NASA/CR—2002-211903

NASA Aviation Safety Program Weather Accident Prevention/Weather Information Communications (WINCOMM)

Arthur Feinberg and James Tauss
Aviation Management Associates, Inc., Springfield, Virginia

October 2002
Since its founding, NASA has been dedicated to the advancement of aeronautics and space science. The NASA Scientific and Technical Information (STI) Program Office plays a key part in helping NASA maintain this important role.

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

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

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

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

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

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

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

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

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


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

- Fax your question to the NASA Access Help Desk at 301–621–0134

- Telephone the NASA Access Help Desk at 301–621–0390

- Write to: NASA Access Help Desk NASA Center for AeroSpace Information 7121 Standard Drive Hanover, MD 21076
NASA Aviation Safety Program Weather Accident Prevention/Weather Information Communications (WINCOMM)

Arthur Feinberg and James Tauss
Aviation Management Associates, Inc., Springfield, Virginia

Prepared under Contract C–77109–T

National Aeronautics and Space Administration
Glenn Research Center

October 2002
Executive Summary

Weather is a contributing factor in approximately 25-30% of general aviation accidents. The lack of timely, accurate and usable weather information to the general aviation pilot in the cockpit to enhance pilot situational awareness and improve pilot judgment remains a major impediment to improving aviation safety.

NASA Glenn Research Center (GRC) commissioned this 120 day weather datalink market survey to assess the technologies, infrastructure, products and services of commercial avionics systems being marketed to the general aviation community to address these longstanding safety concerns.

A market survey of companies providing or proposing to provide graphical weather information to the general aviation cockpit was conducted. Fifteen commercial companies were surveyed. These systems are characterized and evaluated in this report by availability, end-user pricing/cost, system constraints/limits and technical specifications. An analysis of market survey results and an evaluation of product offerings were made. In addition, recommendations to NASA for additional research and technology development investment have been made as a result of this survey to accelerate deployment of cockpit weather information systems for enhancing aviation safety.

A methodology for this market survey was initially established. Survey forms were prepared to insure consistent questions were asked of each vendor and appropriate information obtained.

Aviation Management Associates traveled to the annual Sun & Fun Air Show in Lakeland, Florida and the AOPA Fly-In at Frederick, Maryland to meet with vendors and General Aviation (GA) operators. Aviation Management also contacted aviation associations and others such as AOPA and NBAA, FAA, NASA Centers, MITRE and related industry groups. Additional meetings and phone conversations with commercial vendors were conducted to complete this market survey, assessment and recommendations.

The market survey confirmed that the number of GA operators currently using graphical weather products in the cockpit is small. Further, the commercial products being marketed are new and as yet have unsubstantiated marketing claims. It was concluded that graphical weather data links will achieve greater GA market acceptance as costs continue to decline. GA graphical weather data requirements, however, need to be better defined and standardized to maximize value to the GA user.

It is recommended that NASA conduct an R&D flight test and evaluation of representative commercial weather data link systems. Actual in-flight performance needs to be evaluated and measured against claims of usefulness and performance. It also appears there is a need for NASA to continue its research and development in optimizing weather data links based upon GA pilot weather requirements (both strategic and tactical) and validated through an in-flight evaluation program.

Additional recommendations for future NASA R&D efforts include investigating the utilization of the VHF VDL-3 data link and satellite digital radio service providers for providing graphical weather information to the GA cockpit. NASA should also participate with RTCA committees and the FAA in the Safe Flight 21 program including UAT data link evaluation. Test and evaluation of a hybrid satellite and ground-based weather data link architecture is a candidate for future NASA research and development as well.
# Table of Contents

Executive Summary: ........................................................................................................ iii  
Objective .......................................................................................................................... 1  
Background ................................................................................................................... 1  
Objectives in the Statement of Work .......................................................................... 4  
Products and Services .................................................................................................... 4  
System Constraints or Limitations .............................................................................. 5  
Technical Specifications ............................................................................................... 5  
Methodology .................................................................................................................. 7  
Information Gathering Methodology .......................................................................... 7  
Information Analysis Methodology ............................................................................. 9  
Vendor Descriptions – Marketing Highlights ............................................................... 11  
Surveyed Commercial Vendors ................................................................................... 11  
Analysis of General Aviation Graphical Weather Data Links ..................................... 27  
Background .................................................................................................................. 27  
Data Link Implementations .......................................................................................... 27  
  Comparison and Analysis of Airspace Coverage for Graphical Weather Providers .... 30  
  Analysis of Recurring and Nonrecurring Cost for Graphical Weather Providers ...... 30  
  Analysis of Avionics Displays including Size, Mounting Considerations, Portability, and Power ........................................................................................................ 32  
  Analysis of Display Functionality in addition to Weather Graphics ....................... 33  
  Analysis of Graphical Weather Products ................................................................ 34  
  Analysis of GA Weather Needs ............................................................................... 34  
  Weather Graphics Available to GA Pilots via Data Link ........................................... 36  
Conclusions ................................................................................................................... 39  
Weather Data Link Conclusions .................................................................................. 39  
Recommendations for Future NASA Research and Development (R&D) Efforts ........ 43  
  Recommendation I .................................................................................................. 43  
  Recommendation II ............................................................................................... 43  
  Recommendation III .............................................................................................. 44  
  Recommendation IV .............................................................................................. 44  
  Recommendation V ............................................................................................... 45  
Appendix One ............................................................................................................... 47  
  Vendor Survey ........................................................................................................ 47  
Appendix Two ............................................................................................................... 49  
  User Survey .......................................................................................................... 49  
Appendix Three .......................................................................................................... 51  
  References ............................................................................................................. 51  
Glossary ....................................................................................................................... 52  
Appendix Four ............................................................................................................. 55  
Appendix Five ............................................................................................................... 57
Objective

Background

General Aviation (GA) airplanes and operations encompass a wide range of aircraft types and applications. GA airplanes are operated in support of business and recreation, as well as everything from emergency medical evacuations to border patrols and fire fighting.

They are also used by individuals, companies, state governments, universities and other interests to quickly and efficiently reach the more than 5,000 small and rural communities in the United States that are not served by commercial airlines.

GA is the backbone of the nation’s air transportation system and can be a primary training ground for the commercial airline industry. It is also an industry that contributes positively to the nation’s economy. GA aircraft range from small, single-engine planes to mid-sized turboprops to the larger turbofans capable of flying non-stop from New York to Tokyo.

Improved safety of flight is critical for continued growth in this arena. In 1997, President Clinton called for an 80% reduction in the rate of fatal accidents by 2007 and a 90% reduction by 2017. In response to this goal, the National Aeronautics and Space Administration (NASA) Aeronautics Safety Investment Strategy Team (ASIST) defined technical objectives for an Aviation Safety Program (AvSP).

The AvSP, in partnership with industry and other Government agencies such as the Federal Aviation Administration (FAA), recognized that weather was a major contributor or factor in aviation incidents and accidents. This has been corroborated in several studies, such as FAA Safer Skies: Focused Safety Agenda [1], and others conducted by the National Transportation Safety Board (NTSB) [2], Aircraft Operators and Pilots Association (AOPA)[3], that concluded a significant percentage of delays, accidents, and fatalities incurred by GA aircraft are due to weather. For the period 1993 through 2000 weather was a direct cause or factor in approximately 24% of total GA accidents and approximately 30% of total GA fatalities (Table 1).

Table 1: NTSB GA Weather Accident Statistics, 1993-2000

<table>
<thead>
<tr>
<th>GA Accident Statistics 1993-2000</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Total Accidents</strong></td>
</tr>
<tr>
<td>24%</td>
</tr>
<tr>
<td><strong>Fatal Accidents</strong></td>
</tr>
<tr>
<td>32%</td>
</tr>
</tbody>
</table>

By building on the FAA’s National Airspace System (NAS) modernization plan, GA manufacturers have been busy developing new products that are anticipated to dramatically increase safety and efficiency of the current aviation system. Of all the future technologies that await the GA community, it is envisioned that the availability of improved weather information, such as textual and graphical products and forecasts, could provide the greatest safety benefit.
To achieve these benefits it is important to understand when, where, and for what purpose weather information is needed.

According to the FAA Office of System Safety, an analysis of the Aviation Safety Reporting System 2001 database revealed that the majority of incidents occurred in the en route or descent phase of flight. During these phases of flight there are numerous operational decisions made by the GA pilot as a result of weather. These include in-flight altitude, route or destination changes, as well as decisions affecting approach and landing. Changes in aircraft configuration and performance can also be driven by weather conditions.

According to the FAA’s Mission Need Statement for Aviation Weather, 2002 [4] and the FAA’s Concept of Use for Weather, Draft 2002 [5], that link weather phenomena to specific operational decisions, weather plays a preeminent role in pilots’ operational decisions in both a pre-flight and in-flight environment.

For example, icing, volcanic ash, non-convective turbulence, and cloud top information affects decisions for pre-flight route, or altitude. Unanticipated convective activity or convective activity that develops or moves faster or slower than forecasted can affect GA in-flight operational decisions (Figure 1). Approach and runway selection and are based on acceptable approach procedures that can be affected by cloud base conditions, visibility, crosswind component, and minimums both prior to flight as well as immediately prior to transitioning from the en route to arrival phase of flight.

Thus, the need for pre-flight and in-flight weather information to assist in making good operational decisions appears obvious. To make this a reality weather information collection, processing and dissemination systems must be in place and consistently perform with the highest levels of accuracy, availability, timeliness, reliability, and integrity.

The recent development and deployment of in-flight airborne weather systems demand that weather information providers, methods for up-linking data, and cockpit displays must meet these same high levels of system performance as required for traditional pre-flight systems.

NASA’s Weather Accident Prevention (WxAP) project under AvSP was formed to achieve several objectives to assist in the development of in-flight weather capabilities:

- Develop technologies to provide information to aviation decision-makers such as pilots, dispatch, and ATC. The Aviation Weather Information (AWIN) program was formed to address this objective.
• Develop standardized communication technologies to meet the first objective. The Weather Information Communications (WINCOMM) program was formed to address this objective.

• Provide on-board turbulence sensors for advanced warning.

• Define flight management systems to reduce effects of turbulence. The Turbulence Detection and Mitigation research programs were formed to address these two objectives.

The AWIN program element, centered at NASA Langley, performs research and development geared to decreasing accidents by improving weather information available to aviation users. The program is focused on human factors issues including the development of technologies that will lead to improved design and use of improved cockpit weather information via graphical displays of data linked weather products.

However, as good as the weather graphics may be, they are of no use to the GA pilot unless the information can make the trip to the cockpit. In this regard, the WINCOMM program element, centered at the Glen Research Center (GRC) in Cleveland, is geared towards the development of emerging communication technologies and supporting standards definitions, needed to satisfy weather informational needs in the cockpit.

How information reaches the cockpit is called data link and refers to the communication transmission between a service provider and the aviation cockpit while in-flight. Current techniques include ground-based and satellite-based architectures.

Ground-based architectures range from a nationwide cellular network using existing telecommunications tower infrastructures, to very high frequency (VHF) broadcast network using FAA provided spectrum, and a VHF network using the Aircraft Communications and Reporting System (ACARS) existing infrastructure.

Satellite-based architectures currently leverage Low Earth Orbiting (LEO) constellation networks. Planned architectures will use the Geosynchronous Earth Orbiting (GEO) satellite for broadcast dissemination of weather information.

How well these architectures perform in bringing timely weather graphics to the cockpit and what future data link technologies will be marketable to GA users is a topic of some debate.

For data link in particular, the constraints of bandwidth, sometimes expressed as a function of how fast data transmissions take place, capacity (the ability to add products), and coverage (the ability to receive information when and where it is needed), are major factors. Weather graphics can contain large amounts of data which make for huge file sizes and slow data transmission rates. The information is often quite perishable meaning that its value to the pilot for decision making diminishes with time.
With these constraints in mind, strategies for getting graphical weather products to the cockpit are still evolving. Of particular importance to the WINCOMM program is:

- **Information Throughput:** This refers to emerging communication technologies that will be able to improve delivery rate of weather information to the cockpit.

- **Communications System Capacity:** This refers to the development of technologies to enable anticipated communication system capacity.

- **User Connectivity:** This refers to an improvement in coverage and access to weather information in the cockpit.

### Objectives in the Statement of Work

Commercial avionic systems are being marketed to the GA community to address aviation safety and efficiency of flight concerns.

The NASA WINCOMM group has a critical interest in the availability and potential effectiveness of these commercial offerings in bringing graphical weather information to the cockpit to address GA pilot weather needs.

An assessment of data link technologies, infrastructure, and proposed weather products and services will facilitate the determination of technological maturity of the industry in order for the WINCOMM program to strategically plan for future research investment decisions.

### Products and Services

A market survey of companies currently providing or proposing to provide graphical weather information to the GA cockpit has been performed. The surveyed systems have been evaluated by the following factors:

#### Availability in the Market:

Several commercial offerings are currently available. This means that avionics can be ordered in the form of a turnkey system and various weather products can be received in the cockpit, usually on a subscription basis. FAA certification has been approved for installed equipment. FAA certification of avionics equipment is important since this ensures that minimum safety and performance standards for aircraft installed systems have been met.

Several commercial offerings are still in the planned or proposed stages. This generally means that strategic partnerships between avionics manufacturers and weather data providers are being formed. Avionics software to receive weather products and/or to transmit requests for products may be in development.

#### End-user pricing and cost:

Costs to receive weather graphics in the cockpit fall into two categories: Nonrecurring and recurring.

Nonrecurring costs apply to the one-time purchase of avionics equipment and refer to all hardware and software components required to create a turnkey “system” for weather graphics in the cockpit. Nonrecurring costs would also include installation. It is important to realize the costs of all required components of such a system in order to clearly understand what, if any, legacy equipage can be leveraged to display weather products. It is also important to understand what additional functionality can be performed or information displayed along with weather graphics to determine relative value to GA operational decision making over weather graphics alone.

Recurring costs generally refer to those occurring on a regular basis such as a monthly or yearly service or subscription for
graphical weather products. Over the course of a year or two, some service costs may not be trivial. This can occur if the GA pilot does not fly year round and monthly charges continue without product use. Additionally, costs can accumulate quickly if a cost-per-product arrangement has been made and the pilot either flies more often than planned or desires more frequent product updates than anticipated.

Others as Appropriate:

Maintenance and warranty are important for in-service upgrades for both avionics and weather service providers and overall manufacturer product or service liability and repair practices. Compatible functionality and interfacing between avionics manufacturers, suggesting open architecture capability, is important for equipage with legacy avionics and to realize broader acceptance between manufacturers.

System Constraints or Limitations

Aircraft Type:

It is important to realize the specific GA market commercial manufacturers are targeting and the types of GA aircraft that will be compatible with offered avionics hardware and software. This will address whether specific segments of the GA market are not being adequately served.

