt that I precisely knew the aircraft position relative to any storms.
(mean score of 3.47, standard deviation of 1.39)

The mean score of 3.47 indicated that the pilots generally did not believe they precisely knew their relative position to storms when relying on the weather display. However, the relatively large standard deviation of 1.39 suggests a wide variation in the pilots' perceptions of how precisely relative position to storms was known.

Question 14. The purpose of this question was to determine if the pilots believed they had enough valid information to make confident decisions concerning hazardous weather. The question was given to all pilots. There were significant differences in the average response to the question across the three display conditions $F(2,44)=3.91$, $p < .03$.

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

Table 5.3-3. Pilots' Perception that They Had Adequate Weather Information To Make Confident Decisions

Condition	Mean Score	Standard Deviation
Control	2.93	1.53
NCWF Display	4.06	1.31
NEXRAD Looping Display	4.13	1.12
Total	3.72	1.41

The mean scores indicate that pilots with the NCWF display and the NEXRAD Image Looping display felt they had adequate sources of weather information to make confident decisions. Pilots without a weather display, however, felt they had relatively inadequate sources of weather information to make confident decisions.

Question 15. This question assessed the extent to which the pilots perceived that the presence of the weather display increased their head-down time and scanning workload. In other words, this question partially captures the extent to which the pilots perceived they cognitively tunneled on the weather display. Only participant pilots who flew with a weather display received this question. There was not a significant difference in the mean response to the question between pilots who flew with the NCWF display and pilots who flew with the NEXRAD Image Looping display.

The weather display increased head-down time and scanning workload.

(mean score of 3.56, standard deviation of 1.34)

The mean score of 3.56 indicates that the pilots were generally unaware of any influence the weather display may have had on head-down time or scanning workload. However, the relatively large standard deviation of 1.48 suggests a wide variation in the perception of the effects of the displays on head-down time and scanning workload.

Question 16. This question explored the pilot's perception of the latency of the weather information, and the extent to which the weather display was showing depicted weather in "real time." Only participant pilots who flew with a weather display received this question. There was not a significant difference in the mean response to the question between pilots who flew with the NCWF display and pilots who flew with the NEXRAD Image Looping display.

I was aware of the latency of the weather data appearing on screen as I flew and assessed alternative flight paths.

(mean score of 4.23, standard deviation of 1.12)

The mean score of 4.23 indicated that pilots were generally aware of the latency of the weather information.

Question 17. This question tapped the pilot's perception of the usefulness of the range-rings in determining their proximity to weather cells. Only participant pilots who flew with a weather display received this question. There was not a significant difference in the mean response to the question between pilots who flew with the NCWF display and pilots who flew with NEXRAD Image Looping display.

I found the range rings very useful in enhancing my weather cell awareness.

(mean score of 3.63, standard deviation of 1.48)

The mean score of 3.63 indicates that the pilots generally had no opinion one way or another as to the usefulness of the range-rings. However, the relatively large standard deviation of 1.48 suggests a wide variation in the perception of the usefulness of the range rings among the pilots.

Question 18. This question tapped the pilot's perception of the flight-path waypoints on decision making. Only participant pilots who flew with a weather display received this question. There was not a significant difference in the mean response to the question between pilots who flew with the NCWF display and pilots who flew with the NEXRAD Image Looping display.

The presentation of flight path waypoints facilitated my decision-making.

(mean score of 3.91, standard deviation of 1.38)

The mean score of 3.91 indicates that the pilots generally perceived the depiction of waypoints on the weather display as facilitating decision-making. However, the relatively large standard deviation of 1.38 suggests a wide variation in the perception of the usefulness of the waypoints on decision-making among the pilots.

5.4 Findings from the Structured Interview

The subject pilots' answers to several key questions asked in the structured interview that are related to their decision making processes will be considered in this section.

Question 3. This Question was asked to determine if the pilots believed they had enough information to make an accurate and confident decision during the Richmond leg of the flight.

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

Pilot responses to the question are plotted by display type in Figure 5.4-1. Logistic ANOVA was conducted on the pilot responses. A logistic ANOVA Likelihood Ratio test indicated that the type of display influenced the likelihood that pilots perceived themselves as having enough information on the Richmond Leg of the flight ($\chi^2(2,45)=16.91, p < .001$). The results indicate control pilots were significantly less likely to respond that they had enough information than pilots with the NEXRAD Image Looping display or the NCWF display. Also, few pilots who flew with a weather display responded that they did not have enough information.

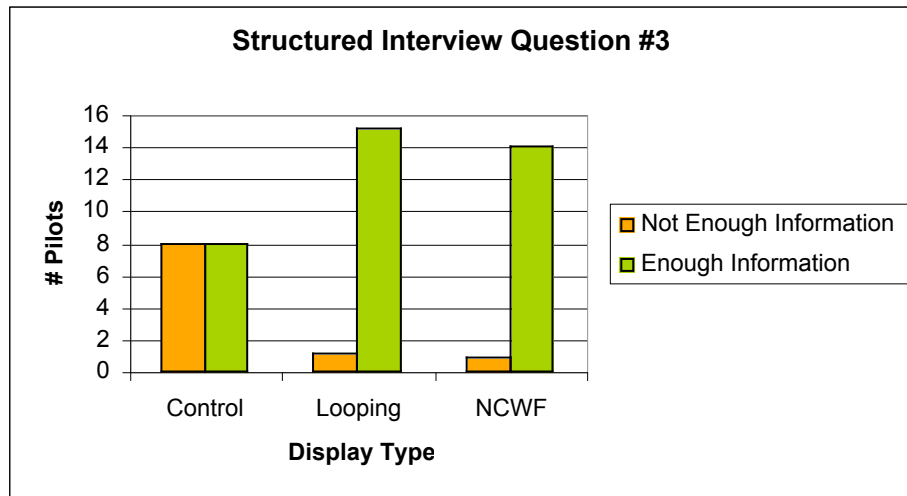


Figure 5.4-1. Pilots' Perception that They Had Sufficient Information to Make Confident Decisions on Richmond Leg

Question 7. This question explored the extent to which the pilots believed they had enough time to get all the information they needed to make a decision in the Richmond leg of the flight. This question captured workload by tapping into the extent pilots perceived they were under time pressure.

Do you feel that you had enough time to gather all the information that you wanted?

Pilot responses to the question are plotted by display type in Figure 5.4-2. Logistic ANOVA was conducted on the pilot responses. A logistic ANOVA Likelihood Ratio test indicated that the type of display did not influence the pilots perception of whether they had enough time on the Richmond leg to gather all the information they wanted ($\chi^2(2,45) = 1.30, p < .52$). The results indicate that the majority of pilots across all conditions believed they had enough time to gather information on the Richmond leg of the flight.

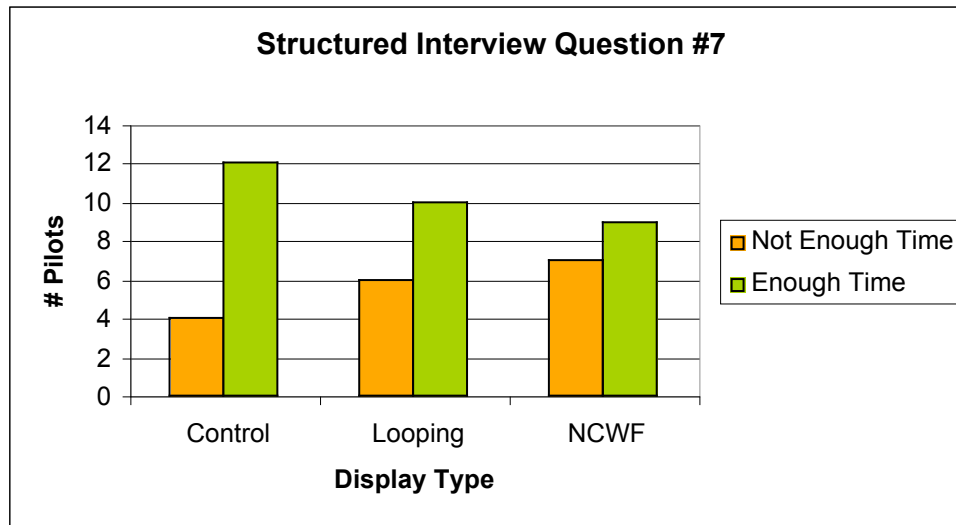


Figure 5.4-2. Pilots' Perception that They Had Sufficient Time to Collect Information They Wanted On Richmond Leg

Question 11. This Question was asked to determine if the pilots believed they had enough information to make an accurate and confident decision during the Wallops leg of the flight.

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

Pilot responses to the question are plotted by display type in Figure 5.4-3. Logistic ANOVA was conducted on the pilot responses. A logistic ANOVA Likelihood Ratio test indicated that type of display did not influence the pilot responses to this question ($\chi^2(2,41) = 1.24, p < .54$). The results indicate that the majority of pilots in all conditions believed they had enough information on the Wallops leg of the flight.

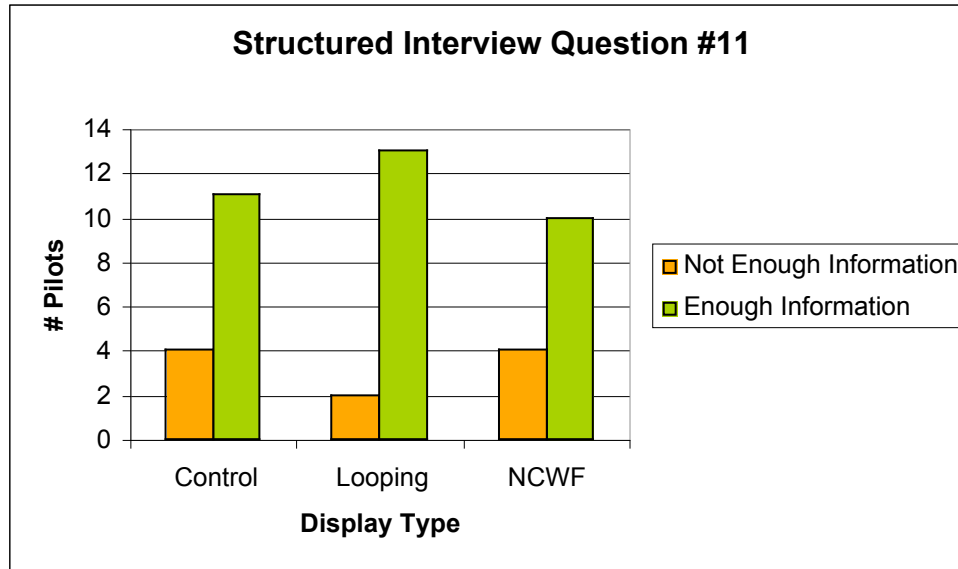


Figure 5.4-3. Pilots' Perception that They Had Sufficient Information to Make Confident Judgment of Situation on Wallops Leg

Question 15. This question explored the extent to which the pilots believed they had enough time to get all the information they needed to make a decision in the Wallops leg of the flight. This question captures workload by tapping into the extent pilots perceived time pressure during the Wallops leg of the flight.

Do you feel that you had enough time to gather all the information that you wanted?

Pilot responses to the question are plotted by display type in Figure 5.4-4. Logistic ANOVA was conducted on the responses. A logistic ANOVA Likelihood Ratio test indicated that type of display did not influence the pilot responses to the question ($\chi^2(2,40) = 2.30, p < .32$). The results indicate that the majority of pilots across all conditions believed they had enough time on the Wallops leg of the flight. Also, note that only one control pilot reported that he did not have sufficient time.

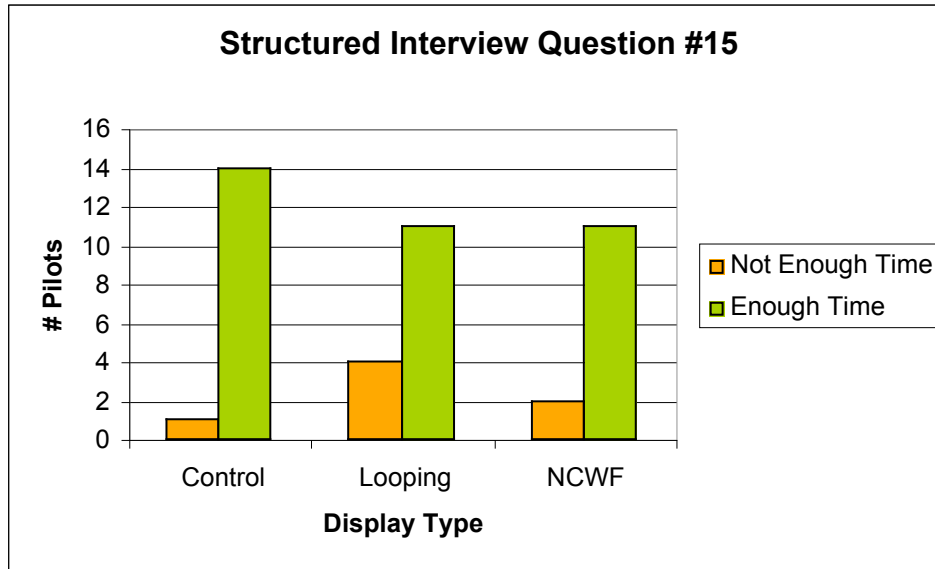


Figure 5.4-4. Pilots' Perception that They Had Sufficient Time to Collect Information They Wanted On Wallops Leg

Question #22. This question explored the pilots' perceptions of the usefulness of the Weather Displays in comparison to conventional sources of weather information.

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

Pilot responses to the question are plotted by display type in Figure 5.4-5. Logistic ANOVA was conducted on the responses. A logistic ANOVA Likelihood Ratio test indicated that type of display did not significantly influence the pilots' responses to the question ($\chi^2(2,27) = 1.50, p < .48$). The results indicate that the majority of pilots believed the weather display was more useful than traditional sources of weather information.

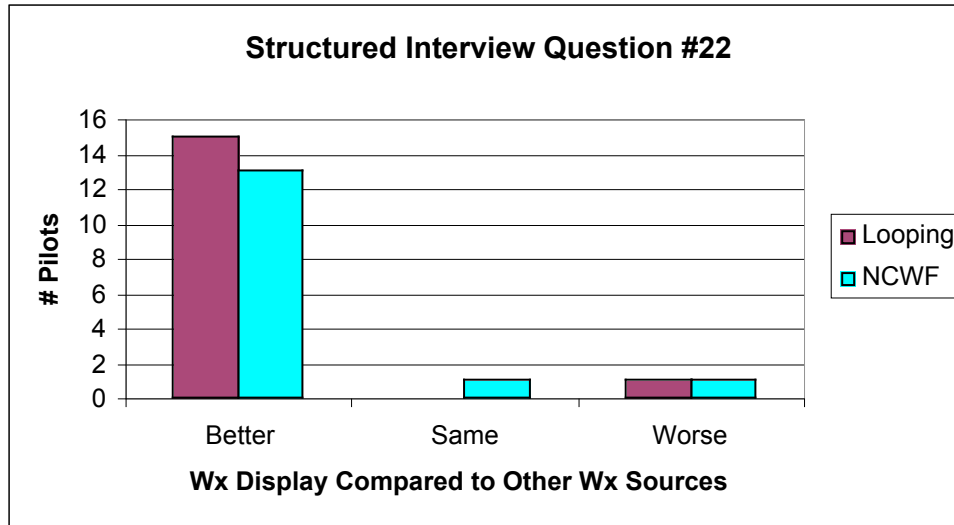


Figure 5.4-5. Pilots' Perception As To Usefulness of Weather Display Information To Other Sources of Weather Information (ATIS, Flight Watch, etc.)

Question #23. This question explored the extent to which the pilots believed they used the weather display for navigation.

Did you use the weather display to help you navigate?

Pilot responses to the question are plotted by display type in Figure 5.4-6. Logistic ANOVA was conducted on the responses. A logistic ANOVA Likelihood Ratio tests indicate that type of display significantly influenced the pilots' responses to the question ($\chi^2(1,29) = 2.85, p < .10$). The results indicate that a relatively large number of pilots with the NEXRAD Image Looping display responded that they used the weather display for navigation. Moreover, the majority of pilots who flew with a weather display responded that they used the weather display for navigation.

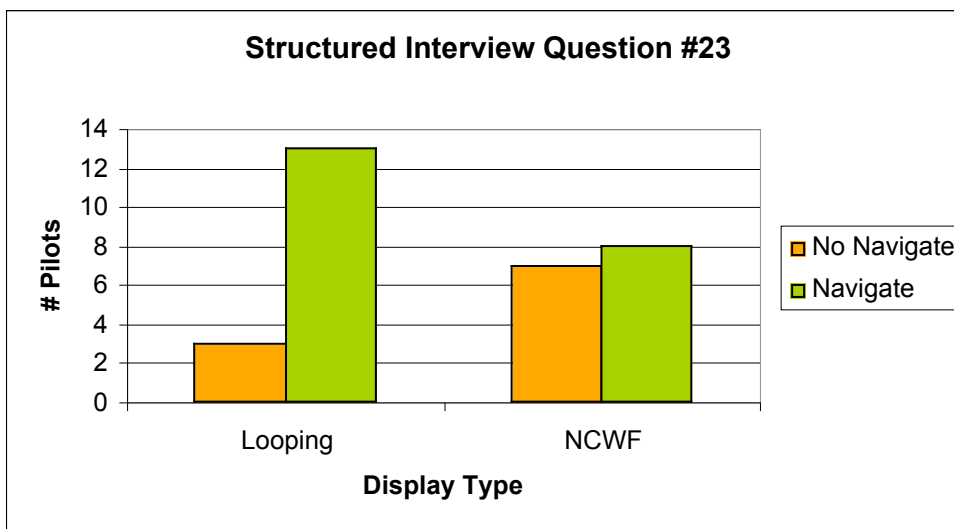


Figure 5.4-6. Pilots' Perception as to Whether Or Not They Used Weather Display to Navigate

Question #24. This question explored pilot perceptions of how the weather display influenced workload.

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

Pilot responses to the question are plotted by display type in Figure 5.4-7. Logistic ANOVA was conducted on the responses. A logistic ANOVA Likelihood Ratio test indicated that type of display did not significantly influence pilot responses to the question ($\chi^2(2,26) = 2.53, p < .29$). Figure 5.4-7 indicates that the majority of pilots who flew with a weather display did respond that the weather display increased their workload.

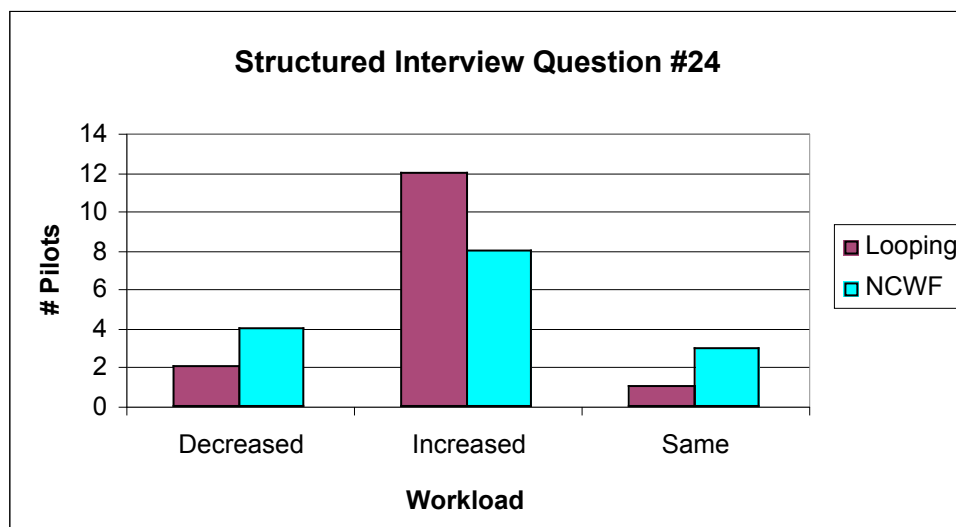


Figure 5.4-7. Pilot's Perception of the Effect of Use of Weather Display On Workload

Question #25. This question explored the pilots' perceived trust in the accuracy of the information presented on the weather display.

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

Pilot responses to the question are plotted by display type in Figure 5.4-8. Logistic ANOVA was conducted on the responses. A Logistic ANOVA Likelihood Ratio test indicated that type of display significantly influenced pilot responses to the question ($\chi^2(1,30) = 2.91, p < .09$). The results indicate that all pilots with NEXRAD Looping and most of the pilots with NCWF responded that they had confidence in the reliability of the information presented by the display.

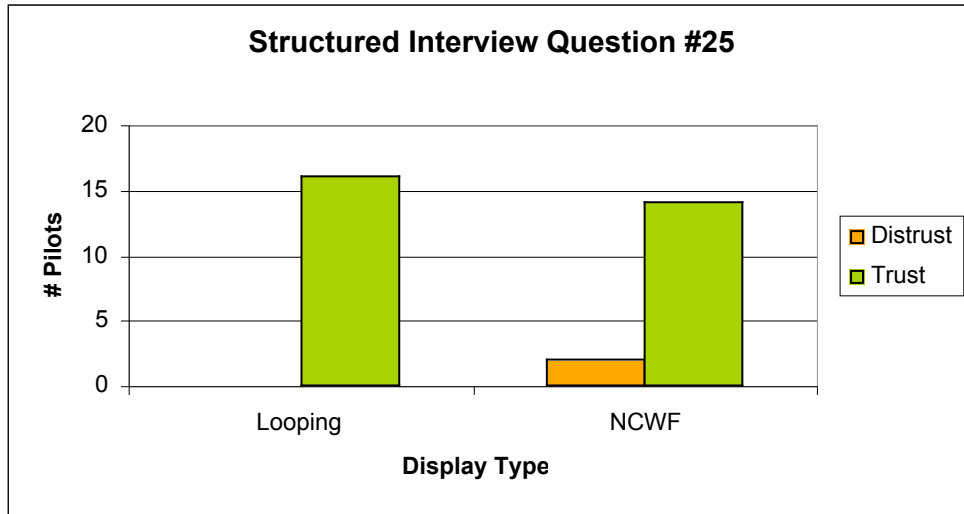


Figure 5.4-8. Pilots' Perception As Whether They Could Trust Weather Display

Question #26. This question explored the extent to which the pilots perceived confusion concerning ownship symbol.

Was there any confusion with the ownship symbology?

Pilot responses to the question are plotted by display type in Figure 5.4-9. Logistic ANOVA was conducted on the responses. A logistic ANOVA Likelihood Ratio test indicated that type of display did not significantly influence pilot responses to the question ($\chi^2(1,29) = .01, p < .92$). Figure 5.4-9 indicates that the majority of pilots responded that there was no confusion concerning the ownship symbol.

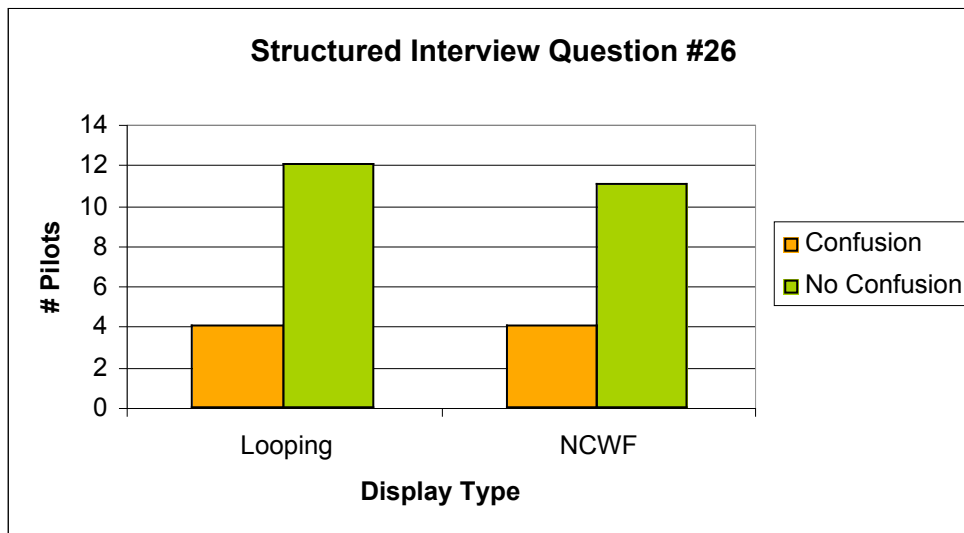


Figure 5.4-9. Pilots' Perception As to Whether They Had Any Confusion in Use of Ownship Symbology

Question #28. This question explored whether pilot workload due to flying the aircraft was within comfort zone.

Did you feel ahead of the airplane?

Pilot responses to the question are plotted by display type in Figure 5.4-10. Logistic ANOVA was conducted on the responses. A Logistic ANOVA Likelihood Ratio test indicated that the type of display did not significantly influence pilot responses to the question ($\chi^2(2,28) = .54, p < .77$). Figure 5.4-10 indicates that the majority of pilots responded that they were behind the airplane. Thus, the workload necessary to fly the airplane took the majority of pilots out of their comfort zones.

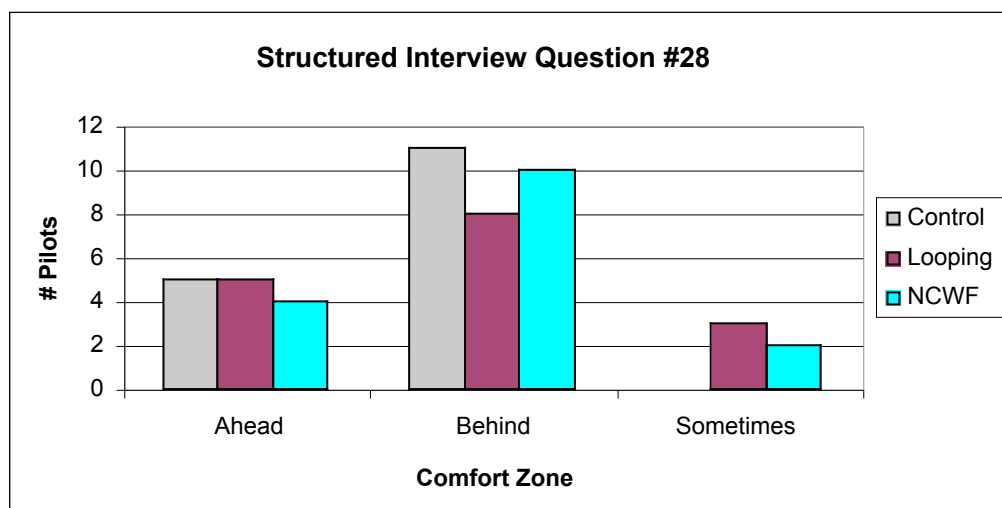


Figure 5.4-10. Pilots' Perception of Whether They Were Ahead or Behind Airplane

5.5 Effects of Display Type on Workload

A subjective evaluation of the workload of the subject pilots was undertaken by the observers through their observations made during the simulated flight, and was obtained from each of the subject pilots upon completion of the flight.

In the following subsections, each figure is followed by the data and relevant analysis that led to the diagrams.

5.5.1 Observers' Assessment of Pilot Workload

The observers made a workload rating on a 100 mm Likert scale for each participant pilot on each leg of the flight. The Likert scale had two labels "Extremely Low" and "Extremely High" that anchored the scale (see Appendix I, Observer Forms). The observer workload ratings were combined for the following analyses.

Average workload ratings for each type of display (i.e., NCWF, Looping NEXRAD, and Control) are plotted by decision type (i.e., Richmond or Wallops) in Figure 5.5.1-1. Repeated measures ANOVA was conducted on the observer workload ratings. The ANOVA indicates that there is a significant main effect of decision type, $F(1,40) = 12.95$, $p < .001$. Thus, the pilots were observed experiencing significantly higher workload in the Richmond leg than in the Wallops leg. There was no effect of type of display on the observer ratings of workload, $F(2,40) = .167$, $p > .84$. That is, pilots with weather displays were not observed experiencing significantly higher workload than pilots without weather displays. Also, the decision type by display type interaction was not statistically significant, $F(2,40) = 1.38$, $p > .15$. Note that the general pattern of results from the combined observer workload ratings is consistent with the results from each observer's workload ratings.

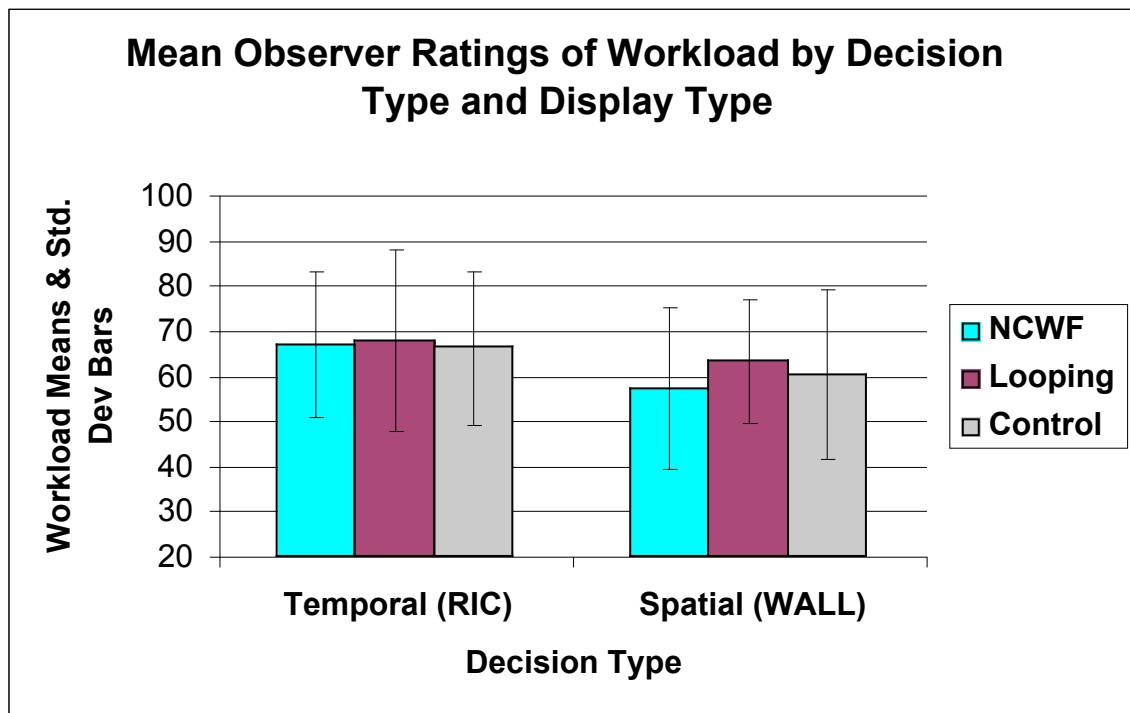


Figure 5.5.1-1. Mean Observers' Ratings of Pilot Workload

General Linear Model

Within-Subjects Factors

Measure: MEASURE_1	
DTYPE	Dependent Variable
1	WLRICQ
2	WLWALQ

Between-Subjects Factors

		N
CONDITIO	Control	13
	Looping	15
	NCWF	15

Descriptive Statistics

	CONDITIO	Mean	Std. Deviation	N
WLRICQ	Control	66.3346	17.0319	13
	Looping	67.8433	20.0625	15
	NCWF	66.9900	16.2121	15
	Total	67.0895	17.4655	43
WLWALQ	Control	60.4192	18.8540	13
	Looping	63.1767	13.7165	15
	NCWF	57.2267	17.9440	15
	Total	60.2674	16.6715	43

5.5.2 Subject Pilot Self-Assessment of Workload

The participant pilots were asked to provide a self-assessment of their workload during the simulated flight just before the structured interview was conducted. The NASA TLX, a subjective taskload index, was used in this assessment. The questionnaire consisted of 6 questions with responses elicited using a 19-point Likert scale (see Appendix O, Subject Pilots' Self-Assessment of Workload). Pilots were asked to use the NASA TLX-Rating Scale Definitions depicted in Table 5.5.2-1 in completing the questionnaire. Note that the TLX questions tap six subjective workload dimensions (i.e., mental demand, physical demand, temporal demand, performance, effort, and frustration).

Table 5.5.2-1. NASA TLX-Rating-Scale Definitions

Title	Endpoints	Descriptions
Mental Demand	Low/High	How much mental and perceptual activity was required (e.g., thinking, deciding, calculating, remember, looking, searching, etc.)? Was the task easy or demanding, simple or complicated, exacting or forgiving?
Physical Demand	Low/High	How much physical activity was required (e.g., pushing, pulling, turning, controlling, activating, etc.)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?
Temporal Demand	Low/High	How much time pressure did you feel due to rate or pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic?

Performance	Good/Poor	How successful do you think you were in accomplishing the experimenter (or yourself)? How satisfied were you with your performance in accomplishing these goals?
Effort	Low/High	How hard did you have to work (mentally and physically) to accomplish your level of performance?
Frustration	Low/High	How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task?

The average ratings on the six TLX subjective workload dimensions for each type of display are plotted in Figure 5.5.2-1. As Figure 5.5.2-1 illustrates, the pilots with the NCWF product rated themselves as experiencing higher workload than control pilots or pilots with looping NEXRAD on four of the six TLX dimensions. A one-way ANOVA indicated that the average rating on the mental demand dimension significantly differed across the display type conditions, $F(2,45)=4.01$, $p < .03$. Tukey LSD post-hoc tests employing Bonferroni alpha adjustments indicated that pilots with NCWF [$t(30) = 2.69$, $p < .05$] and Control pilots [$t(30) = 2.10$, $p < .05$] rated themselves as experiencing significantly higher mental demand than pilots with Looping NEXRAD experience. The post-hoc analyses also indicated that the average ratings on mental demand did not significantly differ between NCWF pilots and Control pilots. Note that the average ratings on the other five TLX dimensions did not significantly differ across the display conditions.

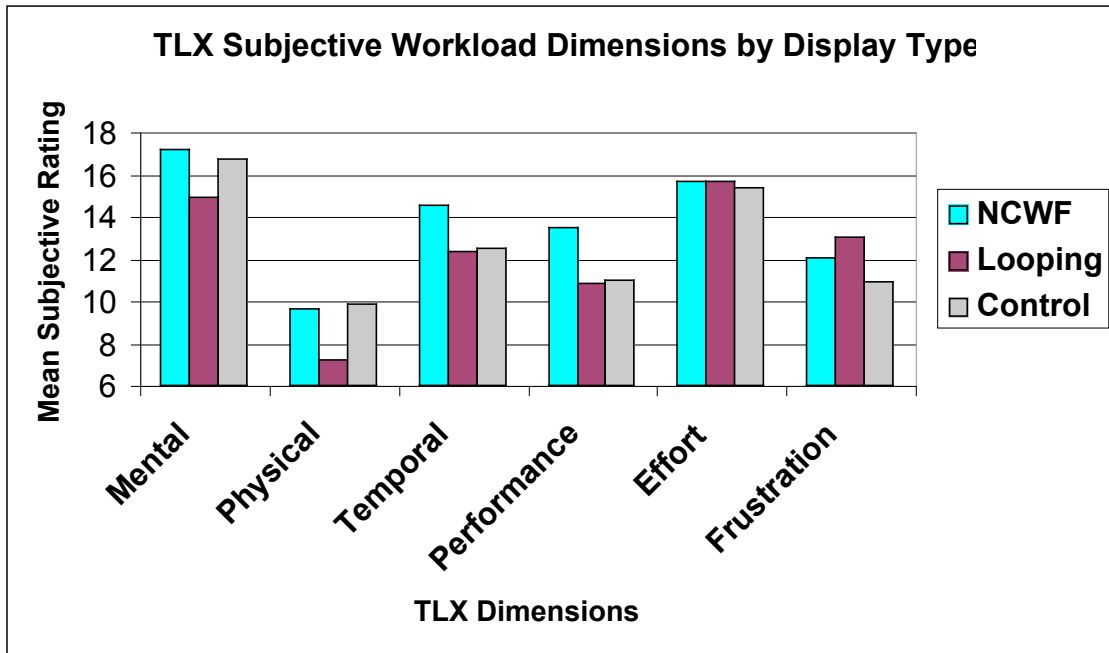


Figure 5.5.2-1. Pilots' Self Assessment of Workload using NASA TLX Rating Scale

The six TLX dimensions were aggregated to form a composite measure of subjective workload. The TLX composite is plotted by display type in Figure 5.5.2-2. A one-way ANOVA indicates that the mean TLX composite scores do not significantly differ across display type. Although the effect is not significant, the overall pattern of TLX results suggests that pilots with the NCWF display generally rated themselves as experiencing higher workload than control pilots or pilots with the NEXRAD Image Looping display.

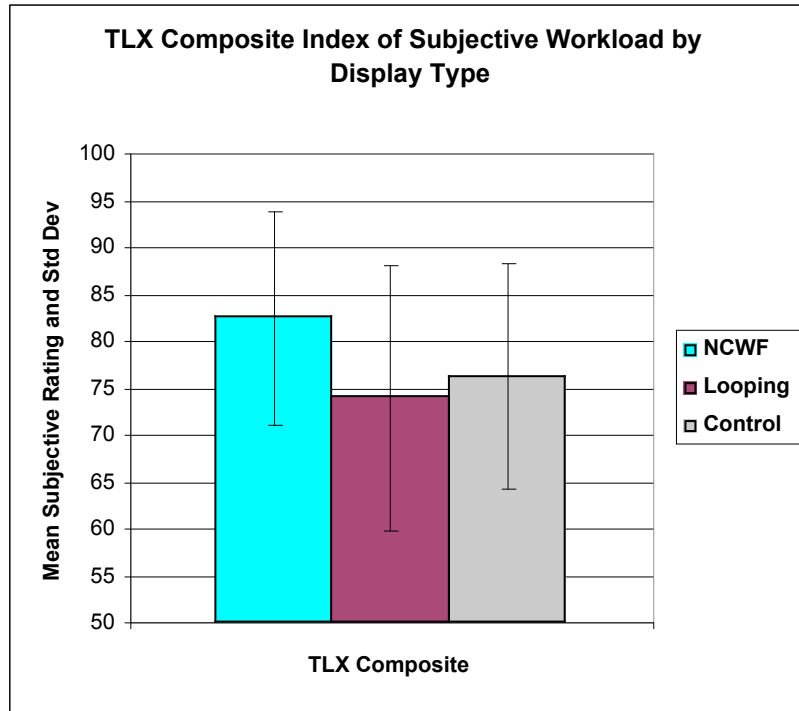


Figure 5.5.2-2. TLX Composite Index of Pilots' Self-Assessment of Workload By Display Type

Univariate Analysis of Variance

Between-Subjects Factors			Descriptive Statistics		
			Dependent Variable: COMPOSIT		
CONDITIO		N	CONDITIO	Mean	Std. Deviation
Control		16	Control	76.2500	12.0083
Looping		16	Looping	73.9375	14.1585
NCWF		16	NCWF	82.5000	11.3608
			Total	77.5625	12.8277

Tests of Between-Subjects Effects						
Dependent Variable: COMPOSIT						
Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared
Corrected Model	627.875 ^a	2	313.938	1.988	.149	.081
Intercept	288765.187	1	288765.187	1828.673	.000	.976
CONDITIO	627.875	2	313.937	1.988	.149	.081
Error	7105.938	45	157.910			
Total	296499.000	48				
Corrected Total	7733.813	47				

^a. R Squared = .081 (Adjusted R Squared = .040)

5.5.3 Workload and Decision Quality

There were no statistically significant associations between the metrics of decision quality and the metrics of workload.

5.6 Effects of Display Type on Pilot Procedures

It is important to understand how the introduction of cockpit weather information displays may influence pilots' normal operating procedures. For instance, the introduction of additional weather information could influence the extent to which pilots sample conventional sources of weather information. Introduction of weather displays into the cockpit could also increase workload leading to more pilot induced control actions. That is, pilots may have a more difficult time flying the airplane when interacting with the weather display. Also, pilots who rely on the weather display for tactical navigation could experience navigation problems, which could lead to increased interactions with NAV radios. Thus, the following sub-sections address the extent to which the introduction of weather displays into the cockpit affect pilot procedures.

In the following subsections, each figure is followed by the data and relevant analysis that led to the diagrams.

5.6.1 Pilot Utilization of Conventional Weather Information Sources

The observers and air traffic controller kept a record of the conventional weather information sources utilized by each pilot for each leg of the flight. The average number of weather sources used for each type of display is plotted by decision type (i.e., Richmond or Wallops) in Figure 5.6.1-1. Repeated measures ANOVA was conducted on the number of weather information sources utilized. The ANOVA indicates that there is a significant main effect of decision type, $F(1,45) = 83.35$, $p < .001$. Pilots were observed sampling a significantly higher number of conventional weather sources in the Richmond leg than in the Wallops leg. There was no effect of type of display on the number of weather sources utilized, $F(2,45) = 2.13$, $p > .13$. That is, pilots with weather displays did not sample fewer conventional weather information sources than pilots without weather displays. The decision type by display type interaction is statistically significant, $F(2,45) = 4.44$, $p < .02$. The interaction implies that a particular type of display (e.g., NCWF display) had differential effects on the number of conventional weather information sources utilized depending on the type of decision being made by the pilots. For example, pilots with the NCWF display sampled the largest number of conventional weather sources during the Richmond leg (i.e., temporal decision), but sampled the fewest conventional weather sources during the Wallops leg (i.e., spatial decision).

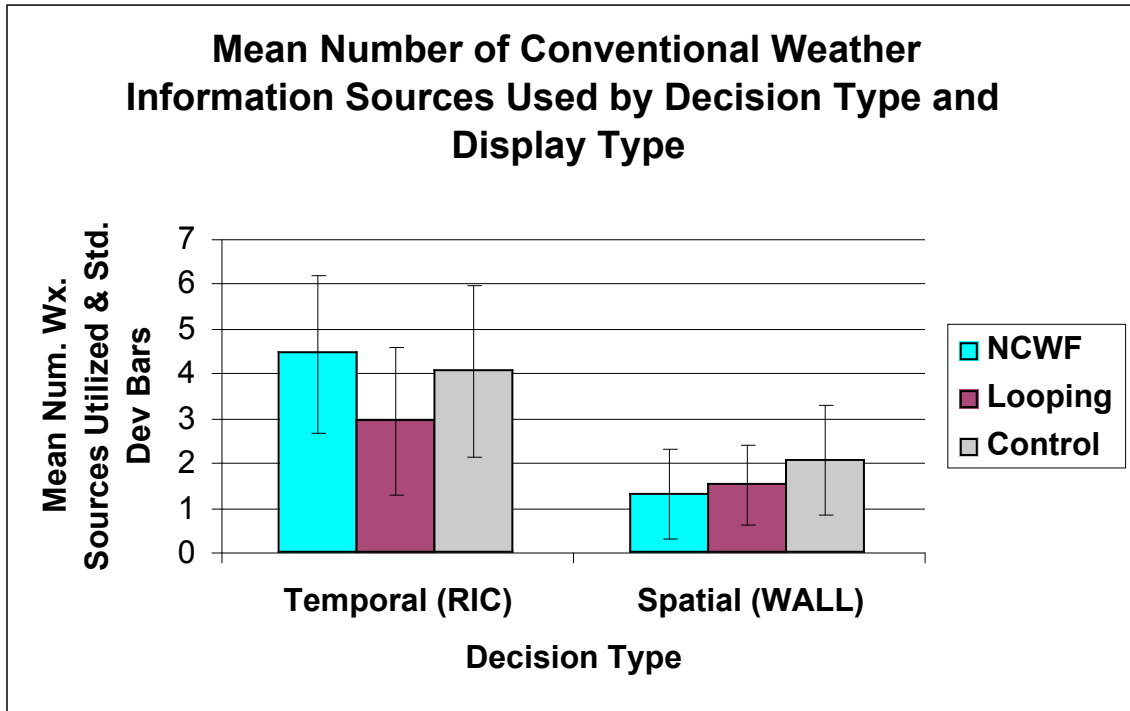


Figure 5.6.1-1. Mean Number of Conventional Weather Information Sources Used by Decision Type and Display Type

General Linear Model

Within-Subjects Factors

Measure: MEASURE_1	
DTYPE	Dependent Variable
1	NUMWXRIC
2	NUMWXWAL

Between-Subjects Factors

		N
CONDITIO	Control	16
	Looping	16
	NCWF	16

Descriptive Statistics

	CONDITIO	Mean	Std. Deviation	N
NUMWXRIC	Control	4.0625	1.9138	16
	Looping	2.9375	1.6520	16
	NCWF	4.4375	1.7500	16
	Total	3.8125	1.8526	48
NUMWXWAL	Control	2.0625	1.2366	16
	Looping	1.5000	.8944	16
	NCWF	1.3125	1.0145	16
	Total	1.6250	1.0842	48

The number of pilots who utilized each of the weather information sources available at Richmond (as noted by the observers) is plotted by display type in Figure 5.6.1-2. Logistic ANOVAs were conducted on the number of pilots who utilized each weather information source during the Richmond leg. Logistic ANOVA Likelihood Ratio tests indicate that the type of weather display did not influence the likelihood that pilots would utilize PHF ATIS, RIC ATIS, WAL ASOS, ATC, Tower, Approach Control, or Departure Control during the Richmond leg of flight. Logistic ANOVA Likelihood Ratio tests did indicate that type of display influenced the probability that pilots would utilize FSS/FW ($\chi^2(2,45)= 5.29, p <.07$), PIREP ($\chi^2(2,45)= 5.14, p <.08$), METAR ($\chi^2(2,45)= 23.40, p <.001$), and Wx Display ($\chi^2(2,45)= 54.92, p <.001$). Pilots with NEXRAD Looping were significantly less likely to utilize FSS/FW and PIREPs than pilots with NCWF or control pilots. Also, control pilots did not utilize METARs or Wx Displays because they did not have access to this information.

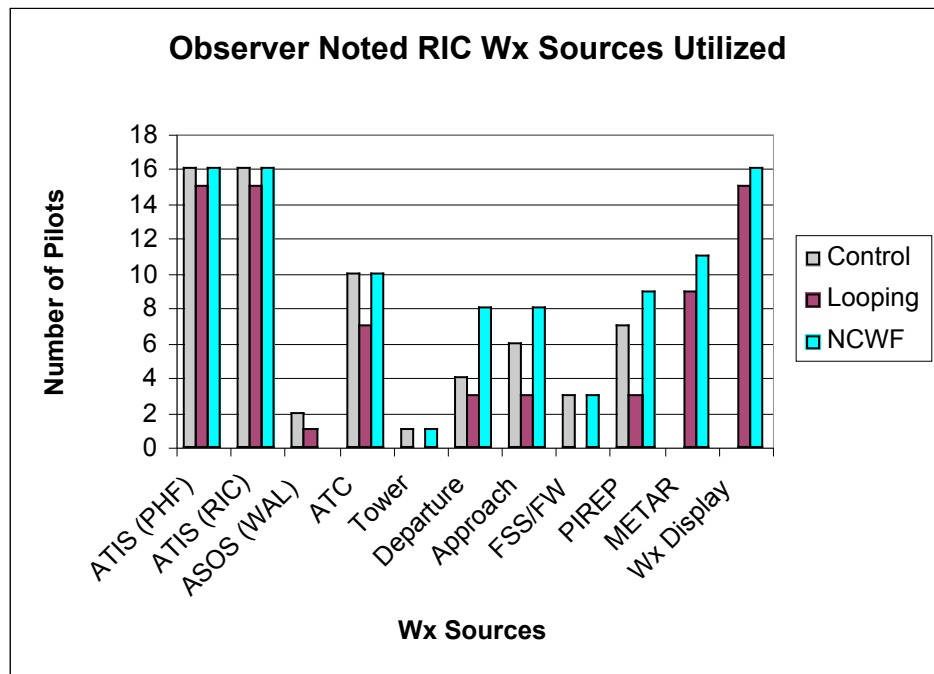


Figure 5.6.1-2. Weather Information Sources Used On Richmond Leg as Recorded by Observers

The number of pilots who used each of the weather information sources available at Wallops (as noted by the observers) is plotted by display type in Figure 5.6.1-3. Logistic ANOVAs were conducted on the number of pilots who utilized each weather information source during the Wallops leg. Logistic ANOVA Likelihood Ratio tests indicate that the type of weather display did not influence the likelihood that pilots would utilize PHF ATIS, RIC ATIS, Tower, Approach Control, Departure Control, or PIREPs during the Wallops leg of flight. Logistic ANOVA Likelihood Ratio tests did indicate that type of display influenced the probability that pilots would utilize WAL ASOS ($\chi^2(2,43)= 6.17, p <.05$), FSS/FW ($\chi^2(2,43)= 14.30, p <.001$), ATC ($\chi^2(2,43)= 4.69, p <.10$), METAR ($\chi^2(2,43)= 24.85, p <.001$), and Wx Display ($\chi^2(2,43)= 25.99, p <.001$). The results

indicate that pilots with NCWF were significantly less likely to utilize WAL ASOS or ATC than pilots with NEXRAD Looping or control pilots during the Wallops leg of the flight. Pilots with NCWF, however, were significantly more likely to utilize FSS/FW than pilots with NEXRAD Looping or control pilots during the Wallops leg of flight. Also, control pilots did not utilize METARs or Wx Displays to the same extent as the other pilots because they did not have access to this information.

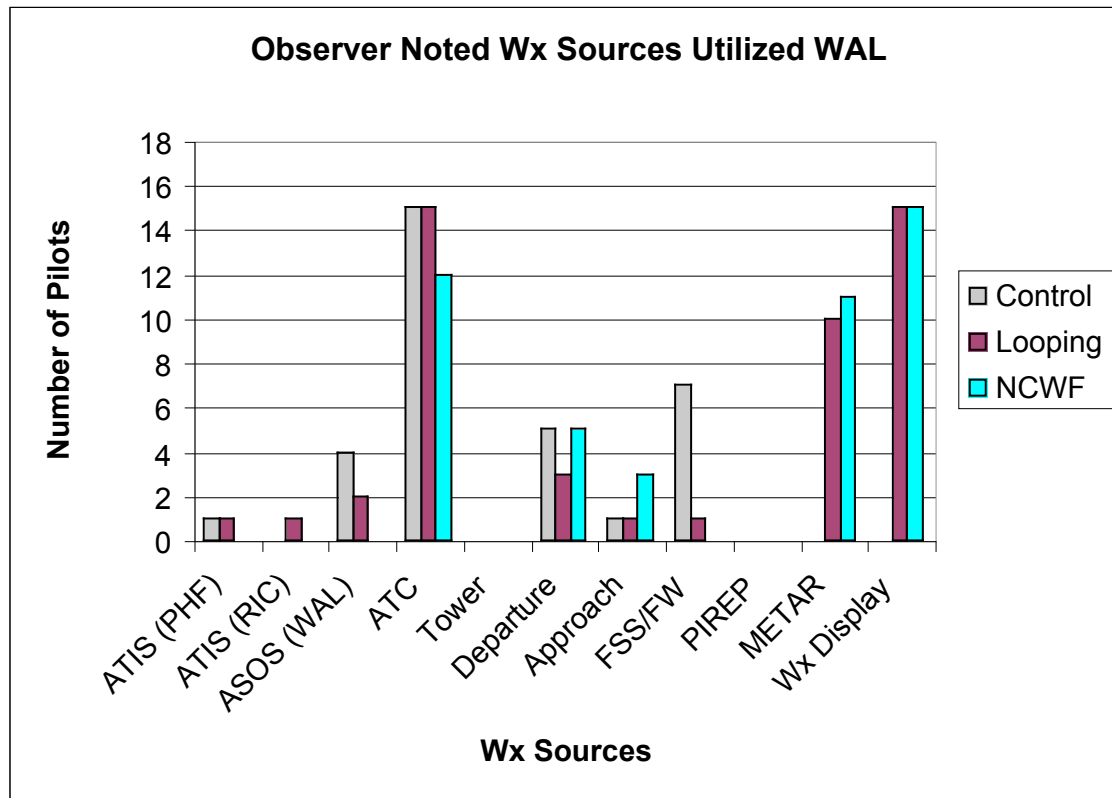


Figure 5.6.1-3. Weather Information Sources Used On Wallops Leg as Recorded by Observers

Question # 4 in the structured interview asked the participant pilots to identify their primary and secondary sources of weather information in the Richmond leg of flight. The number of pilots who identified each of the weather information sources available at Richmond as primary is plotted by display type in Figure 5.6.1-4. Logistic ANOVAs were conducted on the number of pilots who identified each weather information source as primary in the Richmond leg of flight. Logistic ANOVA Likelihood Ratio tests indicated that the type of weather display did not influence the likelihood that pilots would identify ATIS, ATC, FSS/FW, PIREP, METAR, or a combination (i.e., Combo) of weather sources as primary in the Richmond leg of flight. Logistic ANOVA Likelihood Ratio tests did indicate that type of display influenced the probability that pilots would identify Pre-Flight Briefing ($\chi^2(2,44)= 11.64, p < .01$) and Wx Display ($\chi^2(2,44)= 16.23, p < .001$) as primary in the Richmond leg of flight. The results indicate that control pilots were significantly more likely to identify the Pre-Flight Briefing as primary during the Richmond leg of flight than pilots with the NEXRAD Image Looping display or NCWF

display. Also, control pilots did not identify Wx Displays as primary because they did not have access to this information.

