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The Influence of Data Link-Provided Graphical Weather on Pilot Decision-Making

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6 April 1994

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16. Abstract

This report documents the findings of a human factors study conducted to estimate the effects of the Graphical Weather Service (GWS) on general aviation (GA) aircraft utility, pilot situational awareness, and the weather dissemination workload imposed on ground personnel. GWS is a data link application, being developed at MIT Lincoln Laboratory through the sponsorship of the Federal Aviation Administration, that will provide near-real-time graphical weather information to the General Aviation pilot in the cockpit.

Twenty instrument-rated pilots participated in the study. Subjects were presented with recorded actual weather information in the context of a series of hypothetical pre-flight briefings and accompanying "flights." GWS images were accessible on a Macintosh™ Computer. The study design enabled the analysis of the effects of GWS and the determination of whether those effects were influenced by the experience level of the pilot/user. Objective and subjective measures of effectiveness were collected.

Results indicate that GWS had a substantial effect on weather-related decision-making. This was true for pilots with varying levels of instrument experience. Subject confidence in the ability to assess the weather situation was markedly increased when GWS was used. Subjects with GWS made fewer calls for weather information to weather dissemination ground personnel, thus indicating a potential decrease in ground personnel workload. Subjects found GWS to be very useful and were enthusiastic about receiving data link services in the GA cockpit in the future.

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EXECUTIVE SUMMARY

BACKGROUND

MIT Lincoln Laboratory, through the sponsorship of the Federal Aviation Administration, is developing a data link application that will provide graphical weather information to the general aviation (GA) pilot in the cockpit. The transmission of these complex images is made possible through application of image compression algorithms developed at MIT Lincoln Laboratory.

The availability of near-real-time graphical weather information via data link will significantly affect pilot decision-making. To assess this effect, as well as to aid in the proper design, implementation and certification of use of the Graphical Weather Service (GWS) in aircraft, a series of human factors studies is being conducted. This report describes the methodology and results of Phase One in this series of studies.

STUDY METHOD

Twenty male instrument-rated pilots participated in this study. The number of actual instrument hours of the pilots ranged from 40 to over 2,000 hours.

Subjects participated in five hypothetical flights, one for training and four for data collection. GWS images were available to the subject during the training flight and two of the four data collection flights. Images were accessible on an Apple Macintosh™ Computer at three times within a hypothetical flight. The study was conducted in an office setting and did not involve a dynamic flight simulation.

Subjects were provided with relevant navigational charts and weather briefing material prior to each "flight." For each flight, a pre-flight interval was provided during which the subject could become familiar with the proposed route of flight and the weather conditions. Next, at three decision points within each flight, the experimenter told the subject the aircraft position and altitude, described the current weather conditions in the immediate vicinity of the aircraft, and asked the subject what action he would take. The subject could respond immediately or he could seek additional information using GWS (in the GWS Condition) or via queries to weather dissemination personnel (in the GWS and No GWS Condition). An experimenter, who sat in the room with the subject, played the role of the weather dissemination personnel.

Pilots were asked to "think aloud" throughout the hypothetical flights. The experimenter recorded the subject's choices of GWS images, queries to weather dissemination personnel, and all comments made at each decision point. In addition, the subject completed a questionnaire at each decision to assess his confidence in his ability to assess the weather situation and to assess the usefulness of GWS as an aid in the decision-making process.

RESULTS

Results indicate that GWS had a substantial positive effect on the weather-related decisions made by the subjects. With GWS, subjects could see the weather graphically displayed and could make informed decisions regarding whether to embark on a flight and regarding the need for deviations for weather avoidance during flight. This effect was found for pilots with both moderate and extensive levels of experience in actual instrument flight.

Subjects' confidence in their ability to assess the weather situation was markedly increased when GWS was used. It was also found that subjects with GWS made fewer calls for weather information to weather dissemination ground personnel, thus indicating a potential decrease in ground personnel workload.

Subjects found GWS to be very useful and cost-effective. Pilots were enthusiastic about receiving graphical weather information in the GA cockpit. Moreover, they expressed an appreciation for the multi-functional aspect of data link. In addition to receiving data link-provided graphical weather information pilots could potentially receive: traffic information, ATC (Air Traffic Control) clearances, text ATIS (Automatic Terminal Information Service), and new products as they are developed and made available.

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1. INTRODUCTION

1.1 BACKGROUND

The collection, synthesis, and delivery of timely and accurate weather products is central to the productivity and safety of the National Airspace System. The Federal Aviation Administration (FAA) is currently supporting the development of the Aviation Weather Products Generator (AWPG) and the Integrated Terminal Weather System (ITWS), that will combine the inputs from weather sensors and other sources of meteorological observations and forecasts to deliver improved weather products to Flight Service Stations, Air Traffic Control Facilities, and airline Dispatch Offices. Flight crews will gain access to these weather products in flight by digital data link.

Many of the products generated by AWPG and ITWS will be in the form of weather graphics. Examples of these include graphical depictions of regions of precipitation, turbulence, icing, or other phenomena. A typical text weather message (e.g., a series of terminal forecasts or surface observations), when coded in digital form, consists of approximately 1000 bits of data and requires relatively little bandwidth when transmitted to the flight deck by data link. A typical weather graphics image may consist of several million bits and would require considerably more data link bandwidth for transmission. Because of the large number of aircraft that would request this information and the increasing number of aviation-oriented graphical weather products that will become available on the ground, some means must be employed to decrease the bandwidth required to transmit weather graphics images. Standard image compression algorithms are insufficient to achieve the large (approximately 100:1) image compression ratios that are necessary for data link transmission [1].

1.2 GRAPHICAL WEATHER SERVICE: A DATA LINK APPLICATION

With support from the FAA, MIT Lincoln Laboratory has developed an image compression algorithm that is applicable to data link transmission of weather graphics. The algorithm [2] is based upon the underlying geometric structure of weather phenomena and operates by coding the graphical image as a set of polygons and ellipses (see Figure 1). The compression algorithm forms the basis for the Graphical Weather Service (GWS), a data link application that operates as follows: When a data link message requesting a specific image is received from an aircraft, it is passed to a ground-based image compression processor. This processor selects the appropriate image area from a weather data base, based on the location, time, and scale specified in the data link request. The processor then compresses the image and encodes it for data link transmission to the requesting aircraft. When received by the aircraft, an on-board processor decodes the data link message, decompresses the image and displays it to the pilot.

To use the Graphical Weather Service application, the aircraft must be equipped with the appropriate data link avionics (see Figure 2). In general, this consists of a data link "modem" such as a Mode S transponder or a VHF data radio that transmits and receives the data link messages. In addition, a Control and Display Unit (CDU) is required to allow the pilot to request data link services and display the results. It is estimated that the data link avionics suite for a typical general aviation aircraft will cost approximately $5000. This low cost is attractive when compared to either airborne weather radar or lightning detection equipment. The same avionics that support GWS may also be used for the display of data-link provided traffic information, text weather products, Air Traffic Control communications, and other data link applications.

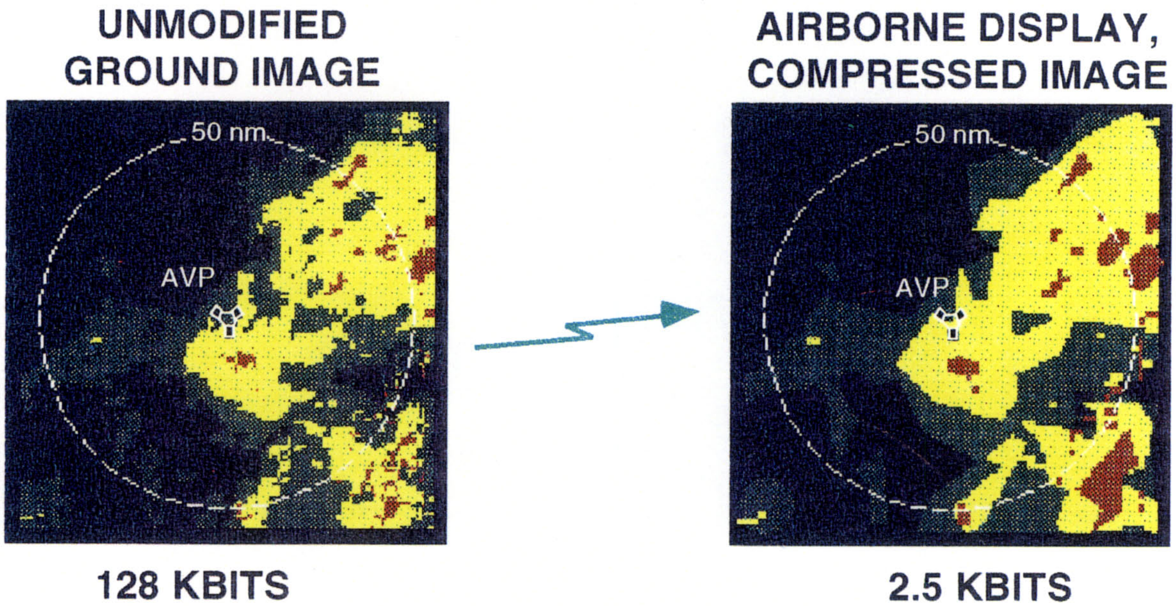

Figure 1-1 The application of the Poly-Ellipse compression algorithm to a weather radar precipitation image. The image at left consists of a square region 138 nautical miles on a side with a resolution of 2km for a total of 128 kbits and the compressed image at right consists of 2.5 kbits. Note the loss of detail in the compressed image.

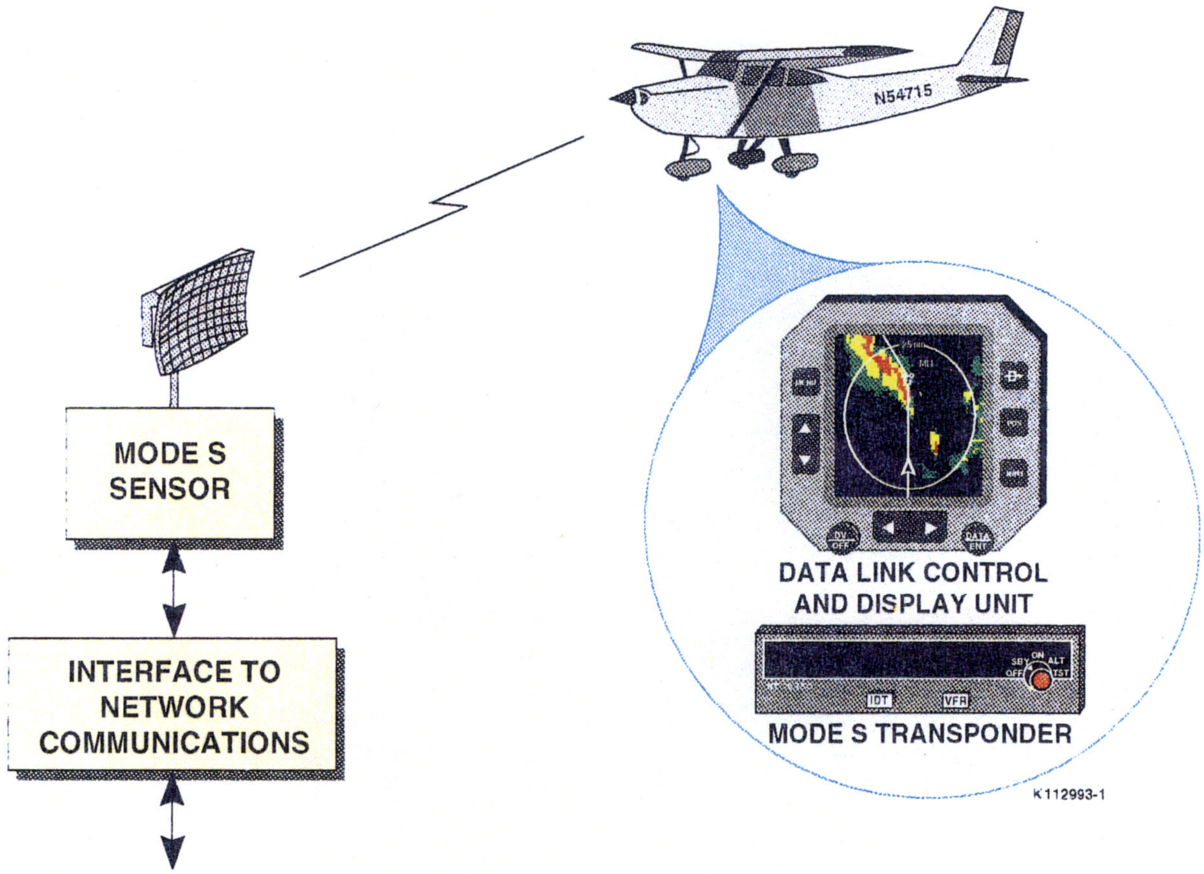

Figure 1-2 Basic avionics required for two-way Mode S data link in a general aviation aircraft. This avionics package will support multiple data link applications including Graphical Weather Service. The avionics for a VHF or satellite data link differs only in the "modem" used, i.e., a VHF or satellite data link transceiver would replace the Mode S transponder.

