NASA / CR-2001-211047

Use of a Data-Linked Weather Information Display and Effects on Pilot Navigation Decision Making in a Piloted Simulation Study

Daniel E. Yuchnovicz, Paul F. Novacek, Malcolm A. Burgess, Michael L. Heck, and Alan F. Stokes
Research Triangle Institute, Hampton, Virginia

August 2001

The NASA STI Program Office ... in Profile

Since its founding, NASA has been dedicated to the advancement of aeronautics and space science. The NASA Scientific and Technical Information (STI) Program Office plays a key part in helping NASA maintain this important role.

The NASA STI Program Office is operated by Langley Research Center, the lead center for NASA's scientific and technical information. The NASA STI Program Office provides access to the NASA STI Database, the largest collection of aeronautical and space science STI in the world. The Program Office is also NASA's institutional mechanism for disseminating the results of its research and development activities. These results are published by NASA in the NASA STI Report Series, which includes the following report types:

- TECHNICAL PUBLICATION. Reports of completed research or a major significant phase of research that present the results of NASA programs and include extensive data or theoretical analysis. Includes compilations of significant scientific and technical data and information deemed to be of continuing reference value. NASA counterpart of peer-reviewed formal professional papers, but having less stringent limitations on manuscript length and extent of graphic presentations.

- TECHNICAL MEMORANDUM. Scientific and technical findings that are preliminary or of specialized interest, e.g., quick release reports, working papers, and bibliographies that contain minimal annotation. Does not contain extensive analysis.

- CONTRACTOR REPORT. Scientific and technical findings by NASA-sponsored contractors and grantees.

- CONFERENCE PUBLICATION. Collected papers from scientific and technical conferences, symposia, seminars, or other meetings sponsored or co-sponsored by NASA.

- SPECIAL PUBLICATION. Scientific, technical, or historical information from NASA programs, projects, and missions, often concerned with subjects having substantial public interest.

- TECHNICAL TRANSLATION. English-language translations of foreign scientific and technical material pertinent to NASA's mission.

Specialized services that complement the STI Program Office's diverse offerings include creating custom thesauri, building customized databases, organizing and publishing research results ... even providing videos.

For more information about the NASA STI Program Office, see the following:

- Access the NASA STI Program Home Page at ***http://www.sti.nasa.gov***

- E-mail your question via the Internet to help@sti.nasa.gov

- Fax your question to the NASA STI Help Desk at (301) 621-0134

- Phone the NASA STI Help Desk at (301) 621-0390

- Write to:
  NASA STI Help Desk
  NASA Center for AeroSpace Information
  7121 Standard Drive
  Hanover, MD 21076-1320

NASA / CR-2001-211047

Use of a Data-Linked Weather Information Display and Effects on Pilot Navigation Decision Making in a Piloted Simulation Study

Daniel E. Yuchnovicz, Paul F. Novacek, Malcolm A. Burgess, Michael L. Heck, and Alan F. Stokes
Research Triangle Institute, Hampton, Virginia

National Aeronautics and
Space Administration

Langley Research Center
Hampton, Virginia 23681-2199

Prepared for Langley Research Center
under NASA Agreement NCA1-130

August 2001

Available from:

NASA Center for AeroSpace Information (CASI)
7121 Standard Drive
Hanover, MD 21076-1320
(301) 621-0390

National Technical Information Service (NTIS)
5285 Port Royal Road
Springfield, VA 22161-2171
(703) 605-6000

Acknowledgement

The authors of this report wish to acknowledge the help of several colleagues whose contributions were key to the successful completion of this study. Mr. James Henion from Research Triangle Institute prepared specialized software required for this simulation and operated the simulation. Mr. James Murray, Air Traffic Control consultant, developed and executed the ATC scripts used during the simulation runs. Dr. Raymon McAdaragh of the Federal Aviation Administration obtained and organized the weather documentation used by the subject pilots in the study. Dr. Holly Travers of Rensselaer Polytechnic Institute, performed the statistical analyses of the data obtained in the study. Mr. Alex Viale, Masters Student at Rensselaer Polytechnic Institute, assisted in the extensive literature search.

We would like to thank Mr. Brian Haynes of Honeywell for cooperation in the modification and use of a prototype Flight Information Services Data Link display system in the simulation. We would also like to acknowledge the contributions of the subject pilots who participated voluntarily in this study. Traveling at their own cost from as far away as Arizona, New York, and Pennsylvania, these individuals were magnificent in the generosity of their contribution of time, patience and piloting skills.

Table of Contents

Tables

Figures

Executive Summary

Reason for Study

Significant progress has been made in recent years toward the provision of data-linked weather information to pilots. Recently, the FAA entered into a government-industry partnership to develop the broadcast Flight Information Services Data Link (FISDL) service, which is scheduled for an initial operational capability in 2000. There are also non-FAA FISDL systems under development, some of which use request-reply links. However, many questions remain unanswered about the form and function of airborne data link weather information. Some specific issues include:

- Appropriate use of data-linked weather information for in-flight decisions (strategic and/or tactical);
- Use of data-linked weather information as a supporting in-flight information source and not as a sole source of in-flight weather information;
- Display of real-time ownship aircraft position and/or flight path information on cockpit displays of time-delayed weather products.

This study was conducted as the first in a series of studies to examine such issues and to develop a better understanding of the use of data-linked weather information. The results of such studies serve to validate the existing FAA guidance, RTCA standards and training materials for cockpit weather systems, and to provide recommendations for future guidance.

Overview of Study

The study reported herein is the first in a series of rigorous investigations using piloted simulation of the effects of data link weather displays upon pilot decision performance. An experiment was conducted with twenty-four current instrument rated pilots who were divided into two equal groups and presented with a challenging but realistic flight scenario involving weather containing significant embedded convective activity. The flight scenario was intentionally designed to present significant stress for pilot decision-making in a challenging weather environment. 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 experimental objective was to investigate the potential for misuse of weather information on their cockpit displays, and to incorporate the lessons learned in recommendations for the design and use of these displays.

The control group performed the flight with access to conventional sources of pre-flight and in-flight weather products. In addition to the conventional weather sources, the treatment group was provided with a weather display in the cockpit that presented text and graphical weather products.

Conclusions of Study

Test configuration of cockpit weather display did not improve decision-making

The configuration of the weather display system implemented in this study did not improve the decision making of the pilots using the display. Reasons for this finding included:

1. Pilots were unable to easily perceive their proximity to potentially hazardous convective weather conditions depicted graphically by the display.

2. Pilots were unable to easily estimate the juxtaposition of their flight path with the path of graphically depicted hazardous convective weather conditions (NEXRAD mosaic images) because own path was not depicted on display and probable path of the hazardous weather was not depicted.

3. Use of the cockpit weather display increased the workload for at least half of the pilots, decreasing the time available for decision making.

4. Many pilots experienced difficulty in deciphering METAR textual data.

Pilots with the cockpit weather information display, relied less on other available weather information sources

The display of NEXRAD mosaic images substantially increased the pilots' awareness of the general location of convective weather in their vicinity. The compelling nature of the display of these images, however, caused some pilots to depend too heavily on the weather display for their information regarding hazardous convective weather conditions. As a result, they failed to obtain other essential and corroborating information from other available sources.

Standards are needed for a cockpit weather information display

Standards for system performance, display content and format, and operational use do not yet exist and must be developed in a timely fashion to support the safe implementation and effectiveness of cockpit weather information displays. These standards must be based on substantial and well-founded research in lieu of trial and error in the market place.

Training is required to effectively use a cockpit weather information display

Substantial training in the use of a cockpit weather display system will be required to help pilots understand the limitations of a weather 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.

An autopilot may be required to use a cockpit weather information display in instrument conditions

The safe and effective use of a cockpit weather information display in actual instrument conditions will almost certainly require the support of an autopilot for most pilots.

Recommendations

Recommendations are provided based on the findings of this study for possible incorporation in the FAA Aeronautical Information Manual (AIM) and other FAA guidance for users and manufacturers of a cockpit weather information display.

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

- Consider Providing Ownship Information
- Provide Direction and Rate of Hazardous Weather
- Provide Distance Determination
- Provide Intuitive NEXRAD Image Age Information
- Provide METAR Code Translation

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

- Further development of weather information integration and display design enhancements,
- Further evaluations of specific FISDL issues to support standards for design, implementation and use of FISDL services,
- Development of a training curriculum for weather information displays.

Recommended information to be added to the AIM and to advisory circulars now in draft stage includes:

- The requirement that pilots become fully proficient in determining and maintaining awareness of the age of all FISDL service products,
- Limitations on the use of FISDL service products due to their age,
- Further warning that a cockpit weather information display cannot be used for navigation purposes,
- The value of an autopilot to offset workload and free up mental processes to support use of a cockpit weather information display.

1 Introduction

Statistics indicate that there is, on average, one fatal general aviation accident per day in the United States alone.[1] Some of the reasons for these fatalities include pilot-related causes, mechanical failure, midair collisions and other problems.[2] While mechanical failure accounts for only 14.1 percent of the total accidents, pilot-related causes account for over 73 percent of the total accidents. The primary causes of fatalities were weather, maneuvering flight and approaches. Weather-related accidents were more likely to be fatal than any of the other major causes of fatal accidents.[3] With an overall fatality rate of 83.1 percent, weather accidents were the deadliest of the pilot-caused fatalities. Most fatalities involving weather were the result of controlled flight into terrain or other objects, spatial disorientation leading to uncontrolled flight, or pilot-induced structural failure of the aircraft. Some accidents attributed to other causes involved weather as a contributing factor as in the cases of improper IFR approach accidents. Windshear and crosswind also caused weather-related accidents. Most troubling is that 72.2 percent of the weather-related fatalities were caused by attempted VFR flight into Instrument Meteorological Conditions (IMC).

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

Advances in display system design are attempting to reduce the pilot's cognitive workload, by doing much of the integration work for them. These designs are moving toward flat-panel displays with terrain, traffic, routing, and weather all overlaid on a single screen, thereby fostering a more intuitive mental model of "the big picture" for the pilot. By reducing the workload involved in mentally integrating multiple elements, pilots' can

---

[1] 341 fatal accidents occurred in general aviation in 1998 out of a total of 1,679 accidents. The 341 fatal accidents resulted in 619 fatalities. Source – 1999 Nall Report, Aircraft Owners and Pilots Association (AOPA) Air Safety Foundation.

[2] A full 70 percent of all accidents resulted in little or no injury. However, 73.4 percent of all accidents (1,233 total/247 fatal) were attributed to pilot-related causes, 14.1 percent (236 total/19 fatal) were attributed to mechanical/maintenance problems, with the balance of accidents attributed to midair collisions (14 total/11 fatal), alcohol and drugs (2 total/1fatal), fuel mismanagement (136 total/9 fatal), off airport injuries (i.e. bystander injuries/fatalities from debris and impact) (7 total/5 fatal), pilot incapacitation (3 total/2 fatal), and homebuilt aircraft (199 total/54 fatal).

[3] Weather-related accidents had an 83.1 percent fatality rate (65 total, 54 fatal), maneuvering flight accidents had a 46.7 percent fatality rate (135 total/63 fatal) and approach accidents had a 36.5 percent fatality rate (96 total/35 fatal).

allocate attention elsewhere, particularly to higher level situation assessment, judgment and decision making tasks. Extra attention to these tasks should reduce the opportunity for error and enable the individual to make more considered decisions.

However, because human performance research has lagged well behind the display manufacturers, many of the performance issues have 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.

The Federal Aviation Administration (FAA) awarded contracts in 1999 for the development of two Flight Information Services Data Link (FISDL) systems. The FISDL systems will broadcast text and graphical products via data link for reception and display in equipped aircraft. An overview of the FISDL systems is provided in Appendix A. At present, however, the initial FAA guidance is limited to a description of the FISDL system included in the AIM and draft material on FISDL display standards being developed by the RTCA. The guidance provided in the AIM is reproduced in Appendix R. The experiment reported here was undertaken to develop a better understanding of the use of a cockpit weather information display.

The Research Triangle Institute's Center for Aerospace Technology, sponsored by the FAA and NASA, investigated pilot performance using a new airborne weather display in a full mission simulator expressly developed for the study of new cockpit technologies in general aviation. An experiment was conducted with instrument rated pilots who were presented with a challenging but realistic flight scenario involving weather with significant embedded convective activity. The experiment objective was to investigate the potential for misuse of weather information, and thus provide guidance to the FAA. A corresponding hypothesis was developed and investigated through experimentation: "Delayed weather information data linked to the cockpit display may lead to navigation decision errors."

1.1 Potential Issues with Datalinked Weather Displays

One potentially significant, indeed critical issue, in the use of displayed weather is that weather products are not displayed in real time as are most other cockpit data including the data provided by on-board weather radar.[4] This presents the pilot with complex issues of interpretation and prediction. It is not clear, for example, whether pilots will try to extrapolate, from delayed data, the current position of storm cells, and attempt to weave between areas of perceived danger (tactical use), or adopt a more conservative approach of longer-term route planning to avoid potential hazards altogether (strategic use). The term "perceived" is crucial here, as studies to date suggest that a "keep out of the red"

[4] The latest graphical NEXRAD products will be broadcast to aircraft within one minute of reception from the weather service provider, but will be five or six minutes old when received from the weather service provider for transmission to the aircraft.

heuristic procedure may be adopted when, for example, viewing a NEXRAD baseline reflectivity product indicating amounts of rain fall according to a color coding scheme. Of course, the cessation of red cells (indicating areas of heavy rainfall) does not imply the cessation of peril. Areas of low visibility, turbulence and windshear may not appear as coded zones in certain weather products so any such heuristic procedure is a dangerous one.

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

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

1.2 Survey of Relevant Literature

The literature pertaining to display of weather information provided by data link to the cockpit as it exists today is still in its infancy. The next generation of research must begin in order to catch up to rapidly emerging technology. The results of a search of the literature relevant to the display of data link weather information are provided in Appendix B, Literature Search Results; a summary is provided below.

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

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

Spatial displays have also been found to improve accuracy over text in presenting information for an analog operation/tactical decision task (Wickens & Scott, 1983).
All these findings are consistent with the multiple resource theory of attention, and the proximity/compatibility principle, which 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).

Studies conducted to date represent a mere fraction of the studies that the introduction of new technologies will need, if progress is to be made to resolve the appreciable number of issues that arise.

2 Participants

This study was a cooperative effort between the Federal Aviation Administration (FAA), National Aeronautics and Space Administration (NASA) and the Research Triangle Institute (RTI).

2.1 FAA Data Link Office

The FAA Data Link Office AND-520 is the prime sponsor for this study. This effort was undertaken to support the periodic revisions to the Aeronautical Information Manual (AIM) performed by AFS-410 of the FAA, and development of other FAA guidance for the manufacture and use of cockpit weather information displays supported by data link communications.

2.2 NASA AWIN Project

The NASA AWIN (Aviation Weather INformation) project provided additional funding, technical support, and contract management for this study in support of the FAA. The AWIN project is an element under the Aviation Safety Program Office of NASA Langley Research Center, Hampton, Va.

2.3 Research Triangle Institute

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

3 Methodology

It was decided to base this study on an experiment in which subject pilots representative of probable users of the FISDL products would use the FISDL equipment in typical operational conditions. The objective of the experiment was to investigate the potential for misuse of the weather information, and thus provide recommendations to the FAA. In particular, the concern was that delayed weather information datalinked to the cockpit display might lead to tactical navigation decision errors. Thus, the experiment was designed to prove or refute such a hypothesis, while extracting other information useful for regulatory and procedural guidance.

3.1 Experimental Design

The experiment was designed to have certain desirable properties. It was moderate in length (approximately one hour depending on pilot actions) in order to eliminate fatigue-related effects. It was made up of sufficiently independent phases to test responses to discrete weather conditions. The “incident density” was to be plausible and would be designed to occur while crossing informational boundaries (where most decision related errors are more likely to occur). The mission scenario and cockpit simulator were to be sufficiently realistic such that the subject pilot would be immersed in the experiment. The simulator instrument panel in the control group did not have a weather display. The instrument panel used by the treatment group provided a weather information display.

The experiment employed a “between-subjects” design, whereby two groups of similar subject pilots were divided into control and treatment groups. Performance differences between the two groups could then be attributed to differences between the control and treatment conditions. This is in contrast to a “within-subjects” design, whereby an identical group of subject pilots perform two “equivalent” flights to test the hypothesis. With the “between-subjects” approach, it is not necessary to design two functionally equivalent flight scenarios, which must be sufficiently different in order to minimize training effects. However, twice as many subjects are required and care must be taken to assure equivalence of the two subject groups using the “between-subjects” approach.

In addition to determining the impact on navigation decision errors due to delayed weather information datalinked to the cockpit display, several co-variables were identified, and addressed in the course of the experiment to provide advisory information for the FAA and feedback to the avionics manufacturers. For example, it was noted how much instruction and practice was required to familiarize and operate the display. The pilots were questioned about their understanding of the data content, refresh rate, staleness, and NEXRAD cell size resolution. Post flight questionnaires were administered to determine if the pilots were able to determine both their location and their proximity to displayed weather (note: ownship position was *not* provided on the display used during the experiment). Pilots in the treatment group were invited to comment on the utility and shortcomings of the display.

A simulated flight was designed (using actual recorded weather) that originated in Newport News, Virginia, and consisted of two decision points: 1) approaching the Richmond, Virginia, airport, and 2) enroute to Wallops Island, Virginia. The actual weather consisted of two converging frontal boundaries. One frontal system included convective activity moving rapidly west to east across the vicinity of the Richmond airport. Another system—a low-pressure trough—contained convective activity developing along a north/south line over the Chesapeake Bay. The first decision emphasized the time-delay (temporal) aspects of the weather while the second decision emphasized the spatial aspects. Details of each scenario providing the two decision conditions are given in paragraph 4.2.

3.2 Pilot Selection Process

Because of the nature of the flight scenario, it was decided to limit subject pilot candidates to those who were currently *instrument rated*. To maximize the likelihood of navigation decision errors (i.e., tactical use of the display instead of strategic use) while performing the scenario's mission, the pilots were further selected according to their risk aversion tendencies and their knowledge of weather. Risk aversion was measured using a PC-based test described in Appendix C, Risk Aversion Test. The risk aversion test is a domain independent measure of what a subject pilot *does* in response to a risk-reward opportunity, not of what they *say* they will do.

Weather knowledge was measured with a written test, included in Appendix D, Weather Knowledge Questionnaire and Key. The test was promoted as a general aviation questionnaire to disguise the true nature of the experiment, thereby reducing any tendency for a subject pilot to study weather interpretation before the actual simulator trials began. There was a total score of 39 possible correct answers.

Following administration of the risk aversion and weather knowledge pre-screening tests, the scores were reviewed to assure sufficient diversity. The mean and standard deviation of the raw risk and weather knowledge scores were independently computed, normalized, and added for each subject. The highest composite positive scores represent high weather knowledge/low risk candidates; the lowest negative scores represent low weather knowledge/high risk candidates.

The tests were administered to 57 current IFR-rated pilot candidates. To provide a reasonable probability that differences in the responses between the control and treatment groups would be statistically significant (while working within a very limited budget), the experiment was conducted with 24 subject pilots: 12 control pilots (*without* the data-linked cockpit weather display) and 12 treatment pilots (*with* the cockpit weather display).

Figure 3.2-1 depicts the sorted raw risk aversion test results for the 57 candidate subject pilots. The test scores are tabulated in Appendix E, Subject Pilots Screening Test Results and Statistics. Scores of 3.0 or lower correspond to risk-averse characteristics, that is, pilots who display a low tendency to take risk. Alternatively, scores of 5.0 or greater correspond to very high risk individuals.

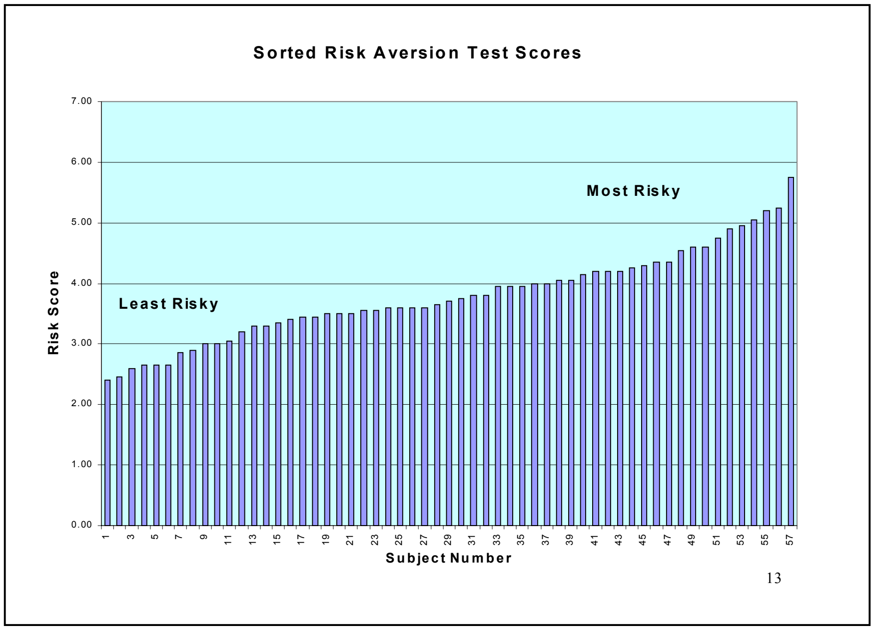


Figure 3.2-1. Sorted Risk Aversion Scores

A histogram of the risk aversion test scores is provided in Figure 3.2-2. The scores have been quantized to multiples of 0.4. The mean risk score was 3.79, with a standard deviation of 0.75.

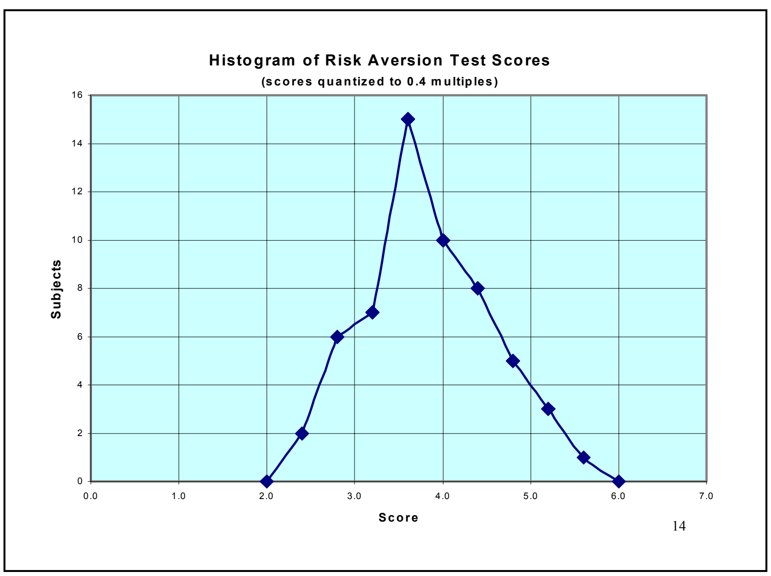


Figure 3.2-2. Risk Histogram

Figure 3.2-3 depicts the sorted weather knowledge scores for the 57 candidate subject pilots (see Appendix E, Subject Pilots Screening Test Results and Statistics). Of the 39 weather-related questions, three candidate subject pilots scored a near perfect score of 38. The lowest weather knowledge test score was 12 correct answers.

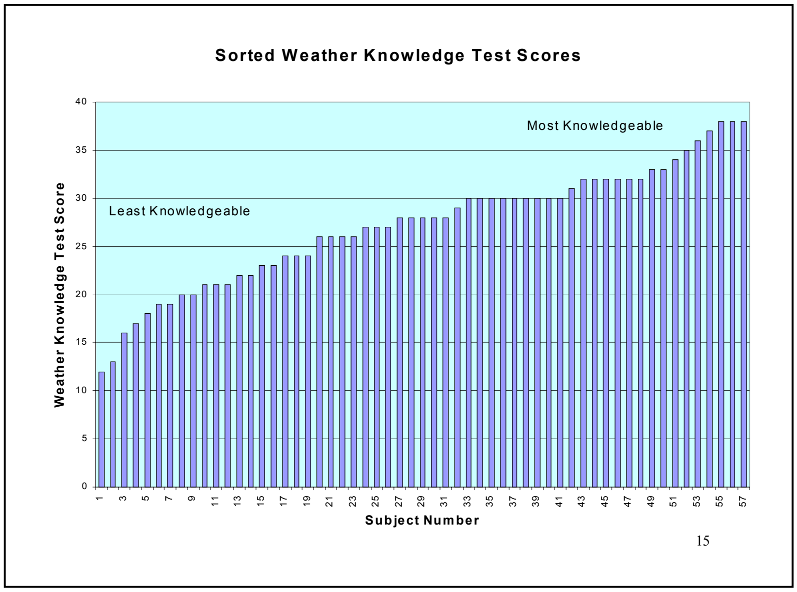


Figure 3.2-3. Sorted Weather Knowledge Scores

A histogram of weather knowledge test scores is provided in Figure 3.2-4. The scores have been quantized to multiples of 5.0. The average weather knowledge score was 27.2, with a standard deviation of 6.2.

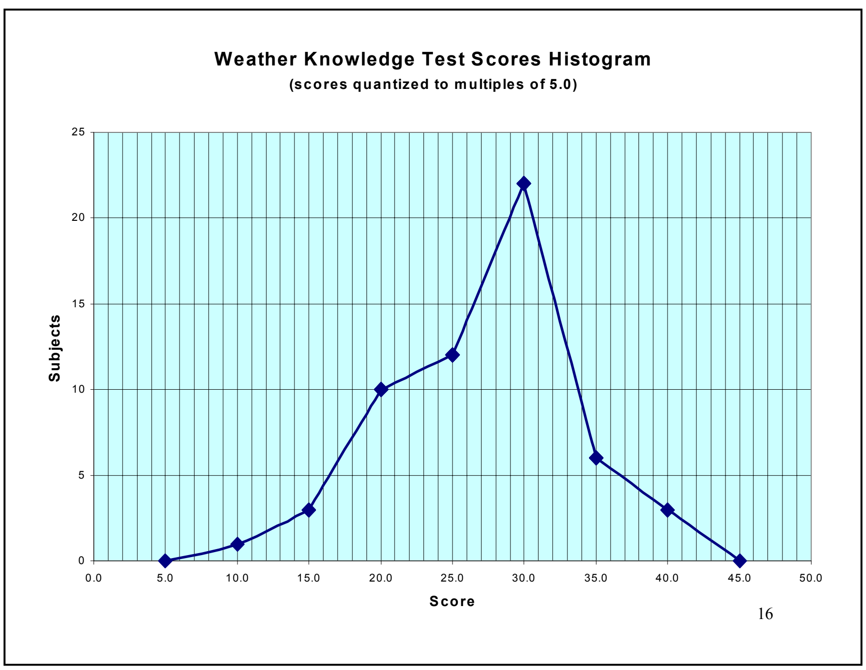


Figure 3.2-4. Weather Knowledge Test Scores Histogram

The mean and standard deviation of the raw risk scores and weather knowledge scores were independently computed, normalized, and added for each subject. The results are depicted in Figure 3.2-5 and summarized in Appendix E, Subject Pilots Screening Test Results and Statistics. The 24 subjects having the 12 highest and 12 lowest scores are highlighted.

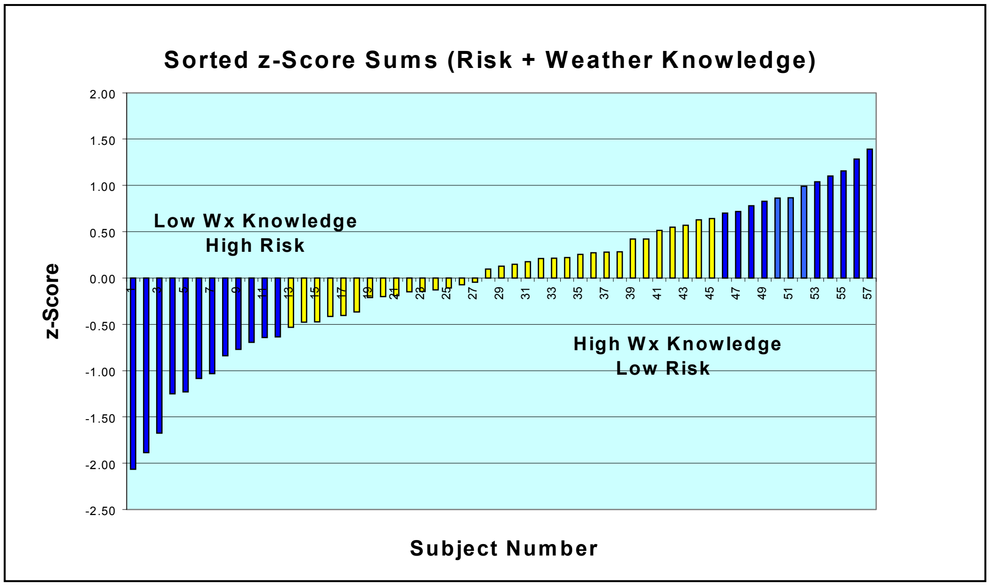


Figure 3.2-5. Sorted z-Score Sums (Risk + Weather Knowledge)

A histogram of the combined risk aversion/weather knowledge z-score sums is depicted in Figure 3.2-6. The scores have been quantized to multiples of 0.5 (a half standard deviation).

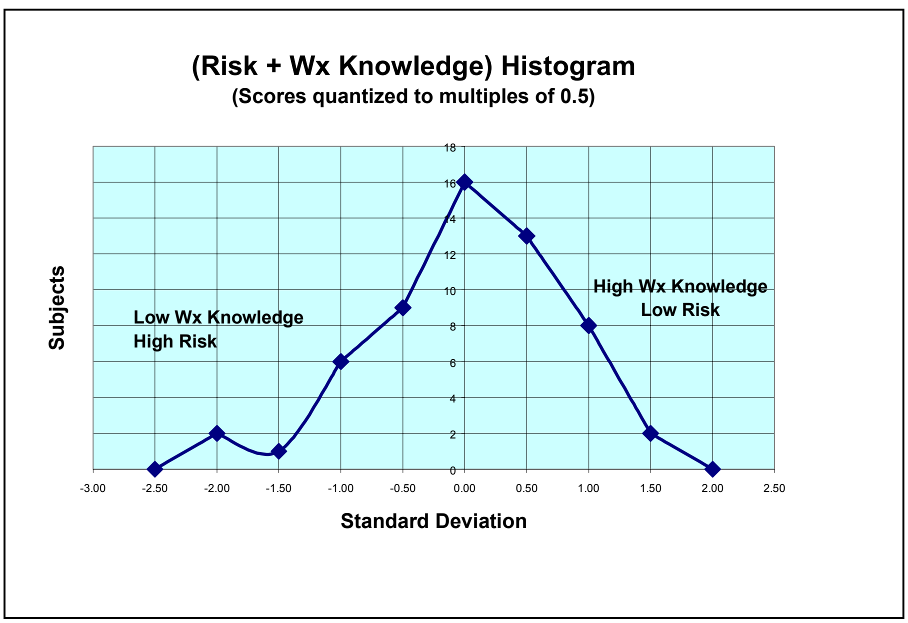


Figure 3.2-6. (Risk + Weather Knowledge) Histogram

A stratified random selection was performed to populate the control and treatment groups. The individual with the highest combined, normalized score went into treatment group #1. The individual with the second highest score went into control group #1. The third highest went into treatment group #1, the fourth highest into control group #1, etc. Similarly, the individual with the lowest combined score went into treatment group #2, the second lowest into control group #2, and so forth until the four groups were populated with six pilots apiece. In addition, two alternate subjects were identified for each of the four groups (similarly selected) to accommodate any contingency "no-shows" from among the primary candidates (in fact, after having been selected and scheduled, two of the primary 24 pilots were not able to participate in the experiment, and were replaced by their alternates).

Thus, following the pilot selection process, a treatment group of 12 pilots (subdivided into two groups based on their combined risk/weather knowledge scores), and a control group of 12 pilots (similarly subdivided), were selected to participate in the experiment. The subject pilot distribution is illustrated in Figure 3.2-7. After the experiment, an analysis was performed to determine if the subject pilot's risk/weather knowledge had any influence on tactical navigation decision errors.

During the conduct of the experiment, an additional subject pilot was invited to participate in case it was decided to discard the results obtained from one particularly anomalous pilot who did not completely "buy-in" to the mission scenario. Thus, a total of twenty-five mission simulations were conducted.

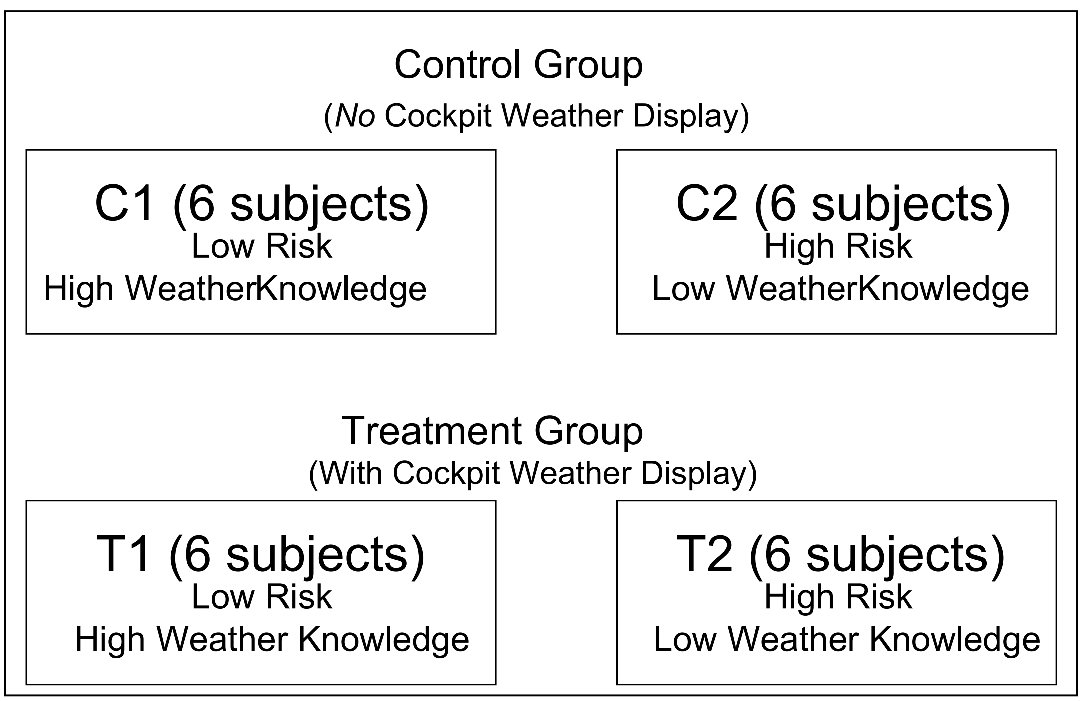


Figure 3.2-7. Subject Pilot Distribution

3.3 Experimental System

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

3.3.1 Pre-Flight Planning Tools

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

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

3.3.2 Flight Simulation Facility

The flight simulation facility consisted of a full-mission simulator that provided a simulation of a complex, high-performance single-engine, single-pilot IFR-equipped airplane having the major features and performance of a Piper Malibu PA-46-310P. The key elements of the simulation facility used are illustrated in Figure 3.3.2-1 and Figure 3.3.2-2. This full-mission simulator facility consisted of three major sections as follows:

- Aircraft Cockpit Simulator – Consisted of the cockpit mockup with controls, instruments, radios and indicators. A closed-circuit television camera was mounted behind and above the pilot's left shoulder to provide live images from the cockpit to the Scenario Controller and Observer positions. The simulated cockpit instrumentation is shown in Figure 3.3.2-3. For the treatment group, the weather display was located between the primary and secondary instruments to maximize its visibility and probability of use. The display was removed for the control group.

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

- ATC Controller Position – Consisted of a custom ATC workstation developed for performing 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. A display of the current pilot-selected communication frequencies was also provided so that the ATC controller could verify that the pilot was contacting ATC on the correct frequency before responding to an initial contact.

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

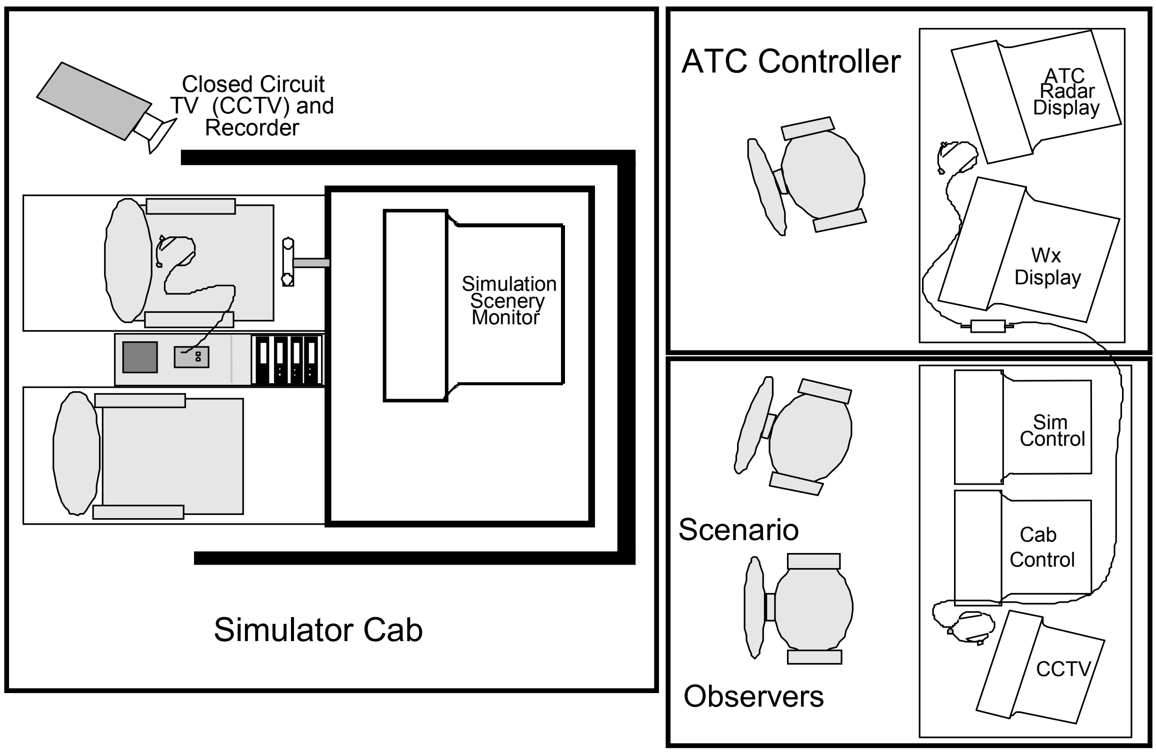


Figure 3.3.2-1. Experimental System Facility Layout

Figure 3.3.2-2. Key Simulation Facility Stations

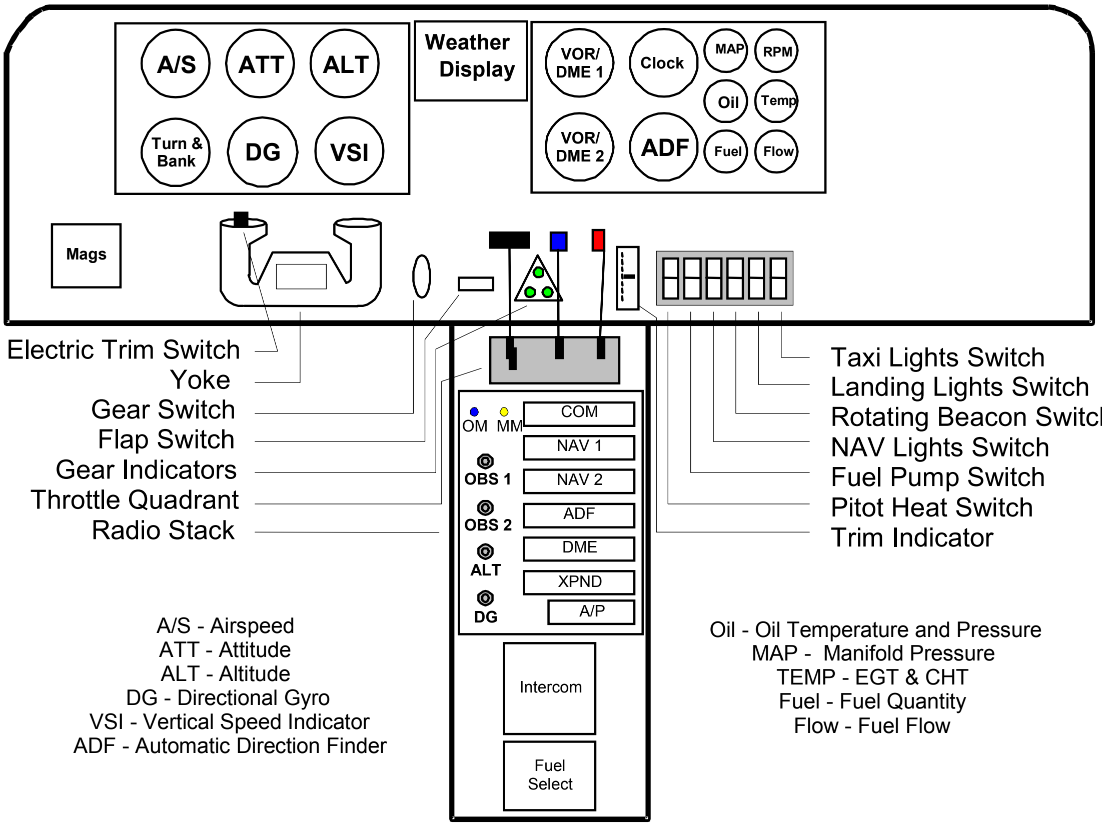


Figure 3.3.2-3. Cockpit Simulator Instrumentation

3.3.3 Computer Recorded Data Items

All essential data items were collected at a rate of 7.5 hertz by the scenario control computer during the conduct of the mission scenario. A list of the data items collected is provided in Appendix G, Cockpit Research Facility Description.

3.3.4 Weather Information Display

The major features of the weather display used in the experiment are depicted in figures 3.3.4-1 and 3.3.4-2. Details of the FISDL system of which this display is a part are provided in Appendix A, Flight Information Services – Broadcast Description.