Electrical Requirements:

It is important to verify that GA aircraft electrical requirements can support offered weather avionics systems.

Mounting and Surface Area:

Physical aircraft mounting limitations for currently available or proposed avionics systems are important for compatibility in the GA cockpit and again, to determine market limitations. This includes panel display, antenna fuselage installations, cockpit controls, and processors.

Others as Appropriate:

It is important to survey all other GA aircraft system physical and electrical constraints to determine other limitations that may restrict market penetration.

Technical Specifications

Weather Data Sources:

A survey of commercial companies providing textual and graphical weather information to the GA cockpit is important to realize the kinds of products currently available and to compare offerings with regard to known or postulated GA weather requirements. This will identify all the major players providing weather data and will serve to determine if product content is congruent with pilot weather needs. Standardization of product and product content is important for collaborative decision making (CDM) or information parity, when applicable, between pilot and controller.

Resolution:

Resolution of weather graphics is important to determine overall weather graphic quality and to determine if all weather features important to the GA pilot can be adequately depicted.

Timeliness:

Timeliness of weather graphics to the cockpit is important. Weather information is perishable – its relative value towards enhancing GA safety diminishes greatly with time. Confidence in the product integrity can also diminish with time since some weather phenomena will have moved from valid time positions towards increasingly unknown positions. Further, with each passing minute the aircraft will have moved relative to the weather phenomena. This may lead to more reactive decision making and a compromise of safety.
**Display:**

Display characteristics such as brightness, heads up/heads down, clarity, size, colors, etc., generally fall into human factor considerations. However, human factors issues are not within the purview of this study. The displays of avionics vendors will be surveyed and compared but human factors considerations are addressed in other NASA initiatives.

**Delivery:**

The focus of this study is to survey and evaluate the methods used to data link weather graphics to the GA cockpit. As mentioned in the background section, various delivery architectures have emerged based on perceived GA weather product needs, technological abilities, strategic partnerships, market profiles and related business models for anticipated market penetration. It is important to understand advantages and disadvantages that each delivery architecture brings with regard to product, service, and technical metrics previously outlined as well as any technological constraints that may be preventing or hindering further market penetration.

**Others as appropriate:**

A survey of other technical specifications as appropriate will be performed to provide further technical understanding of commercial weather data link systems and services to make research investment recommendations to enhance GA safety. For example, product offerings will be evaluated in terms of expected or planned future technology trends and developments that could potentially benefit from additional research and development investments to accelerate deployment of cockpit weather information systems.
Methodology

There are three goals to this study. The first is to identify and survey commercial vendors and weather graphics service providers who currently provide or are planning to provide graphical weather to the GA cockpit. The second is to assess the maturity of the market with respect to various criteria such as data link technology, available avionics, cost, weather products, etc., towards the ability to satisfy GA weather needs and improve safety of flight. The third is to identify areas that could benefit from additional research and development technology investment.

Information Gathering Methodology

Identification of commercial vendors and users of graphical weather avionics was conducted by several methods including in-house knowledge, Internet searches, and interfacing with Government organizations (FAA, NASA). Also, reviews of professional publications (Aviation Week and Space Technology, Avionics, AOPA Pilot Magazine, Avionics News (AEA), etc.) were accomplished. In addition, professional organizations including Aircraft Electronics Association (AEA), Experimental Aircraft Association (EAA), National Business Aircraft Association (NBAA), General Aviation Manufacturers Association (GAMA), Aircraft Owners and Pilots Association, etc) were contacted. Meeting were also held with GA user groups (AOPA, NBAA, GAMA, AEA, etc.), and at GA user shows and conferences (Sun N Fun, AOPA Fly-in, etc).

The focus here was to identify the major players who had current capability to bring graphical weather to the cockpit or who had seemingly realistic plans to do so in the near future.

Identification of users was made through direct pilot contacts, vendor contacts, and avionics dealer lists.

The results of the identification task revealed that 15 commercial vendors had current or planned capabilities. These are:

- Aircell, Inc.
- ARNAV
- Avidyne
- ControlVision
- Echo Flight
- Flytimer
- Garmin
- Goodrich
- Honeywell Bendix/King.
- Jeppesen
- Rockwell Collins
- Satellite Technologies, Inc.
- Universal Avionics
- UPS Aviation
- WSI Corp.

With 15 major vendors comprising the marketplace, an interview-style approach as opposed to a mass mailing was used to conduct the survey. Further, due the available time to perform the survey, one major decision-maker from each company was identified to participate in the survey such as President/CEO, Lead Business Developer, GA Avionics Program Manager, etc.

Before the survey could be developed, it was essential to determine the intended use of the data towards addressing goals two and three, and to build into the design survey features such as focus and question type necessary to allow use in that way (Sonquist and Dunkelberg, 1977 [6]. Further, the most informative comparisons between different organizations working towards similar market goals can be revealed when the questions are standardized and highly focused. Finally, length of the survey was considered. Higher participant interest was envisioned if the questions were kept fairly short and to the point with overall question numbers kept reasonably low. This was especially valid for the user survey.
The information gathering methodology, shown in Figure 3, began with the development of questions derived from various sources to elicit answers that would satisfy study goals. These sources included knowledge of GA graphical weather needs, knowledge of data link communication architectures and protocols, study SOW requirements or goals, and perceptions from NASA.

GA graphical weather needs have been described in various sources such as the General Aviation Users' Forum, 1993 [7], National Aviation Weather Users' Forum, 1999[8], Mission Need Statement for Aviation Weather, #339, 2002, “Concept of Use for Weather”, 2002, as well as various other professional papers as referenced in Appendix 3. These references were used as guidance for weather product question development and overall background weather knowledge.

In-house knowledge of the SOW issues of interest were used to develop question type sections. These included background in the operational use of GA avionics, operational GA use of weather information, communication data link history and technical issues, and product installation, integration, and certification issues.

---

**Figure 3: Information Gathering Methodology**

---

**Figure 3: Information Gathering Methodology**
An additional source of input was perceptions provided from NASA including perceived level of product or service maturity and real in-service experiences with weather graphics vs. advertised capability. Survey questions were developed to validate or dispel these perceptions.

Questions were arranged by type including the broad categories:

- **Current or proposed product type** (name, description, H/W or S/W, transceiver, etc)
- **Display devices** such as Multi-Functional Display, lap-top, etc., and weather products offered such as radar and other graphics, text messages, etc.
- **Data link architectures** such as Cellular, VHF, satellite, etc., and considerations such as line of site issues, availability, etc.
- **Recurring and nonrecurring costs.**
- **Market penetration and customer feedback** from vendor provided sales and user survey comments.

This led to the development of two sets of highly focused questions; one applicable for the commercial vendor, and one for the user. The questions were designed to be open-ended or qualitative and not requiring yes or no answers. Questions that would tend to lead to proprietary-type answers were avoided. Each of these final survey forms is shown in the appendices.

Individual interviews were conducted with identified decision-makers. In many cases the person surveyed was able to review the questions beforehand. Most interviews were conducted in person while others were conducted on the phone. The questions were asked in an unbiased manner. Commercial vendors provided brochures and marketing materials describing avionics and graphical weather services. In some instances a review of the answers and accompanying brochures required follow-up questions to clarify the provided information. The vast majority of the commercial vendors were quite cooperative in participating in the survey.

Survey responses resulted in company facts, avionics product listing, graphical weather products and capability, cost and sales information. In addition, data link architecture and understood constraints, strategic partnerships, current focus including types of GA customers or aircraft and/or planned direction(s), opinions and attitudes regarding perceived market desires, expected (vendor provided) and actual (user provided) operational performance or experiences, and recommended Government initiatives for improved market penetration were also provided.

**Information Analysis Methodology**

An information analysis methodology was developed to summarize and distill the raw comments received from vendors and users (Figure 4). In order to determine technological constraints experienced by the vendors, a methodology was developed to compare system, service, and product offerings based on the data link architectures.

For example, it was envisioned that technological issues would be data link specific. Therefore, commercial vendors using like data link technologies were compared and contrasted against each other. Comparison of data link architectures in this way translates the information into quantified assessments of the data link maturity with regard to graphical weather products. From this assessment, recommendations for improved data link technologies can be made.
Information Analysis Methodology

![Diagram of Information Analysis Methodology]

Figure 4: Information Analysis Methodology
Vendor Descriptions–Marketing Highlights

The following section highlights each of the 15 surveyed commercial vendors from a marketing perspective and is not intended to serve as a detailed comparison. Such comparisons can be found in the Analysis section and the matrix table in the Appendix.

A "high-level" comparison matrix has also been included as an appendix to introduce the reader to the more salient considerations.

These vendor descriptions are, intended to introduce the reader to the companies who are currently providing or planning to provide graphical weather products to the cockpit.

The following company provided information is included:

- Company name, address, phone, and point of contact for business development or technical management.
- Products that bring graphical weather to the cockpit, their availability and data link architecture.
- A selection of features, including costs, emphasized in various marketing brochures and/or sales and technical literature. NOTE: Costs do not generally include installation unless otherwise noted.
- Photographs or diagrams of the product or data link architecture.
- A selection of considerations, both positive and negative, described either in the marketing literature or during the interview process with identified points of contact.

There are four major commercial vendors providing graphical weather data to the high-end GA market. These are Honeywell, Rockwell Collins, Teledyne, and Universal Avionics. Because the main focus of this market analysis was towards the pleasure and occasional, or low-end, GA user, commercial vendors targeting this market are only partially illustrated here and in the analysis.

Surveyed Commercial Vendors

- Aircell Inc
- ARNAV
- Avidyne
- ControlVision
- Echo Flight
- Flytimer
- Garmin
- Goodrich
- Honeywell Bendix/King
- Jeppesen
- Rockwell Collins
- Satellite Technologies, Inc
- Universal Avionics
- UPS Aviation
- Weather Services International
Product:
- Guardian 1000 transceiver @ $3,500
- DataComm 500 Transceiver @ $2,000
- AT.02 Transceiver @ $4,000
- AGT.02 Transceiver @ $8,000

Availability:
- All current except for DataComm 500

Weather Data Link:
- Ground-based Cellular Network
- Weather provider is Meteorologix

Features:
- Voice and Data/Graphics in air
- FAA-approved in-flight cellular telephone
- Dual certification: Up to 250kts for Guardian; Up to 600kts for AT.02
- Flight Guardian S/W displays NEXRAD images on MFD’s, EFB’s, and PDA’s
- Several rate plans from $9.95/month to $499.95/month depending on service (voice or data alone) and included minutes
- 1 and 2 year limited warranty

Considerations:
- Line of site constraints; Typically starts above 5K AGL
- Only pay for link when data transmitting (R/R by the minute)
- Flexibility to add more channels
- 20-25kbyte files download in about a minute
- 16 levels of reflectivity for NEXRAD products; 2km resolution
**Product:**
- Wx Link is a multi-mode, multi-frequency weather broadcast data link portion of the ARNAV Aeronautical Network (AAN)
- DR-100 receiver/antenna @$1,495
- SatPhone transceiver @$19,995
- MFD 5200 display @$6,000
- MFD ICDS display @$8,000

**Availability:**
- Satellite data link current; ARNAV network limited availability, FISDL not available

**Weather Data Link:**
- LEO Satellite
- VHF GMSK ground-based digital broadcast
- Weather provider is Meteorologix

**Features:**
- Voice and data via satellite; R/R
- FAA certified products
- Free weather text via FAA provided spectrum
- Premium weather graphics @$495/year
- VHF ground-based network uses a periodic broadcast technique; Plan to convert to VDL-Mode2 in 2004
- DR-100 receiver is compatible with several other manufacturer MFD’s

**Considerations:**
- Currently implementing VHF GMSK
- FAA and ARNAV not making any public statements on FISDL deployment; Web site indicates limited availability of weather products over ARNAV proprietary network only
- 4 levels of reflectivity on NEXRAD products; 64km resolution nationally, 8km resolution regionally
Product:
- FlightMax DX50 transceiver @ $2,950
- Weather graphics can be shown on all FlightMax MFD’s which range in price from the 850 series @ $17,950 to the 450 series @ $9,950

Availability:
- DX50 availability planned mid-late 2002

Weather Data Link:
- LEO satellite
- Weather provider TBD

Features:
- Bi-directional R/R via satellite
- All-altitude, CONUS data link coverage
- MFD can be stand-alone, mounted remotely, and VHF compatible
- Combination transceiver can interface with several technologies (i.e., GPS flight plan functionality, traffic, terrain, etc)
- $599/year (30 updates/month) or $349/year (10 updates/month) planned pricing
- 2-7 minutes typical response time

Considerations:
- Data only
- Weather provider not announced yet
- DX50 designed to interface only with FlightMax systems
- FAA certification planned
- Geared towards higher-end GA users
ControlVision
Box 596
Pittsburgh, KS 66762
(800) 292 1160
www.anywheremap.com
POC: Richard Herbst, Marketing Manager
(620) 231 6647
richard@anywheremap.com

Product:
- Anywhere Wx integrated GPS flight manager S/W @ $2,899 introductory package (inc. S/W, GlobalStar Phone, GPS receiver, PDA display, power pack, and Yoke Mount)
- Anywhere Wx with Aircell interface @ $1,295 ($1,995 with PDA but no other Aircell equipment included)

Availability:
- Current

Weather Data Link:
- LEO satellite
- Ground-based cellular network (Aircell)
- Weather provider is Meteorologix

Features:
- Satellite R/R data link service; Ground-based network data and voice
- Aircraft phone serves as a dialer and modem
- $30-110/month plus $1.49-1.69/minute for weather products; Rates dictated by number of free plan minutes
- 6 months of free upgrades then $115/year for 12 upgrades
- 6 month limited warranty for H/W
- Proprietary compression allows for NEXRAD display and METARS to be available in less than 1 minute from request

Considerations:
- Need Aircell Guardian transceiver @ $3,500 for Aircell service
- Communications line is dropped after 1 minute, Not IFR certified
- Need to purchase the moving map S/W
- 6 levels of reflectivity on NEXRAD products
Product:
- Echo Flight S/W and satellite transceiver communicator @ $1,795 (additional $180 for antenna)
- Flight Cheetah 270 MFD @ $5,995 turnkey package (inc. GPS and VHF antenna, S/W and transceiver)

Availability:
- Current

Weather Data Link:
- Orbcomm LEO
- Weather provider is Meteorologix

Features:
- RS-232 serial port allows for use on laptop loaded with Echo Flight S/W; S/W can be used on Garmin 400 and 500 series MFD’s
- MFD has modified display screen to reduce glare and improve brightness
- Subscription packages range from $9.95/month to $55/month plus $1 each access. Package deals available
- Composite NEXRAD, ceiling and visibility charts (graphical METARS), wind speed/direction, temp/dp spreads, METAR text (no TAFs)
- Compression and burst transmission mode technique (2.4Kbps uplink; 4.8Kbps downlink); 98% of requests within 20 minutes of receipt
- R/R only, however, download intervals can be set up to emulate periodic “broadcast”