1.3 CHOICE OF A WEATHER PRODUCT FOR GWS DEVELOPMENT

To develop the operational concept for the Graphical Weather Service, it was necessary to identify an appropriate weather graphics product. The NOWrad™ composite radar precipitation product[1] was selected as appropriate for GWS implementation because of its current commercial availability and its relevance to general aviation operations. The NOWrad™ product is a mosaic of precipitation images generated by the U.S. network of (Weather Service Radar) WSR-57/74/88 weather radars. A complete NOWrad™ image covers the contiguous United States with 2km resolution, is updated every 15 minutes and characterizes precipitation intensity within each 2km-cell as one of six levels. Because of the utility and widespread use of airborne weather radar in aviation and the inherent graphical complexity of ground-based radar precipitation images, the ground-based composite weather radar image was selected for development as the first product of the Graphical Weather Service.

1.4 HUMAN FACTORS EVALUATION OF GWS

The availability of near-real-time graphical weather information via data link will significantly affect pilot decision-making. To properly design, implement, and certify the use of GWS in aircraft, it is necessary to understand its effect on pilot actions. This report describes the first of three phases of human factors studies aimed at predicting the impact of GWS on general aviation aircraft utility, pilot situational awareness, and the weather dissemination workload imposed on ground personnel (Air Traffic Control and Flight Service).

In Phase One, subject pilots were given prepared flight plans, weather briefings, and graphical weather images. This was done in an office setting and graphical weather images were presented on an Apple Macintosh™ Computer. Subjects were asked to make weather-related decisions without time constraints and the workload demands of actual flight. While this methodology does not replicate all the parameters of actual flight, it allowed for an early look at the complex issue of in-cockpit weather display, interpretation, and decision-making. This methodology made it feasible for subjects to make comments and answer questionnaires. It also facilitated discussions of the human interface aspects of the display.

In Phase Two, subjects will use GWS in a simulated flight environment. This will be done to study real-time issues such as pilot workload and attention to multiple tasks. The simulator environment will also be used to aid in the design and assessment of the user interface.

Phase Three will consist of an operational evaluation of GWS. Data Link avionics will be installed in one or more test aircraft and will be flown to validate the results of the previous studies under actual flight conditions.

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[1] NOWrad™ is a product of WSI Corporation, a commercial weather information provider.

1.5 REPORT ORGANIZATION

Section 2 provides a description of the experimental design of the Phase One Study. Section 3 includes a detailed account of the methodology used. Section 4 describes the data collection process and provides definitions of the objective and subjective measures. Section 4 also describes the types of analyses performed. Section 5 presents the results obtained and Section 6 lists the conclusions that are based on these results.

2. EXPERIMENTAL DESIGN

2.1 INDEPENDENT VARIABLES

In assessing the effect of the Graphical Weather Service (GWS) on pilot decision-making two independent variables were studied: Information Mode and Experience Level. The variable "Information Mode" refers to the manner in which the subjects were able to receive their weather information at each of the three decision points within a particular hypothetical flight. There were a total of four flights. During two flights the subject had access to GWS and during two flights the subject did not have access to GWS, resulting in a GWS Group (n=10) and No GWS Group (n=10) for each flight. For all flights subjects had access to weather information through verbal query of ground-personnel, played by the experimenter. Analysis of this variable enables the comparison of subject performance with and without the use of GWS, and the resulting determination of the effects of GWS. Table 2-1 shows the division of subjects between the two Information Mode Groups.

Table 2-1

Subject Exposure to Information Mode

Flight Number	Subjects (n=10)	Subjects (n=10)
1	No GWS	GWS
2	GWS	No GWS
3	No GWS	GWS
4	GWS	No GWS

The order of presentation of the four flights to each subject was counterbalanced to control for effects that might be attributed to order of presentation. For example, if the four flights were presented to all subjects in the same order, for example 1, 2, 3, 4, then subject performance on Flight 4 could be affected by having previous training and familiarity with GWS in preceding flights. Therefore, subjects were presented with flights in a counterbalanced order. If subject performance improved during the later presentations, differences should average out across all subjects.

The variable "Experience Level" refers to the number of actual instrument hours held by the subjects. All subjects were experienced in instrument flight. The subject pool was divided evenly into two levels of experience in order to assess whether performance with GWS varied as a function of experience level. Subjects with 40 to 150 hours of actual instrument flight were assigned to the Moderate Experience Group (n = 10), while subjects with over 150 to over 2,000 hours were assigned to the Extensive Experience Group (n = 10). Analysis of this variable enables the comparison of the performance of moderate vs extensive experience pilots, and the resulting determination of the effect of experience on use of GWS.

As shown in Table 2-2, the 2 x 2 design matrix consisted of two Information Mode Conditions (GWS vs No GWS) and two Experience Level Groups/Conditions (Moderate vs Extensive Experience).

TABLE 2-2

Design Matrix

		Information Mode: GWS	Information Mode: No GWS
Experience Level	Moderate	n=5	n=5
	Extensive	n=5	n=5

In studying the effects of the variables Information Mode and Experience Level, a between-subject design was used. In a between-subject design the responses of one group of subjects are compared to the responses of another group of subjects. That is, the responses of all subjects in the GWS Group were to be compared to the responses of all subjects in the No GWS Group. Likewise, the responses of all subjects in the Moderate Experience Group were to be compared to the responses of all subjects in the Extensive Experience Group.

2.2 RESEARCH QUESTIONS

The study was designed to answer the following research questions:

1. Does GWS affect pilot actions, specifically, go/no-go decisions, in-flight deviations, and calls to weather dissemination personnel for weather information?
2. Does GWS affect pilot confidence in his ability to assess the weather situation?
3. Does GWS affect the pilot's perception of the level of hazard of a weather situation?
4. Do pilots find GWS to be useful?
5. How do pilots use GWS? Specifically, how often do they use it, what ranges do they request, and is it used with other sources of weather information?
6. Is GWS cost-effective, i.e., do pilots believe that the utility of GWS justifies the cost of equipage?

3. METHOD

3.1 SUBJECTS

Twenty instrument current, instrument-rated pilots from the New England area participated in the study. The subjects had single engine and/or light twin engine experience. The two following Sections explain the recruitment process and provide background information on the flying experience of the subjects.

3.1.1 Recruitment

An advertisement was placed in the Atlantic Flyer, an aviation newspaper. Appendix A contains a copy of the ad. The ad specified that instrument-rated pilots with single engine and/or light twin engine experience were needed to volunteer as subjects in the evaluation of a new air/ground data link service being developed by the Federal Aviation Administration (FAA). The GWS Program and studies were briefly described.

While it is expected that GWS would be useful during all types of flying, it is expected that it would be most useful for instrument flight. Therefore, an instrument rating and a significant amount of actual instrument experience were required for subject participation. It was also required that the instrument rating be current. Setting these requirements ensured that all subjects had experience in judging actual weather situations and that some of that experience was recent.

The potential subject called an experimenter at MIT Lincoln Laboratory, who conducted a telephone screening. The main purpose of the screening was to ensure that all subjects met the criteria for subject selection, i.e., were instrument current, had single engine and/or light twin engine experience, had at least 40 hours of actual instrument flying. Once the pilot qualified for participation, he was assigned to one of the two groups related to pilot experience level.

3.1.2 Subject Background

Pilots who were selected to be subjects, were sent a Pilot Background Questionnaire, which is contained in Appendix B. The questionnaire was mailed to them and could be completed at their leisure, giving the subject time to refer to his log book in answering questions regarding flight hours. The subject returned the questionnaire on the day he participated in the study.

Responses to the questionnaire provided information on the pilot's flying experience, including: pilot age, license held, ratings held, flight hours, level of familiarity with the New England Region, types of navigational or weather detection equipment that is in the aircraft they usually fly, any training they may have had in weather interpretation, and how they usually obtain their pre-flight weather briefing.

The subjects had a wide range of pilot experience. Subjects had a minimum of 555 hours, and a maximum of 28,000 hours of flight time, with a mean of 5,318 hours. These subjects had a range of actual instrument hours from 35 to 2,700 hours, with a mean of 427 hours.

Subject age ranged from 28 to 70 years, with a mean of 44 years. All subjects were male. Several female pilots responded to the advertisement but did not meet the criteria for subject selection.

The subjects held a wide variety of licenses and ratings. Two were private pilots, nine were commercial pilots, and nine were Airline Transport Pilots (ATP). Sixteen of the twenty subjects had multi-engine ratings. Fifteen subjects were flight instructors. All of the subjects were rated in single engine airplanes, additionally four had helicopter ratings, and five had glider ratings.

The subjects had a wide range of recent Instrument Flight Rules (IFR) experience. The subjects had flown an average of 36 approaches in the past year, with a range of 1 to 68 approaches. The average number of actual instrument hours in the past year was 22, with a range of 0 to 68 hours.

The hypothetical flights used in the study all occurred in New England. We, therefore, wanted subjects who were familiar with flying in the area. All the subjects were residents of New England and fly in the area. Subjects rated how familiar they were with flying in the New England region. They were given a scale from 1 (Not at All Familiar) to 5 (Very Familiar). One of the subjects replied 2 (Somewhat Familiar), one replied 3 (Moderately Familiar). All the remaining subjects replied 4 or 5 (More Than Moderately Familiar or Very Familiar).

In a related question the subjects were asked the distance of their average IFR flight in the prior year. The average distance was 234 nmi (nautical miles) with a range of 25 to 1200 nmi. The conclusion is that most of the pilots have flown a significant amount in the New England area and are familiar with some of the issues, such as terrain, that are local to the area.

The subjects came from diverse flying backgrounds, from weekend flyers to retired airline captains. They were asked how often they fly for each of several different reasons. In each case they were asked to rank the answer from 1 (Never) to 5 (Always). The number and percentage of people who answered "Usually" or "Always" were then calculated for each option. Table 3-1 lists the reasons for flying and the number and percentage of responses indicating a "Usually" or "Always" rating. The percentage column adds up to greater than 100% because subjects could answer with a rating of "Usually" for more than one type of flying.

TABLE 3-1

Reason for Flying
"Usually" and "Always " Responses Combined

	Number	Percentage
Recreation	8	40
Business	10	50
Commuter	1	5
Airline	2	10

The subjects were asked the means by which they get their pre-flight weather briefings. Again for each option they were asked to score from 1 (Never) to 5 (Always). The number and percentage of people who answered "Usually" or "Always" were then calculated for each option. As noted above, this allows for a total of greater than 100%. Table 3-2 lists the source of pilot pre-flight briefing and the number and percentage of pilots who usually or always use that source.

TABLE 3-2

Sources of Pilot Pre-Flight Briefings
"Usually" and "Always" Responses Combined

	Number	Percentage
Over the Phone from Flight Service Station (FSS) Personnel	12	60
In Person from FSS Personnel	0	0
DUAT	8	40
Other Computer Service	2	10
Facsimile Service	2	10
Other Service	1*	5

* This one subject usually uses the Weather Channel on cable television as well as DUAT.

To determine how familiar the subjects were with in-flight weather detection equipment, they were asked what weather equipment is on board the aircraft that they usually fly. Seven subjects listed Stormscope, and four subjects listed weather radar. In addition, the pilots were asked if they have had any weather training beyond basic pilot training. Nine of the subjects said that they had additional weather training, including: college meteorology classes, military and airline training, and radar training courses.

3.2 FACILITIES, STIMULI, AND APPARATUS

3.2.1 Facilities

The study was conducted in a module/office at MIT Lincoln Laboratory in Bedford, MA. GWS images were displayed on an Apple Macintosh™ personal computer using "Hypercard" software. The office contained enough chairs for the subject and two experimenters and a desk large enough to accommodate the Apple Macintosh™, weather briefing materials, a small tape recorder and study questionnaires.

3.2.2 Stimuli

All of the weather images, text and verbal descriptions used in the study were constructed from actual recorded data (NOWrad™ images), made available to us by a commercial vendor, WSI Corporation. NOWrad™ is a composite, national radar precipitation image formed by decluttering and mosaicing the output of NWS WSR-57/74/88 radars. Mosaiced data should be substantially less subject to attenuation and terrain blocking effects that degrade single site data. A new national image is released every 15 minutes. For quality-control, a meteorologist at WSI reviews the image prior to release.

For this study, regional NOWrad™ images were recorded at WSI Corporation during designated 3-hour intervals. Recording intervals were started at WSI Corporation at the initiation of Lincoln Laboratory staff when "interesting" weather was forecast to pass through New England. The regional images were windowed from the national NOWrad™ images; the window was centered on Worcester, MA and covered an area 760 km (East-West) by 480 km (North-South). In addition, WSI Corporation recorded and made available the other weather data that were necessary for the experiment.