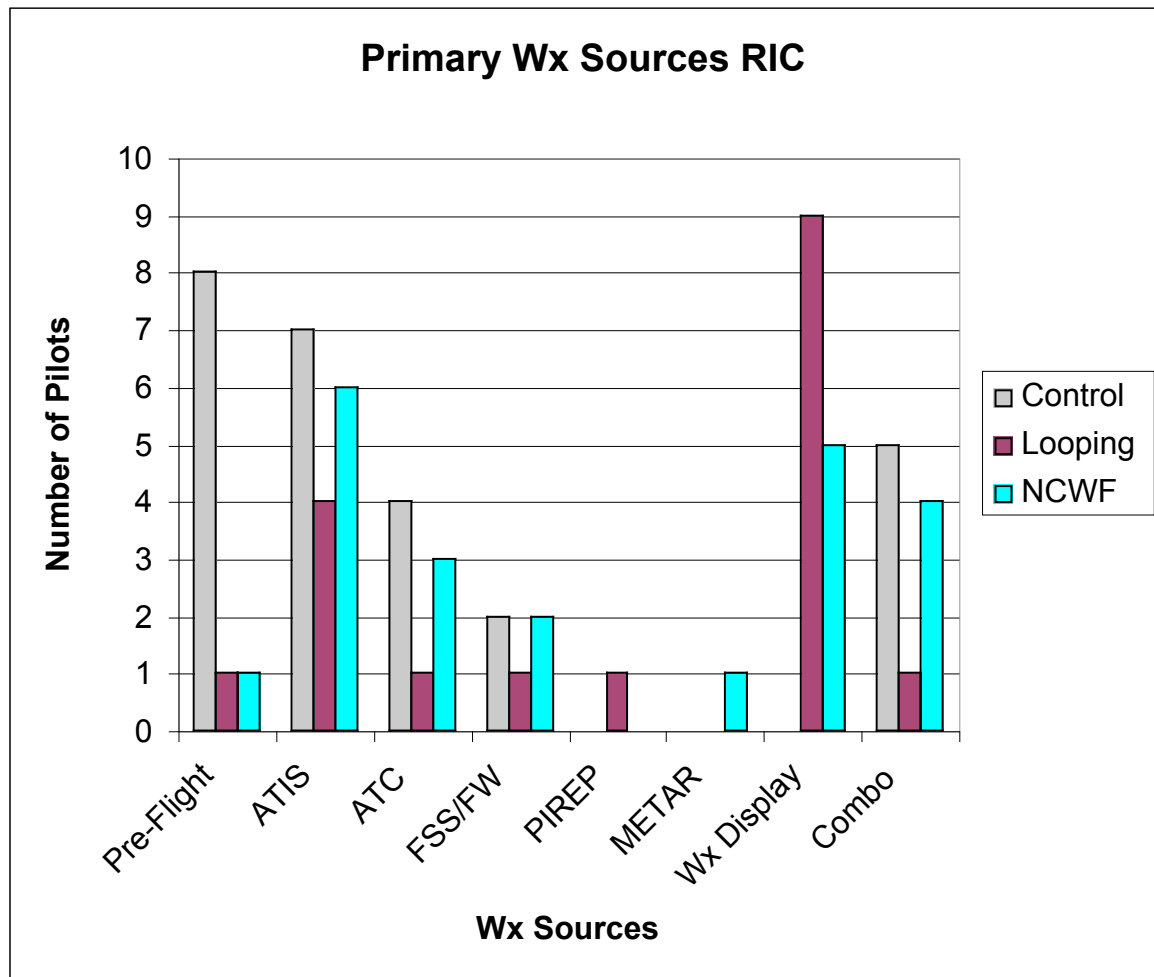


Figure 5.6.1-4. Pilots' Self-Assessment of the Primary Source of Weather Information Used on Richmond Leg

The number of pilots who identified each of the weather information sources available at Richmond as secondary is plotted by display type in Figure 5.6.1-5. Logistic ANOVAs were conducted on the number of pilots who identified each weather information source as secondary in the Richmond leg of flight. Logistic ANOVA Likelihood Ratio tests indicated that type of display influenced the probability that pilots would identify Wx Display ($\chi^2(2,44) = 16.23, p < .001$) as secondary in the Richmond leg of flight. Control pilots did not identify Wx Displays as a secondary source of weather information because they did not have access to this information.

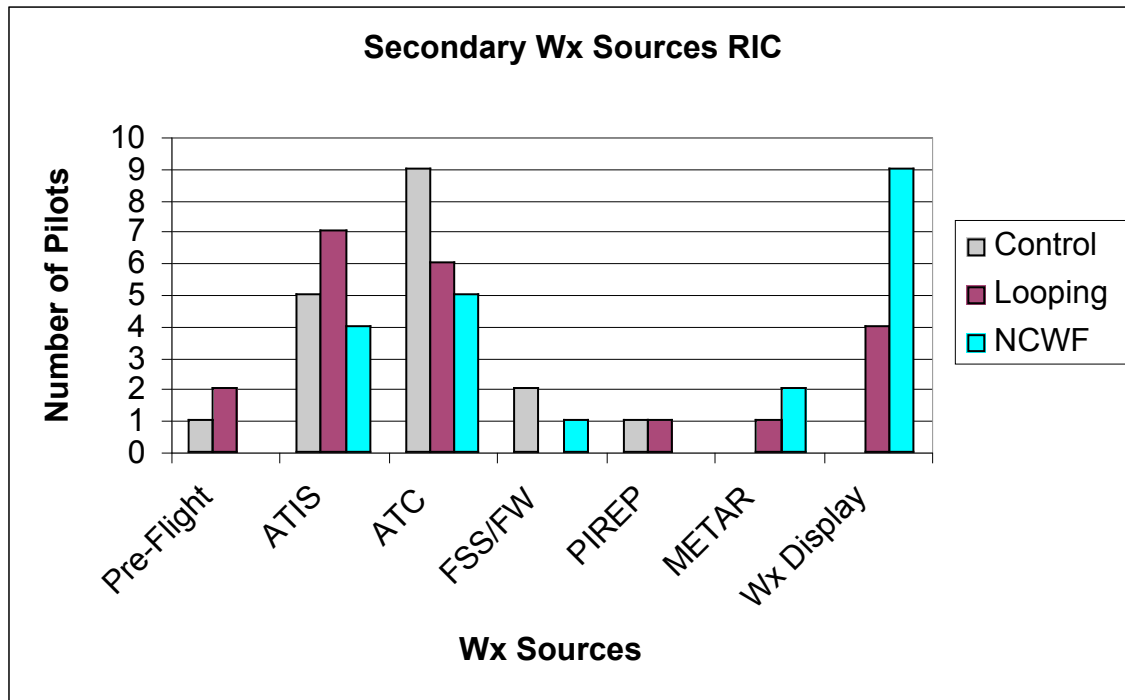


Figure 5.6.1-5. Pilots' Self-Assessment of the Secondary Source of Weather Information Used On Richmond Leg

Question # 12 in the structured interview asked the participant pilots to identify their primary and secondary sources of weather information in the Wallops leg of flight. The number of pilots who identified each of the weather information sources available at Wallops as primary is plotted by display type in Figure 5.6.1-6. Logistic ANOVAs were conducted on the number of pilots who identified each weather information source as primary in the Wallops leg of flight. Logistic ANOVA Likelihood Ratio tests indicate that the type of weather display did not influence the likelihood that pilots would identify ATIS, PIREP, METAR, or a combination (i.e., Combo) of weather sources as primary in the Wallops leg of flight. Logistic ANOVA Likelihood Ratio tests did indicate that type of display influenced the probability that pilots would identify Pre-Flight Briefing ($\chi^2(2,40)= 9.22, p <.01$), ATC ($\chi^2(2,40)= 6.06, p <.05$), FSS/FW ($\chi^2(2,40)= 6.17, p <.05$) and Wx Display ($\chi^2(2,40)= 30.48, p <.001$) as primary in the Wallops leg of flight. The results indicate that control pilots were significantly more likely to identify the Pre-Flight Briefing and FSS/FW as primary during the Wallops leg of flight than pilots with NEXRAD Image Looping display or NCWF display. Pilots with the NEXRAD Image Looping display were significantly less likely to identify ATC as a primary source of weather information than pilots with the NCWF display or control pilots. Also, control pilots did not identify Wx Displays as primary because they did not have access to this information. When compared to pilots with the NEXRAD Image Looping display, pilots with the NCWF display were less likely to identify Wx Display as a primary weather information source during the Wallops leg of flight.

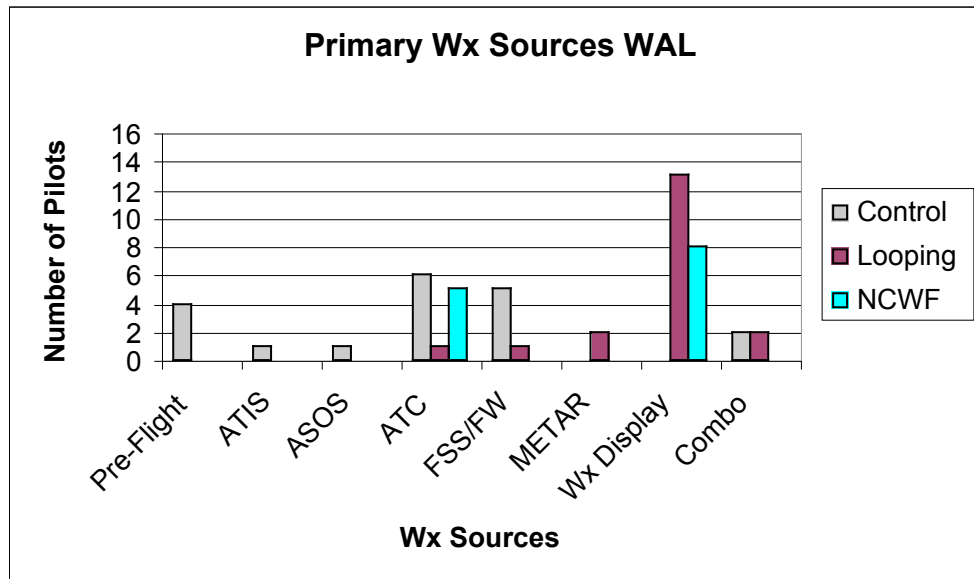


Figure 5.6.1-6. Pilots' Self-Assessment of the Primary Source of Weather Information Used on Wallops Leg

The number of pilots who identified each of the weather information sources available at Wallops as secondary is plotted by display type in Figure 5.6.1-7. Logistic ANOVAs were conducted on the number of pilots who identified each weather information source as secondary in the Wallops leg of flight. Logistic ANOVA Likelihood Ratio tests indicated that type of display influenced the probability that pilots would identify Wx Display ($\chi^2(2,39) = 9.78, p < .01$) as secondary in the Wallops leg of flight. Control pilots did not identify Wx Displays as a secondary source of weather information because they did not have access to this information.

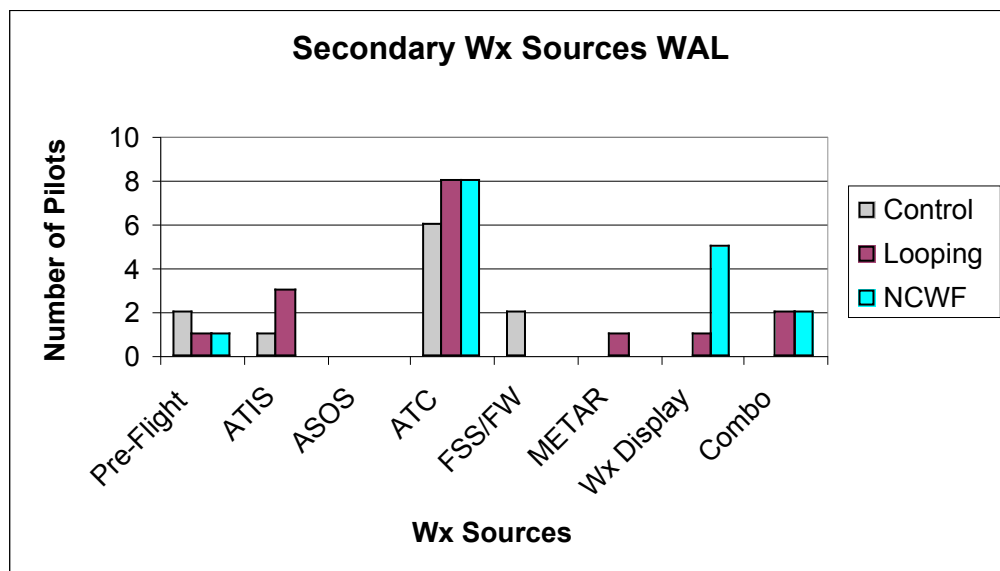


Figure 5.6.1-7. Pilots' Self-Assessment of the Secondary Source of Weather Information Used On Wallops Leg

The observers recorded several workload considerations for both the Richmond leg and Wallops leg of the flight (see Appendix I, Observer Form). The workload considerations included communication lapses/errors, judgment errors, procedural errors, and flight-path deviations. The number of pilots that committed each type of error is plotted by display type in Figure 5.6.1-8. Logistic ANOVAs were conducted on the number of pilots who committed errors during the Richmond leg of the flight. Logistic ANOVA Likelihood Ratio tests indicate that type of display had no significant influence on the likelihood that pilots would commit communication lapses/errors, judgment errors, procedural errors, or flight-path deviations in the Richmond leg of the flight.

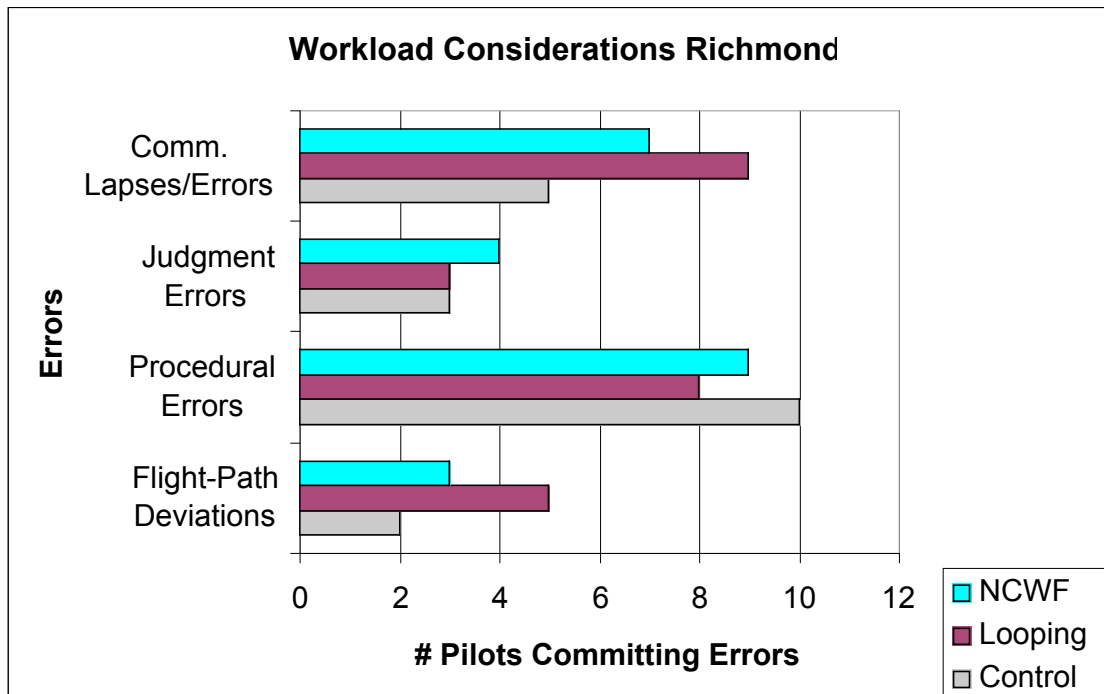


Figure 5.6.1-8. Pilot Workload Considerations on Richmond Leg as Recorded by Observers

The number of pilots that committed communication lapses/errors, judgment errors, procedural errors, and flight-path deviations in the Wallops leg is plotted by display type in Figure 5.6.1-9. Logistic ANOVAs were conducted on the number of pilots who committed errors in the Wallops leg of the flight. Logistic ANOVA Likelihood Ratio tests indicate that type of display had no significant influence on the likelihood that pilots would commit communication lapses/errors, judgment errors, procedural errors, or flight-path deviations on the Wallops leg of the flight.

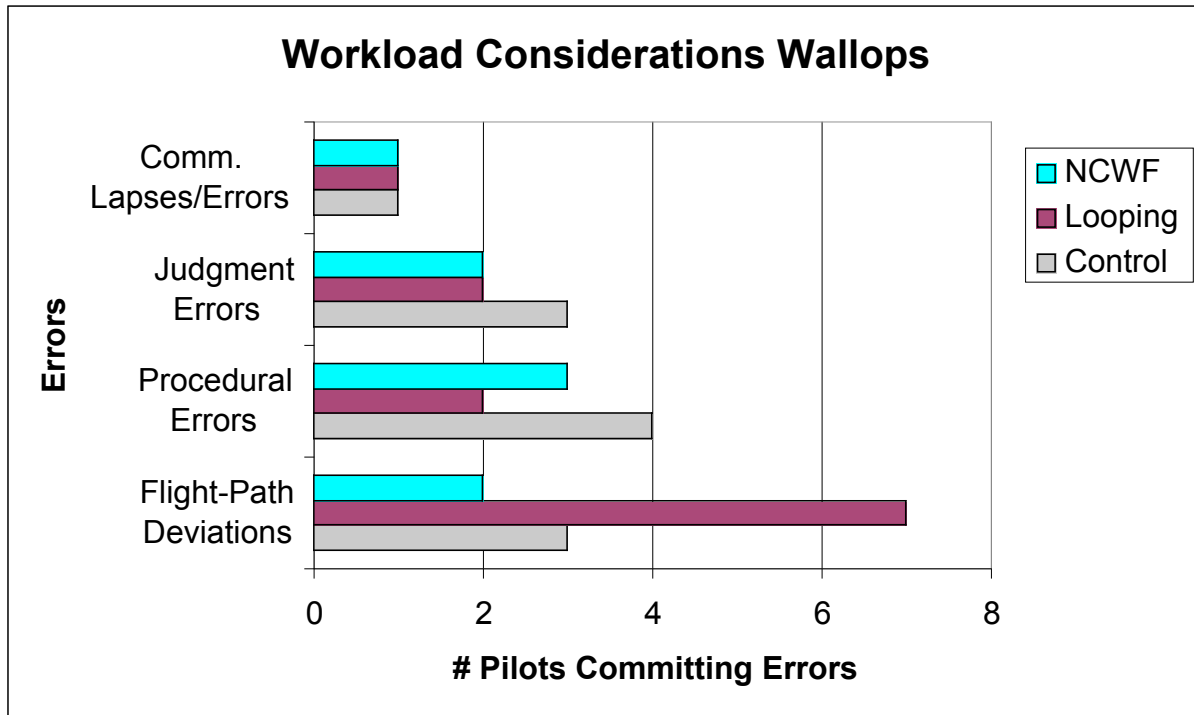


Figure 5.6.1-9. Pilot Workload Considerations on Wallops Leg as Recorded by Observers

5.7 Pilot Flight Control Actions, Navigation, and Communications

The number of pilot induced control actions was extracted from the data recorded by the simulator. The measures of pilot induced control actions included the number of heading changes, airspeed changes and altitude changes. The number of pilot induced control actions is plotted by type of display in Figure 5.7-1. The control action variables were analyzed using MANOVA. The MANOVA and follow-up univariate ANOVA analyses found no significant associations between type of display and the number of pilot induced control actions.

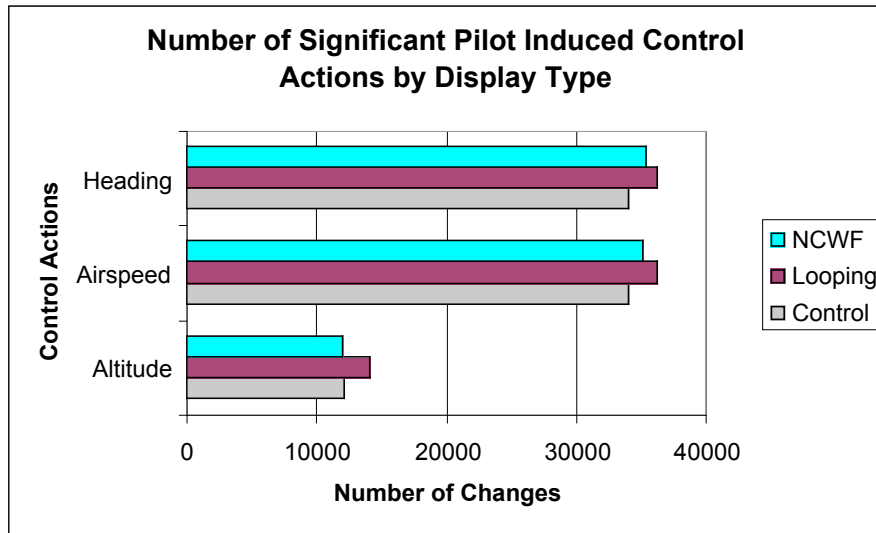


Figure 5.7-1. Number of Pilot Induced Control Actions during Mission

The number of radio frequency changes was extracted from the data recorded by the simulator. The number of frequency changes was recorded for both of the navigation radios (NAV1 and NAV2) as well as the communication radio (COMM). The number of frequency changes for each radio is plotted by type of display in Figure 5.7-2. Univariate ANOVAs indicate there were no significant associations between type of display and number of frequency changes for any of the radios.

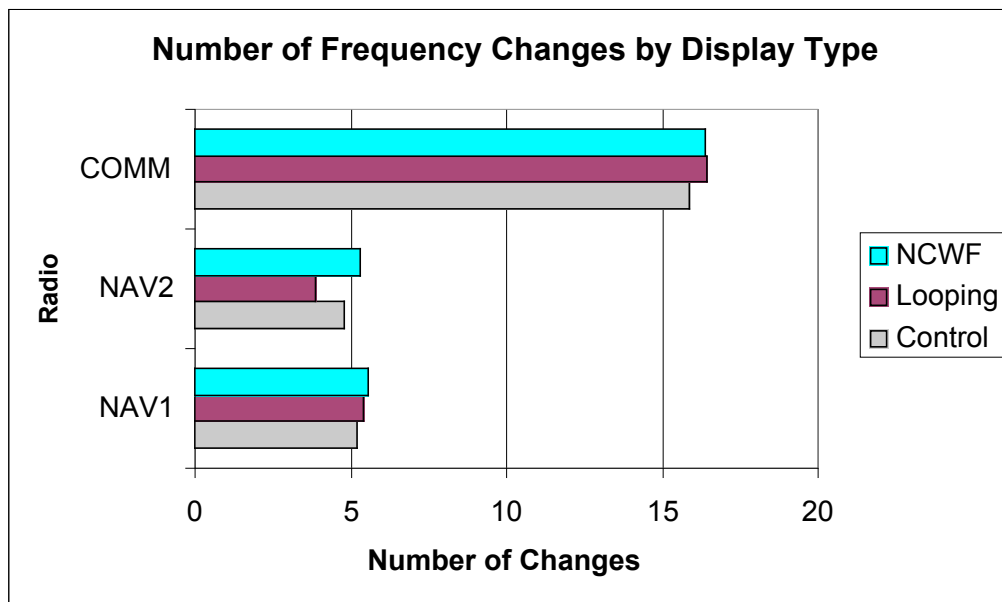


Figure 5.7-2. Number of Radio Frequency Changes (Communication and Navigation Radios) During Mission

5.8 Pilot Interaction with Autopilot

The number of times the autopilot was engaged/disengaged, the number of times the heading hold function of the autopilot was engaged/disengaged, and the number of times the altitude hold function of the autopilot was engaged/disengaged were measures used to determine the degree of pilot interaction with the autopilot. The autopilot interaction measures are plotted by type of display in Figure 5.8-1. The autopilot interaction variables were analyzed using MANOVA. The MANOVA and follow-up univariate ANOVA analyses found no significant associations between type of display and the number of interactions with the autopilot. As Figure 5.8-1 illustrates, however, the pattern of results is quite consistent across the autopilot interaction measures. Pilots with the NEXRAD Image Looping display had the most interactions with all autopilot functions.

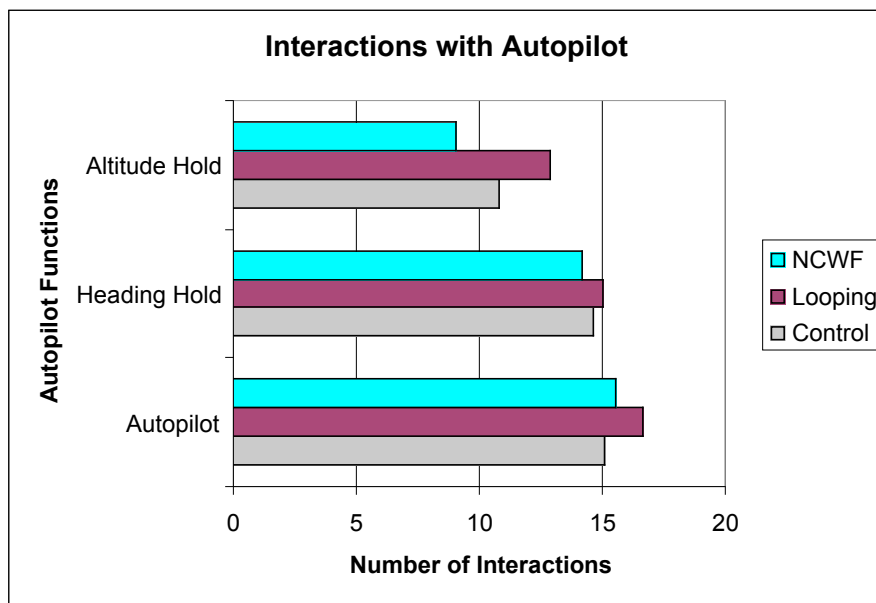


Figure 5.8-1. Pilot Interactions with Autopilot During Mission

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 5.8-2 illustrates the extent to which the pilots used the autopilot in the experiment.

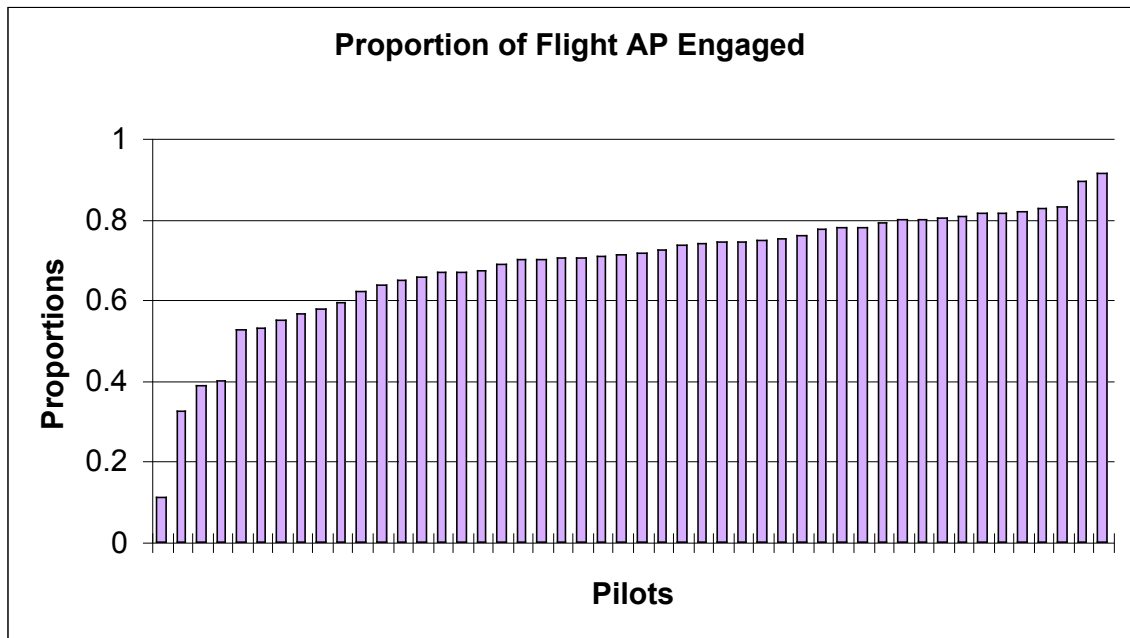


Figure 5.8-2. Percent of Flight Time Autopilot Used During Mission

Even though the autopilot was used for an average of 69% percent of the time in flight across all the participant 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.

The average proportion of time the autopilot was engaged during the flight is plotted by type of display in Figure 5.8-3. Univariate ANOVA indicates that type of display did not significantly influence the proportion of time the pilots had the autopilot engaged, $F(2,45)=.871$, $p<.43$. As Figure 5.8-3 illustrates, however, the control pilots engaged the autopilot the lowest proportion of the time compared to pilots flying with weather displays. Thus, the results suggest that pilots flying with a weather display may have been experiencing higher workload than control pilots, which led them to engage the autopilot a higher proportion of the time.

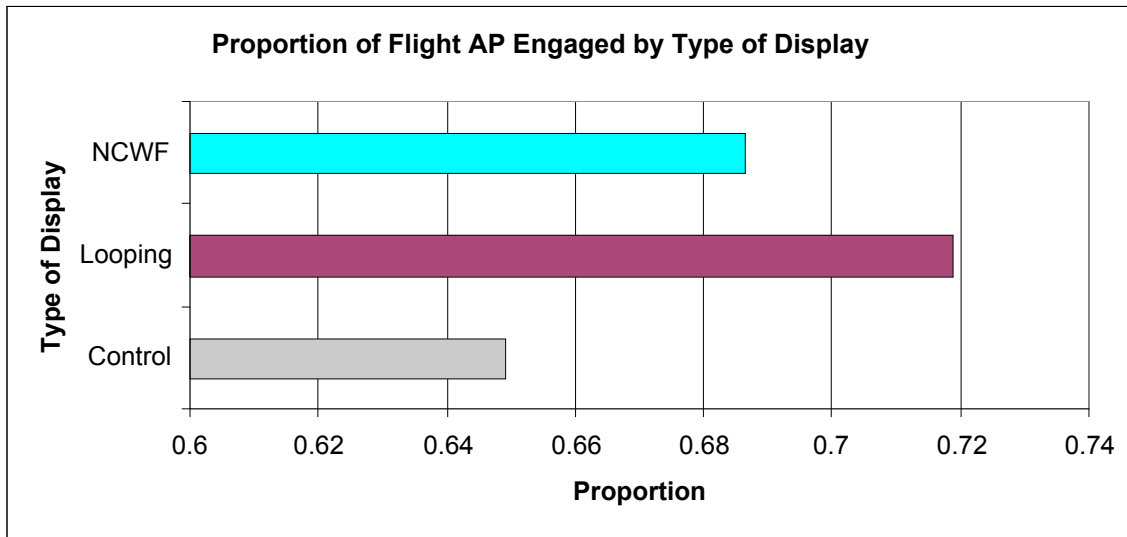


Figure 5.8-3. Proportion of Flight Autopilot Engaged by Type of Display

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 69% 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. 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.

6 Conclusions

The purpose of the current experiment (CWE III) was to determine the effects of the use of NEXRAD looping and the use of the NCWF product on pilot workload and decision making. These two features were implemented as additional capabilities in a cockpit weather display already providing NEXRAD mosaic images overlaid on a moving map display.

6.1 Confirmation of Experiment Design

The elements of the experiment design were substantiated. These elements included the selection method for subject pilots, the prototype cockpit weather information display system design, the experiment scenario, the simulator fidelity (cockpit instrumentation, out-the-window scene generation, ATC communication environment, etc.), the use and recording of actual weather, the pre-flight training, the adequacy of the output data observed and recorded, the content and technique for the post-flight debriefing, and corroboration of the qualitative expert assessments with quantitative results.

6.2 Support for Experimental Hypotheses

Experimental Hypothesis #1 - Pilots using a NEXRAD image looping display will make significantly better decisions with respect to convective weather than will pilots without a weather information display.

The experimental hypothesis that the NEXRAD mosaic image looping feature would improve pilot decision making was not supported by the results of the experiment.

The results indicate that the NEXRAD mosaic image looping feature did not improve pilot decision making over pilots with no weather display in either the temporal decision at the Richmond Airport or the spatial decision enroute to the Wallops Island Facility.

One possible explanation is that NEXRAD image looping may be difficult to use to predict storm movement. NEXRAD image looping provides a history of storm-cell movement, but no storm-movement forecast. Thus, the pilots must extrapolate the future movement of the hazardous weather themselves from the NEXRAD history, which could be a difficult task to perform when in flight with limited training. There is also insufficient information to be gained from the NEXRAD image history, at least as implemented in the NEXRAD mosaic image looping display used in the experiment, for the pilot to understand the speed of the movement of the hazardous weather or the rate at which the hazardous weather is increasing or decreasing in intensity.

A significant part of the explanation is to be found in the observation during the experiment that many of the subject pilots overused the NEXRAD display, placing too much confidence in their interpretation of the information provided by the display. Rather than using their increased understanding of their situation gained from the display to complement their interaction with ATC and other conventional sources of weather information, they would proceed with a still incomplete understanding of the situation without seeking the additional information needed to make a good decision from the

other sources of information available. Resolution of this problem in the use of the NEXRAD display almost certainly includes better training. Further research is needed to determine the minimum level of training required.

Experiment Hypothesis #2 - Pilots using a NEXRAD image looping display will experience significantly higher workload than will pilots without a weather information display.

The experimental hypothesis that NEXRAD image looping would lead to increases in pilot workload was not supported by the results of the experiment. While a majority of the pilots flying with the NEXRAD mosaic image looping feature stated that using the weather information display increased their workload, many said in the next breath that the usefulness of the information gained from the display offset this increase in workload by reducing their anxiety and their need to find information from other sources. The observers in the study did not rate the workload of pilots having the NEXRAD image looping display to be significantly higher than pilots without a weather display. The level of interaction of the pilots with other sources of weather information, and with the autopilot also indicates that pilots with the NEXRAD image looping display did not experience significantly higher workload than control pilots. It is important to note, however, that the majority of pilots with NEXRAD image looping rarely used the looping feature according to the observers. Engaging the looping feature may have substantially increased pilot workload for those subject pilots who did so. Several pilots in the structured interview portion of the experiment stated that they did not have enough time to engage and interpret the NEXRAD image looping feature during the flight. The few pilots who did use the NEXRAD image looping feature extensively reported that while they felt the feature improved their understanding of the movement of the hazardous weather, they felt the time it took to use the feature increased their workload. Several pilots who used the NEXRAD image looping feature suggested that the number of keystrokes required to make the looping function available should be reduced. They suggested that only one keystroke be required to activate the image looping function.

Experimental Hypothesis #3 - Pilots using the NCWF product display will make significantly better decisions with respect to convective weather than will pilots without a weather information display.

The experimental hypothesis that pilots with the NCWF display would make better decisions concerning hazardous weather was not supported by the results of the experiment. Pilots with the NCWF display did not make better decisions than control pilots in the spatial decision at the Richmond Airport. Nor did pilots with the NCWF display make significantly better decisions than control pilots in the temporal decision enroute to Wallops Island.

While nearly all pilots reported that the display greatly enhanced their understanding of the general location of the hazardous weather conditions relative to their own position, the delay in transmission of the NEXRAD mosaic image sometimes led to uncertainty and confusion in its use as a basis for decision making. Other aspects of the current

NCWF product incorporated in the display, such as the deletion of all precipitation radar returns below 17,000 feet and the inability of the product to correctly display hazardous conditions in their early development and as they began to deteriorate, increased lack of confidence in the display.

A significant part of the explanation is to be found in the observation during the experiment that many of the subject pilots overused the NCWF display, placing too much confidence in their interpretation of the information provided by the display. Rather than using their increased understanding of their situation gained from the display to complement their interaction with ATC, they would proceed with a still incomplete understanding of the situation without seeking the additional information needed for a good decision from the other sources of information available. Resolution of this problem in the use of the NEXRAD display almost certainly includes better training. Further research is needed to determine the minimum level of training required.

Another part of the explanation may lay in the complexity of the display. Several pilots reported they felt the display to be too cluttered. While most cockpit weather displays now in or about to reach the market have better resolution than the experimental display used in the experiment, it is likely that better resolution alone would not offset the difficulty in interpretation due to the clutter caused by the large amount of information displayed. Many of the pilots reported that while they understood the key features available in the display, significantly more training would be required to enable them to use the display more effectively.

Experimental Hypothesis #4 - Pilots using the NCWF product display will experience significantly higher workload than will pilots without a weather information display.

The experimental hypothesis that the NCWF display would lead to increases in pilot workload was not supported by the statistical data. Pilots with the NCWF display were not observed to experience significantly higher workload than pilots without a weather display. Analysis of the TLX questionnaire results also showed no significant difference in workload between the pilots using the NCWF display and pilots in the control group, although the overall pattern of TLX results suggests that pilots with the NCWF display generally rated themselves as experiencing higher workload than did pilots in the control group. The level of interaction of the pilots with other sources of weather information and with the autopilot also indicates that the pilots flying with the NCWF display did not experience a significantly higher workload than control pilots.

There are several explanations why the NCWF display may have increased the pilots' self-rating of their workload when compared to that of the pilots in the control group. The NCWF display provided a lot of information concerning hazardous weather that needed to be considered by the pilots (e.g., forecast projection, movement vector, precipitation tops, and NEXRAD radar), which could have contributed to the workload of the pilots. Also, because the NCWF display provides more information, it also has more clutter which might have made it difficult for the pilots to interact with the weather display and

contributed to their workload. In fact, several pilots specifically mentioned, during the structured interview, that the resolution of the weather display was poor and that clutter was somewhat of a problem.

6.3 Comparison of Usefulness of NCWF Display to NEXRAD Image Looping Display

The two cockpit weather displays used in the experiment, the NCWF Display and the NEXRAD Image Looping Display, were compared in terms of their contribution to the quality of the pilots' decision making, their effect on pilot workload, their effect on pilot procedures, and their effect on the pilots' situation awareness.

6.3.1 Effect of Display Type on Decision Quality

The subject pilots as a group made significantly poorer quality decisions in avoiding hazardous weather conditions during the approach to the Richmond Airport than they did while en route to Wallops Island. The pilots with weather displays did not make significantly higher-quality decisions on either leg than did the pilots without weather displays. And the effect of display type on the quality of the decisions made at Richmond and enroute to Wallops Island was not statistically significant.

While the differences were not statistically significant, there were interesting trends in the differences in decision quality between the pilots having the NCWF display and those having the NEXRAD image looping display. Pilots with the NCWF display made the highest quality decisions on the Richmond leg when compared to quality of the decisions made by the pilots with the NEXRAD image looping display and those without a weather display, but they made the poorest quality decisions on the Wallops Island leg when compared to the other two pilot groups. Pilots with the NEXRAD image looping display made the highest quality decisions on the Wallops Island leg, but the poorest quality decisions at Richmond compared to the other pilot groups. These trends were found in the observers' reports of the quality of the pilots' decisions, and in the analysis of the minimum distance to the hazardous weather conditions experienced by the pilots.

Of the two decisions, the relatively quickly changing weather conditions associated with the Richmond leg decision made this the more difficult of the two decisions for the pilots in all three groups (control, NEXRAD looping display, NCWF display) to deal with. Hence the poorer performance of all three pilot groups in dealing with this decision.

The essence of the decision to be made on the Richmond leg of the scenario was to recognize that the hazardous weather conditions were more rapidly approaching the Richmond airport than had been forecast, to determine the location and severity of the hazard, to determine the direction and speed of movement of the hazardous conditions, to determine how close the pilot was willing to come to the hazardous conditions, to determine whether or not the approach could be continued into the airport without flying within the minimum safe avoidance distance of the storm, and if the decision was made not to continue the approach to then make the decision of where in the approach to change course. Of the two versions of the NEXRAD display, certain elements of the information unique to the NCWF display (storm movement vector, storm speed, and one-

hour prediction depiction) were probably more helpful in dealing with this complex decision than was the information unique to the NEXRAD image looping display (historical storm movement).

The essence of the decision enroute to Wallops Island was 1) to recognize the location, dimensions, and severity of the hazardous weather conditions, 2) to determine the direction and speed of movement of the hazardous weather, and 3) once it was realized the hazardous area was fairly static and localized to an area over the Chesapeake Bay, to decide how best to circumnavigate the hazardous area. Since the weather conditions associated with the Wallops Island leg decision were somewhat static, the NEXRAD image looping function probably provided an easier and perhaps more intuitive assessment of the lack of storm movement while the two displays were equally effective in supporting the necessary interpretation of the dimensions of the hazardous conditions (localized over the Chesapeake Bay).

6.3.2 Effect of Display Type On Pilot Workload

While the subject pilots as a group were observed to have experienced significantly higher workload during the approach to the Richmond Airport than they did while en route to Wallops Island, the pilots with weather displays were not observed to have experienced significantly higher workload than pilots without weather displays. Likewise, the analysis of the pilots' self-ratings of workload found no significant difference in workload between display type (although there is a suggestion that pilots with the NCWF display generally rated themselves as experiencing a higher workload than did pilots with the NEXRAD image display). The analysis of the observers' reports of workload considerations such as pilots' communication lapses and errors, judgment errors, or flight path deviations also found that type of display had no significant influence.

6.3.3 Effect of Display Type On Pilot Procedures

Analysis of data extracted from the simulator indicates that the type of display had no significant effect on the number of pilot control actions (heading changes, airspeed changes, altitude changes, communication radio changes, navigation radio changes) during the mission. Analysis of the interaction of the pilot with the autopilot found no significant influence of display type on either the number of interactions with the various autopilot functions or on the proportion of the flight in which the autopilot was used.

The display type had no significant effect on the extent to which the subject pilots having the two different displays used other sources of weather information (ATC, ASOS/AWOS, FSS, etc), or on the extent to which they felt the need to crosscheck or verify their conclusions drawn from the weather display with other conventional weather data sources, or in their perception of the need to crosscheck their inferences drawn from the weather display, or on the extent of their agreement that they were aware of the age of the information depicted on their weather display.

There was a significant difference in the extent to which the pilots of the two display groups perceived that they used the weather display to help them navigate. A relatively large number of pilots with the NEXRAD image looping display reported that they used the weather display to help them in their navigation procedures to avoid the convective weather conditions. The pilots having the NCWF display were evenly divided in the perception as to whether they used their weather display to help them navigate. The difference in the perceptions of the pilots of the two display groups as to their use of their weather display to help their navigation did not show up, however, in their performance.

6.3.4 Effect of Display Type On Pilot Situation Awareness

Nearly every subject pilot in the control group stated they could have better performed the mission had they been equipped with an onboard weather display of some type. And nearly every subject pilot in the two display groups stated they felt the weather display greatly improved their awareness of their situation with respect to the location and movement of the convective weather conditions along the route. The pilots of both display groups stated that the weather display increased their situational awareness during the decision-making process.

There were no significant differences in the responses of the pilots having the two different displays to the questions regarding their perception of the proximity of convective weather conditions to the Richmond Airport and across their path enroute to Wallops Island, or to the questions regarding the degree to which they knew their relative position to storms when relying on their weather display, or to the questions regarding their confidence that they had adequate sources of information to make confident decisions.

There were no significant differences in the responses of the pilots having the two different displays to the questions regarding their understanding of the latency of the information provided by their weather display.

6.4 Effectiveness of Modifications to the Basic NEXRAD Display

The graphical weather depiction age indicator, added to the lower left corner of both of the NEXRAD displays so that pilots could, at a glance, determine the age of the weather information, was found to have substantially reduced the mental effort required to calculate the age of the weather information.

Translation of the text METARs from the ICAO format to English text substantially decreased pilot workload for most of the subject pilots, enabling them to more effectively use the text METAR. An option should be provided to permit pilots to choose between the ICAO format and the translated format.

A depiction of flight path, including key waypoints and their identifiers, is essential for effective use of a NEXRAD mosaic image display.

Provision of a 25 nm range-ring on the 10 mile and 25 mile scales was found to substantially improve the pilots' determination of their proximity to hazardous weather.

Also, making the 25 nm range-ring invariant across display scale selection (i.e., range modes) substantially reduced mode errors associated with the display scale selection.

6.5 Use of Autopilot to Complement Weather Information Display

This study was not designed a priori to measure the effects of the use of an autopilot on a pilot's ability to safely and effectively use the cockpit weather information display. In this experiment, however, the subject pilots equipped with the weather information display and the observers were nearly unanimous in their assessment that the autopilot contributed significantly to the safe and effective use of the display. The observers reported a clear correlation between the extent of the subject pilot's use of the weather information display and their use of the autopilot.

Even though the autopilot was used for an average of 69% percent of the time in flight across all the participant 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. In many cases the subject pilots reported they would not have continued with the flight had they not had the use of the autopilot. 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.

7 Recommendations

The following recommendations are based on the findings of this study, loosely formatted for possible incorporation in the FAA Aeronautical Information Manual (AIM), draft FAA Advisory Circular No: 00-FIS, titled "Use of Cockpit Displays of Digital Weather and Operational Information," and draft FAA Advisory Circular No: 20-FIS, titled "Safety and *Interoperability* Requirements for FIS Equipment". The recommendations pertaining to the AIM are limited to information that does not duplicate information already provided in the latest edition of the AIM (February 1, 2002).

Additional recommendations are provided for the consideration of the FISDL display system manufacturers.

7.1 Aeronautical Information Manual and Advisory Circular Recommendations

The depiction of weather information, 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 to produce the NEXRAD mosaic 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 into one national mosaic before the NEXRAD national mosaic is available from which to create the FISDL cockpit images for transmission.

METAR observations are only produced at the top of the hour. The hourly METAR observation remains as the "official" observation for the airport throughout the hour and is included in the airport ATIS. During approach the pilot will be provided the direct readout wind and altimeter information by the tower controller. Also, pilots can obtain the aural report of the latest minute ASOS observation while in radio range of the airport ASOS. During dynamic, changing weather conditions, SPECI observations are issued and are included in new ATIS reports, but they are unscheduled and are thus unpredictable in terms of knowing or anticipating when they should be available. Also, TAF forecasts are issued four times per day at scheduled intervals and remain valid until amended or superseded by the next issued TAF. TAF AMEND, like SPECI observations, are unscheduled and are thus also unpredictable in terms of when they should be available. The availability of SIGMET, AIRMET, PIREP and AWW reports is similarly unpredictable in that they are primarily event driven and issued (or amended) when weather conditions dictate.

Another delay introduced into all the FISDL products is a product of the FISDL broadcast transmission cycle. The communication architecture of the FISDL broadcast will determine the magnitude of that delay for any specific FISDL product. For example, the FISDL Service Provider may decide to place a priority on transmitting NEXRAD

products and thus "interrupt" any text transmissions when a new NEXRAD product is received.

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 so as to 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.

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.

The mental activity required to use the FISDL display can increase the pilot's workload in instrument conditions for some pilots. An autopilot can offset this workload increase, freeing up the mental processes to support more effective use of the display. Some pilots have reported that an autopilot is essential to their effective use of the FISDL display.

7.2 Weather Display Manufacturer Recommendations

7.2.1 Consider Providing Flight Path Information

Both subjective and objective measures have found in previous experiments in which flight path information was not displayed on the weather information display that most of the pilots had difficulty determining their position in relation to the weather and their distance to the convective weather activity. With the proliferation of moving map displays in modern cockpits, pilots are used to seeing ownship symbology, which they use to determine their position, and flight path information, which they use to determine proximity of hazardous convective weather information to their future flight path.

The benefits of ownship symbology and flight path depiction appear to outweigh the concerns associated with the display of real-time position information (ownship ground track) and old information (7 minute old NEXRAD) on the same display. During the post-flight briefings with the subject pilots, most commented that they realized the NEXRAD images were not real time and would take the staleness into account when comparing their future position and flight path in relation to the weather depiction.

7.2.2 Provide Direction and Rate of Hazardous Weather Motion

Many of the pilots in previous studies 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). In this study, the pilots stated their situation awareness with respect to the hazard of convective weather activity in their vicinity was significantly increased.

7.2.3 Consider Providing A Range Ring to Assist Distance Determination and Avoid Mode Confusion

Many of the pilots in previous experiments 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 FISDL display. In this study the pilots' performance and reduced workload argue persuasively for the provision of a range ring around the ownship symbol to assist in more accurate estimation of distances and to assist in minimizing pilot confusion as to the display range scale that has been selected.

7.2.4 Provide Intuitive NEXRAD Image Age Information

In this study the pilots' performance and reduced workload argue persuasively for the provision of an intuitive indication of the age of the NEXRAD mosaic image.

7.2.5 Provide METAR Code Translation As A Pilot Option

In this study a translation of the METARs into English text was provided when the pilots selected the text METAR feature on their cockpit weather display. In this study, nearly all of the pilots used the METAR text reports to one degree or another – a major improvement over the very limited use of these reports in previous studies in which the reports were provided in the ICAO format. A majority of the general aviation pilots' who participated continued to comment, as they have commented in previous studies, that when presented in the ICAO METAR format the METAR reports are difficult to interpret, and take too much time to interpret. Only those few general aviation pilots who use the ICAO METAR format regularly reported that they were more comfortable with the ICAO format and felt that it substantially reduced the time required to assimilate the information provided.

Additionally, consideration should be given to the provision (via data link) of direct readouts of current controlling conditions to the pilot.

7.2.6 Consider Providing the NEXRAD Image Looping Feature As an Option

In this study, the NEXRAD image looping feature provided a relatively intuitive and useful means of enabling a pilot to determine the direction of movement of convective weather activity. Manufacturers of data link NEXRAD weather displays could consider providing this feature as an optional feature of their product.

7.2.7 Develop and Provide Comprehensive User Training for FISDL Display Customers

In this study, the display of NEXRAD mosaic images substantially increased the pilots' awareness of the general location of convective weather in their vicinity. The compelling nature of the display of these images, however, caused some pilots to depend too heavily on the display for their information regarding hazardous convective weather condition. As a result, they failed to obtain other essential and corroborating information from other available sources and proceeded to fly into what would have been extremely hazardous conditions had they not been flying in a flight simulator. Substantial training in the use

of the FISDL display system is required to help pilots understand the limitations of the FISDL display and its data, to reduce the workload otherwise required to access and interpret weather information, and to enable the pilot to fully exploit the potential safety contributions of the display.

7.2.8 Emphasize Need for Autopilot for Safe and Effective Use of FISDL Display

In this study, nearly every pilot emphatically stated that safe and effective use of the data link cockpit weather display can only be undertaken with the assistance of a capable autopilot. Their performance underscored the importance of the use of the autopilot as a means to offset the additional workload incurred in using the cockpit weather display.

7.3 Recommendations for Further Research

Proposed research topics fall into three broad categories: evaluation of specific issues of interest to the FAA, weather information integration and display design enhancements, and development of a training system for aircraft cockpit weather information management.

7.3.1 Conduct Evaluations of Specific FISDL Issues to Support Standards

This research topic is motivated by the need for standards and design guidelines to assure safety. Issues to be addressed include 1) how to minimize the effort required to learn to use the display, 2) how to facilitate interpretation of the display, 3) how to minimize the likelihood that the displayed weather information can be misused, leading to poor navigation decisions, and 4) how to efficiently obtain and coordinate the data necessary for incorporation in appropriate standards.

7.3.2 Develop Concepts for Information Integration and Display Design Enhancements

A variety of weather related products and onboard sensor derived data are currently available or pending implementation in aircraft, e.g., NEXRAD images, lightning data, data linked icing warnings, convective weather turbulence, etc. Display concepts are needed which integrate the available data into more useful representations of spatial and temporal information incorporating the lessons learned to date by the RTI/NASA team and other organizations working in this area. The cognitive skills required of the pilot to integrate weather data from many sources would be greatly reduced, as would the comprehensive weather data interpretation training currently required.

Further investigation should be undertaken to determine the extent to which the NCWF product, or at least selected features of this capability as it now exists, might be incorporated in cockpit weather information displays.

7.3.3 Develop Training Curriculum 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 and

reinforce appropriate operational procedures for the use of weather display systems. Accompanying experiments should be undertaken to evaluate the efficacy of the training curriculum.

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Appendix A. 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.

En-Route Forecast:

**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 B. Cockpit Research Facility Description

1. Cockpit Research Facility (CRF) Description

The Cockpit Research Facility (CRF) provides a means to evaluate both conventional and experimental cockpit displays and flight control configurations for single engine General Aviation (GA) aircraft. Experiments can be performed with any combination of conventional or experimental instruments/displays and controls in a fully immersive communications, navigation and surveillance (CNS) environment. Illustrated in Figure B-1, the CRF consists of three major components:

- **Rapid Prototype Simulator Cockpit** - The cockpit mockup with controls, instruments and indicators.
- **Scenario Controller** - The master control station used for scenario generation, selection, monitoring, fault injection and recording of flight progress. This station transfers all data between the controls and indicator in the cockpit and the simulation models in the Scenario Controller. Display of all current control positions, switch positions and instrument displays and Out-the-Window scene are also available. A Closed Circuit Television (CCTV) is used for monitoring and recording subject pilot's actions and conversations with simulated Air Traffic Manager (ATM).
- **ATM Controller** - An extension of the Scenario Controller, provides a plan view of the simulated aircraft's progress and flight plan, similar to an ATC console, along with other traffic in the scenario. A display of the current pilot-selected COM frequencies is available so that the ATM controller can verify that the pilot is contacting ATM on the correct frequency before responding to an initial contact.

A high-level diagram of the major system components is illustrated in Figure B-2. These major components are described in the following paragraphs.