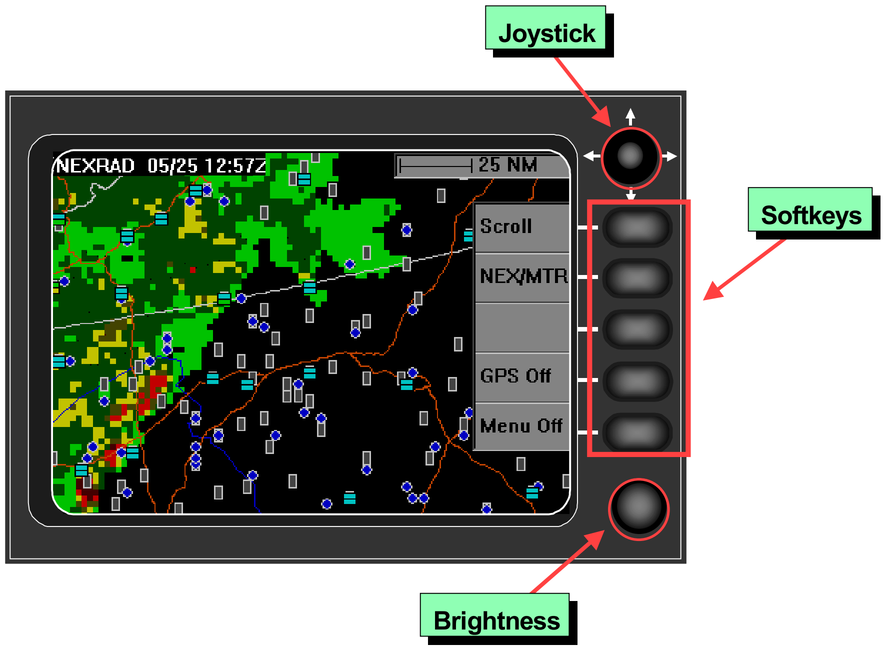


Figure 3.3.4-1. Weather Information Display Controls

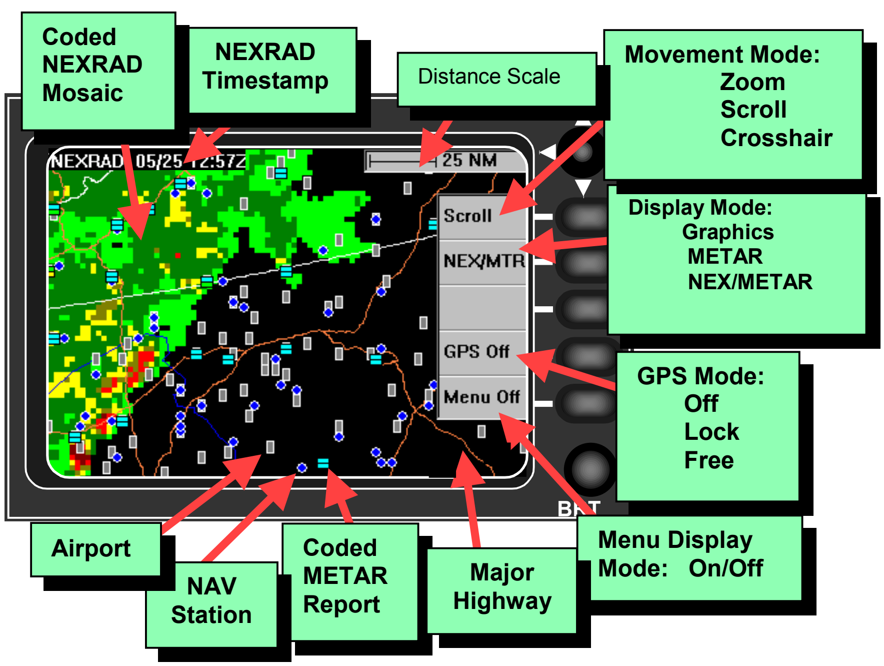


Figure 3.3.4-2. Weather Information Display Screen Labels

4 Procedure

4.1 Key Phases of Experiment Procedure

The experiment procedure consisted of the following five phases:

- Mission briefing
- Simulator familiarization
- Pre-flight planning
- Simulator mission
- Post-mission briefing

4.1.1 Mission Briefing

The subject pilots were given a briefing of the mission objective, mission scenario, and an overview of the simulator. The pilots that would be using the display were also given an overview of the display operation. The briefing scripts are included in Appendix H, Subject Pilot Pre-flight Briefings and Simulator Training.

4.1.2 Simulator Familiarization

All subject pilots were provided with a familiarization session and practice flight in the simulator. Systems, controls, and displays were explained and demonstrated. The trainer answered any questions that the subject pilot had with respect to the operation of the simulator. The pilots that would be using the display (groups T1 and T2) were given a hands-on training session on the use of the in-flight weather display system. The training provided an interactive environment that gave a thorough understanding of the equipment and its capabilities. To assure equal treatment to all subject pilots, the training session was heavily scripted and the pilots were trained to a predetermined performance level derived from the FAA Practical Test Standards for Instrument Pilots.

4.1.3 Pre-Flight Planning

Each pilot was given 30 minutes to plan the mission. Weather reports and flight planning materials were provided. Additionally, a partially completed flight plan form was provided that had the route and aircraft specific particulars completed.

4.1.4 Simulator Mission

The pilots were left alone in the simulator for the mission and observed remotely. The mission lasted approximately one hour, depending on the pilot and route selected around the hazardous weather conditions. Three qualified observers participated in the conduct of the experiment. Their responsibility was to observe and provide a record of the pilot's performance in the execution of the experiment mission. The Observer form is included in Appendix I.

4.1.5 Post-mission De-briefing

Upon completion of the mission, each pilot was given an Immediate Reaction Questionnaire, included in Appendix J, while still seated in the simulator. After completing the questionnaire, the pilot was interviewed by the experiment observers using the Structured Interview Guide found in Appendix K to confirm behavioral actions and decisions. As a last requirement, the pilot was given an open-ended questionnaire. Subject pilots in the treatment group received the Weather Display Questionnaire included in Appendix L. Subject pilots in the control group received the AWIN Study Questionnaire included in Appendix M.

4.2 Mission Scenario

The mission scenario consisted of a flight to deliver medication to a diabetic patient at the NASA-Wallops facility. The NASA-Wallops facility is located on the eastern shore of Virginia. The insulin available in the Wallops area was tainted and a new supply was to be taken to the patient. A possible complication from the diabetes is diabetic ketoacidosis (DKA), a common and potentially fatal complication. Mortality from DKA runs from 5 to 15 percent in various studies. If ketoacidosis develops, one effective therapy is a special form of sodium bicarbonate. Thus, the medical rationale involved the delivery of a **vital** medication, insulin, and a **desirable** medication, sodium bicarbonate. The pilot was informed that a medical mercy mission had been coordinated and that he/she was to be the pilot.

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

The pilots were told that their supervisor for operations has already cleared the flight to the NASA facility and that the insulin had already been loaded into the aircraft.

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

All flights were flown in a full-mission simulation facility in simulated instrument meteorological conditions. Visibility for the pilot was essentially zero from shortly after takeoff until just before landing. The pilots were to conduct the flight in accordance with all appropriate ATC procedures in conjunction with an Air Traffic Controller (ATC) (located in an adjoining room). The ATC workstation fulfilled the roles of clearance controller, ground controller, tower controller, approach/departure controller and FSS briefer as required throughout all phases of the flight. The experiment observers, air traffic controller, simulation supervisor, etc. were aware of whether a subject pilot was in the control or treatment group by virtue of the presence or lack of the cockpit weather display. Otherwise, they were unaware of the risk/knowledge status of the subject until after completion of the experiment. The Air Traffic Control Scripts are included in Appendix N.

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

- FSS - Flight Service Station
- FW - Flight Watch
- ATIS - Automatic Terminal Information Service
- ASOS - Automated Surface Observation System
- AWOS - Automated Weather Observation System

The ATC workstation presented the Air Traffic Controller with a readout of the frequency that the subject pilot selected on the simulator communication radio. When the subject pilot tuned the radio to a frequency that corresponded to a recorded weather message (ATIS, etc.), the scripted weather message was read to the pilot by the Air Traffic Controller (role playing) and repeated as long as the subject pilot stayed tuned to that frequency. If the pilot called either a Flight Service Station or Flight Watch briefer, the Air Traffic Controller again read a scripted briefing to the pilot. These weather scripts can be found in Appendix O, Enroute Weather Information Scripts.

In addition to the previously mentioned services, pilots in the treatment group had the weather information display with which to obtain updated weather text and graphics.

Actual weather data was used to assure the realism of the operational scenario. All weather information used in this experiment was recorded from actual weather conditions that existed in the geographical area of the experiment on the evening of April 25, 2000. The NEXRAD images were recorded during passage of multiple weather fronts through southeastern Virginia from a prototype FISDL system provided to Research Triangle Institute by Honeywell, Inc. The NEXRAD images were replayed on the weather display in the simulation facility cockpit. All NEXRAD mosaic images used in the experiment were recorded with a cell resolution of 4 kilometers. To realistically reproduce actual in-flight weather products, the subject pilot received the NEXRAD Radar mosaic images delayed by seven minutes. The pilot's weather display of NEXRAD images were initially seven minutes old, aging to 14 minutes old before receipt of the next update (of a seven minute-old image). The pilot also had access to graphical and textual Aviation Routine Weather Report (METAR) information.

The NEXRAD weather display used by the Air Traffic Controller was meant to simulate (in spirit) the ASR-9 weather radar. The Air Traffic controller would receive a real-time NEXRAD image that would then age for seven minutes prior to a new real-time update of the NEXRAD image.

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

4.2.1 First Leg of Flight – Newport News to Richmond

During the course of the first leg of the flight, between Newport News and Richmond, the ceiling and visibility at the Richmond airport had descended to below minimums (200 feet) sooner than forecasted. Additionally, there was a thunderstorm approaching the Richmond airport. The only way the pilot could learn of these deteriorating conditions would be to obtain in-flight weather updates. Both pilot groups could use the radio to gather updated weather, but the experimental group also had the ability to obtain NEXRAD and METAR weather information updated through the weather display.

Before reaching the initial approach fix for the Richmond airport, the weather display depicted a thunderstorm cell several miles to the west of the airport but headed toward the airport. See Figure 4.2.1-1. This image on the pilot's weather information display was a minimum of seven minutes old and could have aged up to 14 minutes old. By the time the pilot began the approach, the actual weather cell would have intensified and moved closer to the airport. [The ATC workstation weather display showed the storm a couple miles northwest of the airport.] There were several possible responses to this scenario. The pilot could continue the approach with old data and proceed right into the thunderstorm (poor decision), or, the pilot could decide to abandon the approach into Richmond and proceed directly to Wallops (good decision). A third option had the pilot asking ATC to provide a hold until available information could be obtained and sorted out before deciding to continue into the Richmond airport or proceed to Wallops (good or poor decision depending on proximity of flight path to thunderstorm).

As the aircraft traversed the various precipitation zones – as depicted in the level of precipitation returns on the simulator operator's NEXRAD display (which was identical to the ATC display) – the simulator operator introduced levels of turbulence appropriate to the conditions. 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 depicted hazard.
The turbulence model is described in Appendix G, Cockpit Research Facility.

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, or continue the approach into Richmond. This is the judgement call that the experiment was designed to uncover along with the basis for the decision by the subject pilot.

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

This part of the experiment was designed primarily to determine the pilot's judgment relative to the time-related (temporal) issues in the use of the weather information display.

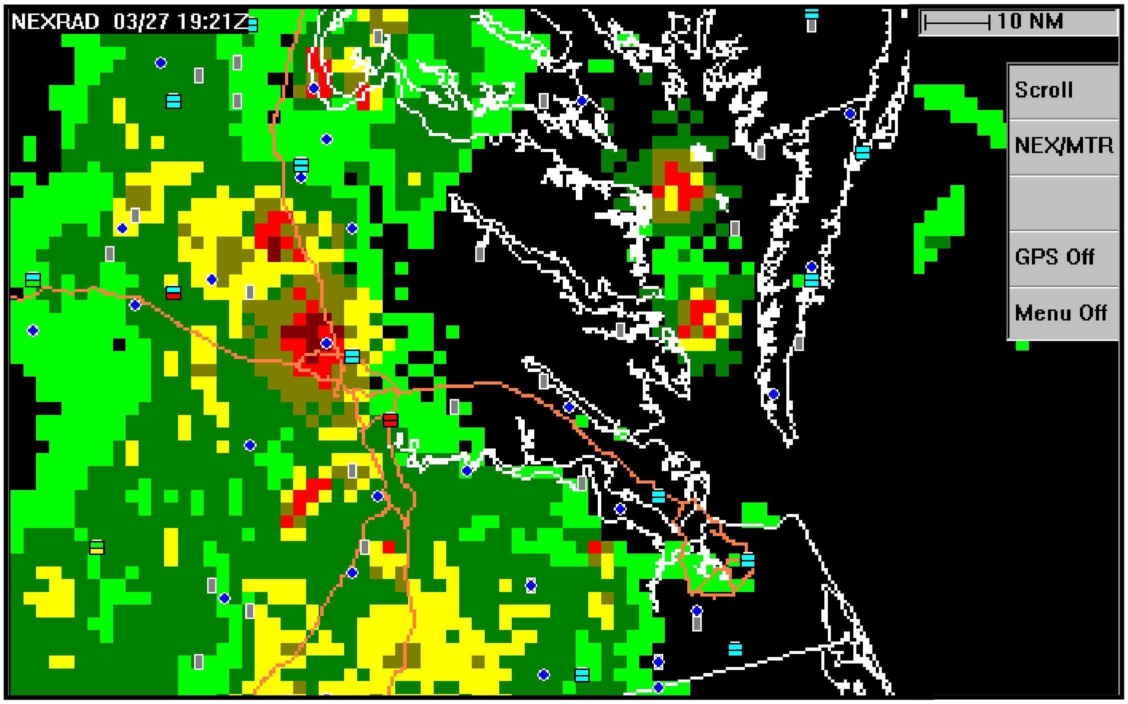


Figure 4.2.1-1. Display Image When Approaching Richmond

4.2.2 Second Leg of Flight – Richmond to Wallops Island

During the leg between Richmond and Wallops, a line of storm cells materialized across the direct route to Wallops, with one storm cell to the north of the direct course and one to the south. The location of this convective activity can be seen in Figure 4.2.1-1. The distance between the red cells was approximately 10-12 miles. The hole between the storms was tempting enough to create a corridor between the areas of hazardous weather. These cells did not move substantially with succeeding NEXRAD images, but slightly changed shape and size. The METAR graphical and textual depiction showed that the Wallops airport was above minimums, therefore giving the pilot an incentive to proceed with the flight to Wallops.

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

5 Results

5.1 Participants

A total of 25 pilots participated in this study. Of these 25 pilots, 13 flew with a prototype weather display and 12 flew without the weather display to enable the experimenters to discriminate between decisions made with and without this potential aid. Participants were pilots qualified for and current in instrument conditions with varying levels of experience. The mean number of flight hours was 1623.2, with a standard deviation of 1445.2 (n=25).

5.2 A Representative Flight from the Data Set

The ground track of each session was recorded and plotted. The path of subject #7 is provided in Figure 5.2-1 as an example of the data collected for each session. Subject #7 was equipped with the display. As can be seen in the figure and from examination of the other data available in this report, subject # 7 decided not to attempt to land at Richmond because of his understanding of the deteriorating weather conditions at Richmond obtained from the ATIS, Richmond Approach Control, and the display. He proceeded instead to the Wallops Island airport, initiating the new route just past the Hopewell VOR at 1925Z. The NEXRAD mosaic image that subject #7 was looking at on his weather information display as he made the decision to proceed directly to the Wallops Island airport is provided in Figure 5.2-2. Note that the time stamp on this image was 19:14Z. Note also that the coded METAR report is indicating VFR conditions at the Richmond airport.

Upon notification of convective weather ahead as he passed the Harcum VOR, subject pilot #7 worked out a new route with ATC to the south around the convective weather and then proceeded safely to the Wallops Island airport. The NEXRAD mosaic image that subject #7 was using as he contemplated how to avoid the convective weather ahead of him is provided in Figure 5.2.3. The display would have updated to the image provided in Figure 5.2.4 shortly after subject #7 turned to the south to avoid the hazardous weather. Upon receipt of this update, and subsequent updates, subject #7 had to continue to re-evaluate the proximity of his flight path to the hazardous weather as he proceeded to his destination.

The ground tracks of all of the subject pilots are provided in Appendix P, Ground Track of All Subject Pilots. The full set of 11 NEXRAD mosaic images for the time frame encompassing the mission scenario for all subjects is provided in Appendix Q, NEXRAD Mosaic Images.

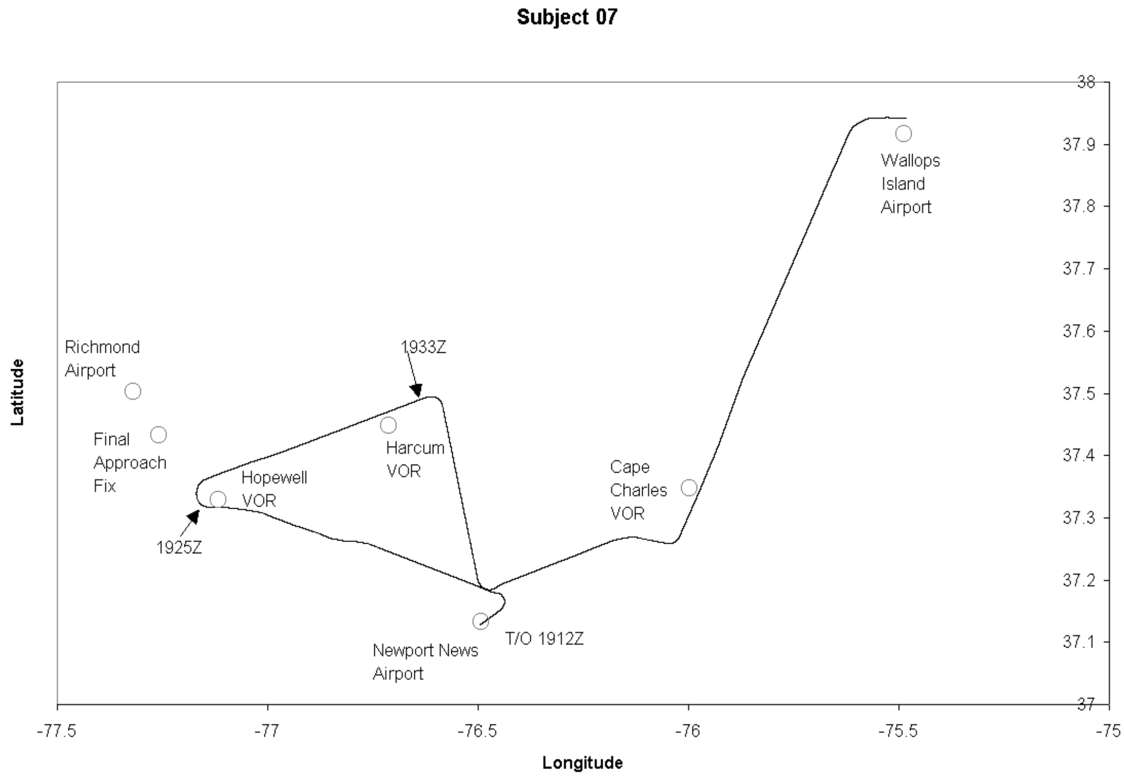


Figure 5.2-1. Ground Track of Subject Pilot #7

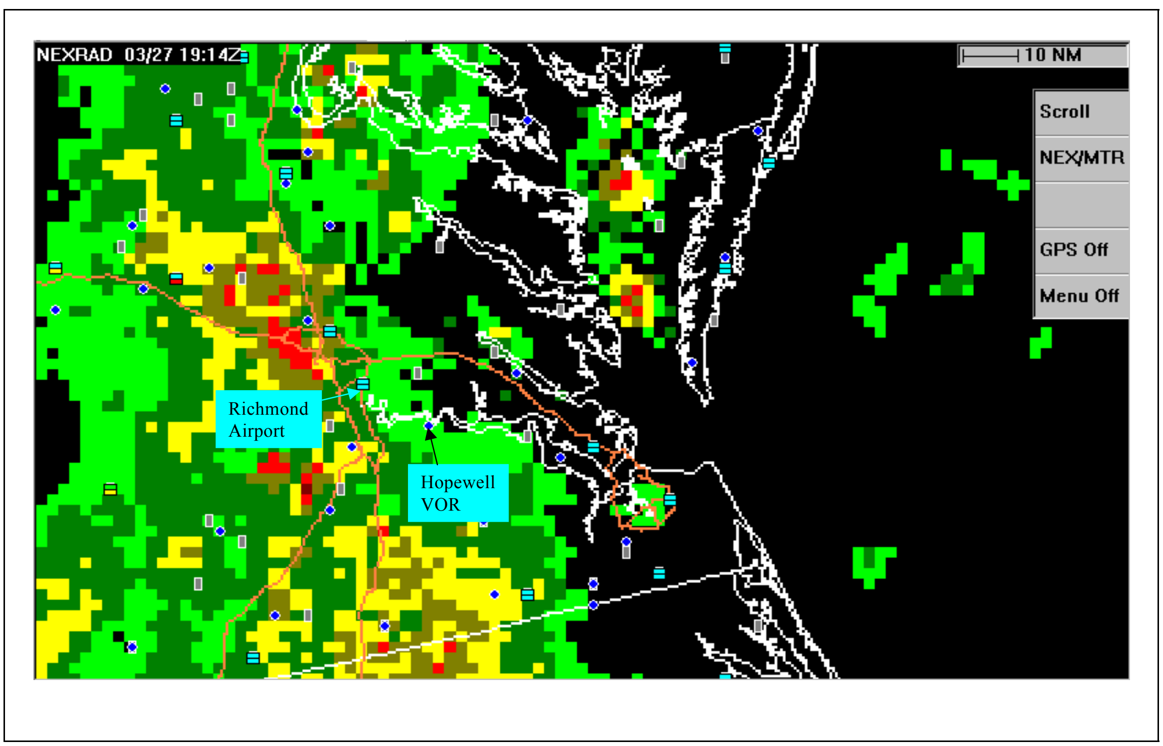


Figure 5.2-2. 19:14Z Display NEXRAD Mosaic Image

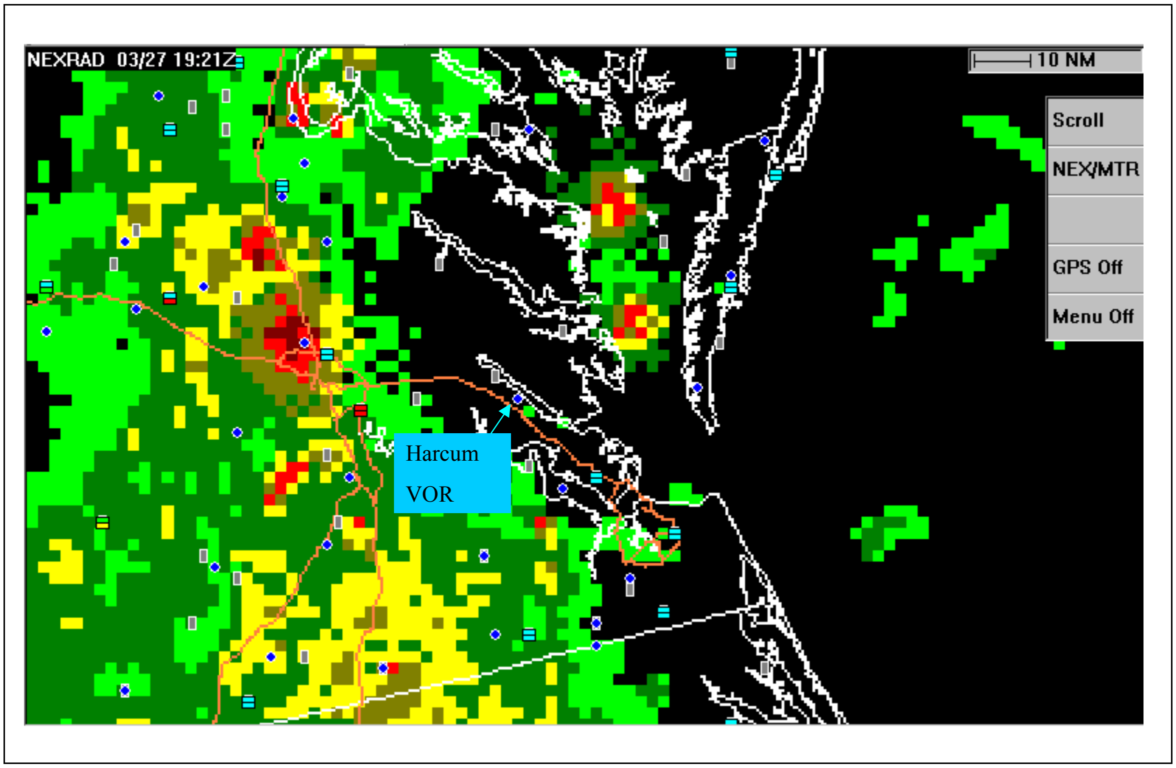


Figure 5.2-3. 19:21Z Display NEXRAD Mosaic Image

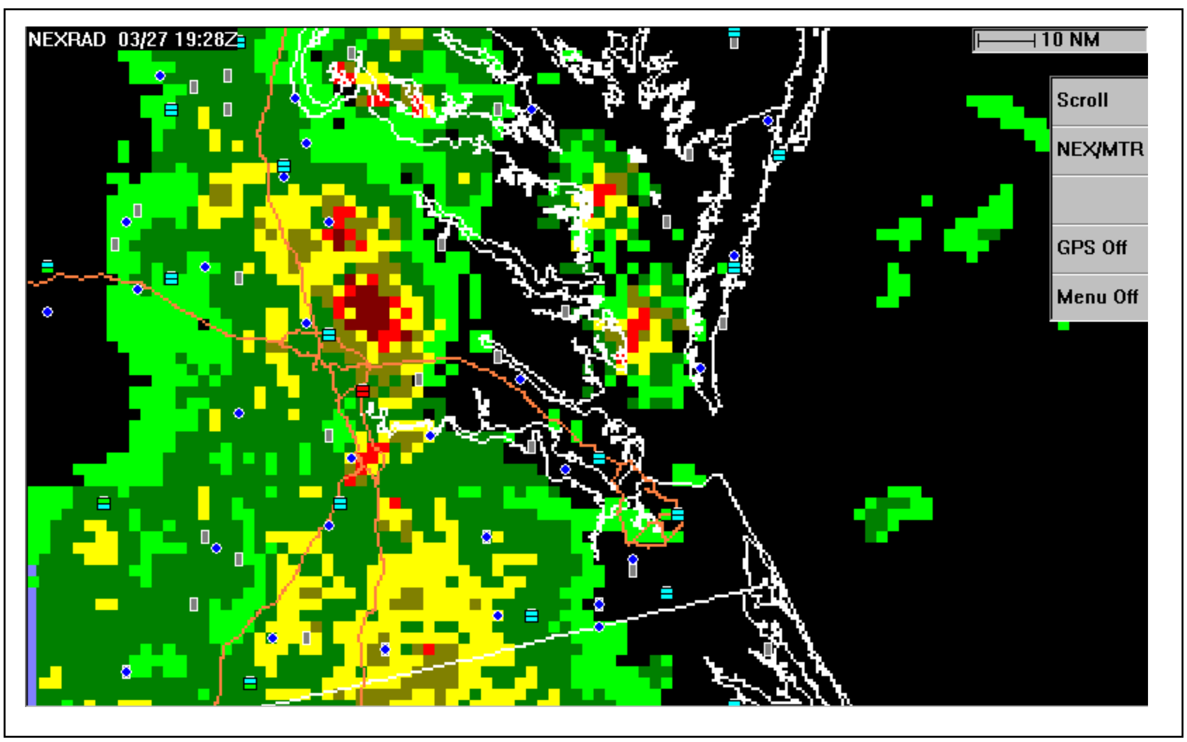


Figure 5.2-4. 19:28Z Display NEXRAD Mosaic Image

5.3 Overview of Richmond and Wallops Decisions

The results of the experiment have been organized around the two key decision points established in the experiment procedure – the "Richmond Decision" and the "Wallops Decision."

The "Richmond Decision" required the subject pilot to decide whether or not to attempt to land at the Richmond airport in the face of a fairly rapidly moving thunderstorm passing within a mile or two at most to the north of the airport. There were a total of 11 different NEXRAD mosaic images displayed to the pilot, updating in 7-minute intervals. Figure 5.2-2 depicts the NEXRAD mosaic image seen by the pilot upon arrival in the vicinity of the Final Approach Fix to the southeast of the Richmond airport. Because of the delay in transmission of the image to the aircraft, the data is about 7 minutes stale. Actual conditions at the Richmond airport in the time frame of this decision can be seen in Figure 5.2.3 which provides the NEXRAD image for 19:21Z. The images depicted in these figures were the 4th and 5th images in the sequence of 11 images used. The thunderstorm seen to the northwest of Richmond is the storm that was designed to elicit a weather decision from the pilots. The actual recorded storm was just a little smaller than the one depicted to the pilot (was enlarged with photo retouching software). This particular storm moved from west to east across the successive NEXRAD images at approximately 40 nautical miles per hour in the early images. The rate of movement of the storm diminished to less than 10 nautical miles per hour in the later images.

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

a. The hazard is a rapidly moving and fairly localized thunderstorm with a well-defined leading edge,
b. The weather condition five miles and greater to the east of the thunderstorm in this actual weather data set were known to be reasonably safe with no significant turbulence, and
c. The motivation created by the medical scenario to proceed to within a reasonable but safe distance.

Table 5.3-1 provides a summary of the results for all subject pilots in the control group (without display) for this decision. Table 5.3.2 provides a summary of the results for all subject pilots in the treatment group (having the display) for this decision. In addition to tabulating the decisions of each subject pilot, this table indicates the sources of weather information the pilots used to make this decision, the separation between the aircraft and the weather hazard, and the major factors influencing the pilots' decisions.

Six of the twelve control group pilots (without the weather information display) were judged to have made good decisions at Richmond. Six of the thirteen treatment group pilots were judged to have made good decisions at Richmond.

The "Wallops Decision" required the subject pilot to decide whether to proceed directly to Wallops or detour around the hazardous weather. To proceed directly required the pilot to find his or her way between the thunderstorms located between the aircraft and the Wallops destination. Figure 5.3-1 provides the approximate image that the pilots equipped with the weather information display would have seen after departing the vicinity of the Richmond airport and upon notification by ATC of weather ahead as they passed the Harcum VOR (about 25 miles to the east of the Richmond airport). Figure 5.3-2 provides the NEXRAD mosaic image more correctly representing the actual conditions in this time frame. In these images, there is a line of convective activity over the Chesapeake Bay and 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 images. These two thunderstorm cells were enhanced slightly with photo retouching software to create an enticing corridor that tempted pilots to fly between them.

A good decision was deemed to be one in which the pilot, upon notification by ATC of weather ahead, circumvented the hazardous area entirely by rerouting to the south around the area of convective activity so as to avoid it by at least ten nautical miles, and then proceeding up the coast of Virginia to the Wallops airport. A poor decision was deemed to be one in which the pilot decided to find his or her way between the thunderstorms in an attempt to proceed by the most direct route to the Wallops airport, and for whatever reason, coming with ten nautical miles of hazardous weather. An attempt to reroute 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 subject pilot. Table 5.3-3 provides a summary of the results for all subject pilots in the control group (without display) for this decision. Table 5.3-4 provides a summary of the results for all subject pilots in the treatment group (having the weather information display) for this decision. In addition to tabulating the decisions of each subject pilot, these tables indicate the sources of weather information the pilots used to make this decision, and the major factors influencing the pilots' decisions.

Eleven of the twelve control group pilots (without the weather information display) were judged to have made good decisions enroute to Wallops. Five of the twelve treatment group pilots (with the weather information display) that proceeded to Wallops were judged to have made a good decision enroute.

Table 5.3-1. Richmond Decision (Subjects Without Weather Display)

Pilot #	WX Display	Divert Distance (NM from RIC)	Prox to Red Cell (NM)	Reason for Diverting			Decision		WX Sources Used for Avoidance				Comments
				Concerned re departing Richmond	Own deci-sion	ATC Direction	Good	Poor	ATIS	ATC	PHF DEP	FSS/ FLT WATCH	
54	N	5 (OM)	2 (while holding)			X		X	X	X			Ignored ATC info re hazards
8	N	20	25		X		X		X	X		X	Aborted Flight due to WX
43	N	30	35	X	X		X		X	X			
24	N	22	20		X		X		X	X			
47	N	5 (OM)	4			X		X	X				Left ATC freq. @ OM to check ATIS (too late)
44	N	5 (OM)	3			X		X	X				Planned to "take a look"
55	N	23	22		X		X		X				
39	N	5 (OM)	3			X		X	X	X	X		Planned to "take a look"
18	N	5 (OM)	1			X		X	X				Seemed unconcerned about hazards
5	N	5 (OM)	4			X		X	X				Seemed unconcerned about WX
33	N	7	6	X	X		X		X				
53	N	23	23		X		X		X	X	X		
						Total	6	6					

"OM" = Outer Marker

Table 5.3-2. Richmond Decision (Subjects With Weather Display)

Pilot #	WX Display	Divert Distance (NM from RIC)	Prox. to Red Cell (NM)	Reason for Diverting			Decision		WX Sources Used for Avoidance				Dis-regarded NEXRAD Data De-lay	Dis-tance Estima-tion Error	Own-ship Posi-tion Uncer-tain	Comments
				Concerned re departing Richmond	Own deci-sion	ATC Direc-tion	Good	Poor	ATIS	ATC	PHF DEP	FSS/ FLT WATCH				
23	Y	24	20	X	X		X		X	X			X	X	X	
30	Y	5 (OM)	3			X		X	X				X	X		Wanted to beat TSTM into RIC
20	Y	5 (OM)	3			X		X	X	X			X			
3	Y	15	5	X	X		X			X					X	Delayed turn to East
50	Y	5 (OM)	5	X	X		X			X				X		
38	Y	33	25		X		X		X	X			X		X	
57	Y	32	30	X	X		X							X	X	
42	Y	5 (OM)	3			X		X		X			X	X	X	
48	Y	5 (OM)	1			X		X	X	X			X	X	X	
49	Y	7	1		X			X	X	X			X	X	X	
45	Y	5 (OM)	3			X		X	X	X		X		X		
6	Y	5 (OM)	3	X	X			X	X	X					X	Over-used METAR function
7	Y	17	10		X		X		X	X						
						Total	6	7								

"OM" = Outer Marker

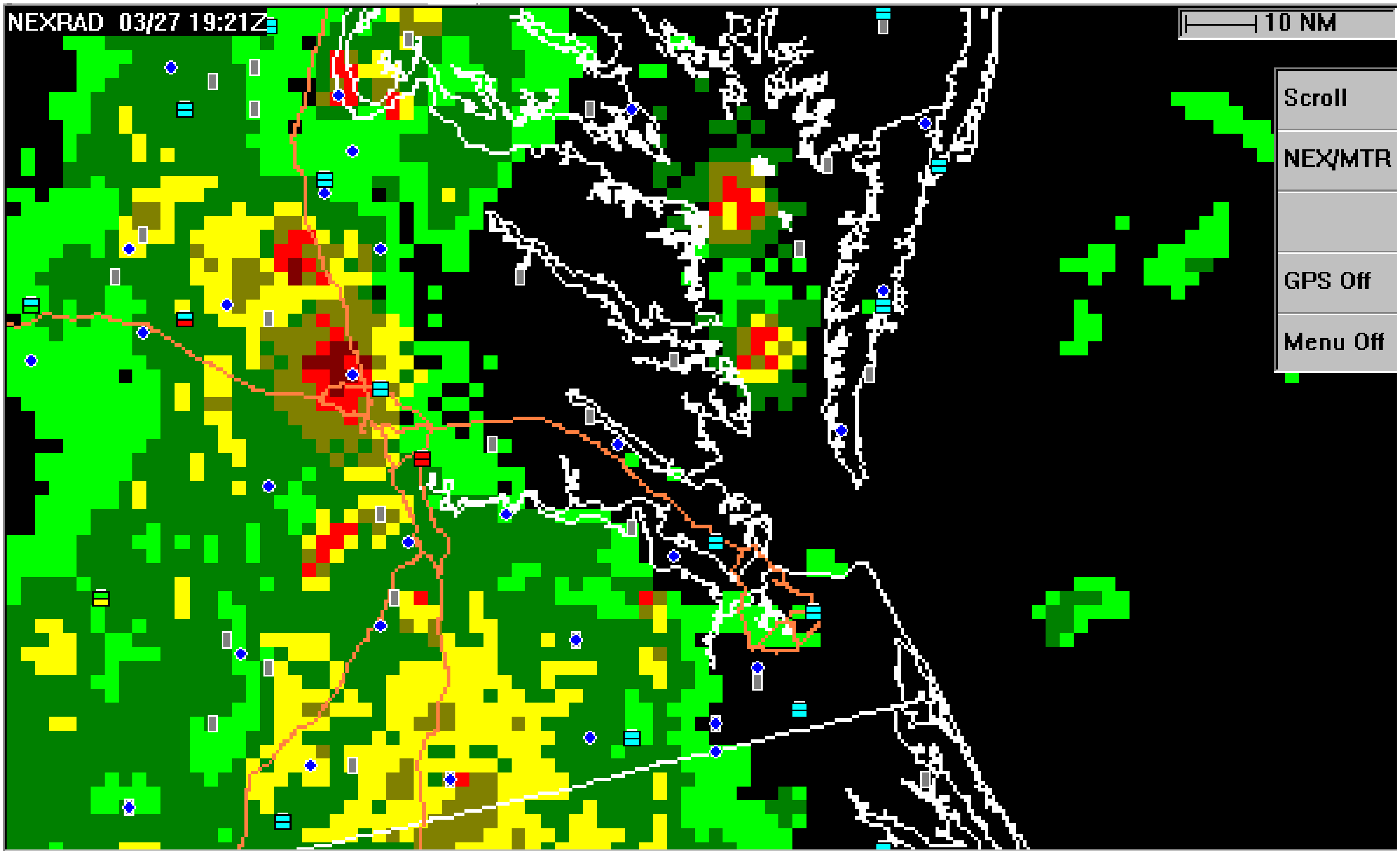


Figure 5.3-1. 19:21Z Display NEXRAD Mosaic Image

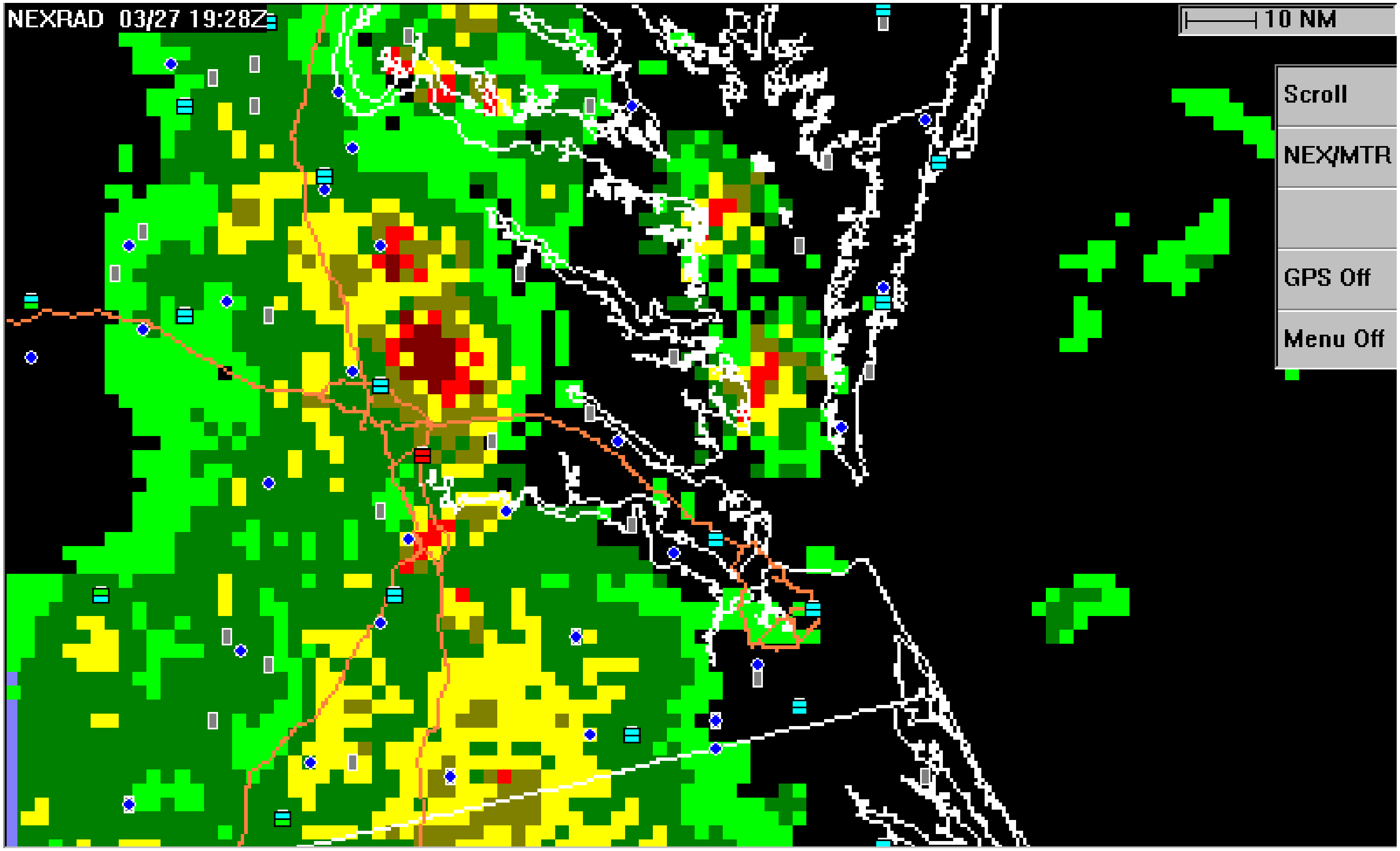


Figure 5.3-2. 19:28Z Display NEXRAD Mosaic Image

Table 5.3-3. Wallops Decision (Subjects Without Weather Display)

Pilot #	WX Display	Prox. to Red Cell (NM)	Decision		WX Sources Used for Avoidance[1]				Delay in Communicating with ATC	Comments
			Good	Poor	ATC	FSS	Flight Watch	ATIS		
54	N	10	X		⊗					
8	N	NA	X[2]		⊗		X	PHF/RIC/ PHF		
43	N	10	X		⊗					
24	N	10	X		⊗	X				
47	N	8	X		⊗		X		X	To much time on FSS Freq.
44	N	10	X		⊗					
55	N	10	X		⊗					
39	N	10	X		⊗	X				
18	N	10	X		⊗		X			
5	N	10	X		⊗		X			
33	N	6	X			X	⊗			
53	N	4		X			⊗			Too much time on Flight watch. Ignored ATC.
		Total	11	1						

[1] Primary source for decision is ⊗.
[2] Enroute to Richmond, decided weather too hazardous to continue mission, returned to PHF.