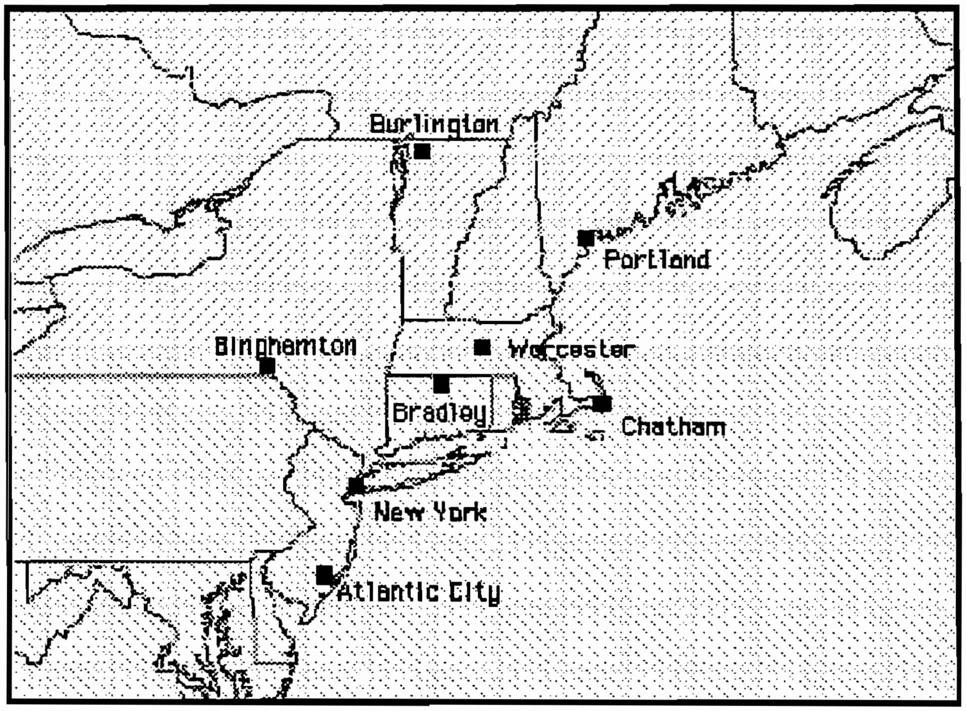


Figure 3-1 Weather image region.

The flights were prepared by first looking at this recorded collection of "interesting" weather. Weather was considered "interesting" if it was possible to fly a light general aviation aircraft in that area, however there was enough weather to make this a somewhat challenging IFR task. This included such conditions as chance of thunderstorms, actual thunderstorms in the region, or ceilings or visibility near minimums. Data were recorded over the summer, therefore, icing was not considered an issue.

The recorded weather was used in constructing five hypothetical flights, which if actually flown would take approximately two hours. One flight was used for subject training and four were used for data collection. The experimenters felt that all of these flights could be completed. However, the scenarios included weather that would create some difficult decisions for the subjects. Three decision points were then chosen for each flight. In all cases the first decision point was at departure, prior to starting the aircraft engine. The second decision point was during the cruise portion of the flight, and the third was near the destination.

The following briefly describes the weather presented in the four hypothetical flights:

Flight 1 A strong cold front laying parallel to the route of flight. This front had strong convective activity associated with it, in a well defined region. The subjects would have to decide whether they could stay far enough ahead of the front for them to feel that the flight could be completed safely.

Flight 2 A surface low in Canada and a warm front associated with a surface low in Canada extend into the region of the flight. Forecasts included chance of embedded thunderstorms. In this case the weather in the region of the flight did not deteriorate as forecast, although during the flight, level one precipitation and low ceilings did develop at and near the destination.

Flight 3 A weak cold front along the route of flight. Widely scattered thunderstorms were forecast but did not develop. However, a region of level 2 precipitation did develop and move over the destination. The precipitation arrived at the destination ahead of the flight, close to arrival time.

Flight 4 In the aftermath of Tropical Depression Andrew, the low pressure was located significantly south of the route of flight. Circulation around the low was bringing moist unstable air into the region, with an associated cold front and forecast thunderstorms. During the first half of the flight visibility was good, with no precipitation. In the second half the flight path crossed a line of convective activity, into a region of scattered strong convective activity. These buildups were localized and not embedded.

For each decision point, experimental images were prepared for four locations (present position, departure, destination, alternate), at four different ranges (25, 50, 100, 200 nmi radius). Ranges greater than 200 nmi were not necessary, since the route of flight did not extend beyond the 200 nmi range.

Counting three decision points per scenario, across five scenarios (3 x 5 x 4 ranges x 4 locations), a total of 240 experimental images were prepared. The experimental images were prepared by windowing a section of the WSI-supplied image, centered on the desired location.

The resulting images were then compressed and decompressed using algorithms developed at MIT Lincoln Laboratory [2], to duplicate the image distortion that will be a part of the proposed delivery process. Note that apart from distortion due to the compression/decompression process, every effort was made to maintain the accuracy of the weather information. Figure 3-2 shows a section of raw image and the resulting sample weather images.

Geographic registration and time of day were unaltered from the WSI-supplied data. Finally, relevant navigation information was overlaid onto the image including a range ring, VOR (Very High Frequency Omni-directional Range) locations, and route of flight. The images were oriented North-up, centered on the specified geographic location. The navigation information was shown in white.

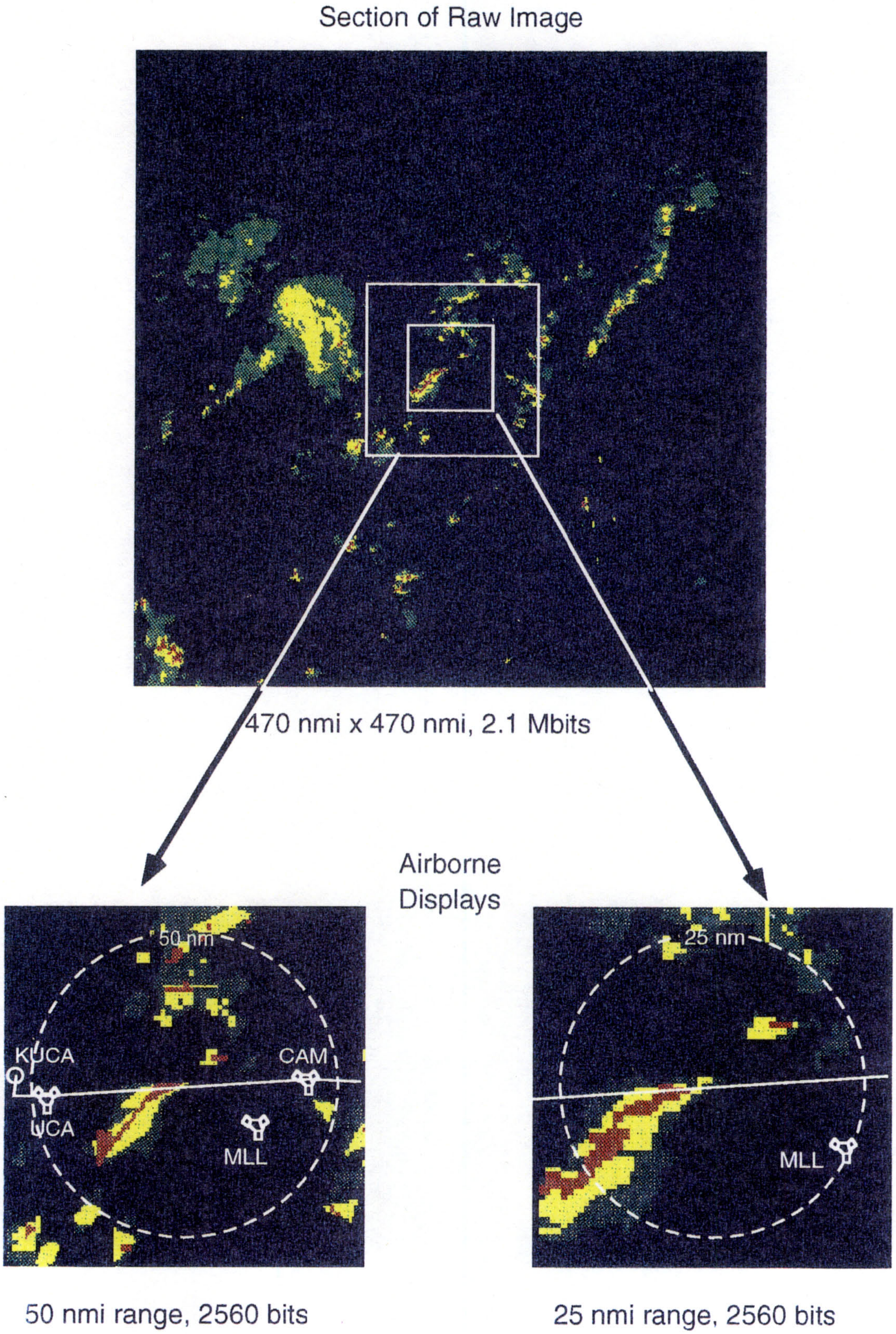


Figure 3-2 Section of raw image and processed sample weather images.

Existing radar systems cannot detect turbulence. However, there is a direct correlation between the degree of turbulence and other weather features associated with thunderstorms and the radar weather echo intensity. The National Weather Service has categorized radar weather echo intensity for precipitation into six levels. These levels are sometimes expressed during aviation communications as "VIP Level" 1 through 6 (derived from the component of the radar that produces the information, i.e., Video Integrator and Processor [3]). GWS uses three colors to depict the echo intensity levels, as follows:

Green (NWS VIP Level 1, weak precipitation)

Yellow (NWS VIP Level 2, moderate precipitation)

Red (NWS VIP Level 3 and above, strong to extreme precipitation)

It should be noted that the raw images prior to compression could contain as many as 524 kbits (for a 1024 km x 1024 km image with 2 km resolution and 3-level weather). Although extensive compression (as much as 50:1) necessarily degrades the images to some extent, and the degradation is a function of both the complexity and size of the image, it was not the function of the Phase One study to identify the direct effects of image degradation upon pilot decision-making. This issue will be addressed in later studies.

Since this study was designed to examine GWS for general aviation (GA), the space limitations of a typical GA panel were represented in the display. A color display was depicted within a 3" instrument hole. The hypothetical data link communications device was a Mode S transponder. The net effect of this equipage was to limit the active display area to a 2.3" square, and to require that images be compressed to less than 2560 bits for transmission. The bit limitation was designed to minimize data link loading; it is our eventual goal to demonstrate GWS with images compressed to less than 1280 bits.

Once the visual images were completed, scripts were prepared for each flight. These scripts were used by the experimenter who played the role of Air Traffic Control (ATC) and Flight Service Station/Flight Watch (FS/FW) personnel to insure that the replies to each subject's requests for information would be uniform across all subjects. The scripts included information that was considered likely to be requested. For example, at each decision point the current surface observation at the destination and the alternate were written out for quick access by the experimenter. In addition to the scripts, in case non-scripted information was requested, the experimenter had the full package of weather information on which the preflight weather briefing and scripts were based. This included the full set of radar images and all of the surface observations and pilot reports related to the time period pertinent to the flight.

3.2.3 Apparatus

Weather images were presented using a Hypercard™-based display on an Apple Macintosh™ computer with a color monitor. As mentioned earlier (Section 3.2.2 Stimulus), the weather image and instrument bezel shown on the Apple Macintosh™ computer were the same size as what is expected to be the display size that will be available for GA cockpit use.

Image selection was accomplished by selecting screen "buttons" corresponding to the desired location and range, and then clicking on "request image." The selected image appeared within 1-2 seconds. Even subjects with minimal computer experience had no problem using the system.

Figure 3-3 shows the display configuration seen by the subjects, including the range and location "buttons" that they would click on by use of a mouse.

A new set of images was made available to the subject pilot at each decision point. The measurement time of the ground image was also presented, to make pilots aware of how old the images were. In this study the images were typically between 2-15 minutes old.

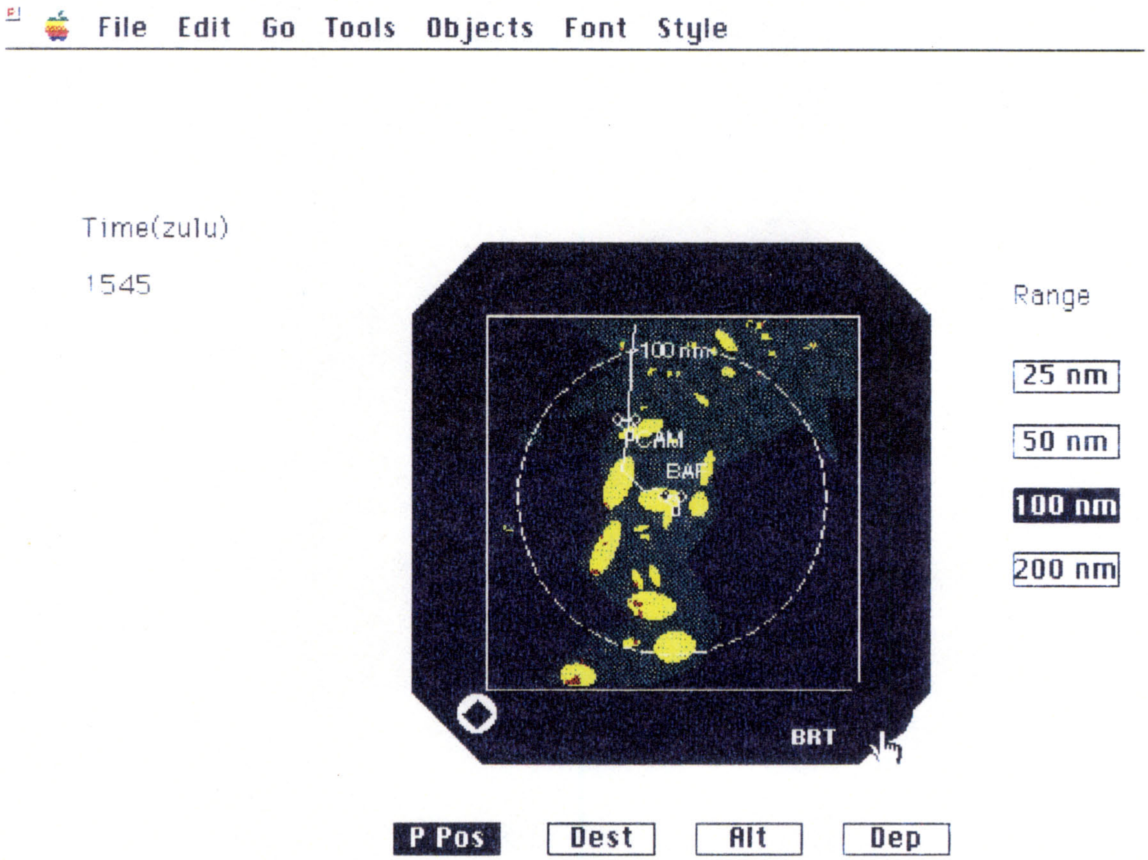


Figure 3-3 Weather image presented on Apple Macintosh™ screen.