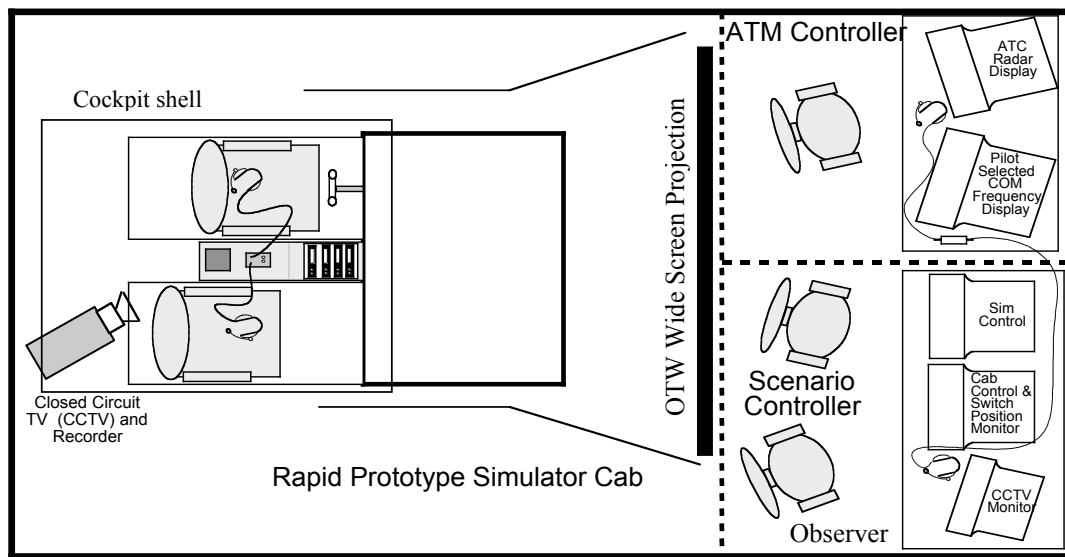


Figure B-1. Cockpit Research Facility



Figure B-2. Simulated Flight (Rapid Prototype Simulator Cab)



Figure B-3. Control Room (Scenario Controller)

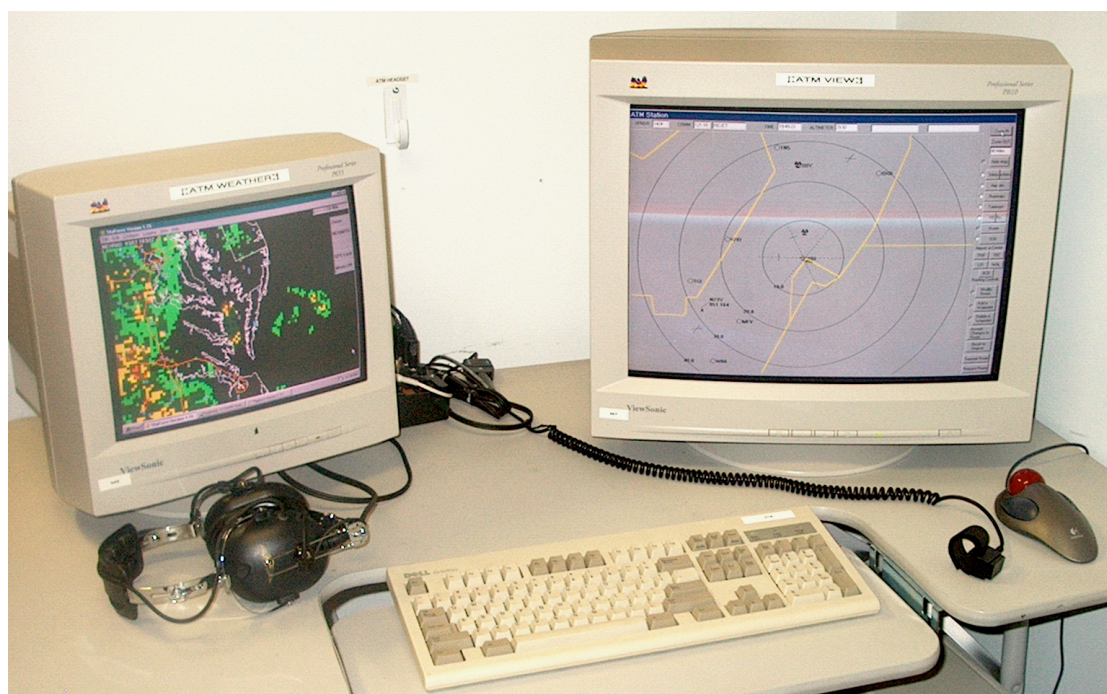


Figure B-4. ATM Station

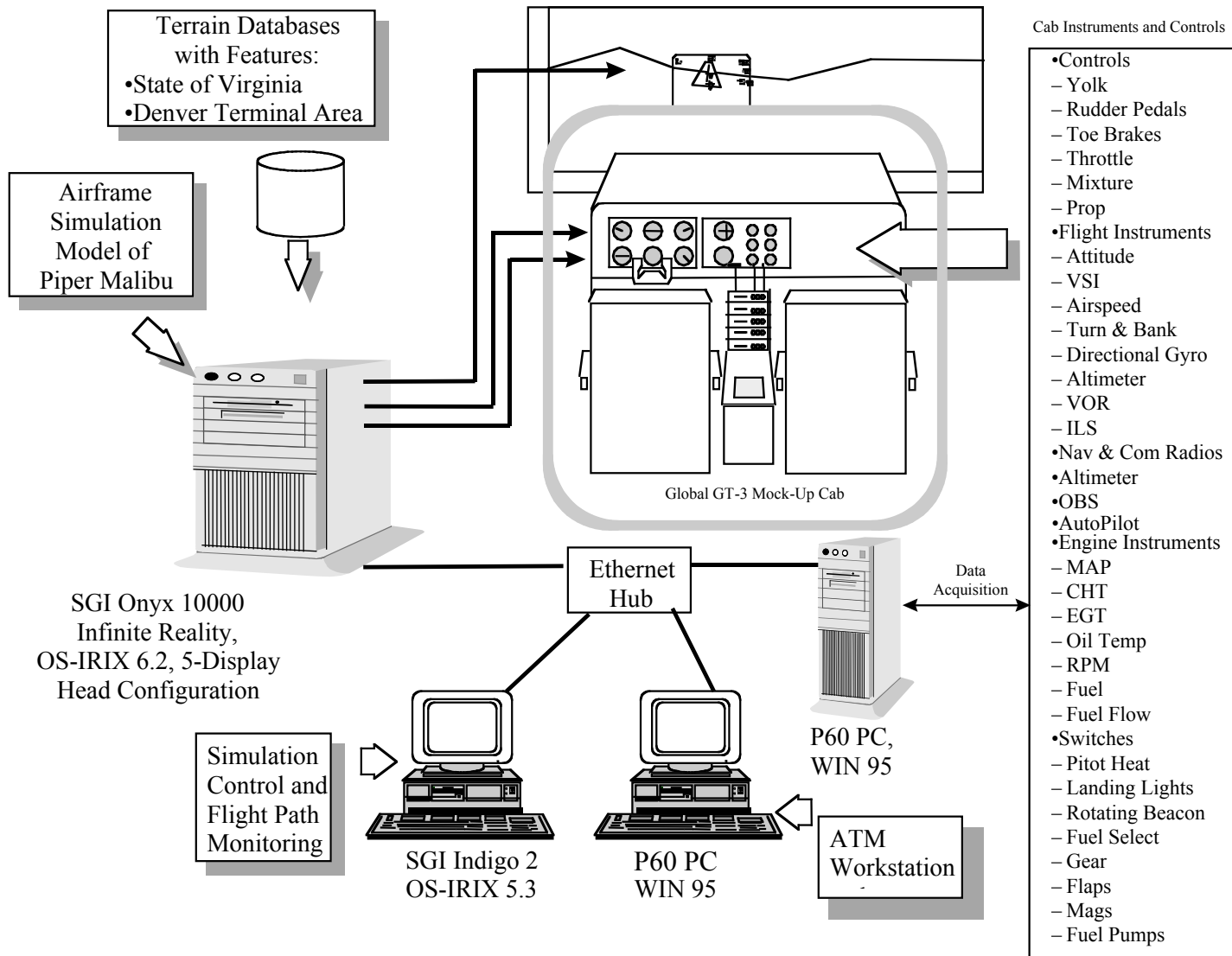


Figure B-5. SGI Configuration - Cockpit Research Facility System Block Diagram

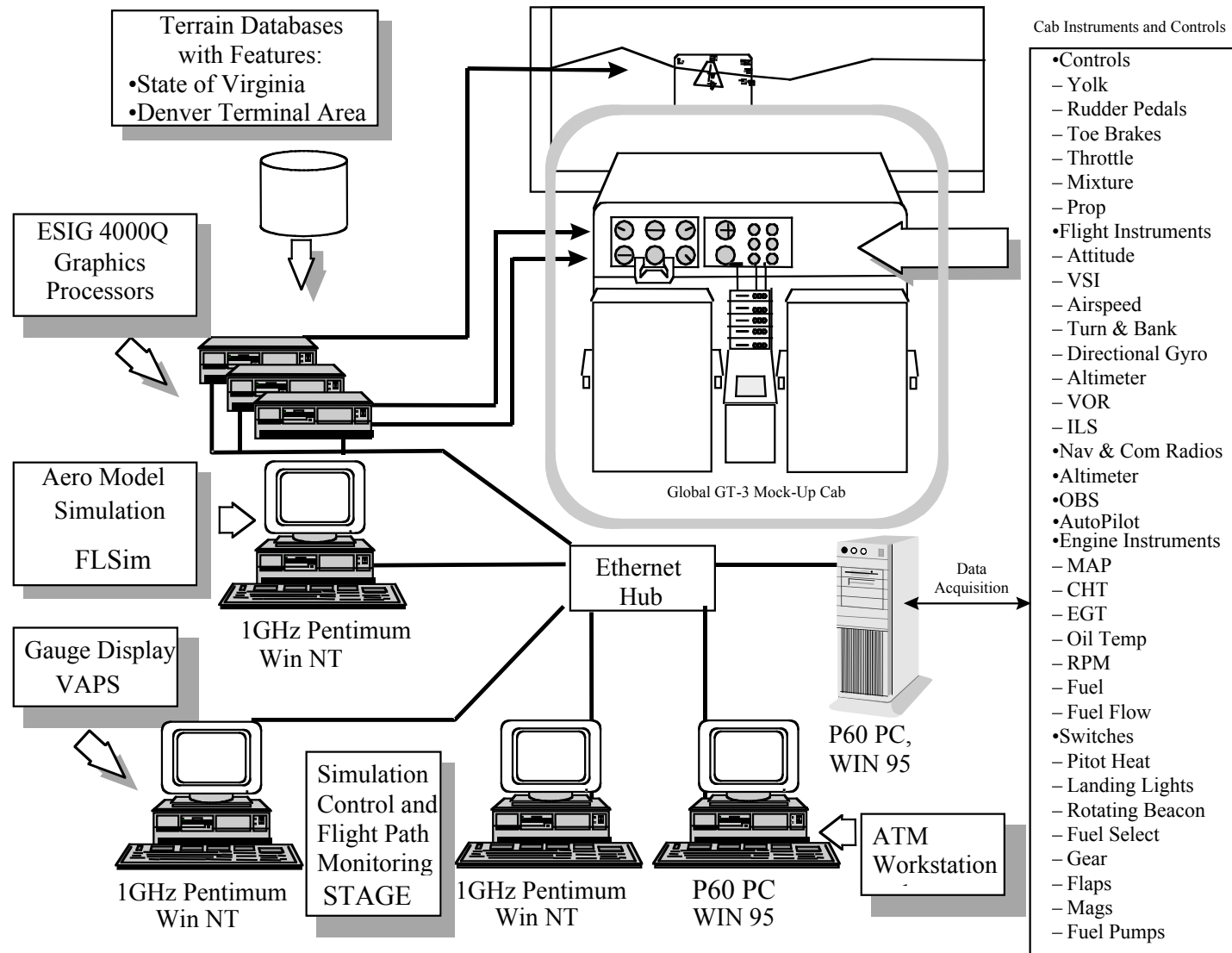


Figure B-6. PC Configuration - Cockpit Research Facility System Block Diagram

2. Rapid Prototype Simulator Cockpit

2.1 Overview

The simulator cockpit is a two-seat cockpit mockup designed for single-pilot IFR operations. The basic ergonomic structure of the mock-up is patterned after the Global Aircraft GT-3 Trainer 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. A left- or right-handed side stick controller is also available. Virtually any flight control system can be implemented. The second seat is used for a test subject observer or non-flying copilot. The interior dimensions of the cockpit enclosure are similar to those of the Cessna 208 Caravan aircraft.

The major features include:

- **Rapid Reconfiguration of the Instrument Panel** - The most flexible aspect of the simulator cab is the ability to quickly change the types of instruments in the instrument panel. Instrument panels currently simulated include the round dial and separate PFD/MFD types. Various PFDs and MFDs are also supported and can be switched into or out of the simulator cab in minutes. Other PFD/MFD systems supported include Seagull, ARNAV 5200 / 2000 series , Archangel, Nav3D systems, UPSAT hardware, and Global/RTI International low-cost HUD configuration.
- **Rapid Reconfiguration of the Cockpit Geometry** - The simulator cab design facilitates rapid changes in configuration. The center console can be moved in or out as required to approximate a cockpit geometry. The rudder pedal placement is adjustable through a wide range of distances from the pilot's seat. The seats are adjustable in distance from the yoke / instrument panel. Further, the pilot's seat and rudder pedals can be moved fore and aft as a single unit in the cab to accommodate most subject pilots and future control mechanisms.
- **Reconfigurable Flight Controls** – The flight controls currently available include a control yoke with simulated cable / mechanical control surface actuation. An electronic side stick hand controller is also available. Both control systems include autopilot assistance and electric trim.
- **Reconfigurable Power Controls** - The center console holds the throttle quadrant and radios. The throttle quadrant can be replaced with the traditional push rod configurations for throttle, mixture and carburetor heat, or a single lever power control and simulated Full Authority Digital Engine Control (FADEC).
- **Spoiler System** – The aero model includes a spoiler system that is controlled by the throttle position which decreases lift, increases drag for investigation into higher approach speeds and steeper approach angles. This spoiler system can be used in

conjunction with a Head Up Display (HUD) system to monitor the effect of the spoiler deployment on the flight path.

- Multiple Visual Scene Databases - The primary out-the-window view is currently provided by a projection system mounted in the ceiling directly over the pilot, and projects an image on a 10 foot wide screen approximately 12 feet from the pilot. Visual terrain scenery includes the Denver terminal area and the state of Virginia with six detailed airports with associated navigation aids.
- Intercom and Video System - Both cockpit positions, Scenario Controller position and ATM position are outfitted with headsets and an intercom system that allows the pilot to communicate with the passenger and with simulated Air Traffic Manager. The passenger (experiment observer) can only communicate with the pilot. A separate hookup is available in the control room for two observers to be placed on the intercom system with communications with the Scenario Controller and the ATM. The Scenario controller can monitor all conversation. All audio is recorded on video tape along with a video image of the subject pilot's actions. Playback of specific ATIS and AWOS stations are available when the pilot tunes to the desired frequency.

2.2 Controls, Instruments and Indicators Description

Multiple instrument panel configurations are available as illustrated in Figure B-7 through B-11. A conventional "round dial" displays configuration or any combination of PFD/MFD/round dial and HUD displays are possible as shown. The controls, instruments and indicator configurations available are typical of those found in an IFR-equipped general aviation aircraft.

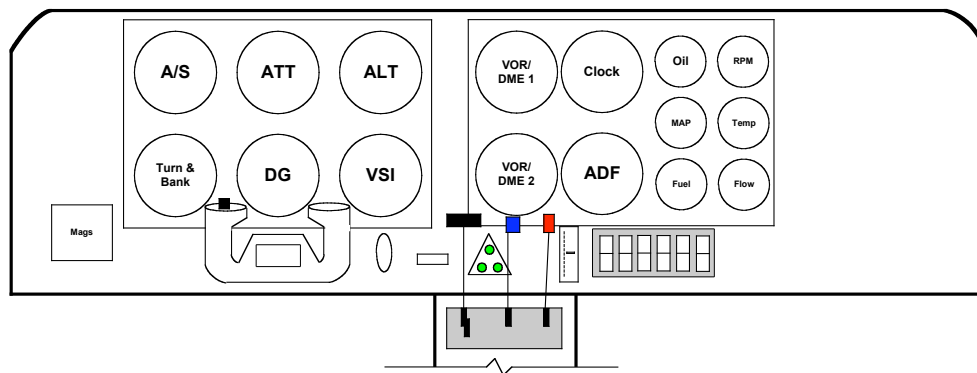


Figure B-7a. Conventional Round Dial Instruments

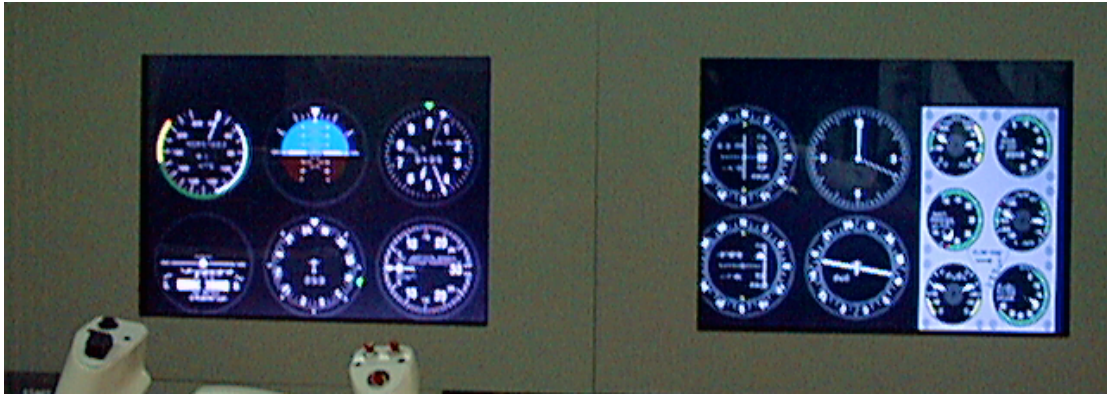


Figure B-7b. Conventional Round Dial Instruments

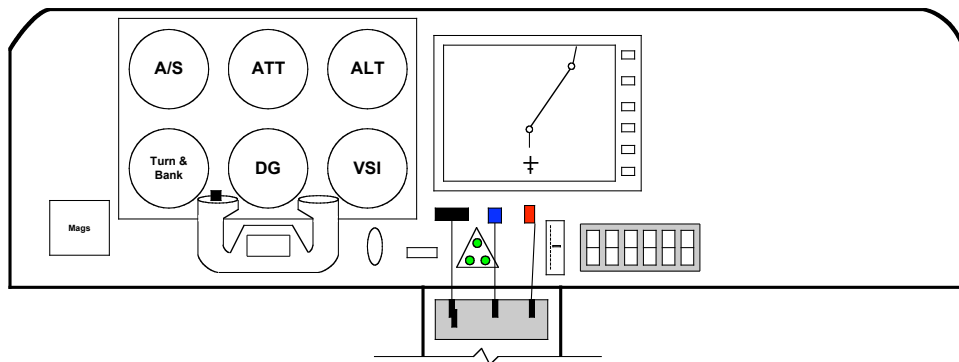


Figure B-8a. Conventional Round Dial Standard “T” and Electronic MFD

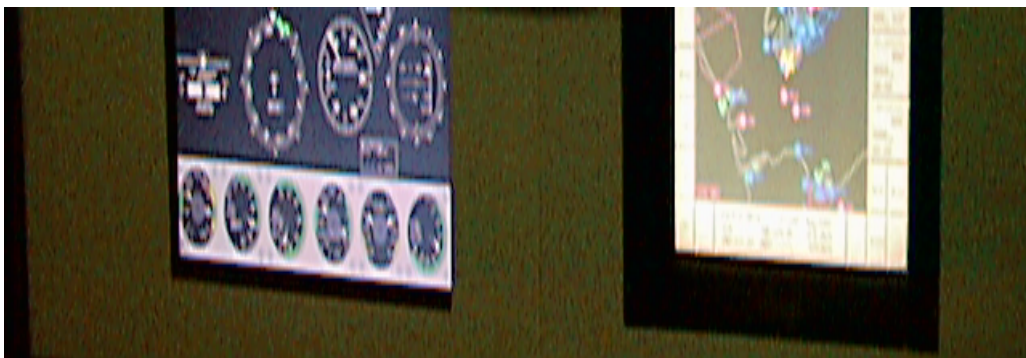


Figure B-8b. Conventional Round Dial Standard “T” and Electronic MFD



Figure B-8c. Conventional Round Dial Standard “T” and Electronic MFD

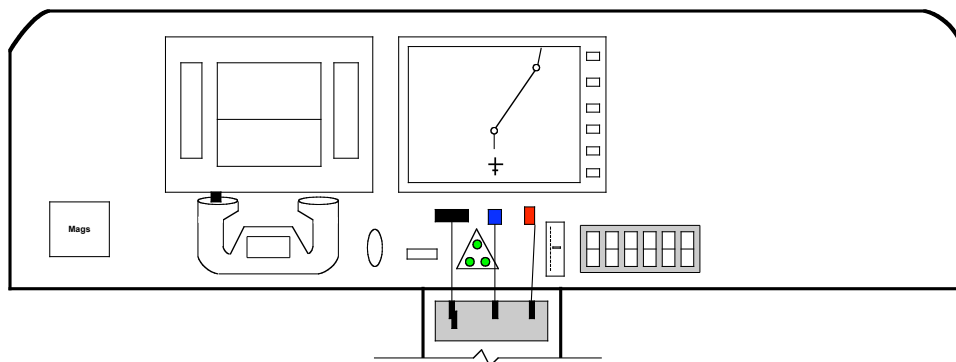


Figure B-9a. Conventional Electronic PFD (EFIS) and Electronic MFD

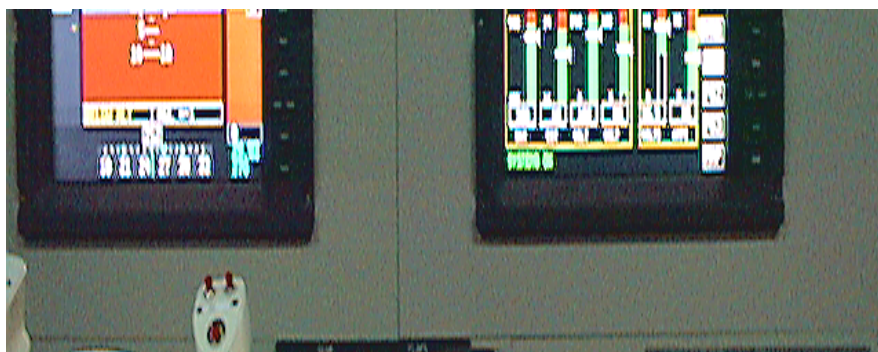


Figure B-9b. Conventional Electronic PFD (EFIS) and Electronic MFD

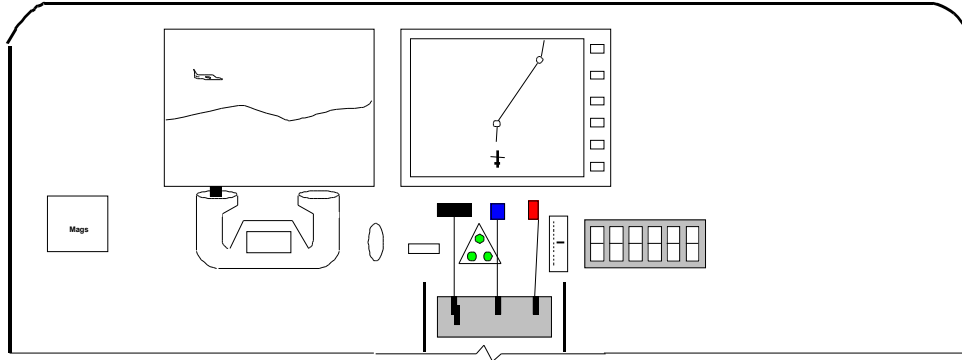


Figure B-10a. 3-D PFD with Terrain and Traffic, and Electronic MFD



Figure B-10b. 3-D PFD with Terrain, Pathway, Traffic and Weather, and Electronic MFD

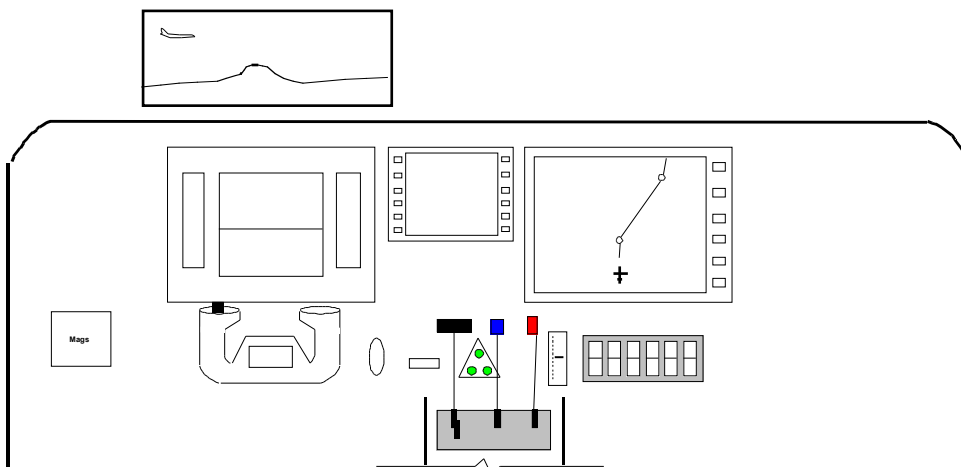


Figure B-11a. Electronic PFD, FMS CDU, MFD and HUD with 3-D Terrain, Pathway, Traffic, Special Use Airspace and Weather.



Figure B-11b. Electronic PFD and HUD with 3-D Pathway, Terrain, and Traffic

The key characteristics of these configurations can be summarized as follows:

- Round Dial Instrument Displays – All instrument panel round dial indicators are realistically 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 provide display area for navigation instruments and engine parameter indicators. All instruments can be designed to recognized Federal Aviation Administration (FAA) Federal Aviation Regulations (FARs), Society of Automotive Engineers (SAE) Aerospace Standards (AS) and RTCA, Inc. performance specifications. Or alternately, an experimental instrument can be designed and displayed that has enhanced or unique characteristics. The instruments can be rendered anywhere on the two LCD displays, in accordance with the FARs or in experimental arrangements.
- Electronic Primary Flight Displays (PFDs) and Multi-Function Displays (MFDs) and HUDs. The instrument panel can accommodate self-contained PFDs and MFDs or a combination of PFD/round dial, including a simulated HUD. A PFD, MFD or other type of display is provided with the required data elements (in accordance with the manufacturer’s Interface Control Document (ICD)) generated by the simulation aero and engine models. Three-Dimensional PFDs and HUDs are currently supported.

One 3-D implementation includes the display of traffic, 3-D pathway as well as terrain. Another implementation provides a 3-D pathway and flight director.

Figure B-12 illustrates the full round dial CRF configuration. Table B-1 contains the types of instruments available for rendering in the cockpit. Flight control instruments provide the pilot with the parameters of the simulated aircraft state vector. Besides a gyro stabilized directional compass, two VOR / DME displays complete with ILS Course Deviation Indicator bars can be used for navigation and approach to landing.

The simulated radio stack in the center console includes COM, NAV radios, an ADF receiver, DME interrogator, transponder and autopilot controls. The radio stack is used to select the proper COM frequencies to obtain ATC clearances, select the required VOR / DME and ILS frequencies. Two Omni-Bearing Selector (OBS) knobs located on the simulated radio stack are used to control the VORs. Two additional knobs located on the radio stack are used to set the barometric pressure for the altimeter and the Directional Gyro (DG). These knobs are located on the console since actual instruments are not used.

The control yoke provides the pilot with an electric trim button, push-to-talk switch for the intercom system, autopilot disconnect switch, chronometer for time calculations as well as a full range of control movement for controlling the flight path of the airplane. A hand controller is also available and can be located at the end of either arm rest. The hand controller contains electric trim and an intercom PTT switch. When configured with the yoke, activation of the electric trim button moves the yoke in or out to relieve the control forces. When using the hand controller, the electric trim button allows the pilot to return the stick to the centered position. The current trim position is displayed on a trim indicator in the instrument panel.

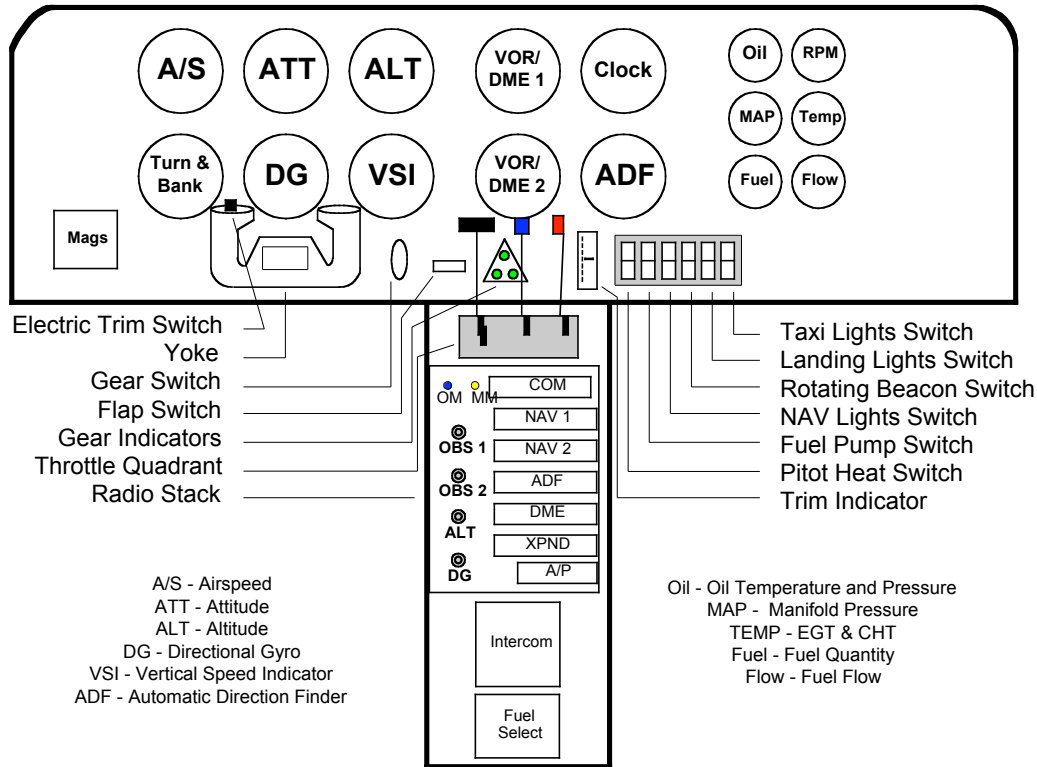


Figure B-12. CRF Round Dial Instrument Panel, Controls and Indicators Configuration

Table B-1. Instruments and Indicators

Flight Control Instruments	Navigation / Communications Instruments	Engine Monitoring Instruments and Control	Indicators
- Attitude - Airspeed - Altitude - Turn and Bank - Slip & Skip - Gyro Stabilized Direction - Vertical Speed - Autopilot	- 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) - Throttle, Mixture, Prop Levers - Throttle, Mixture, Prop Push-rods - Single Lever Power Control	- Trim Position - Flap Position - Gear Position

3. Visual System and Displays Description

SGI Version:

A Silicon Graphics Onyx 10000 is used to generate the instrument panel gages and the Out-the Window (OTW) scene for the pilot as depicted in Figure B-2. A rapid prototyping tool is used to develop and render the regulation-compliant gages in appearance and performance. Round dial instruments and AGATE PFD Highway-in-the-Sky (HITS) configurations are rendered on two 14-inch diagonal active matrix Liquid Crystal Displays (AMLCDs), each having an addressable resolution of 1024 pixels by 768 lines. Any type of instrument face or display can be rendered, including new and novel displays.

PC Version:

Separate Evans and Sutherland simFusion 4000Q are used to generate the instrument panel gages and the Out-the Window (OTW) scene for the pilot as depicted in Figure B-3. A rapid prototyping tool (VAPS) is used to develop and render the regulation-compliant gages in appearance and performance. Round dial instruments and 3-D view PFD Highway-in-the-Sky (HITS) configurations are rendered on two 14-inch diagonal active matrix Liquid Crystal Displays (AMLCDs), each having an addressable resolution of 1024 pixels by 768 lines. Any type of instrument face or display can be rendered, including new and novel displays.

The OTW scene is a photo-textured presentation rendered at a 50 degree horizontal by 37.5 degree vertical field-of-view and displayed utilizing a video projection system at an addressable resolution of 1280 pixels by 1024 lines. The screen is positioned so that active display area subtends approximately 50 degrees horizontal to the pilot's eye point. Both instrument displays and the OTW scene are rendered at a 30 Hz frame rate with a 60 Hz display refresh rate.

Two complete visual databases are available for experimental use. One visual database includes the Denver Stapelton Airport and the new Denver International Airport terminal areas. A second visual database includes the state of Virginia. The Virginia database 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 can be varied to achieve any meteorological conditions required, i.e. overcast, low RVR, cloud decks, etc.

4. Data Acquisition System Description

The data acquisition system allows the pilot's actions in the simulator to affect the state of the aero simulation model, and the outputs from the aero simulation model to be indicated in the cockpit displays and indicators. 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 simulation system for processing in the aero/engine/environment models.

Referring to Figures B-2 and B-3, a data acquisition controller system is hosted in a Pentium 60 - based PC. The data acquisition controller contains a microcontroller which 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 (A/D) conversions on control position information
- Acquiring switch position discreets
- 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, DG and Baro Altimeter knob settings
- Updating the frequency displays in the COM, NAV 1, NAV 2, and ADF radios

Data is moved between the simulation models and the data acquisition controller via a process which runs in the Pentium 60 under the Window 95™ operating system. At a frequency of 30 Hz (7 Hz in the SGI), the simulation model sends a buffer of data over the Ethernet connection to the Pentium 60. The data acquisition process moves the buffer to the data acquisition controller card for processing. The data acquisition process then sends a buffer of the data most recently acquired from the cab to the simulation model at a rate of 50 Hz and awaits the next buffer of data from the simulation model.

The modular nature of the data acquisition system allows additional modules to be added to drive additional LED displays and indicators or relays. Further, digital to analog modules are available for driving analog instrumentation.

5. Simulation Control, Monitoring and Recording

All aspects of the simulation are controlled by the simulation control and flight path monitoring process running in either the SGI Indigo or the PC with STAGE as shown in Figures B-2 and B-3. The simulation control process initializes the simulation models in the SGI Onyx or the PC with FLSim, performs real time data display, 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 the aircraft model, and monitor scenario progress.

Table B-2 lists the data dictionary of parameters available for collection and reduction. These items can be collected during the execution of any given scenario:

Table B-2. Real-time Parameters Displayed During Simulator 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 • Left Spoiler • Right Spoiler	Ground Contact Conditions (Landing) • Rate of Descent • 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 • Side Slip 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 B-3. Data Dictionary of Recordable Parameters and Inducible Faults

Time in tenths of a second
Latitude
Longitude
Altitude
Airspeed
Heading
Aileron deflection
Elevator deflection
Rudder deflection
Throttle position
Prop position
Mixture position
Vertical Speed Indicator
Altitude above ground
Flight Path Marker X and Y positions
Flare symbol Y position
Database X and Y position of ownship
Left and Right Brake position
Switch changes and positioning
Mags
Starter
Master
Pitot heat
Fuel pump
Nav lights
Flashing beacon
Landing lights
Taxi lights
Fuel selector
Toe brakes
Gear position
Flap position
Comm radio frequency
Nav 1 & 2 radio frequencies
Transponder frequency
ADF frequency
Autopilot switch positions
Any induced faults
Phase of flight

All of the above items are automatically sensed and recorded except for the phase of flight. This item is entered by point and click action on the I/O operator console.

6. Simulation Models

6.1 Aerodynamic Simulation Model

The simulation model is a 6 Degree of Freedom (DOF) aerodynamic model that is:

- 1) table driven in the SGI version and
- 2) Formula driven in the PC version

to provide the performance characteristics for the Piper Malibu 46P. The Piper Malibu currently in use represents a high performance single engine GA with a cruising speed of 170 knots. The basic aero model can be adapted to any aircraft.

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 to flare the airplane to a maximum lift stall.

6.2 Wind Models

A cross wind model is available that can direct a cross wind over a large range from any direction. A 15 kt cross wind is shown relative to the nose of the aircraft in Figure B-13. Additional sophistication can be added to the wind model including gusts and wind from any direction.

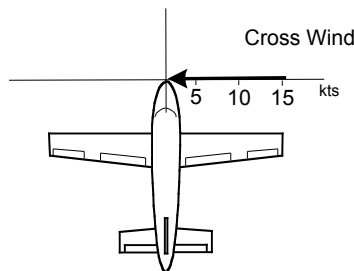


Figure B-13. Cross Wind Model

A turbulence wind model is also available that applies a turbulence factor to the aircraft based on the level desired. cross wind over a large range from any direction. Four levels of turbulence are currently modeled ranging from mild to severe. These factors affect the aircraft's U, V, and W axis within the aero model. The effects of the turbulence are evident in the gauges and the out-the-window scene. Other windshear models are available on the PC version.

Appendix C. Description of Flight Information Services Data Link (FISDL) and Its Use from FAA Aeronautical Information Manual (AIM)

7-1-11. 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 space-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 which 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 which 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 (SPECT'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 [7-1-30](#), Key to Aerodrome Forecast (TAF) and Aviation Routine Weather Report (METAR).

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:

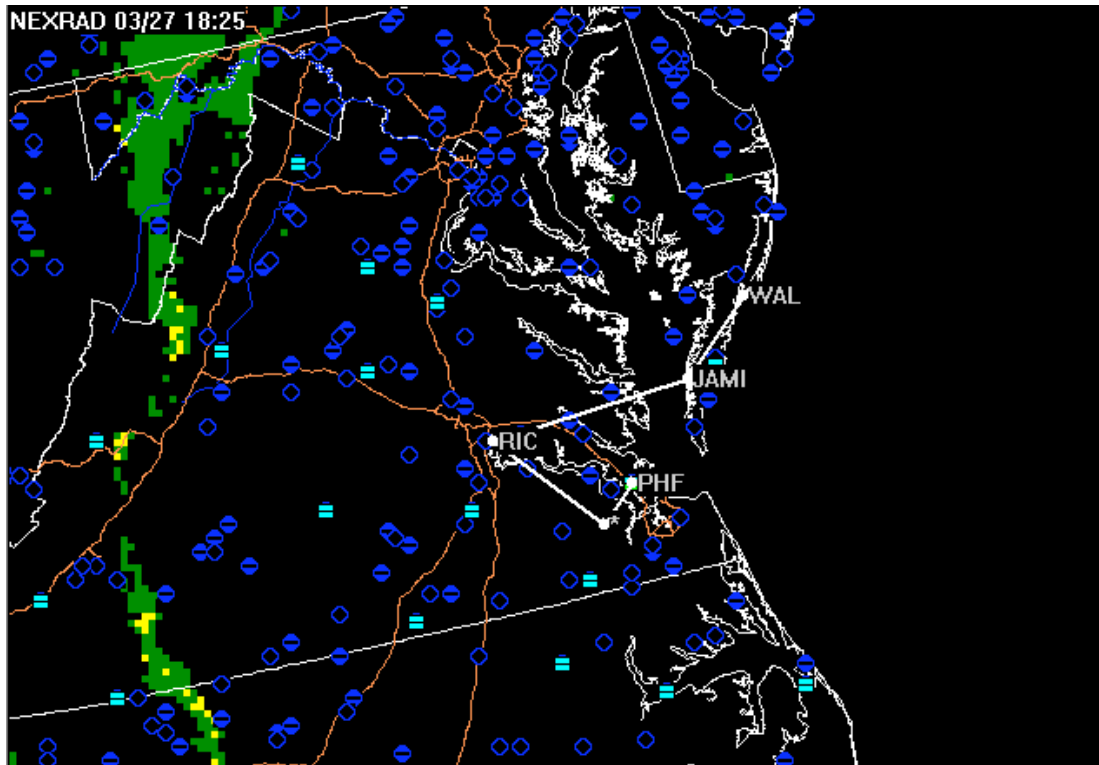
(a) The products should be either FAA/NWS accepted aviation weather reports or products, or based on FAA/NWS accepted aviation weather reports or products. If products are used which do not meet this criteria, they should be so identified. The operator must determine the applicability of such products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

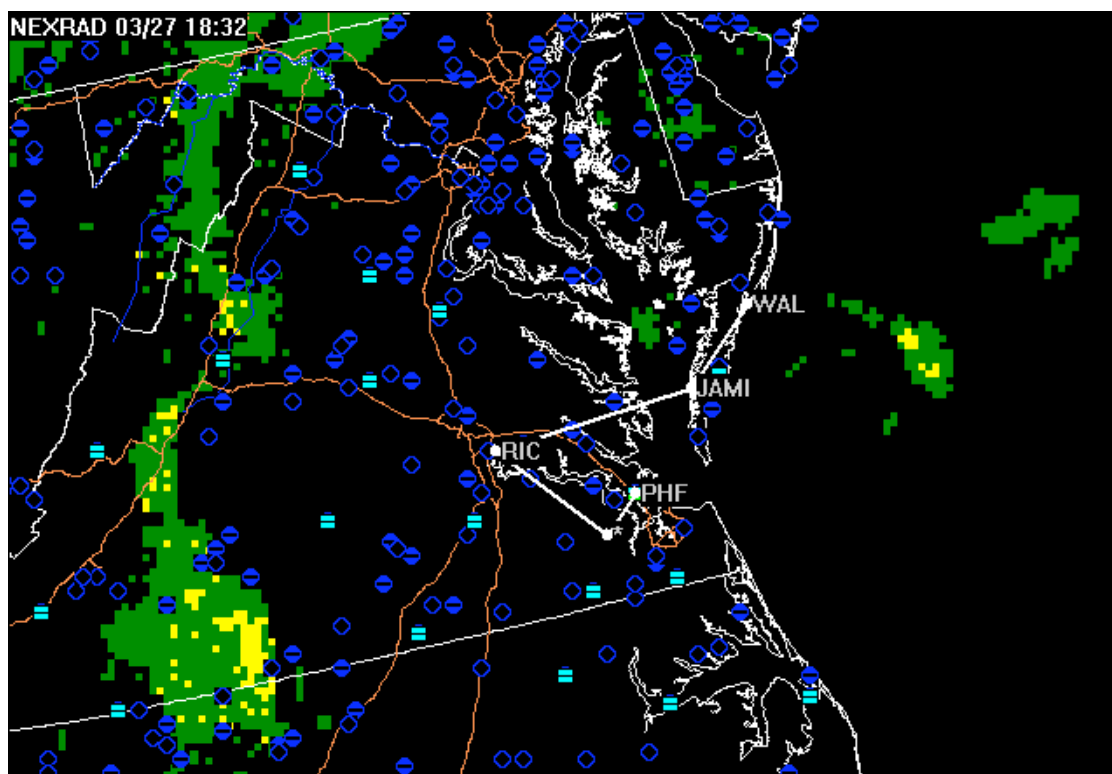
2. An example would be a NEXRAD radar composite/mosaic map, which has been modified by changing the scaling resolution. The methodology of assigning reflectivity values to the resultant image components should be described in the vendor's guidance material to ensure that the user can accurately interpret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

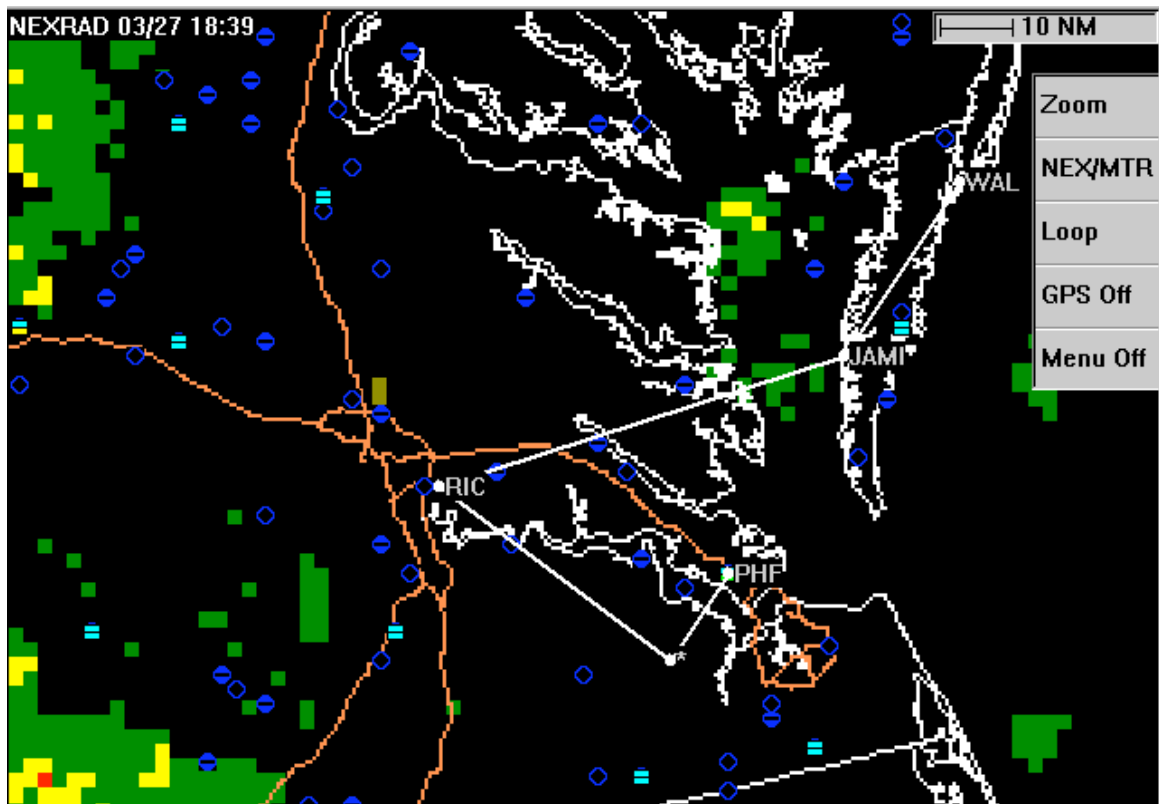
Appendix D. NEXRAD Mosaic Images Used In Experiment



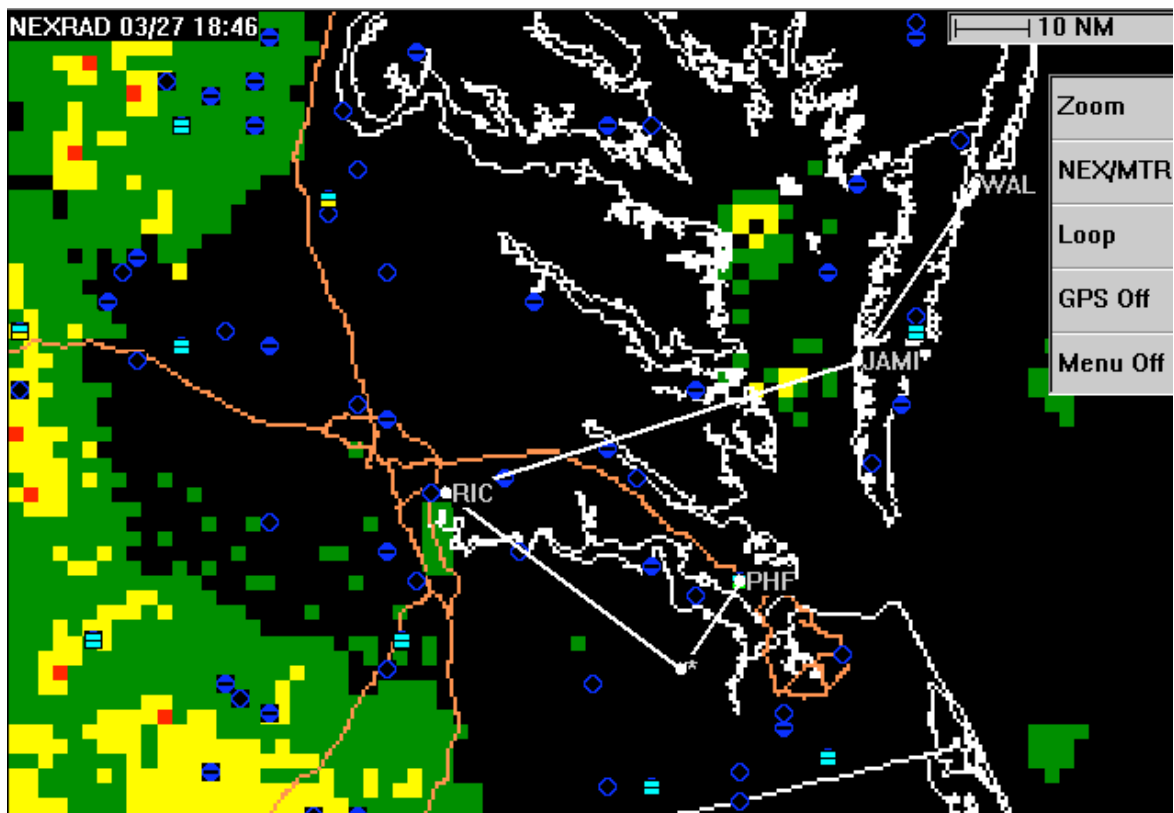
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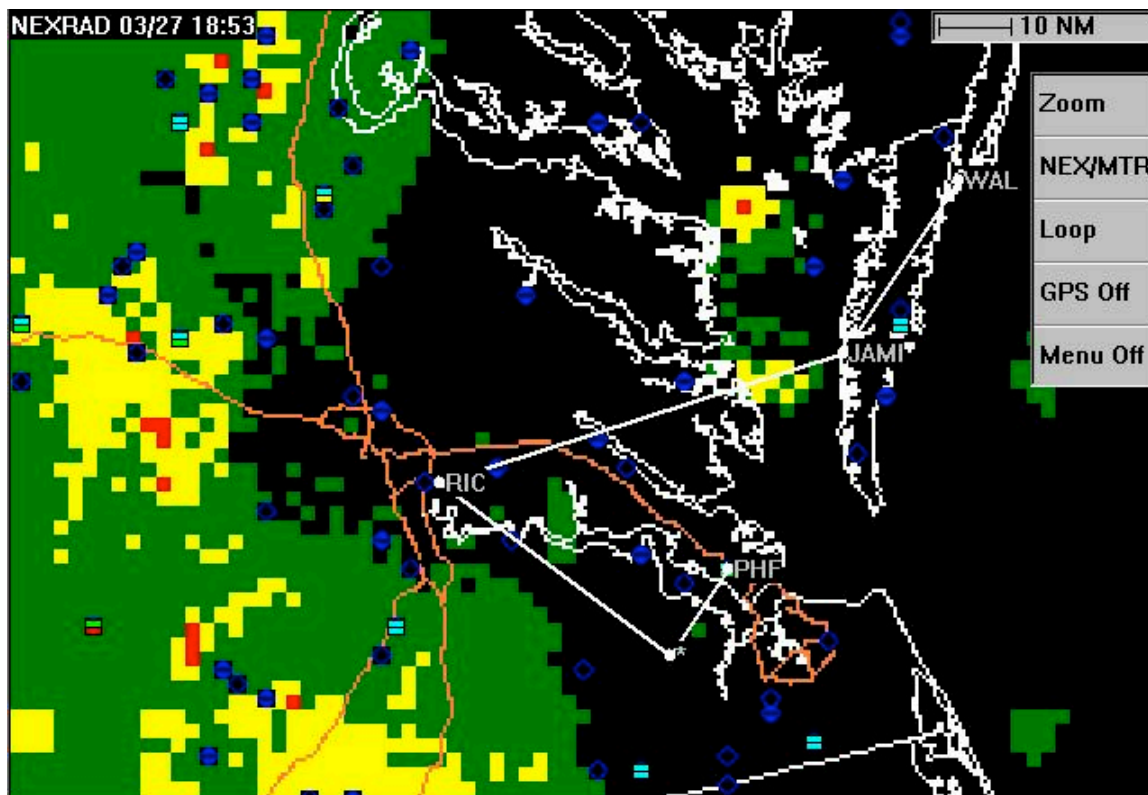
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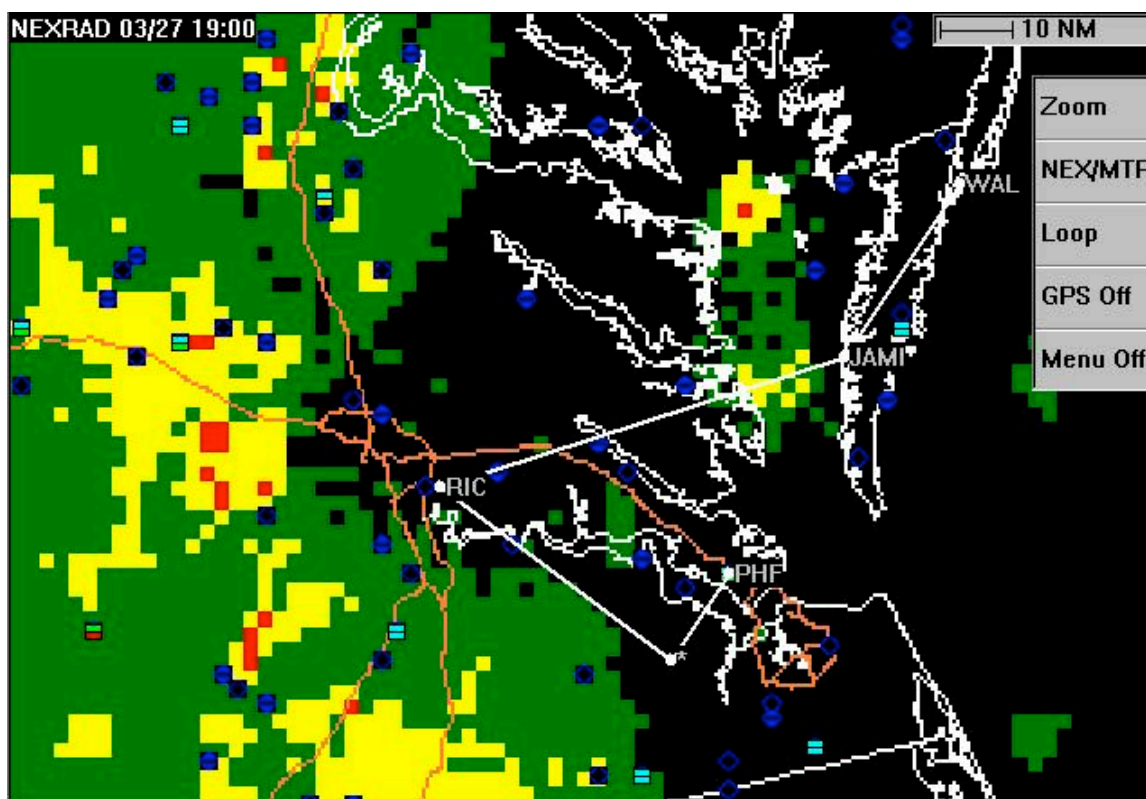
1839Z