Table 5.3-4. Wallops Decision (Subjects With Weather Display)

Pilot #	WX Display	Prox. to Red Cell (NM)	Decision		WX Sources Used for Avoidance[1]						Dis-regarded NEXRAD Data Delay	Misinter-preted Display	Incorrectly Used WX Display for Navigation	Delay in Comuni-cating w/ATC	Comments
			Good	Poor	ATC	FSS	Flight Watch	ATIS	AWOS ASOS	WX Display					
23	Y	1		X	X				X	$\otimes$	X	X			
30	Y	7		X	X				X	$\otimes$	X	X			Decided to go north.
20	Y	10	X		$\otimes$					X	X	X			Wanted to go north. ATC ad-vised south
3	Y	12	X		$\otimes$				X	X					
50	Y	7		X	X					$\otimes$	X	X			Too close to t'storms
38	Y	2		X	X					$\otimes$	X	X	X	X	Imprecise control
57	Y	10	X		$\otimes$					X					
42	Y	7		X	X					$\otimes$	X	X	X		Navigated on display, turned north, lost position
48	Y	6		X	X					$\otimes$	X		X		Shot the Gate
49	Y	7	X		$\otimes$					X	X	X			
45	Y	1		X	X				X	$\otimes$	X	X			
6	Y	--	--	--	--	--	--	--	--	--	--	--	--	--	--
7	Y	10	X		X				X	$\otimes$					
		Total	5	7											

[1] Primary source for decision is $\otimes$.
[2] Misunderstood mission scenario. Did not proceed to Wallops. Data not included in Wallops decision.

One consequence of the selection process was an even distribution of the subject pilots between the control and treatment groups with respect to number of flight hours in actual instrument conditions. Tables 5.3-5 and 5.3-6 provide a summary of the total flight hours and actual instrument flight hours as reported by the subject pilots for the control group (no display) and the treatment group (with display) respectively. These tables also tabulate the workload of the pilots over the entire mission as it was perceived by the pilots themselves and as it was observed by the experiment observers. Finally, these tables tabulate the observers' perception of the overall proficiency of the subject pilots in flight in simulated instrument meteorological conditions as they performed the mission. The average number of actual instrument flight hours of the subject pilots was 135 hours in the control group and 151 hours in the treatment group. The number ranged from a low of 4 hours to a high of 340 hours in the control group, and from a low of 5 hours to a high of 500 hours in the treatment group.

Table 5.3-5. Pilot Performance/Workload and Flight Hours (Control Group)

Pilot #	Total Flight Hours	Act. Instrument Flight Hours	Pilot Reported Workload	Observed Workload	Observed Pilot IMC Proficiency
54	700	250	low	low	high
47	400	13	high	high	low
53	1015	80	high	moderate	moderate
8	725	70	high	moderate	low
5	670	15	high	high	low
33	700	80	high	high	low
55	940	15	moderate	moderate	high
44	1815	340	low	low	high
43	2000	230	moderate	low	high
39	5200	275	low	low	high
24	4100	250	low	low	high
18	250	4	high	high	low
Average:	**1542.9**	**135.2**			
Standard deviation:	**1557.0**	**123.7**			

Table 5.3-6. Pilot Performance/Workload and Flight Hours (Treatment Group)

Pilot #	Total Flight Hours	Act. Instrument Flight Hours	Pilot Reported Workload	Observed Workload	Observed Pilot IMC Proficiency
57	690	25	moderate	moderate	high
50	1800	200	moderate	moderate	high
49	1856	200	high	high	low
48	350	15	high	high	low
45	3000	300	moderate	moderate	high
42	900	5	very high	very high	very low
30	1000	200	high	high	moderate
23	1070	50	high	high	very low
20	800	50	high	very high	very low
7	1500	150	high	moderate	high
3	5600	250	high	high	moderate
6	2500	500	moderate	moderate	moderate
38	1000	20	high	high	low
Average:	**1697.4**	**151.2**			
Standard deviation:	**1393.0**	**145.6**			

5.4 Results of Immediate Reaction Questionnaire

Upon completion of the simulator session, each subject pilot was given a questionnaire (Appendix J, Immediate Reactions Questionnaire) to obtain their immediate reactions. The pilot was given this questionnaire while still seated in the simulator, thereby reducing distraction issues and obtaining valuable subjective information while the pilot was still in the "flight mode." Some questions pertained to the use of the weather information display, so the pilot of the control group without the display received a scaled down questionnaire.

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

Question 1a. Pilots using the weather information display were asked if an ownship symbol would have been useful. (The prototype unit used in the experiment did not feature ownship symbology.)

> **An "ownship" aircraft symbol, cross-hairs or some similar *position* indication would be a useful addition to the weather display.**
> *(mean score of 5.0)*

All of the respondents circled the **Agree** selection.

Question 1b. Pilots using the weather information display were asked if the absence of an indication of ownship position on the display compromised the usefulness of the weather display.

> **Without some way to ascertain position relative to other displayed features, the display's usefulness is significantly compromised.**
> *(mean score of 4.15)*

Questions 2a, 2b, & 3. These questions were primarily to determine the extent to which the subject pilots "bought into" the medical scenario presented to the pilots and were given to all the subject pilots. Essentially, the same question was asked three different ways to gain concurrence and validity.

> **I took the medical emergency scenario seriously, in the sense that I factored the emergency into my decision making.**
> *(mean score of 4.24)*

> **While taking the medical aspect of the flight seriously, it did not figure at the forefront of my in-flight decision making.**
> *(mean score of 2.84)*

> **My knowledge that this was all a simulation, that nobody's health or welfare was really at stake, influenced the way in which I managed the flight.**
> *(mean score of 1.68)*

Question 4. This question explored if the treatment group pilots' perception of the extent to which the weather information display depicted weather in "real-time."

> **An advantage of the onboard Weather Display was showing the weather in real-time, that is, as it actually was at that moment.**
> *(mean score of 4.38)*

During the post-flight interview, some of the pilots were aware that the NEXRAD images were up to 14 minutes old. Others stated that 14 minutes old is real-time compared to pre-flight weather charts that could be over an hour old.

Question 5. This question explored the treatment group pilots' perception of the degree to which they felt they were able to interpret the weather information display and the extent to which the display influenced their decision making.

> **I attribute much of my decision making to my interpretation of the Weather Display**
> *(mean score of 4.08)*

Question 6. This question asked all of the pilots their perception of the extent to which they used all available weather information sources.

> **I tried to systematically sample all sources of weather information open to me.**
> *(mean score of 3.20)*

Question 7. This question explored the treatment group pilots' perceptions as to their willingness to depend solely on the weather information display without cross-checking with information from other sources.

> **I used the Weather Display but felt the need to cross-check or verify my conclusions from conventional weather sources (ATC, etc.)**
> *(mean score of 3.38)*

Questions 8a and 8b. Two questions were asked of all the subject pilots about their comfort with and reliance on the autopilot.

> **I felt comfortable with the autopilot, in terms of understanding its use & operation.**
> *(mean score of 4.32)*

> **Without the autopilot my completion of the flight would have been compromised.**
> *(mean score of 4.4)*

Most of the pilots felt comfortable with the autopilot and relied on its use to reduce the workload. This is also reflected by the fact that the autopilot was in use 83% of the time (for all the subject pilots). Many of the pilots stated that without the autopilot, they would have succumbed to an early termination of the flight.

Question 10a. When asked about the validity of the weather information display, there were mixed reactions.

> **The degree of validity of the weather data appearing on-screen was a factor I felt I held in mind as I flew.**
> *(mean score of 3.69)*

Question 10b. Pilots who used the weather information display were asked if they regularly referred to the timestamp of the weather information.

> **I have been monitoring the weather display time stamp very regularly in my instrument scan.**
> *(mean score of 2.42)*

Question 11. All the pilots were asked what they perceived the weather conditions to be in the vicinity of the Richmond airport.

> **At the time of my arrival at Richmond's Airport, I knew that there was a storm...**
>
> **a. about 10 nm North West of the field.** *(1 selection)*
>
> **b. about 5 nm North West of the field.** *(2 selections)*
>
> **c. near the field.** *(9 selections)*
>
> **d. right at the field.** *(13 selections)*

The pilots that did not fly with the weather information display picked either answer C or D only (placing the storm close to the field), but the pilots that flew the weather information display were not certain of the actual distance and their responses varied.

Question 12. Pilots who flew with the weather information display were asked what they perceived the weather conditions to be on the route to Wallops Island.

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

6 Analyses and Discussion

Quantitative assessments were undertaken of the probable relationships between the weather display and the two key decisions around which the experiment was set up. Qualitative assessments based on the observations and expertise of the experiment team were also undertaken of significant issues related to the weather display that surfaced in the course of the experiment.

6.1 Quantitative Assessment

Some of the data collected in the experiment were purely nominal with zero representing "no" or "not good," and 1 representing "yes" or "good." The form of these data, therefore, favored non-parametric tests, such as the Chi-Square test. This technique was used in testing the relationship of several variables to decision making adequacy, and provided a value for chi together with the probability (p) that a result was due purely to chance. A less than a one in twenty chance that a result was merely a random fluke ($p< 0.05$) is generally regarded as statistically significant. This report adheres to that convention. Where the p value of a result does not meet that criterion (i.e. is "not significant"), does not, of course, imply that the result is without importance, or even that it is a mere fluke. Rather it flags the result as one that *may* be simple chance and, therefore, cannot be safely generalized to circumstances beyond the experiment from which it was derived.

Other data, however, were continuous numeric data such as weather test scores, flight hours, questionnaire responses (a 1 to 5 Likert Scale), etc. The SPSS Inc. software program was used to analyze a data set containing all information collected in this experiment. Pearson Product Moment correlation coefficients were calculated to evaluate the relationships among the continuous numeric data (Table 6.1-1), and a regression analysis was conducted on the two decision points.

6.1.1 Richmond and Wallops Decisions (with/without weather display)

As described earlier in the Methods section, the experiment scenario featured two critical decision points, one on the approach to the airport at Richmond, and one en route to the Wallops Island airport, the briefed destination. These decisions were considered singly, independently, and together as a group. First, the Richmond decision was examined alone. Using the decision rating criteria set out earlier, 6 of the 12 pilots flying without a weather display made a good decision at Richmond (coded as 1 in the data file) and the remaining 6 made a decision rated as poor (and coded 0). Of those who flew with the weather display, 7 made decisions rated as good and 6 made decisions rated as poor. Preliminary inspection of these raw scores alone suggests little performance difference as a function of weather display presence or absence. A Chi-Square statistical test was used to examine the data and determine if there were any significant differences in expected and observed frequencies (for a discussion of the role of these in Chi-Square, see Heiman, 1992[5]). In the case of the analysis of Richmond singly, the Chi-Square result was not statistically significant — bearing out the initial appearance of the data.

For the decision en route to the Wallops Island airport (hereafter referred to simply as the Wallops decision or decision point), it appears that better decisions were made in the absence of the weather information display.

With the weather display, 5 pilots made a good decision, and 7 made a poor decision. When there was no weather display installed, 11 made decisions rated as good and only a single pilot made a decision rated as poor. Again, a Chi-Square statistic test was used to examine the expected and observed frequencies at the Wallops decision point. In this case the differences in frequencies are statistically significant ($\chi^2 = 6.75$, $p < .05$), supporting the conclusion that at the Wallops decision point, better decisions were made when there was no weather display.

RICHMOND:

	Weather Display	No Weather Display
Good Decision	6 pilots	6 pilots
Poor Decision	7	6

WALLOPS:

	Weather Display	No Weather Display
Good Decision	5 pilots	11 pilots
Poor Decision	7	1

6.1.2 Display vs. No Display for Both Decisions Together

Additional analyses were conducted to examine the combination of decisions at the two decision points, depending on whether the pilots received a weather display or not. The following table displays the frequency of good and poor decisions at each of the decision points. The table shows the number of pilots who made a decision that was rated as good at both decision points, the number said to have made poor decisions at both decision points, and the number rated as having made a poor decision at one and a good decision at the other.

Pilots Given Weather Display:

	Wallops Decision	
	Poor	Good
Richmond Decision Poor	0 Pilots	6 Pilots
Richmond Decision Good	1	5

[5] Heiman, G. (1992) Basic Statistics for the Behavioral Sciences, Boston: Houghton-Mifflin

Pilots Not Given Weather Display:

	Wallops Decision	
	Poor	Good
Richmond Decision Poor	4 Pilots	2 Pilots
Richmond Decision Good	3	3

The data from the above table were analyzed with the Chi-Square technique to examine whether access to a weather display resulted in better decision making at the two decision points of Richmond and Wallops (considered together as a unit of performance). This Chi-Square result was not statistically significant. This result suggests that combined Richmond/Wallops decision performance was unaffected by the presence or absence of the weather display.

In this context, however, one cautionary note needs to be expressed. In the statistical literature, some authors suggest that the validity of the Chi-Square analysis is questionable for cell populations less than 5. As can be seen in the table above, the expected frequencies fell below 5 in six of the eight cells.

6.1.3 Flight Hours, with/without Weather Display, and Decisions Enroute

Flight experience is, of course, a potentially important variable in understanding the dynamics of behavior in any experiment such as that reported here. One measure of experience of the subject pilots collected in this experiment was the number of total flight hours. An analysis was conducted to examine the relationships between total flight hours, weather display condition (presence or absence of the weather display), and decision making. In order to examine whether the number of flight hours played a role in decision making, the Chi-Square test was used to compare decisions made at Richmond and at Wallops.

RICHMOND:

No Weather Display	Richmond Decision	
	Poor	Good
Under 1000 Flight Hours	4 Pilots	3 Pilots
Over 1000 Flight Hours	2	3

Weather Display	Richmond Decision	
	Poor	Good
Under 1000 Flight Hours	3 Pilots	2 Pilots
Over 1000 Flight Hours	4	4

This Chi-Square was not significant for the decision at Richmond. The number of total flight hours did not seem to interact with the weather display condition to affect the decision quality.

WALLOPS:

No Weather Display	Wallops Decision	
	Poor	Good
Under 1000 Flight Hours	0 Pilots	7 Pilots
Over 1000 Flight Hours	1	4

Weather Display	Wallops Decision	
	Poor	Good
Under 1000 Flight Hours	3 Pilots	2 Pilots
Over 1000 Flight Hours	4	3

The Chi-Square for the Wallops decision was also non-significant. Total flight hours again did not appear to interact with the weather display condition to affect decision quality.

Even though the Chi-Square results were not significant with the number of cases run in this experiment, there does appear to be a discernible trend with regards to the decision making at Wallops. This suggests that less experienced pilots tended to make decisions rated as good when flying *without* the weather display. The possibility that this is a pure chance related to the characteristics of the pilots and the conditions of this study cannot be excluded. However, it is indicative of a potentially perilous trend that warrants the need for larger scale studies capable of building upon the exploratory analyses reported here in order to seek more definitive answers.

6.1.4 Risk Aversion, WX Knowledge, Experience, and Decision Making

A regression analysis was conducted to examine the influence of risk aversion, total flight time, weather knowledge, and presence or absence of weather display on decision ratings. For the Richmond decision, the Multiple R = .37, and $R^2 = .14$. This is a non-significant result.

A regression analysis was also conducted for the Wallops decision. Multiple R = .60, and $R^2 = .36$, p =.06, the largest factor being the presence of the weather display. This is not significant by reference to our p=0.05 cut-off. Rather than a 1 in 20 chance of being a fluke, the result has about a 1 in 17 chance of being a fluke. It is, therefore, still unlikely to be mere happenstance. Traditionally, "nearly significant" results, though themselves properly unreportable, have been taken to suggest that a real effect may exist and might be identified in further studies, especially where larger subject numbers increase the power of the statistics to identify effects unambiguously.

The results of a Pearson Product Moment correlation coefficient computation performed for the ten variables represented by continuous numeric data in the experiment is provided in Table 6.1-1. The ten variables define the rows and columns of the table. Each table cell contains two entries. The top entry is the correlation coefficient, which is a measure of the tendency of the intersecting variables to occur together (not necessarily cause and effect). Values close to 1.0 indicate that a high value in one variable tends to occur with a high value in the second variable. Likewise, values close to –1.0 are indicative that a high value in one variable tends to occur with a *low* value in the second variable. The second value contained in each table cell is the probability that the correlation coefficient computed is due to random chance.

For example, the correlation between "Weather Knowledge" and "Combined Score" is a rather high value of 0.866, with a low probability that this result is due to chance. This result is expected since the candidate pilots were purposefully divided into groups such that high weather knowledge pilots were placed in the high combined score group, and low weather knowledge pilots were placed in the low combined score group. Conversely, high *risk* pilots were also placed in the low combined score group; note the *negative* correlation coefficient of –0.8688 with a p value approaching 0, indicating a high probability that this result is statistically significant.

In addition to the data based on the 10 continuous variables measured on the population of 25 pilots and shown in Table 6.1-1, a database consisting of some 41 variables measured or observed on the treatment pilot group was recorded and archived using the SPSS software. The 41 variables are listed in Table 6.1-2. A database of the variables in Table 6.1-2 is available from the RTI Flight Systems Engineering Office for further analysis. A far more comprehensive set of data was collected in the experiment for each subject in the form of simulation control inputs, flight path performance, observed data, and pilot debriefing records, and pilot questionnaires. This data is also available from RTI for further analysis.

Taken in conjunction with the Chi-Square results, the best predictor of decision rating for the Wallops decision was whether the individual was flying with a weather display or not. The direction of the relationship might be considered disappointing, since the presence of the display may be associated with poorer rather than better decision making.

The results of the quantitative assessments presented here are consistent with some of the fears that have been expressed regarding undue optimism about the likely performance effects of the first generation of cockpit weather display systems. The sources of performance difficulties observed are complex and varied, however, and substantial information was also found in qualitative assessments of the performance of the subject pilots.

Table 6.1-1. Pearson Product Correlation Coefficient Computation Results

	Risk Score	Weather Score	Combined Score	Flight Hours	Question #2A	Question #2B	Question #3	Question #8A	Question #8B	Question #11
Risk Score		**-0.5048** **0.005**	**-0.8688** **0.000**	0.2110 0.156	-0.0890 0.336	-0.0362 0.432	-0.1664 0.213	0.1583 0.225	0.1416 0.250	-0.2786 0.089
Weather Score			**0.8660** **<0.000**	0.3131 0.064	0.1529 0.233	0.1494 0.238	0.3592 0.039	-0.2756 0.091	-0.2465 0.117	-0.0211 0.460
Comb. Score				0.0578 0.392	0.1400 0.252	0.1064 0.306	0.3024 0.071	-0.2505 0.114	-0.2232 0.142	0.1489 0.239
Flight Hours					-0.0820 0.348	-0.0181 0.466	-0.2029 0.165	-0.2473 0.117	-0.1560 0.228	-0.2198 0.146
Question #2A						-0.6434 <0.000	-0.0031 0.494	-0.1239 0.278	-0.1248 0.276	-0.2432 0.121
Question #2B			*corr coeff* *p value*				0.2105 0.156	0.1282 0.271	0.1968 0.173	-0.0186 0.465
Question #3			(typical)					0.3542 0.041	0.2106 0.156	0.0458 0.414
Question #8A									0.1690 0.210	-0.0503 0.406
Question #8B										0.0692 0.371
Question #11										

$-1.0 \leq$ correlation coefficient ≤ 1.0

p = probability that calculated correlation coefficient is due to chance.

Table 6.1-2. Measured or Observed Experiment Variables

1	Richmond decision	
2	Wallops decision	
3	Risk Score	
4	Weather Score	
5	Combined Score	
6	Flight Hours	
7	Answer to Question 1a	Immediate Response Questionnaire Answers
8	Q1b	
9	Q2a	
10	Q2b	
11	Q3	
12	Q4	
13	Q5	
14	Q6	
15	Q7	
16	Q8a	
17	Q8b	
18	Q10a	
19	Q10b	
20	Q11	
21	Q12	
22	Pilot Unaware of data stale @ Richmond	
23	Pilot Unable to estimate distances @ Richmond	
24	Pilot Unable to determine ownship location @ Richmond	
25	Pilot reported Richmond departure concerns	
26	Pilot waved-off by ATC @ Richmond	
27	Pilot used Richmond weather source: ATIS	
28	Pilot used Richmond weather source: ATC	
29	Pilot used Richmond weather source: FSS	
30	Pilot used Richmond weather source: FlightWatch	
31	Pilot used Richmond weather source: METAR text	
32	Pilot used Richmond weather source: WX display	
33	Pilot Disregarded NEXRAD @ Wallops	
34	Pilot Misinterpreted display @ Wallops	
35	Pilot Used display for Navigation @ Wallops	
36	Communication delay incurred enroute to Wallops	
37	Pilot used Wallops weather source : ATC	
38	Pilot used Wallops weather source : FSS	
39	Pilot used Wallops weather source : FlightWatch	
40	Pilot used Wallops weather source : METAR text	
41	Pilot used Wallops weather source : WX display	

6.2 Qualitative Assessment Results

The difficulties in the use of the weather information display suggested in the quantitative analysis appear to include workload problems, incorrect assumptions about the accuracy and timeliness of displayed weather data, misuse of the display as a navigation aid and failure to cross-check information from other available sources.

While it was required that all candidate subject pilots for this experiment be qualified and current as instrument pilots, the 25 pilots ultimately selected to participate demonstrated a very wide range of performance in instrument flight. Their selection from the pool of candidates was based on their scores on the risk aversion test and weather knowledge test and not on their total flight hours nor on their number of flight hours in actual instrument conditions. Their proficiency in instrument flight operations was very probably quite representative of the population of general aviation pilots having similar qualifications and levels of experience.

As indicated in Tables 5.3-5 and 5.3-6, there was remarkably good correlation between demonstrated instrument flight proficiency (at least as observed in the simulation facility used in the experiment) and actual instrument flight time. The five pilots within the control group who stated they had 250 or more hours of actual flight time in instrument conditions were observed to have no significant problems in performing the mission. The other seven pilots with less actual instrument flight time were all observed to be less proficient and experienced a significantly higher workload in performing the mission. Among these seven less experienced pilots, the most experienced in actual instrument flight reported he had 80 hours of actual instrument flight time while the least experienced reported he had 4 hours of actual instrument time.

Within the treatment group, there was a similar trend, although the correlation was not as pronounced. Six of these pilots reported they had 200 or more hours of actual instrument flight time; five of the six were observed to have no significant problems in performing the experiment mission. The sixth pilot reported that he had flown most of his 200 hours of actual instrument time several years before in the military, and had only flown a few hours of actual instrument time in the past several years. Among the six subject pilots in the treatment group who reported they had less than 200 hours of actual instrument flight time, all six were less proficient and experienced a significantly higher workload in performing the experiment mission.

Despite the observed instrument flight experience/flight proficiency relationship, there was no apparent correlation between the actual instrument flight time of the subject pilots and the decisions they made at the two decision points in the experiment. Among the six pilots within the treatment group with 200 or more hours of instrument flight time, only three made good decisions at the Richmond decision point and only three made good decisions at the Wallops decision point.

Nor does there appear to be any correlation between the actual instrument flight time of the subject pilots in the treatment group and their success in use of the weather information display. Among the five pilots within the control group with 250 or more hours of actual instrument flight time, only two made good decisions at the Richmond decision point.

Of the 12 subject pilots in the control group, five made good decisions at both the Richmond and Wallops decision points. Three of these pilots were observed to be highly proficient in instrument flight and experienced a relatively low level of workload; two were observed to be low in proficiency in instrument flight and experienced a relatively high level of workload.

Of the 13 subject pilots in the treatment group (had weather display), only two made good decisions at both the Richmond and Wallops decision points. One of these pilots was observed to be highly proficient in instrument flight and to have experienced a relatively low level of workload; the other was observed to be low in proficiency in instrument flight and to have experienced a relatively high level of workload.

6.2.1 Workload Issues

This study was not designed to specifically measure or quantify workload in relation to the use of the weather information display, however, general observations were made by the observers who participated in the experiment. The observers gathered workload cues such as incorrect or inappropriate procedures, fixation, body movements, hesitation in communication, changes in voice pitch, control excursions, flight technical errors, procedural hesitation, navigation errors, haphazard search techniques, autopilot use, training transfer problems and physiological cues such as perspiration.

Observed workload, and self-perceived workload of the subject pilots participating in the experiment with and without the weather information display were reported as follows (see Tables 5.3-5 and 5.3-6):

Pilots without Weather Display

	Observed Workload	Self-perceived Workload
High	4 Pilots	6 Pilots
Moderate	5	2
Low	3	4

Pilots with Weather Display

	Observed Workload	Self-perceived Workload
High	8 Pilots	9 Pilots
Moderate	5	4
Low	0	0

The subject pilots in the treatment group (with weather display) were asked if they felt the weather display had an impact on their workload. Seven of the 13 subject pilots with the weather display reported that they felt the display increased their workload. Six reported that they felt the display decreased their workload.

As indicated previously, the overall workload observed by the experimenters as well as the overall workload perceived by the pilots themselves appeared to be relatively higher overall for the treatment group than for the control group. The lowest level of observed workload in the treatment group was reported to be a moderate level for 5 pilots whereas in the control group 5 pilots were reported to have experienced a low level of workload.

The observed workload and the self-perceived workload were low for the subject pilots in the control group reporting over 250 hours of flight in actual instrument conditions. The observed workload and the self-perceived workload were relatively higher for the subject pilots in the treatment group reporting over 200 hours; four of the six experienced a relatively moderate workload and the other two experienced a relatively high workload.

The subject pilots were asked to comment on the workload for the entire mission, and were also asked what the workload would have been if an autopilot had not been available. All but one of the subject pilots had experience in the use of autopilots typical of the one implemented in the experiment; all recognized the autopilot to be an important asset to proficient instrument flight operations. All the pilots had an autopilot available during the experiment and were trained on its use during the training session. During the pre-mission briefing, the pilots were instructed to use the autopilot if they felt it necessary to do so, but there was neither any requirement nor penalty in its use. Figure 6.2.1-1 depicts the extent to which the subject pilots used the autopilot in the experiment.

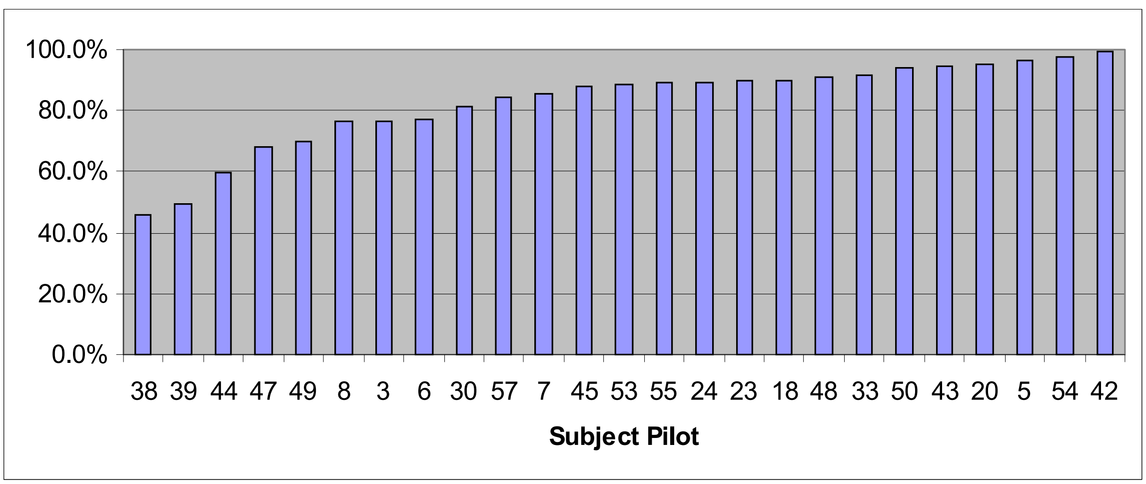


Figure 6.2.1-1. Percent of Flight Time Autopilot Used

Because of their relatively low level of experience and currency in actual instrument flight, the workload was relatively high for approximately one half of the subject pilots. Even though the autopilot was used for an average of 82% of the time in flight across all the subject pilots, some were too busy to effectively integrate the use of the weather information 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 in the treatment group stated that in reducing their workload, the autopilot made it possible for them to make more effective use of the weather information display.

6.2.2 Use of Available Weather Data Sources

The source of weather information of choice for the approach into the Richmond airport was the Richmond airport ATIS. All of the pilots without the weather display used the ATIS while three fourths of the pilots with the weather display also used the ATIS. One half of the control group pilots asked Richmond Approach Control for the latest conditions of the field while all but two of the treatment group pilots asked ATC for the latest conditions. The majority of the pilots having the weather information display queried the textual METARs. There were only two cases, however, of pilots using the Flight Service Station or Flight Watch to update their knowledge of weather conditions enroute to Richmond (one control group pilot and one treatment group pilot).

While enroute from Richmond to the Wallops Island airport, all but one of the subject pilots without the weather display depended on ATC for information and guidance around the hazardous weather conditions. The one pilot who did not depend on ATC for guidance based his navigation decisions on information received from the Flight Service Station and Flight Watch. The subject pilots having the weather display, however, almost totally ignored all other sources of weather information except ATC. Eight out of the twelve pilots with the weather information display used the display as their primary source of information for avoiding the hazardous weather while consulting with ATC. Four of the pilots with the weather information display depended primarily on ATC for avoidance of the hazardous weather while consulting the weather display.

In several cases, pilots with the display made the strategic decision to proceed around the thunderstorm activity without help from ATC even though they had been alerted by ATC. It was interesting that when asked in the post-flight debriefing about their use of in-flight weather advisories from the Flight Service Station, the subject pilots having the weather information display commented that they do not use the service much because the verbal information is difficult to interpret and takes an excessive amount of time to collect. Additionally, the FSS does not generally know their specific location and obtaining specific route information is difficult. Yet, their counterparts in the control group who did not have the display used these sources effectively to develop an understanding of the weather conditions enroute to the Wallops Island airport.

6.2.3 Interpretation of the Weather Information Display

Nearly all of the subject pilots in the treatment group were enthusiastic about the potential for improving their awareness of weather conditions, but many misinterpreted or did not access the information available from the display. Many of the poor weather decisions were made because the pilots, even though they had the weather information display, were not aware of the deteriorating weather conditions and were consequently surprised that they could not get into the Richmond airport or that there were thunderstorms over the bay between Richmond and the Wallops Island airport. Nearly all recognized that a thunderstorm was in the vicinity of the Richmond airport – most failed to correctly recognize the level of the hazard to them. When asked why they proceeded with the approach inside of the outer marker, they said they had not recognized how close they were getting to the hazardous areas of the storm. Many said they had decided to proceed with one approach into the Richmond airport and "see what happens." Most of these pilots said they were looking for clues as to the severity of the weather such as turbulence levels, lightning or level of rain. Only one subject pilot having the weather information display noticed that the graphic METAR depiction of visibility and ceiling at the Richmond airport had changed from VFR to IFR conditions as a result of a special report. He noticed the change *after* he had made the decision to divert to Wallops.

6.2.3.1 Judging Proximity to Hazardous Weather

Many pilots had difficulty correctly determining their position in relation to the storm cells. Some incorrectly determined their own position, others incorrectly determined the distance from their location to the hazardous areas of the storm. When comparing the recorded distance from the aircraft to a hazardous weather condition (a red cell), half of the pilots misjudged the distance by two to four times the perceived distance, and all of the pilots that had a disparity placed the hazard farther away than it actually was.

Most of the pilots were familiar with and experienced in the use of moving map displays, and thus were accustomed to seeing their position portrayed on a display screen such as the one used in this experiment. However, the weather display used in this experiment did not feature an ownship icon or clear indication of range. Half of the pilots with the display demonstrated situational awareness problems that were confirmed in the debriefing. The problems were related to the inability to determine ownship position on the display. The subject pilots stated they spent a disproportionate amount of time attempting to locate their approximate position on the weather display screen – a behavior pattern that was confirmed by the experiment observers.

Even after a generous amount of time devoted to training in the use of the free and lock modes[6], the subject pilots still had difficulty with this feature. This confusion over the positioning modes caused some pilots great difficulty and contributed to the already high workload. Many occasions were noted of the subject pilot scrolling excessively and selecting the METAR icons to determine the position of the weather image in relation to recognizable landmarks or navigation aids. The lack of an ownship position icon was the primary complaint of the display during the post-flight interview.

Compounding the problem of determining proximity to hazardous weather, a number of subject pilots experienced difficulty in estimating distances on the weather information display. Some pilots misinterpreted the display distance equals miles indication on the

[6] The display had two orientation modes, GPS free and GPS lock. GPS free allowed the user to freely scroll the NEXRAD image to any location, thus allowing the range to be set low (for higher storm cell resolution) while scrolling to locations not in the general location of the aircraft. When the GPS lock mode was selected, the NEXRAD image was locked into a position with the physical center of the display becoming the aircraft position in relation to the weather image. In this mode, the weather image moved with changes in aircraft position and use of the joystick to move the image was disabled.

display, thinking the number was an indication of the scale selected and indicated the number of miles from one side of the display screen to the other, or the number of miles from the bottom of the display screen to the top of the screen. Others understood the meaning of the distance scale, but felt they were unable to effectively use this indicator to estimate distance. Many subject pilots suggested that some form of range rings or other similar indication should be available to aid in estimating distances.

In one instance, the subject pilot was making strategic and tactical decisions believing that the display had a track-up orientation instead of the actual north-up orientation, and completely lost confidence in his ability to use the display when his interpretation of the display disagreed with what ATC was telling him.

6.2.3.2 Recognizing and Interpreting Effects of Delay

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

While most of the subject pilots were aware of the delays in the display of the NEXRAD mosaic images, many either forgot the delays or chose to ignore them because of their workload. A few chose to assume some sort of average delay in the display of the image and planned to account for it; most of these pilots incorrectly estimated the impact of the delay in determining the movement of the hazardous weather and their proximity to it, especially near the rapidly moving front at the Richmond airport.

Many of the subject pilots commented that they perceived the NEXRAD weather image to be real time information (without delay). When asked if they were aware of the age of the image, they generally commented that they were aware of the 7 to 14 minute delay at the beginning of the flight, but that they soon started to treat it as real time. Two pilots even commented that, to them, 7 to 14 minutes is real time compared to a preflight weather chart that could be hours old. When asked about how they used the timestamp information, most commented that they did not consistently determine the age of the NEXRAD image, but either ignored the delay or treated the image as delayed a consistent amount and did not try to determine the age of the image. Further investigation revealed that while most subject pilots were aware of the delay, the workload would have been excessive if the age of the image were to be determined every time the display was queried. Many pilots also commented that they were using the NEXRAD images for short term as well as long term decisions.

The graphical depiction of NEXRAD weather images will be available to pilots through paid subscriptions. The effects of aging of the NEXRAD mosaic image on the pilot's understanding of proximity to hazardous weather conditions is likely to become more significant if FISDL service providers or users are allowed to update their NEXRAD image displays even less frequently than the 7 minute intervals used in this experiment.

Many subject pilots noted that an age indicator would have reduced the mental workload of determining the age of the NEXRAD image. Some suggested that an indicator that changed size or shape in proportion to the age of the image would reduce the mental calculations required to compare the image timestamp to the current time.

The subject pilots with the weather information display were briefed twice (during the introduction and again during the familiarization flight) that the METAR information could be as much as an hour old and to check the issue time. Eight of the 12 subject pilots having the weather information display accessed the METAR text data at least once in making the Richmond decision. Three accessed the METAR text data at least once in making the Wallops decision. Most of the pilots were not aware of the METAR age, and admitted that the METAR information is not that timely and was generally not consulted in their decision making. Only one of the pilots having the weather information display noticed that the coded METAR report for the Richmond airport had changed during the flight, and acknowledged that he noticed the change only as he was leaving the vicinity of the Richmond airport enroute to the Wallops Island airport.

The METAR textual information is presented in typical ICAO teletype codes and although identical in content to the information that will be broadcast free of charge, the interpretation of the codes in a high workload environment causes many errors. In this experiment, many of the subject pilots admitted to having difficulty interpreting the codes. Many errors were observed and excessive fixation times were observed when the pilots attempted to decode the METAR information. Other studies reflect similar findings. In a report about Mode-S datalink weather information, Rehmann (1995) notes, "Once the codes are learned for the test, they are promptly forgotten because the FSS briefer will decode them in the weather briefing. With the implementation of DUATS, those codes are once again needing interpretation and come as a shock to our systems." It was noted in this experiment that the airline pilots who participated did not have as much difficulty in interpreting the reports as did the general aviation pilots. This was also a finding in Rehmann. Many of the pilots commented that the METARs would be more useful if they were displayed with their English translation, much as DUATS provides the English translation. Rehmann also found that English translations were less prone to error.

6.2.3.3 Use of Weather Information Display for Navigation

Several pilots were observed to be using the weather display for more than just enhancement of their awareness of their situation with respect to potentially hazardous convective weather conditions. These pilots were attempting to augment their understanding of their position derived from the VOR navigation system, and to then navigate from that position to another location on the display image. In at least one case they were attempting to actually navigate using the weather display in lieu of the VOR navigation system – with disastrous results. In this case, the pilot became totally disoriented, unable to reestablish a workable mental model within which to navigate, and consequently decided to abandon the flight.

The fundamental problem was that the pilots were required to integrate two mental images of their location; mental images developed from and based on two entirely different reference systems. One mental image was based on the integration of data consisting of distance and bearings with respect to several selected navigation facilities with which they were familiar; the other was based on a mental image of distance and bearings with respect to a different set of features depicted graphically on the weather display image. Compounding the problem, all of the features needed for navigation were not available from the weather information display. This invariably substantially increased their workload.

7 Conclusions

The objective of the weather information experiment was to investigate the potential for misuse of weather information, and thus provide guidance for the FAA. The successful completion and documentation of the lessons learned and the knowledge acquired during the conduct of this experiment has met the objective, while indicating directions of future research.

The elements of the experiment design have been substantiated. These elements included the selection method for subject pilots, the prototype FISDL display system selection, the simulator fidelity (cockpit instrumentation, out-the-window scene generation, ATC communication environment, etc.), the "between-subjects" approach, 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,

The navigation decisions were designed into the experiment to test the experiment hypothesis: "delayed weather information datalinked to the cockpit display may lead to navigation decision errors." When the two key decisions in the experiment were considered jointly, the presence of the weather information display had no significant statistical impact on the outcome of the decisions made by the pilots. The purpose of introducing the FISDL display, however, is to reduce the number of poor decisions, which was not the case.

When the two key decisions in the experiment were considered separately, the presence of the display had no significant statistical impact on the Richmond decision; it did have a significant impact on the Wallops decision. A statistically significant greater number of pilots with the weather display made a poor navigation decision with respect to avoiding the hazardous weather enroute to Wallops. The Richmond decision emphasized the temporal hazards associated with time delayed weather information. The Wallops decision emphasized the potential spatial hazards associated with data linked weather displays.

The significant issues having an impact on the outcome of the experiment are summarized below.

7.1 Weather Information Display Interpretation Issues

The configuration of the weather information display system implemented in this study did not improve the decision making of the pilots using the display. Causes for this finding include:

a. Pilots were unable to easily perceive their proximity to potentially hazardous convective weather conditions graphically depicted because of:
   - Difficulty in determining ownship position due to lack of ownship symbol and other features with which to construct and maintain a mental model of position,
   - Difficulty in estimating distances on the display, and
   - Substantial latency in the presentation of NEXRAD and METAR data, and interpretation of the effects of that latency.

b. Pilots were unable to easily estimate the juxtaposition of their flight path with the path of graphically depicted hazardous convective weather conditions (NEXRAD mosaic images) because own path was not depicted on display and probable path of the hazardous weather was not depicted.

c. Use of the weather information display apparently increased the workload for at least half of the pilots, decreasing the time available for decision making.

d. Difficulty for many pilots in deciphering METAR text data.

7.2 Weather Source Information Issues

The weather information display limitations described above not withstanding, 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 weather information 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.

7.3 Training Issues

Substantial training in the use of a weather information display system will be required to help pilots understand the limitations of a weather information 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.

7.4 Autopilot Issues

The safe and effective use of a weather information display in actual instrument conditions will almost certainly require the support of an autopilot for most pilots.

8 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 (August 25, 2000).

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

8.1 AIM 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 once an 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. In addition, 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. In addition, TAF forecasts are issued four times per day at scheduled intervals and remain valid until amended or superceded 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.

Because of the inherent production delays, the weather information provided by a weather information display should not be used for avoiding hazardous weather in a tactical manner, such as finding one's way through a line of thunderstorms. In the time that it takes for a NEXRAD image to be produced and transmitted, a storm cell could have moved a significant distance. Storm cells can also sometimes develop very quickly to hazardous levels within the update time of NEXRAD images. Therefore, NEXRAD images should be used in the more strategic sense to avoid areas of convective activity by a wide margin.

Weather information provided by the FISDL display in text form (METAR, TAF, etc.) should only be used for gathering an understanding of weather conditions over a large geographical area. Other independent sources of information must also be used in conjunction with the FISDL display to assure that a complete understanding of the weather conditions is obtained.

Pilots should be fully aware that a weather information 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 a weather information display can increase a 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 a weather information 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 a weather information display.

8.2 Weather Display Manufacturer Recommendations

8.2.1 Consider Providing Ownship Information

An overwhelming response from the pilots in this study was the need for ownship position information. Both subjective and objective measures found 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 that they use to determine their position.