3.3 PROCEDURE

The following two sections describe the training that subjects received prior to participation in the test flights and the procedures followed during testing. Subjects participated in five hypothetical flights, one for training, and four for data collection. The entire process took approximately four hours.

3.3.1 Training

Before participating in the Training Flight, subjects were briefed on the following: the purpose of the study, confidentiality of their responses, assumptions they should make regarding equipage and fuel in the hypothetical flights, information provided in the display and how to access it. In addition, they participated in a Training Flight, which provided an opportunity for subjects to become familiar with the type of Weather Briefing used in the study, obtain practice in using GWS, and feel comfortable with the procedures and types of questions that would be taken during data collection.

Appendix C contains a copy of the Subject Briefing. The experimenter did not read from the sheet but instead referred to it to ensure that all pertinent information and instructions were given to each subject.

Since the study was designed to examine GWS for general aviation, certain equipage constraints were assumed. As indicated in the Subject Briefing, the subjects were told that the hypothetical aircraft was a Cessna 172, with conventional IFR avionics including: dual navigation/communication radios, Distance Measuring Equipment (DME) and Automatic Direction Finder (ADF). The subjects were told that they had no weather avoidance equipment (e.g., radar or lightning detection) and to assume that the subject was accompanied by a non-pilot passenger, and started each flight with full fuel.

Subjects were provided with relevant pre-flight materials. For each flight the weather briefing portion of this package included: terminal and area forecasts, surface observations, PIREPs (Pilot Weather Reports), SIGMETs (Significant Meteorological Information), AIRMETs (Airmen's Meteorological Information), radar summary charts, surface analysis charts, weather depiction charts, and 12, 24, 36, and 48 hour prognostic charts. Since all of the provided information was actual recorded data, the quality and content of the data varied somewhat.

The subjects were provided with the following: a low altitude en route chart with the route of flight marked on it, an FAA flight plan, sectional chart, approach plates, airport/facilities directory, a Cessna-172 manual, a key to pilot PIREPs from Aviation Weather Services (A Supplement to Aviation Weather AC 00-6A) [4], a key to radar weather echo intensity levels and a key to aviation weather observations and forecasts from the Airman's Information Manual [3]. Subjects were also provided with a list of local reporting stations and their corresponding abbreviations. Reporting stations which were relevant to the flights were included from the full listing included in the publication "Local Identifiers" [5].

3.3.2 Flight Procedure

For each flight, a pre-flight interval was provided during which the subject could become familiar with the proposed route of flight and the weather conditions. When the subject said he was ready (which usually occurred within 15 to 20 minutes), the testing began.

At three times/decision points within each flight, the experimenters told the subject the aircraft position and altitude, described the current weather conditions in the immediate vicinity of the aircraft, and asked the subject "What will you do now?" The subject could respond immediately with a decision regarding the flight or before making his decision he could seek additional information using GWS (in the GWS Condition) or via queries to ATC or FSS personnel (in the GWS and No GWS Conditions). An experimenter, sitting in the room with the pilot, played the role of ATC and FS/FW.

Decision Point 1 was prior to take-off. The pilot was told the time and that "You are in the cockpit and have not yet started the engine. What will you do now?" If he had GWS for this particular flight, he was able to select images now. Whether or not he had GWS he was told that near the aircraft there was a telephone and he could get out and call for weather information if he so desired. If the pilot made a no-go decision he was told that his decision was noted and then he was asked to proceed with the flight for data collection purposes.

Decision Point 2 was en route. The pilot was told the time, his present position, and what he was experiencing, for example: "It is 1922 Zulu, you are over Gardner , MA VOR at 7,000 feet and are in Instrument Meteorological Conditions (IMC). The ride has been calm with occasional light chop. What will you do now?" In the GWS condition he could select images. In the GWS and no GWS condition he could use the radio and seek weather information from ATC and FS/FW.

Decision Point 3 was within 15 nmi of destination. The pilot was told the time, his present position, and what he was experiencing, for example: "It is 2000 Zulu, you are over Kennebunk, ME at 4,000 feet in light turbulence, rain and IMC." The ATIS (Automatic Terminal Information Service) was given. Then the pilot was asked "What will you do now?" The pilot's choices were the same at Decision Point 2.

4. DATA COLLECTION AND ANALYSIS

4.1 DATA COLLECTION

Subjects were asked to "think aloud" throughout the experimental sessions. Their verbal requests for information from ATC, FS/FW, their choices of GWS images, and their comments and actions taken at each decision point were recorded. The experimenter kept written note of these data. A tape recorder was used as back-up to insure that everything the subject said was recorded and considered in the data analysis. A series of questionnaires were used throughout the study to elicit subject response. All unsolicited comments were also recorded.

Both objective and subjective measures of effectiveness were made. Objective measures included: 1) Number of requests for weather information made to ATC and FS/FW, and 2) Action Taken. Subjective measures included: 1) Confidence ratings of pilot ability to assess the weather situation, 2) Ratings of perceived hazard of the weather situation, and 3) Ratings of GWS usefulness. These measures are described in Sections 4.1.1 and 4.1.2.

In addition to the above specified objective and subjective measures, experimenter observations and subject comments were recorded to provide information regarding how GWS was used. These data sources are discussed in Section 4.1.3. Section 4.1.4 describes the Exit Interview, in which subjects provided additional subjective information.

4.1.1 Objective Measures

1) Number of requests for weather information to ATC and FS/FW

The number of requests for weather information made by each subject at each decision point were recorded on a data sheet (see Appendix D) by the experimenter. This was selected as a measure of GWS effectiveness, since it is hypothesized that by having a graphical representation of weather in the cockpit the pilot may need to make fewer calls for weather information, thus reducing workload for both pilot and ATC, FS/FW personnel.

2) Action taken

The action taken by each subject at each decision point was recorded on the data sheet by the experimenter. Actions taken included go and no-go decisions and decisions to deviate or to proceed on course. This was selected as a measure of GWS effectiveness, since it is hypothesized that by having a graphical representation of weather in the cockpit the pilot's situational awareness will be increased and this will be reflected in the decisions made. It is expected that situational awareness will be increased since the pilot can see a picture of the weather rather than having to construct a mental image based on what he hears over the radio. The pilot with GWS can see weather information at present location or at remote sites and destinations.

4.1.2 Subjective Measures

1) Confidence ratings of pilot ability to assess the weather situation

At each decision point the subject completed the Decision Point Data Sheet (see Appendix E). After the subject was asked "What will you do now?" and his response recorded, he was then asked

"Given the information that you have now, how confident are you in your assessment of the weather situation?"

The subject was asked to rate his confidence on a scale of 1 (Not at all Confident) to 5 (Very Confident). To aid the experimenter in understanding the reasoning behind the subject's response, the Decision-Point Data Sheet included questions regarding what information influenced this decision and if the decision-making process was different when GWS was available?

2) Ratings of perceived hazard of the weather situation

After each flight (regardless of whether the subject had or did not have GWS for that particular flight), subjects were asked to rate the perceived hazard of the weather situation depicted throughout the flight (see Post-Flight Questionnaire, Appendix F). Subjects rated the level of hazard on a five point scale of 1 (Not at all hazardous) to 5 (Very hazardous).

3) Ratings of GWS usefulness

After each flight with GWS, subjects were asked to rate the usefulness of GWS throughout the flight. After each flight without GWS, subjects were asked if they thought that GWS would have been useful throughout the flight (see Post-Flight Questionnaire, Appendix F). Subjects rated the level of usefulness on a five point scale of 1 (Not at all useful) to 5 (Very useful).

4.1.3 How Pilots Used GWS

In addition to the two objective and three subjective measures of effectiveness described above, data provided by pilot comments and experimenter observations were collected. These data provided some insights into how pilots used GWS. Data were collected throughout the flights on how many images were requested at each decision point, the ranges requested, and whether or not GWS was used with other data sources.

4.1.4 Exit Interview

After participation in all the flights an Exit Interview (see Appendix G) was conducted. This provided information on how closely the weather briefings used in the study approximated actual weather briefings. It also gave subjects an opportunity to make additional comments on data link in general and GWS in particular. To measure pilot interest in GWS, subjects were asked if they would be willing to pay approximately $5,000 to equip their own aircraft for data link services.

4.2 DATA ANALYSIS

All the data collected were entered into a Microsoft Excel™ spread sheet program. Basic statistics such as means and standard deviations were calculated within Excel. Detailed statistical analyses were performed using the statistical data analysis program SPSS™.

The primary data requiring detailed statistical analysis, included: 1.) frequency of calls to a Flight Service Station/Flight Watch (FS/FW) and Air Traffic Control (ATC), and 2.) confidence ratings in the pilot's ability to assess the weather.

The frequency of calls was analyzed using the chi-square test. This test allows frequency data for two different variables to be tested for independence. The equation for calculation of the chi-square variable is:

$$\chi^2 = \sum \frac{(f_o - f_e)^2}{f_e}$$

where f_O is the observed frequency in that cell, for example the number of radio calls, and f_e is the expected frequency, if the variables are independent. Once the chi-square is calculated the value is looked up on a table to determine if the variables are independent, to a certain criterion of significance [6].

Before selecting the statistical procedure to be used in analyzing the confidence ratings, it was necessary to determine whether the data were normally or non-normally distributed. The use of t-test and analysis of variance (ANOVA) require the assumption that the observations are random samples from normal distributions with the same variance. Since the pilots selections were limited to five values on a scale, and the mean was often skewed to one side, the data were likely to be non-normal. This hypothesis was tested using the Kolmogorov-Smirnov test. This test determines whether data is normal or not, and provides a confidence value. The data were found to be non-normal. Consequently, a non-parametric test was chosen for the analysis.

The Wilcoxon Rank Sum test was selected. The test has an asymptotic relative efficiency of 96% compared to the t-test for normal data [7]. This means there is a modest loss in efficiency, as compared to the t-test. However, when the underlying distributions do not satisfy t-test assumptions, the Wilcoxon is often much more efficient than the t-test in detecting population differences.

The Wilcoxon Rank Sum test compares the ranking of the data from one variable to the ranking of the data from the other variable. It is analogous to the two sample t-test that determines if two samples are from the same population. For the Wilcoxon Rank Sum test the data are assembled in ranked order. The lowest value is given rank 1, while the next highest value is given rank 2, on up through the set of data. If there is a tie, then adjacent ranks are averaged. For example if the value for rank 5 and 6 both are 2, then they both get a rank of 5.5. The mean rank for a group is the average of the ranks that the group receives. Hypothetically, if the two groups are identical, each with 40 samples for example, then the ranks range from 1 to 80, and each should have a mean rank of 40. The difference between these means is then standardized by dividing by the standard deviation, and this statistic is used to find a P value for accepting or rejecting the null hypothesis [8].

5. RESULTS

Section 5.1 and Section 5.2, respectively, provide the results of the analysis of the objective and subjective measures listed above. Section 5.3 provides information from subject comments and experimenter observations regarding how subjects used GWS, including: the ranges they requested most frequently and how GWS was used as a decision-aid in conjunction with other information sources.

Section 5.4 provides the results of the Exit Interview, in which subjects made additional comments on data link services in general and GWS in particular. The interview also contained a question regarding whether or not subjects would be willing to equip their own aircraft for receipt of data link services.

5.1 RESULTS OF OBJECTIVE MEASURES

5.1.1 Information Requests to Air Traffic Control and FS/FW

To assess the effect of GWS vs No GWS on information requests to Air Traffic Control (ATC) and Flight Service / Flight Watch (FS/FW), the number of calls during all flights was summed. This resulted in a total of 33 calls in the GWS Condition and 79 calls in the No GWS Condition. A 4 by 4 chi-square was performed to assess the difference in frequency of calls and no calls to ATC and FS/FW for weather information in the GWS vs No GWS Conditions. The total number of potential calls for the flights is: 4 flights x 3 decision points x 20 subjects = 240. That is assuming one call per subject per decision point. Table 5-1 lists the number of information requests in each cell.

TABLE 5-1

Weather Information Requests to ATC and FS/FW for All Decision Points and All Flights Combined

		Experimental Condition		
		GWS	No GWS	Row Total
ATC & FS/FW Information Requests	No Calls	87	41	128
	Calls	33	79	112
	Column Total	120	120	240

Results indicate that less calls were made in the GWS Condition and that this difference in calls between the GWS and No GWS Condition was found to be highly significant, i.e., <.00001 (Pearson Value = 35.42, 1 df).