Considerations:
- No FAA certification for Flight Cheetah since it is portable
- Flight Cheetah 180 (smaller, cheaper MFD) not available yet
- Potential signal availability/response time issues (not statistically proven)
- 4 levels of reflectivity on NEXRAD products
<table>
<thead>
<tr>
<th><strong>Product:</strong></th>
<th><strong>Features:</strong></th>
</tr>
</thead>
</table>
| • Transceiver-type with generic RS-232 connection; Interface to a MFD, Ipaq, or laptop  
• 3 offerings planned: Low-end @$2,500, mid @$4,500, high-end @$6,500 | • Developing an encoder to compress weather images over the slow network; 2.4Kbps up to plane  
• Recurring subscription costs TBD but “competitive”  
• STC certification for jets and twin-337; Anticipated for EFB  
• Anticipating TAMDAR probe to be integrated  
• Anticipated upgrade to VDL Mode2 with ACARS certification by late ‘02  
• “Auto-tunable” to fit into excess bandwidth |
| **Availability:**  
• Anticipated 4th quarter ‘02 |  |
| **Weather Data Link:**  
• ARINC/ACARS network  
• Weather provider TBD |  |

**Considerations:**  
• None determined
Garmin
1200 E. 151st. Street
Olathe, KS 66062
(913) 397 8200
www.garmin.com

POC: Scott Smith, Manager of Sales
(913) 397 8200

---

**Product:**
- GDL 49 data link transceiver @ $3,495

**Availability:**
- Current

**Weather Data Link:**
- LEO satellite
- Weather provider is Meteorlogix

**Features:**
- Graphical weather provided R/R via strategic partnership with Echo Flight with same features
- $9.95-55/month plus $1.00 each access; package deals available
- Level D certification
- 1 year limited warranty

---

**Considerations:**
- Requires Garmin 400 or 500 series MFD’s along with Echo Flight S/W and Orbcomm communicator
- 4 levels of reflectivity on NEXRAD products
Product:
- SmarkDeck integrated flight display

Availability:
- 2003

Weather Data Link:
- TBD; Looking at GEO satellite

Features:
- Working on eliminating subscription costs
- Nonrecurring cost of avionics TBD

Considerations:
- None determined
Honeywell Bendix/King
One Technology Center
23500 W. 105th Street, MD #45
Olathe, KS 66061-1950
(877) 712 2386
www.bendixking.com
POC: Gary Stuteville, Technical Program Manager
(913) 712 5545
gary.stuteville@honeywell.com

Product:
• KDR 510 VDL Mode 2 Data Link receiver @ $5,495

Availability:
• Current in areas where tower network completed

Weather Data Link:
• VHF VDL Mode 2 ground-based broadcast

Features:
• Broadcast weather instantly available
• Display shows age of products
• Text weather free; Value-added graphics @49.95/month to $89.95/month based on yearly subscription
• Requires MFD; Receiver, interface, antenna, and display “system” priced @ $7,460 for non-radar-equipped aircraft, and $12,406 for radar-equipped aircraft
• Improved reliability in product availability due to storage and buffering
• 2 year limited warranty

Considerations:
• Line of site constraints but available above 5,000 feet AGL as per FAA requirement
• Encryption for value-added products begins in 2003, otherwise currently free
• 4 levels of reflectivity for NEXRAD products; 4km resolution
• Only 50 out of 200+ towers currently implemented (June 2002)
Product:
- FlightMap interface S/W @ $499
- AirCell Phone cost TBD
- Tablet computer display device@ $4-6K

Availability:
- Current

Weather Data Link:
- Ground-Based Cellular Network via Aircell (Current)
- GEO Satellite via Satellite Technologies (Planned)

Features:
- FlightMap includes FlightStar Planning functionality
- Worldwide weather availability
- Unlimited downloads for about $20/month plus per minute call charges as applicable
- No certification issues as components are portable
- Priced for all aircraft and users
- 30-day money back guarantee for FlightMap

Considerations:
- Update subscription plans to Navigational and FlightMap data are available from 1x a year to every 28 days
- “In-Flight” S/W under development to be released with Satellite link; Cockpit optimized interface
- Looking to develop interface S/W for display onto other commercial MFD’s
- 16 level reflectivity on NEXRAD products, 2km resolution
### Product:
- VHF Radio 4000 @ $18K
- Communication Management Unit @ $25K
- Control Display Unit upgrade @ $10K or File Server Unit and Adaptive Flight Display (3010E) @ $40K

### Availability:
- Current

### Weather Data Link:
- ACARS ground-based commercial network; VDL Mode2
- Inmarsat satellite
- Weather provider is Universal Weather

### Features:
- Worldwide graphical weather products available over land or ocean; R/R
- Weather products from $500 – 1500/month
- High-end users; Compare functionality and costs with Universal Avionics, Honeywell (AFIS), and Teledyne systems
- 25Khz channels
- 31.5 Kbps
- Type certified for Challenger 601 by summer ‘03

### Considerations:
- VHF has line of site issues
- Pricing given is for business/region/jet configuration – not the more rugged ARINC 600 connection (Air Transport)
- Plan to be compatible with FIS-B
- Cost to equip is geared to high end General Aviation users only
Satellink Technologies, Inc.
21700 Atlantic Blvd.
Dulles, VA 20166
(703) 788 7010
www.satellinktech.com

POC: Harlan Hamlin, VP and GM of Aviation Services
(571) 238 5058
www.merlin.com

<table>
<thead>
<tr>
<th>Product:</th>
<th>Features:</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Merlin MA SK-1 receiver @ $3,500</td>
<td>• MA SK-1 FAA certification planned after production</td>
</tr>
<tr>
<td><strong>Availability:</strong></td>
<td>• Continual broadcast of weather graphics to be displayed on various MFD’s, EFB’s, PC-based moving map displays, or portable units</td>
</tr>
<tr>
<td>• Late summer 2002 planned launch</td>
<td>• Receiver cost includes 1 year of weather graphics; Otherwise $45/month unlimited access</td>
</tr>
<tr>
<td><strong>Weather Data Link:</strong></td>
<td>• TFR’s and Flight Explorer ASD</td>
</tr>
<tr>
<td>• GEO Satellite</td>
<td></td>
</tr>
<tr>
<td>• Weather provider to be Jeppesen</td>
<td></td>
</tr>
</tbody>
</table>

**Considerations:**
- 16 reflectivity level NEXRAD planned; 2km resolution
### Product:
- Unilink CMU modem @ $20K
- Unilink CMU transceiver @ $28K
- Flight Management System @ $35K

### Availability:
- Current

### Weather Data Link:
- ACARS ground-based commercial VHF network
- Inmarsat Satellite Communication
- Weather provider is Universal Weather

### Features:
- Worldwide graphical weather products available over land or ocean; R/R
- High-end users; Compare functionality and costs with Rockwell Collins, Teledyne, and Honeywell systems
- Unilink can support up to 3 FMS units

### Considerations:
- Cost to equip is geared to high end general Aviation users only
Product:
- Apollo MX-20 MFD @ $7,295
- Interface S/W TBD

Availability:
- Planned late summer 2002

Weather Data Link:
- Ground-based Cellular Network via Aircell
- GEO Satellite via Satellite Technologies
- Weather providers are Meteorologix (for Aircell) and Jeppesen (for Merlin)

Features:
- Various functionality supported on the MFD
- Large 6” diagonal, high resolution screen; Direct sunlight readability
- Monthly graphical weather costs TBD

Considerations:
- Cost for Merlin service/equipage likely to be higher
- Working with Bendix/King to develop FIS-B interface
### Weather Services International

**Address:**
4 Federal Street  
Billerica, MA 01821-3569  
(978) 670 5000  
[www.wsicorp.com](http://www.wsicorp.com)

**POC:** Keith Hoffler, Business Development Manager  
Mobile Weather Division  
(757) 865 1400 x221  
khoffler@wsi.com

---

<table>
<thead>
<tr>
<th><strong>Product:</strong></th>
<th><strong>Features:</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>• Pilot Weather Advisor Receiver $4,000-$5000</td>
<td>• Continual broadcast of weather graphics to be displayed on various MFD’s, EFB’s, PC-based moving map displays, or portable units</td>
</tr>
<tr>
<td><strong>Availability:</strong></td>
<td>• Less than $50/month for premium WSI graphics</td>
</tr>
<tr>
<td>• Late 2002</td>
<td>• Meets RTCA DO-267 standards for usability and interoperability</td>
</tr>
<tr>
<td><strong>Weather Data Link:</strong></td>
<td>• TFR’s, NOTAM’s, icing and turbulence graphics available</td>
</tr>
<tr>
<td>• GEO Satellite</td>
<td></td>
</tr>
<tr>
<td>• Weather provider is WSI</td>
<td></td>
</tr>
</tbody>
</table>

---

### Considerations:

- Sandia Aerospace to build and certify receiver; Planned to be appropriate for all aircraft
- 5 reflectivity levels on NEXRAD products, 2km resolution
- Uncertified receivers currently available

---

*Based on US Patent #5265024  
Nov. 23, 1993*
Analysis of General Aviation Graphical Weather Data Links

Background

There are many commercial offerings that provide various types of graphical weather information to the cockpit. One key aspect that differentiates these system implementations is the communication data link employed.

The choice of the communication link is a major factor determining the accuracy, availability, timeliness, reliability, and integrity of airborne delivered weather products. The communication link also affects recurring cost to the GA operator as well as drives the nature of the service provided from broadcast to request-reply for strategic weather planning to tactical weather response.

Communication systems being utilized or considered to provide graphical weather data to the cockpit include both ground-based and satellite data links.

Commercial ground-based systems include: cellular networks as implemented by AirCell, the ARINC VHF ACARS existing infrastructure as proposed by Flytimer, and the VHF broadcast networks as developed by Honeywell Bendix/King and ARNAV. Although not commercially available, the ground-based Universal Access Transceiver (UAT) developed by MITRE and implemented in the Alaska FAA Capstone program can also provide broadcast weather data from the ground to the cockpit.

Low Earth Orbiting (LEO) satellites systems such as Orbcomm are utilized by GA weather system vendors including Echo Flight and Avidyne with a request/reply data link implementation.

Geosynchronous satellites (GEO) will provide continuously updated broadcast weather information to GA operators with proposed systems from Satellite Technologies (Merlin) and WSI (PWA).

Data Link Implementations

Ground-based VHF Communications/FAA FISDL Program

The FAA has agreements with two companies, ARNAV Systems, Inc. and Honeywell Bendix/King, to provide operational FIS Data Link (FISDL) services. The FAA has provided each company with two VHF frequencies located between 136 and 137 Mhz and provides management oversight including standards guidance. In return at no cost to the FAA, ARNAV and Honeywell are separately implementing their FISDL ground-based infrastructure to provide weather text and graphic products within the continental U.S. Aviation weather text products are provided free with weather graphics available from Honeywell and ARNAV with a monthly recurring cost.

ARNAV currently utilizes a VHF Gaussian Minimum Shift Keying (GMSK) digital data link and has FCC license approval for more than 50 future site locations. Honeywell adopted the VHF VDL-2 digital data link using which is the same RTCA standard that ARINC is transitioning to.

Honeywell is operational today in the Eastern half of the U.S. with approximately 50 VHF transmitter sites (as of mid June, 2002) with 120 planned by the end of this year. Since VHF transmissions are generally line of site dependent, GA operators using FISDL generally need to be operating at 5,000 feet AGL in order to receive FISDL broadcasts reliably. FISDL products conform to FAA and NWS standards outlined in the FAA Aeronautical Information Manual.

Since FISDL is a broadcast service, GA operators can receive continuous weather
systems updates in the cockpit as long as they are operating in areas where service is currently available and flying at or above 5,000 feet AGL.

Graphical weather system updates are frequent limited by NEXRAD updates every five minutes especially in the Western U.S. where there is much less overlapping coverage. Service may not be available to the GA operator when on the ground, flying at low altitudes especially in departure or arrival areas, and or in mountainous terrain where VHF transmissions may be blocked especially at lower altitudes. Ground-based VHF transmitters can also be impacted by adverse weather when GA operators flying in the same area may need critical weather information.

**Ground-based VHF/ARINC ACARS Service**

Many of the same concerns for line of sight coverage for VHF transmissions also apply to using ARINC ACARS service by General Aviation. ARINC VHF coverage is generally very good at altitudes of 5,000 feet AGL and above. Since ACARS is a two-way data link, companies offering weather service such as proposed by Flytimer can implement a request/reply service. Charges then can be set on a per usage basis. Frequent weather system updates in the event of rapidly changing weather could generate significant cost and that could limit GA service utilization.

ARINC is in the process of transitioning to VDL-2 service with a higher 31.5 Kb/sec data rate that would be more efficient and have greater capacity than the current ACARS of 2.4 Kb/sec.

**Ground-based UAT Broadcast Service**

The MITRE developed Universal Access Transceiver (UAT) for the FAA Safe Flight 21 and Capstone programs is a two-way broadcast data link system. Uplinked FIS broadcasts from ground-based stations include continuously updated weather (METARs, TAF and NEXRAD) information. TFRs and SUAs may be available in the future. Approximately 30% of the uplink bandwidth is allocated to weather data broadcasts. The UAT operates at 978 Mhz and has been produced by UPS AT for the Alaska Capstone program (175 equipped aircraft and ten ground stations). Avidyne will build UATs for the SE Alaska Capstone program. There is no GA cost estimate for Capstone UAT service.

UAT has been successfully demonstrated in both Alaska and in the Ohio valley with air cargo carriers (UPS, FedEx, Airborne). RTCA SC-186 has recently approved UAT Minimum Operational Performance Standards (MOPS). National Telecommunications & Information Administration Stage 3 spectrum allocation approval is complete and the FAA has initiated a final Stage 4 action request. FAA has announced a link decision that is the UAT for low flying aircraft including most GA and 1090 Mhz primary for high flying aircraft which already are so equipped.

Preliminary results of limited aviation safety fatality data related to weather in Alaska indicate that the Capstone program and UAT equipped aircraft have seen a reduced accident rate to date. A large number of ground stations, however, would be required in the continental U.S. to provide these services especially to altitudes below 3,000 feet AGL and in terminal areas. That could require between 300 and 500 ground stations to achieve that coverage. FAA communication sites could be candidates for UAT sites. This approach would integrate several aviation services as desired by GA operators and AOPA.

**Cellular Communications**

AirCell provides voice and data communications to General Aviation through a nationwide cellular network. AirCell has installed transceivers and upward looking antennas on U.S. ground-
based cell phone towers. Service availability as with any cellular network may be dependent on specific geographical location as well as altitude. AirCell can provide antennas for aircraft installation to provide cellular phone service both on the ramp as well as airborne. A data/fax modem is required to receive weather data.