The benefits of ownship symbology 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, many commented that they realized the NEXRAD images were old and would take the staleness into account when comparing ownship information in relation to the weather depiction.

8.2.2 Provide Direction and Rate of Hazardous Weather Motion

Many of the pilots in this study 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).

8.2.3 Provide Distance Determination

Many of the pilots in this experiment made poor estimations of the distance between the aircraft and the convective weather. This misperception was a significant contributor to the inability of many of the pilots to effectively use the weather information display. This indicates the need for a means such as range rings to determine range information on the display.

8.2.4 Provide Intuitive NEXRAD Image Age Information

There is a concern that the display of stale weather information in the cockpit may cause interpretation difficulties and lead to tactical use of stale weather information. The pilots that were aware of the staleness of the NEXRAD images used the information correctly, several admitted that they just assumed that the information was a consistent age, generally about 10 minutes old. This rationale was due to the difficulty and cognitive processes required in subtracting the current time from the NEXRAD timestamp. The problem will only be exacerbated should some manufacturers choose to offer NEXRAD images on a "pay-for-view" basis.

8.2.5 Provide METAR Code Translation

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

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

8.3 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.

8.3.1 Conduct Evaluations of Specific Issues to Support Standards

This research topic is motivated by the interest in current and pending cockpit weather displays to be designed and marketed by the manufacturers in the FY01 time frame, and 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.

8.3.2 Develop Concepts for Integration and Display 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, datalinked 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. Such integration would reduce the cognitive skills required of the pilot to integrate weather data from many sources as well as reduce the comprehensive weather data interpretation training currently required.

Based on the lessons learned from the previous experiments, such display concepts might incorporate the following attributes: 1) GPS derived ownship position in real time, 2) more intuitive zoom, pan, and ownship centering capabilities and operations, 3) optimum NEXRAD cell size, 4) an intuitive indication of NEXRAD data staleness, 5) an intuitive indication of map range distances, and 6) borrowing from military applications, depiction of a “threat representation” region to indicate those weather related areas for the pilot to avoid (precipitation, lightning, icing, turbulence, etc.).

8.3.3 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.

Appendix A. Flight Information Services – Broadcast Description

System Overview

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

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

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

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

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

1. The products are either FAA/NWS accepted aviation weather products, or based on FAA/NWS accepted weather products.

2. In the case of a product which is the result of the application of a process which alters the form, function or content of the base FAA/NWS accepted weather product(s), that process must be:

   a) An established, conventional aviation weather process used in standard U.S. aviation weather information systems, and,

   b) Managed by a qualified aviation meteorologist.

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

Operations

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

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

Appendix B. Literature Search Results

Andre, A.D., & Cutler, H.A. (1998). "Displaying uncertainty in advanced navigation systems." ***Proceedings of the Human Factors and Ergonomics Society 42nd Annual Meeting. Vol. 1 pp 31-35.***

Summary:

- Uncertainty may involve lack of accuracy, lack of precision, or time lag.
- Position uncertainty. In creating a scenario where the pilot had to avoid collision while maintaining relative course, "graphical-implicit" (text #'s, or color) and "graphical-explicit" (obstacle surrounded by circle of uncertainty) symbologies aided in reducing the number of collosions under conditions of positive uncertainty, relative to the no-represtation group. However, only the "graphical-explicit" symbology showed benefit under high uncertainty conditions.
- Heading uncertainty – Subjects were found to shoot more bogeys and less friendlies when the known display of uncertainty was shown. Graphical depicted "arcs" proved most successful in displaying uncertaint headings in enemy and friendly aircraft. Text and graphical "rings" also proved beneficial compared to the control condition.

Aretz, A.J. (1988). "A model of electronic map interpretation." Proceedings of Human Factors ***Society – 32nd Annual Meeting.***

Summary:

Map complexity:
Very powerful effect. Do everything possible to reduce complexity of information contained on electronic map displays. Any increase of map complexity will increase time to use the information.

Processing:
To avoid sequential processing, present information simultaneously with HUD or virtual display.

Banbury, S., Selcon, S., Endsley, M., Gorton, T., & Tatlock, K. (1998) "Being certain about uncertainty: How the representation of system reliability affects pilot decision making." Proceedings of the Human Factors and Ergonomics Society 42nd Annual Meeting. Vol. 1 pp 36-39.

Summary:
When presented with a single machine-identified target, pilots were unwilling to accept a level of uncertainty above 9% (lower than 91% confidence). When a secondary aircraft was presented as friendly, pilots were far more reluctant to shoot (when uncertainty level was above 3%) or (when confidence level was below 97%). Results suggest that an explicit suggestion of the risk of fratricide cause pilots to become more conservative, even though they were briefed that all other aircraft were present in equal numbers.

Participants took significantly longer when two aircraft were presented rather than one. When a second plane was presented as a friendly, subjects were far quicker at making the shoot/no shoot decision when the uncertainty level was more than 9% (no shoot).

Reaction times were significantly worse when uncertainty levels were between 6-9%, suggesting that participants found it difficult to make a decision faced with information bordering on maximum level of risk they would accept for fratricide, which is consistent with a study by Selcon (1990) who found that when the probabilities led to some ambiguity as to what to do, decision time was slower than if no probabilities had been presented at all.

There was no difference in whether the information was presented as uncertainty or confidence.

Boyer, B., Campbell, M., May, P., Merwin, D., & Wickens, C.D. (1995). "Three-dimensional displays for terrain and weather awareness in the national airspace system." Proceedings of Human Factors and Ergonomics Society 39th Annual Meeting. pp 6-10.

Summary:
Generally no advantage of 3D display over 2D display, except that.3D display led to trajectories that were "more conservative," taking longer paths, that skirted the hazard by a wider margin – believed to be related to participants having less certainty regarding lateral position of the aircraft relative to the hazard, causing them to take a cautious approach creating paths far enough away from the hazard to compensate for any possible error in their perception of lateral separation.

Campbell, M., May, P.A., & Wickens, C.D. (1995) “Perspective displays for air traffic control: Display of terrain and weather.” Eighth International Symposium on Aviation Psychology. Vol. 1 pp. 375-381.

<u>**Summary:**</u>
Speed advantage for planar displays in categorization of the presence of a threat.

Top-down view provided a more appropriate domain to make lateral judgements.

Planar display provided a more accurate means of travelling to the final destination, however, the subjects needed to make more vector clearances to do so.

Cardosi, K., & Hannon, D. (1999). "Guidelines for the use of color in ATC displays." U.S. Department of Transportation, Federal Aviation Administration.

<u>**Summary:**</u>
Several experts in the field of color vision and displays have compiled recommendations on the use of color in electronic aircraft displays. Most recommend a conservative and consistent use of color, using no more than six color codes for symbols: white, red, green, yellow, magenta, and cyan, while reserving red and yellow for warnings and cautions. The use of more than six symbol colors may degrade performance on search, and identification, especially under high ambient light.

Cohen, M.S. "Taking risks and taking advice: The role of experience in airline pilot diversion decisions 1." NASA Contract.

<u>**Summary:**</u>
Through 10 different scenarios, experienced and inexperienced pilots were given paper and pencil flight-decision scenarios. Relative to their situation, they were then given a worst case, expected case, and best case scenario predictions of the situation which involved possible combinations of weather and/or fuel problems. Dependent variables were decision to divert/continue, and subjects assessment of their confidence of the judgement.

Subjects fell into 3 general categories of either risk takers, non-risk taking experienced, or non-risk taking inexperienced.

Risk takers were willing to accept the "worse case" scenario of no options if the expected case or best case scenario's were good.

Non-Risk taking experienced pilots were the only ones to take dispatch advice, centering their decision making process around the recommendation.

Non-Risk taking less-experienced pilots fell evenly into two categories: cautious-strategy and worst-case strategy. The cautious-strategy saw the worst-case of no options as sufficient but unnecessary to cause a diversion, while the worst-case strategy saw the worst-case of no options as both necessary and sufficient for diversion.

Crabill, N.L., & Dash, E.R. (1991) "Pilot's automated weather support system (PAWSS) concepts demonstration project - Phase 1 - Pilots weather information requirements and implications for weather data systems design." FAA Technical Center Engineering Field Office, NASA Langley Research Center.

Summary:
Flight broken down into stages into pre-flight, take off, departure, climb, cruise, approach, landing, and post flight operations. Information needed by pilots at each of these stages is listed and diagramed. This information is further broken down into surface weather and aloft weather required at each stage. See hard copy for details.

Dershowitz, A., Lind, A. T., Chandra, D.C. & Bussolari, S.R. (1995). "The effect of compression induced distortion of graphical weather on pilot decision making." Eighth International Symposium on Aviation Psychology. Vol. 2 pp. 827-832.

Summary:
Subjects were given high resolution and low resolution weather graphics (referred to as uncompressed and compression respectively) in order to plan a route to a predetermined destination. Results showed that in general, highly compressed data was rated as unacceptable to the pilots. Also, with highly compressed data, route area error was significantly greater (not necessarily a bad thing- see hard copy), and was associated with proximity to weak precipitation. There was no significant differences in route length.

Driskill, W.E., Weissmuller, J.J., Quebe, J., Hand, D.K., Dittmar, M.J., Metrica, Inc., & Hunter, D.R. (1997). "The use of weather information in aeronautical decision-making." National Technical Information Service, Springfield, Virginia.

Summary:
Investigated the values of worth functions pilots attribute to weather and terrain variables in making decisions about flight in a single-engine aircraft under VFR.

Pilots decision policies were found to vary based on 1) general comfort level; 2) mixture of age and general experience 3) number of hours flown in last 90 days and 4) reason for flying (employed as pilot vs. pleasure flying).

While compensatory models (one good weather factor compensates for a bad one) for go/no go decisions are used, they are not always the best - especially for non-experts. In cases where a pilot is inexperienced, compensatory models are sometimes very dangerous, and therefore increased emphasis on risk assessment and self-perception training are recommended.

Although there was common ordering of weather variable importance (many interactions of ceiling, visibility & precipitation), each pilot attributes uniquely different weights to weather conditions for each terrain type depending on familiarity with the terrain.

Fisher, B.D., Brown, P.W., Wunschel, Jr., & Stickle, J.W. (1989) "Cockpit display of ground-based weather data during thunderstorm research flights." 27th Aerospace Sciences Meeting.

Summary:

A prototype system (actual F-106B airplane) was developed to provide a cockpit display of ground-based weather data and was used during thunderstorm research. This system was severely limited due to small image size and the inability to continuously update the data. However, it was found helpful in the selection of the route of flight (strategical decisions), general track to be used, and occasionally in clarifying the location of a specific cell of interest (perhaps tactical). Recommendations for improvement include incorporating an airplane heading up display mode with a digital display of heading while retaining the choice of a north-up display mode, also to provide the pilot with control of the magnification feature and translation of the displayed area

Guilkey, J.E., Jensen, R.S., Caberto, S.C., & Fournier, D.L. "Piloting expertise interven tion strategies for aeronautical decision making." Ohio State University, Columbus, Ohio.

Summary:

Trends in data indicate that "expert" pilots could be differentiated from "average" or "poor" pilots in terms of 1) seeking additional quality information in a more timely manner, 2) making progressive decisions to solve a problem, and 3) communicating readily with available resources.

Attempt to quantify/qualify characteristics of the "expert" pilot in the realm of problem solving, and then to use those methods to teach this problem solving technique to those at the lower end of the continuum.

Hale, S.L., (1988). "Use of color CRT's in aircraft cockpits: A literature search." U.S. Army Human Engineering Laboratory, Aberdeen Proving Ground, Maryland.

Summary:

Luminance:
Contrast ratio should be between 6:1 to 10:1.
Bright background best for color visibility.

Saturation:
Highly saturated colors have little benefit and often cause after images.

Color for coding:
Red for warning or danger and nothing else should not be used as singular information code; use shape or position for redundancy.

Color is highly useful for high-density displays.

Number of colors:
Discrepancies in literature

Color types:
Green: recommended as predominant color for coding.
Yellow: moderate priority.
Red: high priority – threat or danger.
Blue: to perceptually separate related or adjacent symbology. Don't use with shape coding, it reduces legibility.
Desaturated orange: may be used in place of green for sensor imagery or computer imagery.

Background:
Dark background provides high contrast, but black too dark.
Best to have grayish background that remains neutral under ambient illumination.
Primary display should be of similar brightness as other displays so as not to induce eye fatigue.

Task combinations:
When choosing colors it is vital to consider all tasks to be performed.

Cockpit Environment:
Automatic contrast/brightness adjust system is a must for a cockpit display.

Hansman, R.J. & Wanke, C. (1989). "Cockpit display of hazardous weather information." 27th Aerospace Sciences Meeting.

<u>Summary:</u>
Experiment conducted with a GA simulation to compare voice, text, and graphical depiction of weather and aircraft position in recognizing and avoiding microbursts.

Study was extremely weak, using a total of only 8 pilots to evaluate the 3 different conditions. There is no mention of how these 8 subjects were dispersed among these conditions, or if they were all used in each condition, resulting in a massive lack of control of learning effects. Comparisons are drawn using only percentages, with no other statistical data reported.

There does exist some anecdotal evidence that verbal relay of microburst alerts lead to delays.

Pilot survey indicated that PIREPS and visual cues are the best currently available methods for microburst detection, while LLWAS and airborne weather radar are less effective.

Hoffman, R.R. (1990). "Human factors psychology in the support of forecasting: The design of advanced meteorological workstations." American Meteorological Society. Volume 6.

<u>**Summary**</u>:
Recommendations for design in information processing components of Advanced meteorological presentation, (AMP).

Design subsystems in modular form.

Many of the system operations functions, maintenance functions, and hardware aspects should be invisible to the user.

User operation should involve use of icons and menus & minimize control language.

Promote easy navigation (show "go back", "escape", "undo", and "where am i") make clear the next steps to be taken.

Formats should be consistent across data types and should contain explanations in text form, even if long.

Hughes, D. (1989) "Glass cockpit study reveals human factors problems." Aviation Week & Space Technology. pgs 32-36.

<u>**Summary:**</u>
Air Transportation Association Study:
Too much reduction of workload in low workload phases.
Too much increase of workload (monitoring) in high workload phases.
Potential for too much "head-down" time.
Difficulty in recovering from automation failure.
Reluctance of crews to take over a failing automated system.
Deterioration of pilot skills.
Loss of vigilant performance.
Difficulty in detecting system errors.
Incompatibility between new aircraft, ATC, and old fleet.

Hunter, D.R., Driskill, W.E., Weissmuller, J., Quebe, J., Hand. J., & Dittmar, M. (1995). "Analysis of the weights applied to weather information by pilots." Eighth International Symposium on Aviation Psychology. Vol. 2 pp. 833-838.

Summary:
Many pilots use a compensatory model for evaluating weather information, however there has been no data collected to demonstrate that the use of a compensatory model is appropriate for all or even the majority of pilots. It might be argued that in many situations (e.g. mountain flying) a non-compensatory model should be used. One such model might set a minimum value for ceiling values (e.g. sufficient to clear all mountains) which must be met, regardless of the visibility. That is, in such a model, having a very high visibility does not compensate for having a low ceiling.

Kirkpatrick, G.M. (1979). "Real time weather display in the general aviation cockpit." AIAA Aircraft Systems and Technology Meeting.

Summary:
Proposed use of VOR voice channel for the relay of current radar charts. The user will receive a benefit in completion of additional flights which would previously have been delayed or cancelled because of thunderstorms.

Kochan, J.A. "Aeronautical decision making: the expertise method." The Ohio State University Aviation Research Team, Columbus Ohio.

Summary:
Based on subjective interviews, a model of attributes of the "expert pilot" was formed. Study suggests that expert rating comes from more than just flight hours, but from number, variety, meaningfulness, relevancy, and recency. Also suggests risk management, attentional control, and dynamic problem solving are key components. See hard copy for details.

Lee, A.T. (1990). "Aircrew decision-making behavior in hazardous weather avoidance." Aviation, Space, and Environmental Medicine. February, pp 158-161.

Summary:
Evaluated the performance of experienced airline crews in the assessment and avoidance of microburst events in simulation. Compared conventional ATC transmission of weather with 2 display groups receiving visual Doppler returns automatically when the aircraft was within a 60 nm radius of the airport. Microburst events occurring within 3 nm of the approach or departure ends of the active runway were also displayed. The 2 display groups differed only with respect to the time at which the microburst alert was received. The control group and display group 1 received the alerts at 3 nm from the airport, while display group 2 received alert on the downwind leg of the approach.

Real-time visual display of terminal area convective activity exhibited awareness of microburst event probability, found from increased communication between crew members referencing microbursts.

Reduction in decision time with visually displayed information averaged nearly 1 min.

Lind, A.T., Dershowitz, A., & Bussolari, S. (1994). "The influence of data link-provided graphical weather on pilot decision-making." Government Technical Report No. ATC 215, Lincoln Laboratory, MIT.

Summary:
Subject pilots were given prepared flight plans, weather briefings, and graphical weather images. This was done in an office setting and graphical images were presented on an Apple Macintosh Computer. Subjects were asked to make weather-related decisions (both tactical and strategical) without time constraints and the workload demands of actual flight.

Results indicated that all pilots made noteworthy differences in the action taken/decision-making. When pilots could see the graphical depiction on GWS, their situational awareness was better and they were able to make informed GO/NO GO decisions, as well as informed in-flight deviations when compared to access to weather information through verbal query of ground-personal.

Pilots made significantly fewer calls when they had GWS. This could reduce workload of both pilots, and ATC's.

Pilots that had GWS rated their confidence in ability to assess weather higher than those without it.

Pilots with GWS indicated a higher mean hazard rating than pilots who did not have GWS for the same flight, although this was not statistically significant. This may alleviate concerns that with more information the pilots may feel over-confident, and subsequently make poor decisions.

Pilots reported the GWS system very useful, and worth the estimated cost of $5,000.

Lindholm, T.A. (1995). "Advanced aviation weather graphics – information content, display concepts, functionality, and user needs." Eighth International Symposium on Aviation Psychology. Vol. 2 pp. 839-844.

Summary:
Present only the information needed to accomplish the task, and in a form that requires little or no interpretation.

Weather data must be presented in the same spatial and temporal context as the task at hand.

Weather displays must be tailored to the individual class of users (based on why the information is needed) and how the user will use it.

Field evaluations must permit open and free user feedback in the operational setting.

Laboratory evaluations seem to miss essential elements of the task structure, such as stress or task saturation.

May, A. (1997). "Neural network models of human operator performance." ***The Aeronautical Journal.*** **No. 2129 pp 155-158.**

Summary:
Examines the feasibility of using neural networks to represent the effects of human operators in computer models of complex man-machine systems. Data from the man-in-the-loop simulators are used to train the networks. This method was tested on several data sets using a stand alone prototype system with successful results. These results can be used to place constraints on the quality, quantity and type of simulator data required in future applications.

Merwin, D.H., O'Brien, J.V., & Wickens, C.D. (1997). "Perspective and coplanar representation of air traffic: Implications for conflict and weather avoidance." Ninth International Symposium on Aviation Psychology. Vol 1 pp. 362-367.

Summary:
Consistent advantage of the coplanar 2D formats over the 3D perspective format in supporting traffic avoidance maneuvers. (Ambiguity with which the perspective display depicts position and separation along the line of sight or the viewing axis of the display).

Clear advantage of data base integration, suggesting that considerable caution should be exercised in adding separate monitors or display units for separate hazard data bases. If display begins to appear cluttered, then use color or intensity coding or decluttering algorithims.

O'Brien, J.V., & Wickens, C.D. (1997). "Free flight cockpit displays of traffic and weather: effects of dimensionality and data base integration." Proceedings of the Human Factors and Ergonomics Society 41st Annual Meeting. Vol. 1 pp. 18-22.

Summary:
Integrated weather and traffic information tended to result in fewer conflicts than the separated displays.

2D coplanar displays supported better hazard awareness and avoidance than 3D displays.

O'Hare D., & Smitheram, T. (1995). " 'Pressing on' into deteriorating conditions: An application of behavioral decision theory to pilot decision making." ***The International Journal of Aviation Psychology.*** **Vol 5, (4), 351-370.**

Summary:
Looked at the possibility of changing decision making outcome based on situational framing, an approach called "prospect theory."

Participants were shown to select the gains frame rather than the losses frame as the way they would naturally consider the decision of whether to continue with the flight.

Pilots who viewed the decision from a gains (of turning around) framework were significantly less likely to press on into deteriorating conditions than pilots who viewed the decision from a loss perspective.

Pilots should be encouraged to consider in-flight decision about whether to continue with a flight in terms of their current position, and should forget about any past losses such as money spent, time and fuel wasted, and pilots should also be encouraged to make in-flight decisions in terms of gains rather than losses, making them more likely to make risk-averse choices.

Rahman, T., & Muter, P. (1999). "Designing an interface to optimize reading with small display windows." ***Human Factors, Vol. 41, No. 1. UOT, Toronto, Ontario.***

Summary:
Experiment 1 concluded that efficiency was poorer in the Rapid Serial Visual Presentation (RSVP- single word after single word) than other conditions. Efficiency was at least as high in the sentence to sentence condition as it was in a normal paragraph condition. Experimenters introduced a visual completion meter below the word/words to let the reader know how much further the sentence or paragraph had until its end. This did not detract from performance, and in fact significantly improved sentence by sentence comprehension, and was preferred by readers.

Faster presentation of RSVP in Experiment 2 perhaps eliminated the poor performance. RSVP was shown to be just as efficient as sentence by sentence, and normal paragraph form, although it was the least preferred.

Most other experiments cited, found that the "Times Square" method (text scrolling across the screen from right to left) resulted in inferior performance compared with RSVP and page format. See hard copy for examples of text.

Rehmann, A. J. (1995). "A Pilot Evaluation of Text Display Formats for Weather Information in the Cockpit." FAA Technical Center, Atlantic City, N.J., DOT/FAA/CT-TN95/42.

Summary:

Pilots were given various text displays of in-flight weather reports in a part task simulation exercise. The weather reports were presented in both teletype code formats and plain English formats with either a vertical or horizontal orientation. Additionally, various data entry techniques were explored, such as: keyboard entry, cursor select, bezel key select and number selection. Both general aviation and airline pilots were used as evaluators.

Results indicated that the vertical format of text presentation was preferred for its readability, organization and error reduction. The general aviation pilots had difficulty interpreting the teletype code formats because of their unfamiliarity of using those codes in a day to day environment, as the airline pilots are used to. Therefore, the general aviation pilots showed better accommodation, and reduced errors, to the plain English format.

The pilots were asked to enter the station identifier using various data entry methods. The results showed that the bezel key select method was superior from both an operational view and error reduction view.

Rothenheber, E., Stokes, J., LaGrossa, C., Arnold, W., & Dick, A.O. (1990). "Cockpit Ocular Recording System (CORS)." ***Prepared for Langley Research Center under contract.***

Summary:

Experimental Issues:

Findings of experiments suggest the CORS oculometer accuracy is variable and is dependent on, at least, the following: 1) time since calibration 2) location in the visual field and 3) test subject, including the size of pupil and other physiological variables.

Tullis, T.S. (1988). "Screen Design" -(*Chapter 18 of Handbook of Human-Computer Interaction M. Helander (ed.)). Elsevier Science Publishers*

Summary:

Recommendations on screen design:

Most important: Present only that information that the user needs, no more or less. Display most used items on primary display, use a function key or something to access infrequently used items. Presenting them simultaneously with often used items only brings clutter.

Abbreviations: Only to be used when they are standard and familiar to all.

Use familiar forms: For example a persons name, street address, city, state, and zip code are a familiar format, and therefore don't necessarily need to be labeled - therefore saving space.

Use tabular column headings: This will save you from labeling something time & again.

Make use of grouping: Grouping similar items together in a display format improves their readibility and can highlight relationships between different groups of data.

No more than 5 degrees: 5 degrees of visual angle to which the eye is the most sensative (approximately the foveal region of the retina) shows data in chunks that can be taken in at one fixation, and will help speed search time. This visual angle, assuming average display characteristics and viewing distance, translates to an area about 12-14 characters wide and 6-7 lines high.

Better to have few groups defining many variables, than may groups defining a few variables.

Spacing is better than use of color for separating or grouping.

If using brightness as a distinguisher of information, only use two different levels – any more than that is difficult to discriminate.

Flashing should only be used as imminent danger, if used at all.

Search times are shortest for top left, and longest for bottom right.

General elements should precede more specific ones.

Numbers should be tight justified or decimal point aligned.

Use indentation to represent hierarchical relationships.

Usually more effective to put a label to left of item, except when using tabular column headings. Also should use dotted line connectors .

Writing words in upper and lower case will increase reading speed by about 13%.

When looking to draw attention, use all caps. All caps. is read faster than all small.

Text with consistent spacing should always be used, despite ragged right margins.

Space between bottom of one line, and the top of another should be about equal to or slightly larger than a letter.

Space used between paragraphs helps to group concepts.

Line length should not exceed more than about 60 characters, unless line spacing is increased .

Wiener & Curry (1980). "Automation guidelines: Appendix 1." pp 189-190.

Summary:
System operation should be easily interpretable and understandable.

Automation must perform how the operator wants it to perform, not at some lower standard, otherwise it won't be used by the operator and it would have cost you time and money.

Design automation to prevent peak levels of task demand from becoming excessive, ensuring available time for monitoring.

Allow for different operator styles when feasible - (choice of automation).

Make sure system performance will be insensitive to different modes or options (i.e. the pilot may choose to have the autopilot either fly pilot-selected headings or track ground-based navigation stations).

Provide means for checking the set-up and information input to automatic systems.

Extensive training required to ensure proper operation, and to implement correction procedures.

Provide meaningful duties when automation reduces task demand to low levels.

Keep false alarms at acceptable rates.

Alarms with more than one mode or responsible for more than one condition must indicate which condition caused the alarm.

Provide a quick way to check the validity of alarms.

Format of alarm should indicate degree of emergency.

Wickens, C.D., & Scott, B. (1983). "A comparison of verbal and graphical information presentation in a complex information integration decision task." Office of Naval Research Engineering Psychology Program.

<u>Summary</u>
Experiment looked at verbal vs. spatial-graphical display formats in presenting sequential information for a tactical decision making task. Subjects' task involved integrating information to determine which one of two tactical battlefield maneuvers was in effect. Subjects were more accurate using the spatial display which supports the stimulus-central processing compatibility theory stating that the analog operations on which the judgements were based would be best served by spatial displays. This graphical advantage was enhanced when cues in both subject groups were delivered at a slower speed, imposing greater demands on working memory in the verbal group.

Wiggins, M., Connan, N., & Morris, C. "Self-perceptions of weather-related decision-making Ability amongst pilots." University of Newcastle, Newcastle, Austrailia

<u>Summary</u>:
Results suggest that inexperienced pilots are more inclined to rely upon their self-perceived risk-taking behavior than their self-perceived ability to resolve various decisions. More experienced pilots' performance, during complex tasks, is related primarily to their perceptions of their own ability to cope efficiently with a situation.

Wiggins, M., Connan, N., & Morris, C. "Weather-related decision making and self-perception amongst pilots." Applied Aviation Psychology.

<u>Summary:</u>
Support for perception that risk-taking propensity is indicative of pilot performance during simulated weather-related decision making scenarios. More specifically, a negative relationship was found between self-perception of risk and the frequency with which information screens were accessed during the scenario.

Suggest that training must focus on the relationship between risk-taking behavior and the process of decision-making rather than simply the outcome of risk taking behavior.

Wiggins, M., & O'Hare, D. (1995). "Expertise in aeronautical weather-related decision making: A cross-sectional analysis of general aviation pilots." Journal of Experimental Psychology: Applied. Vol. 1, No. 4 pp 305-320.

<u>Summary</u>:
There was qualified support for the notion that through task-specific experience, individuals develop procedures that can be generalized and applied subsequently to a variety of situations, however the performance between groups was delineated more effectively

by the specific type of experience being measured, than mere flying hours alone, because task related experience requires participation of that particular task.

Inexperienced pilots accessed a greater number of information screens, made a greater number of information recursions, and spent more time examining the information screens than the experts.

Inexperienced pilots also exhibited a greater response latency in selecting whether to continue the flight or turn around – base on the weather scenario

Significantly more intermediate and expert pilots chose to continue the flight (well dvised in virtually all cases) than did the inexperienced pilots.

Williams, A.J., & Harris, R.L. (1985). "Factors affecting dwell times on digital displaying." NASA Langley Research Center, Hampton, VA.

Summary:
In an experimental flight simulator, round dial meters demonstrated shorter dwell times and fewer dwells per meter change than the digital displays. The following factors affected digital display scanning behavior: 1) number of digits 2) update rate of the digits 3) display media, and 4) character font (The digit size used here (.28-.50 inches) did not affect scan behavior measures).

Appendix C. The Risk Assessment Task (RAT)

Index Of Risk Taking Predilection

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

Rationale

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

The challenge, therefore, has been to utilize expert knowledge of flying, accident causation and aviation psychology to recreate the kind of environment and circumstances that could be expected to increase the probability of detecting misuse of the new weather display technologies. The experiment is not designed to calculate the prevalence of these "misuse behaviors", but rather to evaluate and assess whether and how such misuse could occur, thus providing guidance for pilots and display manufacturers. With this in mind the study team elected to proceed with a stratified random sample of pilots taken from populations that might be identified as higher risk and lower risk pilots. If weather display misuse accidents are going to occur, then pilots low in weather knowledge sophistication, high in risk acceptance, and motivated to continue a flight seem likely to be over-represented in the incident/accident statistics. Therefore, the subjects were pre-screened for weather knowledge and risk aversiveness. The purpose of the RAT test is to increase the probability of including subject pilots who might exhibit behaviors that would otherwise only emerge in the operational environment. The RAT task is not advertised as a definitive biographical variable nor as a definitive measure or predictor of pilots' decision making prowess. The RAT does, however, have a well-documented history as a psychometric instrument, and, indeed, in a range of applied psychological studies including aviation, as outlined below.

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

Origins of the RAT

The RAT task is one sub-task from a version of a multiple task computerized battery of cognitive tasks that was explicitly designed to evaluate aviators[1] (see, for example, "Neuropsychological screening of aviators: A review,:" Banich, Stokes & Elledge, 1989). The original research began with an information-processing task analysis of aviation and initially identified six primary areas of aviator cognitive proficiency that the battery should cover: working memory, attention (divided and focussed), spatial ability, logical reasoning, perceptual-motor abilities, and processing flexibility (or prioritizing). Risk taking predilection or aversiveness, that is, risk judgment, was subsequently added, as this was clearly a source of pilot variance not captured under the original six headings.

Test sensitivity testing, reporting, and reliability

All of the subtasks were tested against each other empirically in a series of discriminant analyses (reported in, for example, "Testing the tests - An empirical evaluation of screening tests for the detection of cognitive impairment in aviators." Stokes[2], et al. 1991, a.). The sensitivity, specificity and positive predictive value for each subtask in all seven areas of cognitive proficiency were compared, and thus an objective basis for comparison in standard epidemiological terms was determined. Stokes[3] (1999) showed that the tests in the battery are reliable, don't suffer from undue practice effects, and factor load on the appropriate constructs. The risk task is particularly strong in these respects, exhibiting no practice effect and, whereas certain tasks (e.g. maze tracing, hidden figures recognition and spatial memory) all factor load onto one construct (e.g. spatial ability), only the RAT factor loaded on the risk construct.

Applications of the RAT

The original and updated versions of the battery have been utilized extensively in a range of applied studies. (e.g. effects of alcohol on performance[4], of the artificial sweetener aspartame[5] (NutraSweet); of stress and trait-anxiety[6], novice versus expert performance[7] and so on). Several studies have resulted in findings that involve the risk construct.

For example, risk assessment appears to be a specific ability or cognitive dimension which can be directly impaired by neurological deficit. In a clinical study, Stokes[2] et al (1991, b.) showed that pilots evidenced less propensity for risk taking than members of a group of subjects with known neuropsychological diagnoses (Testing the Tests, p.785). Moreover, the range of conditions in these diagnoses was broad, including as it did cerebro-vascular conditions, trauma, neurodegenerative disease and sequelae of alcoholism.

An effect often observed and commented on in the engineering psychology literature (see, for example, Wickens, 1984), is the apparent conservatism associated with age. The clinical study also scrutinized the extent to which older subjects become more risk averse. Generally speaking, risk taking did indeed decrease with age in pilots, while it increased with age in the clinical group. The mechanism underlying the latter, clinical finding is not well understood, but the RAT findings for pilots are consistent with the wider literature on risk and risk aversiveness, increasing confidence in the utility of the measure.

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

The RAT and Flight Training

In a 1995 study, the effect upon flight training success of a number of information processing variables, including risk predilection, was examined in the context of university flight training[8] (Stokes & Bohan, 1995). This study also evaluated the predictive utility of anxiety scores and academic grades. A major influence upon the outcomes of such studies is the nature of the criterion of success. In the 1995 study, several criteria were examined, including a checkride score, hours to solo, landings to solo, and ground school grade. The first three of these are closely associated with psychomotor skill, as the criteria involve maneuvering flight, rather than primarily cognitive skills such as those involved in cross-country flight management. The criteria used are reflected in the results - dual-task tracking tasks best predict success where maneuvering flight is the criterion. An unanticipated finding was that the risk task was predictive of ground school performance (which presumably includes a more "cerebral" element and little psychomotor control). The effect, however, was weak. In this study important additional criteria were examined. Results were compiled for checkride "passers" and "failers", as one might expect, but also for individuals who had not been permitted to take the checkride.

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

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

References

1. Banich, M.T., Stokes, A.F., & Elledge, V.C. (1989). Neuropsychological screening of aviators: A review. *Aviation, Space, and Environmental Medicine*, 60, 361-366.

2. Stokes, A.F., Banich, M.T., Elledge, V., & Ke, Y. (1991). Testing the tests: An empirical evaluation of screening tests for the detection of cognitive impairment in aviators. Aviation, Space, and Environmental Medicine, 62, 783-788.

3. Stokes, A.F. (1999), Assessment of subtle cognitive and neuropsychological dysfunction in the highly skilled.* Proceedings of the Human Factors and Ergonomics Society 43rd Annual Meeting. Santa Monica, California: Human Factors and Erogonomics Society. (*in this paper, aviators)

4. Stokes, A.F., Belger, A., Banich, M.T., & Bernadine, E. (1994). The effects of alcohol and chronic aspartame ingestion upon performance in aviation relevant cognitive tasks. Aviation, Space, and Environmental Medicine, 65, 7-15.

5. Stokes, A.F., Belger, A., Banich, M.T., & Taylor, H. (1991). The effects of acute aspartame and alcohol ingestion upon the cognitive performance of pilots. Aviation, Space, and Environmental Medicine, 62, 648-653.

6. Stokes, A.F. (1995). Sources of stress-resistant performance in aeronautical decision making: The role of knowledge representation and trait anxiety. Proceedings of the Human Factors and Ergonomics Society 39th Annual Meeting, pp. 887-890. Santa Monica, CA: Human Factors and Ergonomics Society.

7. Stokes, A.F., Kemper, K., & Kite, K. (1997). Aeronautical decision making, cue recognition, and expertise under time pressure. In C. Szambok & G. Klein (Eds.), Naturalistic decision making. Hillsdale, New Jersey: Lawrence Erlbaum Associates, pp. 183-196.

8. Stokes, A.F. & Bohan, M. (1995, April). Academic proficiency, anxiety, and information-processing variables as predictors of success in university flight training. Proceedings of the Eighth International Symposium on Aviation Psychology, pp. 1107-1112. Ohio State University, Columbus.

9. Banich, M.T., Stokes, A.F., & Elledge, V. (1988, May). Evaluation of cognitive function in aviators: What should we measure? Paper presented at the 59th Annual Scientific meeting of the Aerospace Medical Association, New Orleans. [Abstract in Aviation, Space, and Environmental Medicine, May, 1988.]

Appendix D. Weather Knowledge Questionnaire and Key

The Weather knowledge test presented here is the key used to grade the test. All graded answers are shown in grey highlight. All other questions were not graded as they were not relevant to weather knowledge.

General Aviation Questionnaire

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

Name: ___________________________________ Date: _____________

Phone number: ____________________ E-Mail: ___________________________

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

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

   Recreational Private Commercial Airline Transport

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

4. Are you an instrument rated pilot? _____________________________________

   If so, are you current to fly instruments? ____________________________

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

   Possible Fog

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

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

   Runway Visual Range, Visibility down Specific Runway

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

9. Briefly describe class C and class G airspace.

   Class C: ____

   Class G: ____

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

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

    ____

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

    ____

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

__________South______________________

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

________High Winds______________

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

    Level (accelerating):____

    Climb:____

    Descent:____

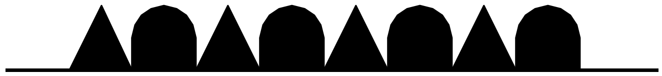
16. In what weather products can you find icing information?

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

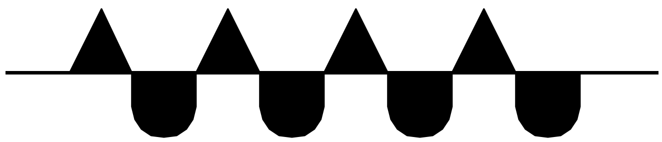
17. What do boundary layer air, and surface winds near the ground have in common?

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

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



A. Occluded Front



B. Stationary Front

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

Regulatory Notices, Charting Changes

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

20 miles

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

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

22. What is a void time clearance?

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

Not available

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

____

25. Please translate the following METAR weather report:

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

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

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

Appendix E. Subject Pilot Screening Test Results and Statistics

Subject Pilot Screening Test Results and Statistics

Total Subjects:	57	
Mean Risk Score:	3.79	
Risk Standard Deviation:	0.75	
Mean Wx Knowledge Score:	27.16	(out of 39 possible)
Wx Knowledge Standard Deviation:	6.20	

Subject Number	Raw Risk Score	Converted Risk Score	Raw Wx Score	Risk z-score	Wx Know z-score	Half Sum z-score	Group Selection
1	4.05	5.95	28.00	-0.35	0.14	-0.11	
2	2.90	7.10	22.00	1.18	-0.83	0.18	
3	3.80	6.20	38.00	-0.02	1.75	0.87	Treatment #1
4	3.75	6.25	30.00	0.05	0.46	0.25	
5	3.60	6.40	17.00	0.25	-1.64	-0.69	Control #2
6	2.65	7.35	35.00	1.52	1.26	1.39	Treatment #1
7	2.40	7.60	30.00	1.85	0.46	1.16	Treatment #1
8	3.20	6.80	33.00	0.78	0.94	0.86	Control #1
9	4.20	5.80	26.00	-0.55	-0.19	-0.37	
10	3.45	6.55	27.00	0.45	-0.03	0.21	
11	3.55	6.45	33.00	0.32	0.94	0.63	Alternate #1
12	3.00	7.00	24.00	1.05	-0.51	0.27	
13	3.95	6.05	32.00	-0.22	0.78	0.28	
14	4.20	5.80	30.00	-0.55	0.46	-0.05	
15	3.65	6.35	21.00	0.18	-0.99	-0.40	
16	3.50	6.50	30.00	0.38	0.46	0.42	
17	3.40	6.60	31.00	0.52	0.62	0.57	Alternate #1
18	4.30	5.70	21.00	-0.68	-0.99	-0.84	Control #2
19	2.85	7.15	22.00	1.25	-0.83	0.21	
20	5.05	4.95	12.00	-1.68	-2.44	-2.06	Treatment #2
21	3.50	6.50	30.00	0.38	0.46	0.42	
22	4.00	6.00	28.00	-0.28	0.14	-0.07	
23	4.00	6.00	23.00	-0.28	-0.67	-0.48	Treatment #2
24	4.60	5.40	26.00	-1.08	-0.19	-0.64	Control #2
25	3.80	6.20	30.00	-0.02	0.46	0.22	
26	4.55	5.45	20.00	-1.02	-1.15	-1.09	"no-show"
27	4.60	5.40	28.00	-1.08	0.14	-0.47	Alternate #2
28	3.55	6.45	32.00	0.32	0.78	0.55	Alternate #1
29	4.90	5.10	34.00	-1.48	1.10	-0.19	
30	2.65	7.35	28.00	1.52	0.14	0.83	Treatment #1

Subject Pilot Screening Test Results and Statistics (Concluded)

Subject Number	Raw Risk Score	Converted Risk Score	Raw Wx Score	Risk z-score	Wx Know z-score	Half Sum z-score	Group Selection
31	3.60	6.40	32.00	0.25	0.78	0.52	
32	3.60	6.40	24.00	0.25	-0.51	-0.13	
33	2.60	7.40	27.00	1.59	-0.03	0.78	Control #1
34	3.50	6.50	26.00	0.38	-0.19	0.10	
35	3.70	6.30	28.00	0.12	0.14	0.13	
36	4.35	5.65	19.00	-0.75	-1.32	-1.03	Control #2
37	3.95	6.05	26.00	-0.22	-0.19	-0.20	
38	4.25	5.75	23.00	-0.62	-0.67	-0.64	Treatment #2
39	4.75	5.25	30.00	-1.28	0.46	-0.41	Alternate #2
40	3.00	7.00	18.00	1.05	-1.48	-0.21	
41	5.20	4.80	37.00	-1.89	1.59	-0.15	
42	3.60	6.40	19.00	0.25	-1.32	-0.53	Treatment #2
43	2.65	7.35	30.00	1.52	0.46	0.99	Control #1
44	5.75	4.25	20.00	-2.62	-1.15	-1.89	Control #2
45	3.30	6.70	36.00	0.65	1.43	1.04	Treatment #1
46	4.35	5.65	30.00	-0.75	0.46	-0.15	
47	4.05	5.95	38.00	-0.35	1.75	0.70	Control #1
48	3.05	6.95	29.00	0.98	0.30	0.64	Alternate #1
49	4.95	5.05	16.00	-1.55	-1.80	-1.68	Treatment #2
50	5.25	4.75	24.00	-1.95	-0.51	-1.23	Treatment #2
51	4.20	5.80	21.00	-0.55	-0.99	-0.77	"no-show"
52	4.15	5.85	32.00	-0.48	0.78	0.15	
53	3.45	6.55	38.00	0.45	1.75	1.10	Control #1
54	3.95	6.05	13.00	-0.22	-2.28	-1.25	Control #2
55	2.45	7.55	32.00	1.79	0.78	1.28	Control #1
56	3.35	6.65	27.00	0.58	-0.03	0.28	
57	3.30	6.70	32.00	0.65	0.78	0.72	Treatment #1

Appendix F. 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.