To assess whether the difference in confidence rating was significant at each decision point, a chi-square was performed for each decision. The difference was found to be significant at each decision point at the .02 or less level. This means that at each decision point there were fewer calls when GWS was used. Table 5-2 lists the number of calls and no calls made at each decision point, the Pearson Value, degrees of freedom (df), and significance level.

TABLE 5-2

Weather Information Requests to ATC and FS/FW for Each Decision Point, All Flights Combined

Decision Point	Calls With GWS	Calls Without GWS	Pearson Value	DF	Significance
1	15	31	13.09	1	.00030*
2	14	36	25.81	1	.00001*
3	4	12	5.0	1	.02535*

* If the probability value is .05 or less, the difference between the mean ranks is considered significant.

When fewer calls for weather information are made to ATC and FS/FW there are several benefits. Since GWS provides a graphical presentation of weather, the pilot does not have to query ATC or FS/FW about particulars on the exact location of cells and their intensity. This not only saves time for the pilot but it provides something that the radio cannot provide. Instead of having to listen, interpret, and construct a mental image of the situation, the pilot can see the situation graphically on GWS. Many of the subjects made comments to this effect. For example, "... graphically I can see the picture rather than having to concoct the picture in my brain from what I would hear. I could see how close the weather is."

GWS could also provide a benefit to ATC. The ATC workload could be reduced, since pilots may call ATC less often for weather information. In the future, GWS will provide other information, such as surface observations. Therefore, one would expect even fewer calls would need to be made to ATC.

To assess the effect of experience level, all calls during all flights with GWS were combined. This resulted in a total of 33 calls in the GWS Condition. Calls were then divided into groups by the experience level of the caller. Subjects in the Moderate Experience Group made 21 calls, while subjects in the Extensive Experience Group made 12 calls. A 4 by 4 chi-square was performed to assess the difference in frequency of calls and no calls in the Moderate vs Extensive Experience conditions. The total number of possible calls for the flights in which the subjects had GWS is: 2 flights x 3 decision points x 20 subjects = 120. Table 5-3 lists the number of calls in each cell.

TABLE 5-3

Weather Information Requests to ATC and FS/FW during GWS Condition All Decision Points and GWS Flights Combined by Experience Level

		Experience Level		
		Moderate	Extensive	Row Total
ATC & FS/FW Information Requests	No Calls	39	48	87
	Calls	21	12	33
	Column Total	60	60	120

Results indicate that fewer calls were made in the GWS Condition by the Extensive Experience pilots than the Moderate Experience pilots, i.e., 12 vs 21. However, the analysis did not find this difference to be significant at the .05 level. Significance was indicated as .065 (Pearson Value = 3.38, 1 df).

The inverse analysis was performed to assess if experience level made a difference in the number of calls when GWS was not used. Results indicate that less calls were made in the No GWS Condition by the Extensive Experience pilots than the Moderate Experience pilots, i.e., 36 vs 43. However, as in the GWS Condition, the analysis did not find this difference to be significant at the .05 level. Significance was indicated as .177 (Pearson Value = 1.81, 1 df).

5.1.2 Action Taken

All the actions taken at each decision point were examined. Regardless of experience level, differences in actions taken could be attributed to the presence of GWS. The number of decisions to deviate from the flight plan at each decision point is shown in Table 5-4. Asterisks indicate the four decision points at which there were noteworthy differences between cases with and without GWS. Following Table 5-4 the noteworthy differences in actions taken are discussed. Figure 5-1 shows a GWS image for each of the four decision points discussed.

TABLE 5-4

Decisions to Deviate from the Flight Plan

Flight Number	Decision Point	Deviations With GWS	Deviations Without GWS
1	1*	5 (no go)	9 (6 no go & 3 deviations)
	2	1	0
	3	0	0
2	1*	0	5
	2	1	1
	3	0	0
3	1	0	1
	2*	8	4
	3	3	3
4	1	5	5
	2*	10	10 (4 landed)
	3	0	0

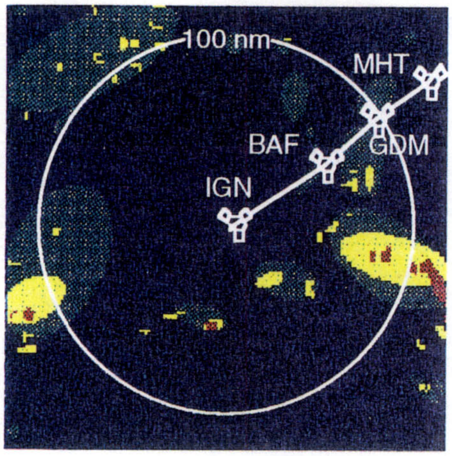
*Indicates decision point at which there were noteworthy differences between cases with and without GWS.

Flight 1 - Decision 1 / Prior to Take-off

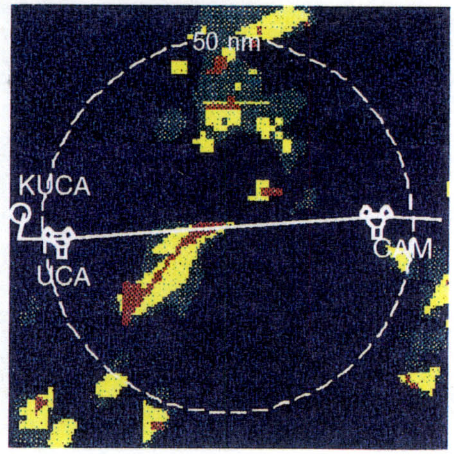
Five subjects with GWS decided to go on this flight and five decided not to go. Four subjects without GWS decided to go, and six decided not to go. Of the four who decided to go, three of them requested deviations.

The planned route of flight was parallel to a cold front. Subject comments indicated that with GWS the subjects were able to determine how close they were going to be to the front, while subjects without GWS were less sure of the present and impending location of the front.

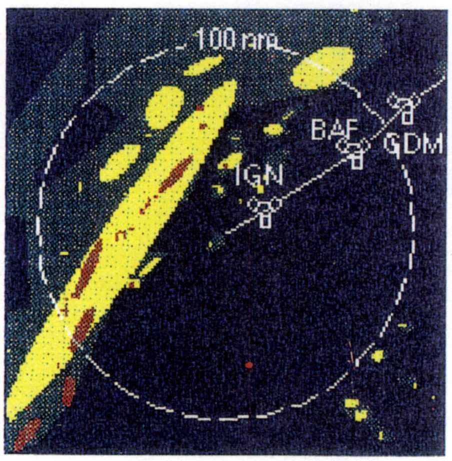
Two of the deviations made by subjects without GWS were made to "stay further ahead of the front." It is believed that the subjects made these deviations, because they did not have adequate information regarding the location of the front. Since they were uncertain of its location, they decided a deviation was necessary. The third subject without GWS who made a deviation requested a change in altitude, as the subject commented, "to keep me below the weather instead of in it". This again appears to be due to the subject being unsure of the location of the front. Figure 5-1, Image "a", shows a GWS image from this flight and decision point.



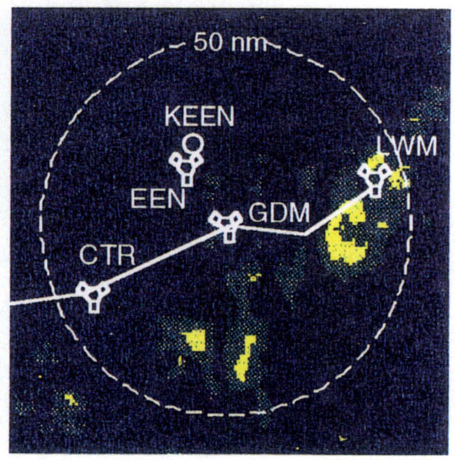
a) Flight 1, Prior to take-off.



b) Flight 2. Prior to take-off.



c) Flight 3. En route.



d) Flight 4. En route.

Figure 5-1 GWS images.

Flight 2 - Decision 1 / Prior to Take-off

All ten of the subjects with GWS decided to proceed with this flight, while only five of the subjects without GWS decided to proceed. A chance of embedded thunderstorms was forecast along the planned route of flight. In fact, no thunderstorms actually developed along the route of flight. This was clear by looking at GWS, but the subjects who did not have GWS were much more concerned by the forecast, and therefore concerned about what might develop later in the flight. Figure 5-1, Image "b", shows a GWS image from this flight and decision point.

Flight 3 - Decision 2/ En route

With GWS there were eight requests for deviations, while without GWS there were four requests for deviations. In this case the subjects were approaching a region of level 1 and 2 precipitation that was along their route of flight. Many of the subjects without GWS asked the Flight Service Station for radar information, then decided to continue.

By looking at GWS the subject could see that the region of precipitation was localized, and that by making a deviation the region could be easily avoided. Without GWS it was more difficult to create a good mental image of the exact extent of the weather, and the subjects were not wary of it, as one subject said, "I'm assuming that I will fly into this, but it's only level 2." Figure 5-1, Image "c", shows a GWS image from this flight and decision point.

Flight 4 - Decision 2 / En route

All twenty subjects deviated whether they had GWS or not. However, four of the subjects without GWS decided to land immediately, while all the subjects with GWS decided to continue the flight.

At this decision point the subjects were several miles from a large buildup that included level 5 precipitation along their route of flight. On GWS the region was red, indicating the presence of level 3 precipitation or above.

With GWS it was clear that this was the only significant region along the route of the flight. None of the subjects with GWS discussed landing at this point. The comments of the subjects without GWS indicated that they were uncertain whether there might be other large buildups in the area. Consequently, four of them decided to land, while a fifth subject considered this option but decided to continue the flight. In this case, GWS was providing additional information, beyond the immediate local area that the subjects with GWS could use in making their decision. Figure 5-1, Image "d", shows a GWS image from this flight and decision point.

5.2 RESULTS OF OBJECTIVE MEASURES

5.2.1 Confidence in Ability to Assess the Weather

To assess the effect of GWS vs No GWS, three separate Wilcoxon Rank Sum Tests were performed on the data from each decision point of all four flights combined. Results indicate that pilot confidence in ability to assess the weather was higher at each decision point when GWS was used.

This higher confidence was shown to be statistically significant for all three decision points. Table 5-5 provides the mean ranks of the two groups at each decision point, number of cases, z value, and the 2-tailed probability that the means are the same. For all decision points the P value indicated there was a significant difference.

TABLE 5-5

The Effect of GWS on Confidence in Ability to Assess the Weather

Decision Point 1

Experimental Condition	Mean Rank	Cases	Z	2-tailed P
GWS vs	49.67	40		
No GWS	31.33	40	-3.6523	.0003*

Decision Point 2

Experimental Condition	Mean Rank	Cases	Z	2-tailed P
GWS vs	48.0	40		
No GWS	33.0	40	-3.0076	.0026*

Decision Point 3

Experimental Condition	Mean Rank	Cases	Z	2-tailed P
GWS vs	48.89	40		
No GWS	32.11	40	-3.3725	.0007*

*If the probability value is .05 or less, the difference between the mean ranks is considered significant.

To assess the effects within and between Experience Level, a series of Wilcoxon Rank Sum Tests were performed. Figure 5-5 shows the 4 by 4 chi-square analysis matrix that was used for the analysis of the data from each decision point.

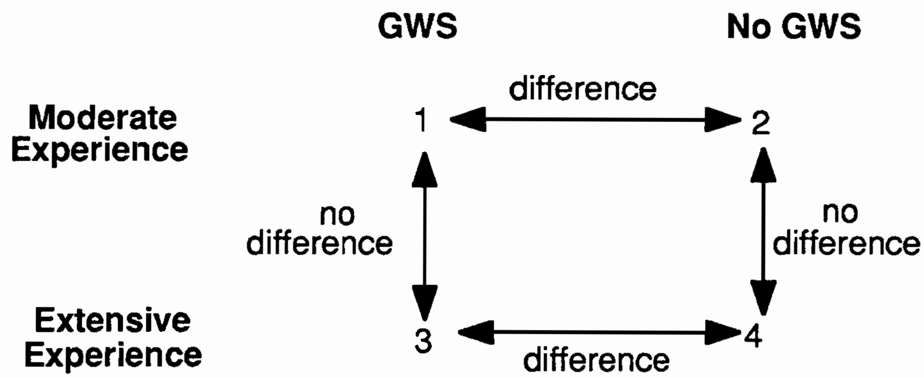


Figure 5-5 Analysis matrix for testing the effects within and between experience level for ratings of confidence in ability to assess the weather.

As seen in Figure 5-5, at each decision point a significant difference was found between cells 1 vs 2 and 3 vs 4. That is, regardless of experience level there is a significant difference in confidence ratings in the ability to assess the weather when subjects had GWS vs did not have GWS. Confidence ratings in the ability to assess the weather situation were significantly higher when subjects had GWS.

No significant difference was found between cells 1 vs 3 and 2 vs 4. That is, when subjects had GWS or did not have GWS, their experience level did not result in a significant difference in this rating. The important variable is the presence of GWS, regardless of experience level. It was found that subjects with a wide range of actual IFR experience reported a significantly increased level of confidence in their ability to assess the weather when they had GWS. Table 5-6 includes the results of the analysis of the effects within and between Experience Level for ratings of confidence in ability to assess the weather.