AirCell uses a request/reply system with airtime charges of about $2.00 per minute. Service plans available begin at $9.95 per month for data only services.

Nonrecurring equipment costs and aircraft installation are comparable to other service providers for operators who do not have AirCell service installed in their aircraft. GA operators may choose to limit their weather data updates knowing that there is a cost with each update. Frequent updates on a continuous basis should contribute more to aviation safety assuming the GA operator takes advantage of the weather information available. AirCell, however, can also provide cellular phone service.

**Low Earth Orbiting (LEO) Satellites**

Several weather data link service providers including Echo Flight and Avidyne are marketing systems that use LEO satellites such as Orbcomm. They use a request/reply implementation. Orbcomm has separate VHF uplink and downlink frequencies. Service charges are applied on an access basis. Weather data is received in approximately 2.5 minutes after a request is sent. Automatic weather updates can be programmed for regular intervals of every 15, 20 or 30 minutes as desired. Service packages are available with monthly charges priced according to usage rate.

Request/reply systems require aircraft onboard transceivers. VHF antennas required for aircraft installation for Orbcomm satellite data link are larger compared to L or X band antennas used by other service providers. Satellite coverage generally is good and reception is available down to the ground. GA operators may obtain weather service products over both land and water compared to physical limitations placed on ground-based transmitters.

The cost of having this capability in the GA cockpit, however, is directly related to frequency of usage. While that might be fine for the GA operator with limited needs, it may also be a disincentive to the higher usage operator who may restrict weather information requests with associated safety tradeoffs because of cost avoidance. Weather data must be current to be of value to GA.

**Geosynchronous (GEO) Satellites**

New offerings to be available this year to GA operators include continuous GEO satellite weather broadcast services. The Merlin system from Satellink Technologies and the Pilot Weather Advisor formerly a division of Vigyan Inc. and now part of WSI Inc. are currently marketing graphical weather services. A small low drag antenna installation is required along with a satellite receiver. Along with graphical weather displays, a variety of other data is anticipated over time including METARs, TAFs, NOTAMs, and PIREPs. Merlin advertises availability of TFR graphics and ATC delays with Flight Explorer’s FE InFlight service.

Since these services use satellite broadcasts, they are geographically available everywhere including on the ground or in the air. Weather data is updated frequently at approximately five minute intervals for a flat rate monthly fee. Availability and system reliability should be high since this is a receive only system and there is no large ground-based infrastructure to support. Current service providers do not have a significant user base at this time. This system approach, however, appears cost effective and is very promising for GA weather data link acceptance.
Comparison and Analysis of Airspace Coverage for Graphical Weather Providers

Ground and airspace coverage of graphical weather products for GA are constrained by the choice of the communication data link selected by the service provider and the network implementation status. A summary of geographical coverage for service providers is as follows:

Ground-based Cellular

AirCell is the communication service provider and offers aircraft antenna options for both airborne and ground communications. An AirCell data/fax modem is required to receive their graphical weather products. UPS Aviation Technologies, Control Vision and Jeppesen also offer weather to the cockpit via AirCell cellular communications. AirCell advertises nationwide coverage. As with any cellular system, some coverage gaps will exist depending on tower locations and terrain. With advertised connectivity to both ground-based and airborne cellular networks, aircraft altitude should not be as limiting a factor as it is with ground-based VHF systems.

Satellite Based

Graphical weather service providers utilizing communication links over either LEOs or GEOs generally have airspace coverage over the entire U.S. down to ground level.

Service providers using LEO satellites utilize a request/reply system. These include Echo Flight, Garmin, Avidyne, ARNAV and Control Vision. Echo Flight, Garmin and Avidyne use the Orbcomm satellites while ARNAV and Control Vision have agreements with the Global Star satellite network.

Merlin and PWA satellite broadcast services use GEO satellites. The Merlin service is also utilized by UPS Aviation Technologies.

Independent of the satellite weather service provider, system coverage will generally be better than with a ground-based network service provider. These performance parameters indicate hybrid systems using satellite broadcast for nationwide data and ground stations for local near real time weather data may provide the best overall weather system approach to meet general aviation weather needs.

Analysis of Recurring and Nonrecurring cost for Graphical Weather Providers

There is both a nonrecurring cost and a recurring cost to GA operators who want
graphical weather data in the cockpit. Some service providers will provide text products free of recurring charges such as Honeywell and ARNAV under the FISDL program. Recurring charges apply for graphical weather displays.

**Nonrecurring costs**

Graphical weather service provider system costs not including displays typically vary between $2,000.00 and $5,000.00 as detailed in the vendor matrix summary. This generally includes an FAA certified data link transceiver or receiver only, aircraft antenna and related interface controls. Aircraft installation can vary between 10 to 20 percent of the system equipment cost.

Portable electronic displays or certified installed aircraft avionics displays will generally cost between $5,000.00 and $15,000.00 depending on aircraft configuration, display size and functionality. Specific displays and associated costs are included in the vendor matrix in the Appendix. Low cost display options include laptop computers that may be awkward in the cockpit and PDAs, such as the Compaq IPAQ, that have small display size and may not be compatible with some service providers.

**Recurring Costs**

GA graphical weather service providers are generally competitive on subscription costs. Recurring costs can be differentiated between request/reply systems and continuous broadcast services. Specific monthly and/or annual plan costs are included in the vendor matrix summary. Service providers utilizing request/reply systems generally have a range of plans that vary as a function of the number of minutes or requests allocated per month. Plans start at $9.95/month and a $1.00 for each request. Broadcast services that provide continual updates have service plans that typically run from $40.00 to $50.00 per month.

**Nonrecurring Cost Analysis**

According to the NASA Langley and Embry-Riddle survey, “General Aviation Pilots’ Perceived Usage and Valuation of Aviation Weather Information Sources”, February 2002 [9], over 88% of the GA respondents were willing to pay under $5,000 for the in-flight weather system.

A study previously performed by Kauffmann and Pothanun from Old Dominion University, “Estimating the Rate of Technology Adaptation for Cockpit Weather Systems”, 2000 [10], revealed that the average acceptable cost for in-flight information systems on a moving map was just under $6,000.

In the Kauffmann study, the cost categories were more sensitive and were noted as a possible cause of the higher acceptance cost results. If a combined survey result of approximately $5,000 was used as a cut-off point for nonrecurring charges for in-flight weather information, then several of the surveyed commercial vendors have their current price-points too high for perceived successful market penetration.

For example, only the offerings from Aircell, ControlVision, and Jeppesen currently fall below this cost threshold assuming that the pilot does not have a MFD already in the cockpit. If such a display device already exists, and the pilot selects a vendor whose receiver and software are compatible, then several other offerings are under the cost threshold. The cost of the display device is, in most cases, the cost driver.

Survey results derived from the referenced NASA study showed that over 75% of respondents were unwilling to pay over $1,000/year for a weather graphics subscription service. The Old Dominion study deduced an average of just under $500/year or about $40/month. However, the respondents included avionics and
airframe manufacturers, and trade groups rather than individual end users.

In a subsequent study by Kauffmann, Sireli, and Ozan, 2001, “A Market Research Study for Future Weather Information Systems in General Aviation” [11], 70% of private and instrument-rated pilots expected recurring costs to be less than $2,000/year while 81% of recreational pilots expected recurring costs to be less than $500/year.

According to the results of these surveys, the recurring costs for commercial weather product offerings reviewed in this study are within cost thresholds.

The exception to this are those vendors currently providing weather graphics and avionics to the highest GA users. These vendors include the Teledyne Telelink, Universal Avionics Unilink, Honeywell AFIS, and Rockwell Collins IDC systems. However, these vendors are all competitive among themselves in the high-end markets they serve.

**Analysis of Request-Reply Versus Broadcast**

For some GA operators who want graphical weather and who may share an aircraft and/or fly infrequently, a request/reply system may be more cost effective. This statement is consistent with previous survey results where the desire to ‘pay by access’ was documented in the 2002 NASA and Embry-Riddle study. This study showed that over 40% of GA pilots surveyed preferred this method over a ‘pay by month’ (27%) or ‘pay by flight’ (17%).

The knowledge, however, that each update will either have an incremental cost or use up an allocated number of requests could inhibit some operators from obtaining weather updates or at least limiting their frequency. The time delay to receive an update could be significant especially if previously obtained weather data had aged considerably. This generally is not an issue with broadcast services where data is usually updated about every five minutes. It should be noted, however, that since request/reply systems have a two-way data link, non weather related air ground data communications can be requested and/or transmitted by the GA operator.

In reviewing in-flight aviation weather for general aviation it must be noted that there is an extensive two-way radio communication infrastructure in place to serve ground and airborne flight planning and weather information requirements. This infrastructure is the FAA’s Automated Flight Service Station (AFSS). Airborne communications are supported from the AFSS En route Flight Advisory (EFAS) position. While AFSS services have been invaluable to GA, there are nevertheless notable challenges that provide opportunities for the development of cockpit weather graphical display systems.

In summary, there is not a clear cut cost tradeoff between request/reply and broadcast. Some aircraft may already be configured with avionics that can be modified with minimal nonrecurring cost to obtain graphical weather data. Some GA operators who are not willing to pay for expensive MFDs may prefer to use their own portable display including Laptops or PDAs. The tradeoff between a broadcast service and a request/reply service may be related to how frequent the GA operator may fly, where he may fly and whether he flies VFR and/or IFR.

**Analysis of Avionics Displays including Size, Mounting Considerations, Portability, and Power**

In addition to cost, there are other considerations that can increase the usability of having graphical weather in the cockpit. These include the size of the device where the graphics are displayed, where in the cockpit is the display mounted, how is the display mounted, and electrical or power issues that are required. Some of
these considerations fall into human factors issues and will not be discussed at length here. A comparable analysis of current offerings, however, are addressed.

**Panel Mounted Display**

The majority of commercial vendors surveyed offered either their own panel-mounted type display device, usually designed to be mounted in the center of the instrument panel, or the ability to display on a similar device manufactured by another vendor. Most were MFD’s. Only Aircell, ControlVision, and Jeppesen current offerings were not compatible on panel-mounted MFD’s.

The preponderance of panel-mounted displays appears to be consistent with the Kauffmann, 2000 survey findings which found that approximately 2/3 of GA users surveyed preferred the weather display to either be integrated into current cockpit display systems or as a separate stand-alone panel mounted cockpit display.

These results were additionally consistent with Burt, et.al., 2000, “Impact of a Weather Information System Display on General Aviation Pilot Workload and Performance”[12], which concluded that pilots preferred the display mounted in the center of the instrument panel followed by the display mounted in the center of the control yoke.

Panel-mounted display devices were fairly comparable in size, shape, and power usage. Of the displays reviewed, most had a diagonal viewing area of approximately 4-6” with the largest being ARNAV’s ICDS 2000 and Avidyne’s EX5000 at a diagonal of over 10”.

Input power used for these displays generally falls in the range of 10-33 VDC. UPS Aviation Technology Apollo MX-20 draws 40 watts maximum and the ARNAV ICDS maximum input power is 50 watts.

**Non-Panel Mounted Display**

Echo Flight’s “Flight Cheetah” is the only portable MFD reviewed. It has a 6.4” diagonal screen and requires between 10-35 VDC. It is important to note, however, that the Garmin panel mounted 400 or 500 series will also display Echo Flight graphical weather products.

The Aircell and ControlVision offerings display weather graphics on IPAQ devices that use minimal power. However, screen size is considerably smaller than any of the MFD’s reviewed.

Jeppesen weather graphics are currently viewed on any Windows compatible laptop computer of which there are several manufacturers.

**Receiver/Transceiver**

There are several commercial offerings that require the purchase and mounting of receiver or transceiver hardware. The mounting can be temporary or permanent. In all cases the mounting can be horizontal or vertical.

Size of the equipage is also similar with most being approximately 7-9” long, 5-7” wide, and 1.5-3” high. Power requirements are similar – generally in the range of as little as 6 to a maximum of 32 VDC.

**Analysis of Display Functionality in addition to Weather Graphics**

There are several other technologies which bring information to the cockpit that are as or more important to the GA pilot for decision making. These include traffic, terrain, and moving maps that contain navigational information.

It has been suggested by informal surveys performed by AOPA that these kinds of information become more valuable for pilot decision making when combined with graphical weather over graphical weather...
alone. This has been more statistically proven by Kauffmann, 2000, which showed that over 60% of GA survey participants believe that the combination of moving map and GPS with graphical weather is a product success factor for the GA market segment.

Multi-Functional Displays

In almost all cases, the vendors surveyed had a current product offering or planned offering that allowed graphical weather products to be displayed with other valuable technologies.

For example, the Honeywell Bendix/King KDR 510 receiver allows for graphical weather to be displayed on the KMD 550 or 850 MFD’s along with traffic, terrain, position, moving map, and flight plan. The flight plan and traffic can be overlaid with graphical weather.

Additionally, if the aircraft is equipped with on-board radar, electrical discharge information can be overlaid with NEXRAD images. Terrain graphics cannot be overlaid with weather due to similarity of colors used for graphical weather.

ARNAV’s MFD 5200 can display graphical weather along with terrain information. Their Terrain Obstruction Proximity System (TOPS) icons indicate where terrain is in the path of the aircraft over the next 60 miles at the current aircraft altitude. The icons are the same color as strong reflectivity echoes so it is unclear what is depicted if strong reflectivity returns are directly over the terrain icons.

Echo Flight’s Flight Cheetah allows for overlay of graphical weather with other technology such as approach overlays and terrain alerts. It should be noted that the enhanced mapping functionality, which depicts terrain contours, is a better overlay than the terrain alert functionality with graphical weather due to different colors used. As with the Honeywell system, the terrain alert map uses similar colors to the reflectivity levels on NEXRAD products. The Flight Cheetah does not have traffic functionality at the current time.

Garmin 400 and 500 series MFD’s allow for overlay of graphical weather information. These include a dedicated weather only display, a separate moving map with weather and flight plan display, a traffic and weather display, and if the aircraft is equipped with a Goodrich Stormscope on-board radar, electrical discharge information can be overlaid as well.

ControlVision’s Anywhere WX offering allows for the overlay of graphical weather information onto a moving map display, flight plan, traffic, and terrain. However, the display used is the IPAQ and as such, the display size is considerably smaller than the average panel-mounted or Echo Flight portable MFD.

The Aircell offering only depicts graphical weather information by itself. There is no moving map so there is no proximity of weather to the current aircraft position information. Further, Aircell does not currently offer any other functionality to overlay with graphical weather.

Analysis of Graphical Weather Products

The objective section described several pilot decisions that can be affected by weather. Graphical weather product requirements should be defined in terms of these decisions so that product content, timeliness, and display characteristics can be of value to the GA pilot.