Standard Pre-Flight Weather Briefing

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 58/53/0910/992
Newport News, Williamsburg International Airport weather report, one, eight, zero, zero universal coordinated time. Measured ceiling eight hundred broken, visibility seven, temperature five eight, dew point five, three, wind zero niner, zero at ten, altimeter two, niner, niner, two.

RIC SA 1800Z 50 SCT M70 BKN 05 57/53/3010/992
Richmond International Airport weather report, one, eight, zero, zero universal coordinated time. Five thousand scattered, measured ceiling seven hundred broken, visibility 5, temperature five, seven, dew point five, three, wind three, zero, zero at one zero, altimeter two, niner, niner, two.

OFP SA 1747Z E50 BKN 150 OVC 10 65/53/2015/960
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 six, five, dew point five, three, wind two, zero, zero, at one, five, altimeter two, niner, six, zero.

LKU SA 1750Z 20 SCT E40 BKN 100 OVC 10 63/53/2415G20/955
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 six, three, dew point five, three, wind two, four, zero at one, five gusting two, zero, altimeter two, niner, five, five.

WAL SA 1749Z CLR BLO 120 10 61/50/1810/969
NASA, Wallops Airport weather report, one, seven, four, niner universal coordinated time. Clear of clouds below one, two thousand, visibility one, zero, temperature six, one, dew point five, zero, wind one, eight, zero at one, zero, altimeter two, niner, six, niner.

MFV SA 1753Z CLR BLO 120 10 64/52/1806/968
Accomack County Airport, Virginia weather report one, seven, five, three universal coordinated time. Clear of clouds below one, two thousand, visibility one, zero, temperature six, four, dew point five, two, wind one, eight, zero at six, altimeter two, niner, six, eight.

SBY SA 1750Z CLR BLO 120 10 60/50/1810/969
Salisbury, Maryland weather report one, seven, five, zero universal coordinated time. Clear of clouds below one, two thousand, visibility one, zero, temperature six, zero, dew point five, 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. After one, eight zero, zero 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. After one, eight, zero, zero 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 1818 1820G30KT SCT100 BKN200
Terminal area forecast for Salisbury, Maryland after one, eight, zero, zero 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 G. Cockpit Research Facility Description

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

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

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

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

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

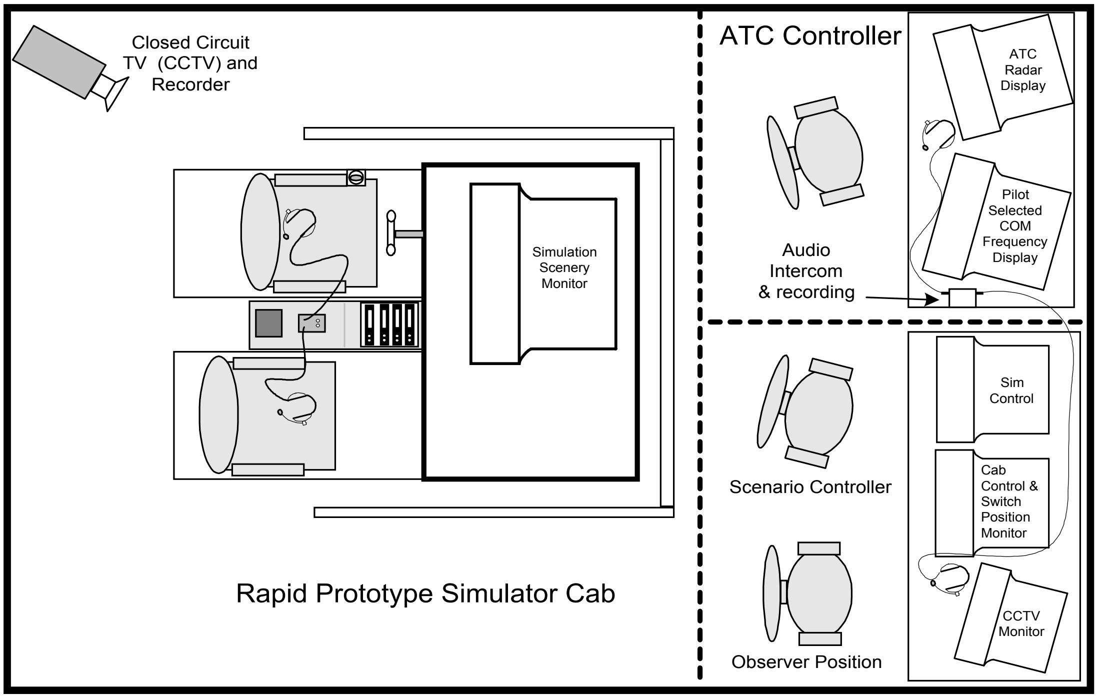


Figure G-1. Cockpit Research Facility

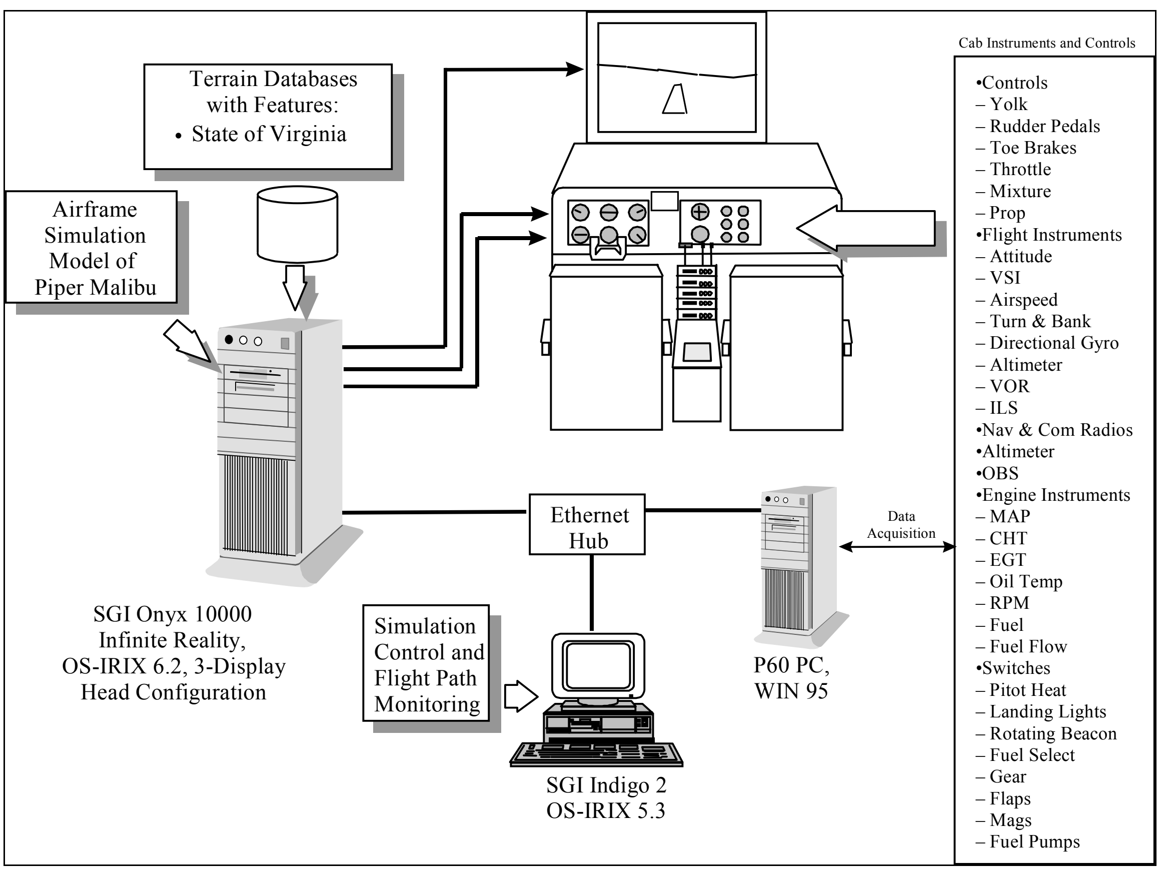


Figure G-2. Cockpit Research Facility System Block Diagram

Simulator Cab Description

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

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

Controls, Instruments and Indicators Description

The controls, instruments and indicator configurations available are typical of those found in an IFR-equipped aircraft as shown in Figure G-3. The characteristics for this configurations are summarized below.

All instrument panel round dial indicators are rendered on flat panel liquid crystal displays (LCDs). The 14-inch diagonal LCDs provide enough display area to fully render the standard instrument "T" configuration with other supplemental indicators as well. A second 14-inch diagonal LCD provides display area for navigation instruments and engine parameter indicators. Table G-1 lists the types of instruments rendered in the cockpit. All instruments provide the operational performance required by the Federal Aviation Administration Federal Aviation Regulations, Society of Automotive Engineers Aerospace Standards and RTCA, Inc. performance specifications as applicable to simulation.

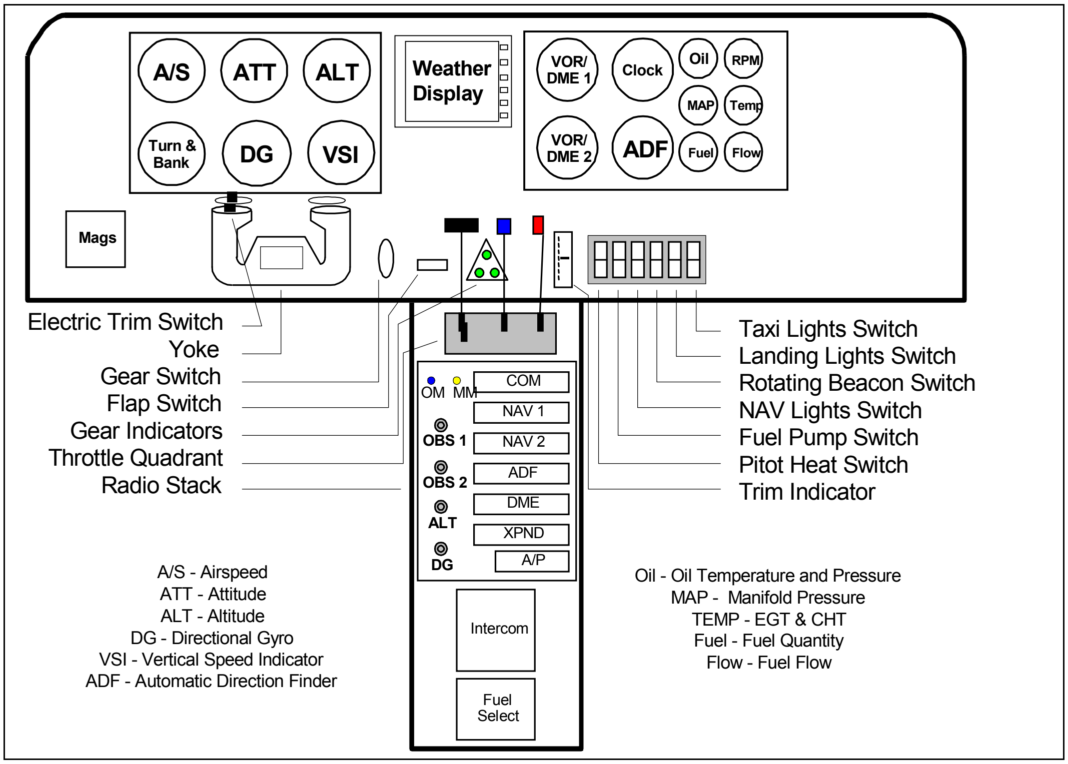


Figure G-3. Instrument Panel, Controls and Indicators

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

Flight Control Instruments	Navigation / Communications Instruments	Engine Monitoring Instruments	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)	• Trim Position • Flap Position • Gear Position • Autopilot Adjustment

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

Visual System and Displays Description

A Silicon Graphics Onyx 10000 is used to generate the instrument panel gages and the Out-the Window (OTW) scene for the pilot as depicted in Figure G-3. A rapid prototyping tool is used to develop and render the regulation-compliant gages in appearance and performance. Round dial instruments are rendered on two 14-inch diagonal active matrix Liquid Crystal Displays (AMLCDs), each having an addressable resolution of 1024 pixels by 768 lines.

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

A visual terrain database for the state of Virginia contains six major airports at which takeoffs and landings can be made. Another 24 airports are rendered at photographic quality to facilitate pilotage along several routes between NASA Langley, Newport News/Williamsburg Blacksburg, Richmond, Manassas, Washington National and NASA Wallops Island runways. The environmental conditions be varied to achieve any meteorological conditions required, i.e. overcast, low RVR, cloud decks, etc.

Data Acquisition System Description

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

A data acquisition controller system is hosted in a Pentium 60-based PC as depicted in Figure G-2. The data acquisition controller contains a microcontroller that performs all input / output (I/O) operations with the hardware in the simulator cab. Operations performed by the controller include:

- Acquiring analog control position information
- Performing the analog to digital (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, DME, ADF, transponder and autopilot interfaces in the radio stack located in the cockpit center console
- Acquiring the OBS 1 & 2, DG and Barro Altimeter knob settings
- Updating the frequency displays in the COM, NAV 1, NAV 2, DME and ADF radios

Simulation Control, Monitoring and Recording

All aspects of the simulation are controlled by the simulation control and flight path monitoring process running in the Silicon Graphics Indigo as shown in Figure G-2. The simulation control process initializes the simulation models in the SGI Onyx, performs real time data display and data collection capture of various flight parameters for later analysis, and presents a plan view of the aircraft's position during operation of the simulation, similar to an ATC console. The system operator uses the simulation control to select various scenarios, position / reposition aircraft model and monitor scenario progress.

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

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

Parameter	Parameter	Parameter	Parameter
Airspeed (A/S) • Calculated A/S • Indicated A/S • True A/S	Aerodynamic Coefficients • $CL_{\text{Total Lift}}$ • $CD_{\text{Total Drag}}$ • $CY_{\text{Total Side Force}}$ • $CM_{\text{Total Pitching Moment}}$ • $CR_{\text{Total Rolling Moment}}$ • $CN_{\text{Total Yawing Moment}}$	Control Surface Deflection • Elevator • Rudder • Aileron • Aileron Trim • Rudder Trim • Trailing Edge Flaps • Left Spoiler • Right Spoiler	Ground Contact Conditions (Landing) • Rate of Decent • Bank Angle • Side & Vertical Forces on Nose Gear • Side & Vertical Forces on Left Gear • Side & Vertical Forces on Right Gear
Ground Speed	Altitude • Pressure • AGL	Position • Latitude • Longitude • Heading	
Aircraft Body Angles • Pitch • Roll • Yaw • Angle of Attack α • Slide Slip β	Atomspheric • OAT • Air Pressure • Barro 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 G-3. Dictionary of Recordable Parameters and Inducible Faults

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

Air Traffic Management Console

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

The screen consists of “radar image data” and associated mapping features, Figure G-4. System controls and informational data is presented on the side and top of the display. The operator may zoom in to a 1 mile scale (used for ground control) to a 100 mile scale (approach, departure, and enroute functions). Features that can be displayed during the operation of the ATM Station include: intersections (with and without names), airports (with and without names), runways (utilized during approaches), taxiways (utilized for ground control), VORs (with and without names), and special use airspace. The display is centered upon the selected airport (currently PHF, RIC, LFI, or WAL). Future implementations include the display and manipulation of the flight paths of multiple aircraft.

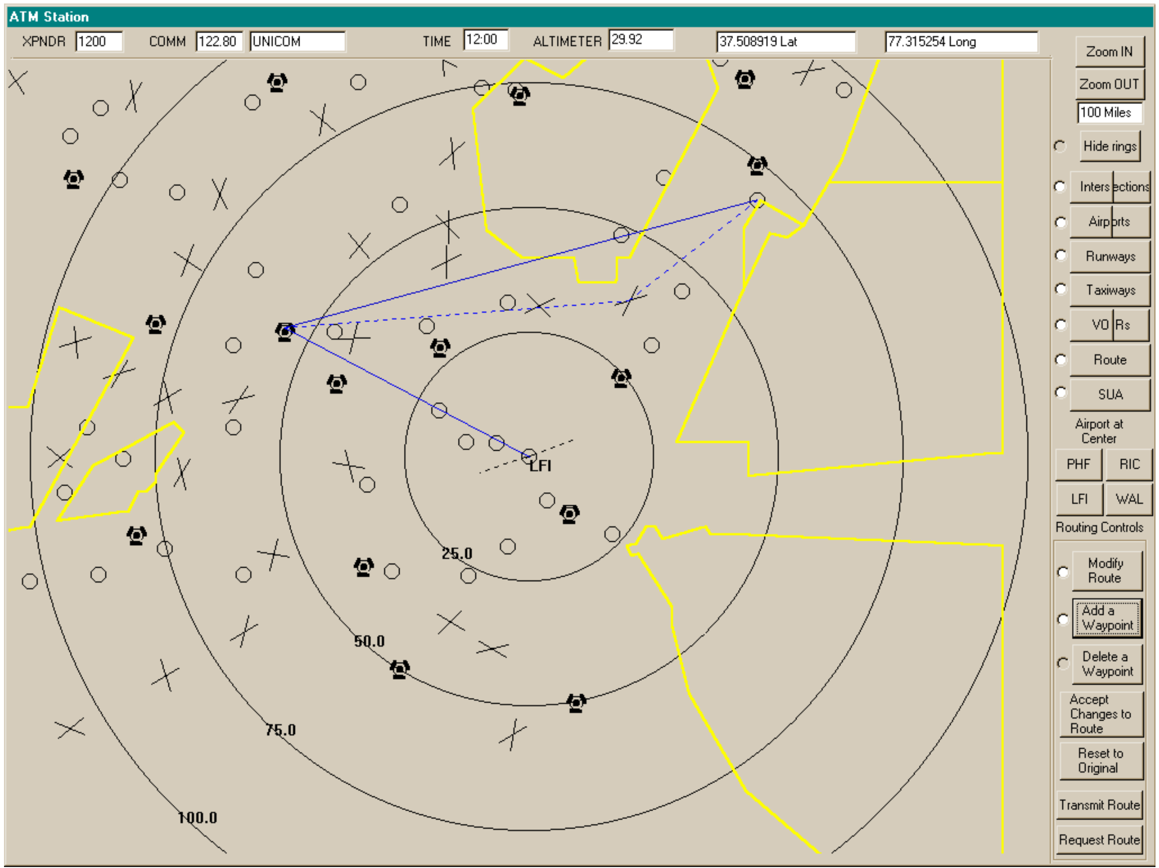


Figure G-4. Air Traffic Management Console Display

Aerodynamic Simulation Model

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

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

Crosswind Model

A 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 G-5.

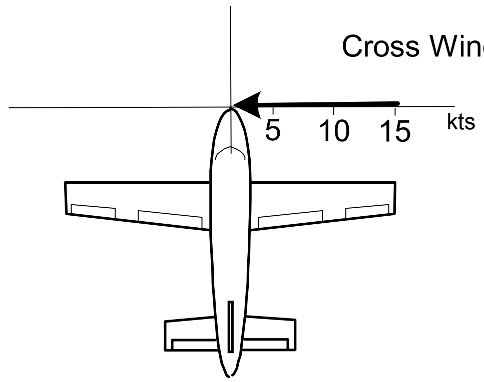


Figure G-5. Cross Wind Model

Turbulence Model

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

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

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

Appendix H. Pre-Flight Briefings and Simulator Training

Contrtol Group Preflight Briefing

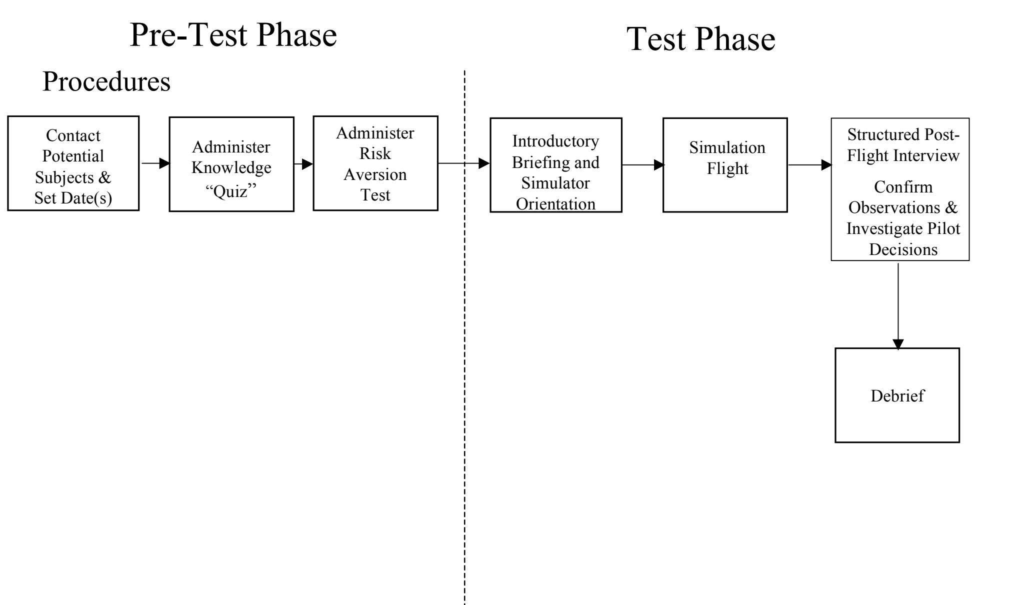
RTI

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

June, 2000

RTI

Experiment Procedure



Subject Pilot Schedule

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

Today's Flight Mission

Situation

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

Today's Mission

(Continued)

RTI

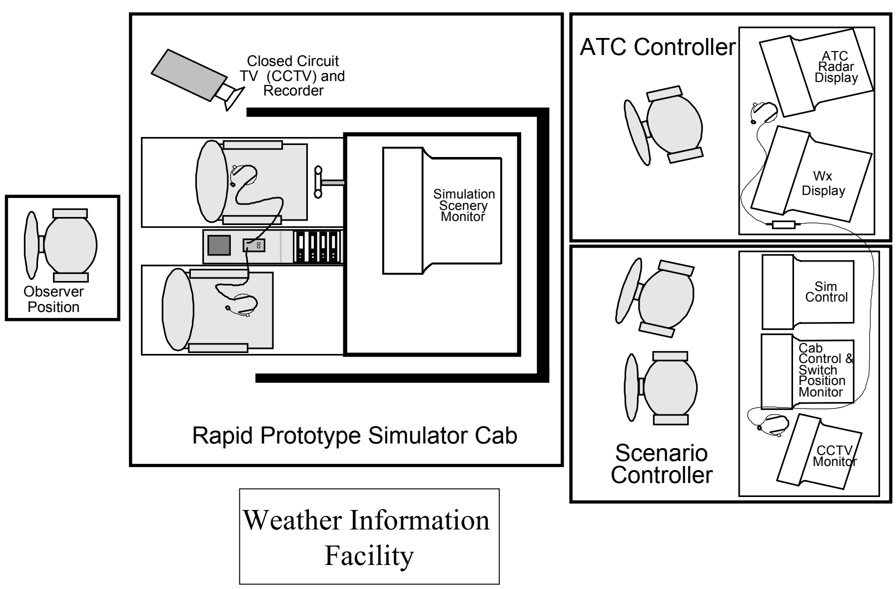
- **RTI Medical Services, Inc. is to deliver insulin to the Wallops Island airport from NNWB airport, stopping enroute to pick up sodium bicarbonate at Richmond, Va airport.**

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

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

RTI

Simulation Hardware Configuration



Simulation Cockpit Configuration

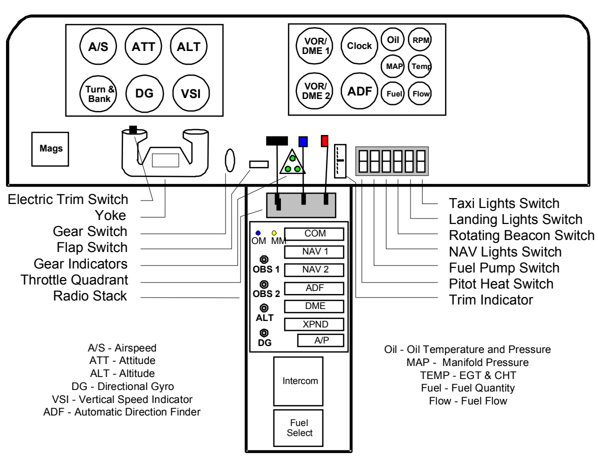
RTI

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

RTI

Simulation Cockpit Configuration



Simulation

Cockpit

Radio

Stack

Treatment Group Preflight Briefing

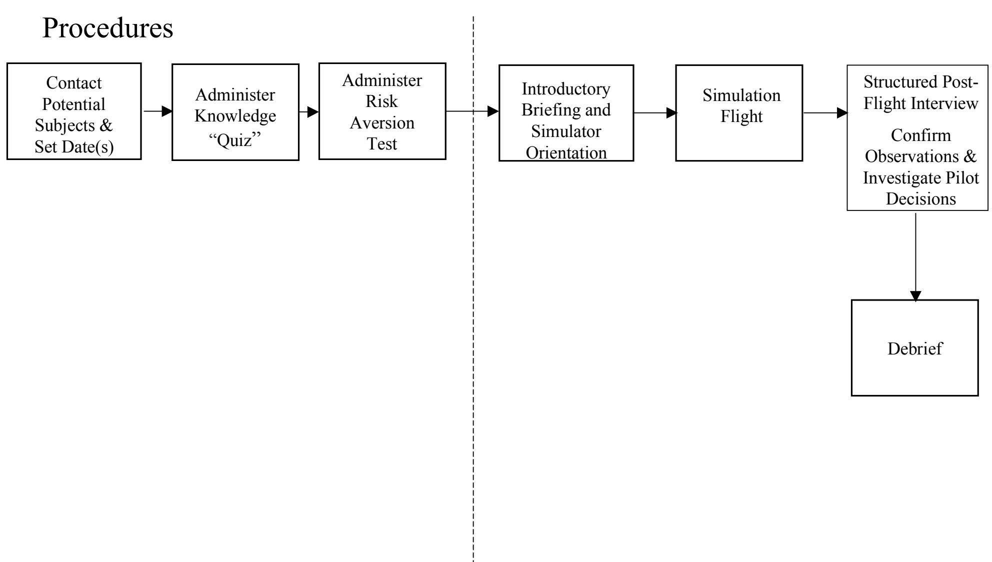
FAA/NASA/RTI Flight Information Services Data Link (FISDL) Experiment

June, 2000

Experiment Procedure

Pre-Test Phase

Test Phase



Subject Pilot Schedule

RTI

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

Today's Flight Mission

RTI

Situation

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

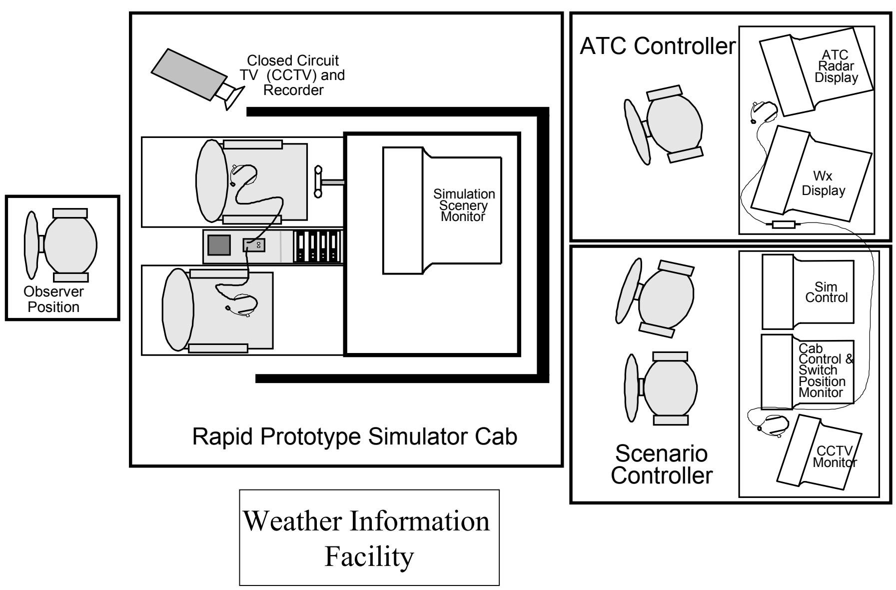
Today's Mission
(Continued)

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

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

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

Simulation Hardware Configuration



Simulation Cockpit Configuration

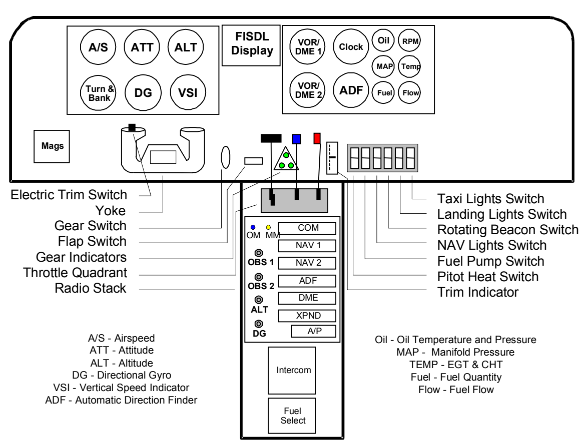
RTI

Weather Information Sources

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

Simulation Cockpit Configuration

RTI



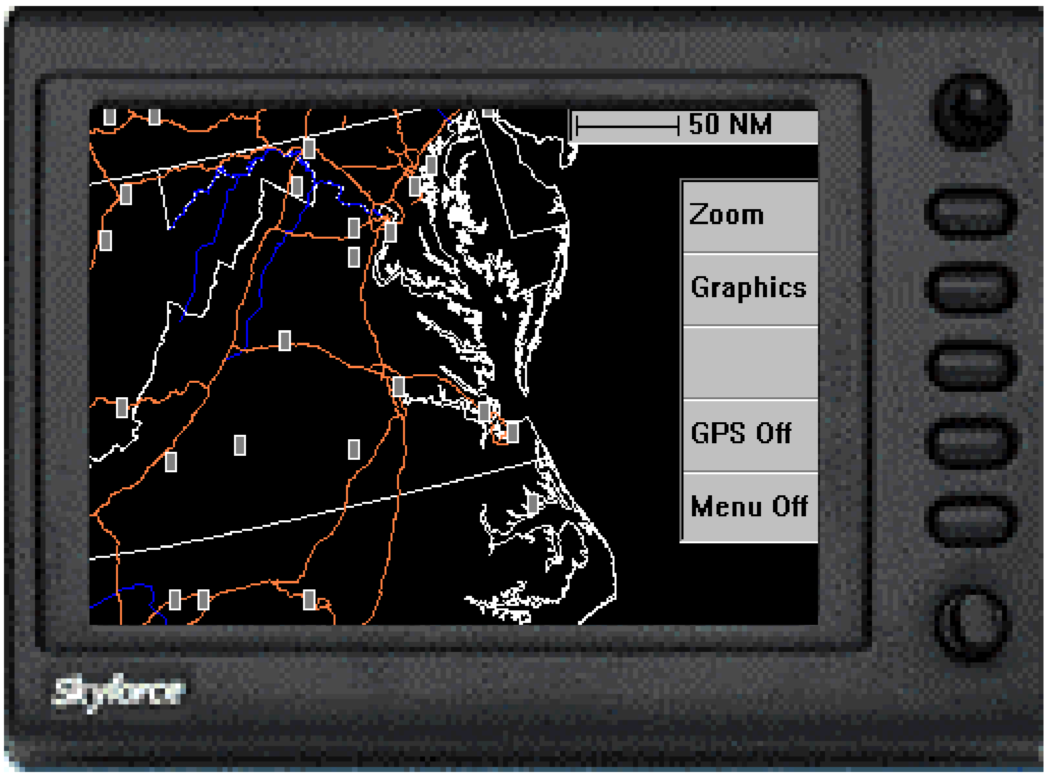
RTI

Simulation

Cockpit

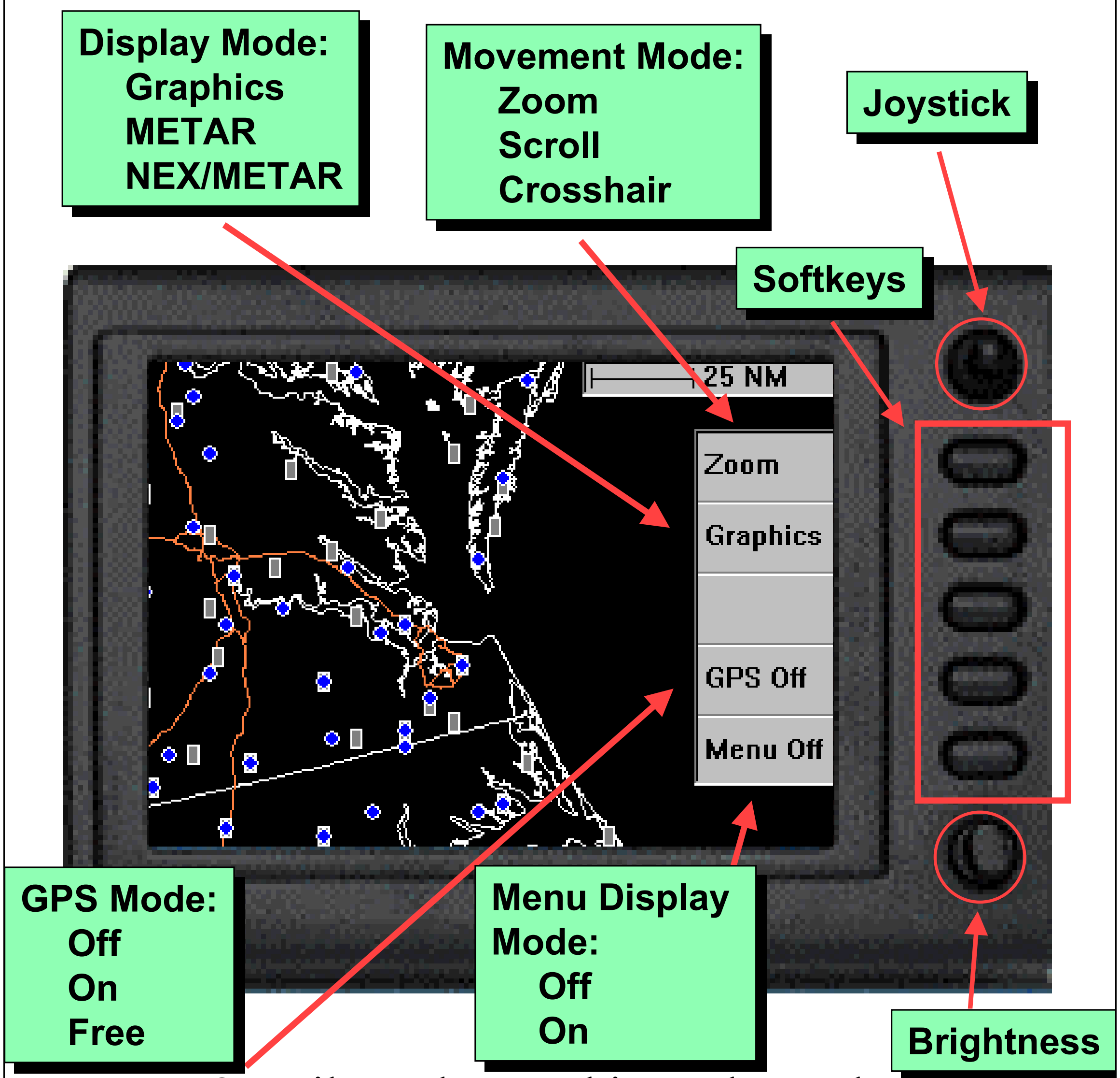
Radio

Stack

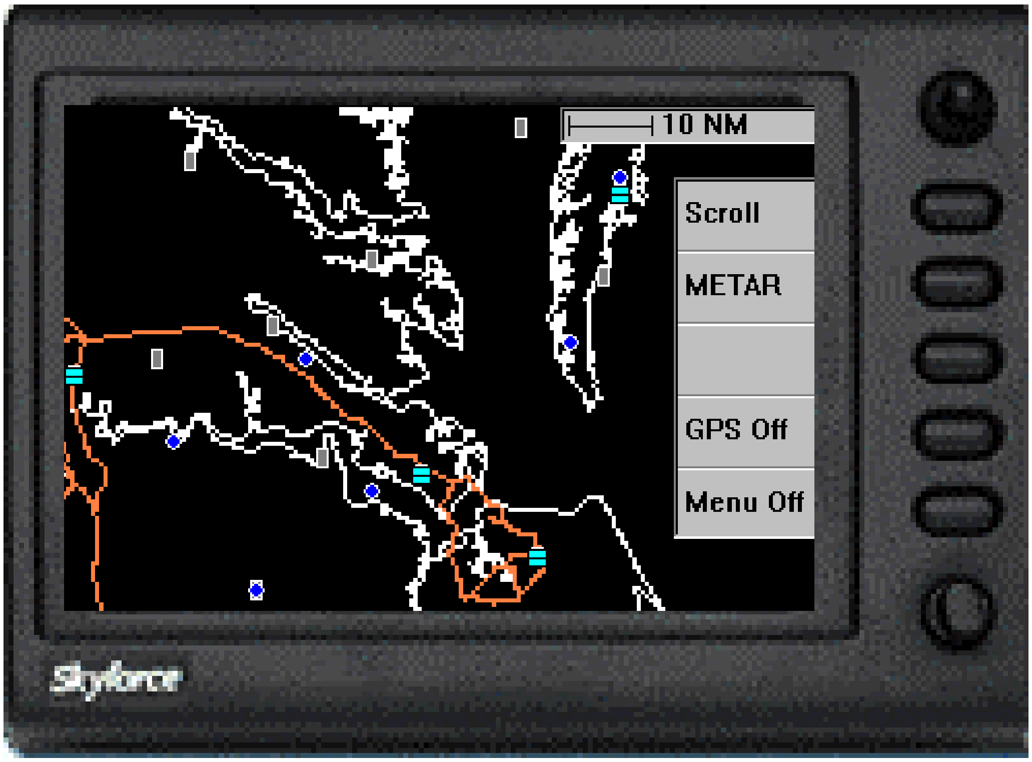


50 mile scale, graphics only mode
just showing airports in gray boxes

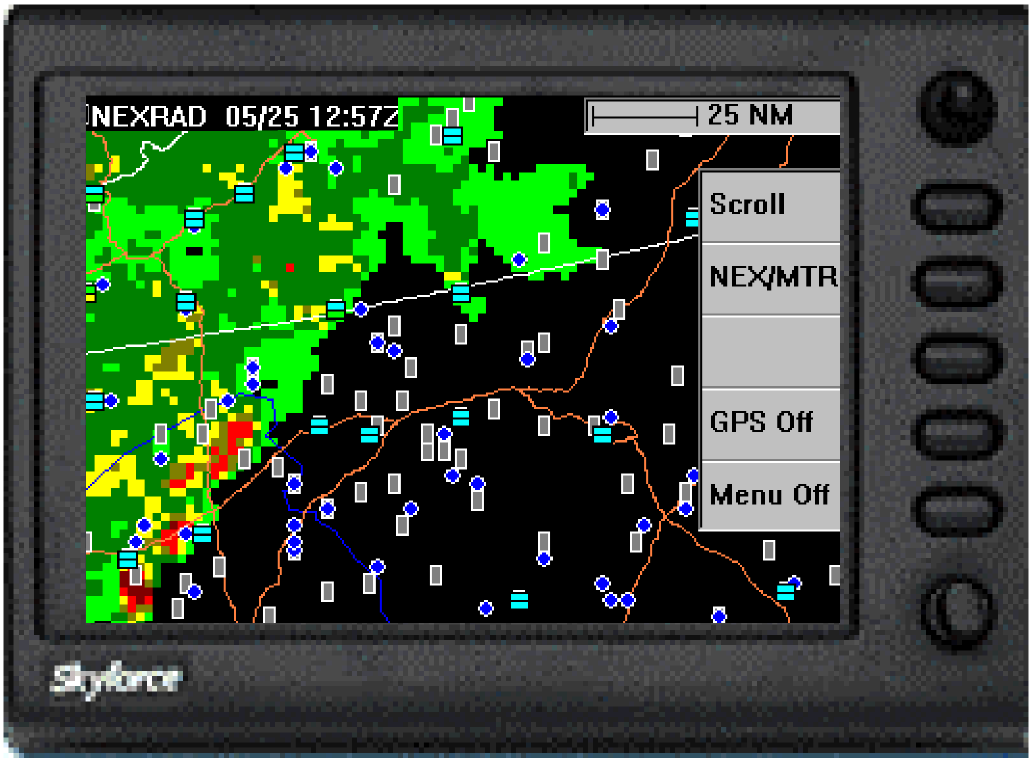
Modes

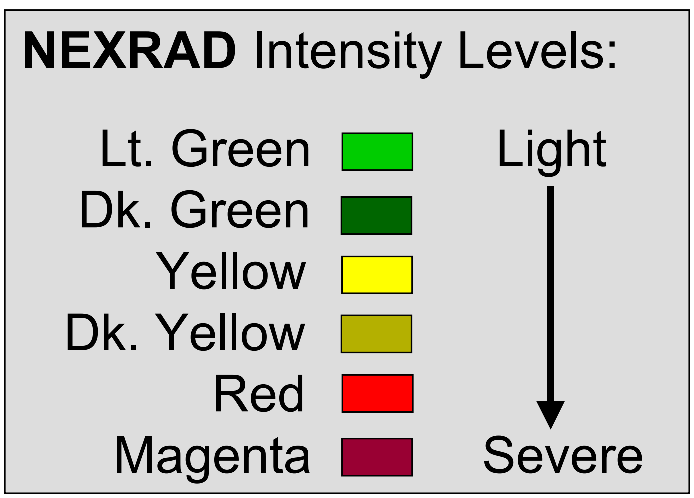


25 mile scale, graphics only mode. Showing airports in gray boxes, and NavAids in blue circles (navaids only shown in scales of 25 miles or less)



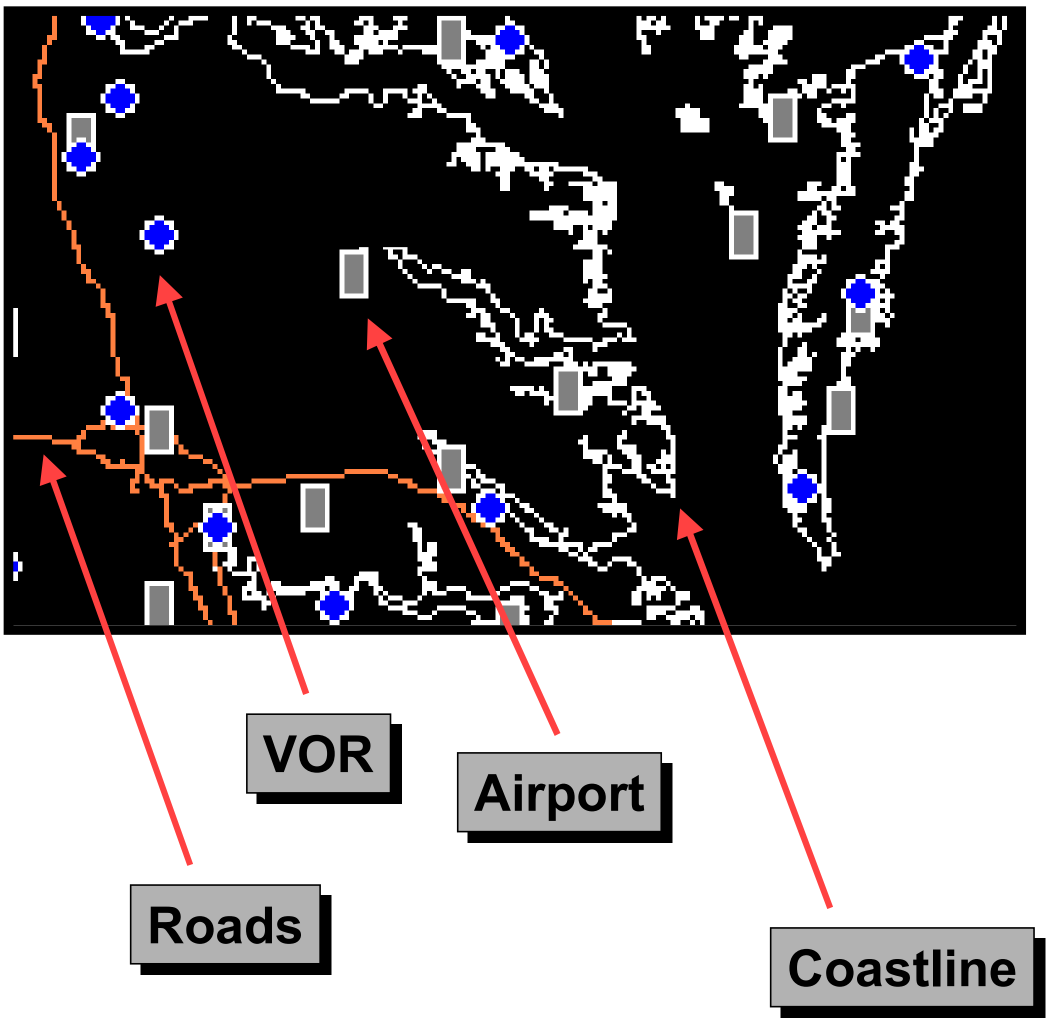
10 mile scale, METAR mode.
Showing airports in gray boxes, NavAids in blue circles, and graphical METARs





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

Graphic Symbols



Simulator Briefing and Training

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

AWIN 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. Runnup and system check

5. Normal takeoff and climb

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

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

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

9. VOR operation (on AP)

10. Use of weather display (on AP)

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

12. Go-around (± 10 kts)

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

Appendix I. Observer Form

AWIN EXPERIMENT FLIGHT RECORD

Pilot Name:______________________________________ Subject # _______

Experimental Group ____

Display Condition: WITH / WITHOUT WX DISPLAY (Circle one)

Risk Score ______ Wx Score _______ Flt Hrs ______ Actual IMC ________

CHECKLIST A: RICHMOND DECISION

BEHAVIORAL RECORD

1. DIVERT TO WALLOPS

2. HOLD

2.1 >10 MINS & SENT TO WAL APPR

(Time in hold = _______ mins)

2.2 <10 MINS & DIVERT TO WAL

2.3 <10 MINS & BEGINS APPROACH

3. MAKE APPROACH

3.1 GO AROUND

3.2 ATTEMPT LAND -BUT SENT ON TO WAL

4. ABORT MISSION

4.1 RETURN TO PHF

4.2 OTHER

INFORMATION SEARCH RECORD

1. R/T INQUIRY

1.1 PHF DEP

1.2 RICHMND

1.3 FSS

1.4 FLT WATCH

2. AUTOM SERVICES

2.1 ATIS

2.2 AWOS/ASOS

3. WX DISPLAY

3.1 TEXT METAR

3.2 GRAPHIC

3.3 CHANGE ZOOM

3.4 GPS LOC/NLOC

4. OTHER INFO SOURCE

WALLOPS DECISION

BEHAVIORAL RECORD

5. **PENETRATED WX DIRECT WALLOPS**

   5.1 CHANGED ALTITUDE

   5.2 REMAINED AT FLTPLN ALT

6. **DIVERTED AROUND WX**

   6.1 TO THE SOUTH

   6.2 TO THE NORTH

7. **ENTERED HOLD PENDING WX CHANGE / UPDATE**

8. **ABORTED**

10.1 TURNED BACK FOR RICHMOND

10.2 TURNED BACK FOR PHF

INFORMATION SEARCH RECORD

1. R/T INQUIRY

1.1 RICH DEP

1.2 WASH

1.3 WALLOPS

1.4 FSS

1.5 FLT WATCH

2. AUTOM SERVICES

2.2 ATIS

2.3 AWOS/ASOS

3. WX DISPLAY

3.1 TEXT METAR

3.2 GRAPHIC

3.3 CHANGE ZOOM

3.4 GPS LOC/NLOC

4. OTHER INFO SOURCE

Appendix J. Immediate Reactions Questionnaire

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

1. a. An "ownship" aircraft symbol, cross-hairs or some similar *position* indication would be a useful addition to the weather display. (Circle One)

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

b. Without some way to ascertain position relative to other displayed features the display's usefulness is significantly compromised.