TABLE 5-6

Effects Within and Between Experience for Ratings of Confidence

Decision Point 1

Experimental Conditions	Mean Rank	Cases	Z	P
GWS / Moderate (1) vs No GWS / Moderate (2)	24.25 16.75	20 20	-2.1093	.0349*
GWS / Extensive (3) vs No GWS / Extensive (4)	25.88 15.13	20 20	-3.0690	.0021*
GWS / Moderate (1) vs GWS / Extensive (3)	21.15 19.85	20 20	-.3675	.7133
No GWS / Moderate (2) vs No GWS / Extensive (4)	22.98 18.02	20 20	-1.3865	.1656

Decision Point 2

Experimental Conditions	Mean Rank	Cases	Z	P
GWS / Moderate (1) vs No GWS / Moderate (2)	24.92 16.08	20 20	-2.5373	.0112*
GWS / Extensive (3) vs No GWS / Extensive (4)	24.05 16.95	20 20	-1.9977	.0458*
GWS / Moderate (1) vs GWS / Extensive (3)	22.45 18.55	20 20	-1.1004	.2711
No GWS / Moderate (2) vs No GWS / Extensive (4)	22.25 18.75	20 20	-.9997	.3175

Decision Point 3

Experimental Conditions	Mean Rank	Cases	Z	P
GWS / Moderate (1) vs No GWS / Moderate (2)	23.95 17.05	20 20	-1.9714	.0487*
GWS / Extensive (3) vs No GWS / Extensive (4)	25.40 15.06	20 20	-2.7575	.0058*
GWS / Moderate (1) vs GWS / Extensive (3)	19.73 21.27	20 20	-.4477	.6543
No GWS / Moderate (2) vs No GWS / Extensive (4)	22.20 18.80	20 20	-.9700	.3321

*If the probability value is .05 or less, the difference between the mean ranks is considered significant.

5.2.2 Ratings of Perceived Weather Hazard

After the completion of each flight, subjects rated the level of hazard that they perceived was present during that flight. They answered the following question, which was contained on the Post-Flight Questionnaire (Appendix F): How hazardous was the weather depicted in this flight scenario? Subjects were asked to give a rating from 1 (Not at all hazardous) to 5 (Very hazardous).

The subjects who could see the weather on GWS indicated a higher mean hazard rating than subjects who did not have GWS for the same flight. For the GWS Group the mean rating was 3.2, sd=1.2 and for the No GWS Group the mean rating was 2.8, sd = 1.3. A Wilcoxon Rank Sum Test was performed to test for the significance of the difference between the ranks of the two groups. Table 5-7 provides the mean ranks of the ratings of the two groups, number of cases, z value, and the 2-tailed probability that the means are the same. The difference was not found to be significant at the .05 level.

TABLE 5-7

Hazard Ratings GWS vs No GWS Condition

Experimental Condition	Mean Rank	Cases	Z	2-tailed P
GWS vs	44.76	40		
No GWS	36.24	40	-1.6729	.0943

A concern about providing graphical weather information in the cockpit is the fear that pilots may have more information about the weather and this might result in under-estimating the level of risk. Instead findings indicate that pilot perception of hazard does not change significantly when GWS is used.

5.2.3 Ratings of GWS Usefulness

In addition to the above discussed question regarding hazard, the Post-Flight questionnaire included the following: How useful was GWS throughout this flight? This was asked after flights in which the subjects had GWS. Subjects were asked to indicate their rating on the following scale:

1 ——— 2 ——— 3 ——— 4 ——— 5

Not at all Useful — Moderately Useful — Very Useful

Table 5-8 provides the mean ratings for each flight in the GWS Condition.

TABLE 5-8

Mean Ratings of GWS Usefulness

Flight Number	Mean Rating
1	4.4
2	3.6
3	4.1
4	4.8

GWS was rated as being more than moderately useful to very useful for each flight in which it was used. This overall opinion was substantiated by subject comments made throughout the study.

Following the flights in which the subjects did not have GWS, subjects were asked "Do you think that GWS would have been useful throughout this flight?" Subjects were asked to use the same rating scale as indicated above. The experimenters considered this to be a somewhat difficult question to answer, since the subject needed to imagine what GWS might have provided. However, subjects had no difficulty in commenting on the hypothetical useful of GWS, had GWS been available for the No GWS flights. Subjects indicated a mean rating of 3.8 for all four No GWS flights combined. That is, subjects felt that GWS would have been more than moderately useful if it had been available for the No GWS flights. Mean ratings for each flight ranged from 3.4 to 4.4.

5.3 HOW GWS WAS USED

Throughout the study subjects made comments regarding how they used GWS. The experimenter made note of all comments and analyzed the nature of their content. The experimenter also recorded all GWS selections made by the subjects to assess how the subjects used GWS. The following sub-sections provide results from these data sources.

5.3.1 GWS as a Decision Aid

A possible concern regarding the implementation of GWS is that pilots may use GWS as a sole source means of information and, therefore, base their decisions on GWS alone without consideration of other sources. Data obtained from subject comments and the observations of the experimenters indicate that GWS was not used as the sole source of information in making a decision. To the contrary, GWS was used to confirm, clarify, and augment information the pilots may have had from other sources.

Throughout the study the subjects obtained information from the sources listed in Table 5-9.

TABLE 5-9

Information Sources Available at Each Decision Point during the GWS Flights

Decision Point	Information Provided to All	Information Given on Request
1 / Prior to Take-off	Pre-flight Weather Briefing, View out the window	Weather from ATC, FS/FW, GWS images
2/ En route	Pre-flight Weather Briefing, View out the window, Ride Quality	Weather from ATC, FS/FW, GWS images
3/ Prior to Arrival	Pre-flight Weather Briefing, View out the window, Ride Quality, ATIS	Weather from ATC, FS/FW, GWS images

Subject comments indicate that GWS was used in conjunction with these sources. To illustrate this point, examples of comments that are representative of the majority of subjects who responded are listed below. After making a decision, subjects were asked "What information influenced this decision?" The following examples are from Flight 1, Decision Point 1:

> "Weather moving toward destination according to GWS and I initially knew this from the updated weather briefing from FS."
>
> "My decision is based on convective SIGMETs, briefing and GWS agrees there is thunderstorm activity."
>
> "From GWS and briefing I expect to get ahead of this stuff."
>
> "GWS confirmed the briefing information."
>
> "I have information from GWS and initial briefing."
>
> "A number of different sources are all confirming, all in agreement."
>
> "I see precipitation on GWS. Just looking at Weather Depiction Chart also gave me a good clue."
>
> "GWS backs up and shows nothing different from the other weather data I have."
>
> "Weather depicted on GWS and forecast weather."

5.3.2 Requests for GWS Images

As an indication of how pilots may use GWS when it is operational in the cockpit, the number of GWS images requested by the subjects was examined. It was felt that this would provide at least a crude estimate of how many images might be requested. The number of GWS images requested is pertinent when considering system demand and data loading. It would also give an indication of whether pilots might request more or less GWS images at any particular phase of flight.

It is expected that the number of GWS images selected during the study would exceed the number of GWS images selected in the same approximate time period and phase of flight during an actual flight. This is because these were hypothetical flights conducted in an office-setting, i.e., involving none of the workload of actual flight. In addition, in the study the subjects received the GWS images almost instantaneously, i.e., there were not delays to simulate the time needed for the request to be sent to the ground, processed, and then for the information to be sent to the aircraft. However, the mean number of requests for GWS images, as reported in Table 5-10 show that at any one time in our study the subjects requested no more than a mean of 4 GWS images and no less than a mean of 1.5.

TABLE 5 -10

Requests for Images

Time	Mean
Prior to Take-off	4.0
En route	2.5
Prior to Arrival	1.5

Note that at the beginning of the flight the subjects requested the most GWS images of the three decision times. Since they had the entire flight ahead of them, the subjects requested GWS images to assess the situation along the entire route of flight.

5.3.3 Requests for Ranges

Frequency counts were made for all range-requests made at each decision point for all subjects combined. Percentages were computed for requests for each range at each decision point. They are listed in Table 5-11.

TABLE 5-11

Percentage of Requests for Each Range at Each Decision Point (All Subjects Combined)

Time	25 nmi	50 nmi	100 nmi	200 nmi
Prior to Take-off	15.3	25.0	26.7	33.0
En route	26.6	50.5	17.4	5.5
Prior to Arrival	64.4	32.2	3.4	0

Each flight consisted of approximately 200 nmi. The selection of ranges at each decision point shows that at the beginning of the flight the subjects were concerned with and, therefore, tended to view the entire route of flight, i.e., anywhere from 25 nmi to the full 200 nmi of their present position. By Decision 3 they were close to destination and were, therefore, concerned only with the remaining route of flight, i.e., anywhere from 25 nmi to 50 nmi of their present position.

Subject range-requests were divided by experience level to assess whether pilot selection or range varied by the amount of pilot experience in actual IFR flying. Results indicated that regardless of experience level the most frequently requested ranges for each decision point remained the same.

Additional data were collected on range through subjects' responses to a question on the Exit Interview. They were asked: "What ranges did you find most useful and when?" In general, subjects stated that on departure 25 nmi or 50 nmi provided a good "local view" and that 200 nmi would show the entire route of flight for the flights in the study. Several subjects stated that they did not believe more than 200 nmi range would be needed. However, the subjects may have been referring to the needs one would encounter in a Cessna 172, flying flights similar in length to those used in our study. Pilots were not asked about the needs of: Cessna 172 pilots during flights to greater distances than used in the study, the needs of pilots in faster moving GA aircraft, and the needs of carrier pilots. To meet the needs of these three groups, GWS may need to provide additional long-range options, perhaps, 400 nmi, 800 nmi, 1600 nmi, and 3200 nmi.

A few subjects suggested some enhancements to the ranges. One subject said that at 50 nmi he would have wanted to see a topographical description on the screen, (i.e., the outline of a bay, islands, coastline, etc.) to enable the pilot to judge position. However, the subject cautioned us not to make the display too busy and overload the pilot with too much information.

Another subject suggested incorporating more range rings. He suggested, for example, that when viewing 50 nmi there should be bands for 10, 20, 30 and 40 nmi. He commented that the concentric circles would help him to know the size of the precipitation area and, therefore, aid him in deciding the distance to maintain between his aircraft and the precipitation area.

Three subjects mentioned that they would like a range that is less than 25 nmi for the approach phase. Two of these subjects suggested a 10 nmi range. However, the subjects were not aware that due to the size of the weather image obtained from WSI, a range of less than 25 nmi would not provide any additional detail. Therefore, there would be no benefit to a smaller range.

5.4 EXIT INTERVIEW RESULTS

Question 1 a. Was the pre-flight weather briefing similar in content to the briefing you would usually receive?

b. Please list any information you received that you usually do not receive.

c. Please list any information that was omitted.

Question 1 was asked in order to verify that the experiment replicated the level of detail and amount of information that pilots would normally have before a flight. All twenty subject-pilots responded "Yes" to this question.

Of the twenty subjects seven said that in the study they had more information than they usually would have, commenting that they usually have only text information or verbal information. They would not usually have the graphical depiction of weather that we provided in the radar summary charts and prognostic charts. One pilot commented that he usually gets Jeppersen Facsimile (JEPP FAX), which he said would give finer detail on the radar summary chart. (JEPP FAX is a commercially available weather service. Weather information is requested via phone and received via facsimile.) One subject said that he gets infrared satellite images that provide a sense of movement.

Question 2 How would you prefer receiving in-flight weather information?

1	2	3	4	5
Voice Communication Only		Equal Distribution of GWS & Voice Communication		GWS Only

Since this question was asked during the Exit Interview, the subjects were familiar with receiving in-flight weather information with and without the use of GWS. Figure 5-6 presents the distribution of the ratings. Following Figure 5-6, the comments made by the subjects in elaborating on their ratings are summarized.

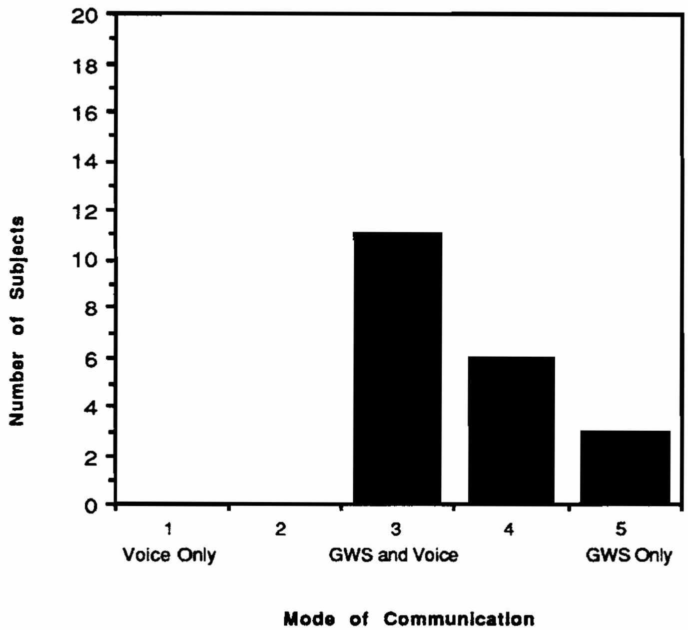


Figure 5-6 Subject preferences for receiving in-flight weather information.