Analysis of GA Weather Needs

Part 91 weather related accident causes or factors statistics for 1989-1997 illustrate that winds have by far produced the most incidents at 43%. Incidents caused by visibility and ceilings produced 24%, turbulence 8.5%, precipitation and density altitude 6%, thunderstorm 2% and windshear 1%.
The study by Keel, et al., 2000 [13], showed that the need for specific weather information varies by phase of flight from en route to approach to landing. Thus, while all of these weather phenomena are important to the GA pilot, their relevance, or focus towards making operational decisions shifts by phase of flight. These include spatial or temporal factors, strategic or tactical use, and display characteristics.

For example, for en route operations, it is important for the pilot to have access to ceiling and visibility information along the flight path to determine if the flight will continue under VFR or IMC conditions. In the approach and landing phase of flight, short-term forecasts at destination airport(s) become important to determine an alternate airport if the destination airport is below minimums. In both cases, a cloud top and bottom graphic would assist in these types of decisions but the focus in both temporal and spatial factors would be vastly different.

In another example, wind information at flight level is critical for both IFR and VFR operations to determine fuel burn and potential to hold or reach the alternative airport. Approach and landing decisions would be more affected by low-level wind shear and crosswind component on the runway.

If flying IFR, icing information is very important en route to either stay above, below, or avoid altogether so that icing encounters are avoided. For landing decisions, surface icing information becomes important to determine breaking distances.

Convective activity along the intended flight path is important for re-routing. However, trend information for reflectivity mosaics, while of some relevance for ground-based strategic planning, tend to be less useful for more tactical pilot decision making (i.e., short-term (30 minutes) forecasted movement of reflectivity cells). This is because neither the future movement of convective cells nor storm growth and decay are linear in time and space. The pilot would find a short-term extrapolation of where cells are expected to be, along with cell strength, much more valuable towards a modification of flight route. In this case, advanced scientific algorithms will have taken much of the guesswork away from the pilot.

Operational decisions can also be affected by level of reflectivity. It can be argued that the 30DbZ reflectivity threshold can be used as a good indicator of the airspace changing from VFR to IFR conditions and the 40DbZ reflectivity threshold can be used as an indication of the onset of convection. If an additional reflectivity level for extreme convection is also shown, it can be concluded that for the GA pilot, the relative value of more than 3 or 4 reflectivity levels decreases quickly for aviation decision making.

PIREPs can also be quite useful for decision making but it must be understood that the same weather can and does affect different aircraft in different ways. Pilot experience will also influence a particular weather’s effect on operations. Lastly, the information contained in a PIREP can be ephemeral in both space and time, meaning highly perishable. A PIREP graphic that is an hour old will have limited value.

In the approach phase, the GA pilot will require similar kinds of information as in the en route phase but the display of the product must have a much higher glance value due to limited pilot attention. Products that have no interpretive aspects and are free of multiple colors, lines, or depictions become much more valuable.

In the landing phase, GA pilots will require a final update on runway winds, visibility (although as previously indicated, VFR pilots will make landing decisions based on ‘personal minimums’ and are not regulated by airport minimums), and surface icing for
braking considerations. During this phase of flight the availability of graphical weather products may have limited use due to other pilot duties required and the overall lack of time and attention available.

Other considerations that should not be overlooked are weather conditions such as temperature, humidity, wind speed and wind direction that directly effect aircraft performance. These are important pre-flight as well as in-flight considerations and can affect a variety or operational decisions such as determining aircraft service ceilings and acceptable takeoff and landing lengths.

In addition to aircraft performance factors weather considerations are also an issue of pilot convenience and comfort, especially for small general aviation aircraft without air conditioning, or without adequate cockpit heating. Turbulence remains a concern. For example, flying above summertime scattered clouds can be an enjoyable flying experience as opposed to below those same clouds in turbulent conditions.

**Weather Graphics Available to GA Pilots via Data Link**

Most of the graphical weather products currently offered to the GA pilot via data link are quite similar. They appear to have been driven by current data link technology and perceived GA pilot weather needs by commercial vendors. This is in contrast to graphical weather needs being driven by the operational decision-maker.

Graphical products include composite NEXRAD mosaics and graphical METARs. Some other commercial offerings provide other aviation graphics such as ceiling and visibility, icing, and turbulence charts from the Aviation Weather Center. These additional charts are already available to ground-based decision-makers for strategic planning. Further, making these products available to a greater potential market, such as GA pilots in the cockpit, serves these companies well as additional sources of income at little additional cost. However, the value of these products towards GA pilot decisions is quite limited at the expense of available limited bandwidth.

With regard to available graphics, Aircell and ControlVision currently only offer NEXRAD mosaics. The Aircell graphic is static, meaning that there is no moving map and the GA pilot does not necessarily know where the plane is with respect to the precipitation. The mosaic offers 16 levels of reflectivity at 2km resolution. However, as indicated earlier, 16 levels of reflectivity probably has limited additional value over 3 or 4 levels.

The NEXRAD composite shown with ControlVision’s Anywhere Map is depicted in 6 levels with 2km resolution. The difference here is that the reflectivity is shown on a moving map display and the pilot can see where the aircraft is with regard to potentially significant weather.

Echo Flight currently offers NEXRAD composites, ceiling and visibility, precipitation, wind speed and direction, temperature and dew point spreads, and graphical METARs. The NEXRAD product is shown in 4 levels (3 colors) and from 8km resolution for a national depiction to 2km resolution for regional depictions.

Garmin depicts similar weather products on their MFD’s as they receive weather information from Echo Flight. Garmin also provides electrical discharge information overlaid with NEXRAD graphics if the aircraft has a Goodrich Stormscope on-board radar.

The indication of electrical discharges enhances pilot awareness of convective activity and relative storm strength above and beyond simple depiction of 40 DbZ reflectivity contours. This can assist IFR pilots in making the widest avoidance possible from the convective activity. Additional value to the lower-end GA or VFR only pilot is much more limited as
these users would not likely be able to afford the relative expensive Stormscope equipage and the fact that they would not likely be flying in any vicinity of convective activity.

ARNAV premium graphical weather products, as available over their ARNAV proprietary network, include NEXRAD composite graphics, winds aloft graphics, significant weather report graphics including 3-D turbulence and icing graphics, graphical METARs, and National Convective Weather Forecast (NCWF) 1-hour products. The NEXRAD graphics are shown with 4 levels of reflectivity and a 64km resolution for national mosaic and 8km regional mosaic. The regional mosaic comprises the area within 150nm from the aircraft. NOTE: FISDL graphical weather products are to include the national and regional mosaics at the same resolutions mentioned, and graphical METARS. However, these are not currently available via FAA provided frequencies.

Honeywell Bendix/King graphical weather products include NEXRAD composite mosaics, graphical METARs, and lightning graphics. Both national and regional NEXRAD mosaics are depicted in 4 levels of reflectivity and 4km resolution. NEXRAD composite mosaic reflectivity animation is planned.

Jeppesen weather products include NEXRAD composite graphics with 16 levels of reflectivity and 2km resolution. Additional graphics are numerous and include winds aloft, significant weather prognostications, surface weather analysis, wind and temperature forecasts, etc. As indicated in the opening paragraphs of this section, these kinds of charts had limited value to GA pilots while en route. This is consistent with the results of the NASA and Embry-Riddle study.

Graphical weather products planned from other vendors not currently offering data link services are not evaluated in this section. However, a sampling of planned products are listed in the detailed matrix in the Appendix.
Conclusions

Weather Data Link Conclusions

Analysis of current and projected communication data links for providing graphical weather data to the cockpit indicates that a broadband satellite broadcast implementation is effective for timely, strategic GA flight planning. Ground-based broadcast service of local and/or airport terminal weather conditions could complement and/or enhance satellite broadcast service by providing more tactical GA flight planning information.

Aviation weather providers are now offering continuous broadcast services over GEO satellites channels with adequate bandwidth. Satellite digital radio service providers could also be candidates for satellite broadcast of aviation weather data. GEO satellite transmission time delays are not a factor for this type of GA advisory information.

Ground-based candidates for broadcast of local weather conditions include the recently FAA selected L band UAT data link and the VHF VDL-2/3 data links. Weather data transmission loads per RTCA documents [14] indicate that UAT and VHF data links will support local graphical weather services to the cockpit.

In order to facilitate accelerated GA acceptance of weather data links, weather information services must be provided in conjunction with other aviation communication services. These services could include ADS-B, TIS-B, voice communications, GPS moving map displays, and satellite-based navigation aids for en route and terminal navigation. These services need to be incorporated into multifunctional avionics to reduce weight, power and space requirements while limiting cost and taking into account human factors issues for GA pilots.

In addition to limiting nonrecurring avionics cost, recurring cost must be affordable to the low end GA community to achieve significant utilization. This could be accomplished if data link transmission costs are significantly reduced or eliminated for aviation users. Recurring subscription costs might then be based solely on charges for weather and aviation related flight products. This would require the Government to provide free aviation data communication data link transmissions in a similar manner to current FAA voice communication services.

Graphical Weather Product Conclusions

Weather needs for aviation have, in general, been derived in three ways. They have been derived by meteorologists or other non-aviation users, as opposed to NAS decision-makers, they have been derived by phase of flight, and they have been derived by technology that is currently available.

Unfortunately, each of these methods is flawed and has lead to the development of products that do not entirely satisfy the end user’s weather needs. It is becoming more understood that aviation weather needs are derived by operational decision making and the kinds of weather, product content and focus, and display characteristics that affect those decisions.

Weather needs derived by non-users will invariably not be satisfactory because of their lack of operational understanding that is required to develop valuable aviation focused weather products. Many aviation products contain far too much information than is necessary for aviation operational decision-making. NEXRAD mosaics that contain 16 levels of reflectivity are a good example of this.
Weather needs derived by phase of flight is only partially satisfactory. While an understanding of the kinds of weather that affect operations during specific phases of flight will be revealed, and is important, a breakdown of this methodology occurs when it is realized that the same operational decisions can be made in different phases of flight. For example, while en route, encountered windshear activity that has not been forecasted can cause a change in route or altitude. However, windshear encountered in the approach or landing phase of flight may cause an escape decision. In other words, the GA pilot will have different “options” depending on the phase of flight when aviation-impacting weather is encountered. This leads to the need for similar products but with differing focus. As mentioned in the analysis section, focus can change for strategic or tactical use, spatial and temporal extent, or display characteristics.

If technology is allowed to drive weather needs, satisfaction of that need may never be achieved. For this reason it is important to separate weather needs from weather requirements. Weather needs should be derived based on operational decisions, not technology (solutions). As long as operational missions do not change, properly defined weather needs will not change. Once understood what weather and appropriate characteristics (focus) affect operational decisions, technological solutions can then be evaluated towards satisfying those needs. These solutions become the weather requirements. Weather requirements can change with time as technologies improve. Concepts of Operations are classic examples of how perceived improvements in technology will better satisfy user needs at specific future points in time.

For this particular study, the assessment of data link technologies for bringing graphical weather to the GA cockpit appears to be technology driven, not user driven. In order to properly assess data link solutions, GA graphical weather needs must be defined first. Because such needs have not been validated, commercial providers have no way of knowing what products or product characteristics to provide to the cockpit.

Currently, GA graphical weather needs do not appear to have been well defined or validated. Where there have been attempts to do so, the methodology may have been flawed. By focusing on GA user operational decisions, specific graphical weather needs can be identified.

For example, specific graphical weather needs may include a particular set of products required for decision making. Some of these products may be required during all phases of flight while some others may not. Some may require much bandwidth. Others may require less bandwidth but need to be extremely timely, perhaps every 30 seconds. While en route, operational decision making may be satisfied by requesting graphical weather product updates only when deemed necessary. When making approach or landing decisions, perhaps the pilot will not have time to request graphical weather products. In this case, a continuous broadcast may be necessary and, suffice to say, availability below 5,000 feet AGL is obvious.

While not a driver for specific data link technologies, an important factor to maximize the value of graphical weather to the GA user is specific product characteristics and how they may change based on decisions made during each phase of flight. This includes product resolution, accuracy, display, and integrity. GA operational thresholds also need to be considered in order to determine certain product characteristics. A good example of this was mentioned earlier regarding the number of reflectivity levels depicted in a composite mosaic.

Where resolution and accuracy will certainly change as the pilot moves from the en route phase to approach. For example, a resolution
of 2 or 4 km for convective cells may be quite satisfactory while en route. This can be driven by the expectation that reasonably precise navigation allows for a 2–3 mile lateral deviation from filed flight path. However, lateral deviations decrease significantly in the approach phase of flight. Resolutions of 1 km or less for convective cells may be necessary for operational decision making.

Integrity can be defined as the minimum percent of validation (for whatever product characteristics apply) that the decision maker will accept before using the product “with confidence”. To this end, a forecast product that projects convective activity 2 hours in the future, with a certain resolution and accuracy, may have an integrity of 70%. This means the convective activity within this resolution and accuracy will be valid 70% of the time. However, a 30 minute forecast may require an integrity of 80 or even 90% before it is used for decision making.

In conclusion, once a well defined standardized set of GA graphical weather products is validated based on decisions affected, when they are needed, and their characteristics, then various data link solutions can be properly assessed to determine which architecture can best satisfy the users’ graphical weather needs.
Recommendations for Future NASA Research and Development (R&D) Efforts

Recommendation I

- Flight test and evaluate representative commercial weather data link systems.

A flight test and evaluation of some or all of the surveyed vendors in this report is recommended. NASA should obtain at least one system of each representative technology and conduct an objective evaluation utilizing a typical GA aircraft types flown by a diverse group of GA pilots.

NASA could contract out this evaluation, if desired, to an independent aviation company or an aviation oriented university. The FAA, for example, has contract vehicles with universities including a multi-university Center of Excellence for General Aviation with over three hundred training aircraft. The lead university in this consortium is Embry-Riddle University.

This flight testing should be conducted in representative GA aircraft with as a diverse group of pilots as practical to perform evaluations. Pilot members of professional organizations such as AOPA, EAA, NBAA, etc. could participate. The results of this evaluation would indicate which current technologies have the greatest potential for accelerated market penetration.

Follow-on R&D efforts could then be explored to further reduce nonrecurring and recurring costs of the preferred technologies for GA operators to increase market penetration. As indicated by an Embry-Riddle pilot survey, these costs significantly influence GA pilot interest and utilization of weather data links.

Recommendation II

- Investigate FAA NEXCOM VDL-3 data link FIS services

It is recommended that NASA initiate an R&D effort to investigate FIS utilization of the new VHF VDL-3 two-way digital data link standard proposed by FAA for their Next Generation Air/Ground Communication (NEXCOM) program. It should be tested and evaluated for aviation weather data link applications.

Assuming prioritization is incorporated for all ATC message traffic over VDL-3 data channels, FISDL information including text and graphical weather should be evaluated for ATC VDL-3 transmissions on a not-to-interfere basis.