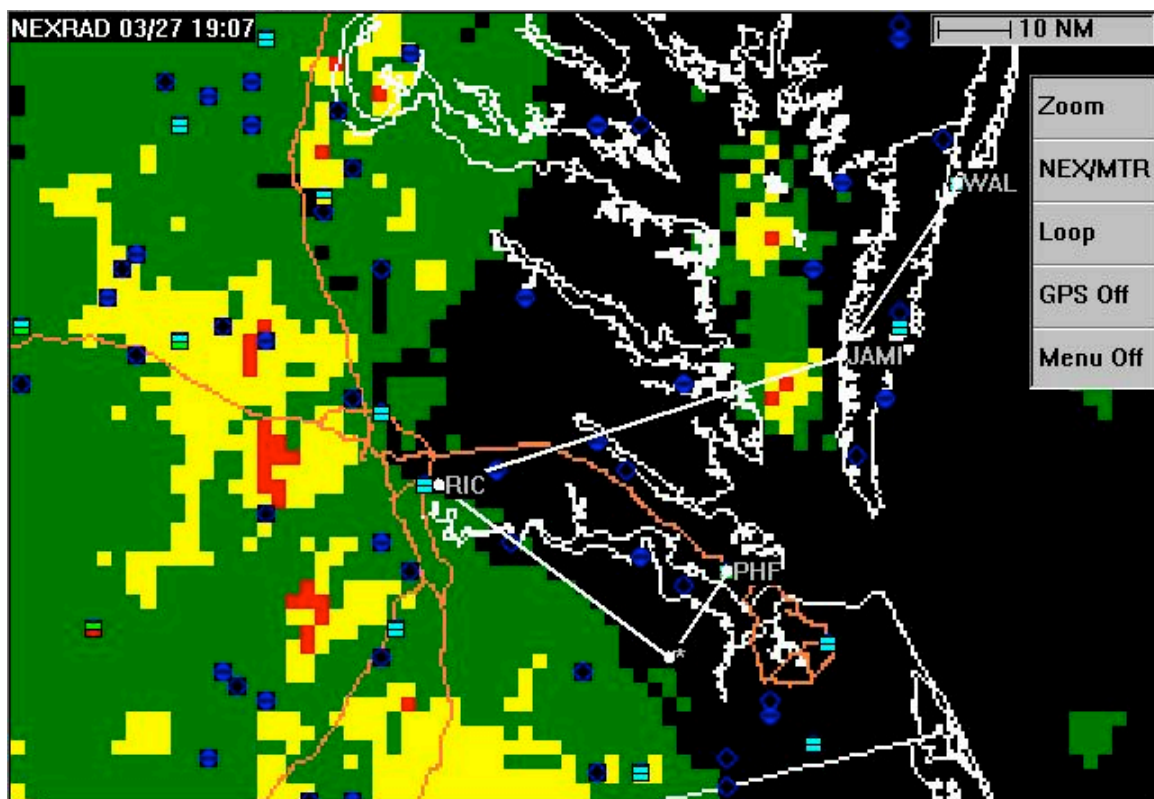
1846Z



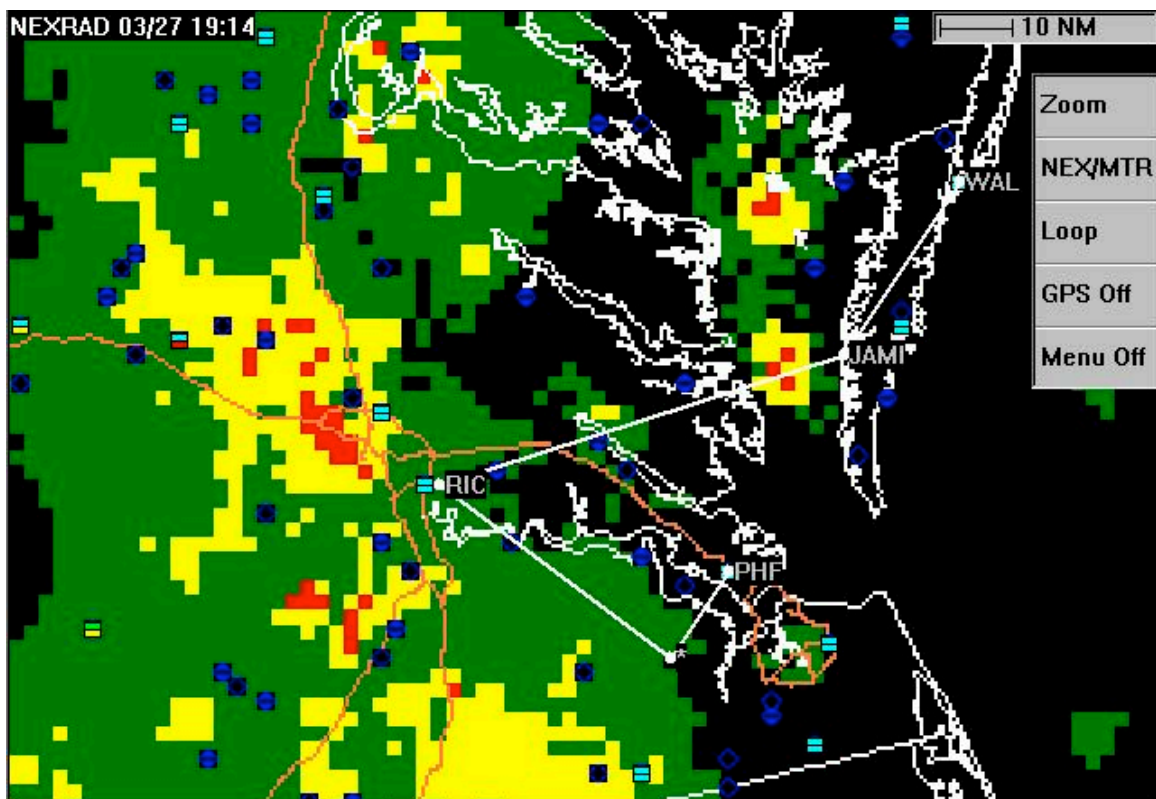
1853Z



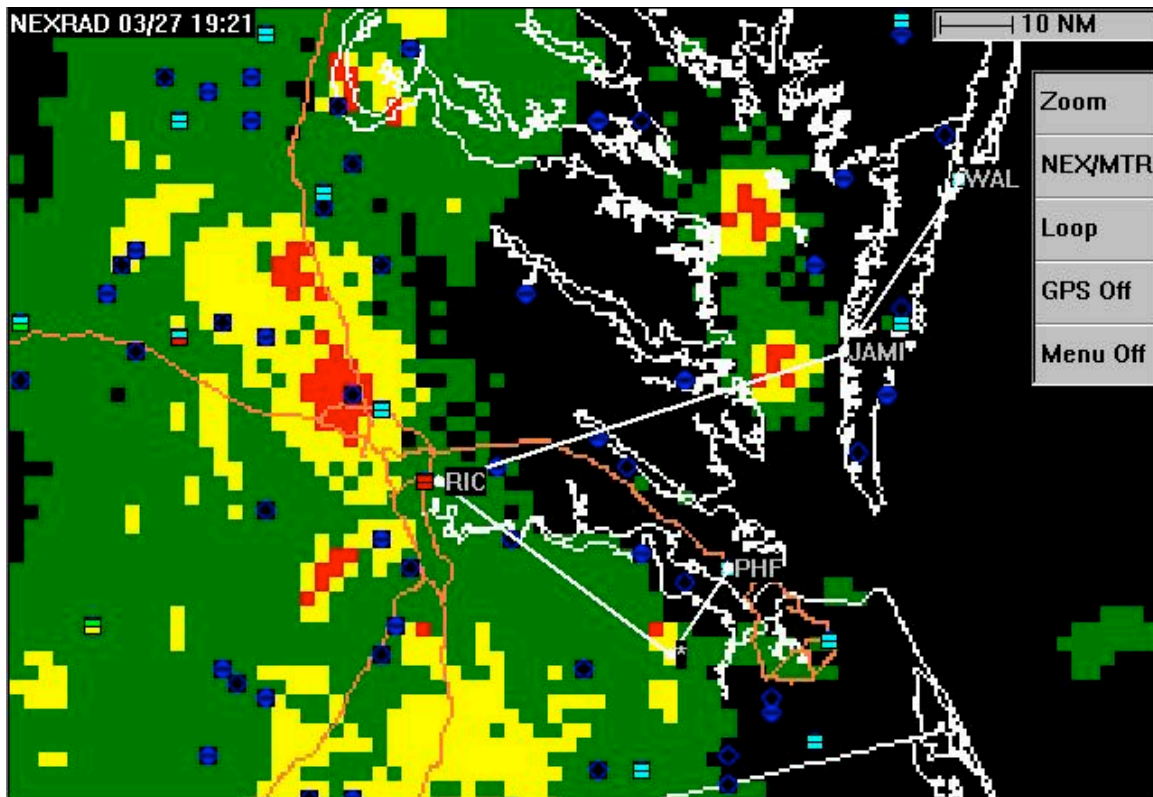
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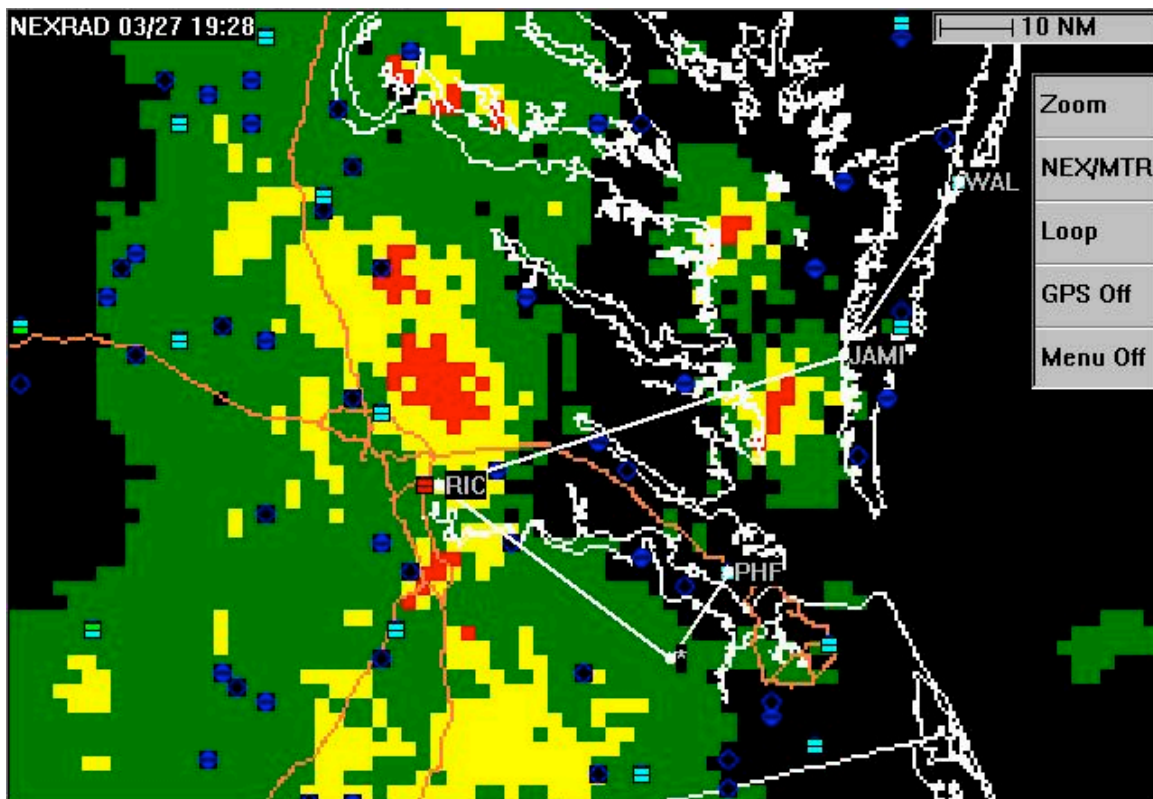
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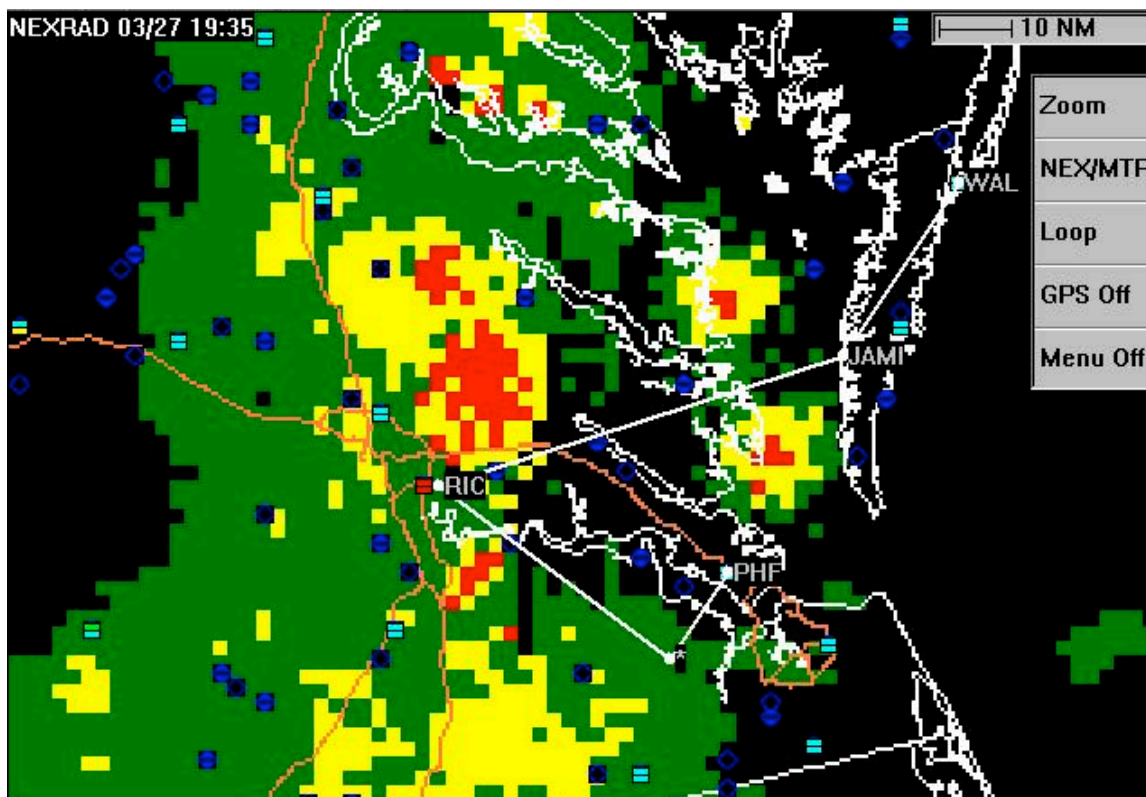
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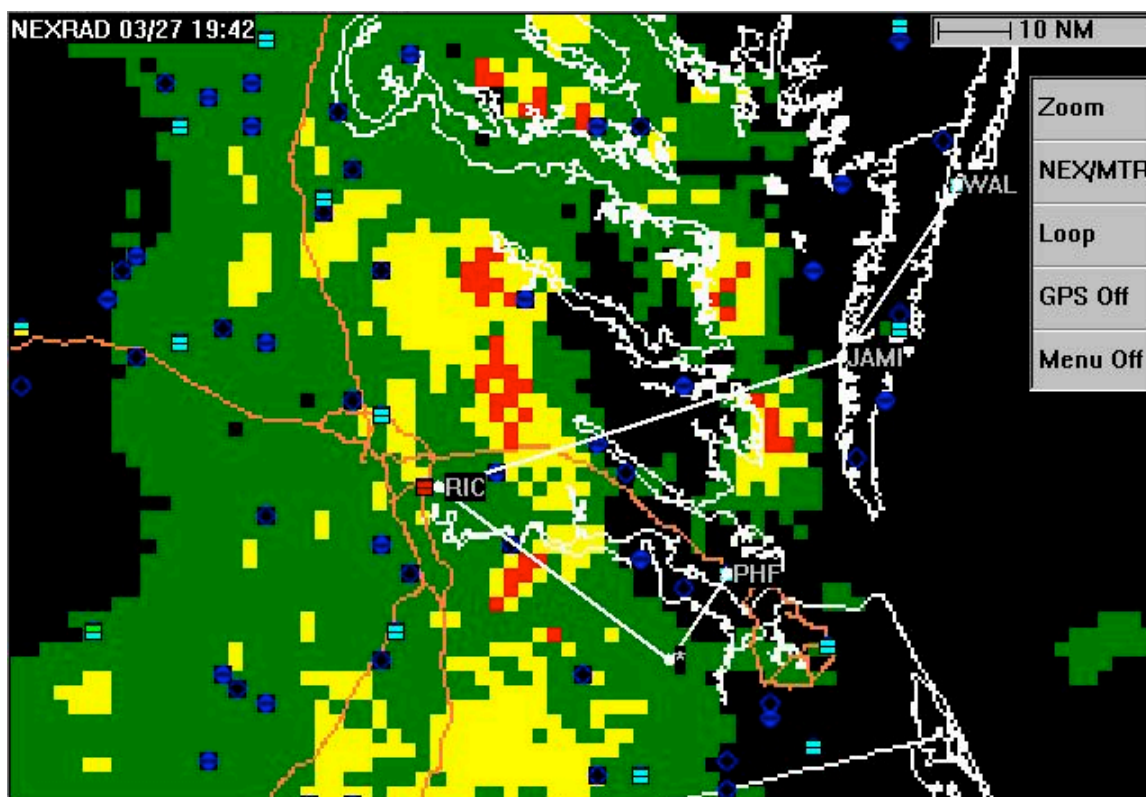
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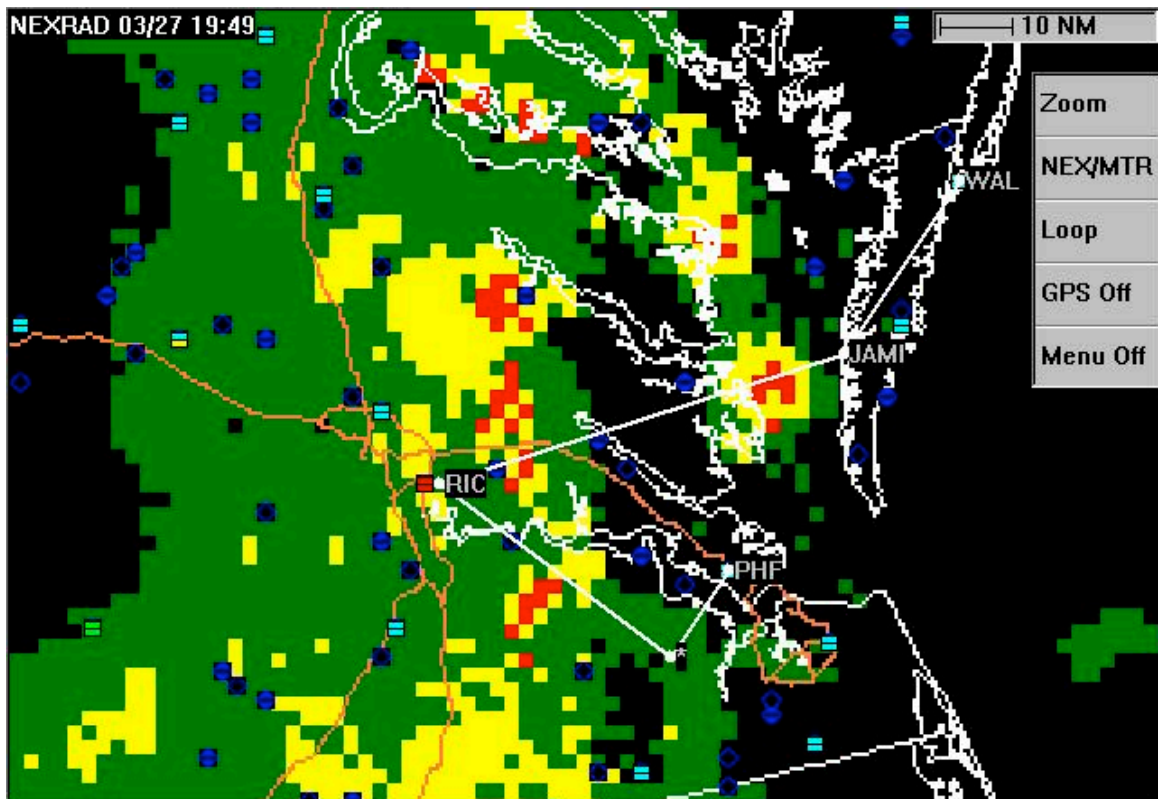
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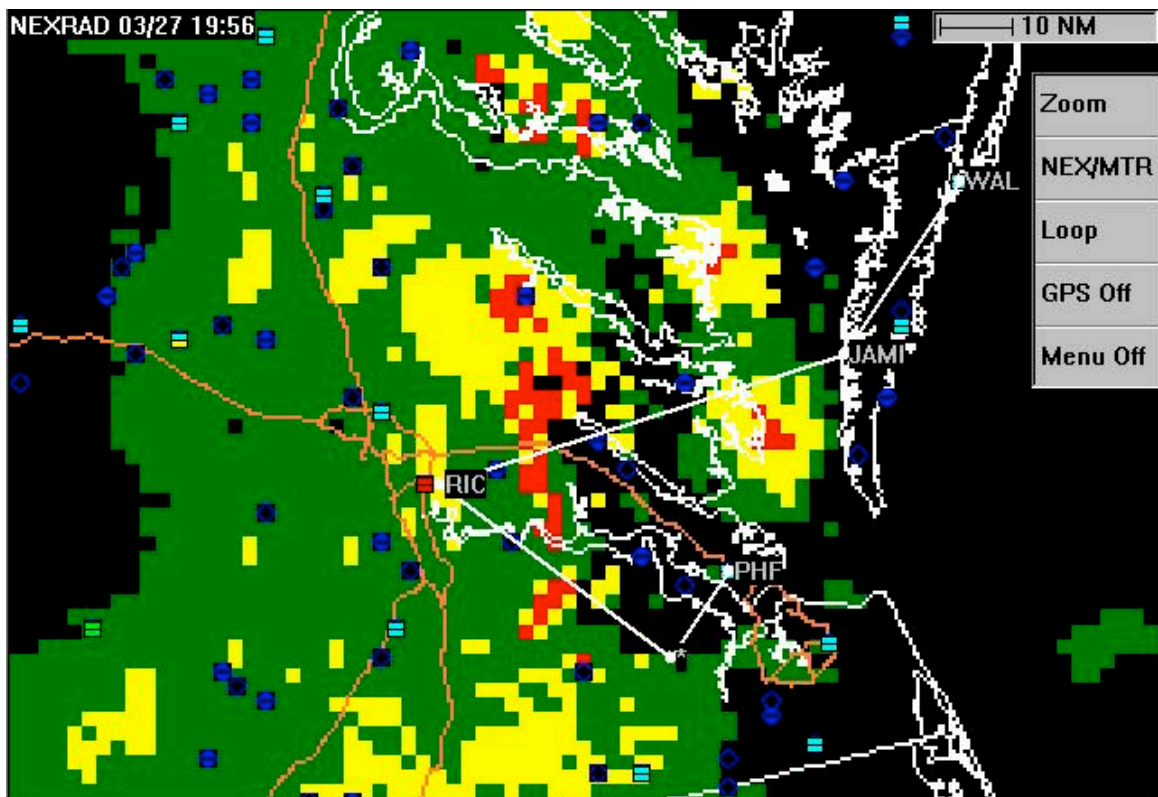
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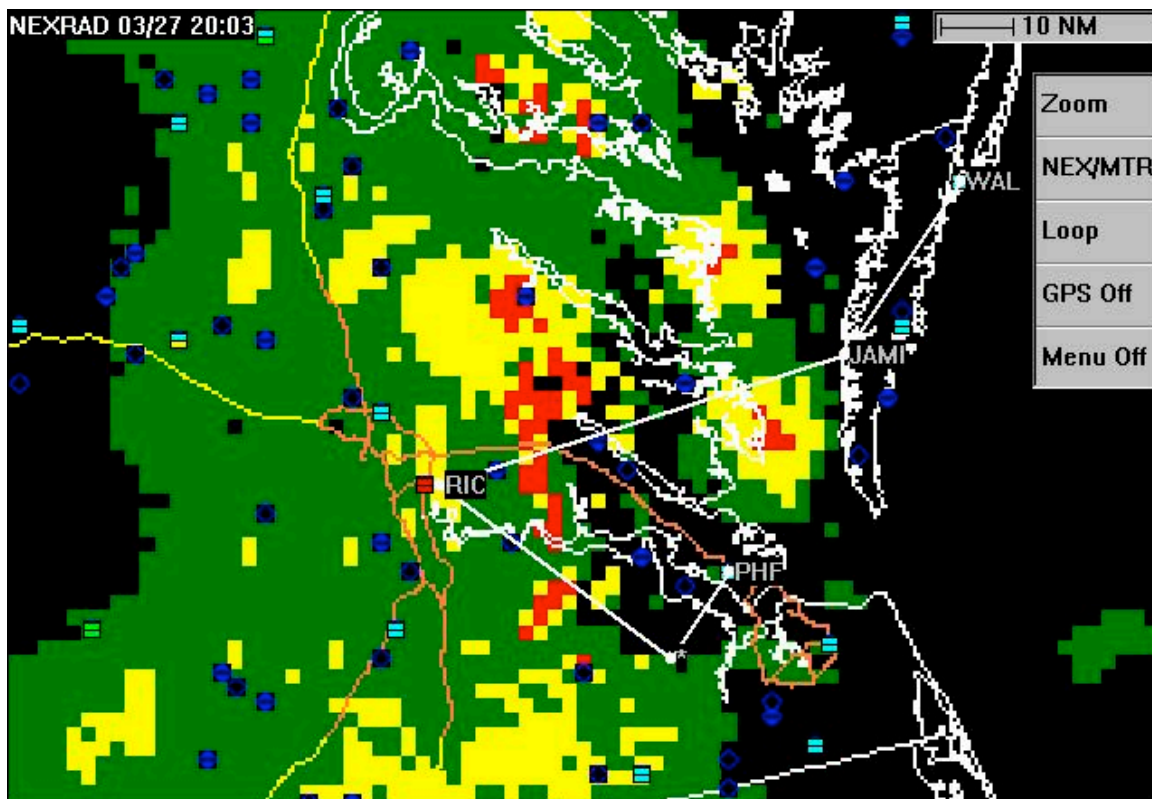
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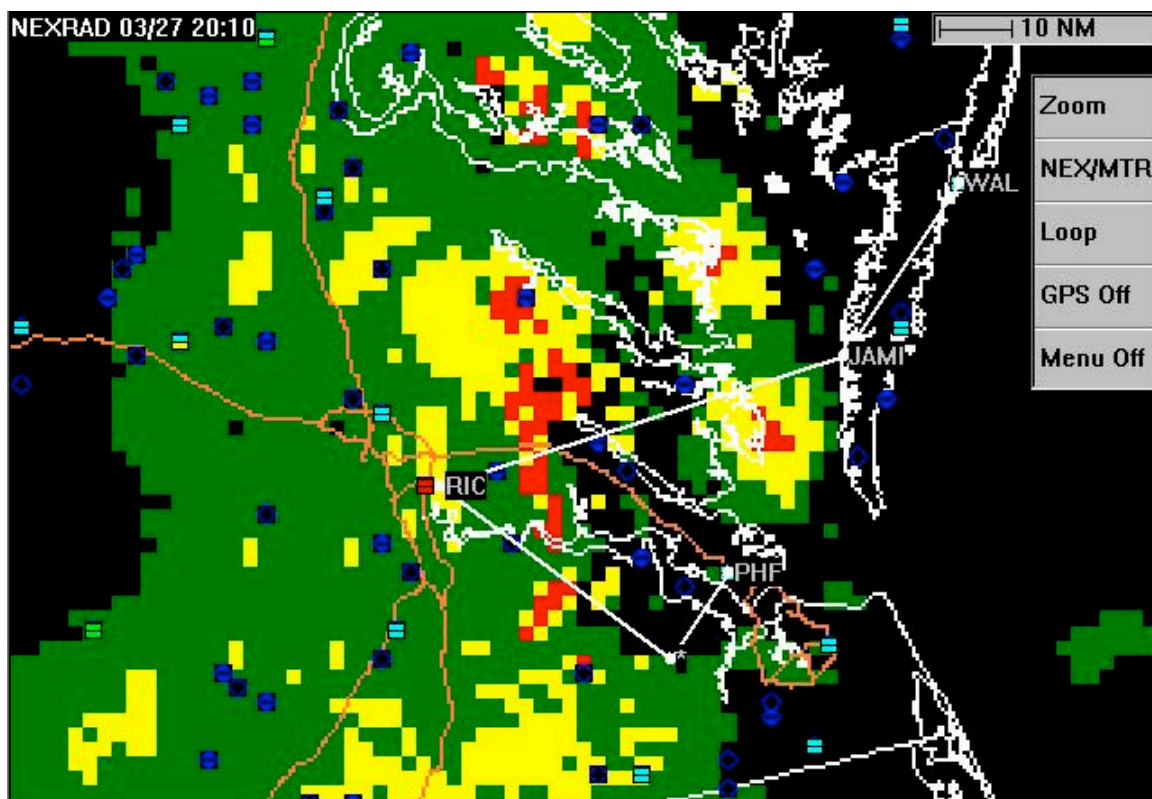
1949Z



1956Z



2003Z



2010Z

Appendix E. Description of National Convective Weather Forecast (NCWF) Product and Its Use from FAA Aeronautical Information Manual

February 21, 2002

7-1-14. National Convective Weather Forecast (NCWF)

a. Description.

1. The NCWF is an automatically generated depiction of: (1) current convection and (2) extrapolated significant current convection. It is a supplement to, but does NOT substitute for, the report and forecast information contained in Convective SIGMET's (see paragraph [7-1-6d](#)). Convection, particularly significant convection, is typically associated with thunderstorm activity.
2. The National Weather Service Aviation Weather Center (AWC) updates the NCWF based on input from the Next Generation Weather Radar (NEXRAD) and cloud-to-ground lightning data.
3. The NCWF is most accurate for long-lived mature multi-storm systems such as organized line storms. NCWF does not forecast initiation, growth or decay of thunderstorms. Therefore, NCWF tends to under-warn on new and growing storms and over-warn on dying storms. Forecast positions of small, isolated or weaker thunderstorms are not displayed.
4. The NCWF area of coverage is limited to the 48 contiguous states.

b. Attributes.

1. The NCWF is updated frequently (every 5 minutes) using the most current available data.
2. The NCWF is able to detect the existence of convective storm locations that agree very well with concurrent radar and lightning observations.
3. The NCWF is a high-resolution forecast impacting a relatively small volume of airspace rather than covering large boxed areas. The location, speeds and directions of movement of multiple convective storms are depicted individually.
4. The NCWF extrapolation forecasts are more accurate when predicting the location and size of well organized, unchanging convective storms moving at uniform speeds. The NCWF does not work well with sporadic, explosive cells developing and dissipating in minutes.
5. In displaying forecast cell locations, the NCWF does NOT distinguish among level 3 through level 6 on the NCWF hazard scale (see [TBL 7-1-3](#)).

6. The NCWF may not detect or forecast:

(a) Some embedded convection.

(b) Low-topped convection containing little or no cloud-to-ground lightning (such as may occur in cool air masses).

(c) Rapidly evolving convection.

7. The NCWF cannot provide information on specific storm hazards such as hail, high winds or tornadoes.

c. Availability and Use.

1. The NCWF is available primarily via the Internet from the AWC Aviation Digital Data Service (ADDS) at <http://adds.aviationweather.noaa.gov>. Used in conjunction with other weather products such as Convective SIGMET's, the NCWF provides additional information for convective weather avoidance and flight planning.

2. The NCWF access by Automated Flight Service Stations and their associated En Route Flight Advisory Service Facilities, Air Route Traffic Control Centers (ARTCC's) or Terminal Radar Approach Controls is planned but NOT currently available.

NOTE-

See AIM, paragraph [7-1-15](#), ATC Inflight Weather Avoidance Assistance, for further information.

d. Display Summary.

1. Existing convective hazards (based on NEXRAD and lightning data) are depicted using the color-coded 6-level NCWF hazard scale shown in TBL 7-1-3. In displaying forecast cell locations, the NCWF does NOT distinguish among level 3 through level 6.

TBL 7-1-3
NCWF Hazard Scale

Level	Color	Effect
5-6	Red	Thunderstorms may contain any or all of the following: severe turbulence, severe icing, hail, frequent lightning, tornadoes and low-level wind shear. The risk of hazardous weather generally increases with levels on the NCWF hazard scale.
3-4	Yellow Orange	
1-2	Green	

NOTE-

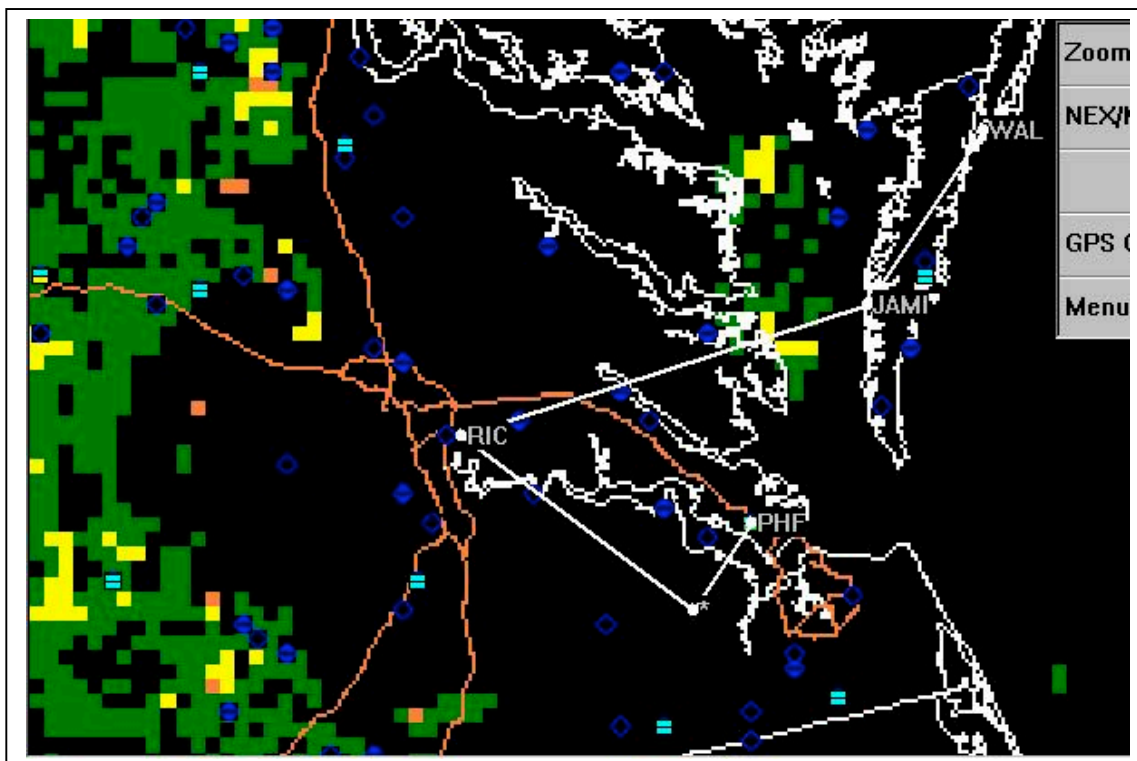
Although similar, the NCWF hazard scale levels are NOT identical to VIP levels.

REFERENCE-

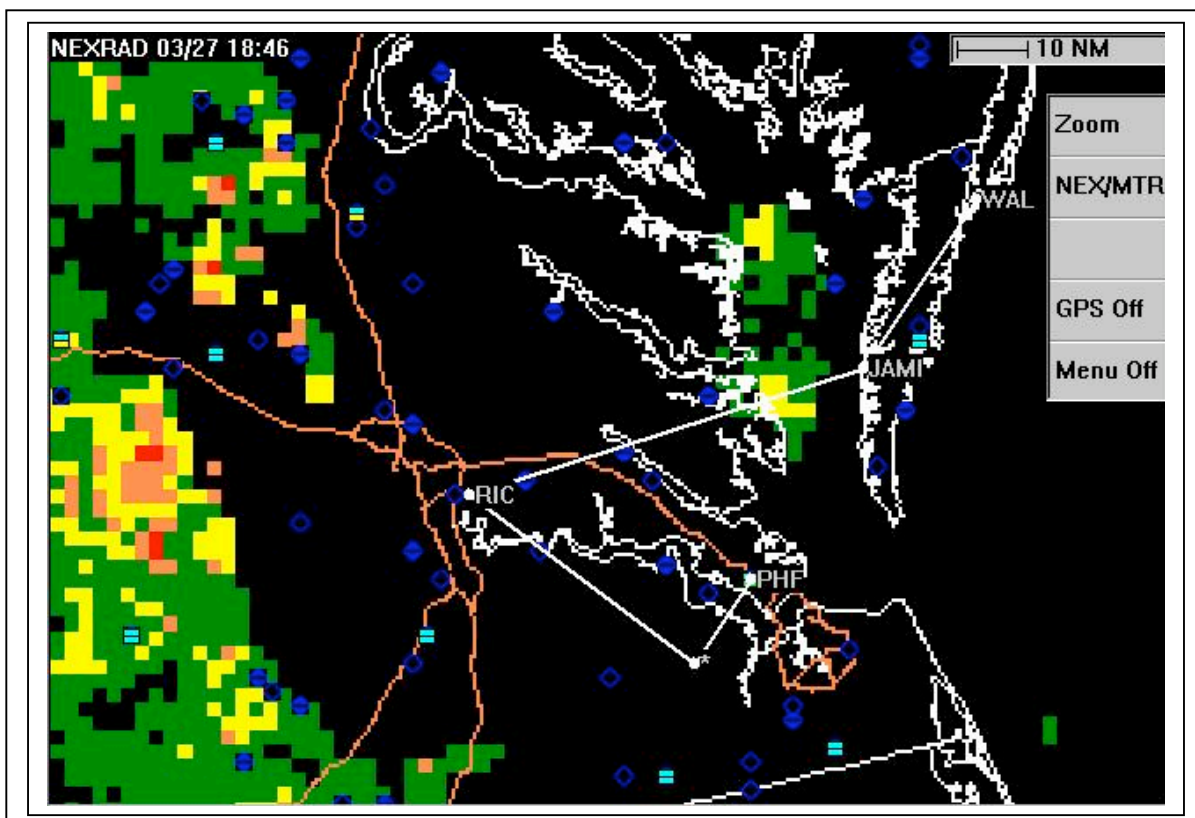
[Pilot/Controller Glossary](#) Term- Radar Weather Echo Intensity Levels.

- 2.** One-hour forecast locations of signification convection (NCWF hazard scale levels of 3 or greater) are depicted with blue polygons. Their directions of movement and storm tops are also shown.
- 3.** The Java display permits some degree of customization. Other means of viewing the NCWF may not offer these display options. Java display options include the following (see [FIG 7-1-12](#)):
 - (a)** "Current Convective Interest Grid."
 - (b)** "One-Hour Extrapolation Polygons."
 - (c)** "Previous Performance Polygons."
 - (d)** Storm speed and altitude of tops.
 - (e)** Overlays of:
 - (1)** Airport locations.
 - (2)** County boundaries.
 - (3)** ARTCC boundaries.
 - (f)** Aviation Routine Weather Reports (METAR's).
 - (g)** Unlimited customized zooms (by holding down the left mouse button and dragging to select the rectangle of coverage desired).
- 4.** The JavaScript display options include the following (see [FIG 7-1-13](#)):
 - (a)** Current convective hazard "Detection" field.
 - (b)** 1-hour extrapolation "Forecast" polygons.
 - (c)** Previous hour "Performance" polygons.
 - (d)** "2 hr Movie" loops of convective hazard detection fields (with forecast polygons included on the last frame).
 - (e)** "24 hr Movie" loops of convective hazard detection fields.
 - (f)** Zoomed views of:
 - (1)** ARTCC boundaries.
 - (2)** Certain major airports.
 - (3)** Seven geographical regions: Northwest, North Central, Northeast, Southwest, South Central, Southwest, the 48 contiguous states.
- 5.** Additional information is available via the "FYI/Help" or "i" links on the Java and JavaScript displays, respectively.

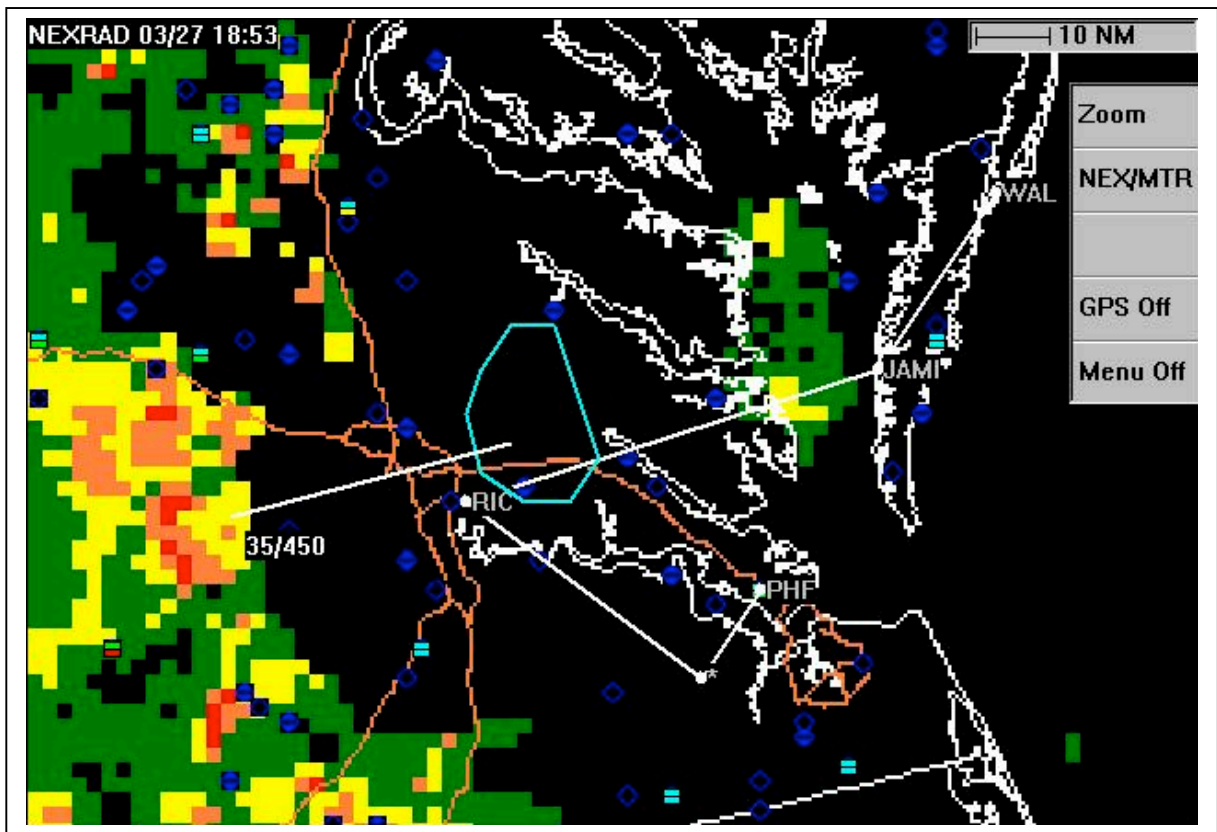
Appendix F. NCWF Product Images Used In Experiment



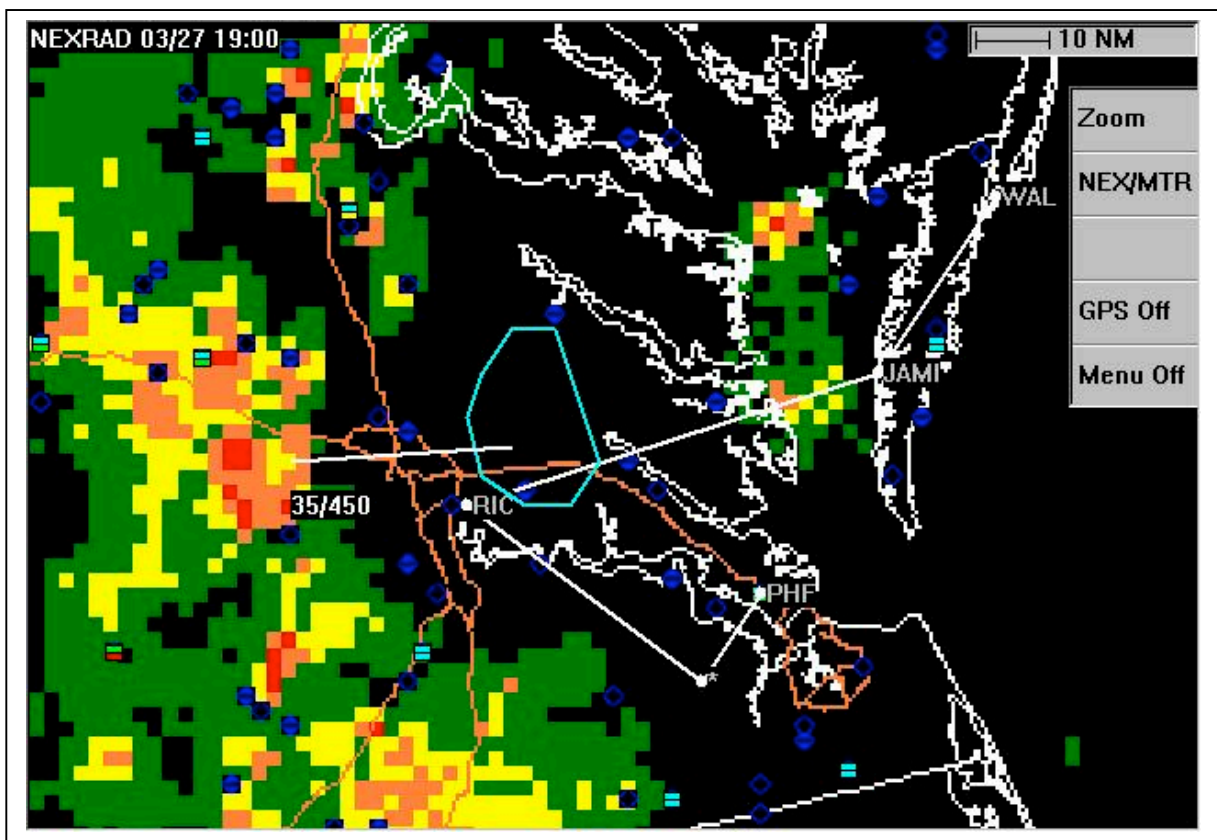
1839Z



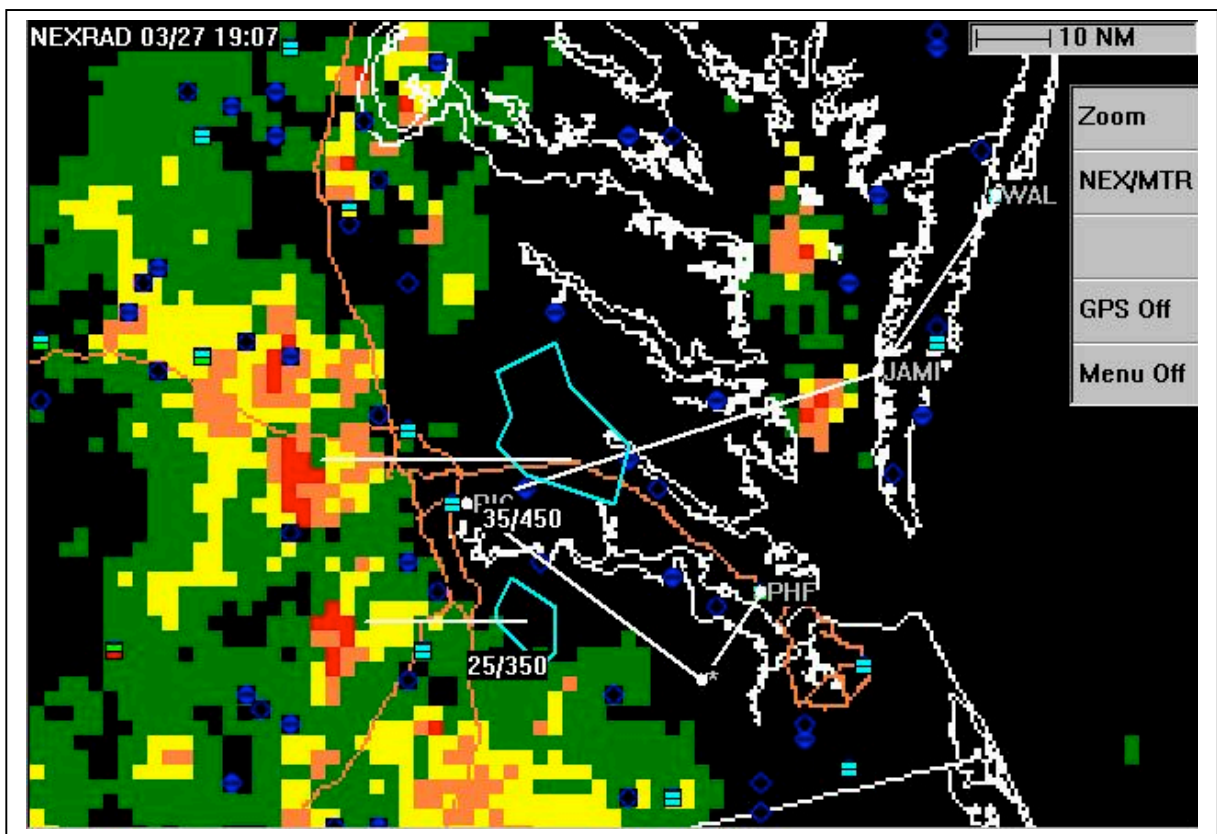
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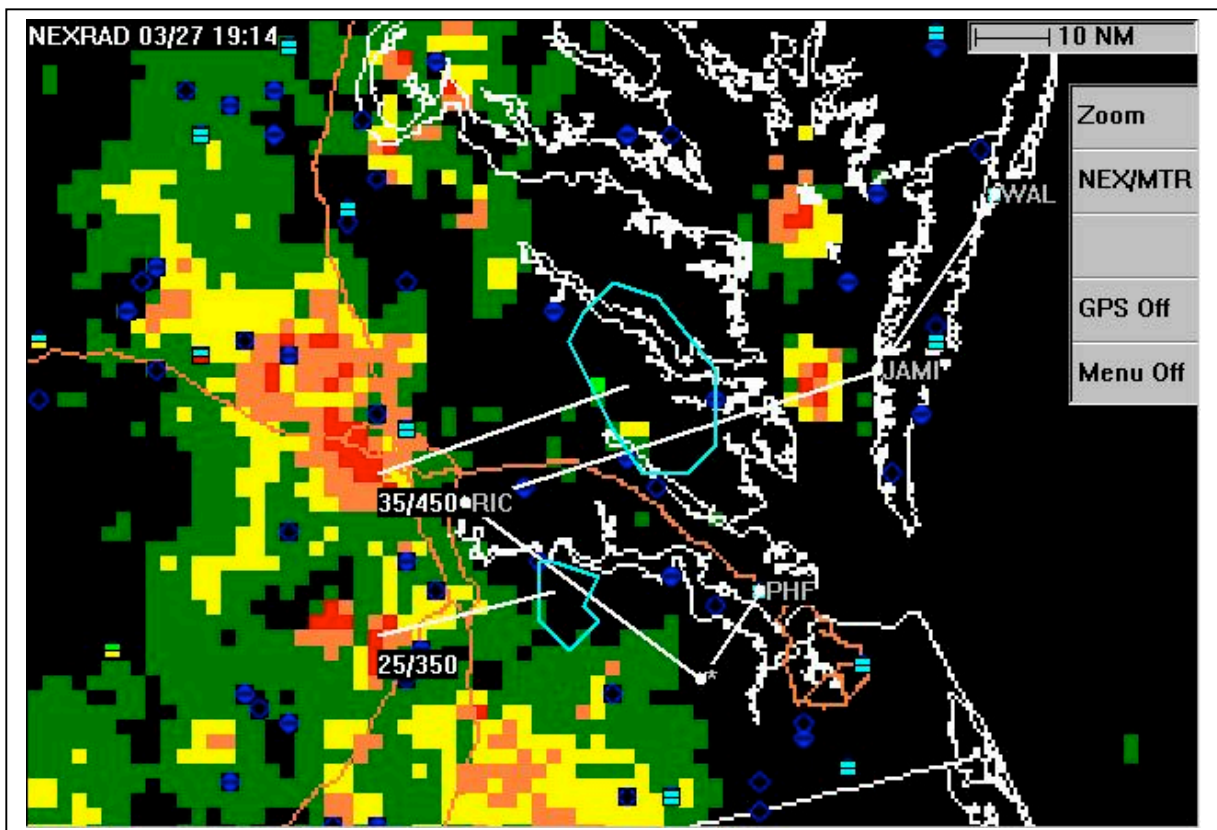
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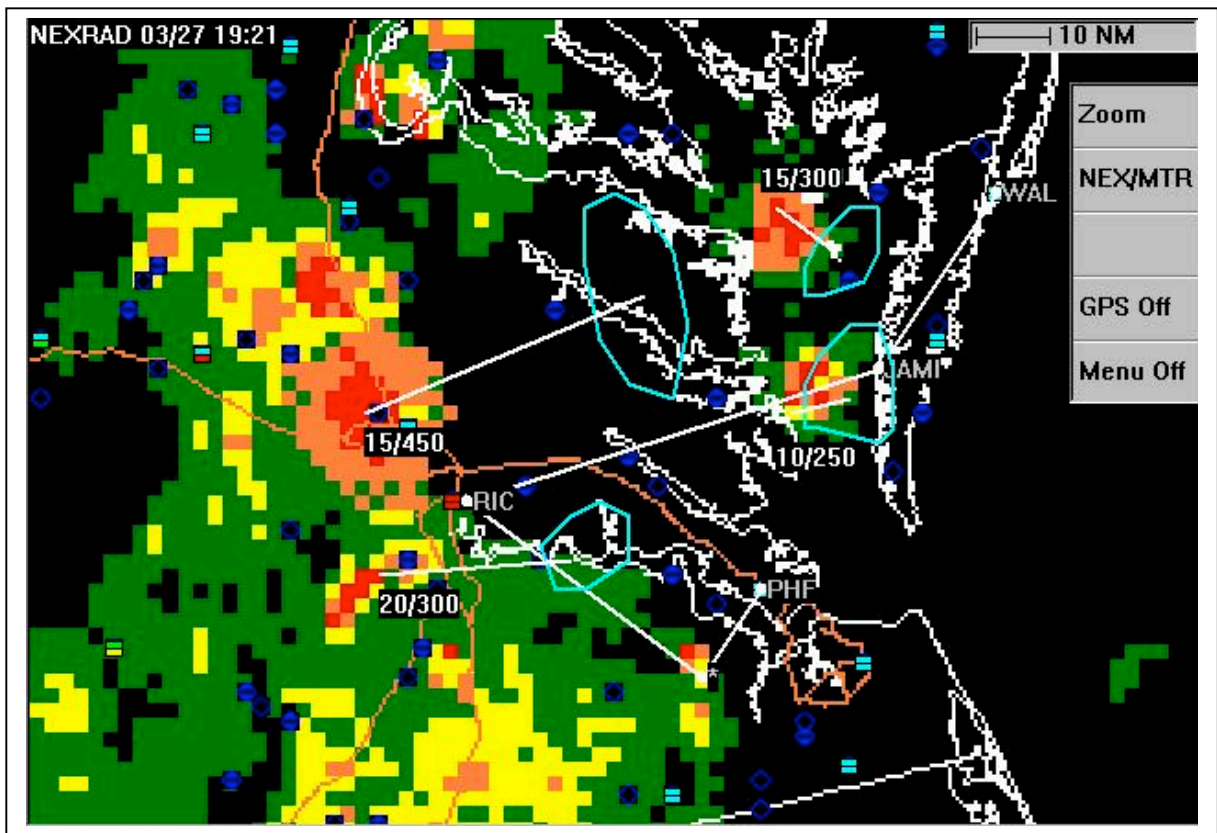
1900Z