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

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

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

b. While taking the medical aspect of the flight seriously, it did not figure at the forefront of my in-flight decision making.

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

3. My knowledge that this was all a simulation, that nobody's health or welfare was really at stake, influenced the way in which I managed the flight.

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

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

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

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

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

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

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

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

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

8. a. I felt comfortable with the autopilot, in terms of understanding its use & operation.

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

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

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

9. a. The degree of validity of the weather data appearing on-screen was a factor I felt I held in mind as I flew.

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

b. I have been monitoring the weather display time stamp very regularly in my instrument scan.

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

10. At the time of my arrival at Richmond 's Airport I knew that there was a storm (check one)

a. About 10 nm North West of the field

b. About 5 nm North West of the field

c. Near the fied

d. Right at the field

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

a. a penetrable storm

b. a navigable opening between convective cells

c. a non navigable opening between cells

d. a wall of convective activity requiring diversion.

Appendix K. Structured Interview Guide

The interviewer follows the procedure set out on this form, opening with the following explanatory statement to the pilot:

"In this debriefing we first give you a short questionnaire to complete while your memory is fresh. Then we conduct what we call a structured interview, which means we ask everyone the same set of questions in pre-determined categories (what, why, & so on), using this checklist form. The form's in 3 parts. We'll begin with Part A, which is just verifying the purely factual aspects of your flight, without getting into reasons, or other commentary. That comes under B. Your own, open-ended feedback on the flight is very important to us & we'll cover that last in Part C."

<u>A. BEHAVIORAL RECORD CONFIRMATION</u>

"We show that you …."

The interviewer here uses the previous printed checklists and verifies i. the behavioral record, & ii. the information search record, then completes this form.

- ❑ BEHAVIORAL RECORD CONFIRMED
- ❑ INFORMATION SEARCH RECORD CONFIRMED
- ❑ BEHAVIORAL RECORD DISCREPANCIES (Enter nature below)

____
____
____
____

- ❑ INFORMATION SEARCH RECORD DISCREPANCIES

____
____
____
____

“O.K., that’s the verification of *what* took place. Now we move on to *why* questions.”

B. DECISION RATIONALE

“Going through the flight again, looking at it phase by phase in sequence, I’d like you to tell me why you chose to adopt certain courses of action and not to select other options. This might entail your repeating certain rationales (as some options overlap others), and sometimes it may *feel* like you are having to state or restate the obvious. This doesn’t matter – it just happens sometimes in structured interviews. So please bear with us. Doing it this way helps the researchers cross-check the data, identify subtleties, and avoid making assumptions or inferences about what was or was not obvious ”

RICHMOND DECISION

1. DIVERT TO WALLOPS

“First, why did you / didn’t you divert to Wallops on the leg to Richmond?”

____

____

2. HOLD

“O.K., why did you / didn’t you stay put in a holding pattern?”

____

____

3. MAKE APPROACH

“Why did you choose to / choose not to make the approach into Richmond?”

____

____

“Why did you / didn’t you go around ?”

____

____

“Why did you / didn’t you attempt to land?”

4. ABORT MISSION

“Why did you / didn’t you abort the mission?”

“Why did you / didn’t you return to PHF?”

OTHER (Optional)

“Why did you choose to [*insert any other behavior not anticipated in the form*]?”

EN ROUTE WALLOPS DECISION

1. PENETRATION OF WX EN ROUTE TO WALLOPS

“Why did you choose to / not choose to penetrate the weather en route to Wallops?”

2. DIVERSION AROUND WALLOPS

“ Why did you/didn’t you divert north around the weather en route to Wallops? (e.g. pending a wx update or change of wx.)

“Why did you/didn’t you divert south around the weather en route to Wallops?”

3. ENTERED HOLD

“Why did you / didn’t you enter a holding pattern en route to Wallops?”

4. ABORT ATTEMPT TO REACH WALLOPS

“Why did/didn’t you abort efforts toward the Wallops destination & return to Richmond / PHF?”

OPEN COMMENTS & QUESTIONS (OC & Q) SECTION

"Thanks. That's the structured or formal part over with. Now we can go on to the Open Comments & Questions stage where you can give us your feedback & we all pitch in."

Note to ourselves: The OC&Q PERIOD HAS TWO MAIN FUNCTIONS

1. To enable us to go back & **correct, expand or qualify earlier responses** in the questionnaire or debrief. The subject's responses may not all have seemed consistent & these apparent inconsistencies can be explored & reconciled. The data we collect here is non-quantitative but has an important role - <u>it becomes prime content for the discussion sections of the TR</u>. So notes should be made at appropriate points in the questionnaire or debriefing guide. Major new points should be appended below.

2. To enable the subject pilot and the research team to **identify new issues, contribute new views**, perspectives, and "takes" on the issues that may not have been anticipated in the formal debrief, or that may involve dissenting or alternative interpretations of events, etc. Important points not captured elsewhere should be appended below. Again, <u>the point is to secure context & richness for the TR.</u>

Appendix L. Weather Display Questionnaire

The following is the questionnaire given to the pilots that flew with the weather display. It includes basic flight experience questions, previous in-flight weather display use, and their open opinions about the weather display.

Subject Pilot #: ___________________   Date: ______________________

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

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

3. Approximately how many simulator hours do you have? _________________

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

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

Private   Commercial   ATP   Glider   Airship   Sea

Instrument   CFI   CFII   MEI   Helicopter   A&P   IA

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

____

____

7. Have you ever used a datalinked in-flight weather display system in a flight?
____________ (not including onboard radar or Stormscope)

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

____

____

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

____

____

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

____

____

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

____

____

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

____

____

12. Do you feel that you took the simulator as seriously as a real airplane?

____

____

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

____

____

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

____

____

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

____

____

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

____

____

17. What features of the weather display did you find helpful in updating your route?

____

____

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

____

____

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

____

____

20. Did you find that the weather display increased or decreased your workload?

____

____

21. How did the use of the autopilot help or hinder the use of the weather display?

____

____

22. Did you find that the weather display increased or decreased your situational awareness?

____

____

23. Have you ever been in a situation that you would not have placed yourself in, if you had an in-flight weather display?

____

____

24. Can you think of any specific instances where you wished you had this type of cockpit weather information? Please be brief.

____

____

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

Appendix M. AWIN Study Questionnaire

The following is the questionnaire given to the pilots that did not fly with the weather display. It includes basic flight experience questions and previous in-flight weather display use.

Subject Pilot #: ___________________ Date: ______________________

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

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

3. Approximately how many simulator hours do you have? ________________

4. Approximately how many instrument hours do you have in the last 90 days? _____________

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

   Private Commercial ATP Glider Airship Sea

   Instrument CFI CFII MEI Helicopter A&P IA

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

____

____

7. Have you ever used a datalinked in-flight weather display system in a flight? ____________ (not including onboard radar or Stormscope)

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

____

____

8. If you answered yes to the last question, how many times have you used that datalinked in-flight weather display system to make actual weather judgements? (Instead of just experimenting with the display).

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

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

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

12. Do you feel that you took the simulator as seriously as a real airplane?

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

Appendix N. 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.

AWIN EXPERIMENT: FIRST LEG

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

N73Y: (Tunes 128.65 for ATIS)

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

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

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

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

(Tunes 121.9)

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

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

N73Y: Malibu 73Y, Roger.

(Tunes 118.7)

N73Y: Tower, N73Y ready for takeoff.

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

N73Y: Malibu 73Y Roger, cleared for takeoff.

(Departs)

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

(Tunes 124.9)

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

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

N73Y: Malibu 73Y Roger, Proceeding direct Hopewell.

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

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

(N73Y tunes 119.15 for RIC ATIS)

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

(Tunes 124.9)

N73Y: Departure control, N73Y back on your frequency.

ATC: MALIBU 73Y ROGER.

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

(Tunes 134.7)

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

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

N73Y: N73Y, Roger, descending to 2000.

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

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

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

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

(Tunes 121.1)

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

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

AWIN EXPERIMENT: 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 O. Enroute Weather Information 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.

En-route Abbreviated Weather Reports

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

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

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

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

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

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

LKU SP 1905Z M005 OVC 1/2TRW+FG 57/57/2615G25/950/TSTM OVHD MOV E OCNL LGTCCCG
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)

UUA: /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.

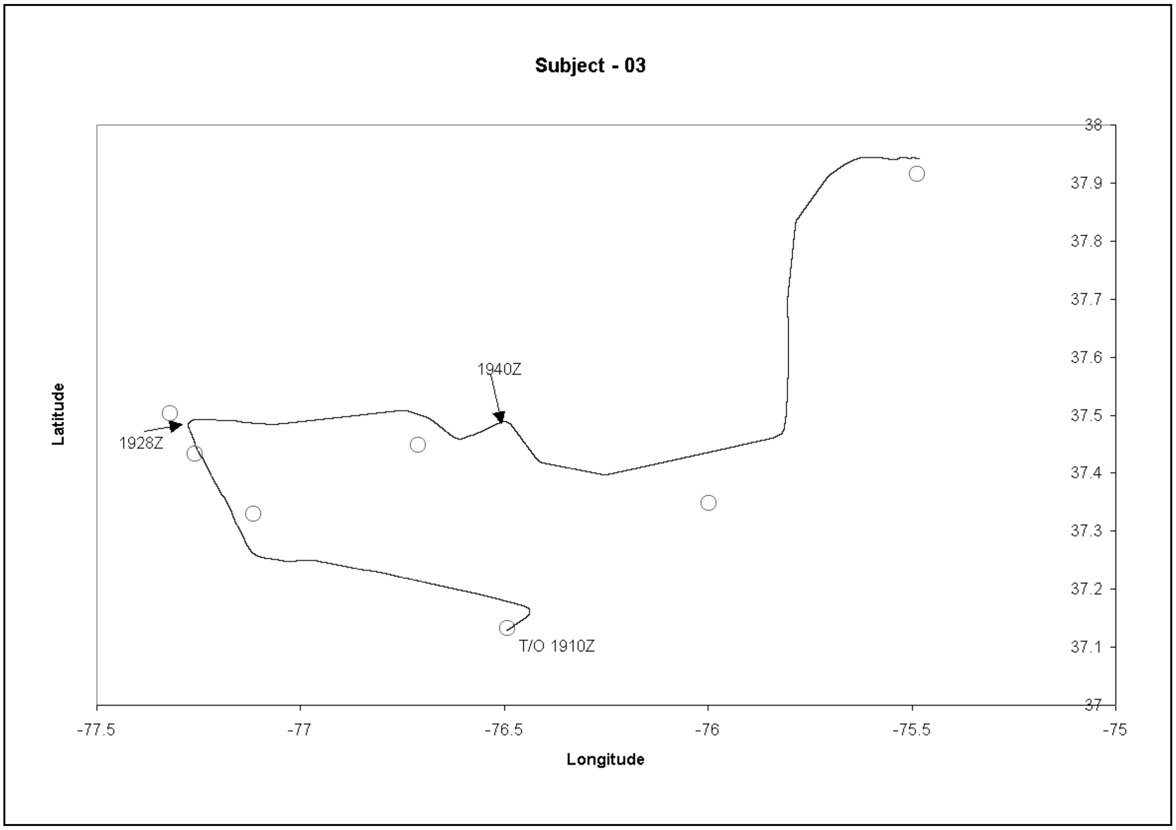
UA: /OV SBY /TM 1905Z /FL 060 /TP BE55 /TB NEG /RM MANY BLD-UPS OVR BAY SW
Pilot report over Salisbury, Maryland at one, niner, zero, five universal coordinated time. At six thousand feet, a Beech five, five reported negative turbulence, and many build-ups over the bay Southwest.

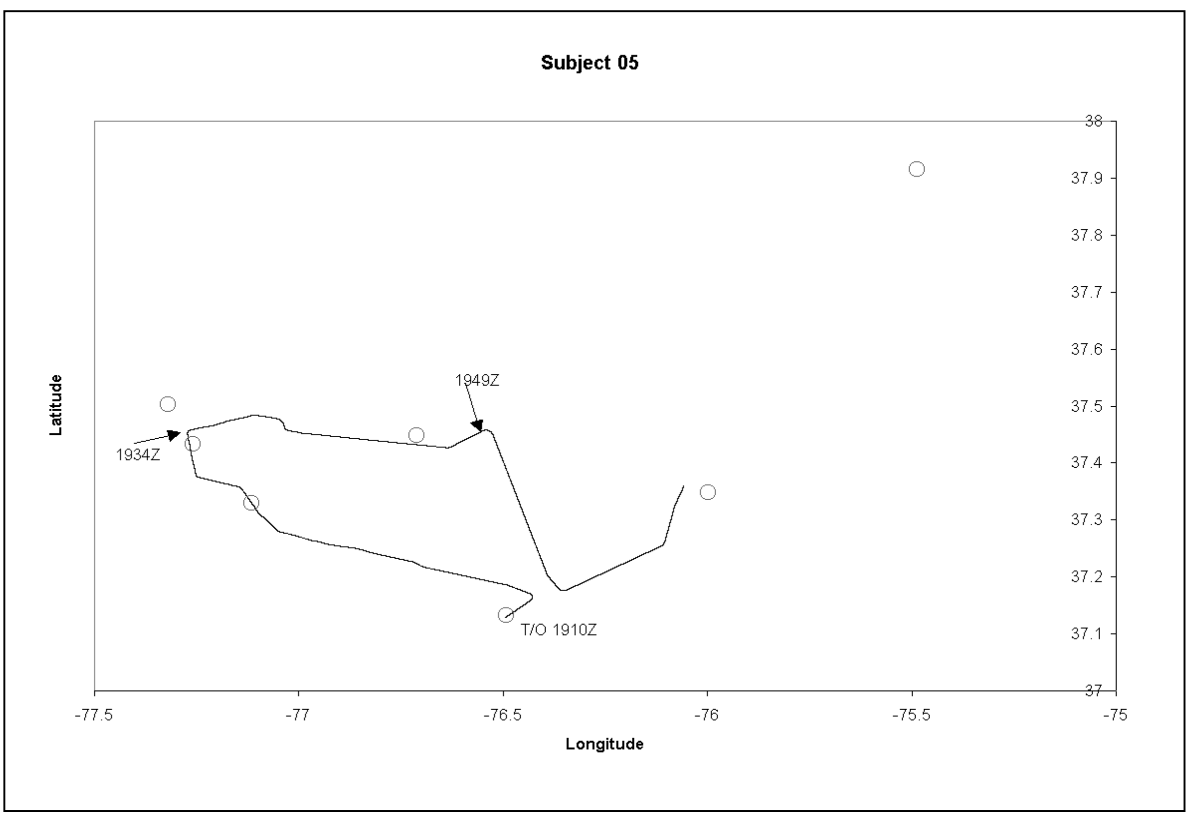
UA: /OV RIC090050 /TM 1900Z /FL080 /TP PA46 /TB NEG /RM BLD-UPS OVR BAY N
Pilot report five, zero miles East of Richmond, Virginia at one, niner, zero, zero universal coordinated time. At eight thousand feet, a Piper four, six reported negative turbulence and build-ups over the bay North.

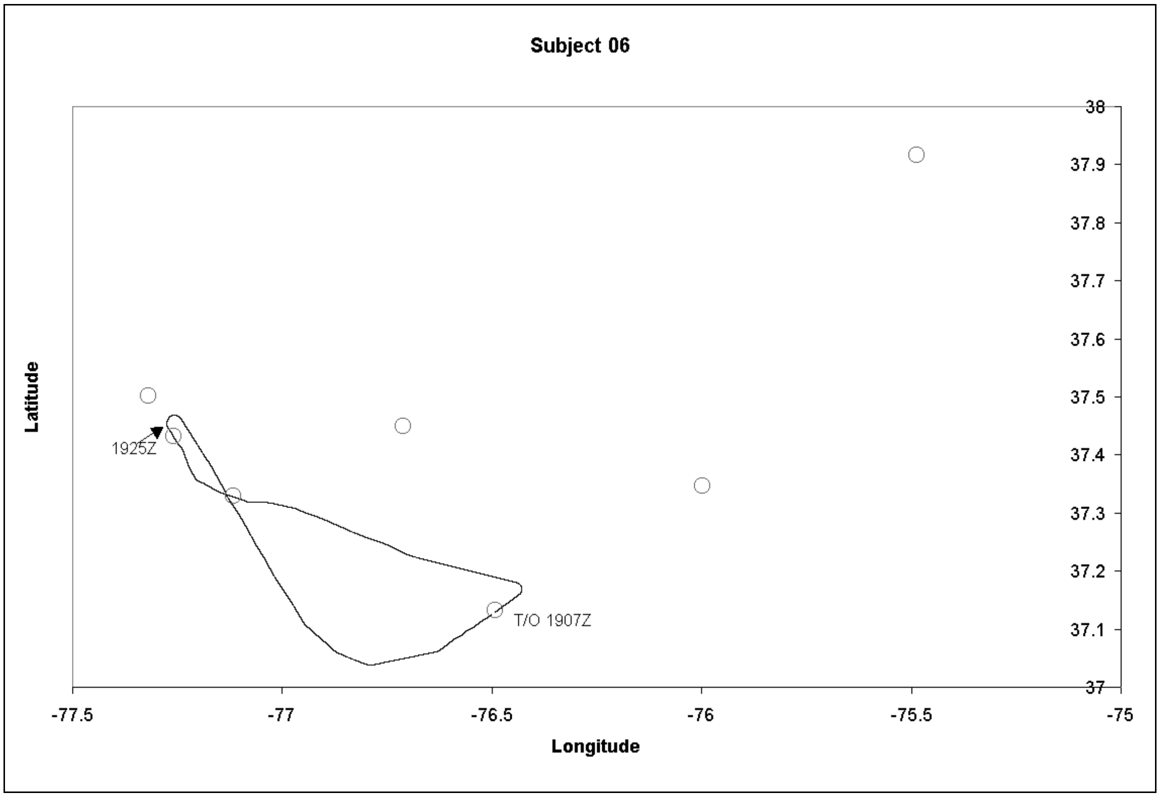
Satellite Imagery indicates solid Build-Ups forming throughout Central Virginia.

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.

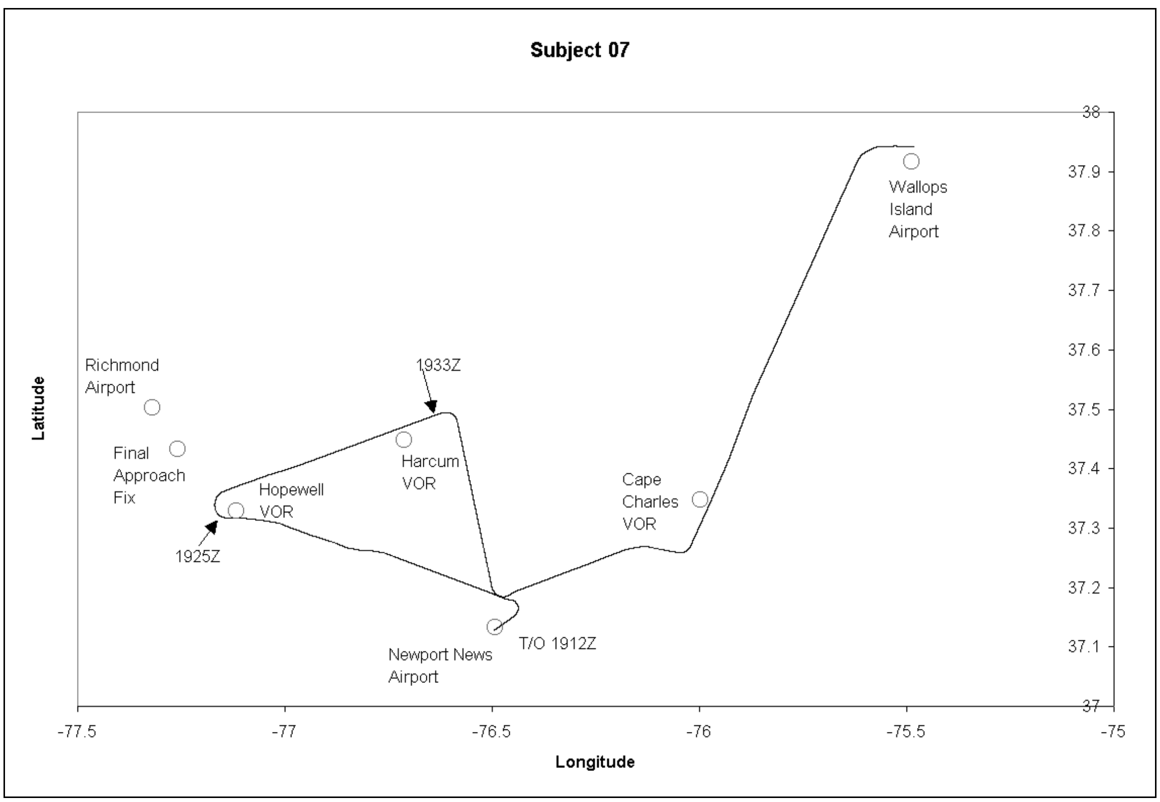
Appendix P. Ground Track Plots of All Subject Pilots



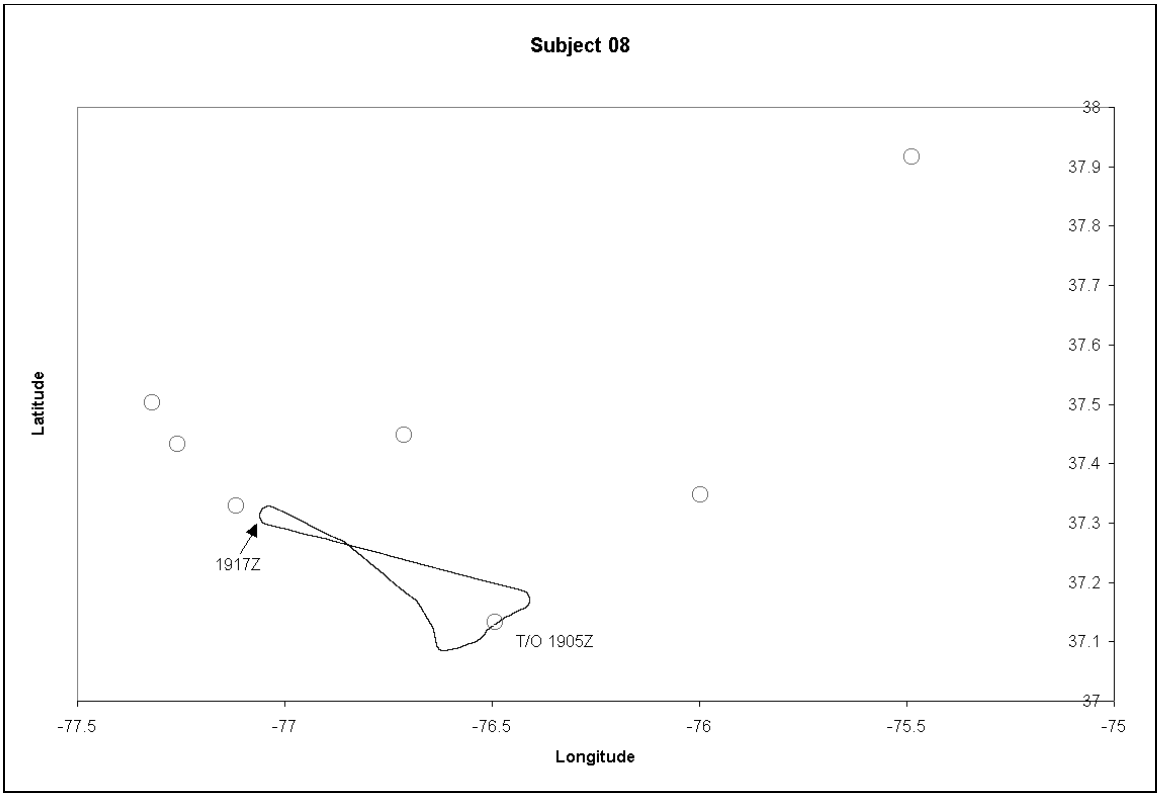


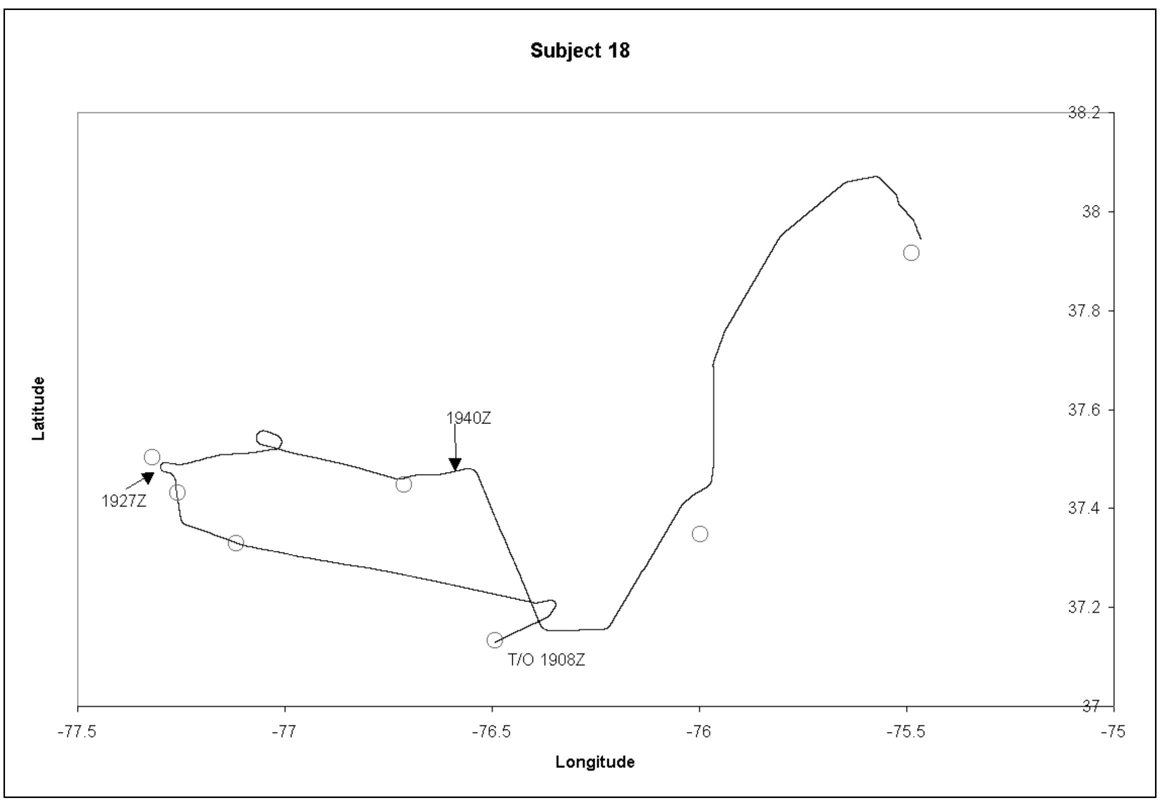


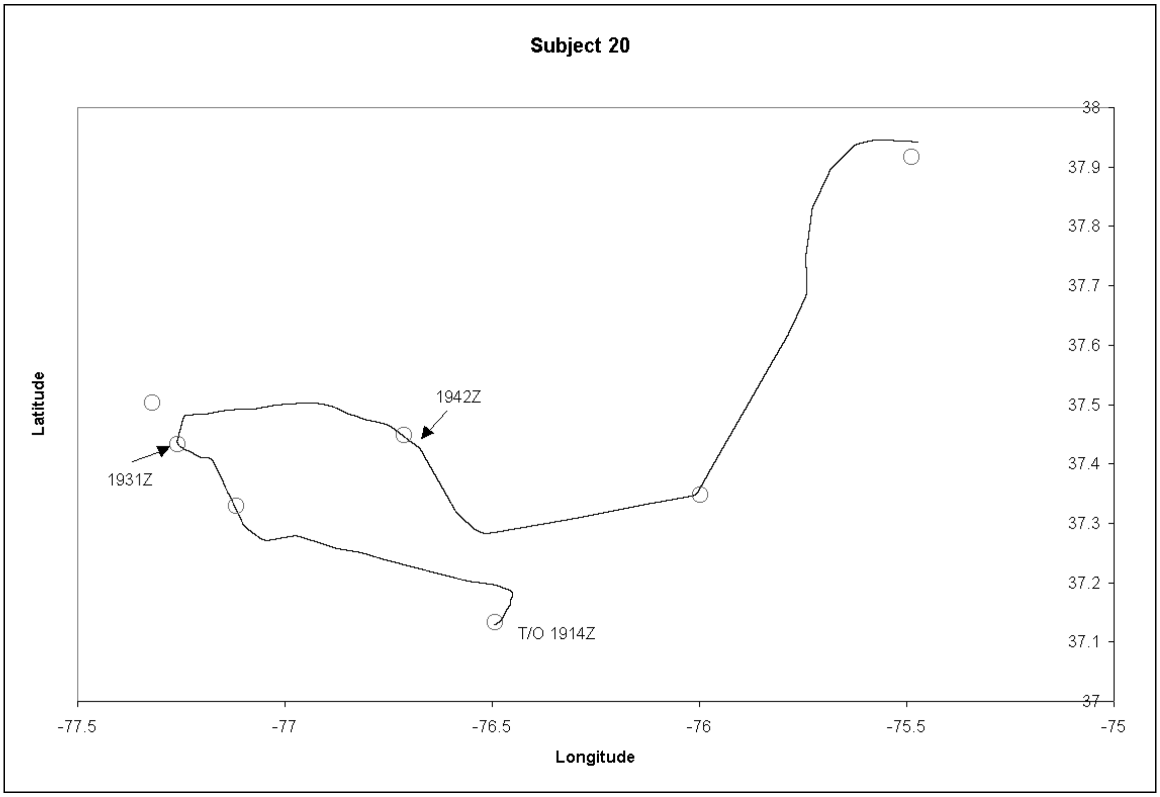
Subject 06
Latitude
Longitude
1925Z
T/O 1907Z

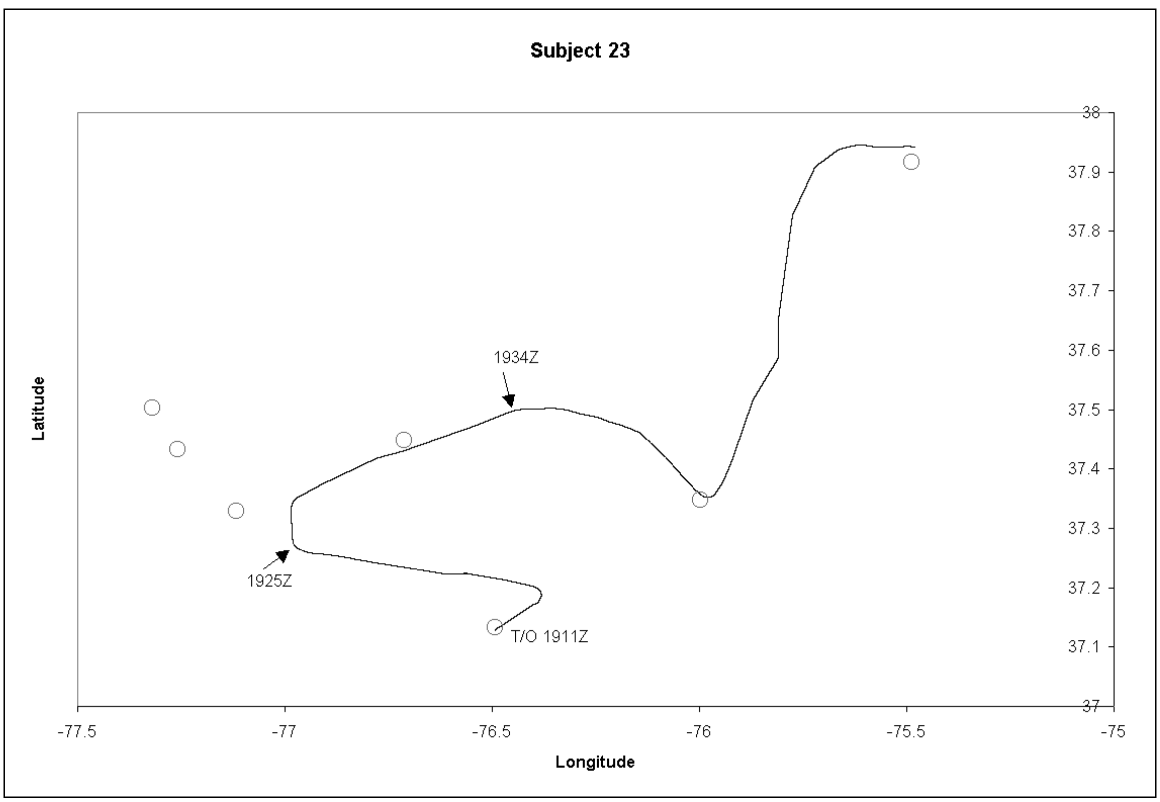


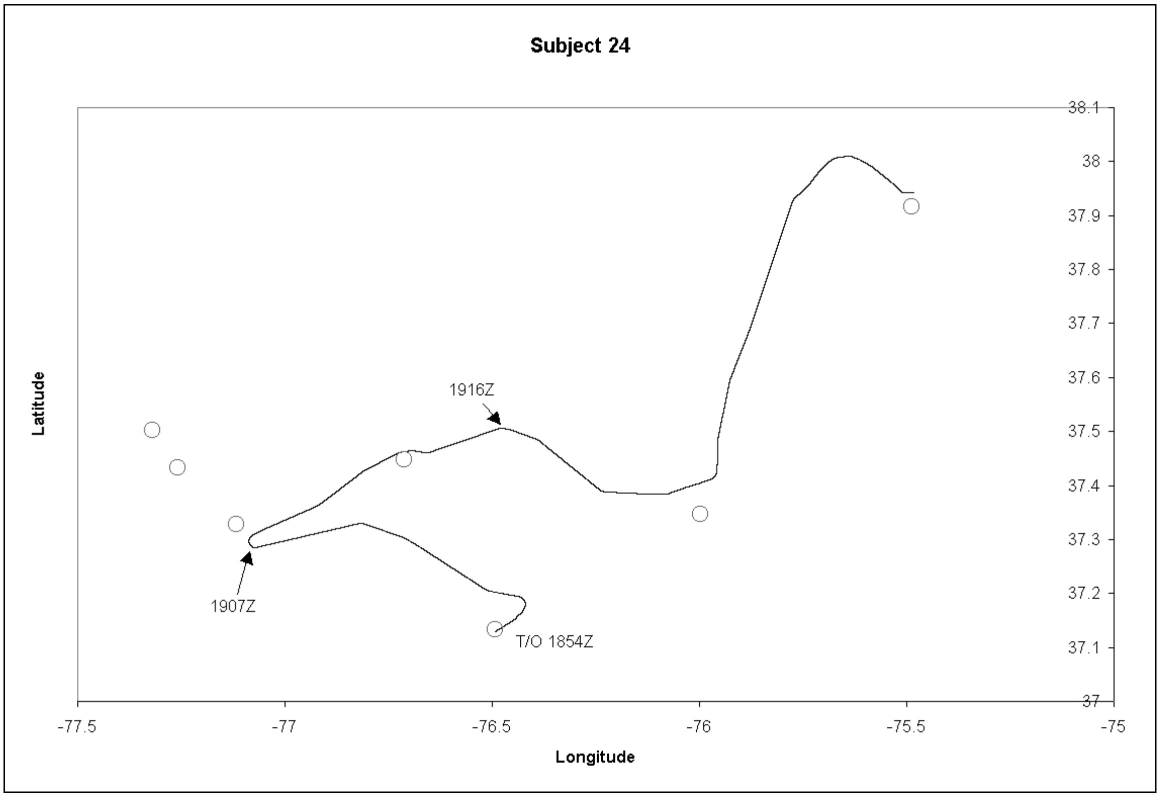
Subject 07
Latitude
Longitude
Richmond Airport
Final Approach Fix
1925Z
Hopewell VOR
1933Z
Harcum VOR
Newport News Airport
T/O 1912Z
Cape Charles VOR
Wallops Island Airport