While VHF VDL-2 GMSK and CSMA data links are currently being used today, the VDL-3 Time Division Multiple Access (TDMA) implementation being proposed by FAA for ATC voice and data communications in the NAS will be initially operational about 2009 with GA utilization towards 2020. Ground-based VHF VDL-2 and UAT broadcasts should be compared with VHF VDL-3 TDMA weather data transmissions for accuracy, efficiency and timeliness.

Assuming VDL-3 potential for GA graphical weather, NASA should coordinate with the FAA NEXCOM team to investigate future integration of weather data link services in the NAS for GA and commercial aviation.

Since FAA has always provided VHF ATC communication services at no cost to NAS users, presumably there would not be communication service charges for weather
data linked to the cockpit by FAA. This could significantly reduce the cost of weather services to GA by eliminating the communication charges currently passed on by aviation graphical weather service providers.

GA users would only require a new multimode VDL-3 digital capable along with an appropriate avionics display. This could address the desire by many GA operators and organizations to have a single radio provide multiple functions and services to the cockpit.

**Recommendation III**

- **Develop R&D partnership with XM and/or Sirius Satellite Radio to investigate their use for FIS**

NASA has investigated the use of state-of-the-art satellite digital audio radio systems (SDARS) for delivery of weather information as highlighted in NASA research paper by Stough and Martzaklis [15]. This paper indicated the feasibility of SDARS for FIS transmission to GA aircraft was demonstrated successfully in South Africa in 1999 using the AfriStar SDARS satellite.

Sirius and XM Radio are the current satellite service providers in the U.S. XM Radio and Sirius advertise approximately 100 entertainment channels with a subscription price of $9.99/month for XM and $12.95/month for Sirius. If these satellite radio broadcast service providers could see a business case for also carrying graphical and text weather products, this would be very attractive to aviation as well as some marine and ground transportation U.S. operators.

GA pilots could display not only weather information in the cockpit, but could listen to digital CD quality musical entertainment as well as news, sports, business, etc. Graphical weather data would most likely increase the subscription cost although the delta increase would be dependent on the number of users ultimately signed up by SDARS providers.

It is recommended that NASA establish and R&D partnership with an SDARS satellite radio provider and an independent aviation company and/or university to evaluate the potential of providing weather information to NAS users via SDARS satellite broadcasts.

NASA should compare this approach with other commercial ventures for providing aviation weather for quality of weather information, timeliness, and value to the GA user.

**Recommendation IV**

- **Participate with FAA and RTCA in Safe Flight 21 and UAT R&D development**

Safe Flight 21 is a government and industry cooperative effort to develop Free Flight capabilities from evolving Communications, Navigation and Surveillance (CNS) technologies. Safe Flight 21 will demonstrate cockpit display of FIS including weather as well as traffic and terrain information for pilots. Traffic information will be realized by utilizing Global Positioning System (GPS) data and Automated Dependent Surveillance-Broadcast (ADS-B).

MITRE CAASD has developed an L-Band radio data link called the Universal Access Transceiver (UAT) for the FAA Safe Flight 21 implementation. UAT incorporates a broadcast architecture with two way transmissions. UAT ground stations can send FIS-B transmissions including weather as well as Traffic Information Services-Broadcast (TIS-B). RTCA SC-186 has drafted MOPS for UAT. MITRE has been flight testing UAT since 1995 with the assistance of the Florida Institute of Technology Aviation program and Embry-Riddle Aeronautical University.
FAA has conducted Safe Flight 21 demonstrations in the Ohio valley with the Cargo Airline Association (CAA) members (UPS, FedEx, and Airborne) as well as the Alaska Capstone tests with 100 to 200 GA aircraft equipped.

It is recommended that NASA join with FAA and RTCA in further development and evaluation of FIS-B weather services for GA. FAA is meeting with GA avionics manufacturers to discuss funding for GA avionics development. NASA can pursue their aviation safety mission goals and their CNS objectives while coordinating with FAA and participating in RTCA technical committees and work groups.

Recommendation V

- **Evaluate hybrid satellite and ground-based architecture**

The SAIC, ARINC, TRW and Crown Communications Weather Data link Architecture Study (May, 2000) [16] supported by NASA analyses concluded that a hybrid implementation of broadband satellite national broadcasts along with ground-based narrowband local broadcasts would be optimal for aviation FIS requirements. The results and conclusions obtained in this market survey and evaluation supports this assessment.

It is recommended that NASA evaluate this architecture approach by integrating a commercially available satellite broadcast service (PWA or Merlin) along with VHF (VDL-2/3) and/or UAT airborne receivers on a GA type aircraft. Data link integration of strategic and local weather data should be investigated. In addition, data link reception reliability in the presence of adverse weather and/or radio frequency interference should also be evaluated.

This R&D effort should be conducted in a context that future avionics must be multifunctional to provide maximum aviation services to the cockpit to enhance safety while minimizing space, weight and power requirements given the very stringent constraints within most GA aircraft.
Appendix One

Arthur R. Feinberg and James W. Tauss
Aviation Management Associates, Inc.
8752 Center Road, Springfield, Virginia 22152
Phone: 703-644-4465 Fax: 703 569 1577 www.avmgt.com

VENDOR SURVEY
Aviation Management Associates (AMA), a consulting firm located in Springfield, Virginia, has a NASA contract to conduct a market analysis of companies providing or intending to provide graphical weather information to the general aviation (GA) cockpit. The effectiveness of these commercial offerings to address pilot weather needs and improve safety are critical for NASA to determine future research investment decisions. Please answer these questions and provide any additional comments as appropriate.

Tell us a little about yourself and your company

1. Your name and title: ________________________________________________
2. Company/Address: ________________________________________________
3. Phone: ________________ FAX:________________ Email:________________

Tell us about your Product Offering

1. Product name and Model #: ___________________________________________
2. Product description/type (transceiver, MFD, etc.): _________________________
   __________________________________________________________________
3. Additional H/W or S/W required: ______________________________________
   __________________________________________________________________
4. Advertised product component costs: ___________________________________
5. Technological concerns and cost drivers: __________________________________
   __________________________________________________________________

Tell us about how the weather products are displayed

1. Cockpit weather display:___________________________________________
2. Additional product functionality:______________________________________
3. Product/functionality growth capability:________________________________
   __________________________________________________________________

Tell us about the weather services your product provides

1. Monthly costs and service plans:_____________________________________
2. Weather graphics included:___________________________________________
3. Weather text or other products included:_______________________________
4. Weather product provider:___________________________________________
5. Product availability and response time:________________________________

AMA
Tell us how graphical weather products are received in the cockpit

1. Transmission media (cellular, satellite, etc): ______________________________
2. Characteristics (request/response, broadcast, etc): _________________________
3. Receiver/antenna specific requirements: _________________________________
4. Technological concerns/cost drivers: _________________________________

Tell us about your ground infrastructure architecture

1. Distribution of weather products: _________________________________
2. Interfaces with NWS, FAA, etc: _________________________________
3. Communications network: _________________________________
4. Technological concerns/cost drivers: _________________________________

Tell us about product installation and integration

1. Product applicable to aircraft types: _________________________________
2. Aircraft modifications: _________________________________
3. Are products FAA certified/certification required? _________________________________
4. Other compliance/integration issues: _________________________________
5. Other compatibility/operational issues: _________________________________

Tell us about your customers

1. Production quantity/unit sales: _________________________________
2. Delivery lead time: _________________________________
3. Reliability, Availability & Maintainability: _________________________________
4. Warranty: _________________________________
5. Target market & approach: _________________________________
6. POC for Customer satisfaction/feedback: _________________________________

Tell us some recommendations for improved market penetration

1. Cost drivers: _________________________________
2. Barriers to market penetration: _________________________________
3. Technological issues: _________________________________
4. Suggested NASA R&D initiatives: _________________________________
5. Additional comments & recommendations: _________________________________

__________________________________________________________________
__________________________________________________________________
Appendix Two

Arthur R. Feinberg and James W. Tauss
Aviation Management Associates, Inc.
8752 Center Road, Springfield, Virginia 22152
Phone: 703-644-4465 Fax: 703 569 1577 www.avmgt.com

USER SURVEY
Aviation Management Associates (AMA), a consulting firm located in Springfield, Virginia, has a NASA contract to conduct a market analysis for the provision of graphical weather information to the general aviation (GA) cockpit. The effectiveness of these commercial offerings to address pilot weather needs and improve safety are critical for NASA to determine future research investment decisions. Please answer these questions and provide any additional comments as appropriate.

Tell us a little about yourself

1. Your name and address: ______________________________________________
2. Phone: ________________ FAX:________________ Email:________________
3. Type of aircraft you own_____________________________________________
4. Where and how often do you fly_______________________________________

Tell us about how you receive graphical weather products in the cockpit

6. Product name/Model # (if known): _____________________________________
7. What other H/W or S/W did you need to purchase: _______________________
   _____________________________________________________________________
8. Were there any issues when installing:___________________________________
   _____________________________________________________________________
9. Did you feel the cost to equip was reasonable:_____________________________
   10. If not, why:________________________________________________________
   11. Maintenance/Service issues:_________________________________________

Tell us about how the weather products are displayed

4. What graphical weather products do you receive:__________________________
5. What products do you NOT use: ________________________________
6. Do you feel the cost is reasonable:_____________________________________
   4. If not, why:________________________________________________________

Tell us about the weather services you receive

6. Does the current service or functionality meet your expectations and if not why:
   _____________________________________________________________________
7. What are the required core capabilities: _____________________________
8. What would you be willing to pay:_____________________________________
9. What would you like to see operationally approved:_______________________
10. Additional comments: _______________________________________________
Appendix Three

References

1. Federal Aviation Administration
   Safer Skies: Focused Safety Agenda
   – Weather Joint Safety Team. Final
2. National Transportation Safety
   Board Office of Accident
   Investigation, Table of general
   Aviation Accident Statistics, 1993-
   2000.
3. AOPA Air Safety Foundation Safety
   Review – General Aviation Weather
   Accident – An Analysis and
   Preventive Strategies. 1996.
4. Federal Aviation Administration
   Mission Need Statement for
5. Federal Aviation Administration
   Concept of Use For Weather. Draft
   2002.
6. Sonquist, J. and Dunkelberg, W.
   Survey and Opinion Research:
   Procedures for processing and
   Analysis. Englewood Cliffs, NJ:
   Prentice-Hall. 1977.
7. Federal Aviation Administration
   Users’ Aviation Weather
   Information Needs and Priorities
   and Government/Industry
   Responsibilities in the provision of
   Aviation Weather Services, National
   Aviation Weather Users’ Forum.
   1993.
8. National Aviation Weather Program
   Council Joint Action Group for
   Aviation Weather: National
   Aviation Weather Program Strategic
   Plan: Office of the Federal
   Coordinator for Meteorology, FCM-
9. Latorella, K., and Lane, S., General
   Aviation Pilots' Perceived Usage
   and Valuation of Aviation Weather
   Information Sources. NASA/TM-
   2002-211443
10. Kauffmann, P. and Pothanum, K.:
    Estimating the Rate of Technology
    Adoption for Cockpit Weather
    Information Systems. SAE paper
11. Sirili, Y., Ozan, E., and Kauffmann,
    P. A Market research Study for
    Future Weather Information
    Systems in General Aviation,
    Proceedings of the American
    Society of Engineering Management
12. Burt, Jennifer; Chamberlain, James
    P.; Jones, Kenneth M.; and Coyne,
    Joseph: Impact of a Weather
    Information System Display on
    General Aviation Pilot Workload
    and Performance, SAE Paper 2002-
    01-1552, April 2002.
13. Keel, B., et. al., Aviation Weather
    Information Requirements Study.
    Georgia Tech Research Institute,
    Atlanta, GA. 2000.
14. RTCA, Inc.: Aeronautical Spectrum
    Planning for 1997-2010.
15. Stough, P., and Konstantinos, S.,
    Progress in the Development of
    Weather Information Systems for
    the Cockpit. NASA LRC and GRC
    and Daniel Garland, Embry-Riddle
    Aeronautical University. NASA
    2002-01-1520
16. TRW, ARINC and SAIC:
    Communications System
    Architecture Development for Air
    Traffic Management & Aviation
    Weather Information Dissemination
    - AWIN 2007 Architecture.
## Glossary