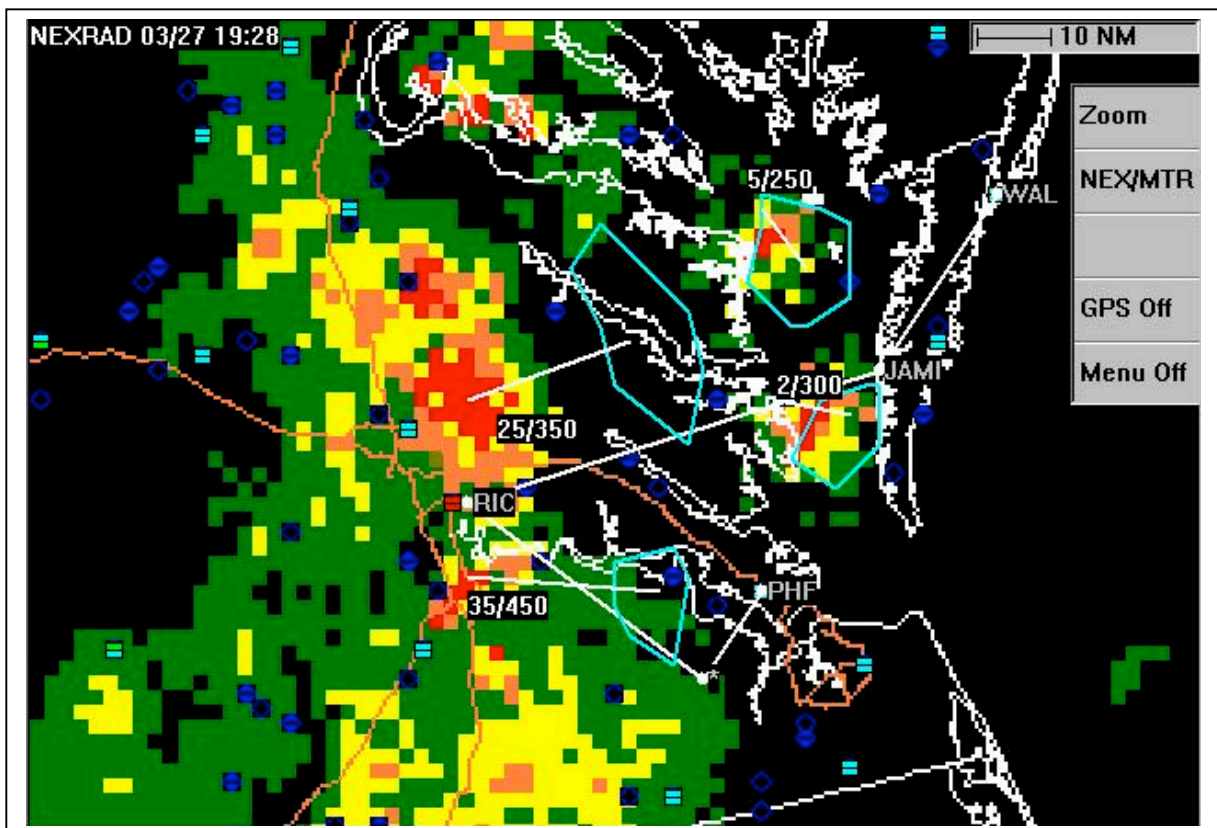
1907Z



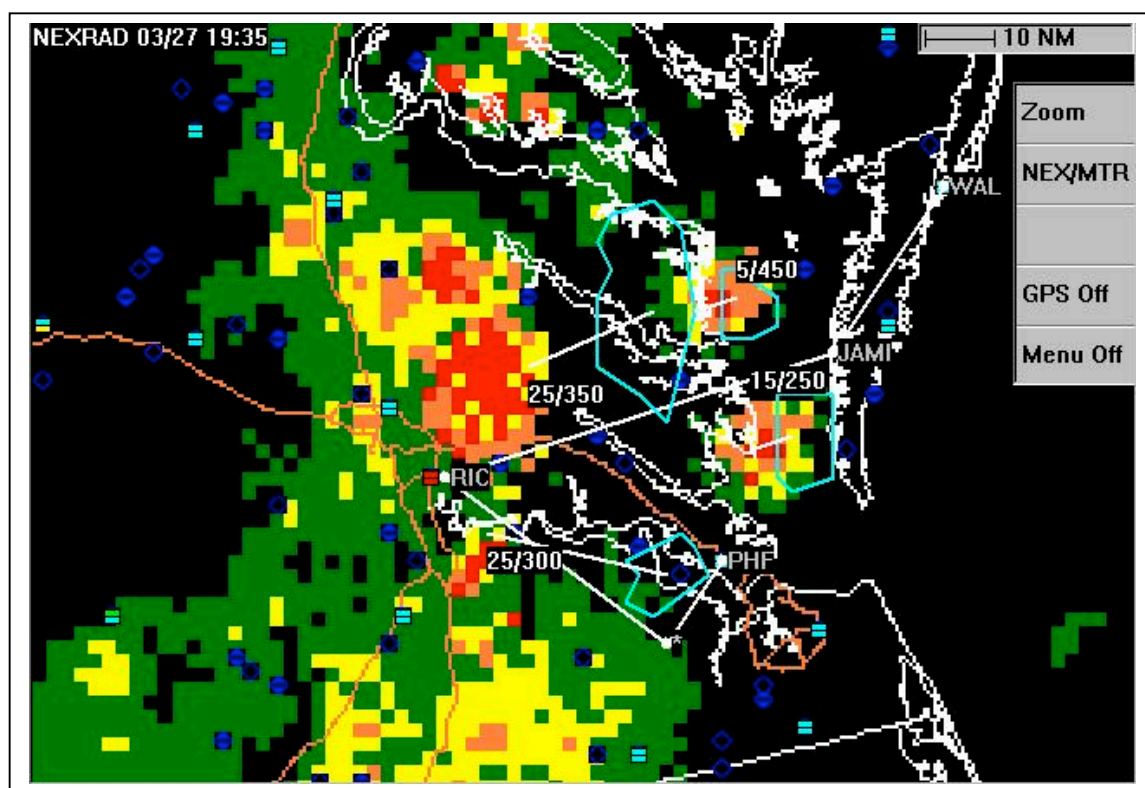
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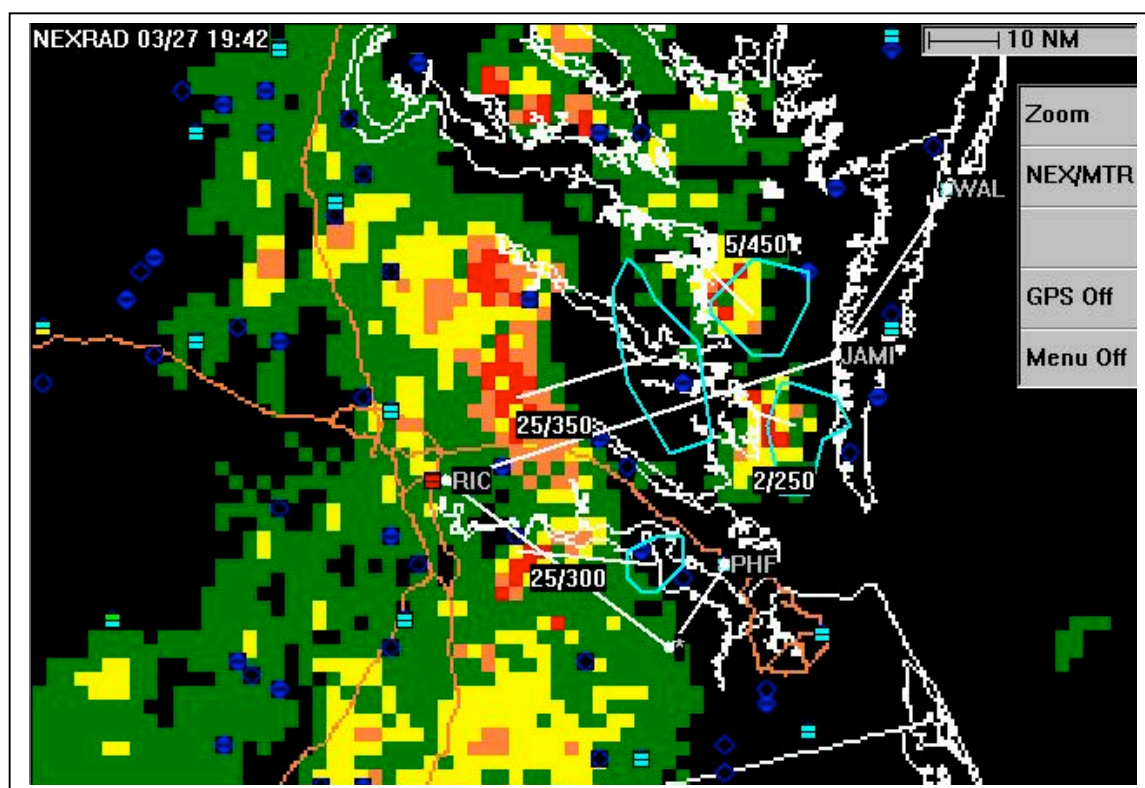
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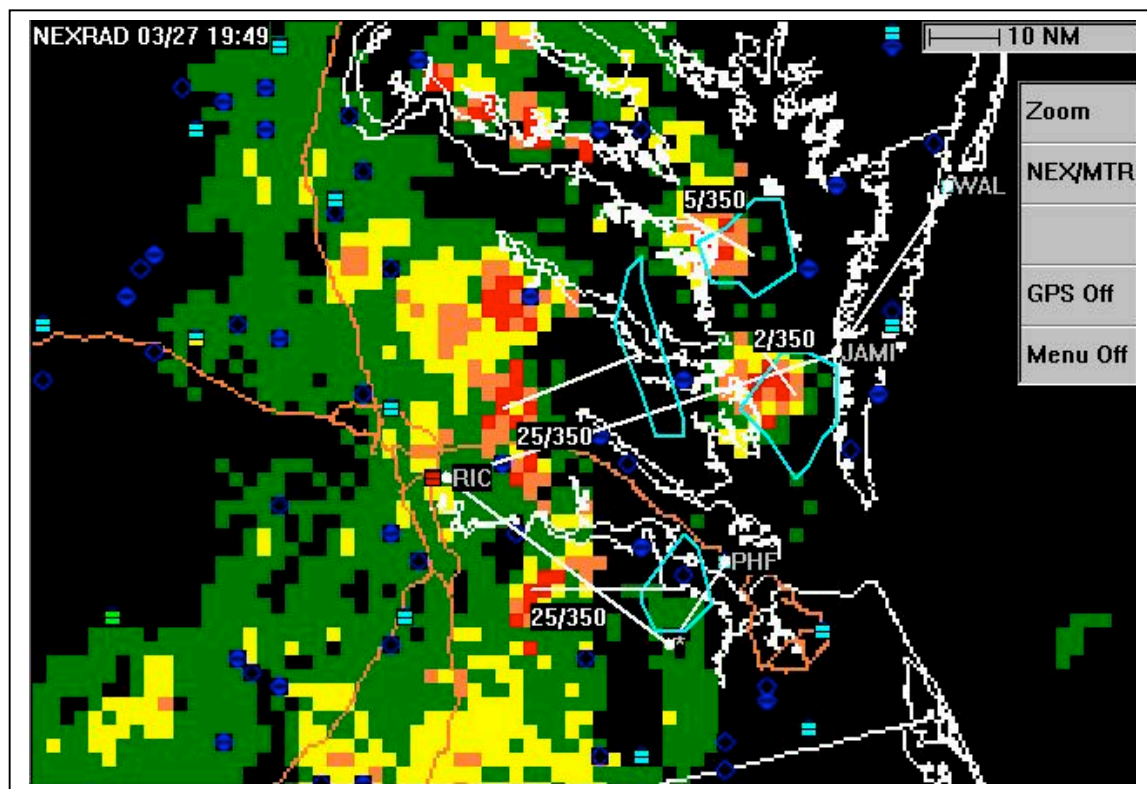
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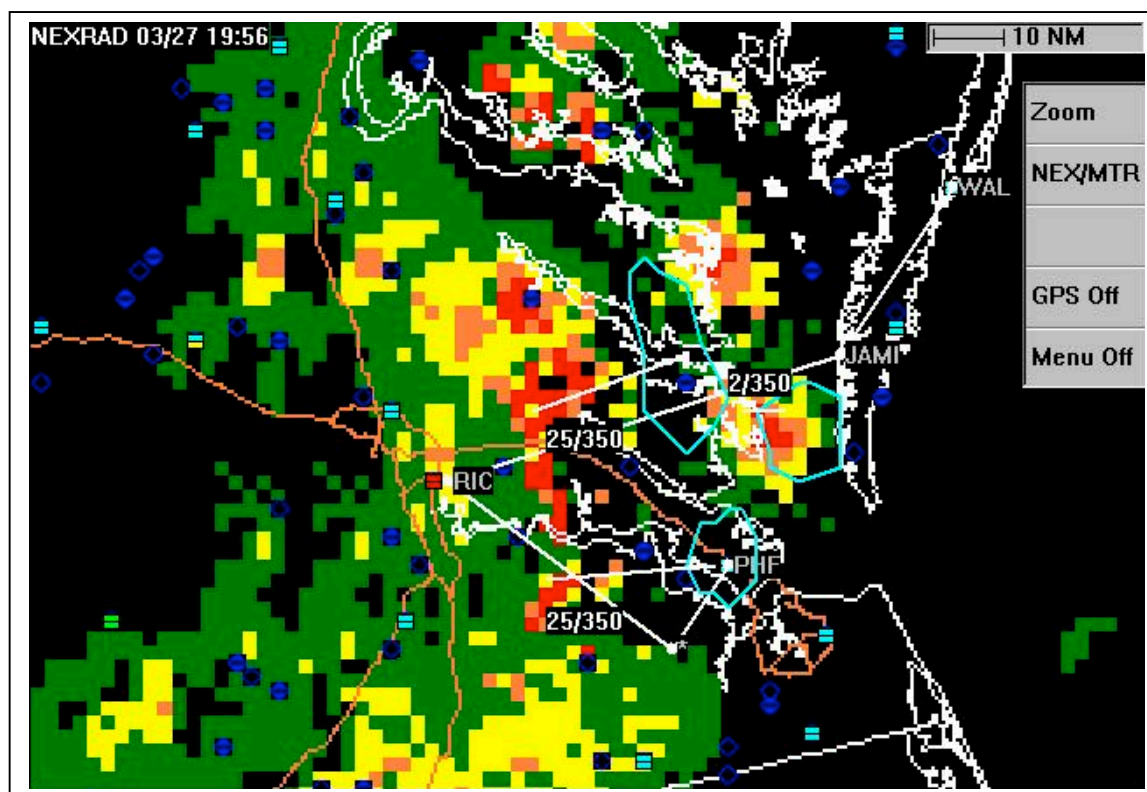
1935Z



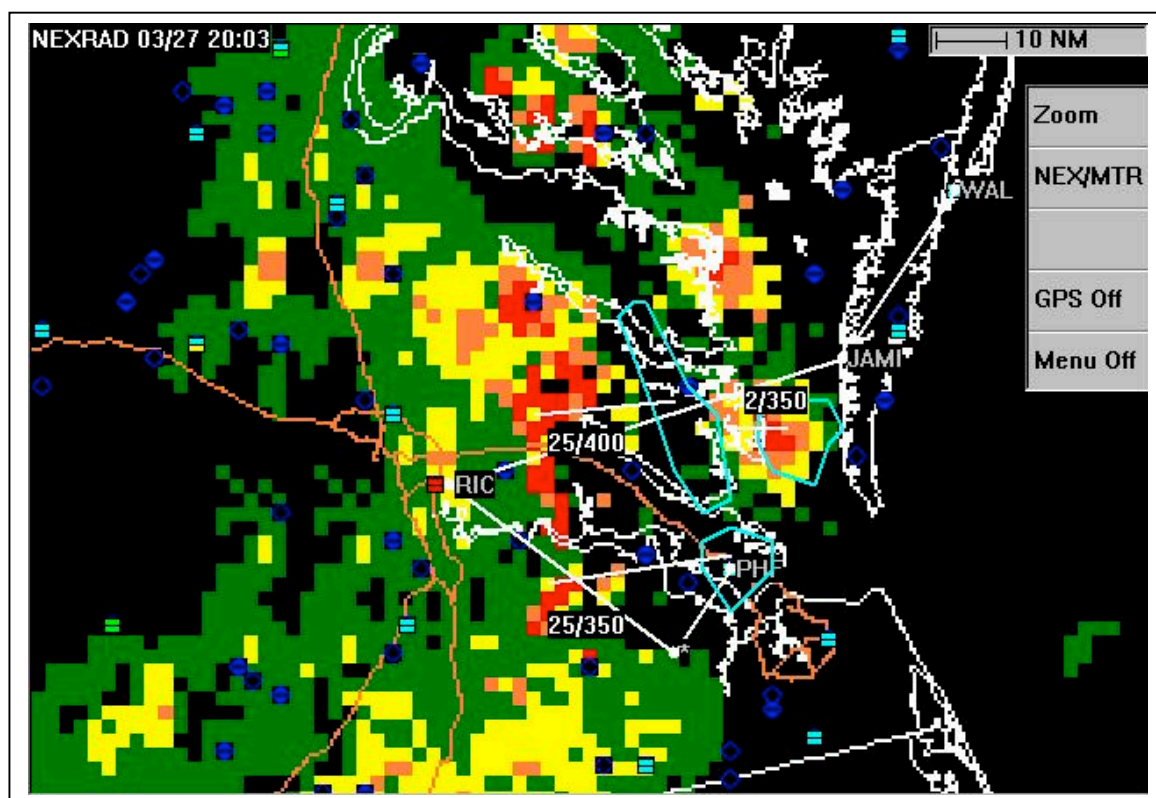
1942Z



1949



1956Z

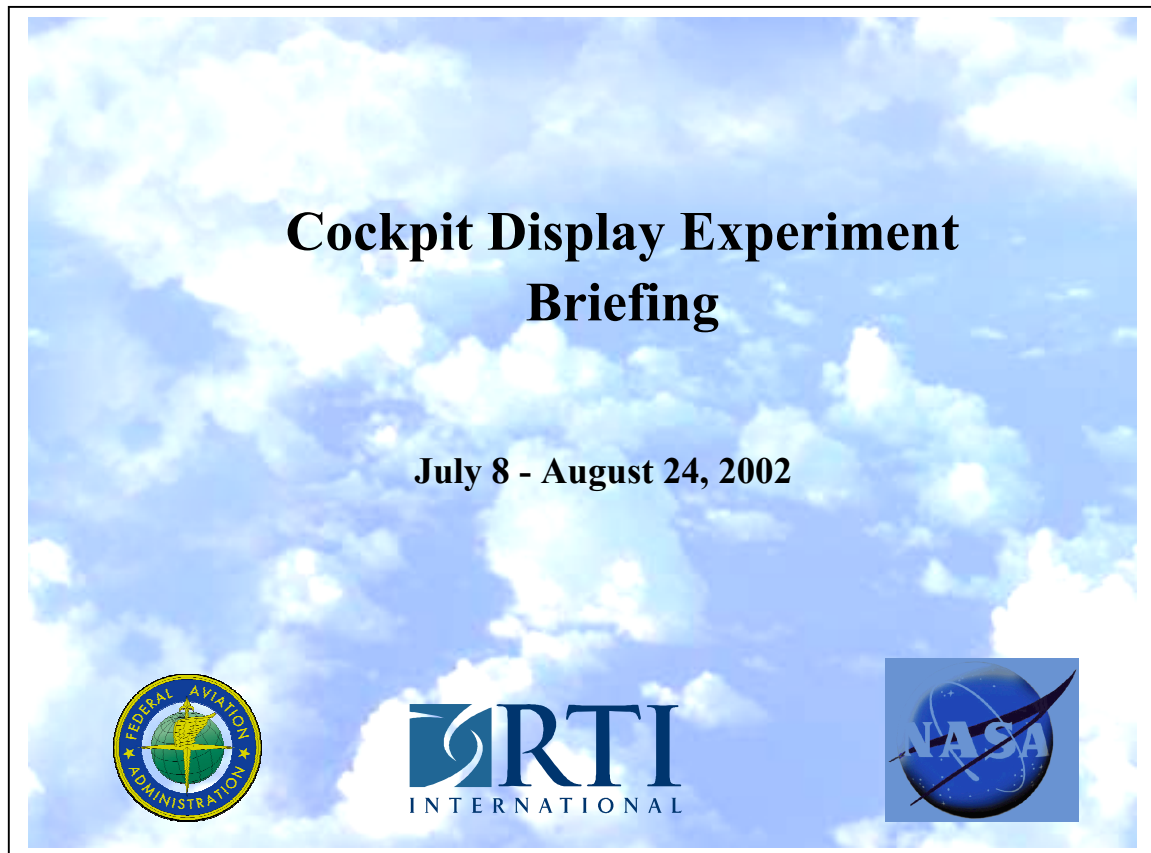


2003Z

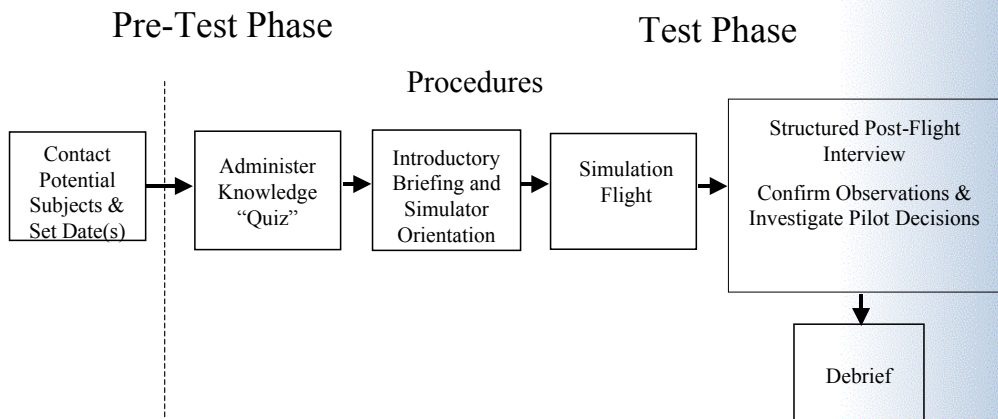
Appendix G. Cockpit Weather Experiment III -- Subject Pilot Familiarization Briefings

- Control Pilot Group Briefing
- NEXRAD Image Looping Display Group Briefing
- NCWF Product Display Group Briefing

Control Pilot Group Familiarization Briefing



Experiment Procedure



Today's Flight Mission

Situation

- **Three pilots have been friends since their military flying tours.**
- **One of the friends lives in Newport News, VA, and will be flying his aircraft to Wallops Island for the wedding of one of the other friends.**
- **The friend who will be flying the aircraft from Newport News - Williamsburg Airport has agreed to stop in Richmond enroute to Wallops Island to pick up the third friend (who is to be the best man) in Richmond.**

Subject Pilot Schedule

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



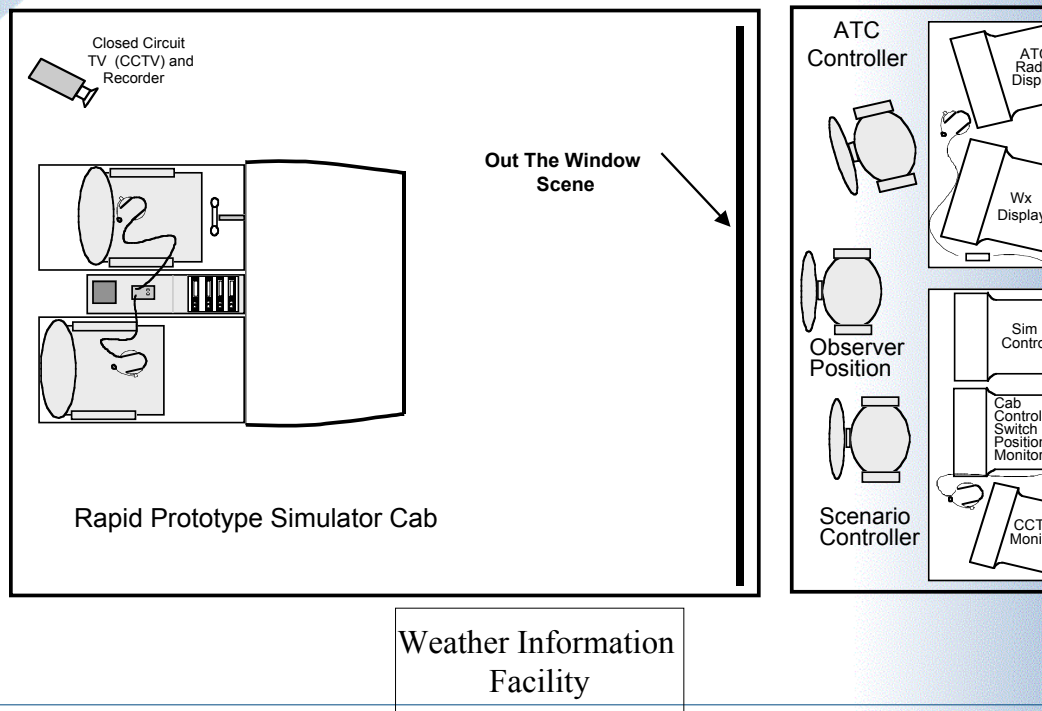
Today's Mission

(Continued)

- **The two friends who are traveling have planned their flight so as to attend a Friday night wedding rehearsal and dinner party. The rehearsal starts at 1700 hours local.**
- **The pilot is delayed at work due to an important meeting, and the planned departure time from the Newport News airport has slipped to 1500 hours local.**
- **There is not sufficient time to drive from Newport News to Wallops and make the rehearsal.**

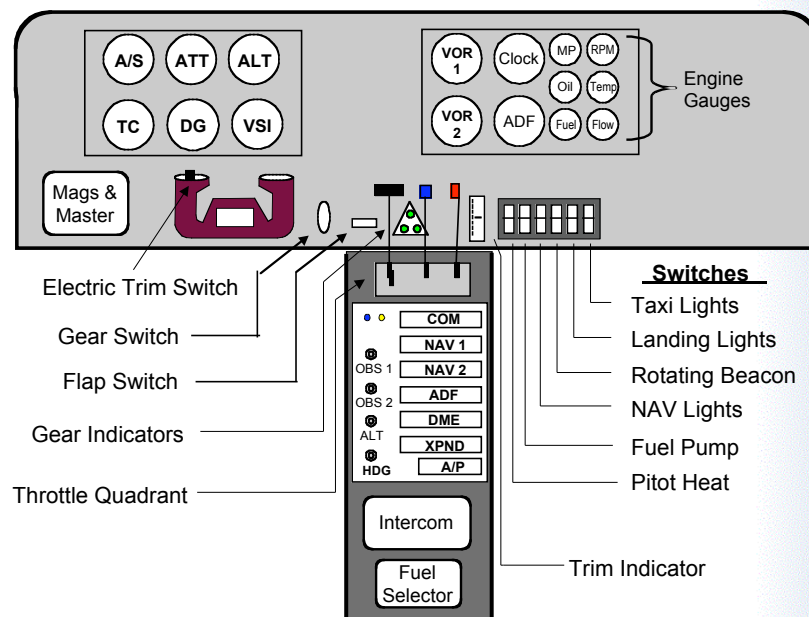


Simulation Hardware Configuration



DTI

Simulation Cockpit 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

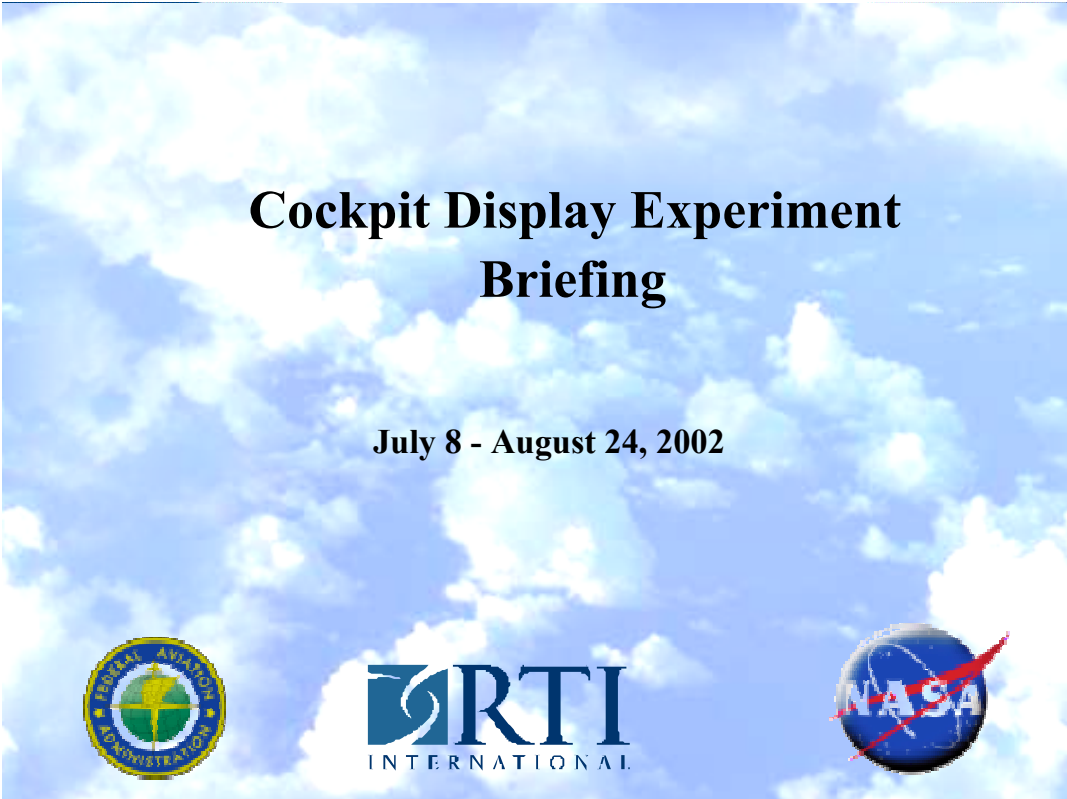
Approach



Simulation Cockpit Radio Stack



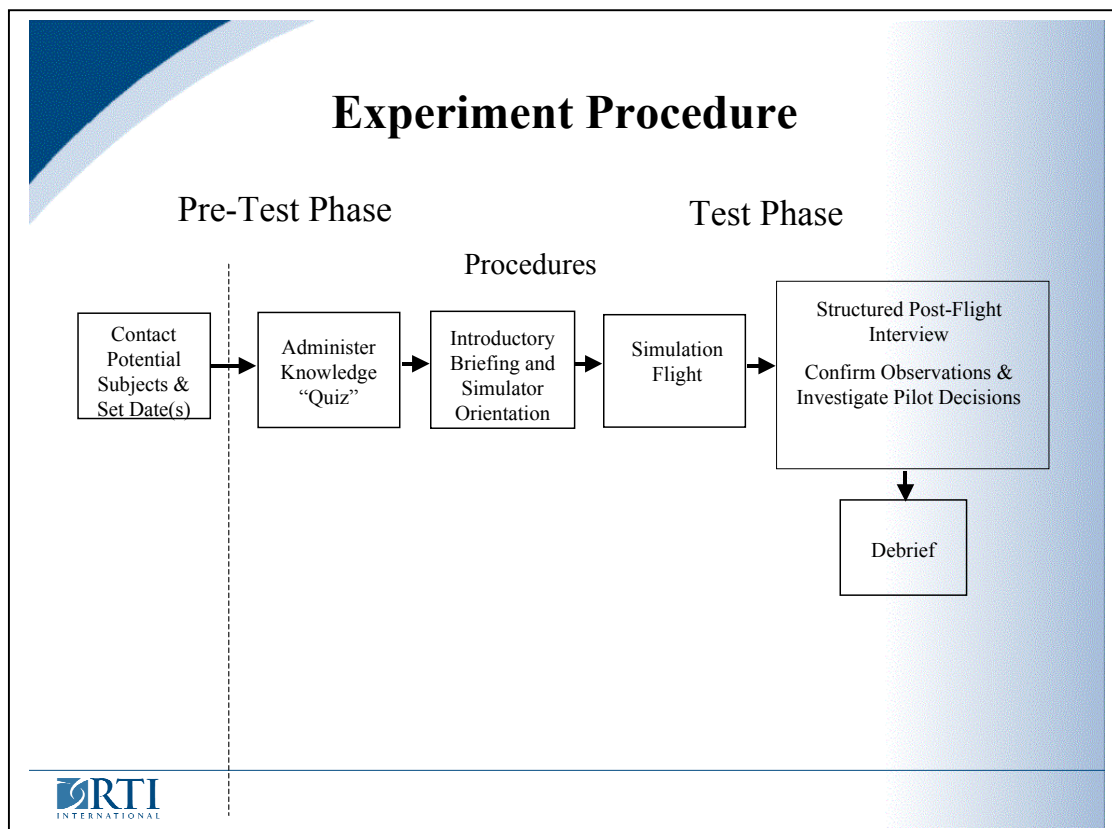
NEXRAD Image Looping Display Group Briefing



Cockpit Display Experiment Briefing

July 8 - August 24, 2002

The slide features a background of a blue sky with white clouds. At the bottom, there are three logos: the Federal Aviation Administration (FAA) logo on the left, the IRTI International logo in the center, and the NASA logo on the right.



Subject Pilot Schedule

<u>Time</u>	<u>Activity</u>
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

- **Three pilots have been friends since their military flying tours.**
- **One of the friends lives in Newport News, VA, and will be flying his aircraft to Wallops Island for the wedding of one of the other friends.**
- **The friend who will be flying the aircraft from Newport News - Williamsburg Airport has agreed to stop in Richmond enroute to Wallops Island to pick up the third friend (who is to be the best man) in Richmond.**

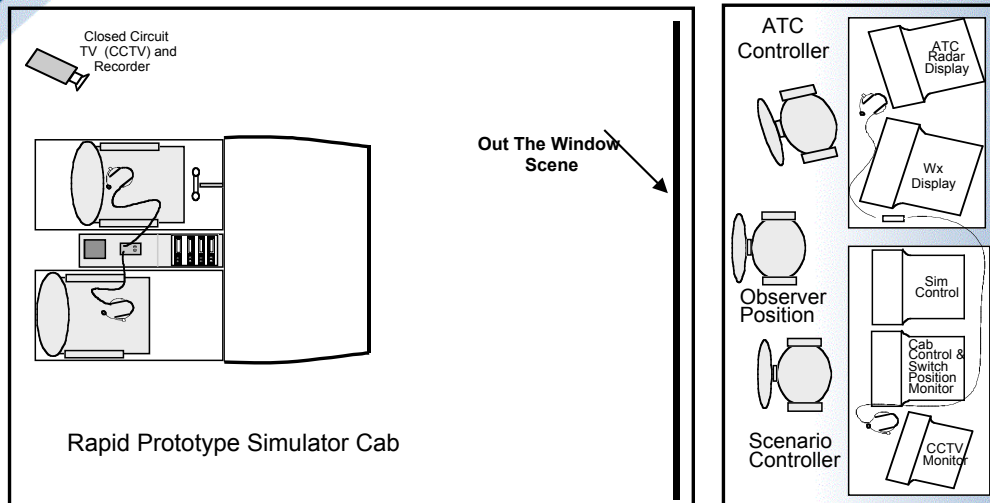


Today's Mission (Continued)

- The two friends who are traveling have planned their flight so as to attend a Friday night wedding rehearsal and dinner party. The rehearsal starts at 1700 hours local.
- The pilot is delayed at work due to an important meeting, and the planned departure time from the Newport News airport has slipped to 1500 hours local.
- There is not sufficient time to drive from Newport News to Wallops and make the rehearsal.



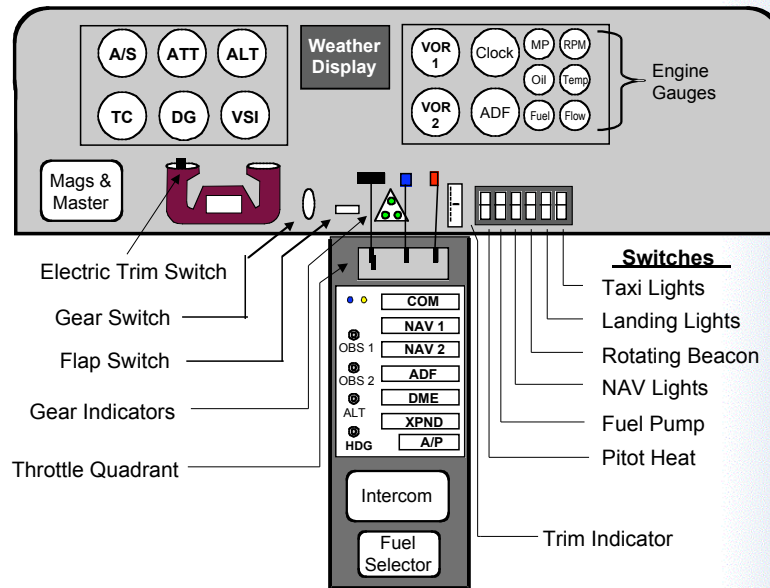
Simulation Hardware Configuration



Weather Information
Facility



Simulation Cockpit Configuration



Simulation Cockpit Radio Stack

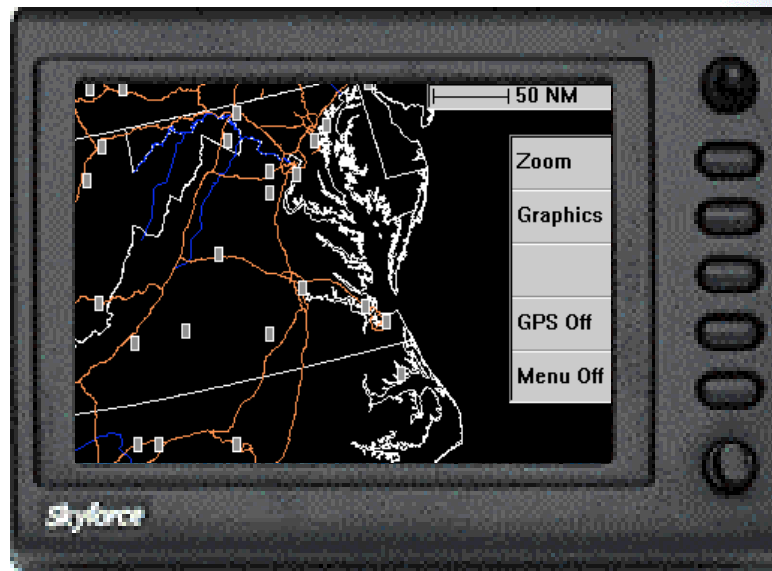
Simulation Cockpit Configuration

Weather Information Sources

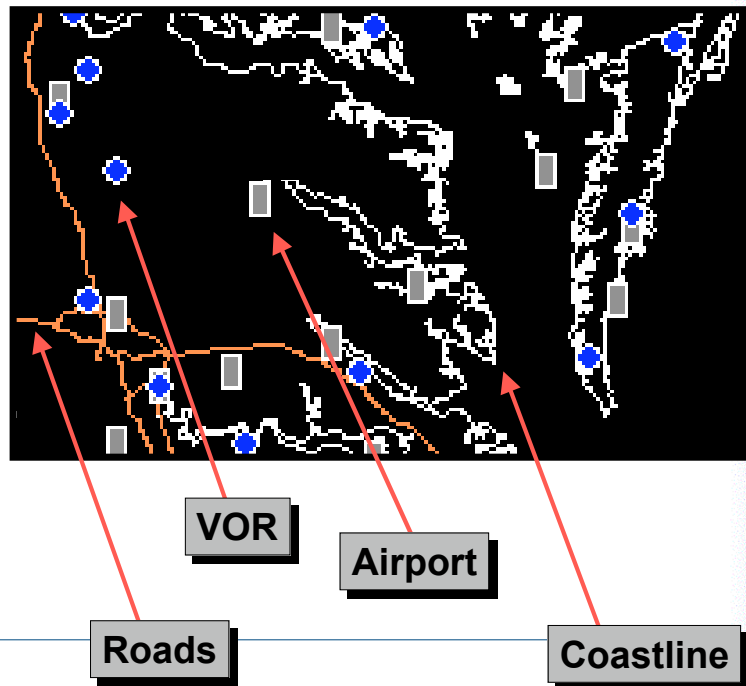
- ATIS
- Flight Service Station
- Flight Watch
- Virginia AWOS/ASOS Reports via radio
- Air Traffic Control (IAW normal NAS procedures)
 - Tower
 - Departure
 - Enroute
 - Approach
- Data Link Cockpit Weather Information Display



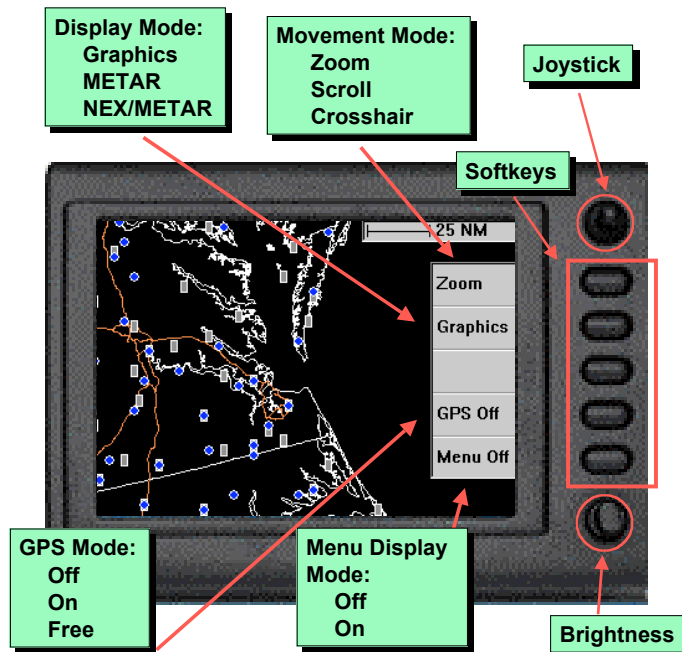
Cockpit Weather Display



Graphic Symbols



Display Modes/Functions



METAR Display



ORTI
INTERNATIONAL

Graphical METAR Codes

CEILING
Red – Less than 500 ft.
Yellow – 500 to 1000 ft.
Green – 1000 to 3000 ft.
Blue – More than 3000 ft.

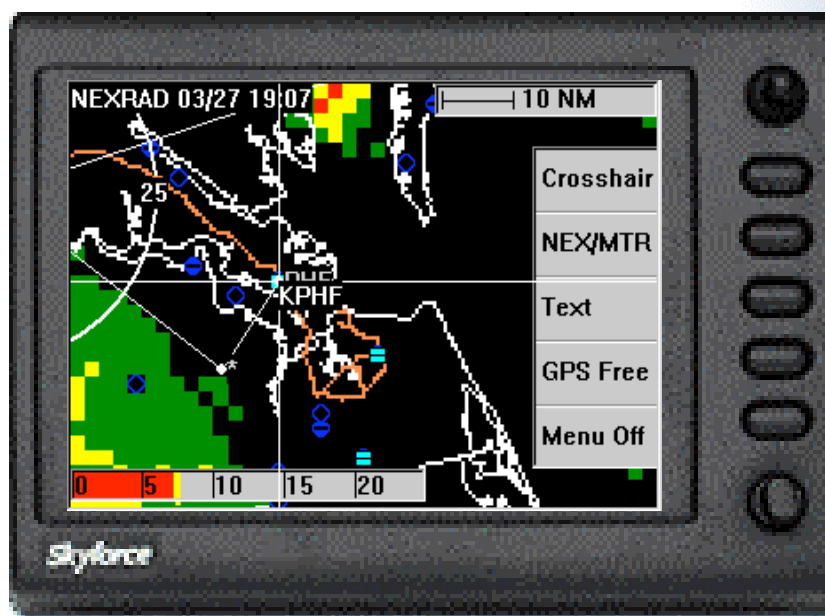
Red – Low IFR
Yellow – IFR
Green – Marginal VFR
Blue – Unlimited



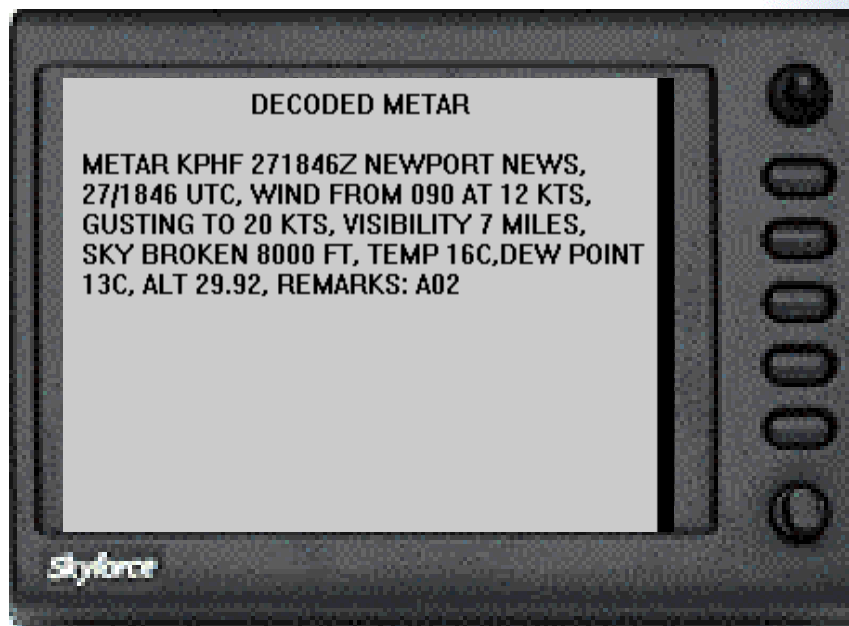
VISIBILITY
Red – Less than 1 mi.
Yellow – 1 to 3 mi.
Green – 3 to 5 mi.
Blue – More than 5 mi.

ORTI
INTERNATIONAL

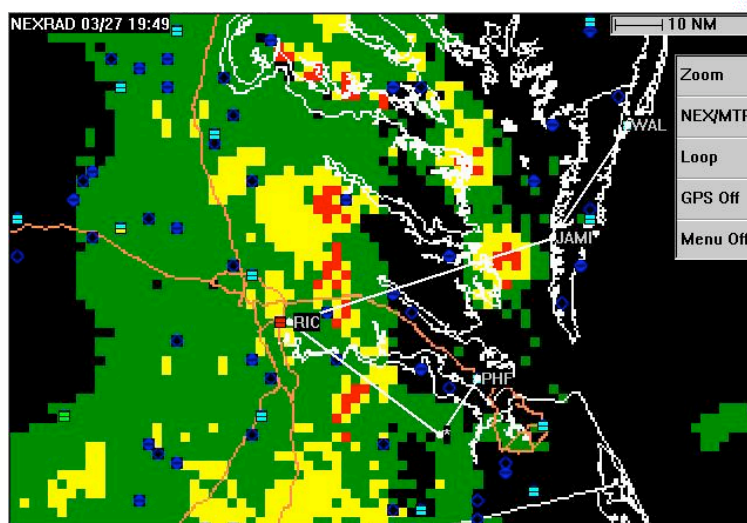
METAR Selection



METAR Text



NEXRAD Intensity Levels

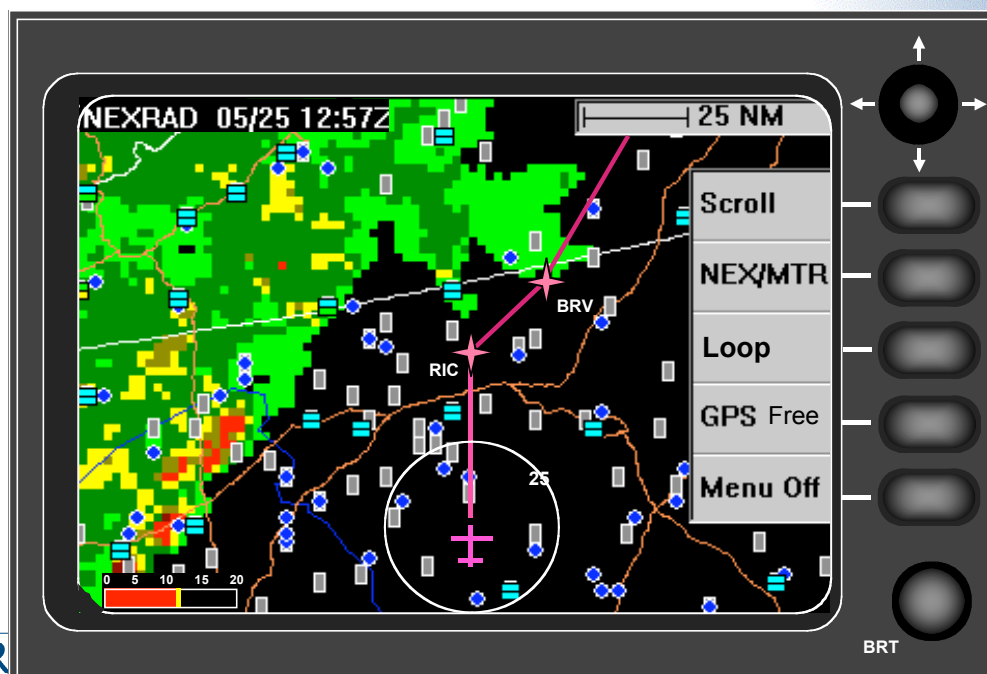


NEXRAD Intensity Levels:

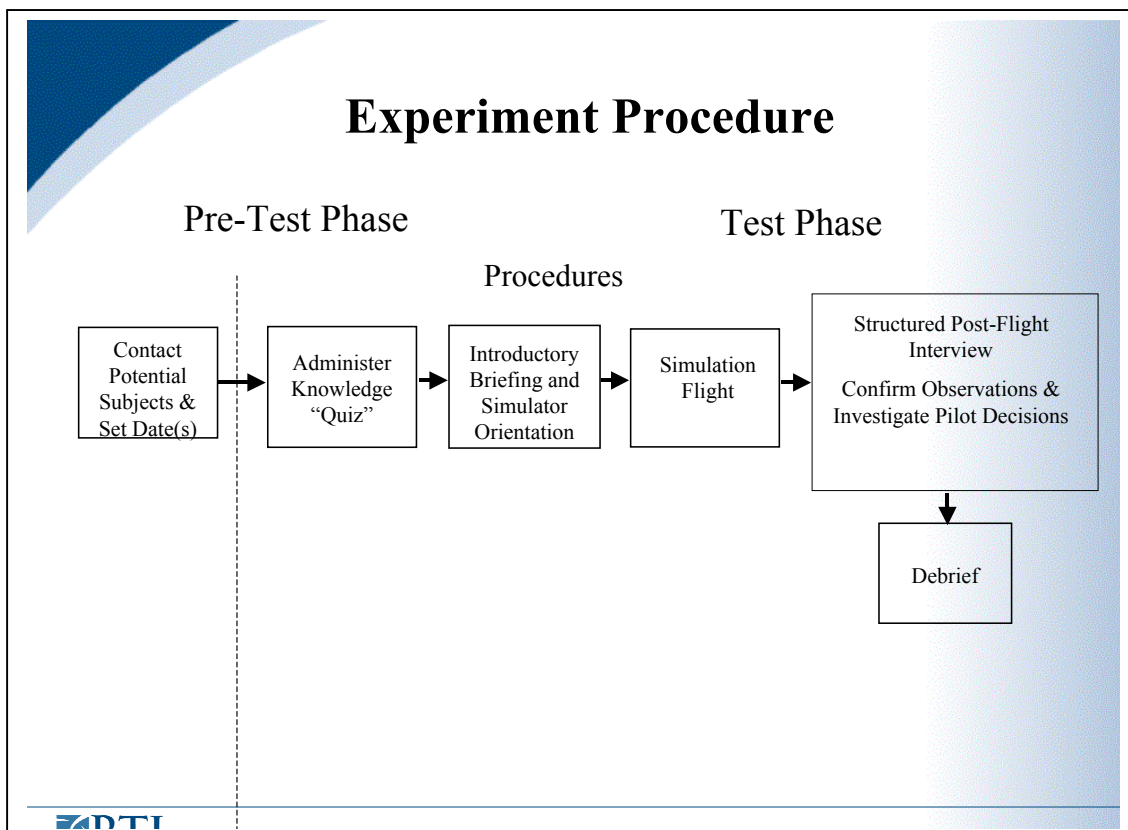
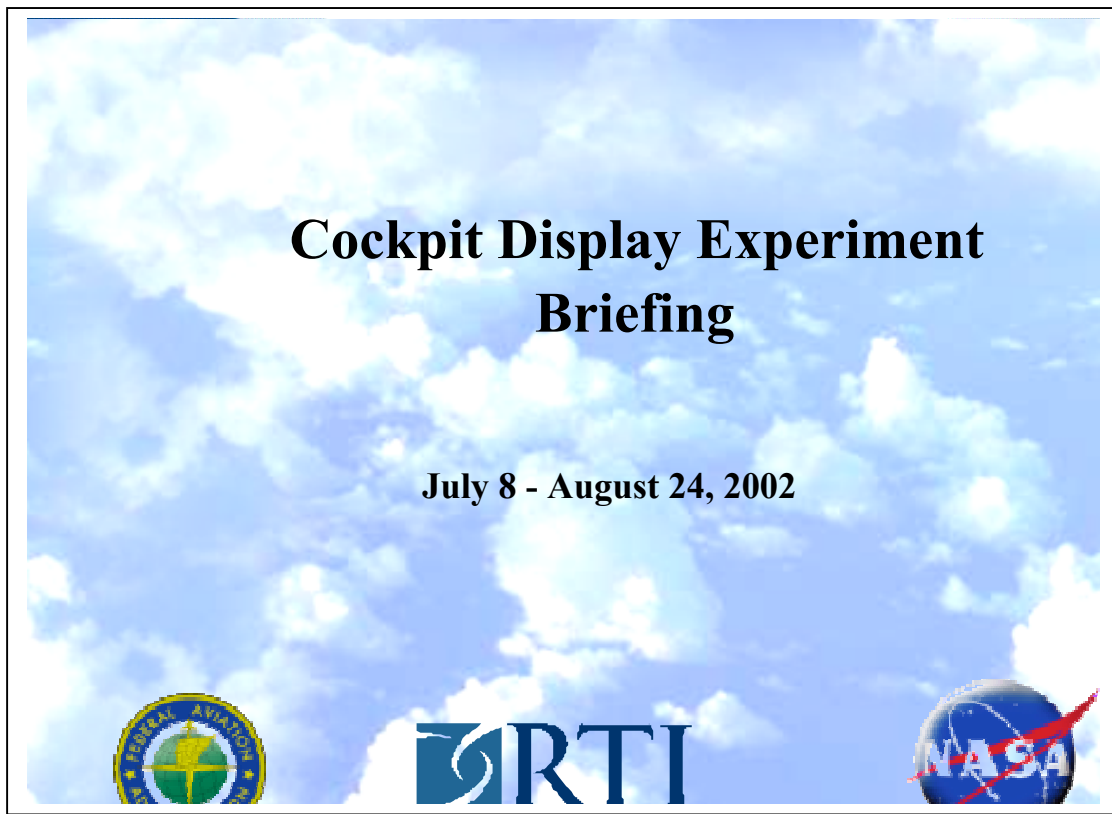
Green	Light
Yellow	
Red	Severe

↓

NEXRAD Image Looping



NCWF Display Group Familiarization Briefing



Subject Pilot Schedule

<u>Time</u>	<u>Activity</u>
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

- **Three pilots have been friends since their military flying tours.**
- **One of the friends lives in Newport News, VA, and will be flying his aircraft to Wallops Island for the wedding of one of the other friends.**
- **The friend who will be flying the aircraft from Newport News - Williamsburg Airport has agreed to stop in Richmond enroute to Wallops Island to pick up the third friend (who is to be the best man) in Richmond.**

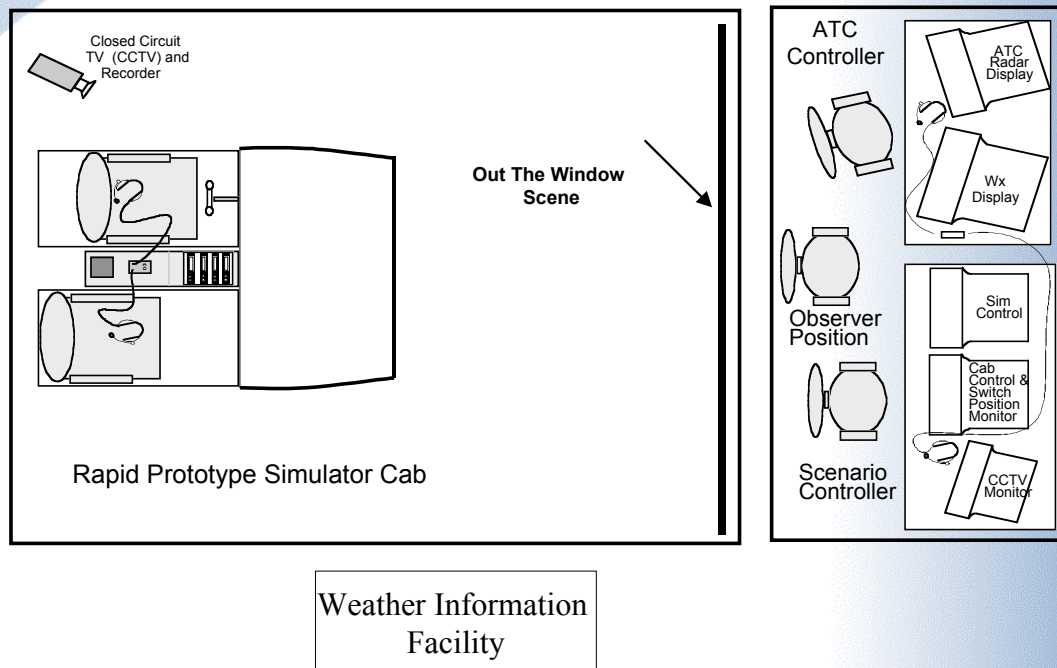


Today's Mission (Continued)

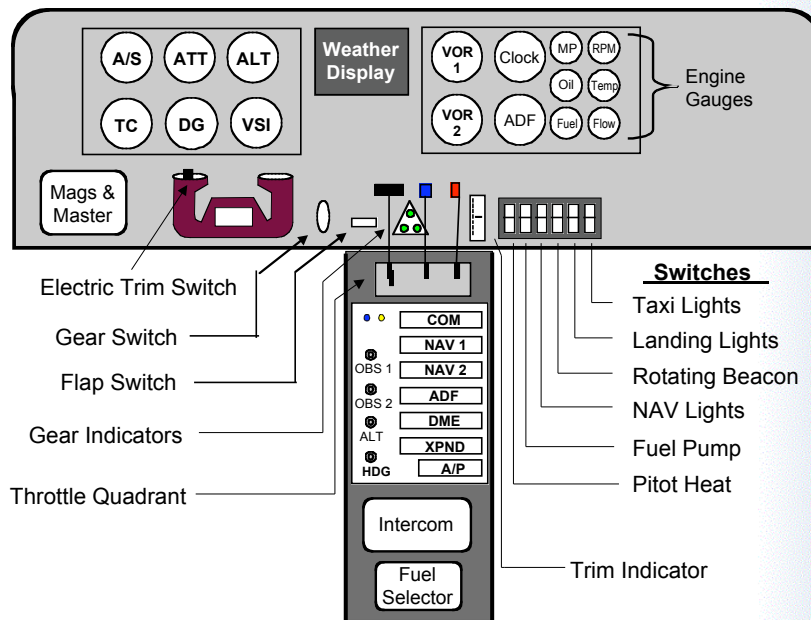
- The two friends who are traveling have planned their flight so as to attend a Friday night wedding rehearsal and dinner party. The rehearsal starts at 1700 hours local.
- The pilot is delayed at work due to an important meeting, and the planned departure time from the Newport News airport has slipped to 1500 hours local.
- There is not sufficient time to drive from Newport News to Wallops and make the rehearsal.