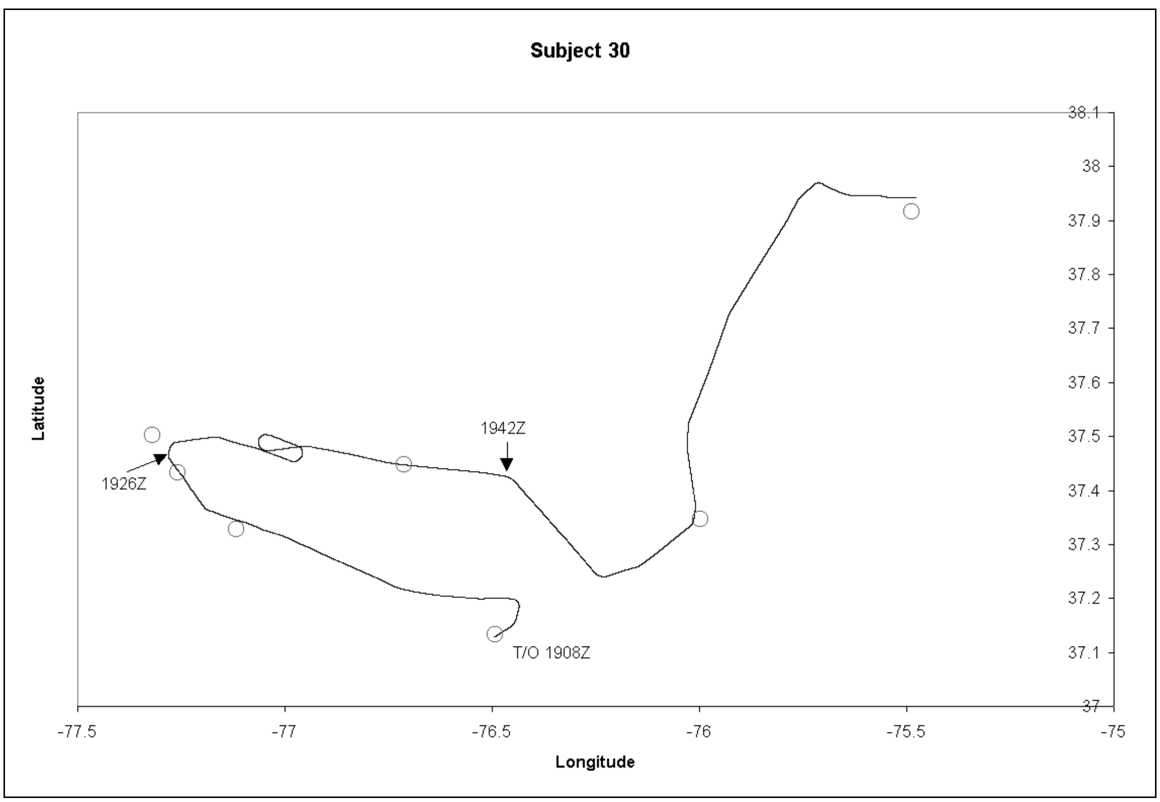

Subject 08
Latitude
Longitude
1917Z
T/O 1905Z
38
37.9
37.8
37.7
37.6
37.5
37.4
37.3
37.2
37.1
37
-77.5
-77
-76.5
-76
-75.5
-75

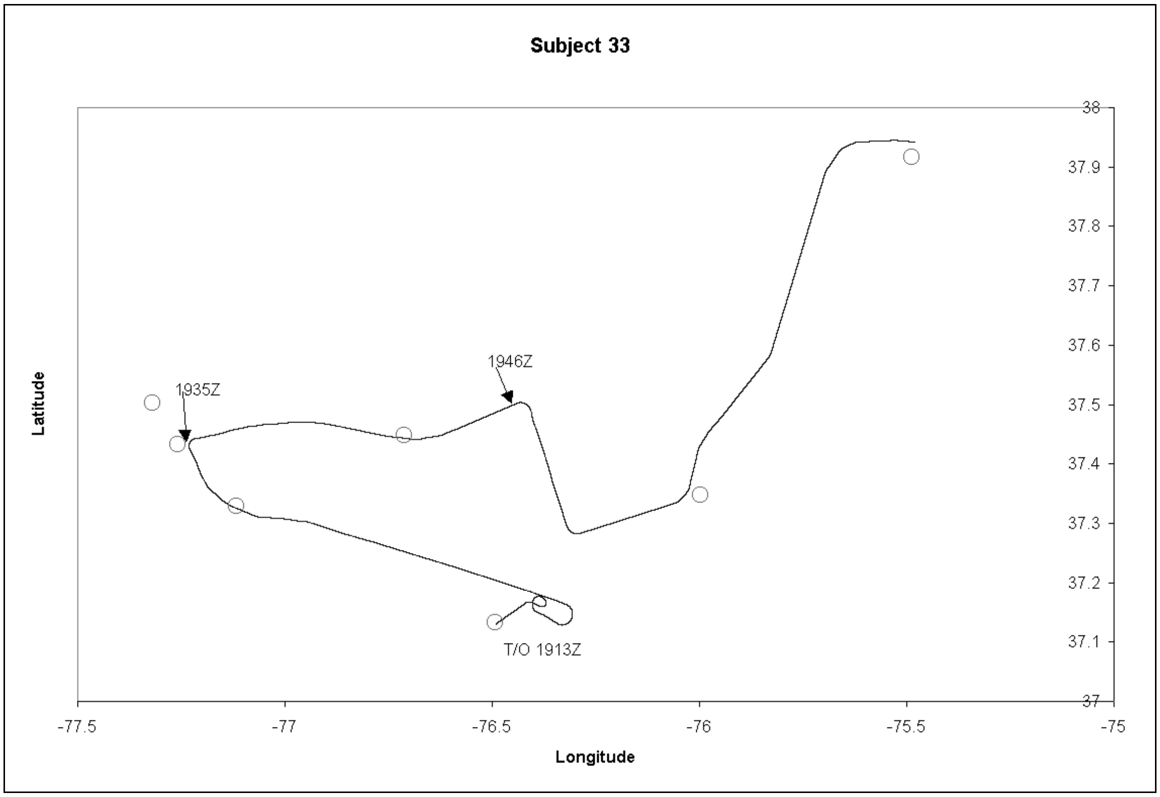

Subject 18
Latitude
Longitude
1940Z
1927Z
T/O 1908Z
38.2
38
37.8
37.6
37.4
37.2
37
-77.5
-77
-76.5
-76
-75.5
-75

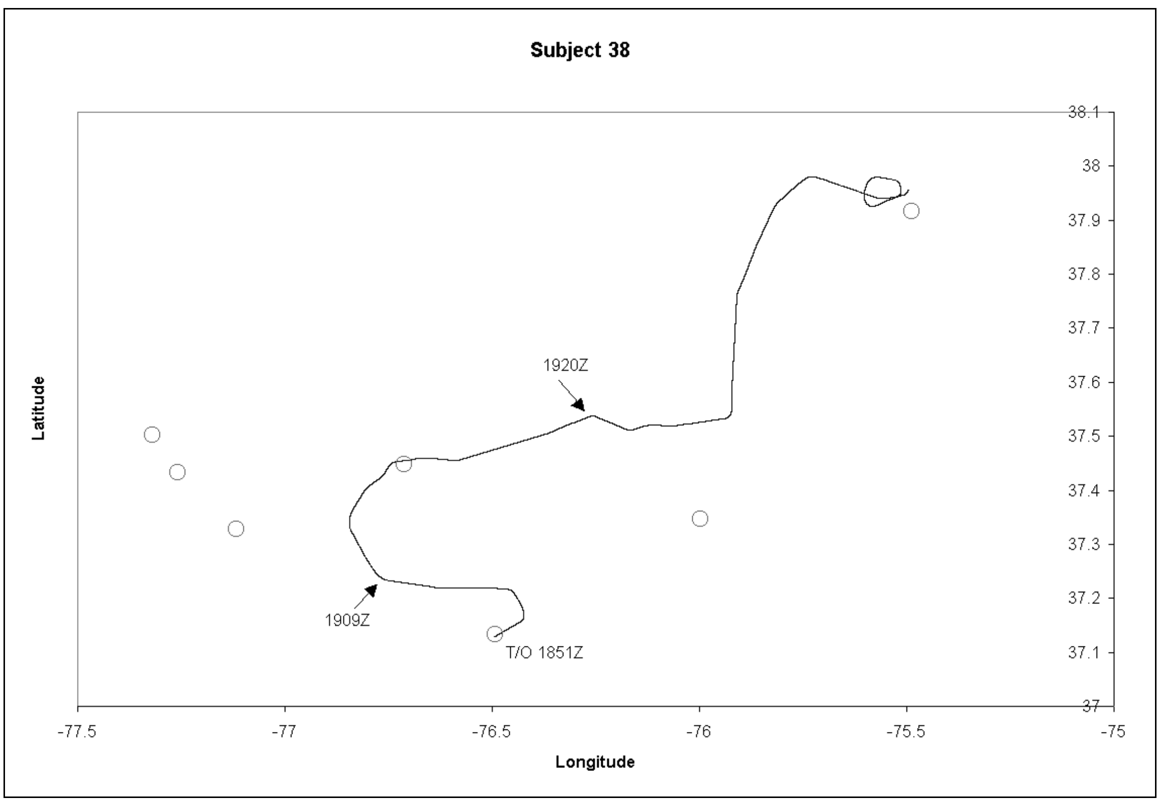

Subject 20
Latitude
Longitude
1942Z
1931Z
T/O 1914Z
38
37.9
37.8
37.7
37.6
37.5
37.4
37.3
37.2
37.1
37
-77.5
-77
-76.5
-76
-75.5
-75

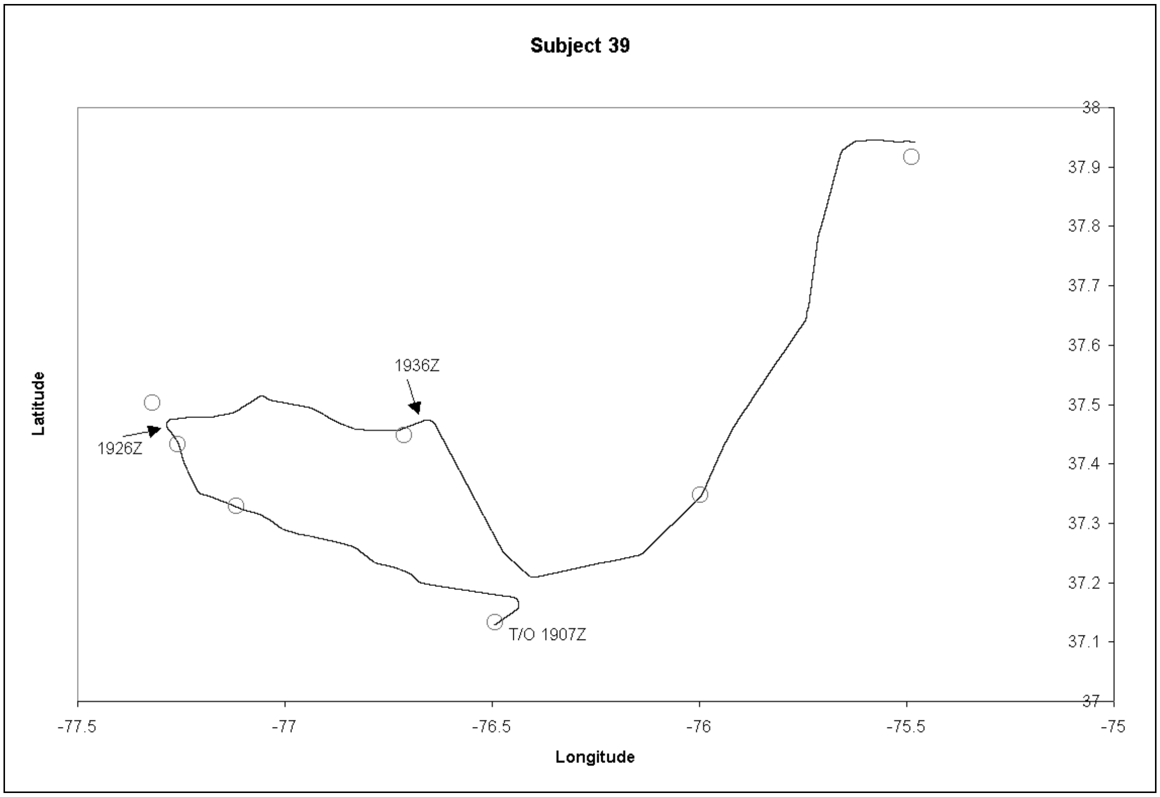

Subject 23
Latitude
Longitude
1934Z
1925Z
T/O 1911Z
38
37.9
37.8
37.7
37.6
37.5
37.4
37.3
37.2
37.1
37
-77.5
-77
-76.5
-76
-75.5
-75

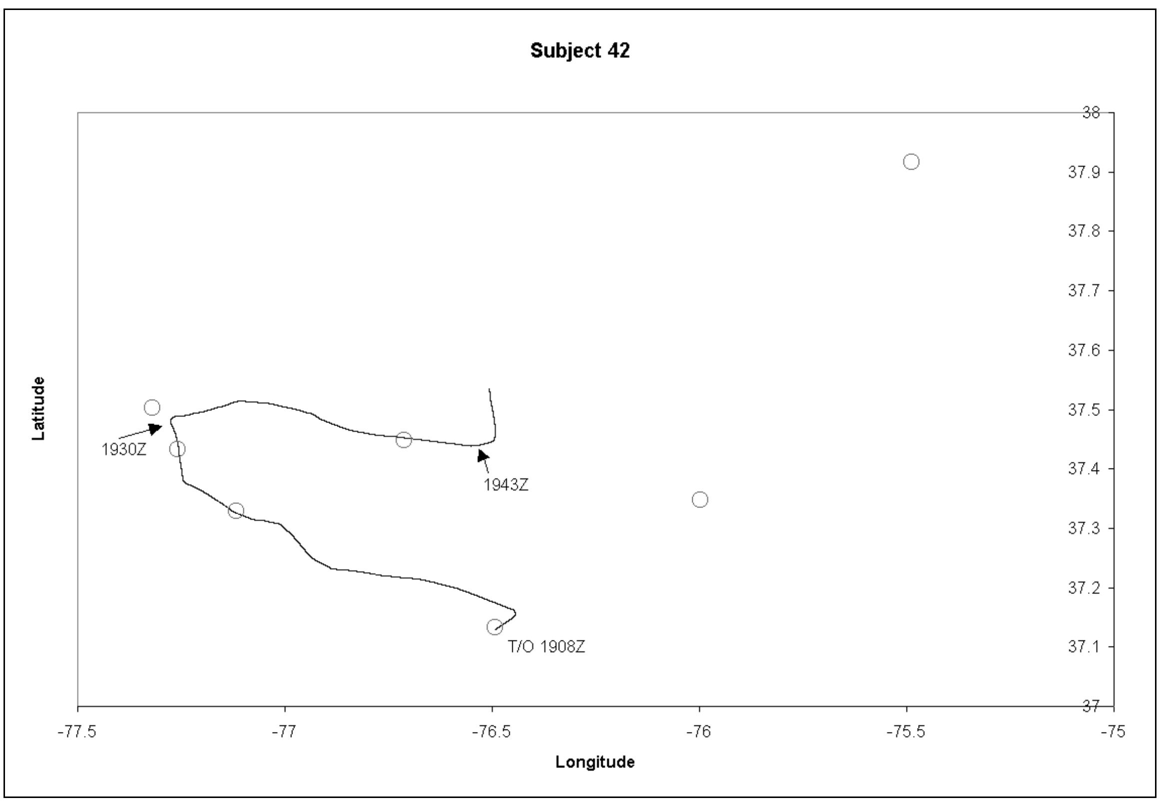

Subject 24
1916Z
1907Z
T/O 1854Z
Latitude
Longitude
38.1
38
37.9
37.8
37.7
37.6
37.5
37.4
37.3
37.2
37.1
37
-77.5
-77
-76.5
-76
-75.5
-75

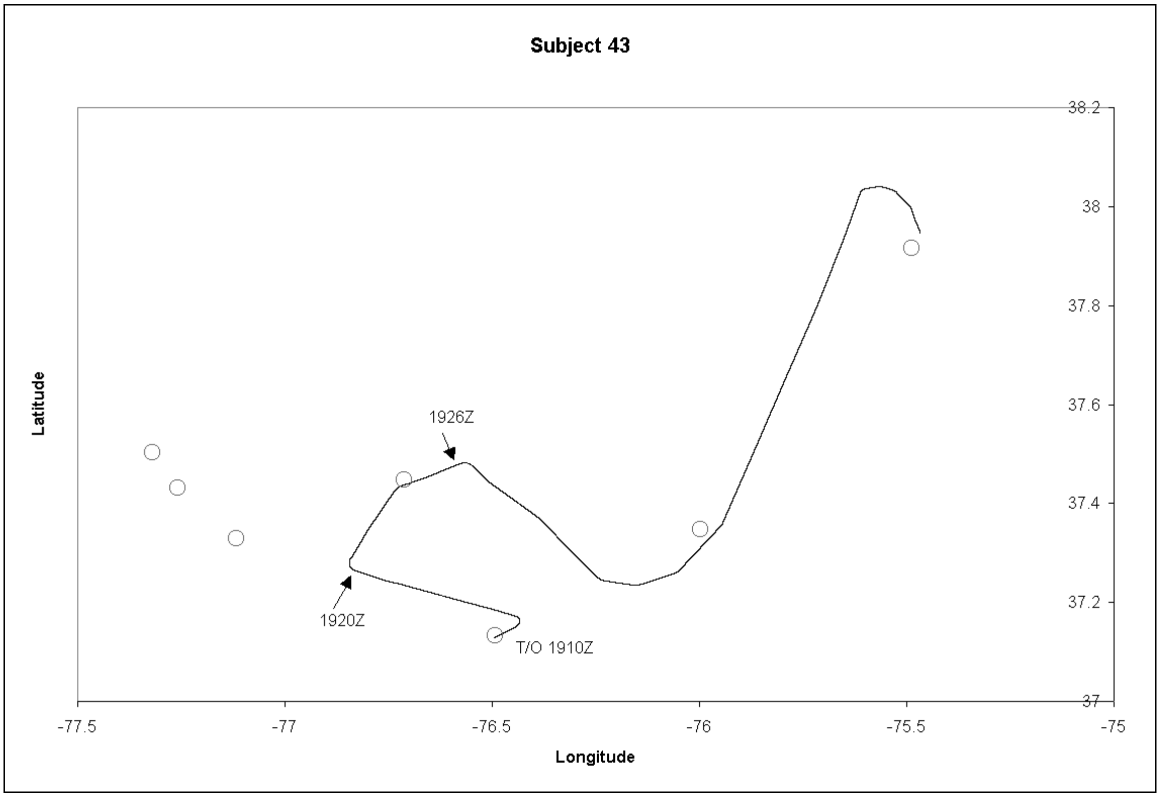

Subject 30
1942Z
1926Z
T/O 1908Z
Latitude
Longitude
38.1
38
37.9
37.8
37.7
37.6
37.5
37.4
37.3
37.2
37.1
37
-77.5
-77
-76.5
-76
-75.5
-75


Subject 33
Latitude
Longitude
1935Z
1946Z
T/O 1913Z
38
37.9
37.8
37.7
37.6
37.5
37.4
37.3
37.2
37.1
37
-77.5
-77
-76.5
-76
-75.5
-75

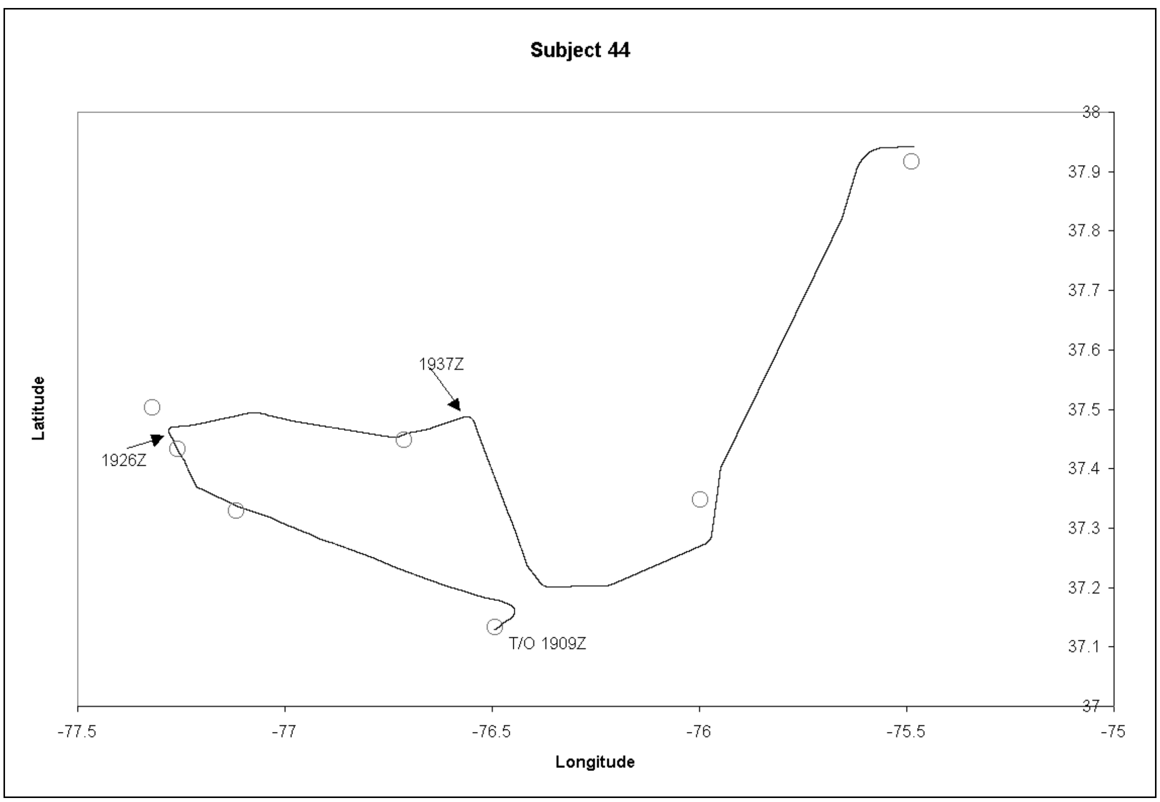

Subject 38
Latitude
Longitude
1920Z
1909Z
T/O 1851Z
38.1
38
37.9
37.8
37.7
37.6
37.5
37.4
37.3
37.2
37.1
37
-77.5
-77
-76.5
-76
-75.5
-75


Subject 39
1936Z
1926Z
T/O 1907Z
Latitude
Longitude
38
37.9
37.8
37.7
37.6
37.5
37.4
37.3
37.2
37.1
37
-77.5
-77
-76.5
-76
-75.5
-75

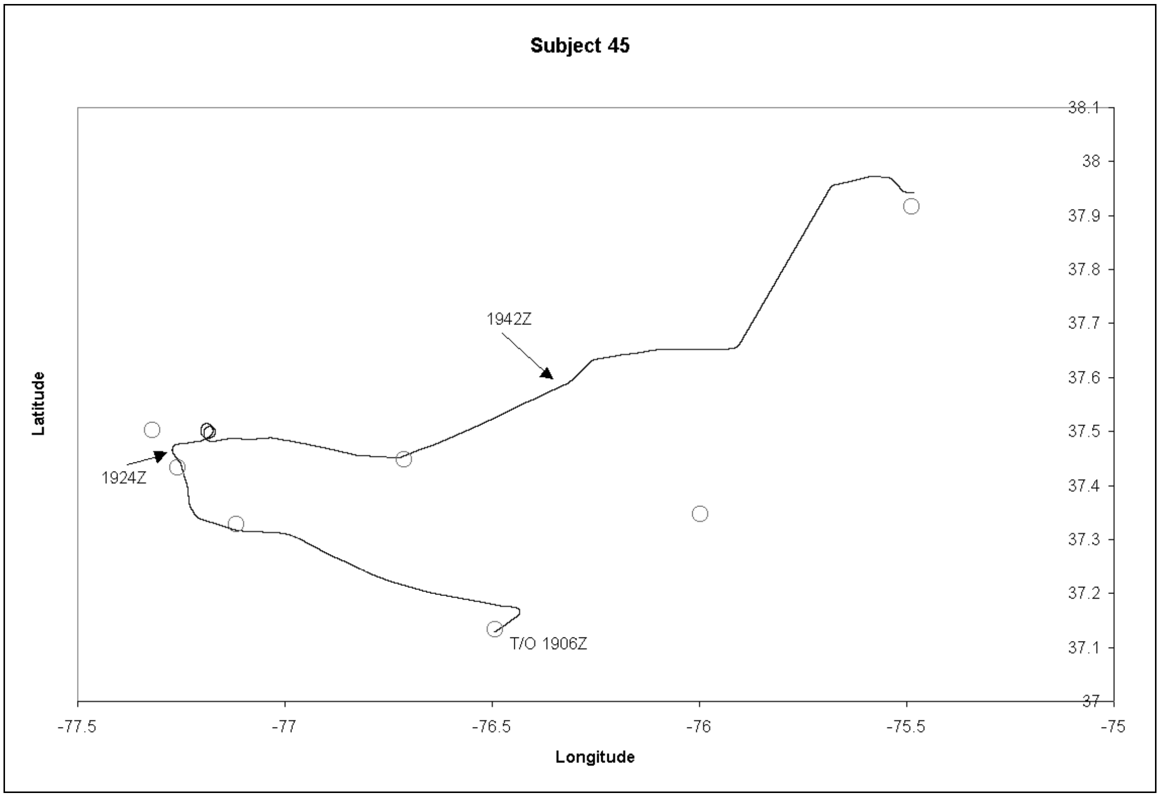

Subject 42
1930Z
1943Z
T/O 1908Z
Latitude
Longitude
38
37.9
37.8
37.7
37.6
37.5
37.4
37.3
37.2
37.1
37
-77.5
-77
-76.5
-76
-75.5
-75

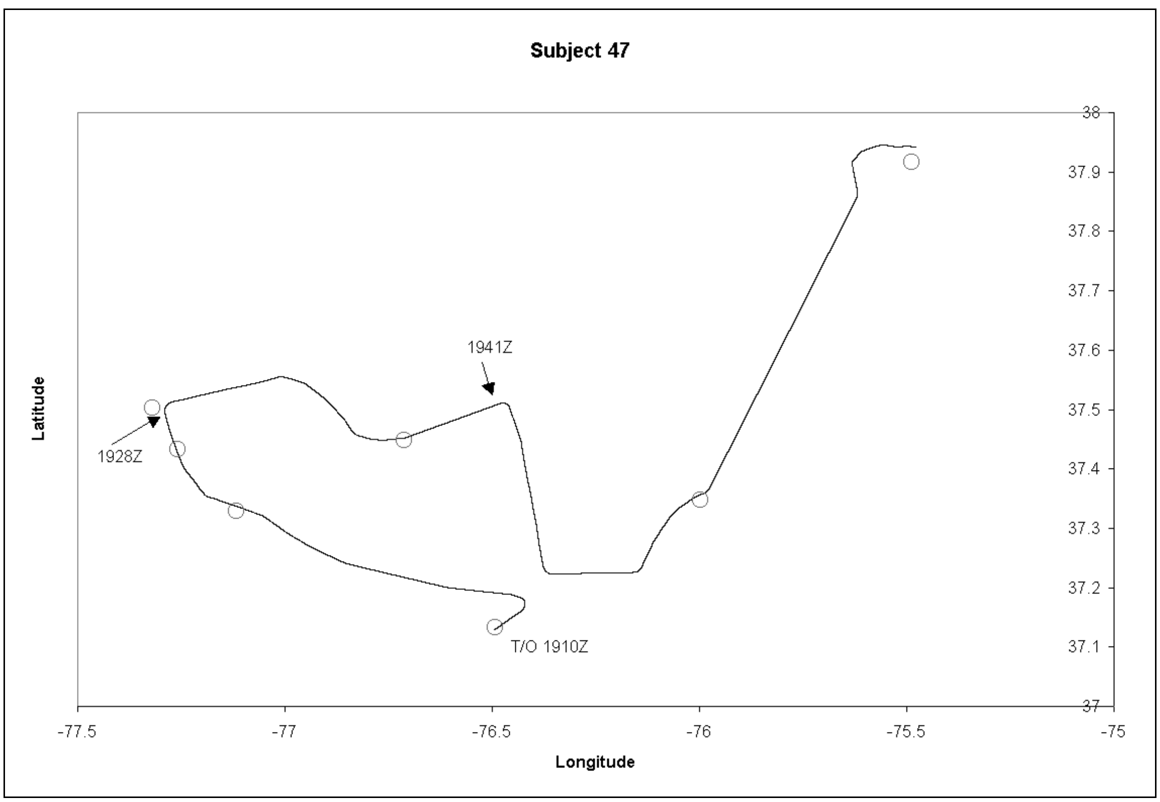


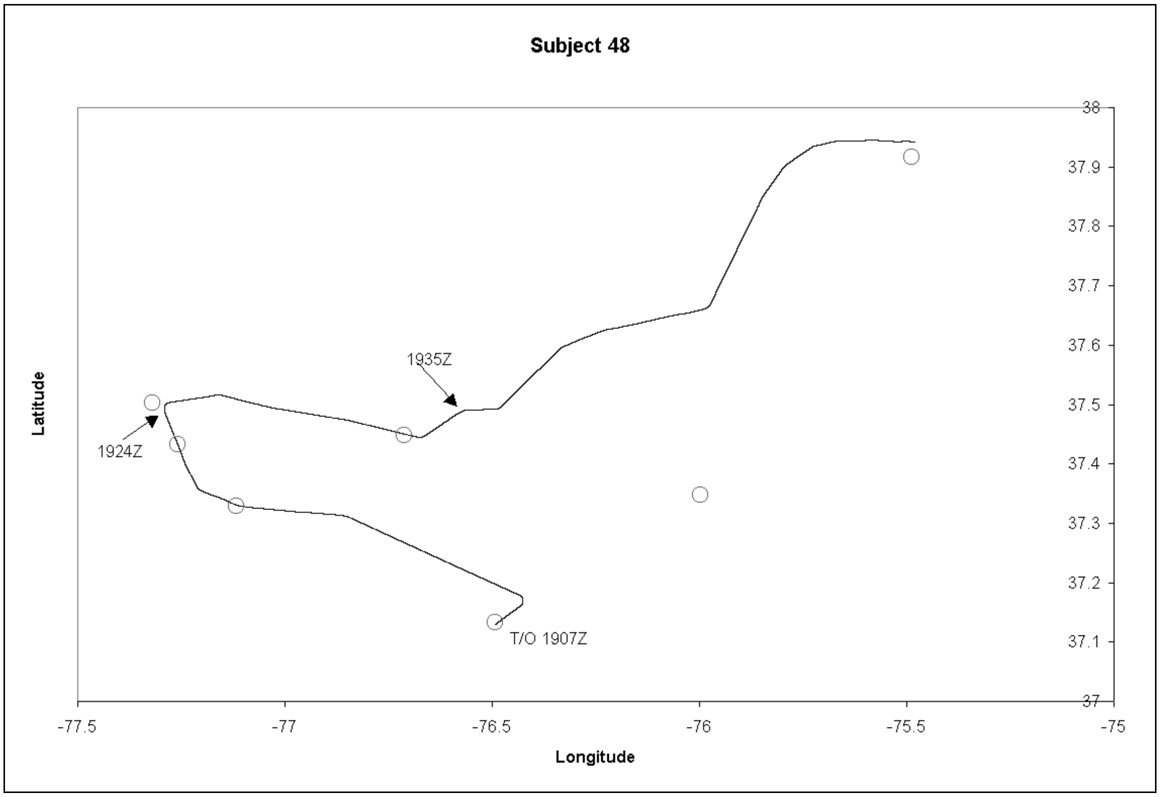
Subject 43
Latitude
Longitude
1926Z
1920Z
T/O 1910Z
38.2
38
37.8
37.6
37.4
37.2
37
-77.5
-77
-76.5
-76
-75.5
-75

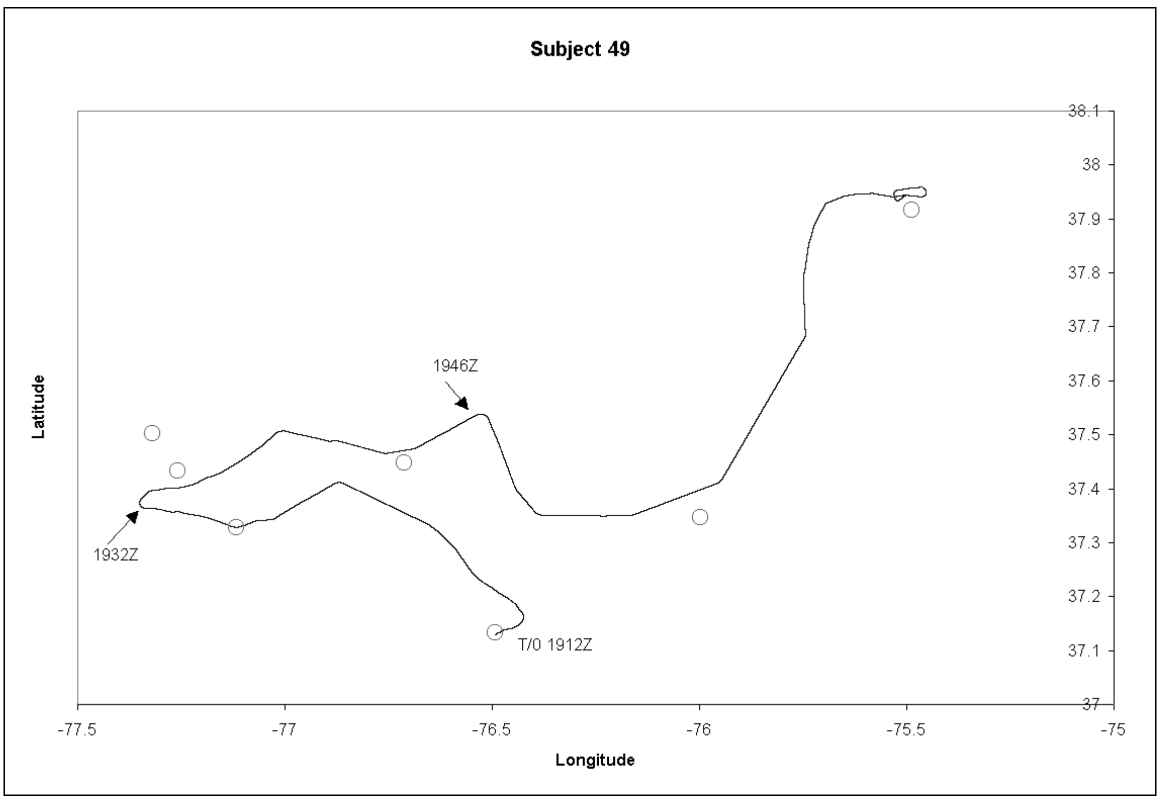


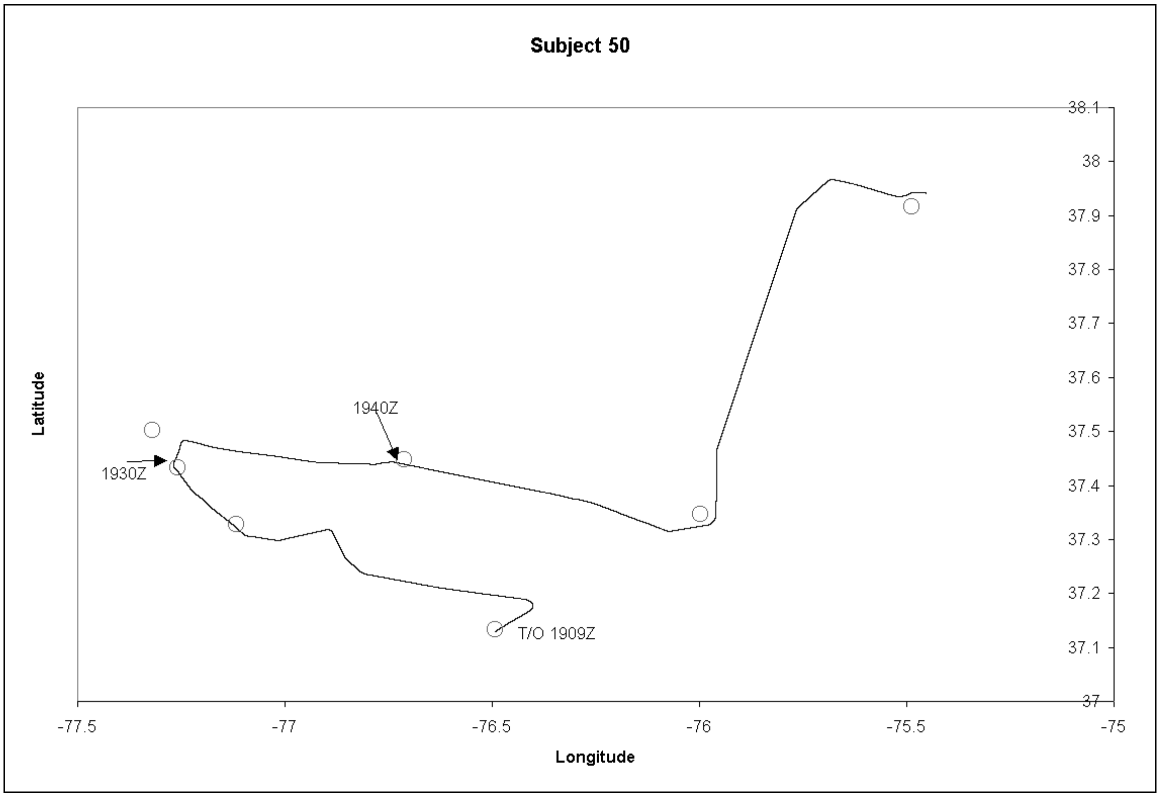
Subject 44
Latitude
Longitude
1937Z
1926Z
T/O 1909Z
38
37.9
37.8
37.7
37.6
37.5
37.4
37.3
37.2
37.1
37
-77.5
-77
-76.5
-76
-75.5
-75

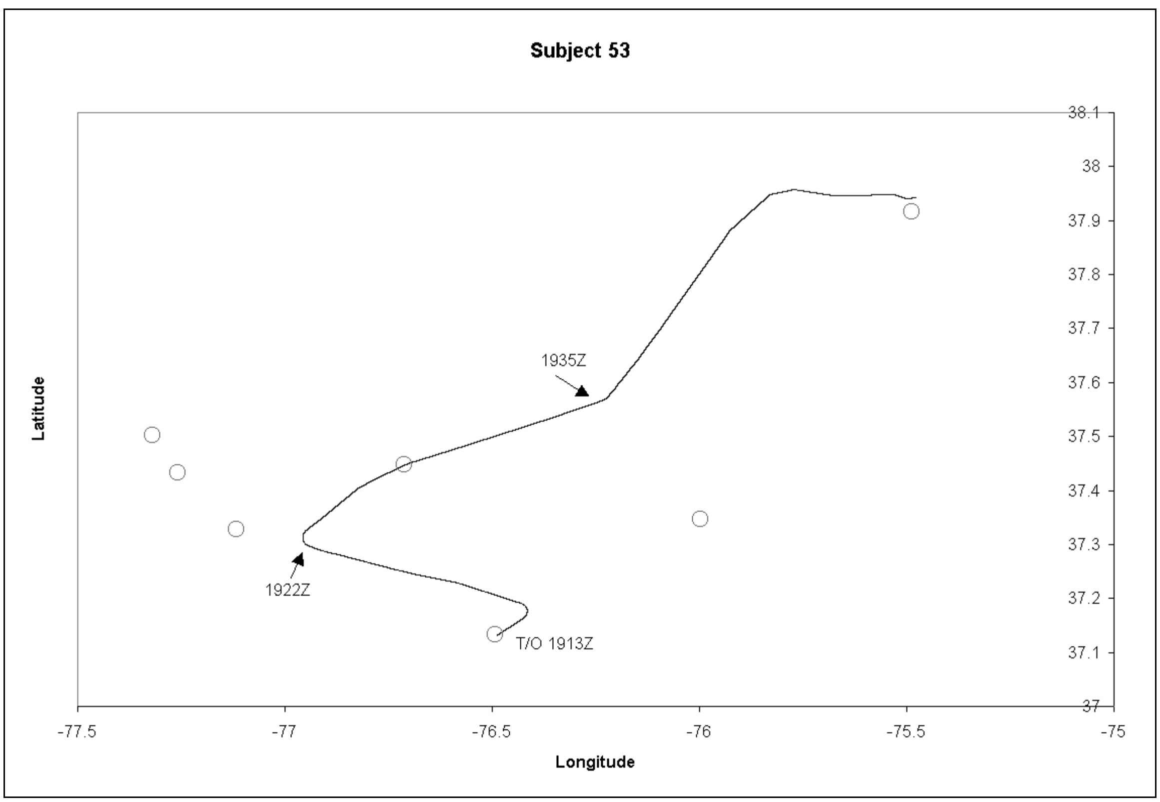

Subject 45
Latitude
Longitude
1942Z
1924Z
T/O 1906Z
38.1
38
37.9
37.8
37.7
37.6
37.5
37.4
37.3
37.2
37.1
37
-77.5
-77
-76.5
-76
-75.5
-75