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACARS</td>
<td>Aircraft Communications and Reporting System</td>
</tr>
<tr>
<td>AIM</td>
<td>Aeronautical or Airman’s Information Manual</td>
</tr>
<tr>
<td>AEA</td>
<td>Aircraft Electronics Association</td>
</tr>
<tr>
<td>AGL</td>
<td>Above Ground Level</td>
</tr>
<tr>
<td>AMA</td>
<td>Aviation Management Associates</td>
</tr>
<tr>
<td>ANN</td>
<td>ARNAV Aeronautical Network</td>
</tr>
<tr>
<td>AOC</td>
<td>Airline Operating Center</td>
</tr>
<tr>
<td>AOPA</td>
<td>Aircraft Owners and Pilots Association</td>
</tr>
<tr>
<td>ASD</td>
<td>Aircraft Situation Display</td>
</tr>
<tr>
<td>ASIST</td>
<td>Aeronautics Safety Investment Strategy Team</td>
</tr>
<tr>
<td>ATC</td>
<td>Air Traffic Control</td>
</tr>
<tr>
<td>AvSP</td>
<td>Aviation Safety Program</td>
</tr>
<tr>
<td>AWIN</td>
<td>Aviation Weather Information</td>
</tr>
<tr>
<td>CAA</td>
<td>Cargo Airline Association</td>
</tr>
<tr>
<td>CDM</td>
<td>Collaborative Decision Making</td>
</tr>
<tr>
<td>CFIT</td>
<td>Controlled Flight Into Terrain</td>
</tr>
<tr>
<td>CSMA</td>
<td>Carrier Sense Multiple Access</td>
</tr>
<tr>
<td>CNS</td>
<td>Communication, Navigation, Surveillance</td>
</tr>
<tr>
<td>CPDLC</td>
<td>Controller Pilot Data Link Communication</td>
</tr>
<tr>
<td>CONUS</td>
<td>Conterminous United States</td>
</tr>
<tr>
<td>EAA</td>
<td>Experimental Aircraft Association</td>
</tr>
<tr>
<td>EFB</td>
<td>Electronic Flight Bag</td>
</tr>
<tr>
<td>FAA</td>
<td>Federal Aviation Administration</td>
</tr>
<tr>
<td>FCC</td>
<td>Federal Communications Commission</td>
</tr>
<tr>
<td>FIS-B</td>
<td>Flight Information System - Broadcast</td>
</tr>
<tr>
<td>FISDL</td>
<td>Flight Information System Data Link</td>
</tr>
<tr>
<td>FMS</td>
<td>Flight Management System</td>
</tr>
<tr>
<td>GA</td>
<td>General Aviation</td>
</tr>
<tr>
<td>GAMA</td>
<td>General Aviation Manufacturers</td>
</tr>
<tr>
<td>GEO</td>
<td>Geosynchronous Earth Orbiting</td>
</tr>
<tr>
<td>GMSK</td>
<td>Gaussian Minimum Shift Keying</td>
</tr>
<tr>
<td>GPS</td>
<td>Global Positioning System</td>
</tr>
<tr>
<td>GRC</td>
<td>Glenn Research Center</td>
</tr>
<tr>
<td>H/W</td>
<td>Hardware</td>
</tr>
<tr>
<td>IFR</td>
<td>Instrument Flight Rules</td>
</tr>
<tr>
<td>IMC</td>
<td>In Meteorological Conditions</td>
</tr>
<tr>
<td>LEO</td>
<td>Low-Earth Orbiting</td>
</tr>
<tr>
<td>METAR</td>
<td>Aviation Routine Weather Report</td>
</tr>
<tr>
<td>MFD</td>
<td>Multi-Functional Display</td>
</tr>
<tr>
<td>MNS</td>
<td>Mission Need Statement</td>
</tr>
<tr>
<td>MOPS</td>
<td>Minimum Operational Performance Standards</td>
</tr>
<tr>
<td>NAS</td>
<td>National Airspace System</td>
</tr>
<tr>
<td>NASA</td>
<td><strong>National Aeronautics and Space Administration</strong></td>
</tr>
<tr>
<td>NBAA</td>
<td>National Business Aircraft Association</td>
</tr>
<tr>
<td>NEXCOM</td>
<td>Next Generation Air/Ground Communication</td>
</tr>
<tr>
<td>NEXRAD</td>
<td>Next Generation Radar</td>
</tr>
<tr>
<td>NOTAM</td>
<td>Notice to Airmen</td>
</tr>
<tr>
<td>Acronym</td>
<td>Description</td>
</tr>
<tr>
<td>---------</td>
<td>--------------------------------------------------------</td>
</tr>
<tr>
<td>NTIA</td>
<td>National Telecommunications &amp; Information Administration</td>
</tr>
<tr>
<td>NRC</td>
<td>National Research Council</td>
</tr>
<tr>
<td>NTSB</td>
<td>National Transportation Safety Board</td>
</tr>
<tr>
<td>NWS</td>
<td>National Weather Service</td>
</tr>
<tr>
<td>PC</td>
<td>Personal Computer</td>
</tr>
<tr>
<td>PDA</td>
<td>Personal Digital Assistant</td>
</tr>
<tr>
<td>PIREP</td>
<td>Pilot Report</td>
</tr>
<tr>
<td>R/R</td>
<td>Request/Reply</td>
</tr>
<tr>
<td>SDARS</td>
<td>Satellite Digital Audio Radio Systems</td>
</tr>
<tr>
<td>SOW</td>
<td>Statement of Work</td>
</tr>
<tr>
<td>STC</td>
<td>Special Type Certificate</td>
</tr>
<tr>
<td>SUA</td>
<td>Special Use Airspace</td>
</tr>
<tr>
<td>S/W</td>
<td>Software</td>
</tr>
<tr>
<td>TAF</td>
<td>Terminal Aerodrome Forecast</td>
</tr>
<tr>
<td>TBD</td>
<td>To Be Determined</td>
</tr>
<tr>
<td>TDMA</td>
<td>Time Division Multiple Access</td>
</tr>
<tr>
<td>TFR</td>
<td>Temporary Flight Restriction</td>
</tr>
<tr>
<td>TIS-B</td>
<td>Traffic Information Services - Broadcast</td>
</tr>
<tr>
<td>TOPS</td>
<td>Terrain Obstruction Proximity System</td>
</tr>
<tr>
<td>UAT</td>
<td>Universal Access Transceiver</td>
</tr>
<tr>
<td>UPS</td>
<td>United Parcel Service</td>
</tr>
<tr>
<td>VDL</td>
<td>VHF Data Link</td>
</tr>
<tr>
<td>VFR</td>
<td>Visual Flight Rules</td>
</tr>
<tr>
<td>VHF</td>
<td>Very High Frequency</td>
</tr>
<tr>
<td>WINCOMM</td>
<td>Weather Information Communications</td>
</tr>
<tr>
<td>WxAP</td>
<td>Weather Accident Prevention Project</td>
</tr>
</tbody>
</table>
## Appendix Four

<table>
<thead>
<tr>
<th>Vendor</th>
<th>Product Description</th>
<th>Weather Display</th>
<th>Data Link Characteristics</th>
<th>Weather Data Source/Pros.</th>
<th>NR Cost</th>
<th>Rec Cost</th>
<th>A/C Type</th>
<th>Technical Considerations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aircell, Inc.</td>
<td>Aircell: Airborne cellular systems, A/C installed</td>
<td>Flight Guardian S/W on MFDs, PDA's, Laptops</td>
<td>Ground based, U.S. cell towers, voice and data.</td>
<td>Meteorlogix, DTC Duals, NEXRAD, FIS data</td>
<td>$4 - $8K</td>
<td>$30 - $499/mo. (voice) plus $2/min</td>
<td>Piston (Guardian) and jets or turbo props (AT or AGT.02)</td>
<td>LOS issues (&gt;5000' AGL)</td>
</tr>
<tr>
<td></td>
<td>Louisville, Colorado</td>
<td><a href="http://www.aircell.com">www.aircell.com</a></td>
<td>Aircell: Guardian 1000, AT.02, AGT.02</td>
<td>Voice and data, CONUS coverage</td>
<td>FAA certified (STC's)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
| UPS Aviation        | UPS MFD | S/W to interface with both Aircell (Guardian) and Satellite Tech (Merlin) | Aircell: Ground based cell tower network, Merlin: Geosync. Satellite | Meteorlogix, Cost of laptop $6K | $7.3K | TBD | Aircell: same as above. Merlin: Antenna, cost, avail?
<p>|                    | Salem, Oregon | <a href="http://www.upsvat.com">www.upsvat.com</a> | Aircell: Meteorologix, Merlin: Jeppesen Products TBD | Global w/US weather data. No TAFs. | Displays (Echo &amp; Garmin) | Portable wGPS (no FAA certification) |
| Echo Flight         | EchoMap S/W and satellite transceiver communicator. | Laptop | LED (Orbcomm VHF) satellites, 2-way data link, R/R, 57.6kbps | Meteorlogix Cost of laptop $6K | $9.5-15K/mo., plus $1 each access | Global w/US weather data. No TAFs. | Portable wGPS (no FAA certification) |
|                    | Boulder, Colorado | <a href="http://www.echoflight.com">www.echoflight.com</a> | Flight Cheetah MFD | Composite NEXRAD, ceil./vis., precip. Wind speed/dir., T/Td, METARs, Graphical METARs. | $8 - $10K | $42/mo. for premium graphics | Most | LOS issues. Not nationwide. FAA certified products. Can be used with several other MFD manufacturers. |
| ARNAV                | ARNAV SW | MFD 5200, ICDS MFD | VHF Towers, FIS GMSK, broadcast, 31.5kbps | Meteorlogix METAR text, graphical surface cond., Premium products: NEXRAD composite, winds aloft, SIG, WX reports inc. 3-D turb, icing, graphical METARs, NCWF | $8 - $10K | $42/mo. for premium graphics | Most | LOS issues. Not nationwide. FAA certified products. Can be used with several other MFD manufacturers. |
|                    | Puyallup, WA | <a href="http://www.arnav.com">www.arnav.com</a> | TouchLink VHF receiver (DR-100) and WindNet transceiver | VHF Towers, FIS VDL Mode 2, broadcast, 31.5kbps | NWS (NOAAPORT/AVC) METAR and TAF text, AWX, PIREFs, AIMETS/SIGMETs, CONV SIGMETs, Premium products: Regional and national NEXRAD w/animation, 0.5 BREF, graphical METARs, DLN | $7.5 - 12.9K | $49/mo. for premium graphics | Lower end GA up to biz. Jets | LOS issues (&gt;5000' AGL) |
|                    | Olathe, Kansas | <a href="http://www.bendixking.com">www.bendixking.com</a> | KDR 510 receiver | VHF Towers, FIS VDL Mode 2, broadcast, 31.5kbps | WSI (NOAAPORT/AVC) METAR and TAF text, METAR and TAF text, AWX, PIREFs, AIMETS/SIGMETs, CONV SIGMETs, Premium products: Regional and national NEXRAD w/animation, 0.5 BREF, graphical METARs, LIFD | $7.5 - 12.9K | $49/mo. for premium graphics | Lower end GA up to biz. Jets | LOS issues (&gt;5000' AGL) |
| Honeywell Bendix/King | WSI Products TBD | WeatherStream's Pilot Weather Advisor (PWA) | Variety of MFD's and portable devices inc. EFB's preloaded | WSI Products TBD | $5K (ass.) | $30 - $50/mo. (est.) | Western Hemisphere Data only | Late 2002 |
|                    | Billerica, MA | <a href="http://www.wsicorp.com">www.wsicorp.com</a> | WSI Products TBD | WSI Products TBD | $5K (ass.) | $30 - $50/mo. (est.) | Western Hemisphere Data only | Late 2002 |</p>
<table>
<thead>
<tr>
<th>Vendor</th>
<th>Product Description</th>
<th>Weather Display</th>
<th>Data Link Characteristics</th>
<th>Weather Data Source/Prods.</th>
<th>NR Cost</th>
<th>Rec Cost</th>
<th>A/C Type</th>
<th>Technical Considerations</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>FAA certification unknown</td>
</tr>
<tr>
<td>Rockwell Collins</td>
<td>Communication Management Unit and Radio Interface Unit, file server</td>
<td>Adaptive Flight Display 3010E</td>
<td>VDL-Mode 2 (land), Immortal (ocean), ACARS protocol</td>
<td>Universal Weather Graphical worldwide weather, NEXRAD</td>
<td>$500</td>
<td>$400-1,300/Mo.</td>
<td>High end but used down to Premier CJ's type carpent in '03 for Challenger 601</td>
<td>Considering forey into lower end GA market with potential leveraging of ARINC infrastructure</td>
</tr>
<tr>
<td>Avidyne</td>
<td>FlightMax DX50 transceiver</td>
<td>FlightMax MFD (EX5000)</td>
<td>LEO (Orbcomm), R/R, digital 2-way VHF format</td>
<td>Wx provider TBD TBD but national and regional NEXRAD mosaics, METAR and TAF (graphical and text) planned</td>
<td>$2,950</td>
<td>$29-49/Mo.</td>
<td>Panel mounted for Part 23</td>
<td>Only CONUS</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>FAA certification pending</td>
</tr>
<tr>
<td>ControlVision</td>
<td>Anywhere WX, GPS flight manager SW</td>
<td>Compaq IPAQ PDA</td>
<td>Aircraft: Ground based cell tower network, LEO (GlobalStar) satellite, R/R</td>
<td>Meteorology NEXRAD mosaics, METAR and TAF</td>
<td>$2,899</td>
<td>$30-100/Mo. Plus $1.75/min.</td>
<td>Cassa 175, other private</td>
<td>Not IFR certified</td>
</tr>
<tr>
<td>Flytimer</td>
<td>ACARS Control Unit Transceiver</td>
<td>MFD's, IPAQ, laptop</td>
<td>ARINC ACARS network, R/R</td>
<td>NEXRAD, METAR, TAF, TAMDAR products planned</td>
<td>TBD</td>
<td>TBD</td>
<td>Low end GA</td>
<td>Digital ATIS and email also available, Auto tunable to take advantage of excess side bandwidth, TAMDAR probe to be integrated, Certification planned this year, Live flight trials planned</td>
</tr>
<tr>
<td>Garmin</td>
<td>GDL 49 Transceiver</td>
<td>MFD's (GNS 430, GNS 530)</td>
<td>LEO (Orbcomm), R/R, 2-Kbps uplink and 4.8 Kbps downlink</td>
<td>Meteorology via Echo Flight data link service NEXRAD, graphical and text METAR and TAF</td>
<td>$3,495</td>
<td>$9.95-55/Mo. Plus $1 each access</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Satellite Technologies, Inc.</td>
<td>MA 5K-1 satellite receiver</td>
<td>GEOS satellite, broadcast</td>
<td>Jeppesen GOES IR images, composite satellite, NEXRAD 0.5 BREF, NEXRAD Echo Tops, SIGMET, CONV, SIGMET, long range, Winds/tempe aloft fests., METAR, TAF, AIRMET, PIREP, TFR, ASD, various NOTAM, Flight Explorer service</td>
<td>Jpepsen</td>
<td>$3.5K</td>
<td>$45/mo. After year 1.</td>
<td>MA SK-1 certification by FAA pending</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Data only</td>
</tr>
<tr>
<td>Company, Address, Phone, Email</td>
<td>Contact</td>
<td>Product and Description</td>
<td>Non-Recurring Cost</td>
<td>Service Plans and Recurring Costs</td>
<td>Availability</td>
<td>Weather Source, FCC and Email</td>
<td>Conmn. Link</td>
<td>Req. Equipment</td>
</tr>
<tr>
<td>-------------------------------</td>
<td>--------</td>
<td>-------------------------</td>
<td>--------------------</td>
<td>----------------------------------</td>
<td>--------------</td>
<td>-------------------------------</td>
<td>-------------</td>
<td>----------------</td>
</tr>
<tr>
<td><strong>AirCell, Inc.</strong> 1172 Century Drive, Suite 280, Building B Louisville, Colorado <a href="http://www.aircell.com">www.aircell.com</a> 303 379 0200</td>
<td>Brian Cox, Director of New Technology Development 303 379 0201 Stefan Pirsig, Technical Sales, and Marketing 817 793 2000</td>
<td>Guardian 1000: Airborne cockpit telephone, panel mounted system provides voice, data, and keypads to avionics, other PDA's or laptop interface service.</td>
<td>Around $3,000 installed, $800-$895 for the SW and PDA</td>
<td>(Bill of materials plus installation fee) Plus Up to $399 installment plan for data. Includes ADS-B, weather, and voice services.</td>
<td>Specific minimum service agreement. Some have 1000s day trial version, others limited coverage. Stations may require it to be hard wired to aircraft.</td>
<td>Designed specifically for aircraft installation. Combined with ADS-B, waypointing, TMC, and 121.5 Mhz. More power than E800.</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>DataComm Inc.</strong> 303 379 0736</td>
<td>Darbe, Technical Sales, and Marketing</td>
<td>Guardian 1000: Modem, internal modem, and RS-232 port. Can connect to MFD's, PDA's, and laptops with no physical integration.</td>
<td>Around $3,000 installed, $800-$895 for the SW and PDA</td>
<td>(Bill of materials plus installation fee) Plus Up to $399 installment plan for data. Includes ADS-B, weather, and voice services.</td>
<td>Specific minimum service agreement. Some have 1000s day trial version, others limited coverage. Stations may require it to be hard wired to aircraft.</td>
<td>Designed specifically for aircraft installation. Combined with ADS-B, waypointing, TMC, and 121.5 Mhz. More power than E800.</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Airequip, Inc.</strong> 10001 Northside Dr. Suite 280 Louisville, Colorado <a href="http://www.airequip.com">www.airequip.com</a></td>
<td>Bill of materials plus installation fee. Plus Up to $399 installment plan for data. Includes ADS-B, weather, and voice services.</td>
<td>Specific minimum service agreement. Some have 1000s day trial version, others limited coverage. Stations may require it to be hard wired to aircraft.</td>
<td>Designed specifically for aircraft installation. Combined with ADS-B, waypointing, TMC, and 121.5 Mhz. More power than E800.</td>
<td>Line of site issues. Typically start at above 5,000 feet ASL in many areas. Certified back of service agreement. Only pay for the data when data going through the network. Costs are $9.95/month plus $1.99/minute for voice and data. Additional $10/month for WX access including NEXRAD images. Graphical weather is stand-alone with no aircraft proximity integration. All other necessary capabilities.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Appendix Five.—Continued.