Simulation Hardware Configuration



Simulation Cockpit Configuration



Simulation Cockpit Radio Stack

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

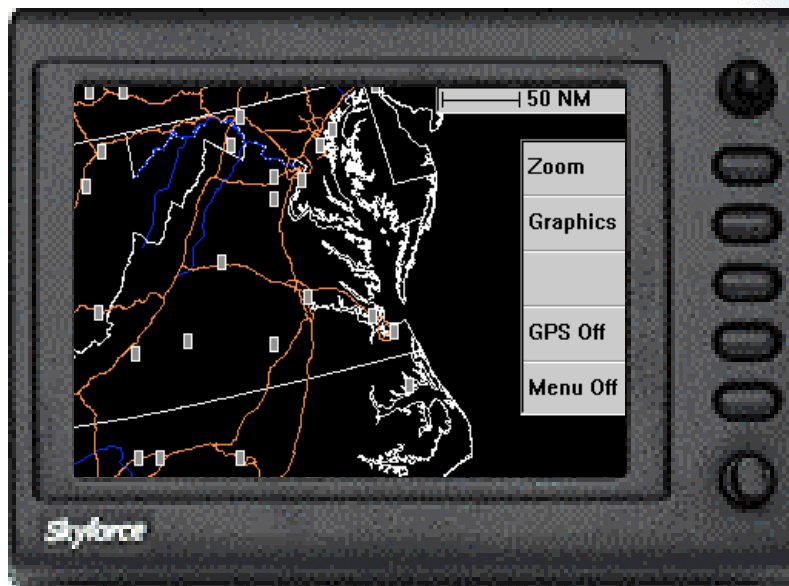
Enroute

Approach

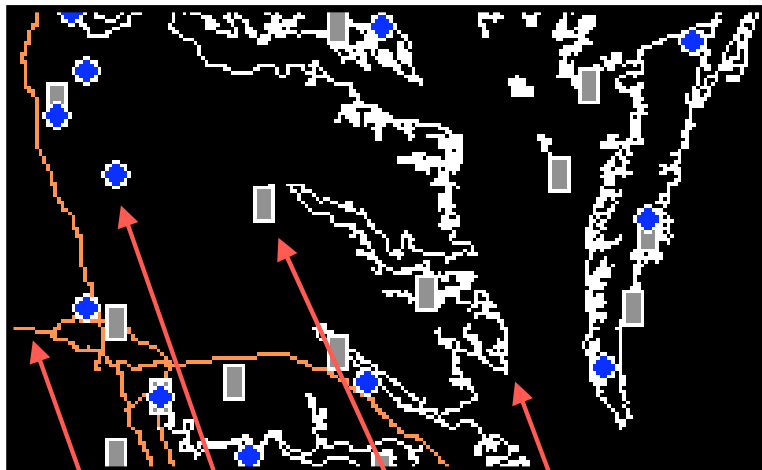
- Data Link Cockpit Weather Information Display



Cockpit Weather Display



Graphic Symbols



VOR

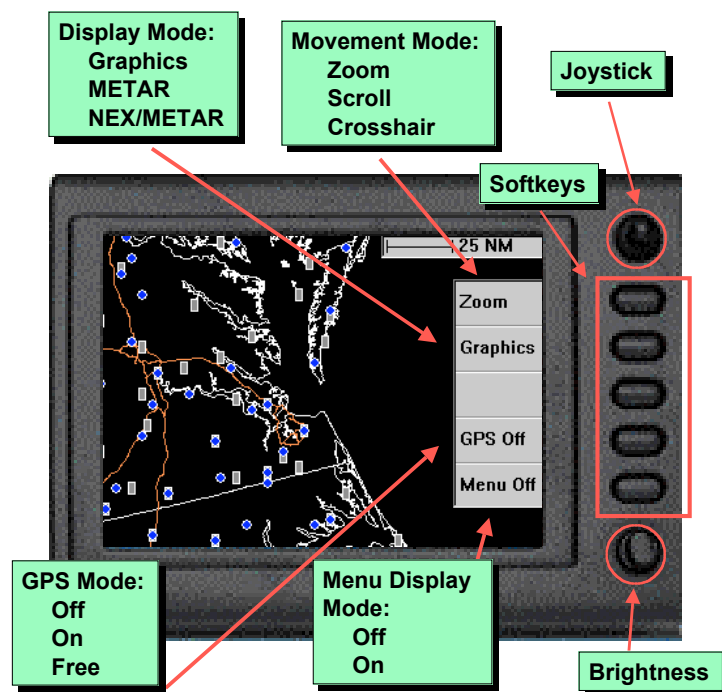
Airport

Roads

Coastline



Display Modes/Functions



METAR Display



Graphical METAR Codes

CEILING
Red – Less than 500 ft.
Yellow – 500 to 1000 ft.
Green – 1000 to 3000 ft.
Blue – More than 3000 ft.

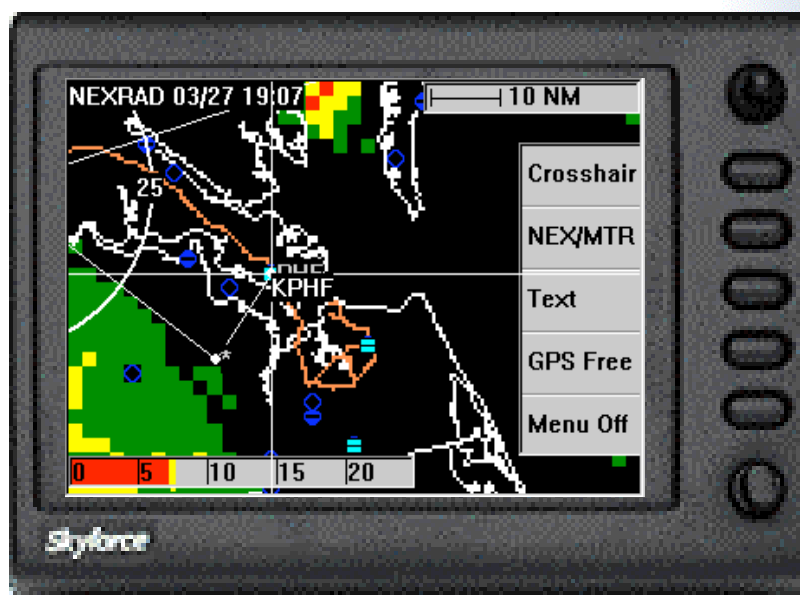
Red – Low IFR
Yellow – IFR
Green – Marginal VFR
Blue – Unlimited



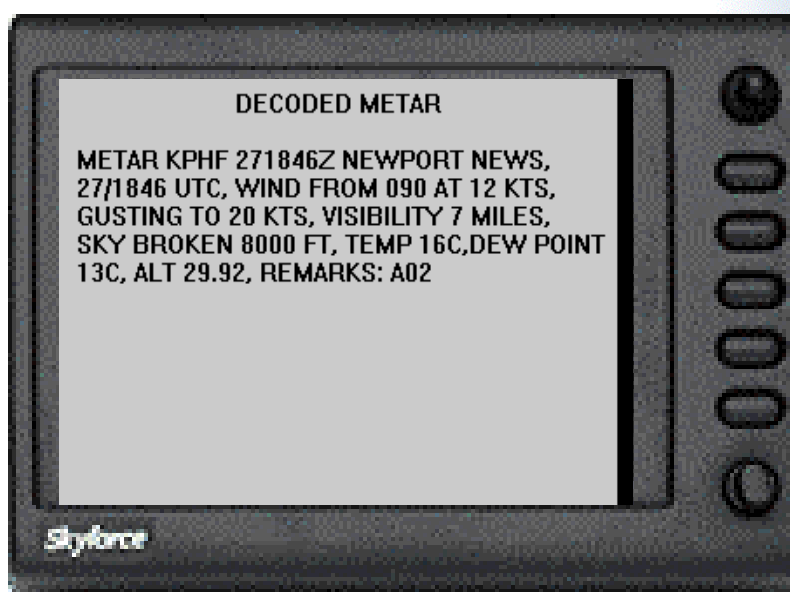
VISIBILITY
Red – Less than 1 mi.
Yellow – 1 to 3 mi.
Green – 3 to 5 mi.
Blue – More than 5 mi.



METAR Selection



METAR Text



NCWF Display

05/25 12:57Z

24/501

BRV

RIC

34/501

39/501

44/399

KDC

25 NM

Scroll

NEX/MTR

GPS Free

Menu Off

BRT

NCWF Hazard Field

Data Time: Jun 02, 1999 03:50 GMT

Legend:

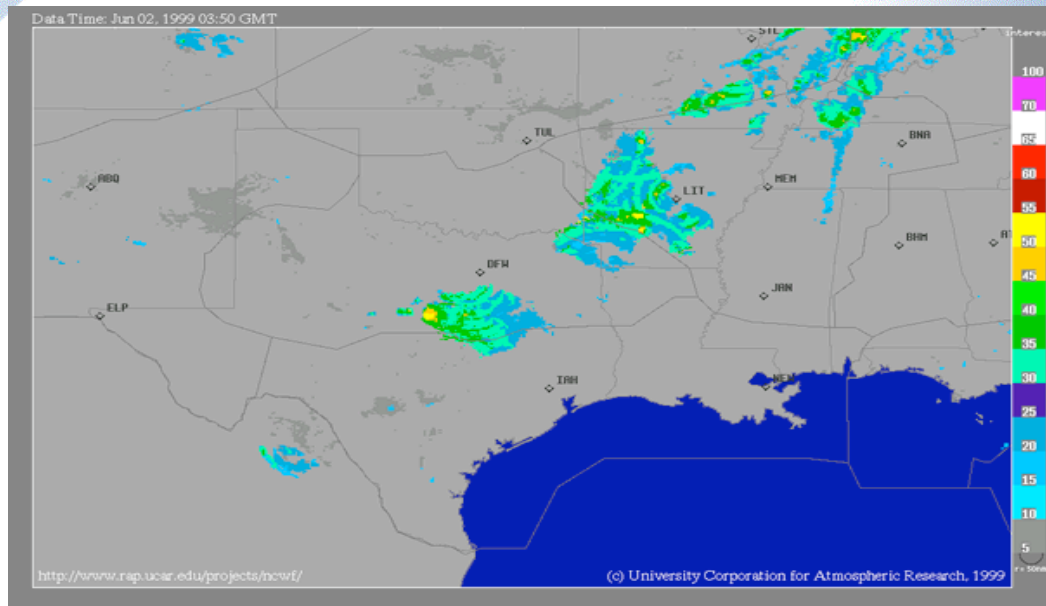
- 5-6
- 4
- 3
- 1-2

<http://www.rap.ucar.edu/projects/ncwf/>

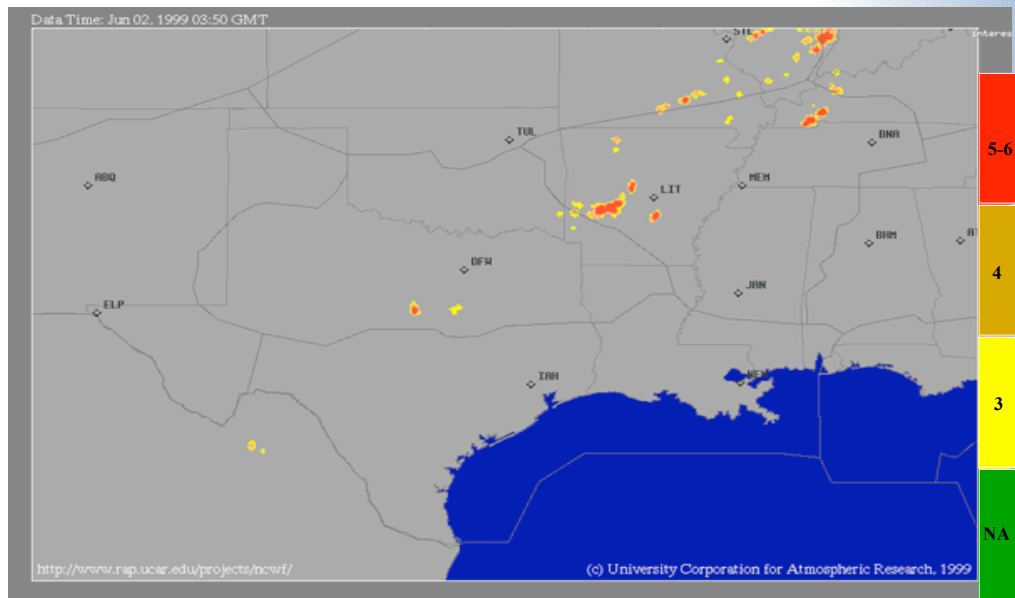
(c) University Corporation for Atmospheric Research, 1999

RTI
INTERNATIONAL

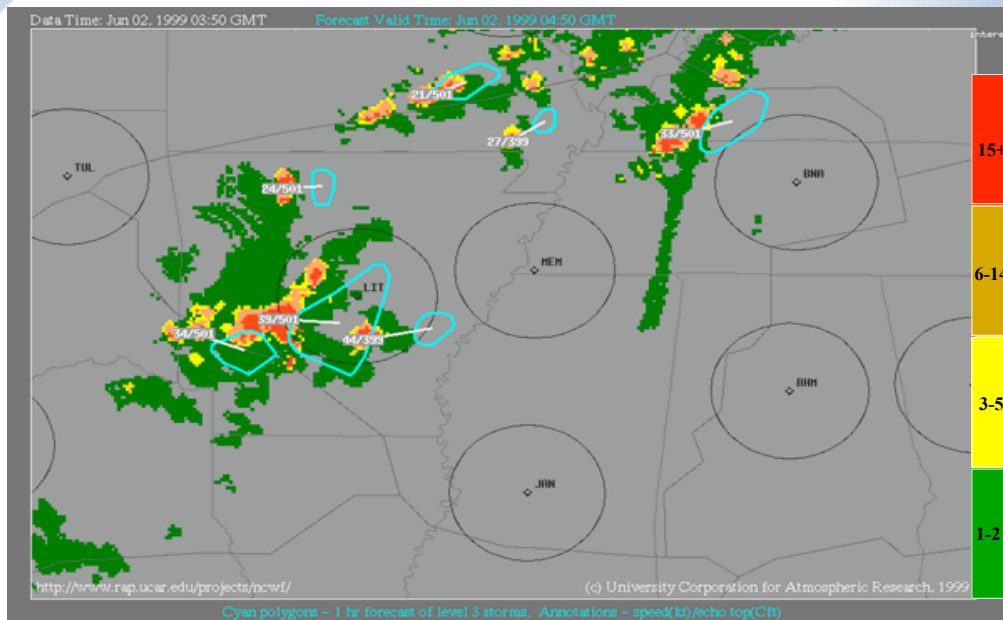
NCWF Tops Filter



NCWF Lightning Grid



NCWF Final Product

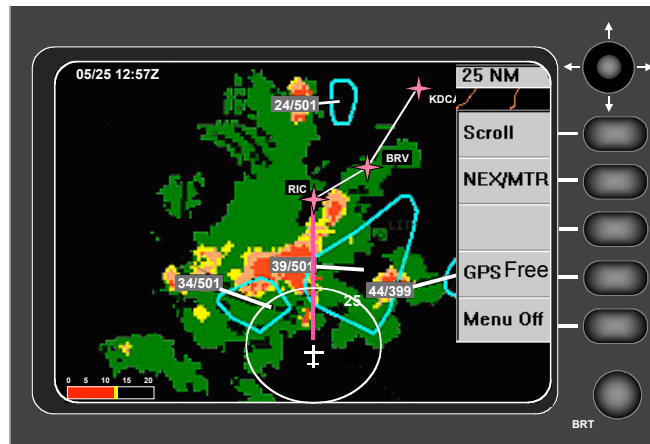


NCWF Summary

Hazard Field			Approximate Correlations			
	VIL (kg/m ²)	Ltg. Rate (/10 min)	Effect	Airborne Radar	Reflectivity (dBZ)	VIP
5-6	12 +	15 +	Severe Turbulence, Lightning Hail likely	Level 4 Very Hazardous	50 +	5 - 6
4	6.9 - 12.0	6 - 14	Possible Severe Turbulence, Lightning	Level 3 Hazardous	45 - 49	4
3	3.5 - 6.9	3 - 5	Possible Severe Turbulence, Lightning	Level 3 Hazardous	40 - 44	3
1-2	0 - 3.5	NA	Light to Mod. Turbulence, Possible Lightning	Level 1-2 weak-moderate	0 - 39	1 - 2



NCWF Display Intensity Levels



NCWF Intensity Levels:			
Lt. Green		Light	
Yellow		↓	
Red		Severe	



National Convective Weather Forecast (NCWF)

- Based on NEXRAD and cloud-to-ground lightning data
- Most accurate for long-lived mature multi-storm systems
- Does not forecast initiation, growth or decay of thunderstorms
- Tends to under-warn on new, growing storms and over-warn on dying storms
- Does not display forecast positions of small, isolated or weaker thunderstorms
- Forecast does not distinguish between level 3 through level 6 on the NCWF hazard scale
- May not detect or forecast:
 - some embedded convection,
 - low-topped convection containing little or no cloud-to-ground lightning (such as may occur in cool air masses),
 - rapidly evolving convection

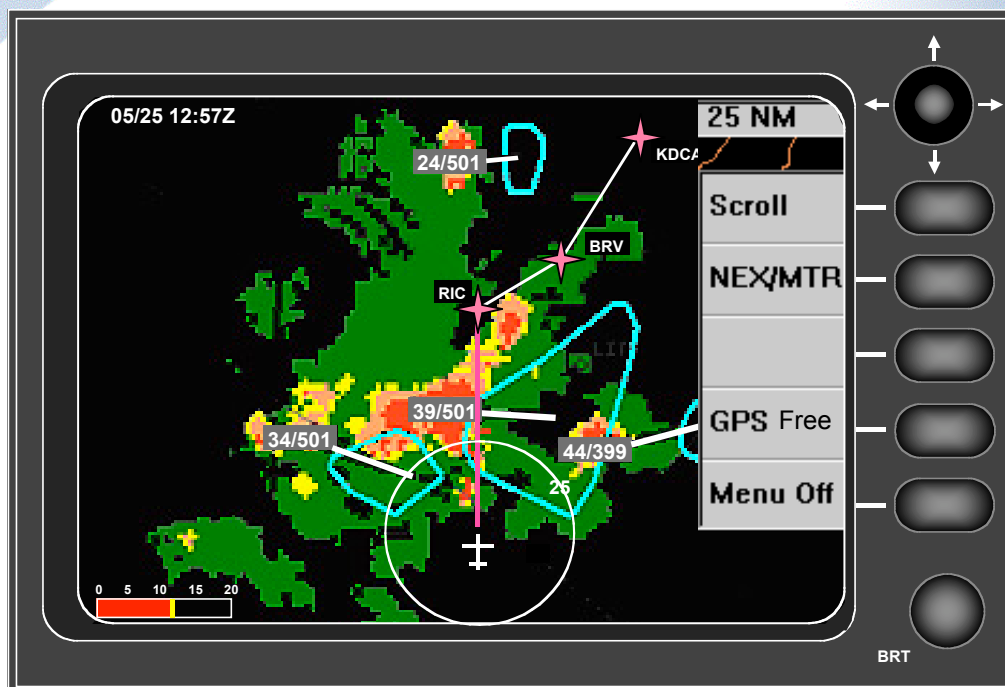


National Convective Weather Forecast (NCWF)

- NCWF is currently available via the Internet from the Aviation Weather Center
- Is to be used in conjunction with other weather products such as Convective Sigmetas to provide additional information for flight planning
- Not to be used as a substitute for Convective SIGMETs
- Cannot provide information on specific storm hazards such as hail, high winds, or tornadoes
- Access by Automated FSS, ARTCCs or Terminal Radar Approach Control planned but not currently available.



NCWF Display



Appendix H. Training & Proficiency Criteria

In addition to a familiarization session of approximately 45 minutes in which the subject pilots were briefed on all functions of the simulation facility including the weather displays (for those subjects having a weather display), all pilots were provided training in the simulation facility itself so as to become sufficiently proficient in flying the simulator to accomplish the mission. 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 2000 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 and ILS operation (with and without AP)
10. Use of all functions of weather display (with and without AP)
11. Vectors to normal VFR landing, touch-and-go (± 10 kts)
12. Go-around (± 10 kts)

13. Vectors to IFR approach and landing

14. Follow up approaches and landings if required until subject pilot able to accomplish all functions of mission without assistance from instructor

Appendix I. Observer Forms

- Richmond Leg
- Wallops Leg

Observer Form Richmond

Condition: _____ Pilot #: _____ Date: _____ Time: _____ Observer: _____

[illegible][illegible]

Types	Locations	Z-Times
_____ ATIS		
_____ ASOS		
_____ AWOS		
_____ ATC		
_____ Departure Control		
_____ Tower		
_____ Approach Control		
_____ Flight Watch		
_____ FSS		
_____ METAR		
_____ Wx Display		

4 = The pilot abandoned the approach more than five (5) miles outside of the outermarker, and flew more than five (5) miles from a red NEXRAD image cell.

None of the Time |-----| All of the Time

Extremely Low |-----| Extremely High

173

Observer Form Wallops

Condition:

Pilot #:

Date:

Time:

Observer:

Comments:

[illegible][illegible]

Decision Quality:

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 a 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.

Workload:

Extent to which the pilot relied on the autopilot to fly the airplane.

None of the Time

All of the Time

Pilot's Workload

Extremely Low

Extremely High

Workload Considerations:

_____ Deviations from
assigned flight path

Procedural Errors

Judgment Errors

_____ Communication
Lapses/Errors

Appendix J. Immediate Reaction Questionnaires

- Control Group
- Weather Display Groups

Immediate Reaction Questionnaire for Control Group

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 wedding scenario as a serious personal commitment, in the sense that I factored the time pressure into my decision-making.

Disagree	Disagree Somewhat	No Opinion	Agree Somewhat	Agree
-----------------	------------------------------	-------------------	---------------------------	--------------

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

Disagree	Disagree Somewhat	No Opinion	Agree Somewhat	Agree
-----------------	------------------------------	-------------------	---------------------------	--------------

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

Disagree	Disagree Somewhat	No Opinion	Agree Somewhat	Agree
-----------------	------------------------------	-------------------	---------------------------	--------------

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

Disagree	Disagree Somewhat	No Opinion	Agree Somewhat	Agree
-----------------	------------------------------	-------------------	---------------------------	--------------

5. 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

6. 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.

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

Disagree

**Disagree
Somewhat**

No Opinion

**Agree
Somewhat**

Agree

IMMEDIATE REACTION QUESTIONNAIRE
for
NCWF and NEXRAD Looping Subject Pilot Groups

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 wedding scenario as a serious personal commitment, in the sense that I factored the time pressure into my decision-making.

Disagree	Disagree Somewhat	No Opinion	Agree Somewhat	Agree
-----------------	------------------------------	-------------------	---------------------------	--------------

2. An advantage of the onboard Weather Display was showing the graphical depiction of the weather to aid in my decision-making.

Disagree	Disagree Somewhat	No Opinion	Agree Somewhat	Agree
-----------------	------------------------------	-------------------	---------------------------	--------------

3. The weather display increased my situational awareness during the decision-making process.

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 crosscheck 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 and timeliness 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 age display 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 precisely 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
-----------------	------------------------------	-------------------	---------------------------	--------------

15. The weather display increased head-down time and scanning workload

Disagree	Disagree Somewhat	No Opinion	Agree Somewhat	Agree
-----------------	------------------------------	-------------------	---------------------------	--------------

16. I was aware of the latency of the weather data appearing on screen as I flew and assessed alternative flight paths.

Disagree	Disagree Somewhat	No Opinion	Agree Somewhat	Agree
-----------------	------------------------------	-------------------	---------------------------	--------------

17. I found the range rings very useful in enhancing my weather cell awareness.

Disagree	Disagree Somewhat	No Opinion	Agree Somewhat	Agree
-----------------	------------------------------	-------------------	---------------------------	--------------

18. The presentation of flight path waypoints facilitated my decision-making.

Disagree	Disagree Somewhat	No Opinion	Agree Somewhat	Agree
-----------------	------------------------------	-------------------	---------------------------	--------------

Appendix K. 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 time 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 time 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 L. General Aviation Questionnaire

(with Answers to Weather Knowledge Questions shaded)

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_____

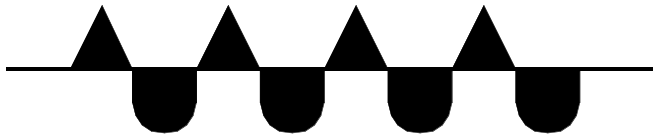
17. What do boundary layer air, and surface winds near the ground have in common?

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

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 M. 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. TEMPERATURE 14 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 N. 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 LGTCCCCG

Richmond International Airport special weather report one, niner, one, zero universal coordinated time. Measured ceiling, two hundred, overcast, visibility __, 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
OCNL LGTCCCCG**

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
BAY SW**

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.

**UA: /OV RIC090050 /TM 1900Z /FL080 /TP PA46 /TB NEG /RM BLD-UPS OVR
BAY N**

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

Appendix O. Subject Pilots' Self Assessment of Workload

TLX Measures								
<i>Pilot #</i>	<i>Condition</i>	<i>Mental</i>	<i>Physical</i>	<i>Temporal</i>	<i>Performance</i>	<i>Effort</i>	<i>Frustration</i>	<i>Composite Workload TLX</i>
1	Looping	16	4	12	14	14	12	72
2	NCWF	16	9	11	19	10	13	78
3	Control	17	7	11	16	16	11	78
4	NCWF	17	5	16	10	16	15	79
5	Control	11	16	7	10	15	6	65
6	Looping	16	1	3	11	13	7	51
7	Looping	16	8	14	17	17	16	88
8	Control	14	6	6	11	15	18	70
9	NCWF	18	8	15	16	16	16	89
10	Looping	16	9	18	8	18	18	87
11	Control	19	5	14	6	18	2	64
12	NCWF	18	7	10	16	16	16	83
13	Looping	15	4	4	13	16	11	63
14	NCWF	15	12	11	14	14	9	75
15	Control	15	7	11	13	14	14	74
16	Control	16	4	11	7	18	7	63
17	NCWF	16	16	18	16	17	9	92
18	Looping	8	9	8	12	8	11	56
19	NCWF	17	9	16	20	17	16	95
20	Looping	16	10	19	7	16	14	82
21	Control	20	16	16	18	18	12	100
22	Control	17	6	12	16	18	17	86
23	NCWF	20	14	17	17	16	15	99
24	Looping	20	6	17	5	20	16	84
25	Looping	11	6	20	15	17	13	82
26	NCWF	15	3	18	3	17	12	68
27	Control	18	15	16	4	17	12	82
28	NCWF	17	10	14	12	17	13	83
29	Looping	17	12	17	17	17	17	97
30	Control	20	11	16	11	16	16	90
31	Looping	17	5	11	2	17	14	66
32	Control	17	11	8	9	12	9	66
33	NCWF	19	7	14	11	13	14	78
34	NCWF	16	15	18	19	17	14	99
35	Control	16	2	11	14	19	3	65
36	Looping	16	16	17	3	18	11	81
37	NCWF	20	4	9	4	20	2	59
38	Looping	16	13	15	18	12	15	89

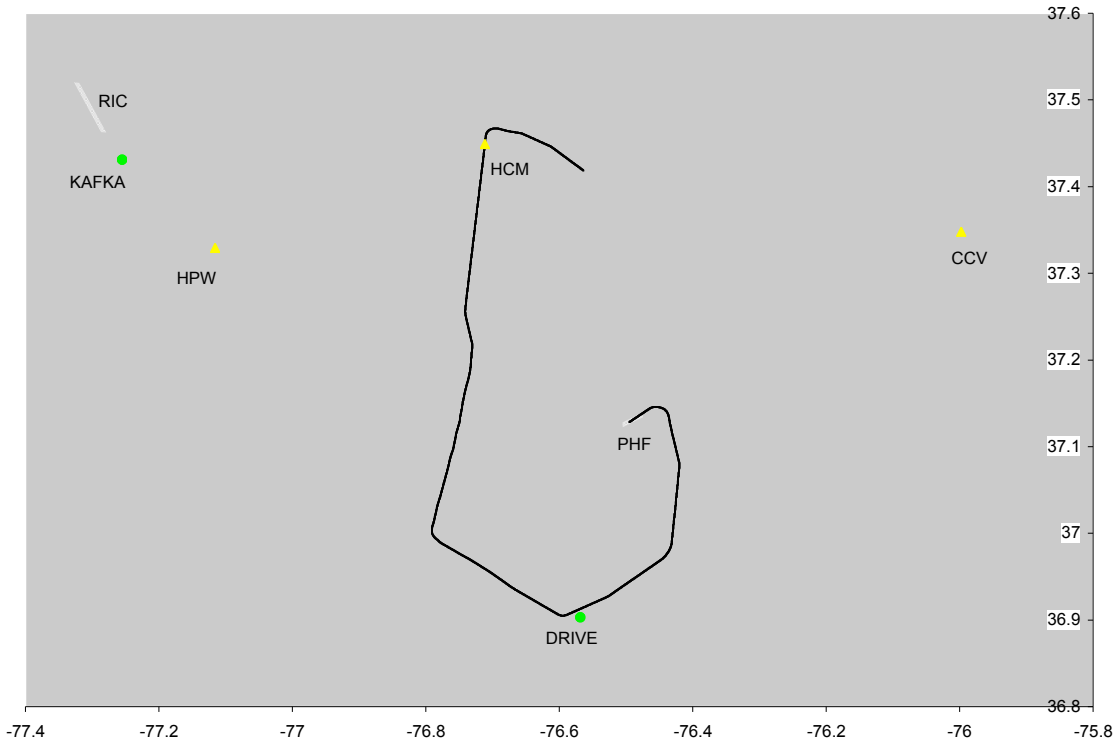
TLX Measures

<i>Pilot #</i>	<i>Condition</i>	<i>Mental</i>	<i>Physical</i>	<i>Temporal</i>	<i>Performance</i>	<i>Effort</i>	<i>Frustration</i>	<i>Composite Workload TLX</i>
39	Control	17	8	15	11	14	14	79
40	NCWF	18	16	15	6	16	6	77
41	Looping	11	3	14	5	14	15	62
42	Control	19	14	13	12	13	7	78
43	Control	14	15	16	1	7	11	64
44	NCWF	15	11	12	16	12	7	73
45	Looping	15	5	5	15	18	11	69
46	Control	17	14	17	17	16	15	96
47	NCWF	18	8	18	16	17	16	93
48	Looping	13	4	4	11	15	7	54

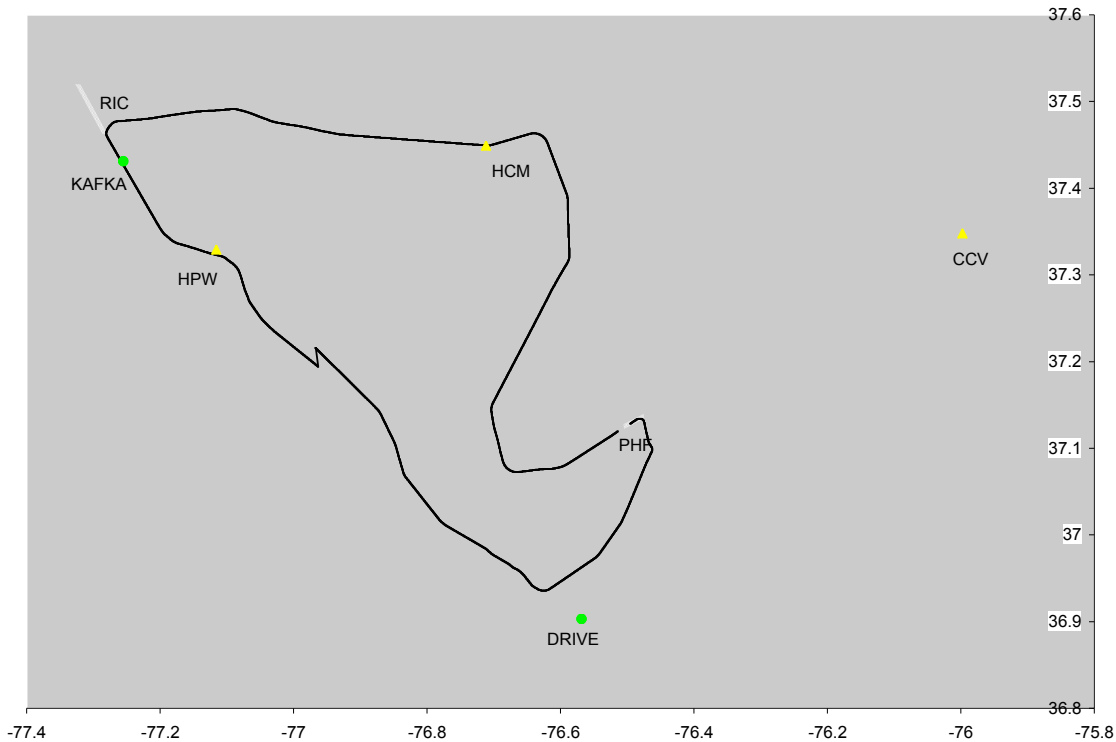
Appendix P. Subject Pilot Schedule And Experiment Group Assignments

Pilot #	Cond. Name	Schedule	Run
1	NEXRAD	7/8/2002	0800
2	NCWF	7/8/2002	1300
3	Control	7/9/2002	0800
4	NCWF	7/9/2002	1300
5	Control	7/12/2002	1300
6	NEXRAD	7/10/2002	1300
7	NEXRAD	7/11/2002	0800
8	Control	7/11/2002	1300
9	NCWF	7/12/2002	0800
10	NEXRAD	7/15/2002	0800
11	Control	7/15/2002	1300
12	NCWF	7/16/2002	0800
13	NEXRAD	7/16/2002	1300
14	NCWF	7/17/2002	0800
15	Control	7/17/2002	1300
16	Control	7/18/2002	0800
17	NCWF	7/19/2002	0800
18	NEXRAD	7/23/2002	0800
19	NCWF	7/23/2002	1300
20	NEXRAD	7/24/2002	0800
21	Control	7/24/2002	1300
22	Control	7/26/2002	0800
23	NCWF	7/26/2002	1300
24	NEXRAD	8/5/2002	0800
25	NEXRAD	8/5/2002	1300
26	NCWF	8/6/2002	0800
27	Control	8/6/2002	1300
28	NCWF	8/7/2002	0800
29	NEXRAD	8/7/2002	1300
30	Control	8/8/2002	1300
31	NEXRAD	8/9/2002	0800
32	Control	8/12/2002	0800
33	NCWF	8/12/2002	1300
34	NCWF	8/13/2002	0800
35	Control	8/13/2002	1300
36	NEXRAD	8/14/2002	0800
37	NCWF	8/14/2002	1300
38	NEXRAD	8/16/2002	1300
39	Control	8/19/2002	1300
40	NCWF	8/20/2002	0800
41	NEXRAD	8/21/2002	0800
42	Control	8/21/2002	1300
43	Control	8/22/2002	0800
44	NCWF	8/22/2002	1300
45	NEXRAD	8/23/2002	0800
46	Control	8/23/2002	1300
47	NCWF	8/24/2002	0800
48	NEXRAD	8/24/2002	1300

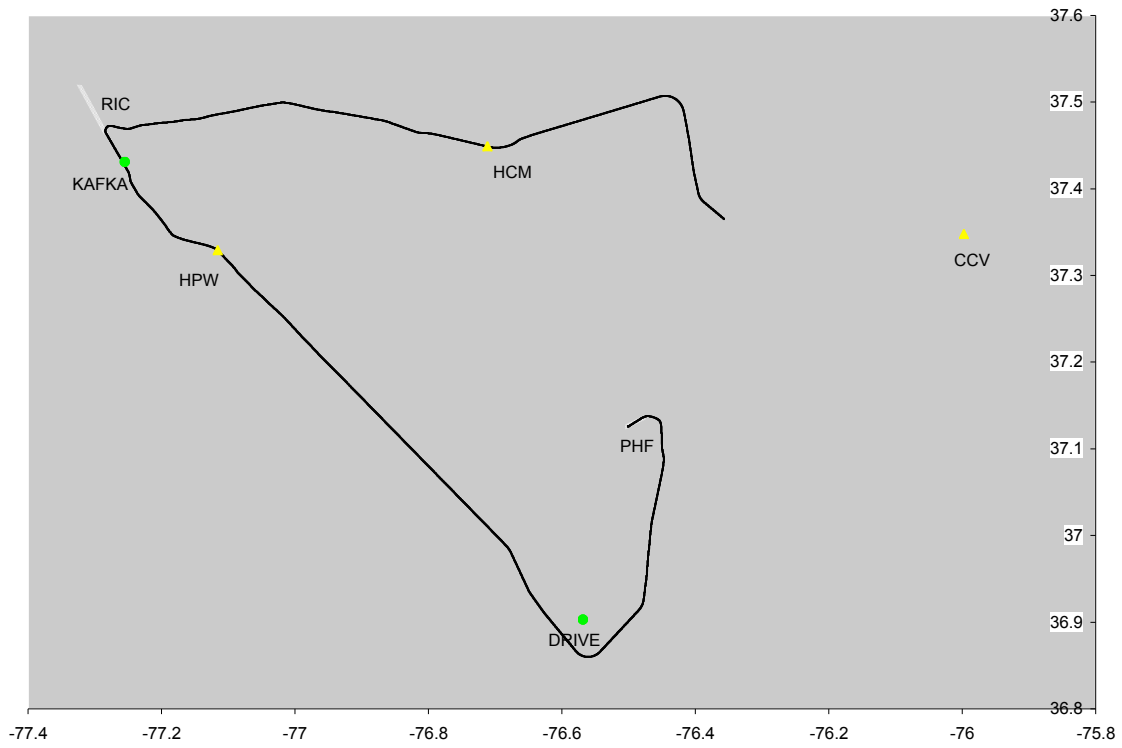
Appendix Q. Flight Paths of Each Subject Pilot