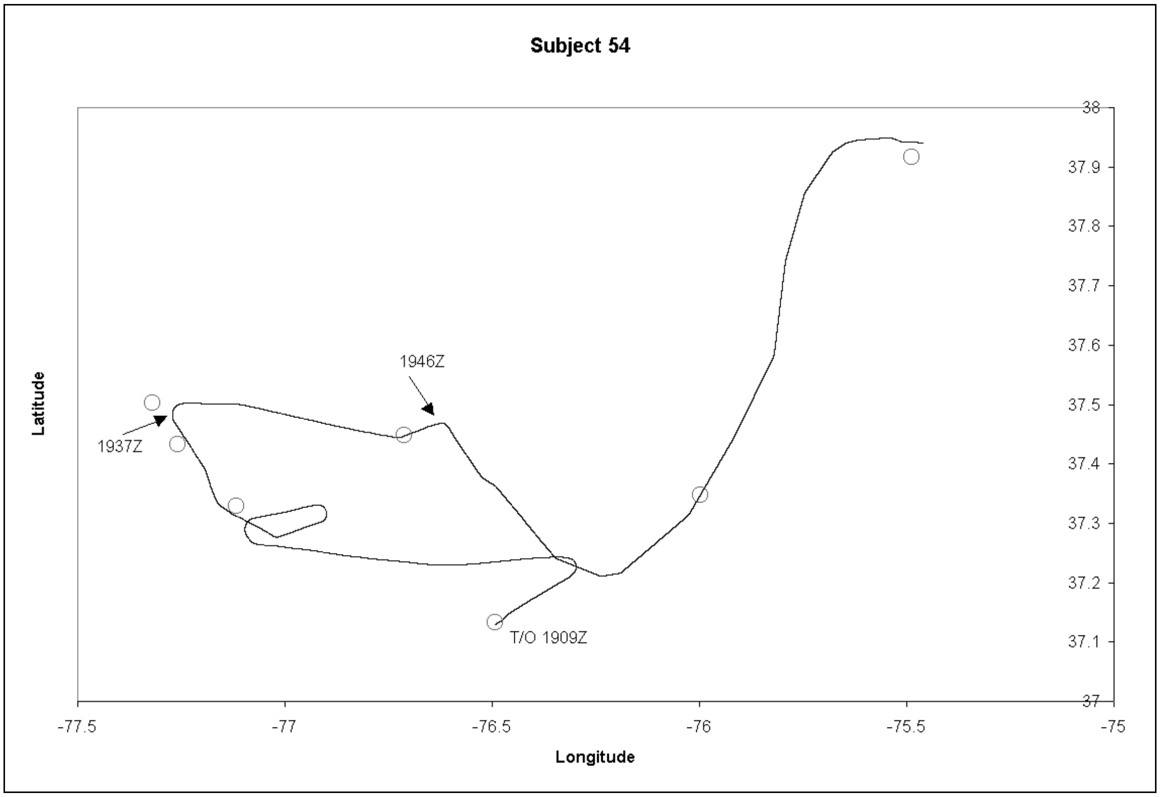

Subject 47
Latitude
Longitude
1941Z
1928Z
T/O 1910Z
38
37.9
37.8
37.7
37.6
37.5
37.4
37.3
37.2
37.1
37
-77.5
-77
-76.5
-76
-75.5
-75

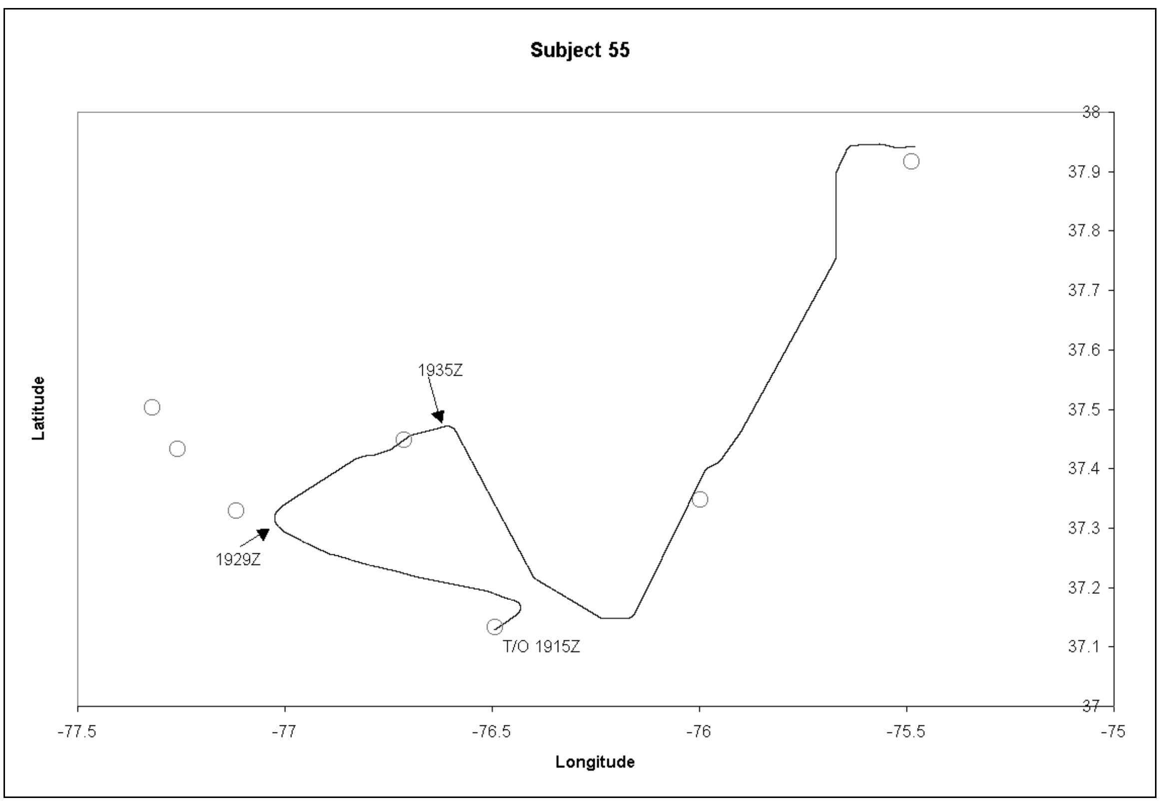

Subject 48
Latitude
Longitude
1935Z
1924Z
T/O 1907Z
38
37.9
37.8
37.7
37.6
37.5
37.4
37.3
37.2
37.1
37
-77.5
-77
-76.5
-76
-75.5
-75

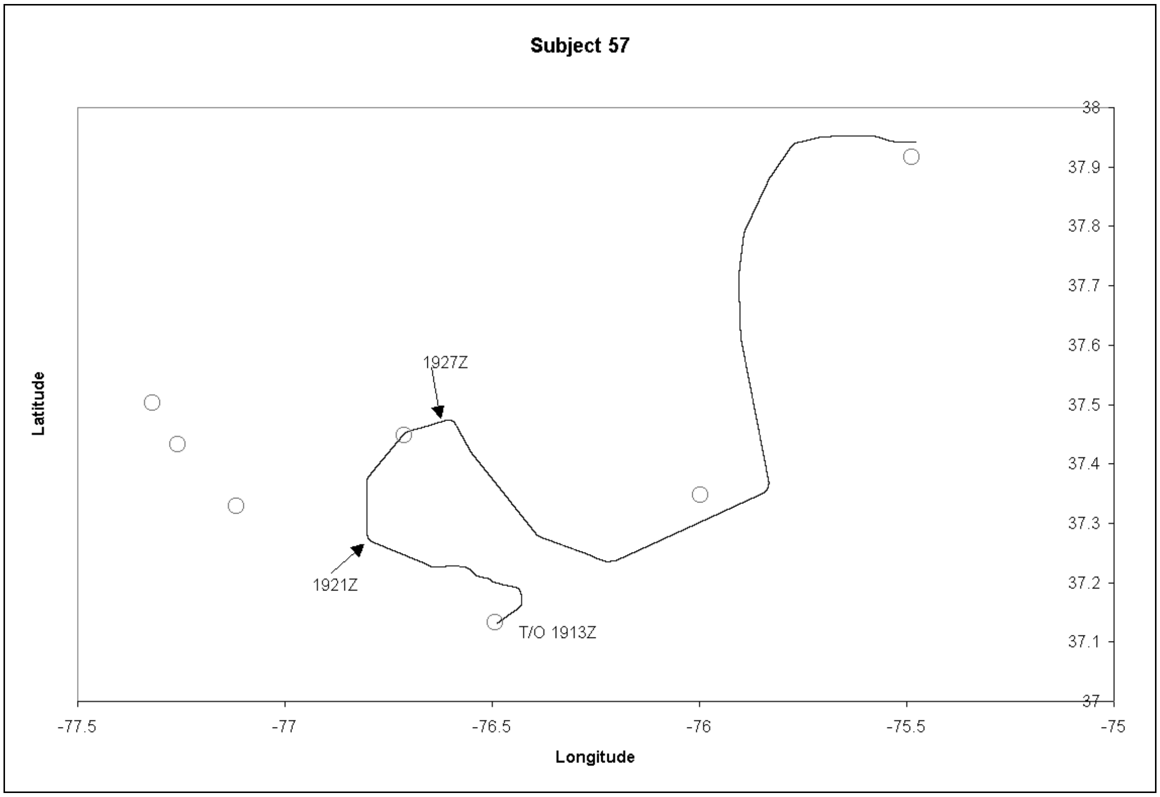

Subject 49
Latitude
Longitude
1946Z
1932Z
T/0 1912Z
38.1
38
37.9
37.8
37.7
37.6
37.5
37.4
37.3
37.2
37.1
37
-77.5
-77
-76.5
-76
-75.5
-75


Subject 50
Latitude
Longitude
1940Z
1930Z
T/O 1909Z
38.1
38
37.9
37.8
37.7
37.6
37.5
37.4
37.3
37.2
37.1
37
-77.5
-77
-76.5
-76
-75.5
-75

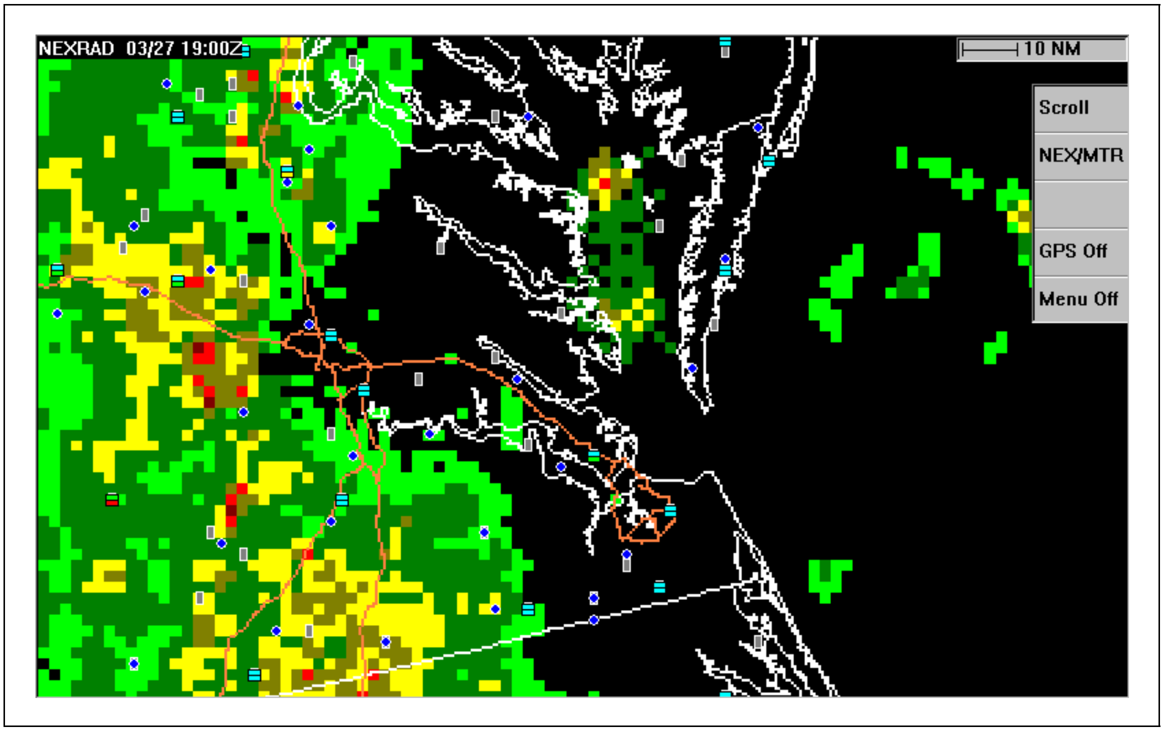

Subject 53
Latitude
Longitude
1935Z
1922Z
T/O 1913Z
38.1
38
37.9
37.8
37.7
37.6
37.5
37.4
37.3
37.2
37.1
37
-77.5
-77
-76.5
-76
-75.5
-75


Subject 54
1946Z
1937Z
T/O 1909Z
Latitude
Longitude
-77.5
-77
-76.5
-76
-75.5
-75
37
37.1
37.2
37.3
37.4
37.5
37.6
37.7
37.8
37.9
38

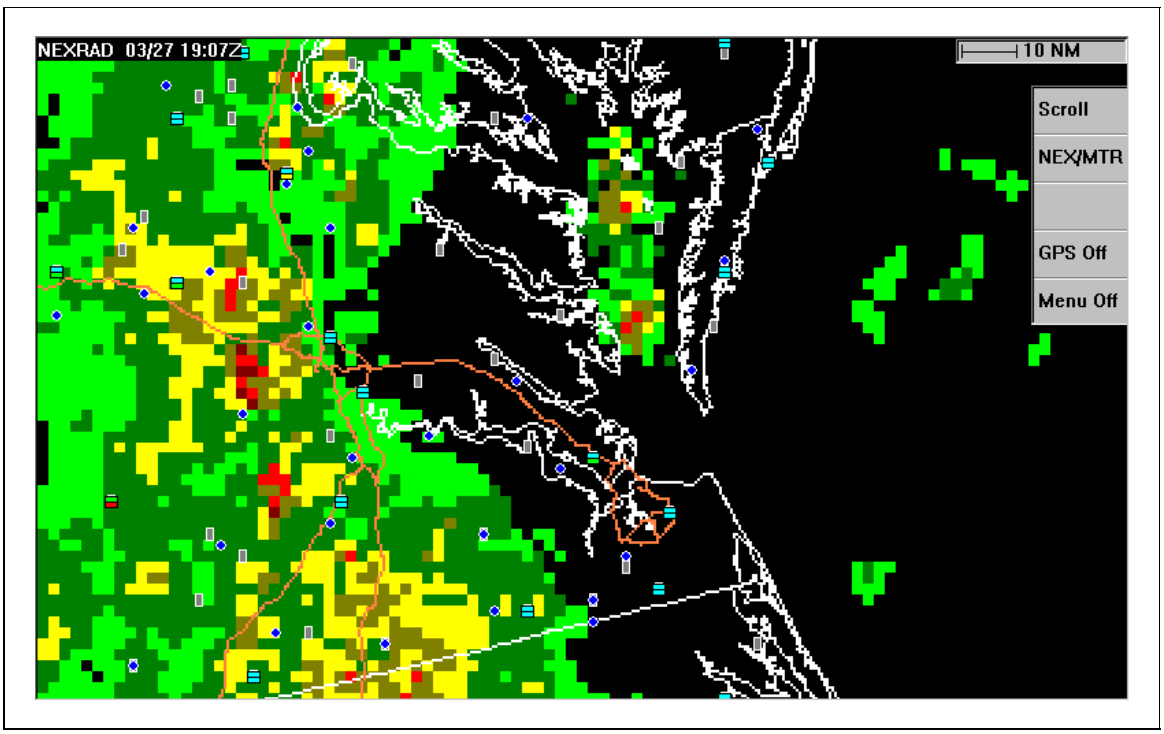

Subject 55
1935Z
1929Z
T/O 1915Z
Latitude
Longitude
-77.5
-77
-76.5
-76
-75.5
-75
37
37.1
37.2
37.3
37.4
37.5
37.6
37.7
37.8
37.9
38


Subject 57
Latitude
Longitude
38
37.9
37.8
37.7
37.6
37.5
37.4
37.3
37.2
37.1
37
-77.5
-77
-76.5
-76
-75.5
-75
1927Z
1921Z
T/O 1913Z

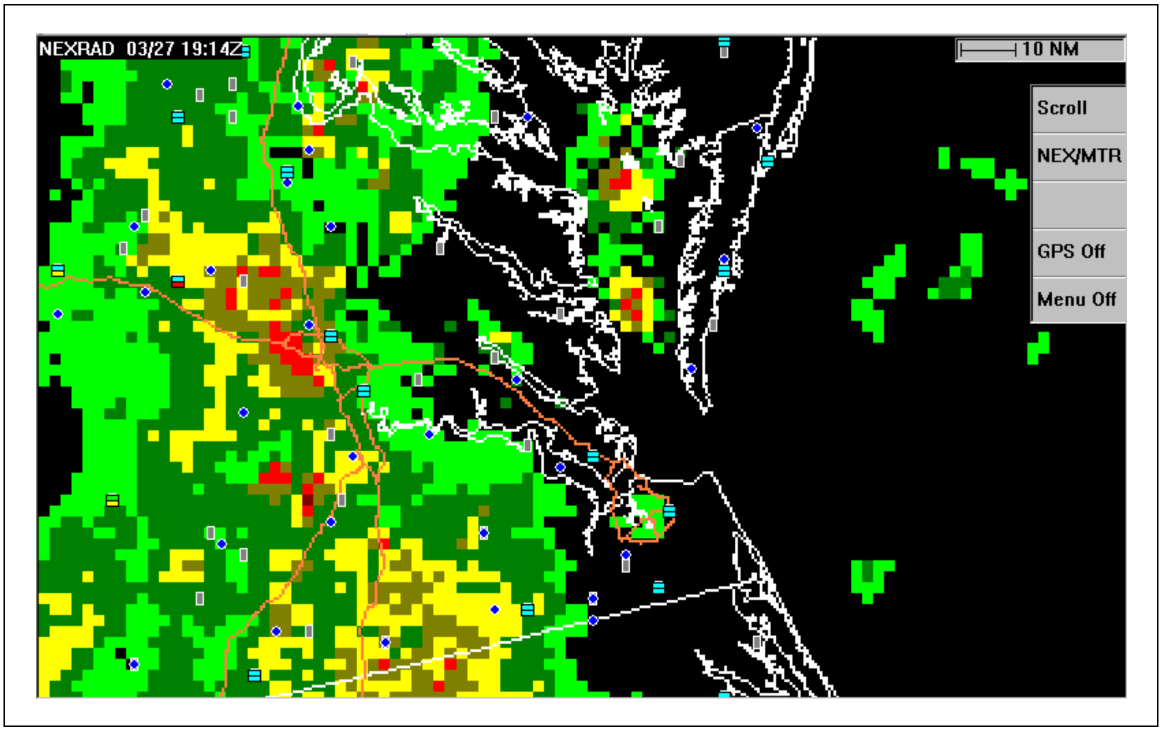
Appendix Q. NEXRAD Mosaic Images



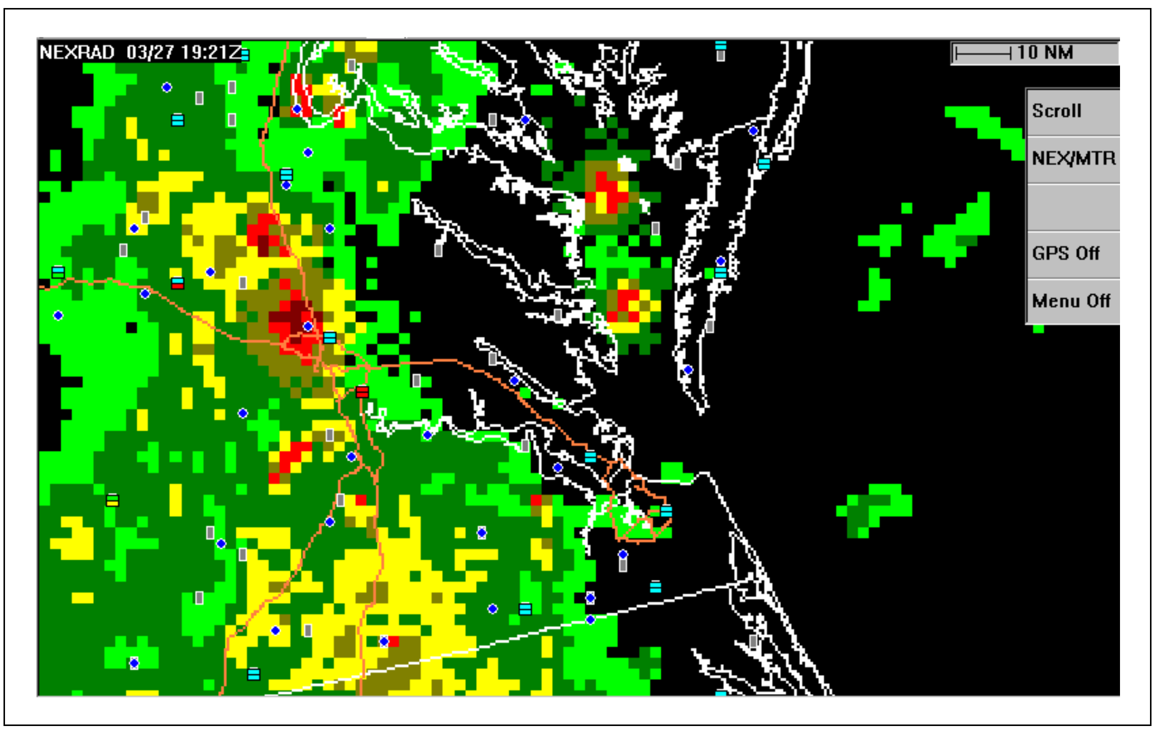
1900Z



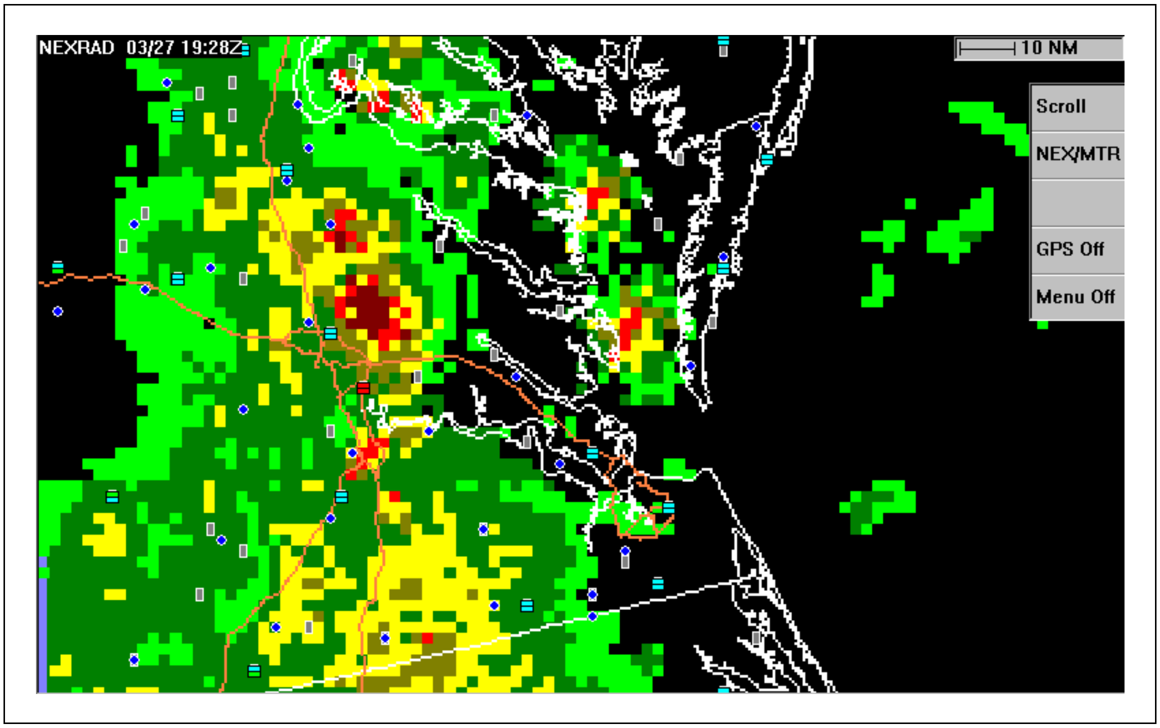
1907Z


NEXRAD 03/27 19:14Z
10 NM
Scroll
NEX/MTR
GPS Off
Menu Off

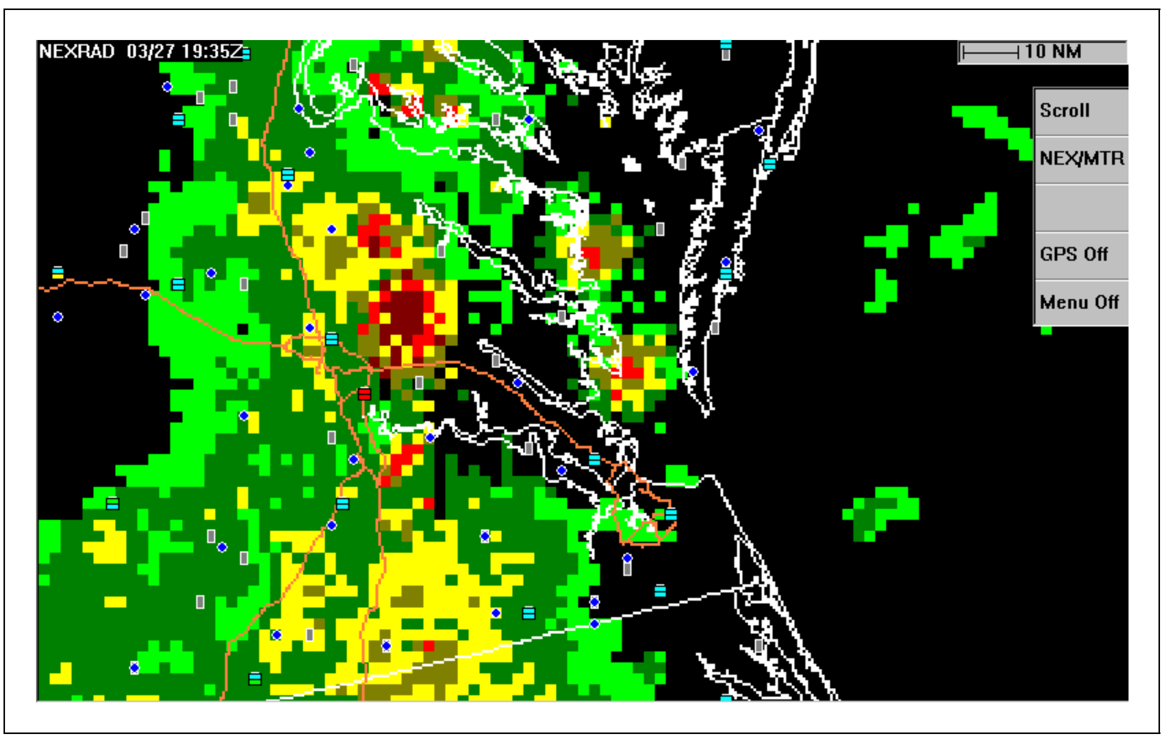
1914Z


NEXRAD 03/27 19:21Z
10 NM
Scroll
NEX/MTR
GPS Off
Menu Off

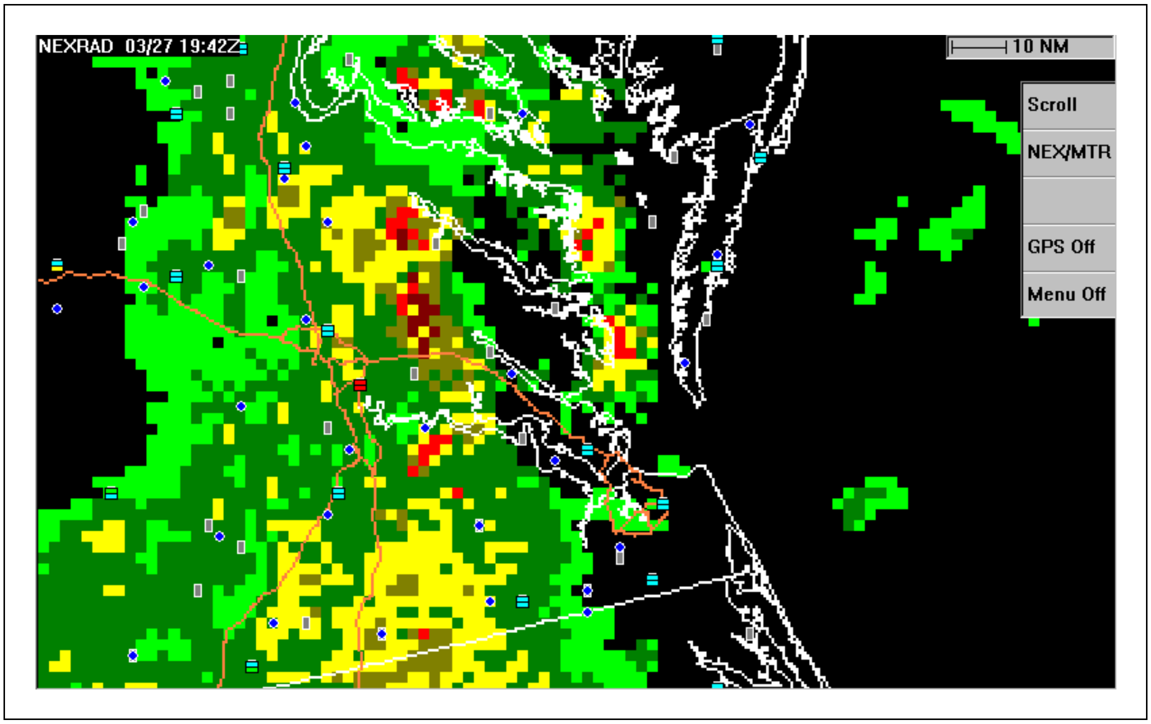
1921Z


NEXRAD 03/27 19:28Z
10 NM
Scroll
NEX/MTR
GPS Off
Menu Off

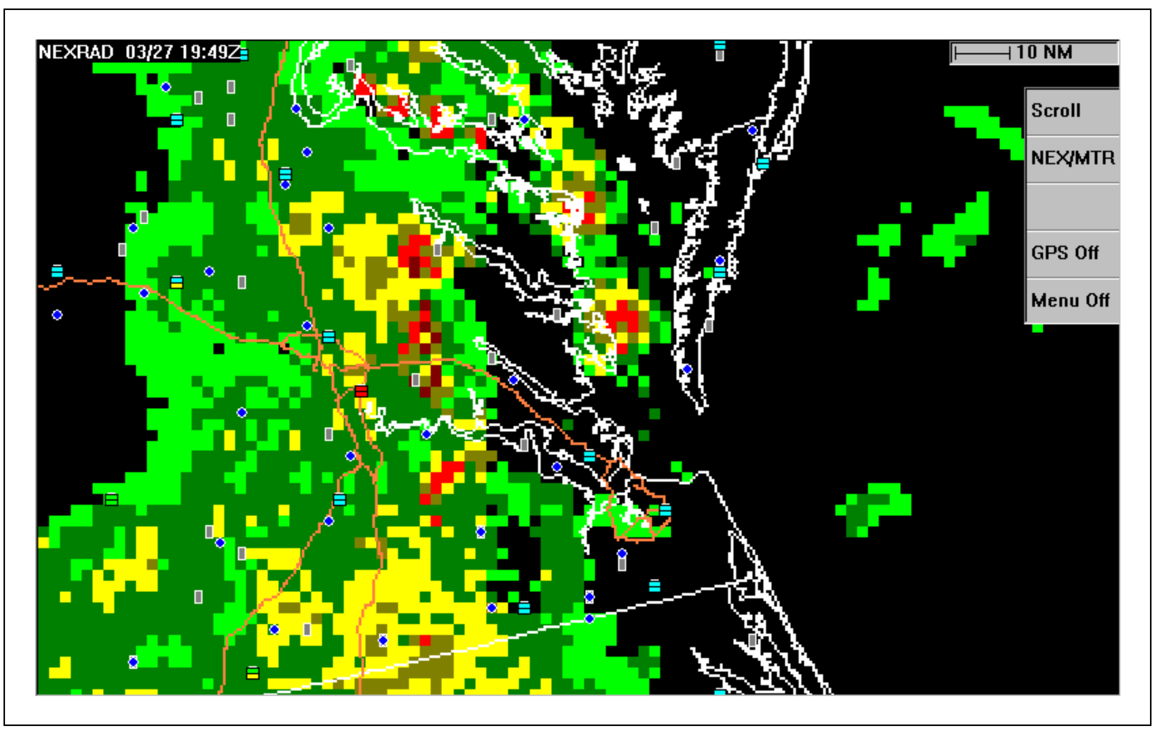
1928Z


NEXRAD 03/27 19:35Z
10 NM
Scroll
NEX/MTR
GPS Off
Menu Off

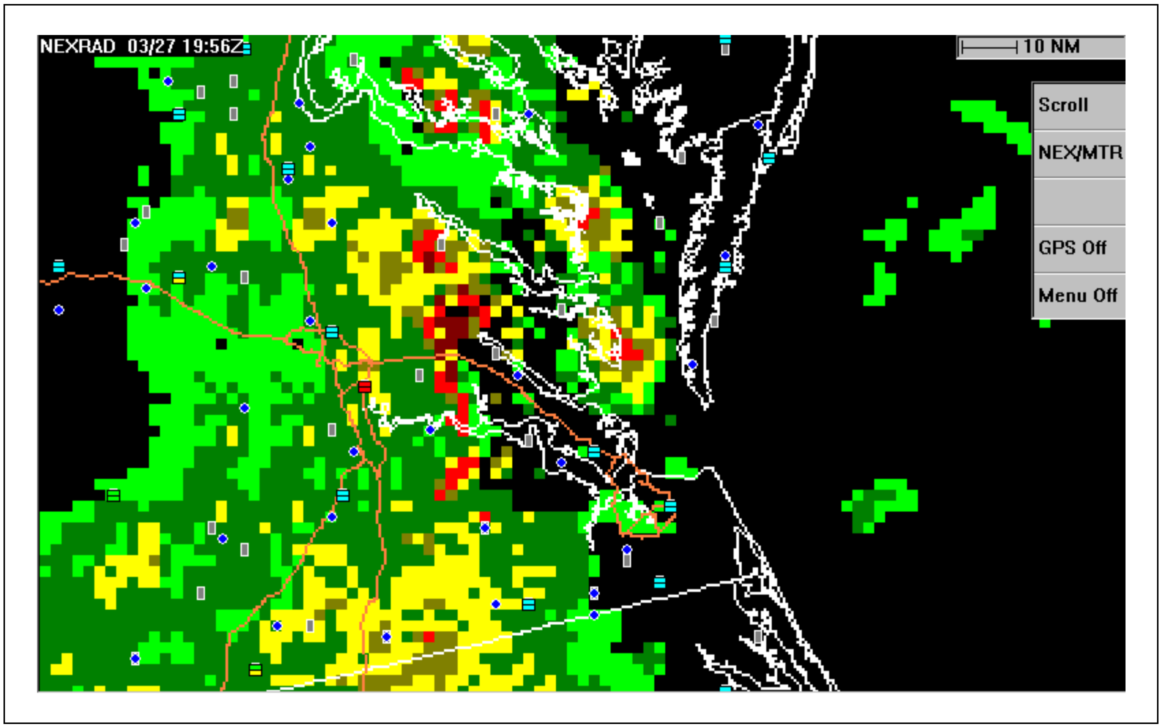
1935Z


NEXRAD 03/27 19:42Z
10 NM
Scroll
NEX/MTR
GPS Off
Menu Off

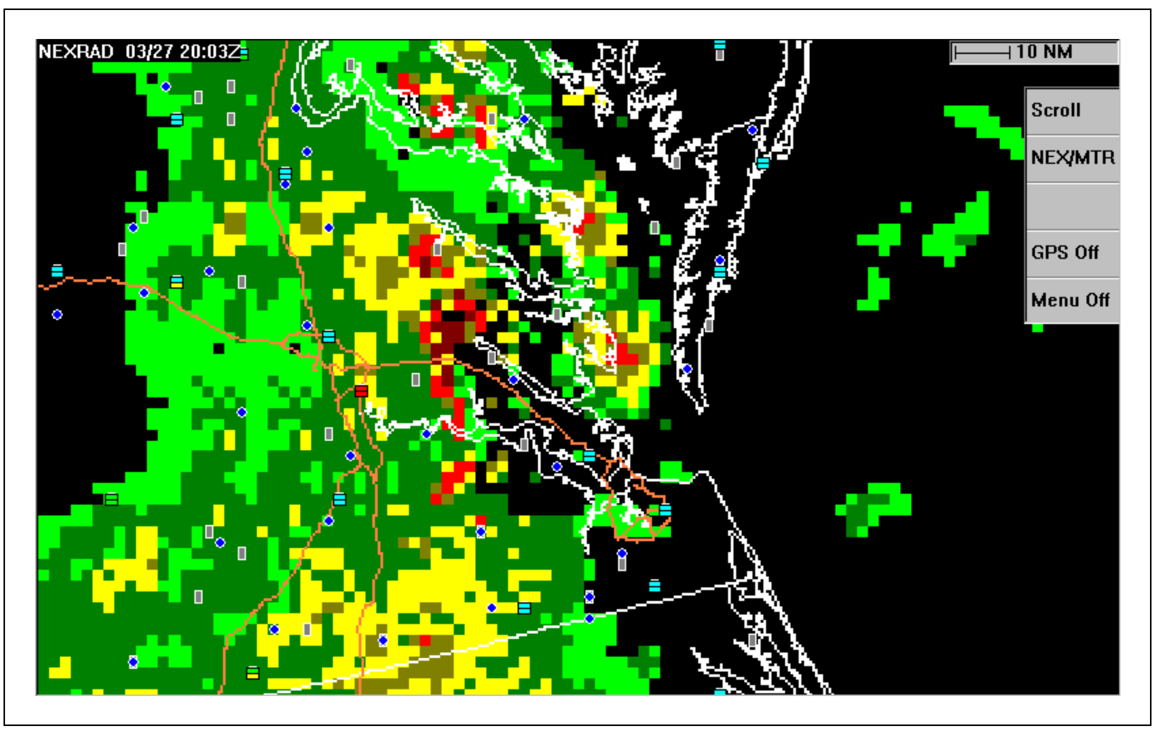
1942Z


NEXRAD 03/27 19:49Z
10 NM
Scroll
NEX/MTR
GPS Off
Menu Off

1949Z


NEXRAD 03/27 19:56Z
10 NM
Scroll
NEX/MTR
GPS Off
Menu Off

1956Z


NEXRAD 03/27 20:03Z
10 NM
Scroll
NEX/MTR
GPS Off
Menu Off

2003Z

Appendix R. Aeronautical Information Manual FISDL Guidance

Issue: 2/24/00

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

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

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

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

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

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

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

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

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

1. Before using FISDL in flight operations, pilots and other flight crew members should become completely familiar with the operation of the FISDL system to be used, airborne equipment to be used, including system architecture, airborne system components, service volume and other limitations of the particular system, modes of operation and the indications of various system failures. Users should also be familiar with the content and format of the services available from the FISDL provider(s). Sources of information 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 it's applicability may place the pilot and his/her aircraft in great jeopardy. In addition, FISDL should never be used in lieu of an individual pre-flight weather and flight planning briefing.

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

c. FAA FISDL. The FAA's FISDL system provides flight crews of properly equipped aircraft with a cockpit display of certain aeronautical weather and flight operational information. This information is displayed using both text and graphic format. This system is scheduled for initial operational capability (IOC) in the first quarter of calendar year

2000. The system is operated by vendors under a service agreement with the FAA, using broadcast data link on aeronautical spectrum on four 25 KHz spaced frequencies from 136.425 through 136.500 MHz. FISDL is designed to provide coverage throughout the continental U.S. from 5,000 feet AGL to 17,500 feet MSL, except in those areas where this is unfeasible due to mountainous terrain. Aircraft operating near transmitter sites will receive useable FISDL signals at altitudes lower than 5000 feet AGL, including on the surface in some locations, depending on transmitter/aircraft line of sight geometry. Aircraft operating above 17,500 MSL may also receive useable FISDL signals under certain circumstances.

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

(a) Aviation Routine Weather Reports (METAR's).

(b) Special Aviation Reports (SPECI's).

(c) Terminal Area Forecasts (TAF's), and their amendments.

(d) Significant Meteorological Information (SIGMET's).

(e) Convective SIGMET's.

(f) Airman's Meteorological Information (AIRMET's).

(g) Pilot Reports (both urgent and routine) (PIREP's); and,

(h) Severe Weather Forecast Alerts (AWW's) issued by the FAA or NWS.

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

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

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

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

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

1. Operators using non-FAA FISDL for in-flight 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.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY (*Leave blank*)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	August 2001	Contractor Report

4. TITLE AND SUBTITLE
Use of a Data-Linked Weather Information Display and Effects on Pilot Navigation Decision Making in a Piloted Simulation Study

5. FUNDING NUMBERS
NCA1-130
728-40-10-02

6. AUTHOR(S)
Daniel E. Yuchnovicz, Paul F. Novacek, Malcolm A. Burgess, Michael L. Heck, and Alan F. Stokes

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Research Triangle Institute
One Enterprise Parkway
Hampton, VA 23666-1564

8. PERFORMING ORGANIZATION REPORT NUMBER
7286.010

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
National Aeronautics and Space Administration
Langley Research Center
Hampton, VA 23681-2199

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
NASA/CR-2001-211047

11. SUPPLEMENTARY NOTES
Langley Technical Monitor: Daniel B. Shafer
Final Report

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Unclassified-Unlimited
Subject Category 03 Distribution: Standard
Availability: NASA CASI (301) 621-0390

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*
This study provides recommendations to the FAA and to prospective manufacturers based on an exploration of the effects of data link weather displays upon pilot decision performance. An experiment was conducted with twenty-four current instrument rated pilots who were divided into two equal groups and presented with a challenging but realistic flight scenario involving weather containing significant embedded convective activity. All flights were flown in a full-mission simulation facility within instrument meteorological conditions. The inflight weather display depicted NexRad images, graphical METARs and textual METARs. The objective was to investigate the potential for misuse of a weather display, and incorporate recommendations for the design and use of these displays. The primary conclusion of the study found that the inflight weather display did not improve weather avoidance decision making. Some of the reasons to support this finding include: the pilot's inability to easily perceive their proximity to the storms, increased workload and difficulty in deciphering METAR textual data. The compelling nature of a graphical weather display caused many pilots to reduce their reliance on corroborating weather information from other sources. Minor changes to the weather display could improve the ability of a pilot to make better decisions on hazard avoidance.

14. SUBJECT TERMS
Aviation weather; DataLink weather; Flight information services; Cockpit weather NexRad display; METAR display; Weather display; Weather decision making

15. NUMBER OF PAGES
187

16. PRICE CODE
A09

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	UL