Subject preference ranged from wanting an equal mix of GWS and voice communication to wanting GWS only. Subject comments to this question indicated that in general, they did not want to eliminate the weather information contact with ATC and FSS personnel. They saw GWS as a way to call ATC and FSS personnel less often, therefore, saving time and avoiding the process of having to construct a mental image based radio communication. In addition, subjects were concerned with errors resulting from misinterpretation of the spoken word. One subject commented: "I have misinterpreted the spoken word so many times. With the spoken word you can miss clearance information, and have to tie up the radio getting something clarified."

Subjects mentioned weather information that was not provided by GWS but could be provided over the radio. One subject said that voice would provide trend information. Two subjects mentioned needing voice to obtain surface observations. Although surface observations (text information) and trend information (showing motion) were not provided by GWS during this study, these products/enhancements may be included in future versions of GWS. The version shown in the experiment was a prototype.

Three subjects mentioned using GWS as a primary means of in-flight weather information and using voice as back-up if GWS equipment failed. One subject mentioned getting much of his in-flight weather information from party-line communications, i.e., other pilots talking with ATC regarding weather information. Throughout the study many of the subjects also made comments regarding receiving party-line information. Although party-line information was not included in this experiment, during actual use of GWS in the cockpit pilots would have the availability of party-line information.

Three subjects mentioned that over time, as they increased their experience with GWS, they would probably use it more frequently. Throughout the study, many of the subjects made similar comments regarding needing time to become familiar with GWS during actual flight, estimating that they would use it more and more frequently as they "trusted" the technology. Subject comments made throughout the study indicated that this trust would grow through hands-on experience and the proven reliability of the system.

Question 3 Data link can provide the general aviation community with services such as: graphical weather depiction, traffic information/collision avoidance information, and ATC clearances. Would you be willing to pay approximately $5,000 to equip your own aircraft for these services? (This cost includes transponder and color display.)

___ Yes ___ No ___ Undecided

If "No," why not:

Table 5-12 lists the distribution of responses. As seen, the vast majority of subjects said that they would purchase the equipage necessary for receipt of data link services.

TABLE 5-12

Subjects Willing to Purchase Data Link Equipage

Response	Number of Subjects
Yes	15
No	2
Undecided	3

The following is a summary of the comments made by the subjects, in elaborating on their "Yes" responses to purchasing the equipage. Regarding the cost, one subject asked if it could be $1,000 cheaper if it were available in monochrome rather than color. Another subject said that it would be worth the cost as long as it would not be maintenance intensive. One subject commented that the price tag is "a big chunk of change, but worth it." He said that the price would be acceptable as long as there were no re-occurring charges, i.e., fee for service. Another subject commented that storm scope is more expensive and that he would order GWS today.

All the subjects were informed of the multi-functional aspect of Data Link. As the question above indicated and as the subjects were verbally informed, data link could provide services in addition to GWS. For example, it could provide traffic information, ATC clearances, and pilot checklists. Four of the subjects made specific comments that indicated that an important part of making the decision to purchase the equipage was the availability of these other services.

The reasons given by the two subjects who said "No" they would not purchase the equipage were quite similar. They both indicated that expense and type of flying were the main factors in their decision. One of these two subjects did not own an aircraft and found it difficult to imagine whether he would purchase the equipage. He also stated that his type of flying (for recreation only) did not warrant the purchase, saying "It's worth it in commercial operation or if used for business." He added that if he had an aircraft used in "heavy traffic" that he would like having traffic information and that if he flew "a lot of IFR" that he would like having GWS. The other subject who said "No", based his response on the expense issue and stated that his recreational flying did not warrant the expense. However, he did say that if his business was flying commuters that he would want data link services.

There were three subjects who were "Undecided" regarding whether they would purchase the equipage. One subject had concerns that the time required to monitor the equipment would interfere with his basic pilot duties. He said that he would need more time to become familiar with the services to see if he would use them and could then make a purchase decision. One subject said he tended toward purchasing the equipage but was concerned with the expense and felt that he would have to investigate whether his money would be better spent in purchasing navigational equipment. The third subject who was undecided, did not own an aircraft and found it difficult to imagine whether he would purchase the equipage. In addition, all three of these subjects commented that they fly for recreation only and that if they flew on business they would be more likely to want to purchase the equipage.

Additional findings are available on pilot willingness to purchase the equipage necessary for receipt of data link services. This question was asked to a larger population of pilot. As part of the FAA's effort to inform the general aviation community of research that benefits GA, MIT Lincoln Laboratory demonstrated two data link applications at the Experimental Aircraft Association (EAA) Convention at the Wittman Regional Airfield in Oshkosh, Wisconsin from 31 July to 6 August 1992. Both GWS and the Traffic Information Service were demonstrated.

During that demonstration MIT Lincoln Laboratory staff briefed approximately 1,000 people on GWS and the Traffic Information Service. In addition to the briefings, staff handed out 254 surveys to active pilots in an attempt to assess pilot reaction to the proposed services [9]. The question regarding purchase of the equipage necessary for receipt of GWS was included in that survey. The survey was printed on a 5 x 7 self-addressed, stamped postcard. Pilots were asked to complete the survey and return it by mail.

The survey response rate was 23% (58 out of 254). Although the survey population was not randomly selected, it did include a diverse population of pilots. Analysis of the survey responses indicated that 54 out of the 55 respondents (98%) felt that GWS was useful, and that 38 out of 58 respondents (66%) would pay up to $5,000 for the equipage needed to obtain data link services that included GWS.

<u>Question 4</u> Any comments on data link in general?

Two of the twenty subjects had general comments regarding data link. One subject commented on being concerned with having to equip for Mode S. He said that it would be a financial burden if he had to equip. One subject questioned the availability of Mode S, asking how many are operational and when there will be more operational.

<u>Question 5</u> Any comments on the GWS in particular?

Seventeen of the twenty subjects responded. Their comments listed praise for GWS, suggested enhancements to GWS, or mentioned concerns about its use. Comments regarding enhancements and concerns are categorized and summarized below. The number of subjects who made a similar comment in response to this question is listed.

Timeliness of Information

-- Three subjects commented that they would like to have a 5 minute update rate.

It was explained to the subjects that, currently weather data are received by WSI every five minutes but to provide quality control by a meteorologist the image is not released until 15 minutes has elapsed. One of the subjects suggested that the image be updated every 5 minutes "as-is" but there be some indication to the pilot to convey the level of quality.

Display Issues

This category includes comments regarding the way in which information is displayed and what information is displayed, i.e., presentation and content.

-- One subject was concerned that he would think of GWS as a radar system and that he would not always be cognizant of the fact that the image could be up to 15 minutes old.

In the GWS implementation shown in the study, the time of each image appeared on the screen. In future versions of GWS the age of the image will appear. This should increase the pilot's awareness that this is not real-time data.

-- One subject commented that it would be helpful if GWS outlined Significant Meteorological Information (SIGMET) areas on an overlay on the radar image.

-- Regarding aircraft position on the display, one subject said that he wants the aircraft to be positioned at the edge of the screen its coming from and that he does not want to see the weather behind him. Two other subjects said they liked the aircraft-centered display so the pilot can see what is behind the aircraft in case they must reverse course to avoid weather.

-- One subject said that he would like GWS to show hail.

-- Three subjects said they would like to see lightning information on GWS.

-- Two subjects said they would like to have surface observations on GWS.

-- Three subjects said that they would like to see an indication of direction and speed of weather movement.

A question regarding future products to be included in GWS was not included in our Exit Interview. In hindsight such a question would have been very useful. However, from comments made by the subjects throughout the study, it is believed that the majority (if not all) of the subjects would desire the additional products suggested above.

Panel Space

-- One subject commented that he was concerned about the limited panel space and suggested that some lesser used instruments be incorporated into the GWS, for example, the auto-directional finder (ADF).

Accessing Information

-- Two subjects commented that GWS should save previously requested images so they would be readily accessible to be seen again if desired.

This will be a feature of GWS when it is used in the cockpit. Previously requested images will be stored and readily available for review by the pilot.

-- One subject said that he would like to have buttons for selecting information. Another subject said he prefers knobs, since he believes buttons are too difficult to press in bumpy conditions. He prefers grabbing onto a knob and holding it and turning it, stating that it is too easy to press a button in error.

The GWS interface is currently being developed. The cockpit environment will be a major consideration in this design.

-- One subject commented that he would like to receive weather information automatically as he neared his destination, rather than having to request it.

-- One subject commented that he would like to keep GWS running and get an automatic update every 15 minutes.

<u>Training</u>

-- One subject commented that GWS was easy to interpret and required very little training. (In addition, throughout the study subjects made comments indicating the ease of use and interpretation of GWS.)

-- One subject commented that training would be needed so pilots would be aware that they should not make their decisions based solely on what they are looking at on GWS.

As stated in Section 5.3.1, data obtained from subject comments and the observations of the experimenters indicate that GWS was not used as the sole source of information in making a decision. To the contrary, GWS was used to confirm, clarify, and augment information the pilots may have had from other sources.

6. CONCLUSIONS

As previously stated, the study was conducted to assess the effects of GWS on pilot decision-making. The results of the study provided answers to the following research questions:

1. Does GWS affect pilot actions, specifically, go / no go decisions, in-flight deviations, and calls weather dissemination personnel for weather information?
2. Does GWS affect pilot confidence in his ability to assess the weather situation?
3. Does GWS affect the pilot's perception of the level of hazard of a weather situation?
4. Do pilots find GWS to be useful?
5. How do pilots use GWS?
6. Is GWS cost-effective, i.e., do pilots believe that the utility of GWS warrants the financial cost?

In this section the results are summarized and their implications are discussed.

Action Taken

Results indicated that for all four flights pilots made noteworthy differences in the action taken/decision-making. When pilots could see the graphical depiction of the weather on GWS, their situational awareness was increased and they were able to make informed decisions on whether or not to embark on a flight. Once "in-flight" they were able to make informed decisions regarding the need for deviations. This was found for pilots with both moderate and extensive experience in actual instrument flight.

This finding has implications for both increasing safety and increasing the utility of aircraft. For example, subjects made numerous comments that part of the standard weather forecast during July and August (the time of the weather presented in our study) in New England (the geographic area in which our flights occurred) is the phrase "chance of thunderstorms." The subject-pilots voiced concern that pilots routinely either ignore this too-frequently-heard prediction or cancel a flight due to this prediction. In their opinion, GWS would greatly change this situation by increasing the pilot's situational awareness of the actual weather conditions. Situational awareness is defined by Endsley [10] as "the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future."

Requests for Weather Information to ATC and FS/FW

It was found that pilots made significantly fewer calls when they had GWS. As indicated in Section 5.1.1, this finding has implications for the reduced workload of both pilots and air traffic controllers. With GWS pilots have a graphical representation of the weather and, therefore, do not need to divert their attention from the tasks of flying in order to query ATC. From the point of view of the controller, with GWS in the cockpit the controller can concentrate his or her attention on the primary task of traffic management rather than playing the role of weather disseminator.

Confidence in Ability to Assess the Weather

It was found that pilots rated their confidence to be higher when they had GWS vs when they did not have GWS. This was found for pilots with both moderate and extensive experience in actual instrument flight.

Ratings of Perceived Weather Hazard

It was found that when pilots had GWS they indicated a higher mean hazard rating than pilots who did not have GWS for the same flight, although this difference was not found to be statistically significant. The implication of this finding is that although GWS increases the information that pilots have about the weather (including enhancing their mental image of the weather situation), this increased knowledge does not tend to alter their perception of the hazard inherent in flying in the specific weather conditions depicted. This finding may allay concerns that with more information the pilots may feel over-confident, minimize the risk-level inherent in a situation, and subsequently make imprudent decisions. As seen by the results of the measurement of perceived hazard and by the actions taken by the subject-pilots, when the pilots had GWS the perception of risk remained basically the same and GWS facilitated the pilots in making informed and prudent decisions.

Rating of GWS Usefulness

It was found by both the results of a subjective question on the Post-Flight Questionnaire and comments made by subjects throughout the study that GWS was considered to be more than moderately useful to very useful. Subjects reported using GWS in conjunction with information obtained from the pre-flight briefing, weather information from ATC and FS/FW, and experiential information, including, ride quality and view out the window. GWS was used to confirm, clarify, and augment these information sources.

Furthermore, regarding use of GWS it was found that at the beginning of a flight pilots viewed the entire route of flight (the hypothetical flights were approximately 200 nmi). In the actual in-cockpit implementation of GWS longer ranges may be provided to accommodate longer flight plans.

Cost Effectiveness of GWS

It was found that the majority of subject-pilots said that they believed the utility of data link services was well-worth the estimated $5,000 to equip an aircraft for receipt of services. Comments indicated that pilots were very interested in the multi-functional aspect of data link services. In addition to receiving the graphically depicted precipitation intensity information demonstrated in this study, they would be able to receive additional services as they became available, such as: text ATC clearances, text ATIS, other graphical weather products, and graphically depicted traffic information. Another issue related to cost was mentioned by several of the subjects. They were very glad to hear that once they had purchased the equipage for receipt of services, there would be no additional user fees.

APPENDIX A

SUBJECT RECRUITMENT ADVERTISEMENT

INSTRUMENT-RATED PILOTS NEEDED

to volunteer as subjects in the evaluation of a new air/ground data link service being developed by the FAA.

The Graphical Weather Service

will provide valuable real-time, ground-based, graphical weather to the general aviation pilot in the cockpit.