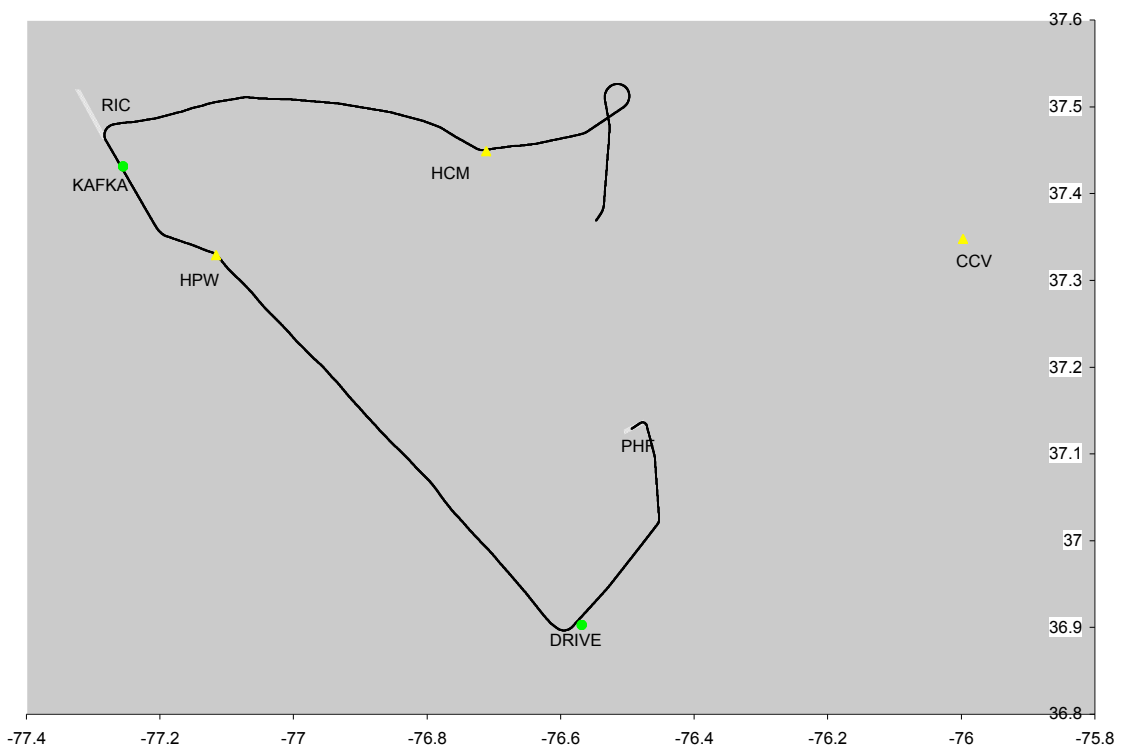
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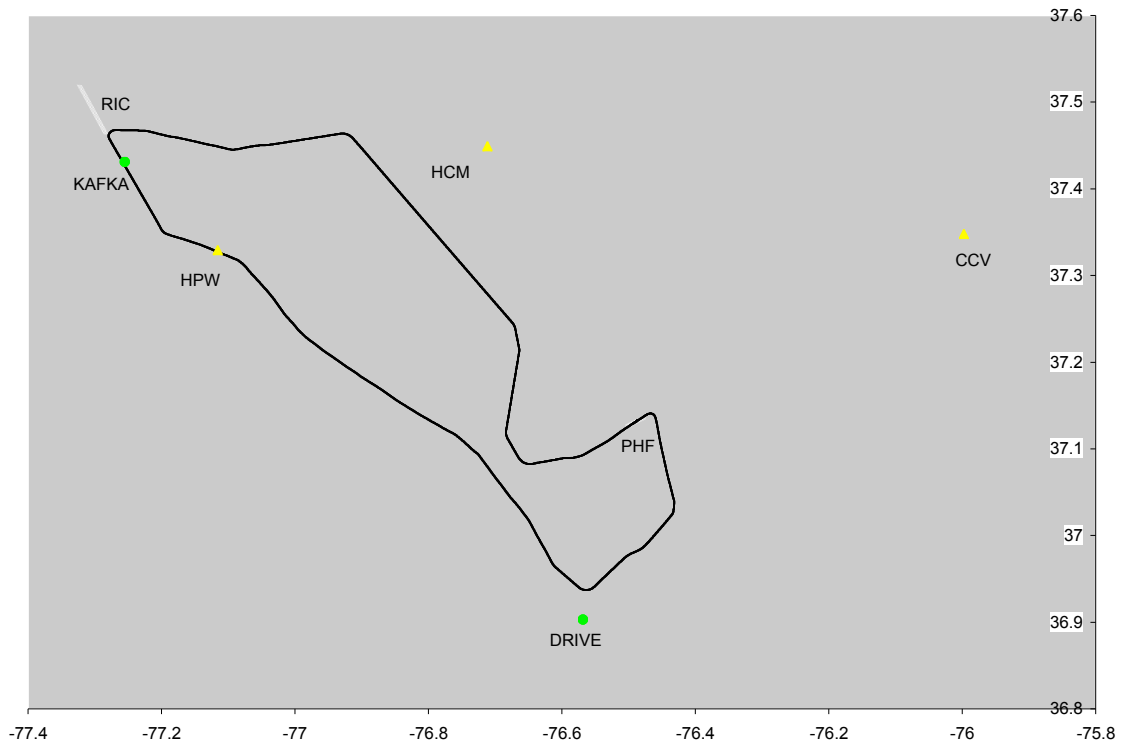
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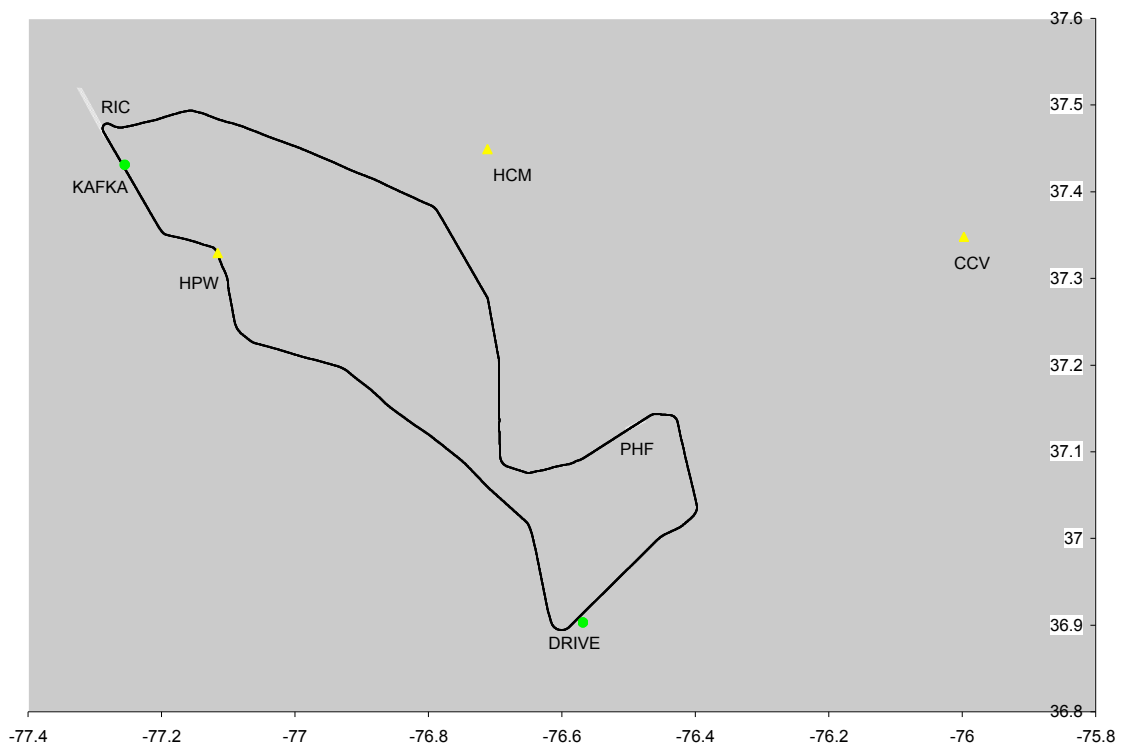
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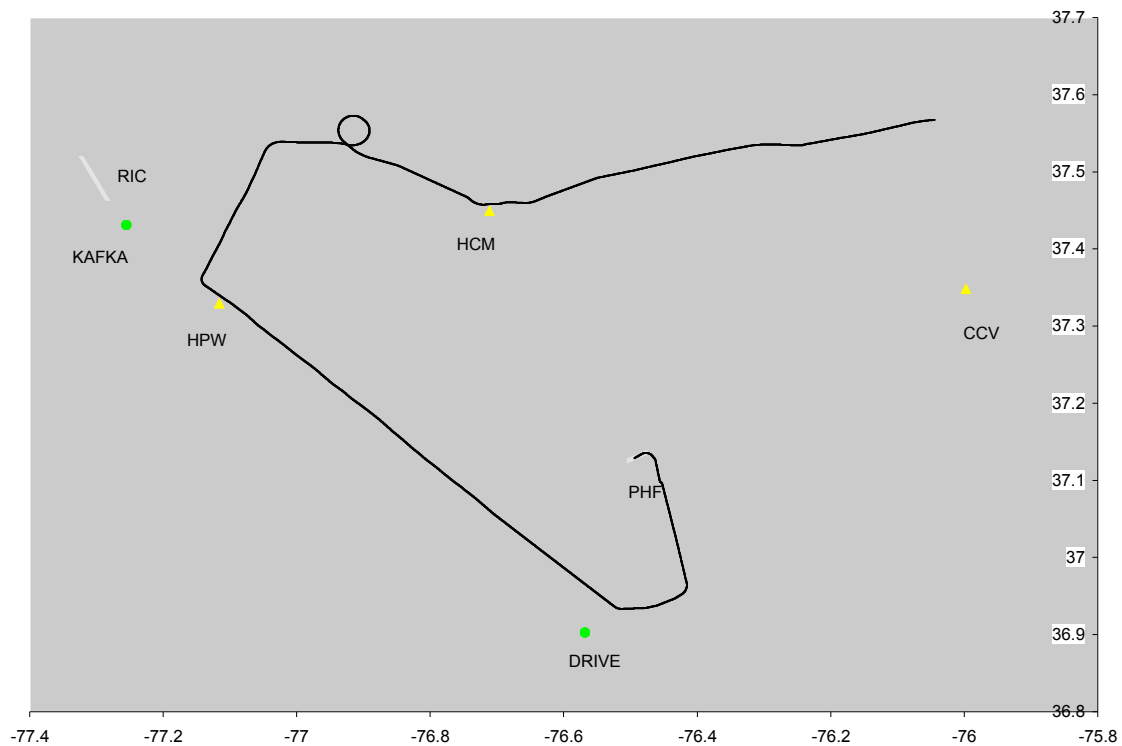
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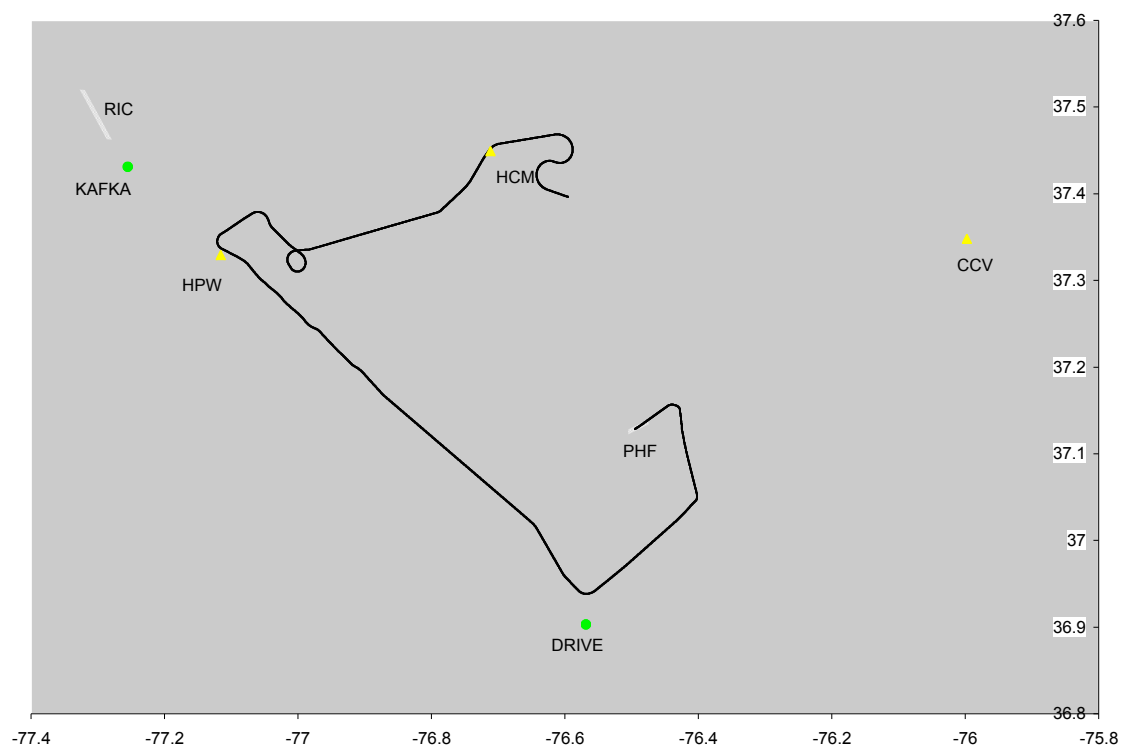
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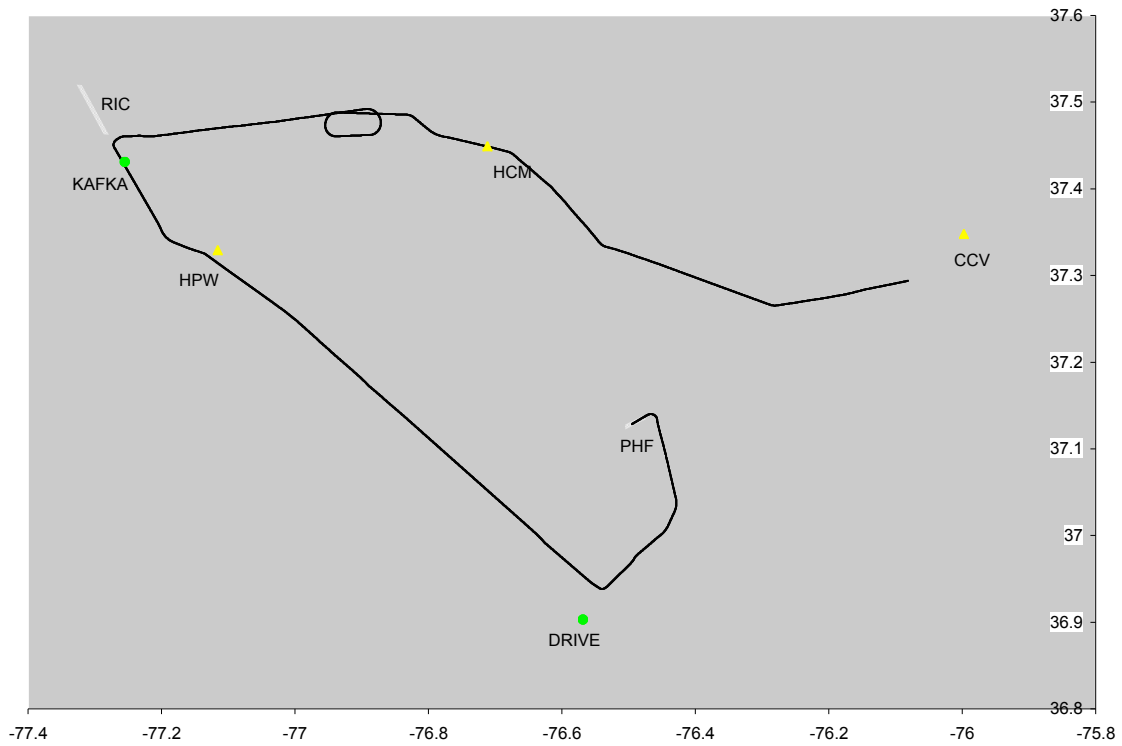
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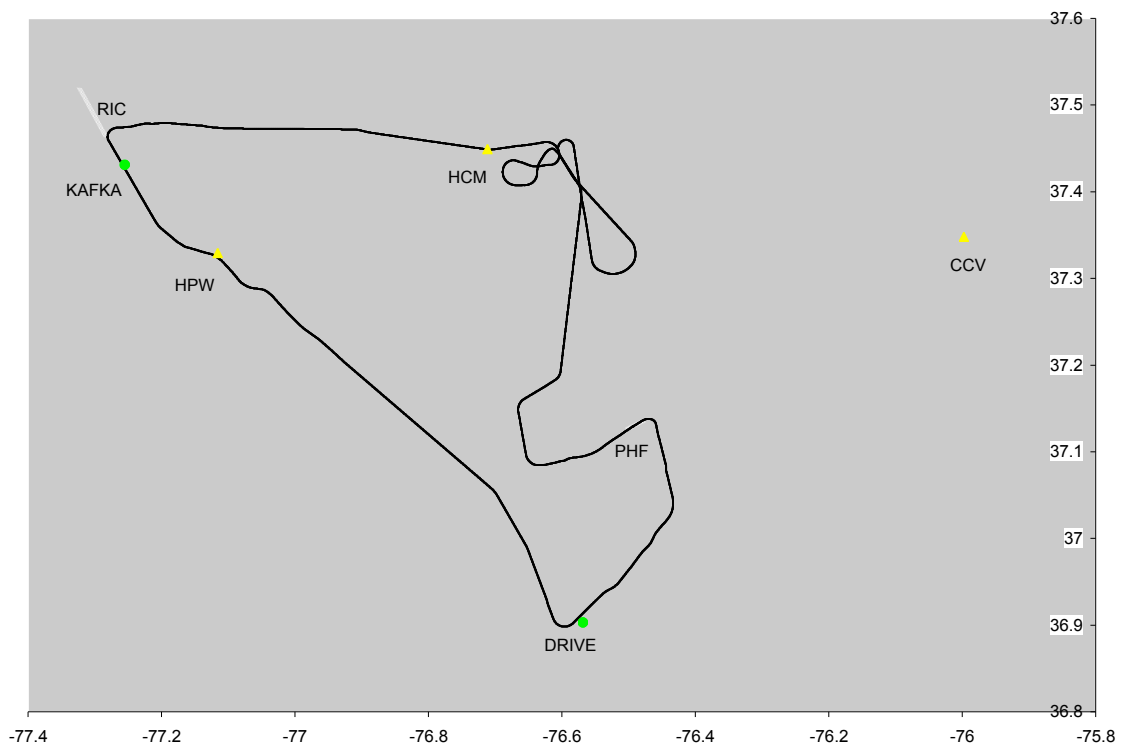
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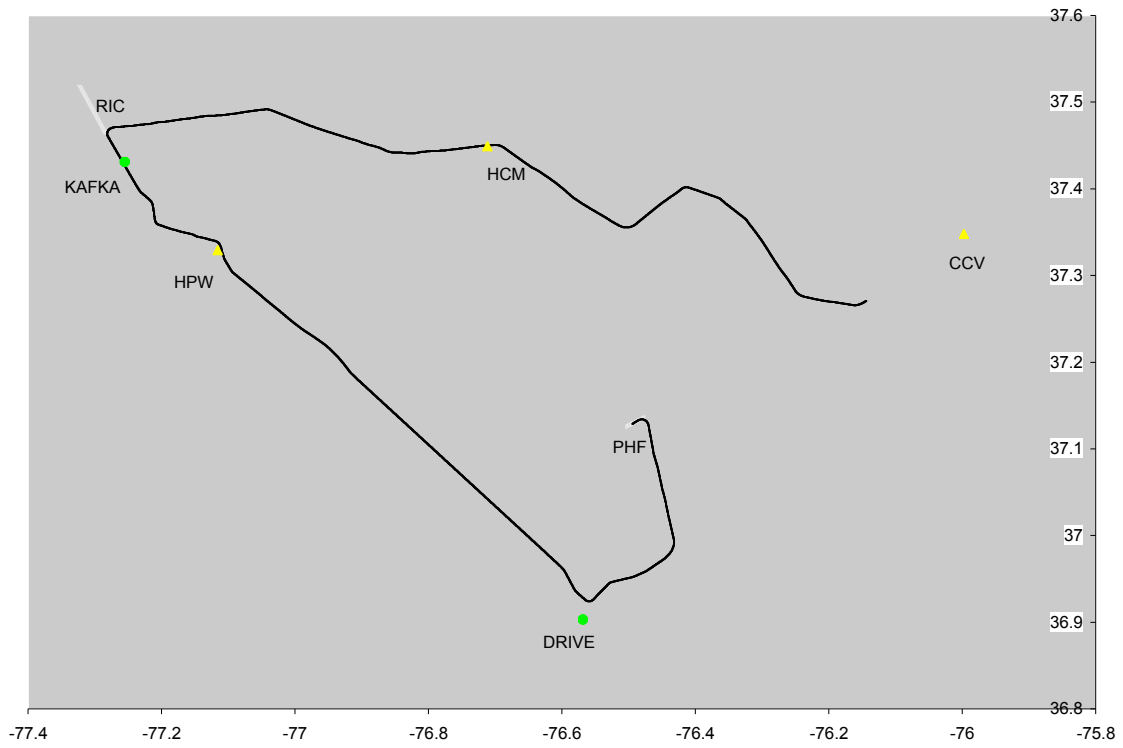
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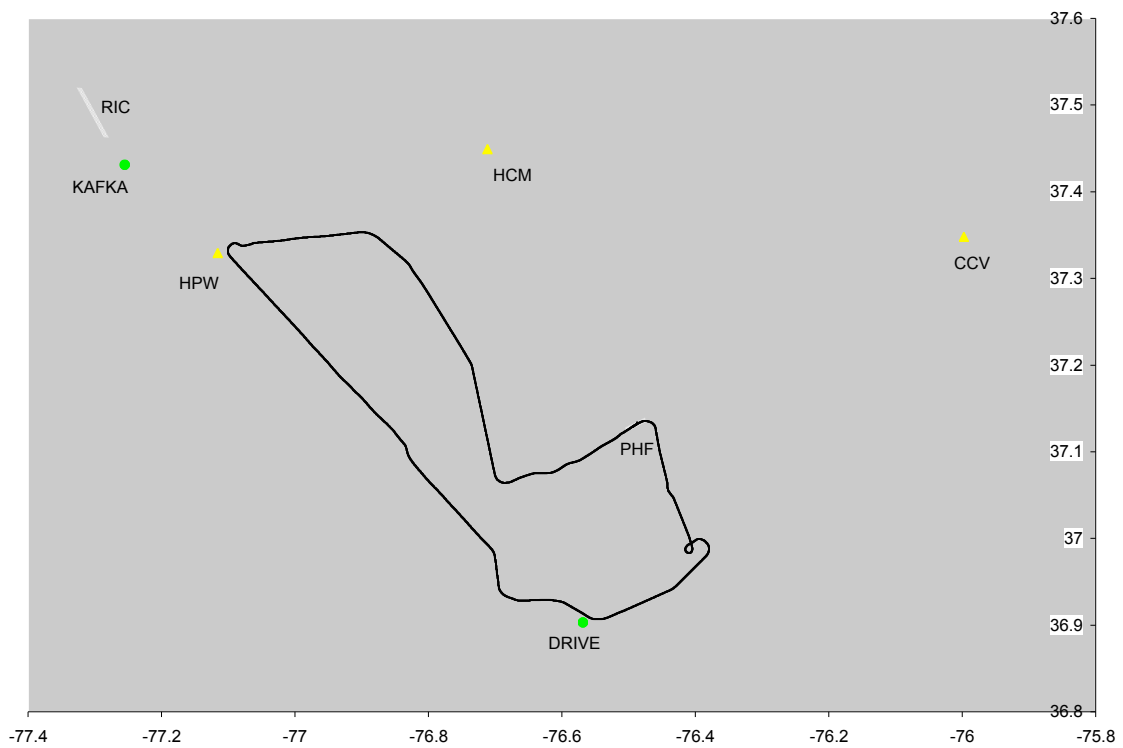
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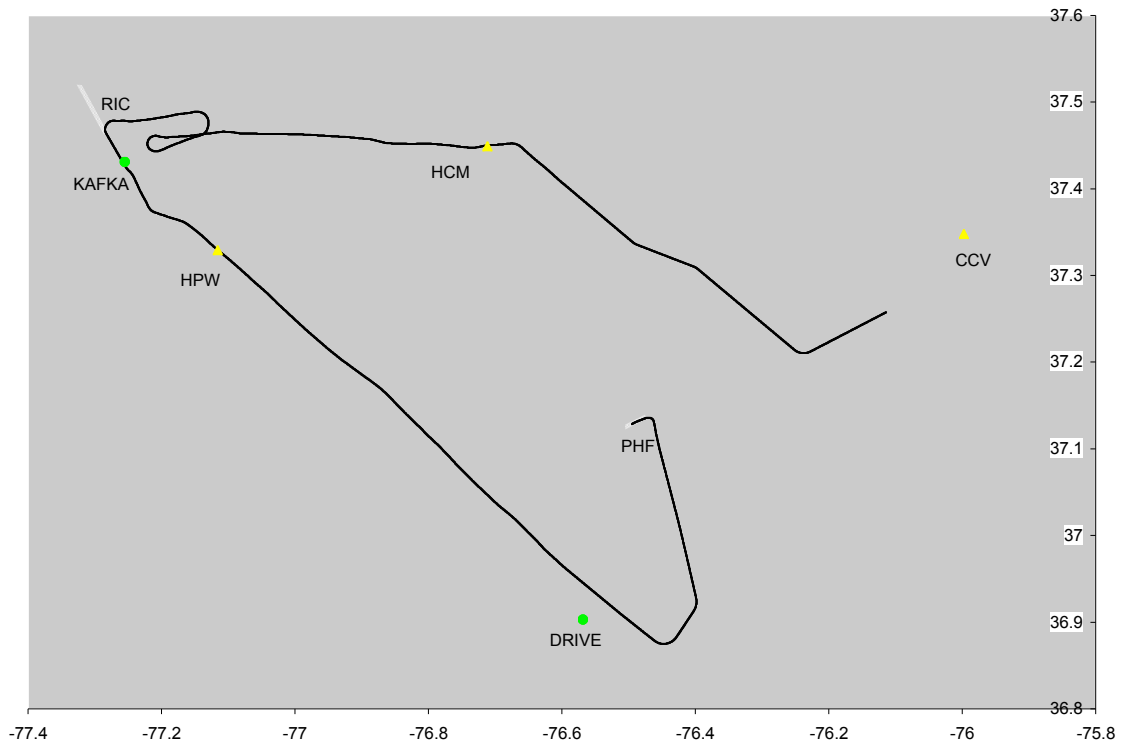
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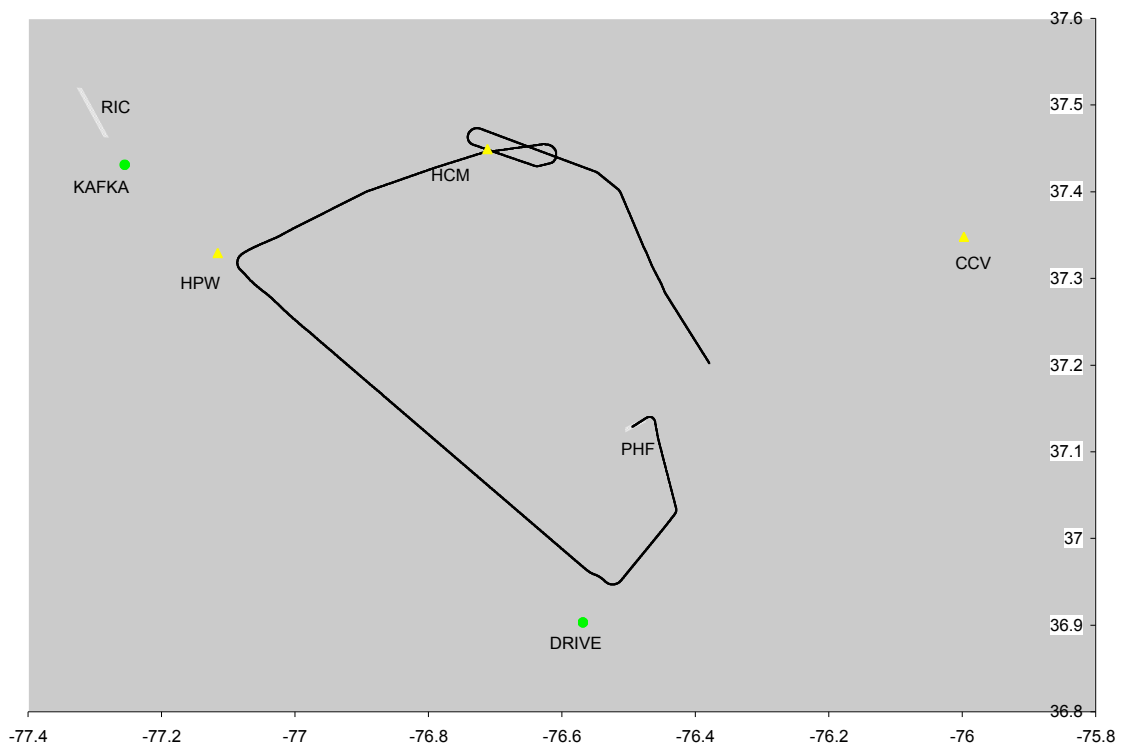
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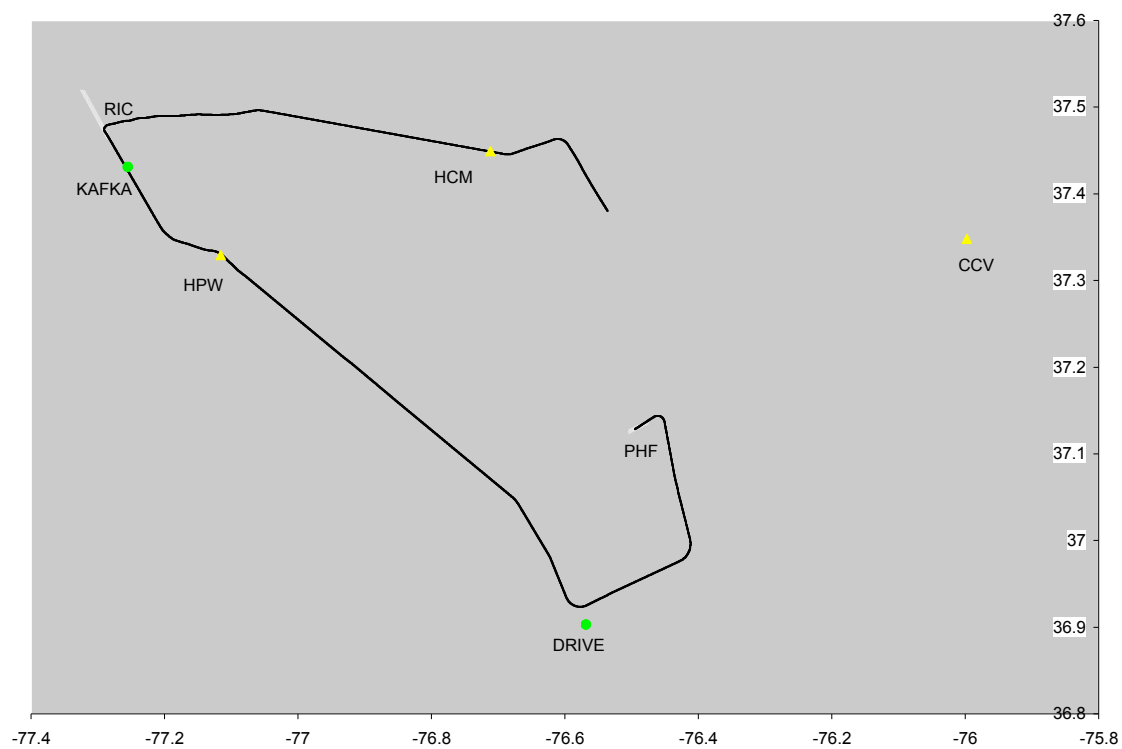
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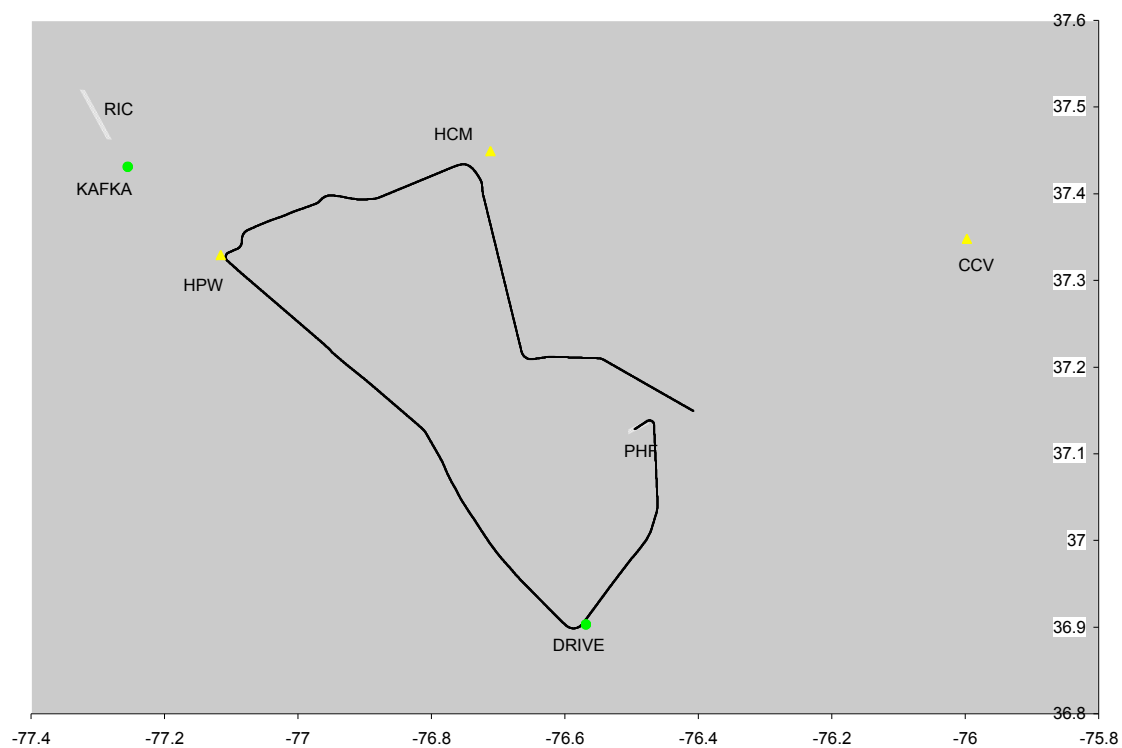
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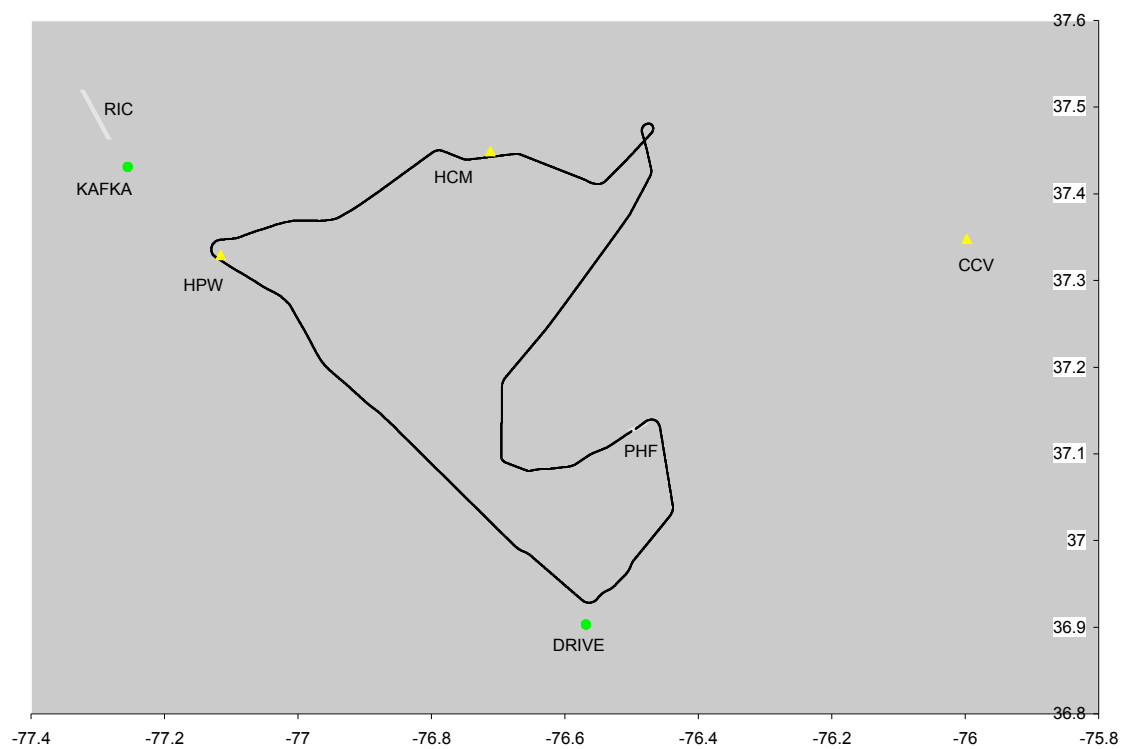
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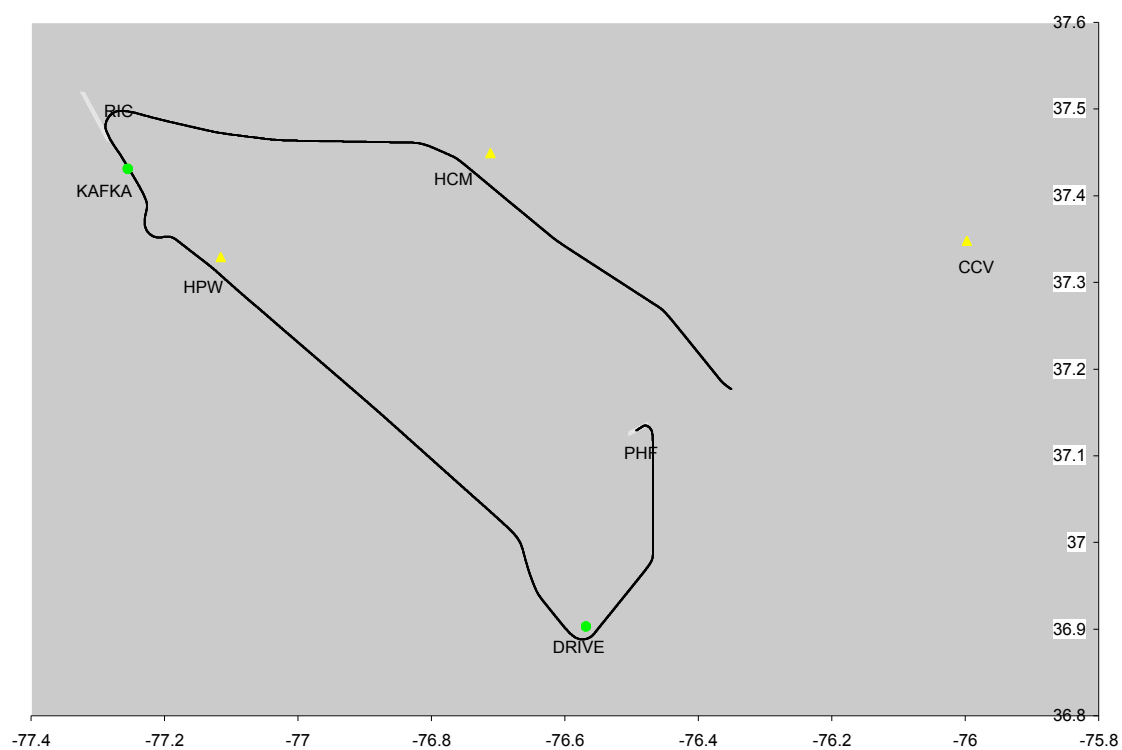
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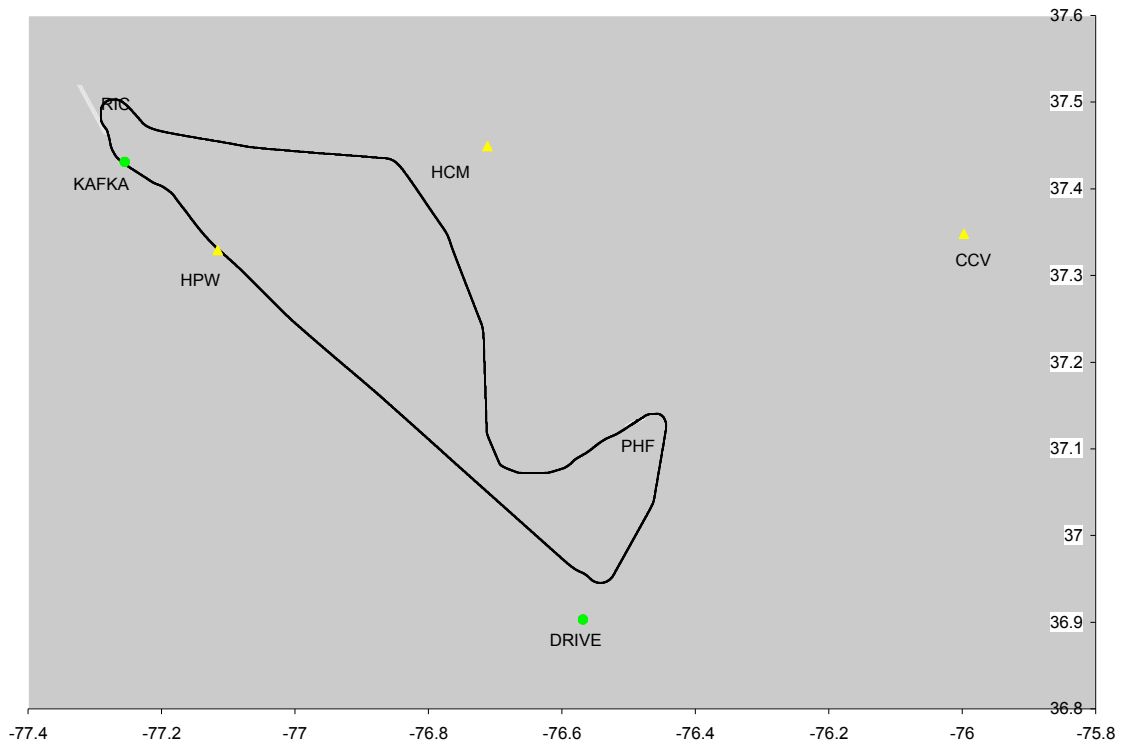
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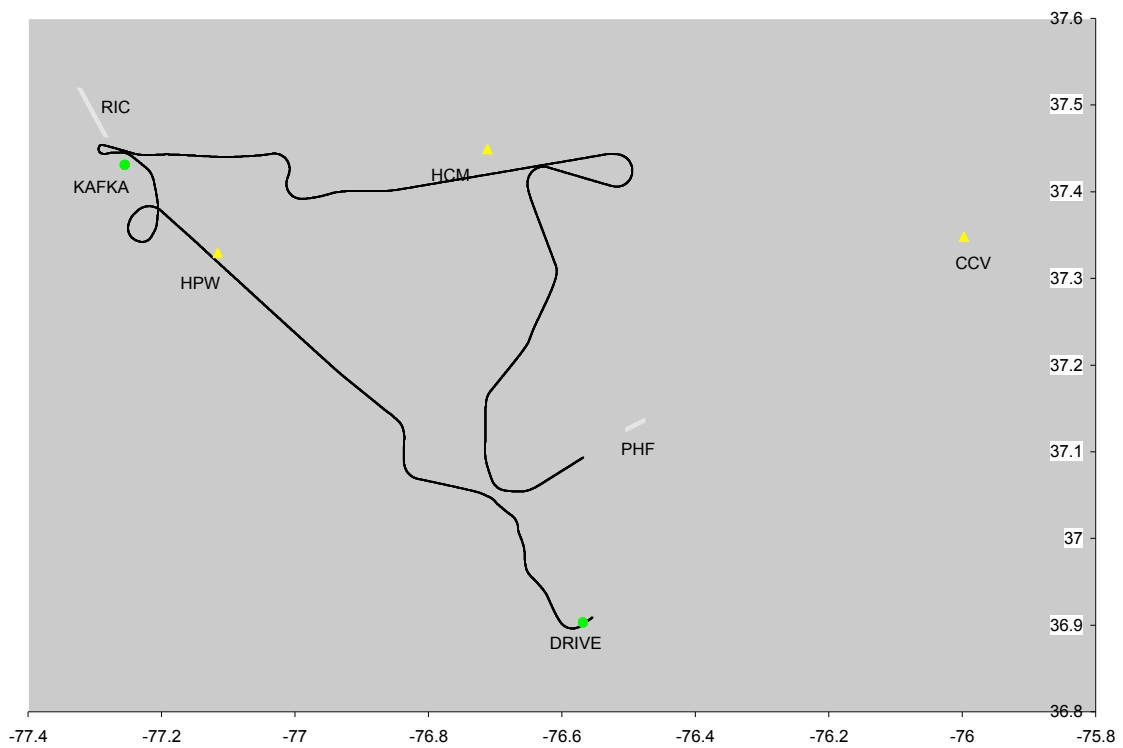
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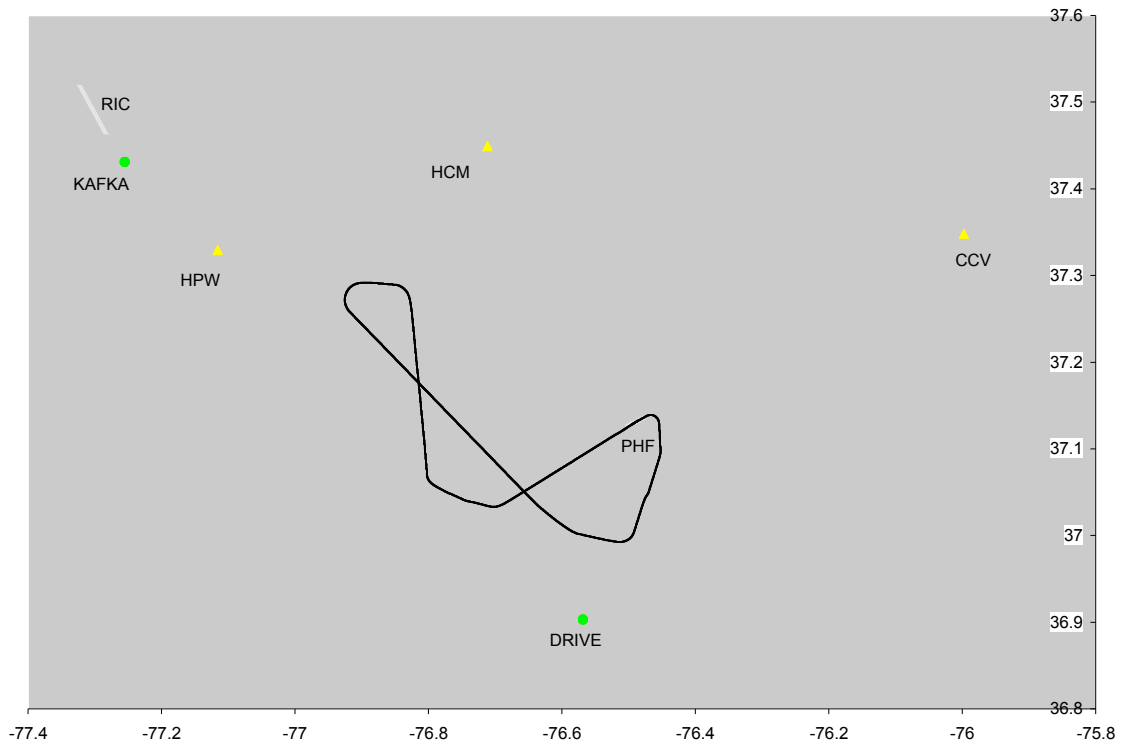
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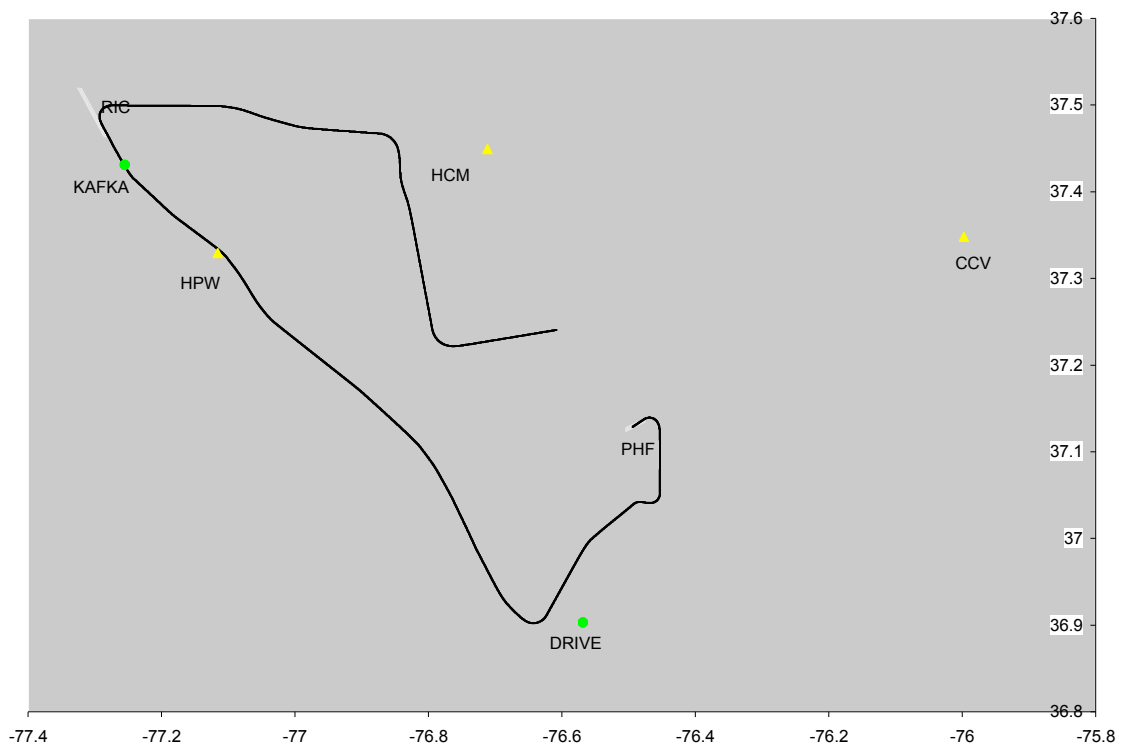
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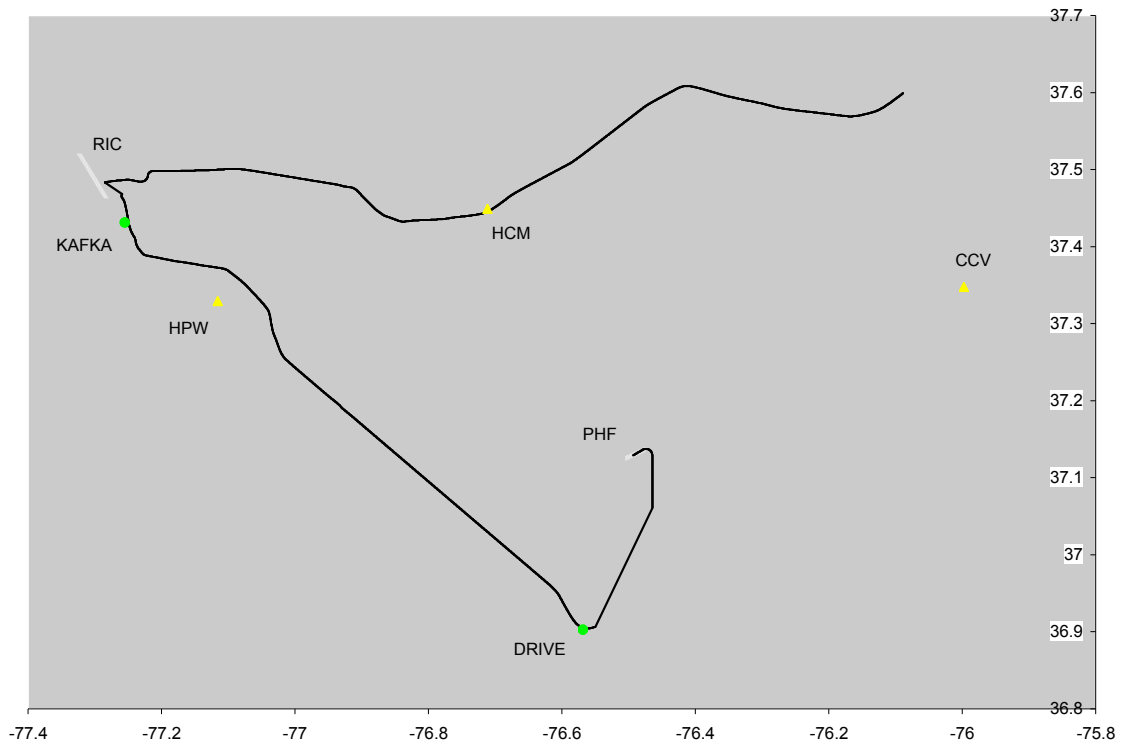
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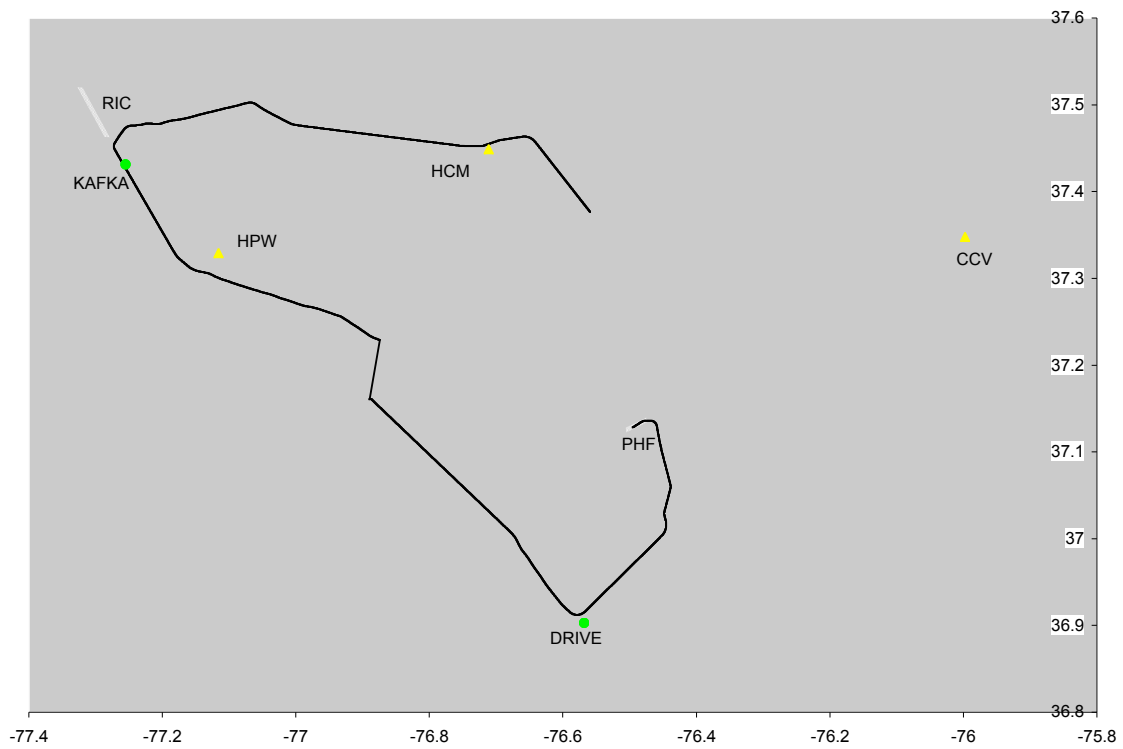
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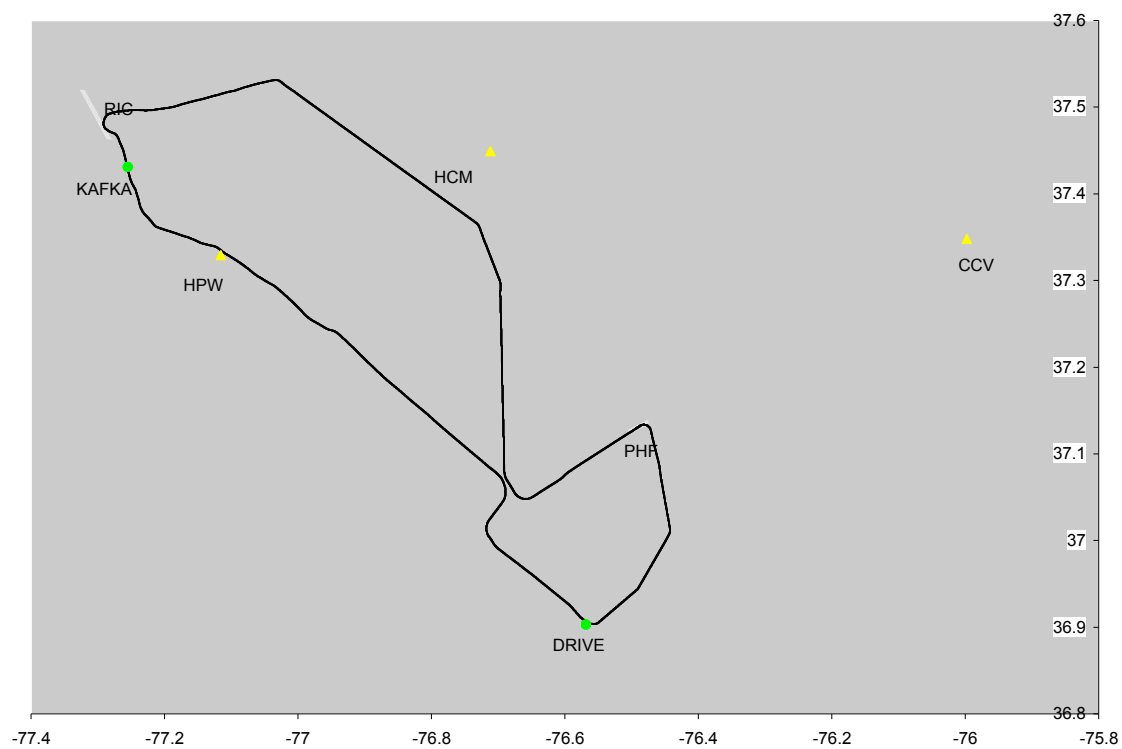
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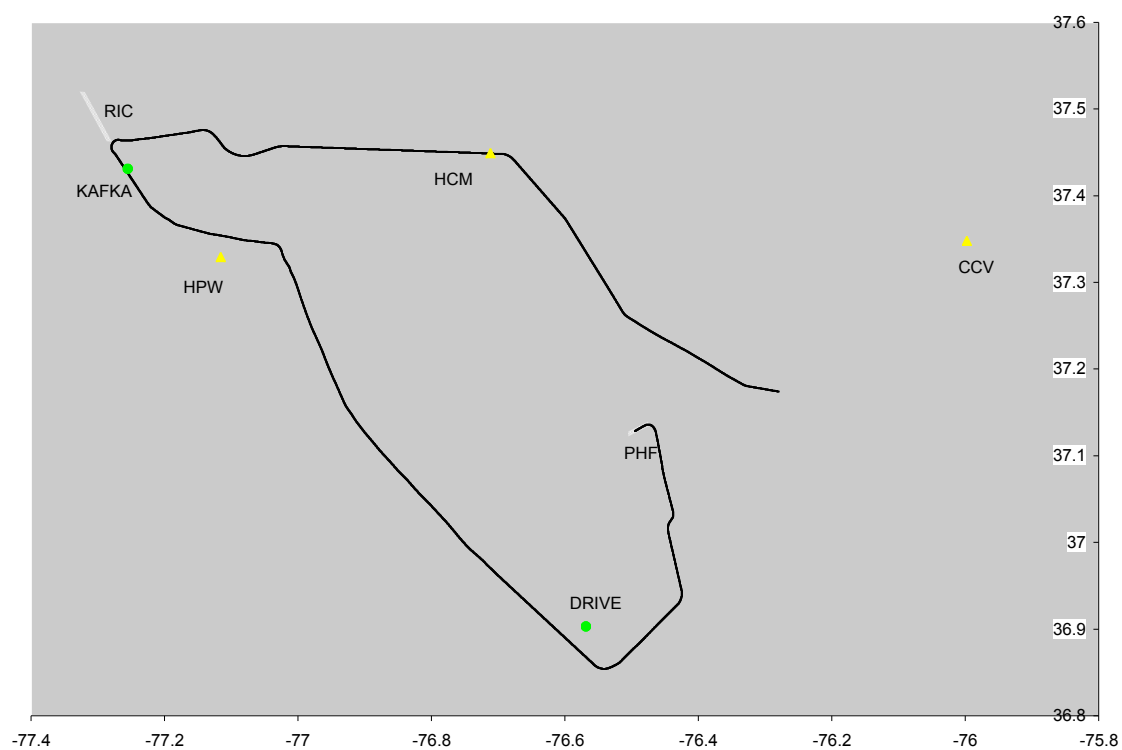
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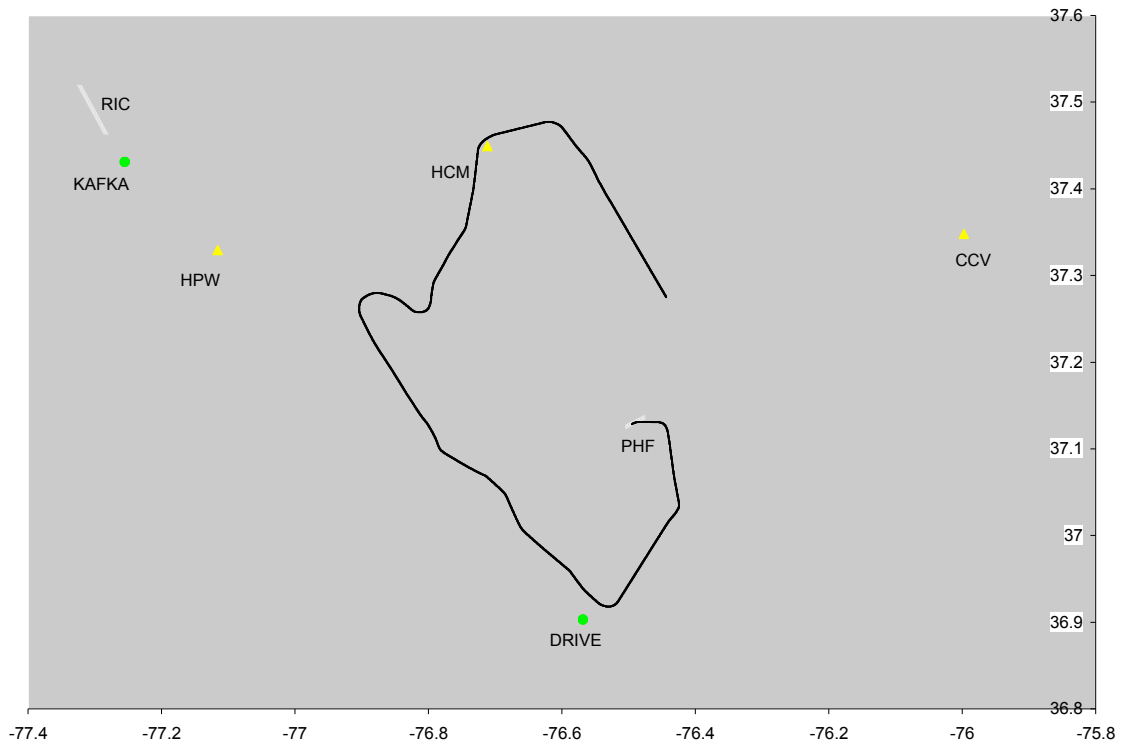
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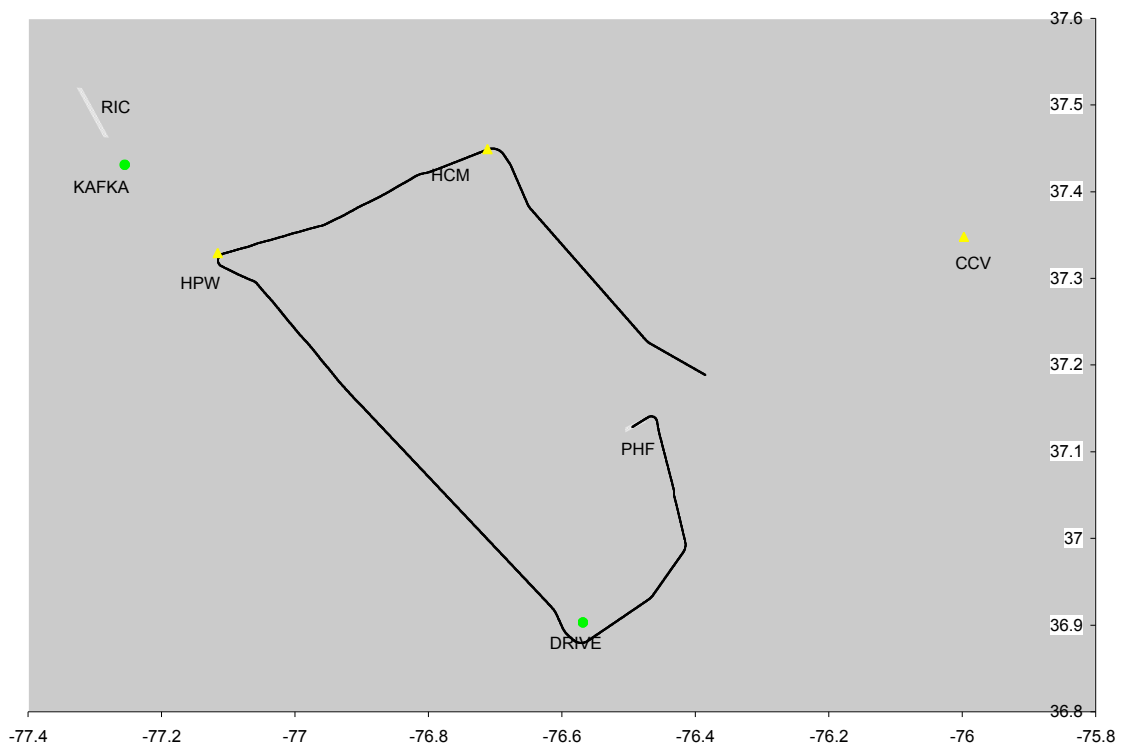
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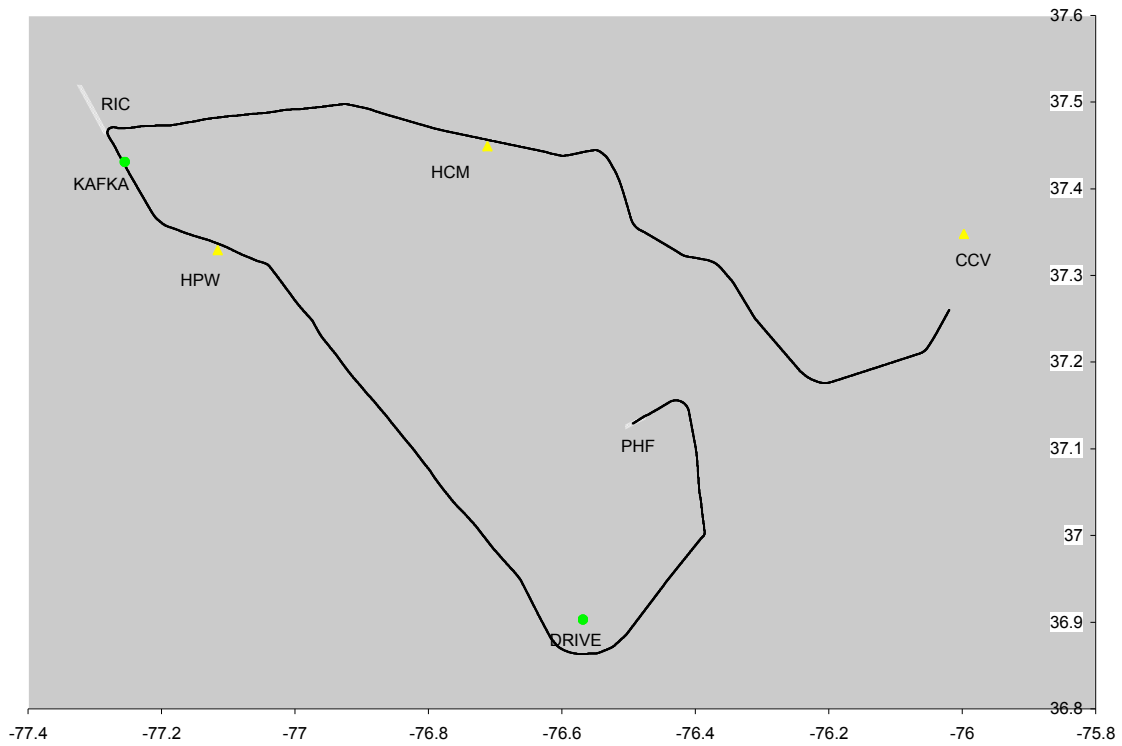
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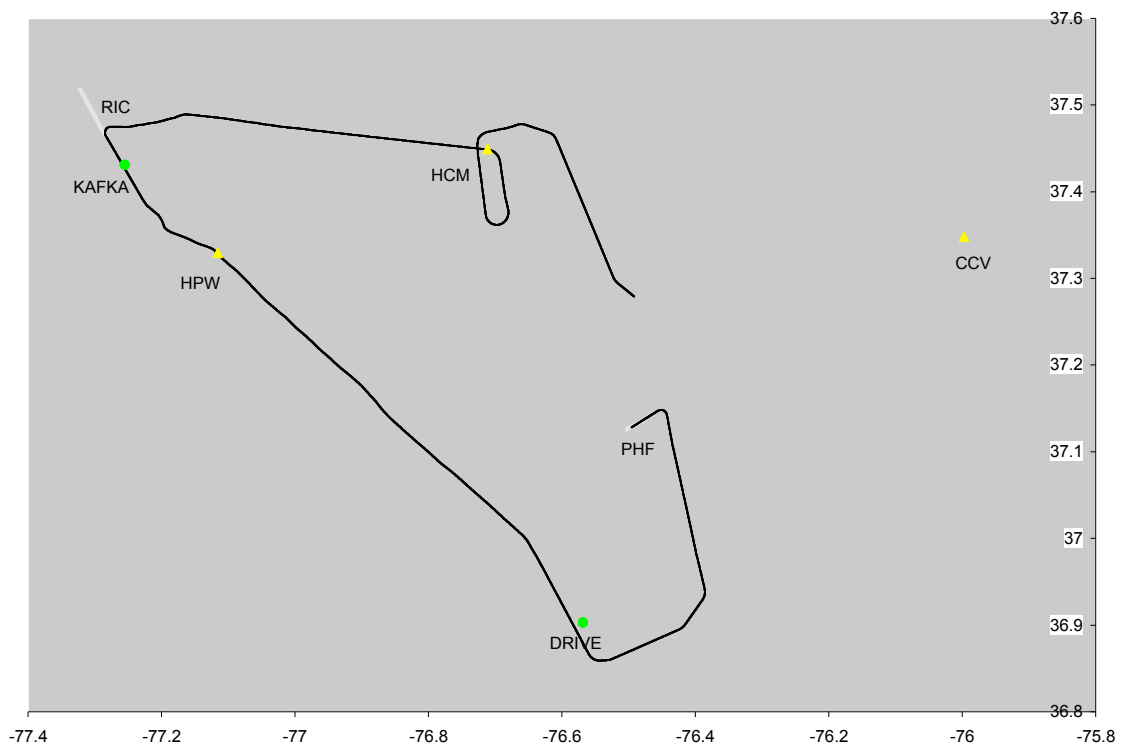
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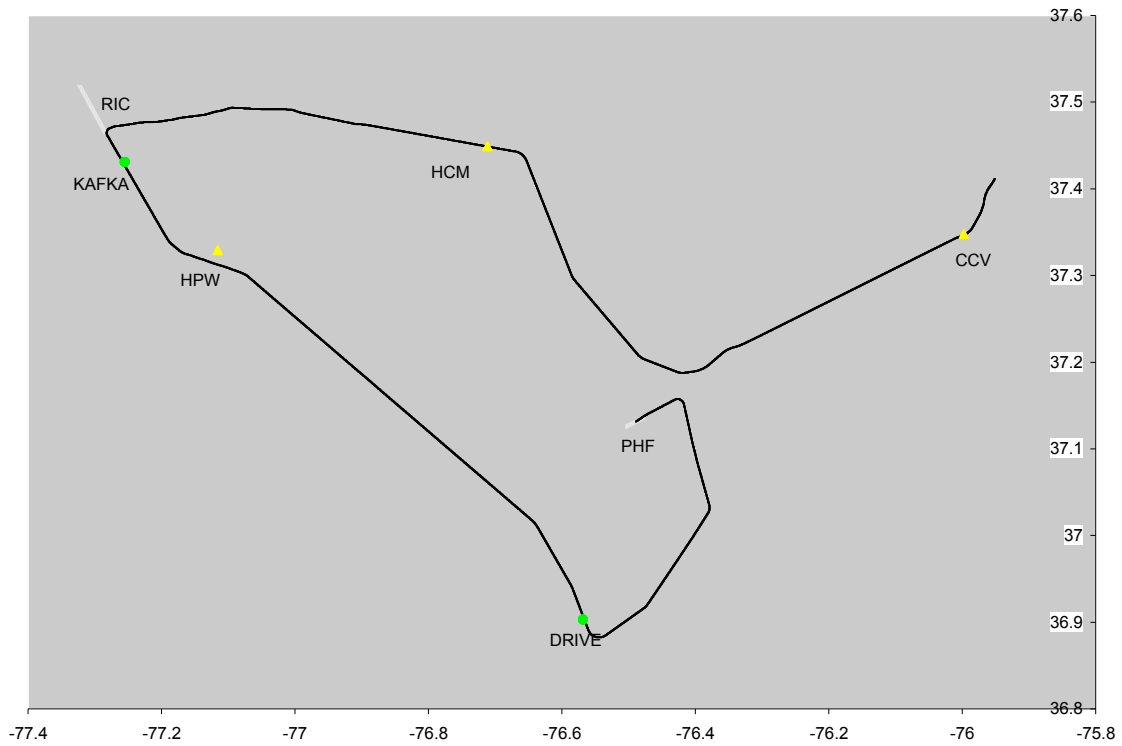
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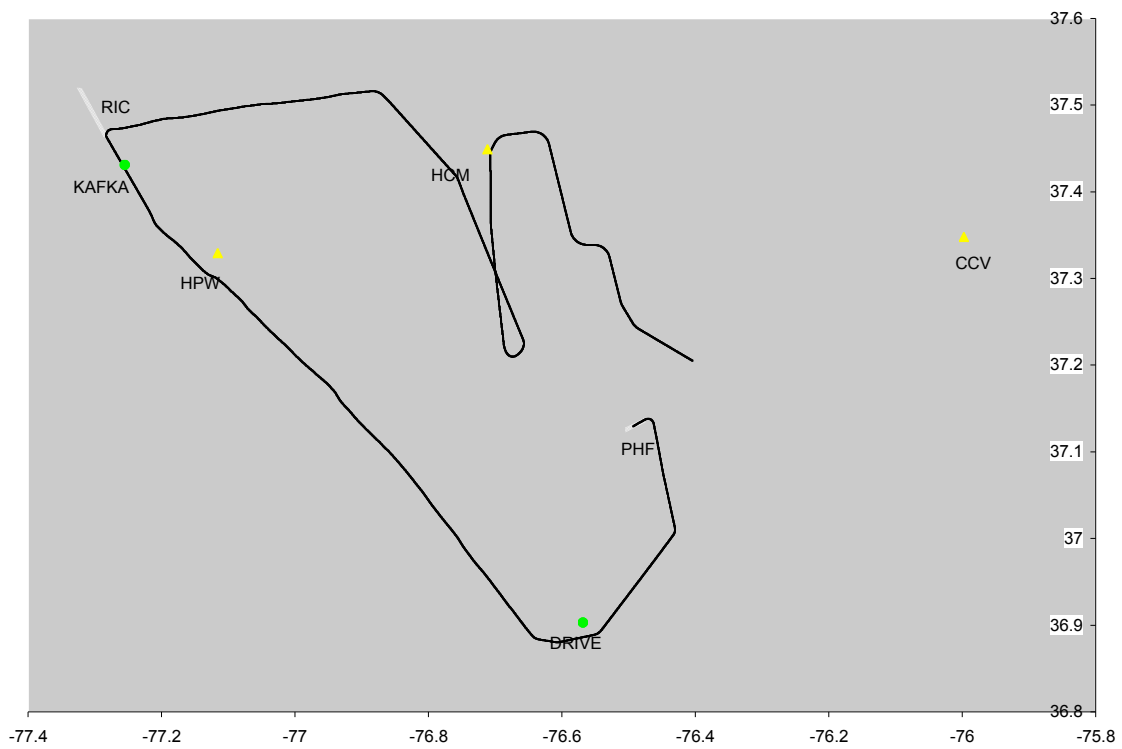