<table>
<thead>
<tr>
<th>Company, Address, Phone, Email</th>
<th>Contact</th>
<th>Product and Description</th>
<th>Non-Recurring Cost</th>
<th>Service Plan and Recurring Costs</th>
<th>Availability</th>
<th>Weather Source, DOI and Email</th>
<th>Coverage Link</th>
<th>Reg. Equipment</th>
<th>Maintenance or Warranty</th>
<th>Applicable Aircraft</th>
<th>Mounting, Power</th>
<th>Constraints or Considerations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Satellite Technologies Inc.</td>
<td>Hooper Harris, VP and CEO, 800-802-3510, 800-802-3510</td>
<td>MX-20 satellite receiver</td>
<td>$55/month plus $1 each access.</td>
<td>$1.00 for additional 20 minutes.</td>
<td>$7,295.00 MX-20 - Multi-Functional Display</td>
<td>$20,000 available worldwide.</td>
<td>Free</td>
<td>Note: Data only</td>
<td>Available worldwide.</td>
<td>Satellite Services (Merlin)</td>
<td>$55/month plus $1 each access.</td>
<td>$1.00 for additional 20 minutes.</td>
</tr>
<tr>
<td>Weather Services International</td>
<td>Keith G. Hefner</td>
<td>FedEx Weather Advisor (FWA)</td>
<td>$100,000 and 10% of revenues</td>
<td>$20,000 fees for airframe maintenance</td>
<td>$20,000 available worldwide 2002 with shipments to customers shortly</td>
<td>Free</td>
<td>Note: Data only</td>
<td>Available worldwide.</td>
<td>Satellite Services (Merlin)</td>
<td>$55/month plus $1 each access.</td>
<td>$1.00 for additional 20 minutes.</td>
<td>Recommend to NASA to make the data link free. EchoFlight makes the data link free.</td>
</tr>
<tr>
<td>A Federal Street, Ellipsis, MA 01057</td>
<td><a href="http://www.wxstream.com">www.wxstream.com</a></td>
<td>888 270-3510</td>
<td>$55/month plus $1 each access.</td>
<td>$1.00 for additional 20 minutes.</td>
<td>$7,295.00 MX-20 - Multi-Functional Display</td>
<td>$20,000 available worldwide.</td>
<td>Free</td>
<td>Note: Data only</td>
<td>Available worldwide.</td>
<td>Satellite Services (Merlin)</td>
<td>$55/month plus $1 each access.</td>
<td>$1.00 for additional 20 minutes.</td>
</tr>
<tr>
<td><a href="http://www.wxstream.com">www.wxstream.com</a></td>
<td><a href="http://www.wxstream.com">www.wxstream.com</a></td>
<td>888 270-3510</td>
<td>$55/month plus $1 each access.</td>
<td>$1.00 for additional 20 minutes.</td>
<td>$7,295.00 MX-20 - Multi-Functional Display</td>
<td>$20,000 available worldwide.</td>
<td>Free</td>
<td>Note: Data only</td>
<td>Available worldwide.</td>
<td>Satellite Services (Merlin)</td>
<td>$55/month plus $1 each access.</td>
<td>$1.00 for additional 20 minutes.</td>
</tr>
<tr>
<td>Satellite Technologies Inc.</td>
<td>Hooper Harris, VP and CEO, 800-802-3510, 800-802-3510</td>
<td>MX-20 satellite receiver</td>
<td>$55/month plus $1 each access.</td>
<td>$1.00 for additional 20 minutes.</td>
<td>$7,295.00 MX-20 - Multi-Functional Display</td>
<td>$20,000 available worldwide.</td>
<td>Free</td>
<td>Note: Data only</td>
<td>Available worldwide.</td>
<td>Satellite Services (Merlin)</td>
<td>$55/month plus $1 each access.</td>
<td>$1.00 for additional 20 minutes.</td>
</tr>
<tr>
<td>Company</td>
<td>Address, Phone, Small</td>
<td>Contact</td>
<td>Product and Description</td>
<td>Non-Recuring Cost</td>
<td>Service Plans and Recurring Costs</td>
<td>Availability</td>
<td>Weather Source, POC, and Email</td>
<td>Comms. Link</td>
<td>Req. Epilogue</td>
<td>Maintenance or Warranty</td>
<td>Applicable Aircraft, Recording, Power</td>
<td>Constraints or Considerations</td>
</tr>
<tr>
<td>---------</td>
<td>----------------------</td>
<td>---------</td>
<td>------------------------</td>
<td>-----------------</td>
<td>-------------------------------</td>
<td>-------------</td>
<td>-----------------------------</td>
<td>-------------</td>
<td>---------------</td>
<td>-------------------------</td>
<td>-----------------------------</td>
<td>--------------------------</td>
</tr>
<tr>
<td>Garmin</td>
<td>1200 E. Tenth Street, Chicago, IL 60622</td>
<td>610-267-5628</td>
<td>FLIGHTREF 751 handheld aviation navigation computer</td>
<td>$2,595 for the transceiver</td>
<td>FLIGHTREF 751 is compatible with Garmin GNS 430 or GNS 530 transceiver. * Requires an external GND-62 datalink receiver.</td>
<td>2001 FAA</td>
<td>FLIGHTREF 751</td>
<td>GE Aviation</td>
<td>FLIGHTREF 751</td>
<td>No announced price yet</td>
<td>FLIGHTREF 751 is compatible with Garmin GNS 430 or GNS 530 transceiver. * Requires an external GND-62 datalink receiver.</td>
<td>FLIGHTREF 751 is compatible with Garmin GNS 430 or GNS 530 transceiver. * Requires an external GND-62 datalink receiver.</td>
</tr>
<tr>
<td>Spatial Vision Systems (SVS)</td>
<td>1200 E. Tenth Street, Chicago, IL 60622</td>
<td>610-267-5628</td>
<td>FLIGHTREF 751 handheld aviation navigation computer</td>
<td>$2,595 for the transceiver</td>
<td>FLIGHTREF 751 is compatible with Garmin GNS 430 or GNS 530 transceiver. * Requires an external GND-62 datalink receiver.</td>
<td>2001 FAA</td>
<td>FLIGHTREF 751</td>
<td>GE Aviation</td>
<td>FLIGHTREF 751</td>
<td>No announced price yet</td>
<td>FLIGHTREF 751 is compatible with Garmin GNS 430 or GNS 530 transceiver. * Requires an external GND-62 datalink receiver.</td>
<td>FLIGHTREF 751 is compatible with Garmin GNS 430 or GNS 530 transceiver. * Requires an external GND-62 datalink receiver.</td>
</tr>
<tr>
<td>Avionics Corp.</td>
<td>200 W. 35th Street, Kansas City, MO 64108</td>
<td>816-281-0165</td>
<td>FLIGHTMAX 5200 compact flat panel display</td>
<td>$3,595 for the transceiver</td>
<td>FLIGHTMAX 5200 is compatible with most Garmin transceivers.</td>
<td>2001 FAA</td>
<td>FLIGHTMAX 5200</td>
<td>GE Aviation</td>
<td>FLIGHTMAX 5200</td>
<td>No announced price yet</td>
<td>FLIGHTMAX 5200 is compatible with most Garmin transceivers.</td>
<td>FLIGHTMAX 5200 is compatible with most Garmin transceivers.</td>
</tr>
<tr>
<td>Digital Flight Services (DFS) Corp</td>
<td>200 W. 35th Street, Kansas City, MO 64108</td>
<td>816-281-0165</td>
<td>FLIGHTMAX 5200 compact flat panel display</td>
<td>$3,595 for the transceiver</td>
<td>FLIGHTMAX 5200 is compatible with most Garmin transceivers.</td>
<td>2001 FAA</td>
<td>FLIGHTMAX 5200</td>
<td>GE Aviation</td>
<td>FLIGHTMAX 5200</td>
<td>No announced price yet</td>
<td>FLIGHTMAX 5200 is compatible with most Garmin transceivers.</td>
<td>FLIGHTMAX 5200 is compatible with most Garmin transceivers.</td>
</tr>
<tr>
<td>Airware Systems Inc</td>
<td>200 W. 35th Street, Kansas City, MO 64108</td>
<td>816-281-0165</td>
<td>FLIGHTMAX 5200 compact flat panel display</td>
<td>$3,595 for the transceiver</td>
<td>FLIGHTMAX 5200 is compatible with most Garmin transceivers.</td>
<td>2001 FAA</td>
<td>FLIGHTMAX 5200</td>
<td>GE Aviation</td>
<td>FLIGHTMAX 5200</td>
<td>No announced price yet</td>
<td>FLIGHTMAX 5200 is compatible with most Garmin transceivers.</td>
<td>FLIGHTMAX 5200 is compatible with most Garmin transceivers.</td>
</tr>
<tr>
<td>Flightware</td>
<td>200 W. 35th Street, Kansas City, MO 64108</td>
<td>816-281-0165</td>
<td>FLIGHTMAX 5200 compact flat panel display</td>
<td>$3,595 for the transceiver</td>
<td>FLIGHTMAX 5200 is compatible with most Garmin transceivers.</td>
<td>2001 FAA</td>
<td>FLIGHTMAX 5200</td>
<td>GE Aviation</td>
<td>FLIGHTMAX 5200</td>
<td>No announced price yet</td>
<td>FLIGHTMAX 5200 is compatible with most Garmin transceivers.</td>
<td>FLIGHTMAX 5200 is compatible with most Garmin transceivers.</td>
</tr>
</tbody>
</table>

* FLIGHT ~ Flightworx, LLC

Appendix Five.—Continued.
### Appendix Five—Concluded.

<table>
<thead>
<tr>
<th>Company</th>
<th>Contact</th>
<th>Product and Description</th>
<th>Non-Resourcing Cost</th>
<th>Service Plans and Recurring Costs</th>
<th>Availability</th>
<th>Weather Source, EQC, and Email</th>
<th>Consol. Link</th>
<th>Req. Equp.</th>
<th>Maintenance or Warranty</th>
<th>Applicable Aircraft, Mounting, Power</th>
<th>Constraints or Considerations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Honeywell BedfordKing</td>
<td>Gary Silberman</td>
<td>KMD 550 Inverness: Digital Displays that do not require a subscription.</td>
<td>$9,685</td>
<td>$550 for digital display only.</td>
<td>KMD 550 3/14/00, 1/12/00, 3/12/00, 12/12/00.</td>
<td>KMD 550 3/14/00, 1/12/00, 3/12/00, 12/12/00.</td>
<td></td>
<td></td>
<td></td>
<td>KMD 550 3/14/00, 1/12/00, 3/12/00, 12/12/00.</td>
<td></td>
</tr>
<tr>
<td>Rockwell Collins</td>
<td>Michael Black</td>
<td>KMD 550 Inverness: Digital Displays that do not require a subscription.</td>
<td>$9,685</td>
<td>$550 for digital display only.</td>
<td>KMD 550 3/14/00, 1/12/00, 3/12/00, 12/12/00.</td>
<td>KMD 550 3/14/00, 1/12/00, 3/12/00, 12/12/00.</td>
<td></td>
<td></td>
<td></td>
<td>KMD 550 3/14/00, 1/12/00, 3/12/00, 12/12/00.</td>
<td></td>
</tr>
<tr>
<td>Universal Avionics</td>
<td>William Johnson</td>
<td>KMD 550 Inverness: Digital Displays that do not require a subscription.</td>
<td>$9,685</td>
<td>$550 for digital display only.</td>
<td>KMD 550 3/14/00, 1/12/00, 3/12/00, 12/12/00.</td>
<td>KMD 550 3/14/00, 1/12/00, 3/12/00, 12/12/00.</td>
<td></td>
<td></td>
<td></td>
<td>KMD 550 3/14/00, 1/12/00, 3/12/00, 12/12/00.</td>
<td></td>
</tr>
<tr>
<td>Jeppesen</td>
<td>John Diamond</td>
<td>KMD 550 Inverness: Digital Displays that do not require a subscription.</td>
<td>$9,685</td>
<td>$550 for digital display only.</td>
<td>KMD 550 3/14/00, 1/12/00, 3/12/00, 12/12/00.</td>
<td>KMD 550 3/14/00, 1/12/00, 3/12/00, 12/12/00.</td>
<td></td>
<td></td>
<td></td>
<td>KMD 550 3/14/00, 1/12/00, 3/12/00, 12/12/00.</td>
<td></td>
</tr>
</tbody>
</table>
NASA Aviation Safety Program Weather Accident Prevention/Weather Information Communications (WINCOMM)

Arthur Feinberg and James Tauss

Aviation Management Associates, Inc.
8752 Center Road
Springfield, Virginia 22152

National Aeronautics and Space Administration
Washington, DC  20546–0001

Project Manager, Gerald Chomos, Communications Technology Division, NASA Glenn Research Center, organization code 5640, 216–433–3485.

Weather is a contributing factor in approximately 25-30 percent of general aviation accidents. The lack of timely, accurate and usable weather information to the general aviation pilot in the cockpit to enhance pilot situational awareness and improve pilot judgment remains a major impediment to improving aviation safety. NASA Glenn Research Center commissioned this 120 day weather datalink market survey to assess the technologies, infrastructure, products, and services of commercial avionics systems being marketed to the general aviation community to address these longstanding safety concerns. A market survey of companies providing or proposing to provide graphical weather information to the general aviation cockpit was conducted. Fifteen commercial companies were surveyed. These systems are characterized and evaluated in this report by availability, end-user pricing/cost, system constraints/limits and technical specifications. An analysis of market survey results and an evaluation of product offerings were made. In addition, recommendations to NASA for additional research and technology development investment have been made as a result of this survey to accelerate deployment of cockpit weather information systems for enhancing aviation safety.