We need your help. M.I.T. LINCOLN LABORATORY is conducting a series of studies to help understand how pilots make weather-related decisions in-flight. We are scheduling pilots with single engine and/or light twin experience for Study 1 to be conducted this fall. Those who participate in Study 1 will be the first called for participation in Study 2 and 3 (yet to be scheduled). The three studies involve:

Study 1— a presentation of hypothetical instrument flights with a prototype graphics display depicting pre-recorded weather.
Study 2— a flight simulator and a dynamic display of pre-recorded weather.
Study 3— actual flight tests in a Cessna 172 and a dynamic display of live weather data.

PLACE: **M.I.T. LINCOLN LABORATORY, Bedford, MA**
TIME: **Participation in Study 1 will be scheduled at your convenience, during the months of November and December 1992. Study 1 will require five hours of your participation.**

To sign-up or for more information call by November 16

M.I.T. Lincoln Laboratory (617) 981-4390

APPENDIX B

THE GRAPHICAL WEATHER SERVICE
PILOT BACKGROUND QUESTIONNAIRE

Subject ID #: ______________ D.O.B: ___________ Date: _________

1. Years as a pilot _______

2. What type of aircraft do you usually fly? ____

3. License held (circle one): Private Commercial ATP

4. Ratings held (circle those that apply): Multi-Engine Instrument Sea Plane CFI CFII Helicopter Glider

5. Aircraft Experience (approx. hours): Single-Engine ___ Multi-Engine ___ Complex ___ Actual Instrument hours ____ Simulated Instrument hours ____

6. Please estimate for the past year: # of Instrument approaches flown _____ Actual Instrument hours ____ Simulated Instrument hours ____

7. During the past year, what percentage of your IFR time has been single pilot IFR? _______________

8. a. During the past year, what percentage of your intended IFR flights did you cancel due to weather? ____

b. Please describe the weather conditions that would cause you to cancel your IFR flight.

9. Please circle the number that indicates how often you piloted for the following reasons:

	never	occasionally	sometimes	usually	always
recreation	1	2	3	4	5
business	1	2	3	4	5
commuter	1	2	3	4	5
airline	1	2	3	4	5

10. a. During the past year, what has been your most frequent point of origin _____________ and destination ________________.

b. Please list some of your other destinations in the past year:

Subject ID #:_________

PILOT BACKGROUND QUESTIONNAIRE
Page 2

11. During the past year, what has been the approximate distance of your average IFR flight (in nmi)?_______

12. How familiar are you with flying in the New England Region?

1	2	3	4	5
Not at all Familiar	Somewhat Familiar	Moderately Familiar	More Than Moderately Familiar	Very Familiar

13. Navigational Equipment -- please circle those that are in the aircraft you usually fly:

VORs	NDBs	Loran (IFR certified)	LORAN (non-IFR certified)
GPS	RNAV	DME	Inertial Navigation

other (specify:___________)

14. Please list any weather detection equipment on board the aircraft you usually fly (for example, weather radar, Stormscope):

15. Have you had any training in weather interpretation other than basic pilot training (for example, courses in meteorology)? If yes, please explain.

16. Please circle the number that indicates how often you get your pre-flight weather briefing in the following ways:

	never	occasionally	sometimes	usually	always
over the phone from FSS personnel	1	2	3	4	5
in person from FSS personnel	1	2	3	4	5
DUAT	1	2	3	4	5
other computerized service (please name: ___________)	1	2	3	4	5
Weather FAX/Jepp FAX	1	2	3	4	5
other (please name: ___________)	1	2	3	4	5

THANK YOU

APPENDIX C

THE GRAPHICAL WEATHER SERVICE SUBJECT BRIEFING

Thank you for volunteering to participate in this study.

Background Questionnaire and Confidentiality

(Background Questionnaire and Consent Forms were mailed to the subject. Get them from the subject and read over to be sure that all responses are understood.)* Remember, all your responses are considered anonymous and confidential. We use ID number and not your name to identify all data sheets and questionnaires.

We ask that you do not discuss with other pilots the particulars of the flights. That pilot might be a future subject in our study and by discussing the flights you could affect his/her responses and jeopardize the validity of our results.

Subject Instructions

We are testing a system that provides ground based weather RADAR images to the GA pilot in the cockpit. We are going to go through a series of hypothetical flights. During this study you will not be flying a flight simulator. A future study will involve the use of a flight simulator. We will present information about these hypothetical flights and ask you to make decisions based on your assessment of the weather situation. The weather information you receive is actual recorded data. You are to use your best judgment in assessing the weather data you receive and in making decisions about your flight.

For each flight we will give you your flight plan and a weather briefing. We are not asking you to do extensive flight planning. We are interested in your in-flight decision-making as it relates to weather, and so we have done much of your pre-flight planning for you. In our hypothetical flights we give you information on time of arrival, route, and fuel on board. Please assume that these are correct. We are not asking you to check our flight planning calculations for errors.

There is no right or wrong answer. We are not testing your skills, we are looking at decision-making as it relates to weather and the use of the Graphical Weather Service (GWS).

In our hypothetical flights, it is important for you to reach the destination but it is not a matter of life or death. You should be concerned with getting to the given destination in a timely fashion, while maintaining flight safety.

The aircraft you are flying is a Cessna 172. The aircraft has two VOR receivers, one with RNAV. It has an ADF and does not have LORAN, Stormscope, or weather radar. It is equipped for ILS and has no autopilot or HSI. You are onboard with one non-pilot passenger.

In some of the flights you will be able to request information from GWS and during some flights you will not have this service. We will be demonstrating to you the information you can request and how to request it. We will be going through a Training Flight before starting data collection. That will give you time to ask any questions about the service and to feel comfortable with using it. It will also give you a chance to become familiar with our weather briefings and the questionnaires that we use in the study.

(Give Subject General Briefing Materials: Cessna Manual, L-chart, flight plotter, Key to Aviation Weather Observations, Key to Aviation Weather Forecasts, Book of Approach Plates, Sectionals, Airport/Facility Directory, paper and pen so the pilot can take notes, weather briefing for the Training Flight.)
These are provided for your information. Feel free to use or not use them, as you wish.

* () indicates that this is an instruction to the experimenter.

Training

We are going to go through a Training Flight so that you will:

become familiar with the Weather Briefings we use in the study
learn how to access information from GWS, and
learn our procedures and the types of questions that you will be asked.

Throughout the training, please feel free to ask any questions.

(Give Subject Packet for Flight 0 and explain the materials:
1. read through the Flight Plan,
2. show L-chart with highlighted route,
3. go through Weather Briefing and describe how it is laid out and decode the information as necessary.)

(Show images to the subject and explain how to access them:
1. range and location selections that can be made,
2. navigational information,
3. color coding used (show chart of intensities),
4. time of the image (the real time we will tell the subject, it is not depicted on the display,
5. what they see is not the final product -- pilot interface has not yet been developed.)

(The experimenter will set up the display for the desired time and location.) You may request images by first clicking on the desired scale and location -- Destination, En route, Departure, or Alternate -- and then clicking on the "Request Image" button. Your route of flight, and some navigational information is displayed over the weather. (Tell the subject what navigational information is depicted.) The range ring is labeled with the appropriate scale, in nautical miles.

Feel free to request as many images as you feel are useful.

(Give the subject time to review the materials and practice on the Macintosh.)

(When the subjects is ready, give him the test instructions that follow.)

For each flight we will tell you whether or not GWS will be available for that flight.

In this Training Flight GWS is available. For all the flights, there is a phone available at the airport so you may call FSS/Flight Watch, if you would like. Since GWS is available for this flight, you will be able to request images in the cockpit prior to take off and during the flight. Whether or not you request images is up to you.

During the flight you can use the radio and seek whatever weather information you normally would throughout a flight. When asking questions of ATC or FSS, please use the terminology you would use during an actual flight. Be specific in the questions you ask. We will answer your questions, but will not volunteer additional information.

When I ask you "What will you do now?", here are some of your options. You may seek information by using: the phone prior to the flight, your radio during the flight, GWS when available, or you may make a flight decision immediately. This is up to you.

At various times throughout the flight I will ask you some questions. Please answer them as if this were an actual flight. I would also like you to try to think out loud. Tell us what you are seeing in the GWS images. Tell us what you think based on the information you have received whether that information was from GWS or via radio. We are trying to learn about how pilots make decisions regarding weather. Anything that you can tell us is valuable information. When you select images and ranges on the Macintosh, say out loud what you are doing. I will be taking notes and tape recording your comments.

Sometimes we will put you into situations that you normally would not have gotten yourself into. Please tell us if you would have done something before this point and, therefore, would have avoided the situation we have placed you in. But given the situation, we will ask you what you would do at that point.

For the purpose of the study, at departure assume that you have received clearance, will fly runway heading, and have received radar vectors.

(Ask the subject if he has any questions. After answering questions, start reading the script of Flight 0/Training Flight. At each decision point remind the subject of the information that can be requested. If subject does not freely request images or verbal information, give examples of information that the subject could receive. Remember, this is a training flight and will not be used for data analysis. The purpose of the flight is familiarization only and, therefore, some prompting may be appropriate.)

Material needed by experimenter:

- Scripts for the flights
- Tape recorder
- Background Questionnaire, Subject Briefing, Data Sheet, Debriefing Questionnaire
- Full package of weather information, on which the preflight weather briefing and scripts were based.

APPENDIX D

THE GRAPHICAL WEATHER SERVICE INFORMATION REQUEST DATA SHEET

<u>Flight #:</u>
<u>Subject ID:</u>
<u>Date:</u>
<u>Condition:</u>
<u>Experimenter:</u>
(Note the sequence of the request.)

Decision 1 Recorder Time: _______to_______

Decision 2 Recorder Time: _______to_______

Decision 3 Recorder Time: _______to_______

APPENDIX E

THE GRAPHICAL WEATHER SERVICE DECISION-POINT DATA SHEET

Subject #: ___________ Flight #: _____ Decision #: ______ Interviewer: ___________

1) a. Given the information that you have now, how confident are you in your assessment of the weather situation? Indicate your amount of confidence by circling a number on the scale.

1 --------------------	2 --------------------	3 --------------------	4 --------------------	5
Not at all Confident	Somewhat Confident	Moderately Confident	More than Moderately Confident	Very Confident

b. What is this rating based on?

2) a. What action will you take now?

b. What information influenced this decision?

3) Is your decision-making process different when you have (or don't have) the Weather display? Please explain.

APPENDIX F

THE GRAPHICAL WEATHER SERVICE
POST-FLIGHT QUESTIONNAIRE

Subject #: ____________ Flight #: __________ Interviewer: ____________

FOR THE NO GWS FLIGHTS --

1. How hazardous was the weather depicted in this flight scenario?

1 ------------- 2 --------------- 3 --------------- 4 ---------------- 5
Not at all Hazardous — Moderately Hazardous — Very Hazardous

On what do you base this rating?

2. Do you think that GWS would have been useful throughout this flight?

1 ------------- 2 --------------- 3 ---------------4 --------------- 5
Not at all Useful — Moderately Useful — Very Useful

Please explain why:

3. Any other comments:

FOR THE GWS FLIGHTS --

1. How hazardous was the weather depicted in this flight scenario?

1 ------------- 2 --------------- 3 --------------- 4 ---------------- 5
Not at all Hazardous — Moderately Hazardous — Very Hazardous

On what do you base this rating?

2. How useful was the GWS throughout this flight?

1 ------------- 2 --------------- 3 ---------------4 --------------- 5
Not at all Useful — Moderately Useful — Very Useful

Please explain why:

3. Any other comments?

APPENDIX G

THE GRAPHICAL WEATHER SERVICE
EXIT INTERVIEW

Subject #: ____________ Date: __________ Interviewer: _________

1a. Was the pre-flight weather briefing similar in content to the briefing you would usually receive?
Yes _____ No _____

b. Please list any information you received that you usually do not receive.

c. Please list any information that was omitted.

2. How would you prefer receiving in-flight weather information?

1 ---------------- 2 ----------------	3 ---------------- 4 ----------------	5
Voice Communication Only	Equal Distribution of GWS & Voice Communication	GWS Only

3. Datalink can provide the General Aviation Community with services such as: graphical weather depiction, traffic information/collision avoidance information, and ATC clearances. Would you be willing to pay approximately $5,000 to equip your own aircraft for these services? (This cost includes transponder and color display.) ____ Yes _____No _____ Undecided
If "No," why not:

4. Any comments on datalink in general?

5. Any comments on the GWS in particular?

6. What ranges did you find most useful and when?

GLOSSARY

ADF	Automatic Direction Finder
AIRMETs	Airmen's Meteorological Information
ANOVA	analysis of variance
ATC	Air Traffic Control
ATIS	Automatic Terminal Information Service
ATP	Airline Transport Pilots
AWPG	Aviation Weather Products Generator
CDU	Control and Display Unit
DME	Distance Measuring Equipment
DUAT	Direct User Access Terminal
EAA	Experimental Aircraft Association
FAA	Federal Aviation Administration
FS/FW	Flight Service / Flight Watch
FSS	Flight Service Station
GA	General Aviation
GWS	Graphical Weather Service
IFR	Instrument Flight Rules
IMC	Instrument Meteorological Conditions
ITWS	Integrated Terminal Weather System
JEPP FAX	Jeppersen Facsmile
NWS	National Weather Service
PIREP	Pilot Weather Reports

SIGMET	Significant Meteorological Information
VIP	Video Integrator Processor
VOR	Very High Frequency Omni-directional Range
WSI	Weather Services International
WSR	Weather Service Radar

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