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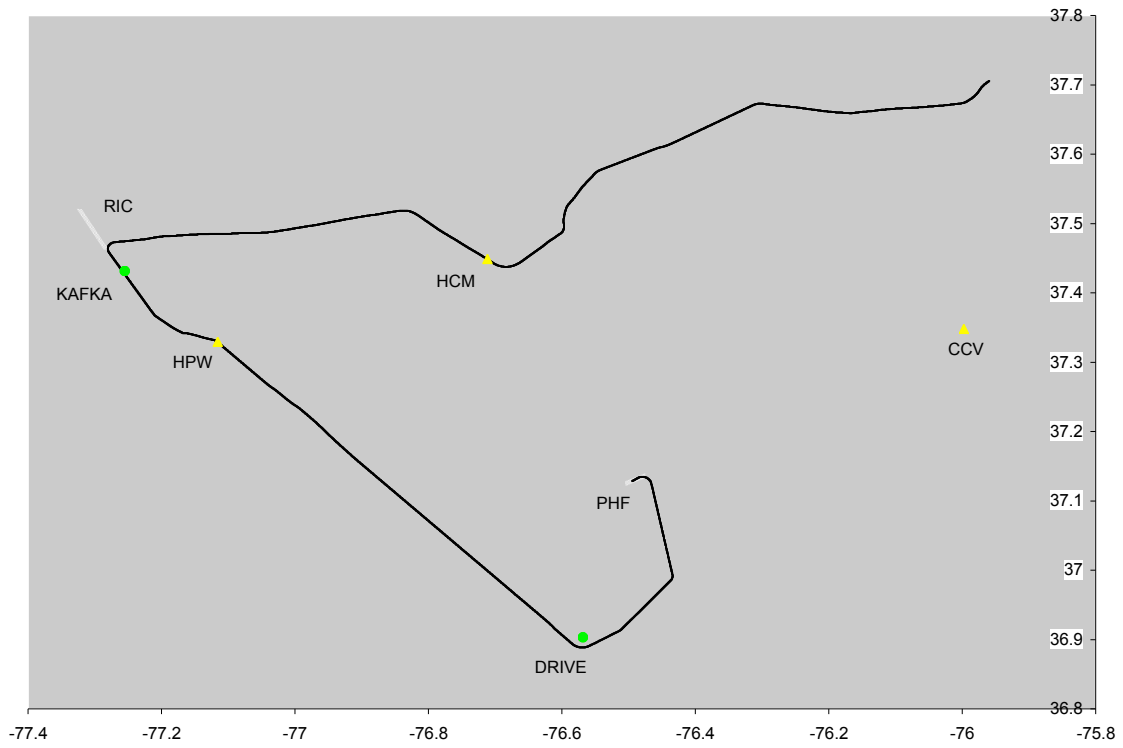
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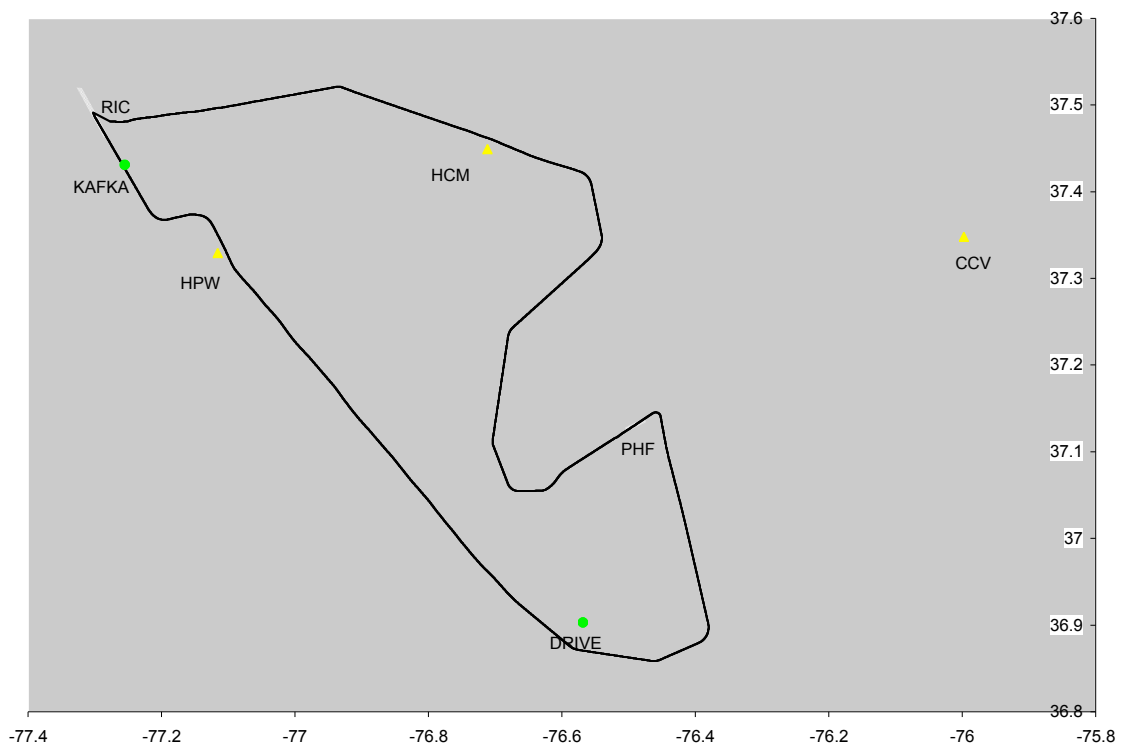
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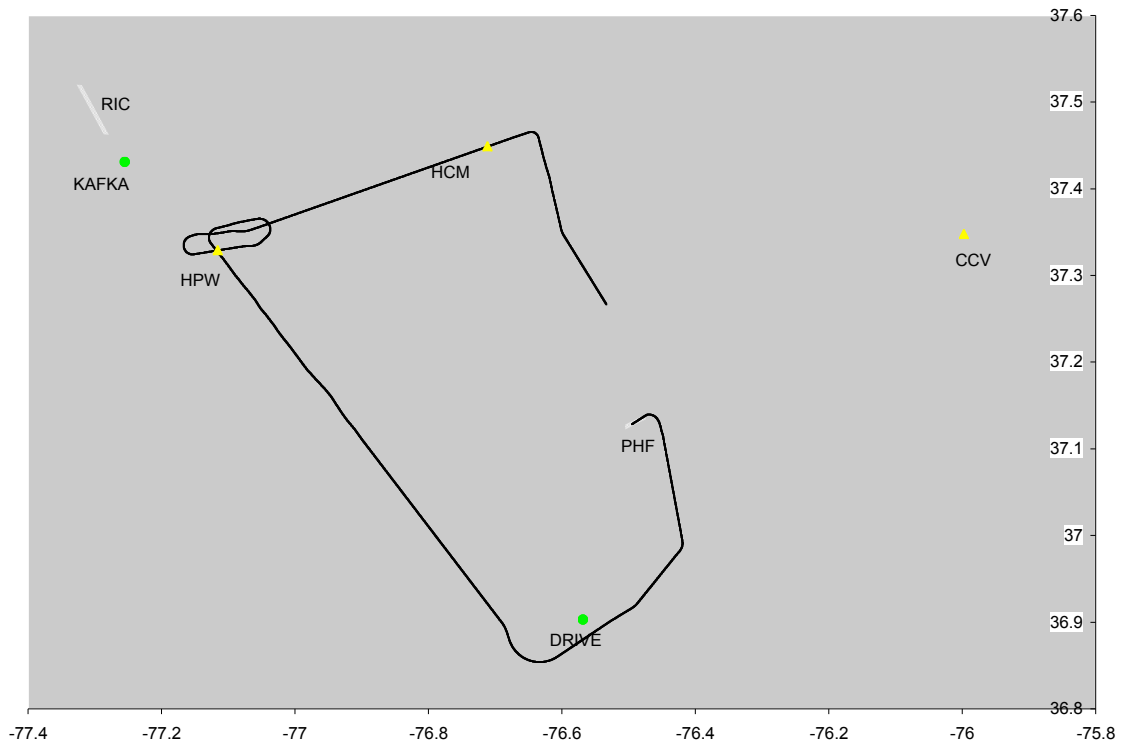
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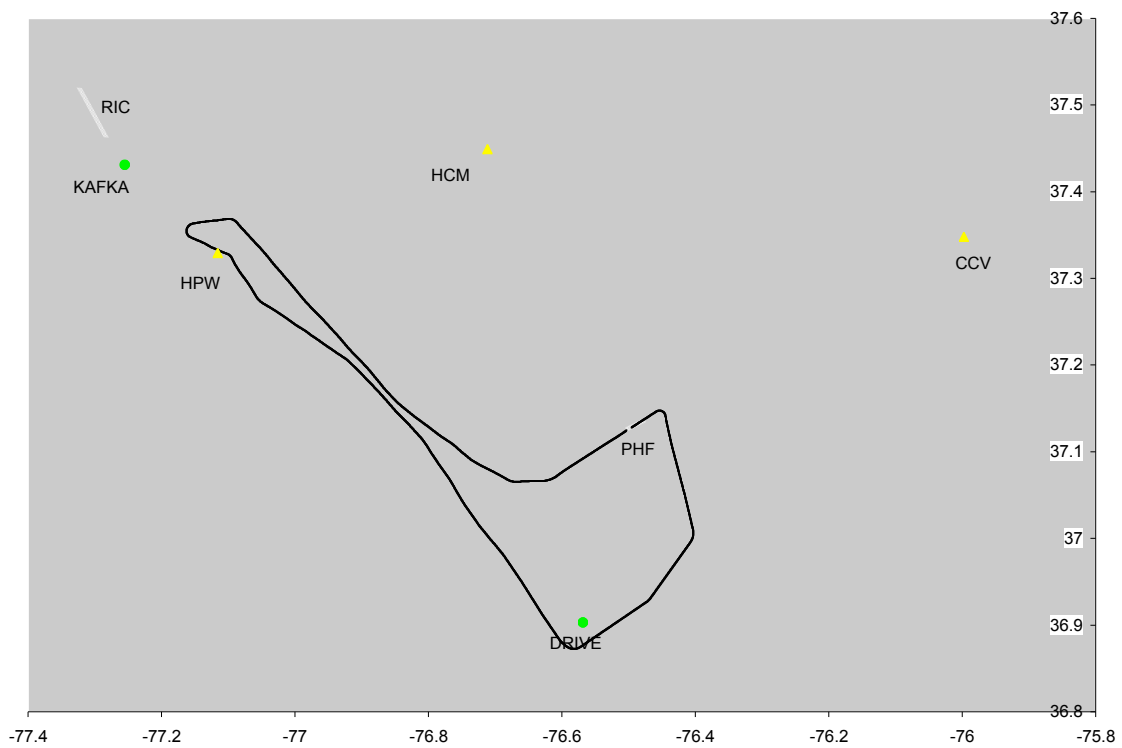
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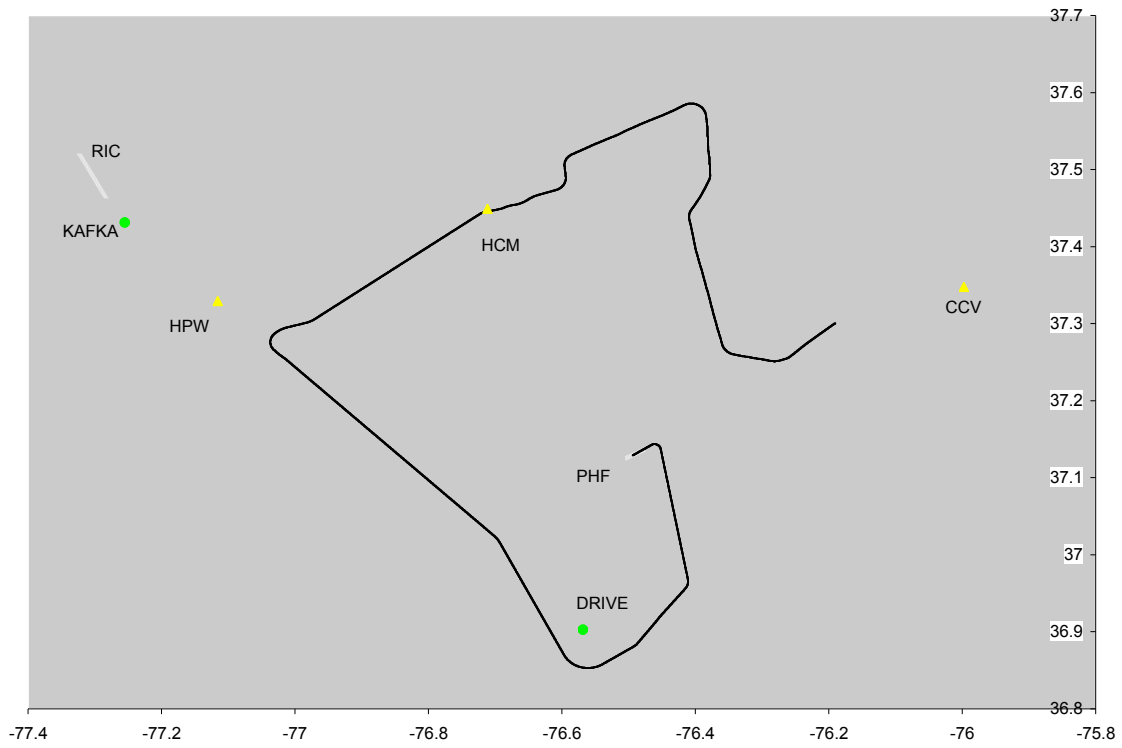
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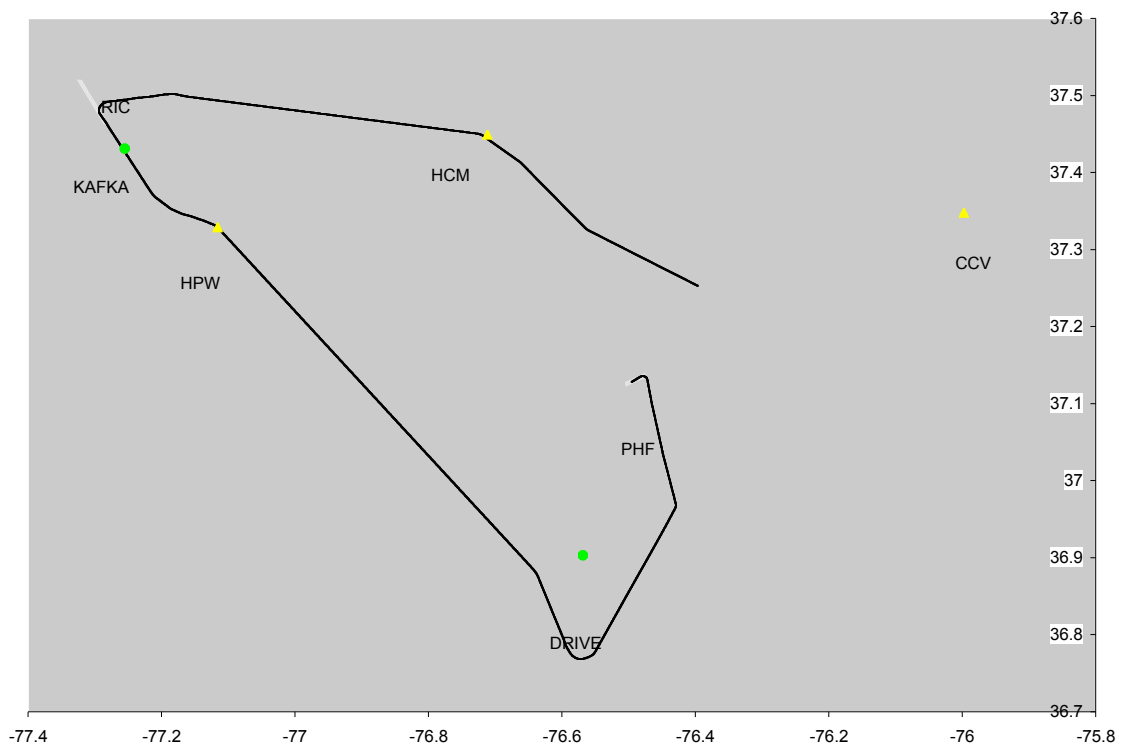
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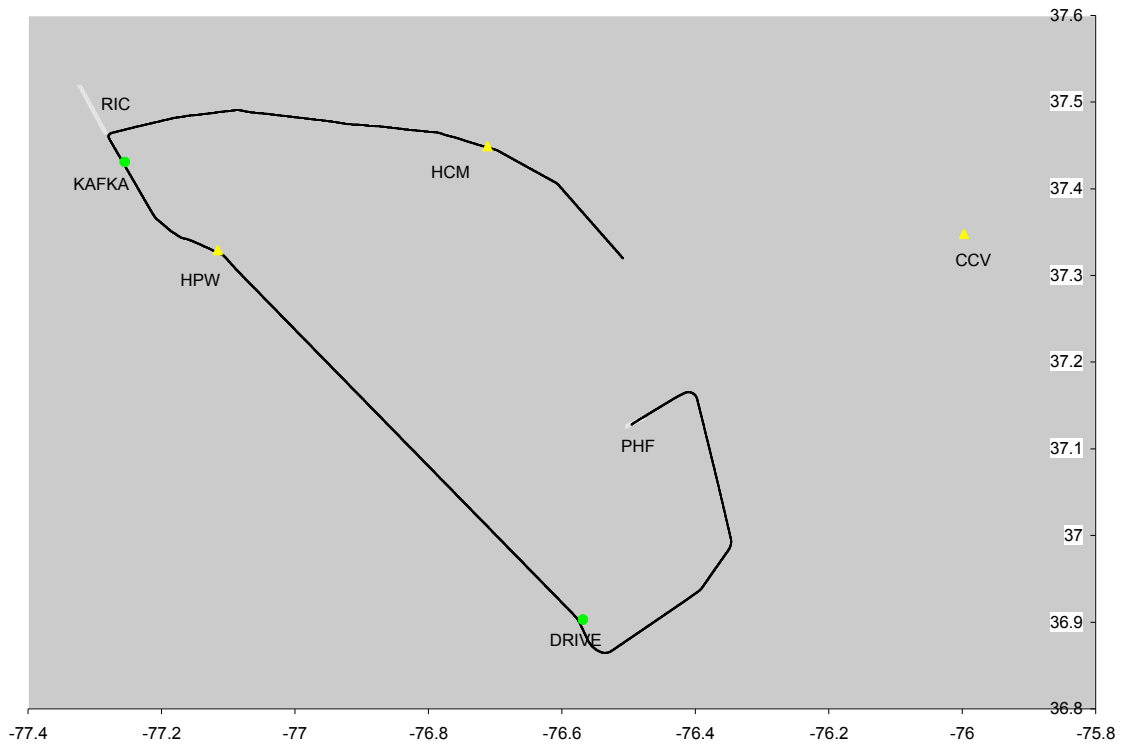
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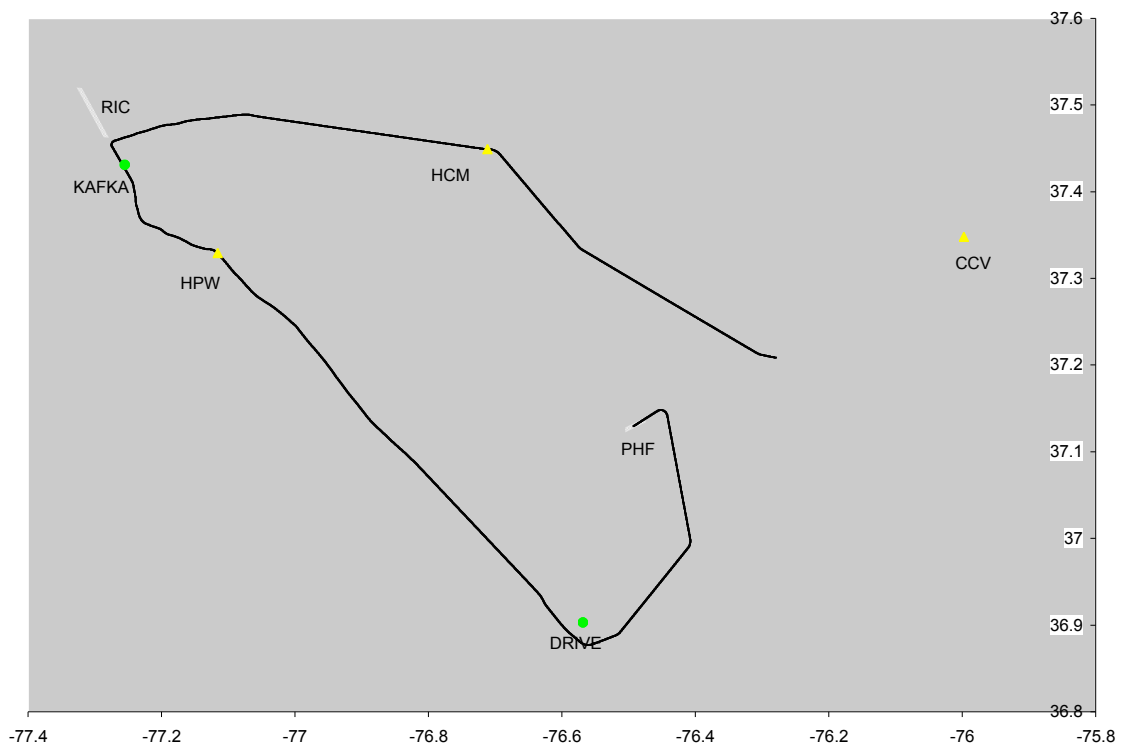
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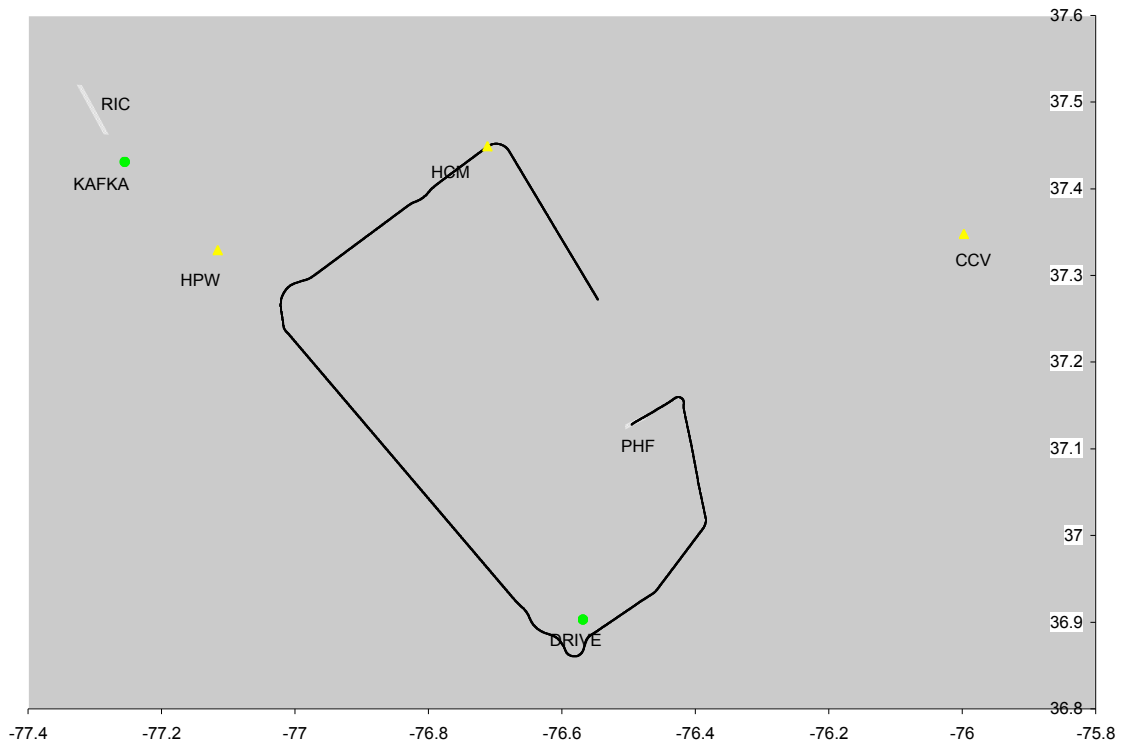
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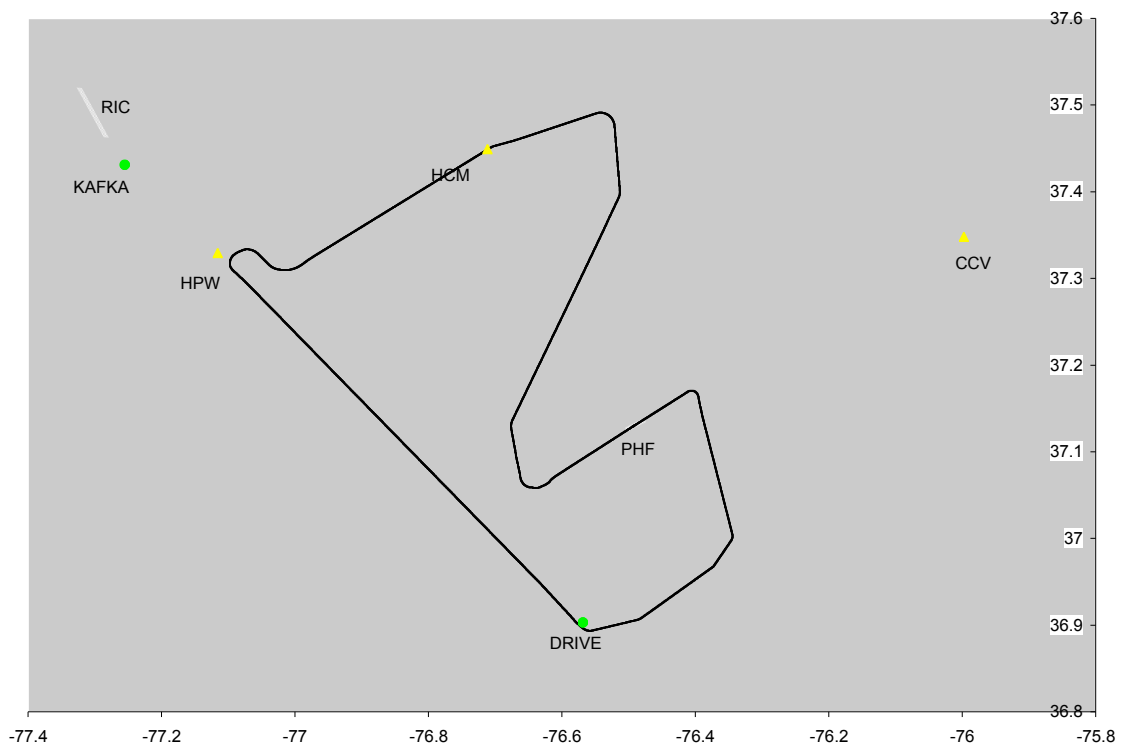
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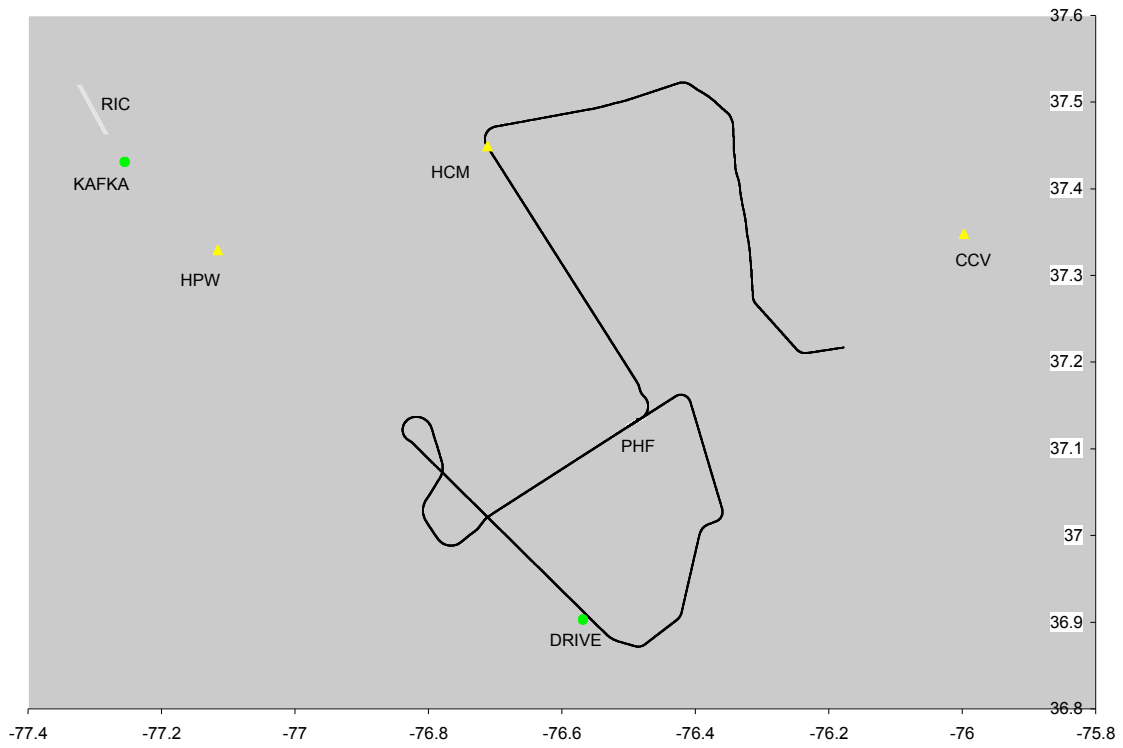
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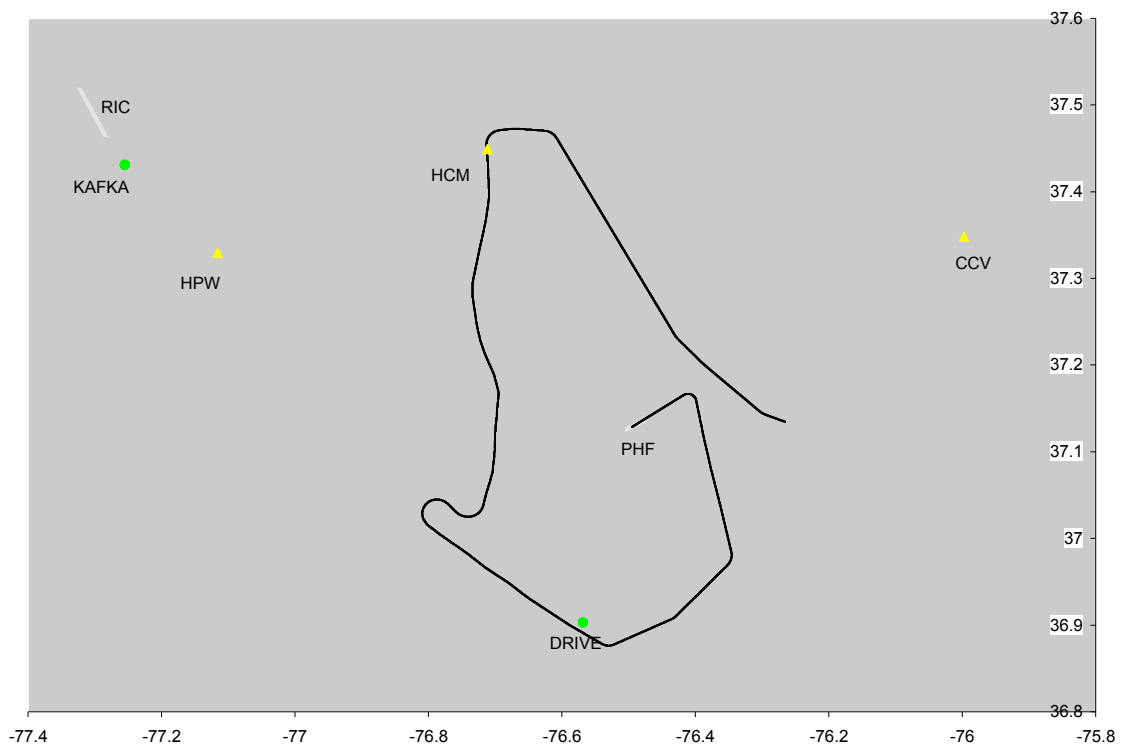
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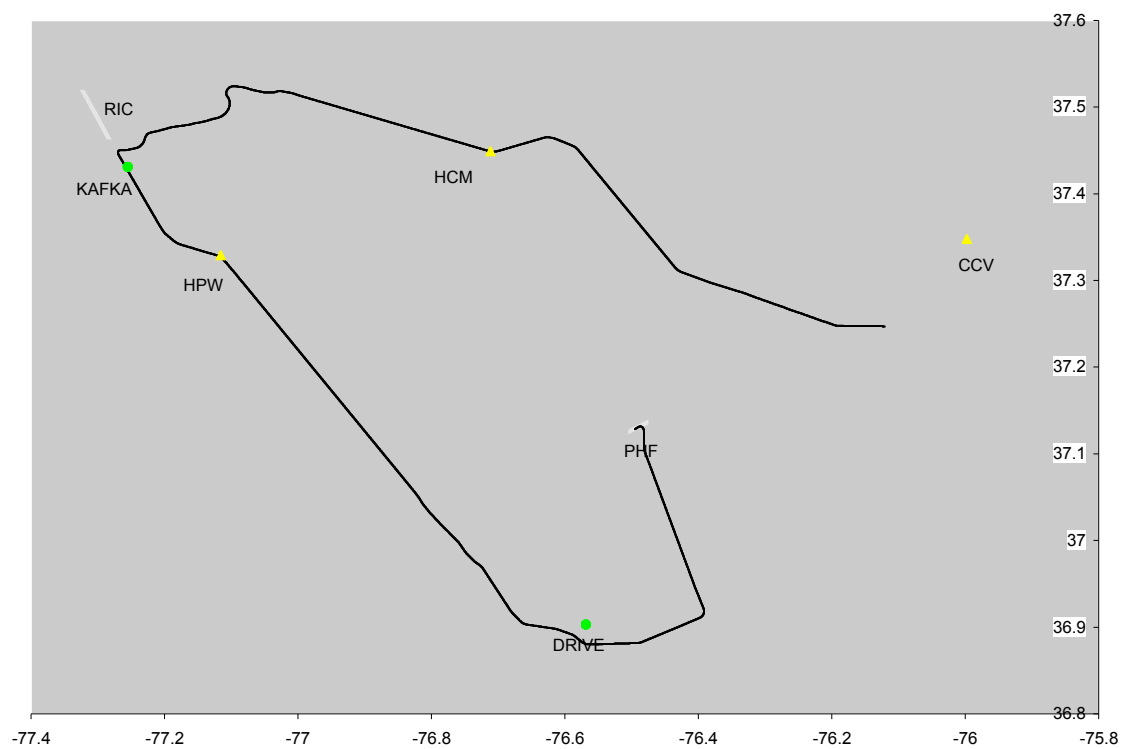
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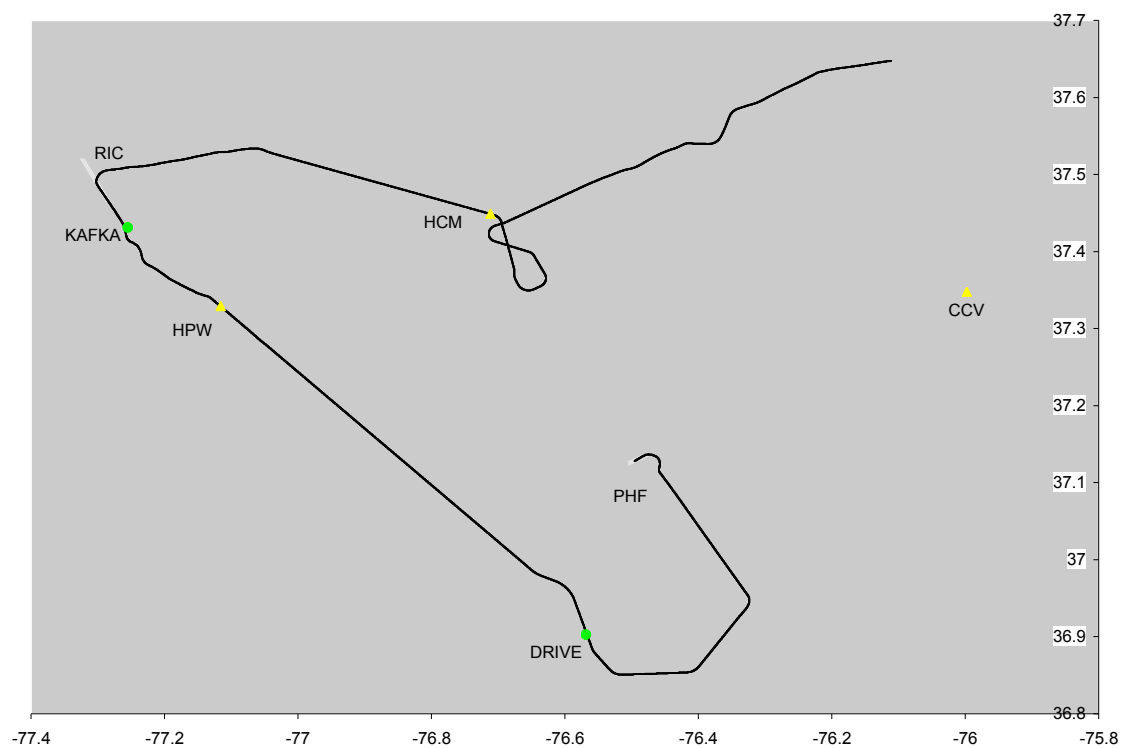
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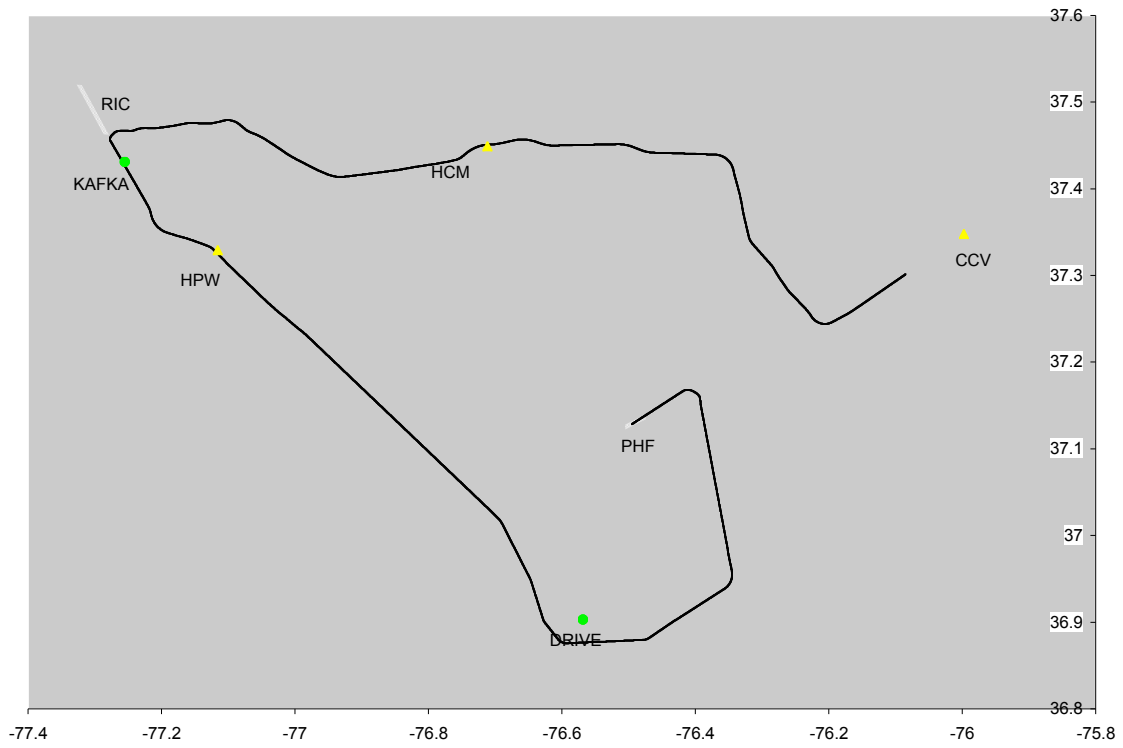
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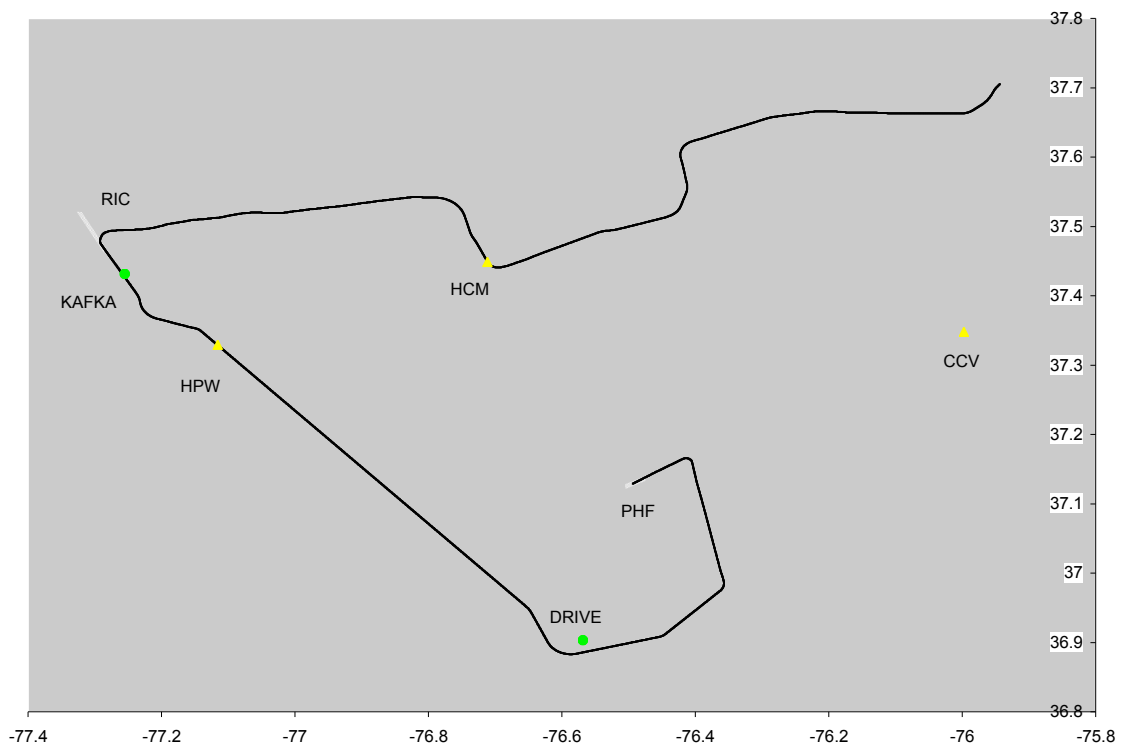
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Subject 46



Subject 47



Subject 48

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14. ABSTRACT This experiment investigated improvements to cockpit weather displays to better support the hazardous weather avoidance decision-making of general aviation pilots. Forty-eight general aviation pilots were divided into three equal groups and presented with a simulated flight scenario involving embedded convective activity. The control group had access to conventional sources of pre-flight and in-flight weather products. The two treatment groups were provided with a weather display that presented NEXRAD mosaic images, graphic depiction of METARs, and text METARs. One treatment group used a NEXRAD image looping feature and the second group used the National Convective Weather Forecast (NCWF) product overlaid on the NEXRAD display. Both of the treatment displays provided a significant increase in situation awareness but, they provided incomplete information required to deal with hazardous convective weather conditions, and would require substantial pilot training to permit their safe and effective use.					
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