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Weather Information Communication Technologies for Increased Safety and Mobility in the National Airspace System

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Summary

The purpose of the NASA Glenn Research Center Weather Information Communications (WINCOMM) project was to develop advanced communications and information technologies to enable the high-quality and timely dissemination of strategic weather information between the flight deck and ground users as well as tactical turbulence hazard information between relevant aircraft and to the ground. This report will document and reference accomplishments on the dissemination of weather information during the en route phase of flight from ground-based weather information providers to the flight deck (ground-to-air), from airborne meteorological sensors to ground users (air-to-ground), and weather turbulence and icing hazard information between relevant aircraft (air-to-air). In addition, references in this report will demonstrate the architecture necessary to implement and perform successful transmission and reception of weather information to the cockpit, show that weather information flow does not impact "normal" traffic, demonstrate the feasibility of operational implementation, and lay foundation for future data link development.

History

In 1997 the White House Commission on Aviation Safety and Security recommended the establishment of a national goal of reducing the fatal aviation accident rate 80 percent by 2007 (ref. 1). As a result of this recommendation, NASA formed the Aeronautics Safety Investment Strategy Team (ASIST), and weather concerns were identified as a subelement within this team. Weather is one of many factors impacting aviation accidents and is responsible for approximately two-thirds of air carrier delays—a $4 billion cost of which $1.7 billion are considered avoidable. NASA and the Federal Aviation Administration (FAA) established a Memorandum of Agreement (FNA/08–00–01) creating a cooperative research program for weather accident prevention research and development activities (ref. 2).

NASA responded with the Aviation Safety Program with the objective of meeting the government goals of reducing aircraft accident rates by 80 percent by 2007 and 90 percent by 2015 (ref. 2). The Aviation Safety Program is now known as the Aviation Safety and Security Program (AvSSP). Within the AvSSP, NASA Glenn formed the Weather Information Communications (WINCOMM) team. This team investigates advanced communications and information technologies that would enable the efficient and reliable electronic delivery of digital advisory weather product information to aircraft in time for pilots to make strategic and tactical routing decisions for safe flight.

The Level I AvSSP is a fully integrated NASA program led by NASA Langley Research Center with lower level management and execution accomplished across all of NASA's Aeronautics centers. The Weather Accident Prevention (WxAP) is a Level II Project and is administered by the Aviation Safety Program Office of the Aeronautics Directorate at Glenn (ref. 3). WINCOMM is a Level III function located within the Aviation Safety and Security Program and Airspace Systems Program Projects Office at Glenn. WINCOMM interacts and coordinates with other Level III projects under WxAP. These Level III projects are the Advanced Weather Information (AWIN) Project at Langley and the Turbulence Prediction and Warning System Project at NASA Dryden Flight Research Center.

The focus of the WINCOMM element is implementation of developed technologies in the 2007 timeframe that are developed to a mature technology readiness level (TRL) 6 and validated in a relevant

system environment. NASA and the FAA developed partnerships with industry and academia to implement the WINCOMM plan. Guided by ASIST recommendations, NASA held a workshop in November 1997 to review with industry plans for soliciting proposals for aviation weather information systems; NASA recognized the importance of obtaining, distributing, and presenting better and more timely weather information to the cockpit, to aircraft operations centers, and to air traffic management facilities. In December 1997, Langley issued a NASA Research Announcement formally soliciting proposals for research, development, prototyping, and implementation of AWIN systems that contribute to a reduction in the rate of fatal aviation accidents. A total of 42 proposals were received in response to this solicitation. The proposals were evaluated by a team of NASA, FAA, and Department of Defense reviewers. A total of nine proposals were selected for development of cooperative research agreements (CRAs) in which NASA and the industry participants would share in funding the proposed research. Of the nine, five contained WINCOMM-relevant research. WINCOMM and AWIN have partnered with industry via formal, cost-shared teaming arrangements. These agreements span the full range of technology development and include a substantial flight experiment campaign to validate the respective technologies. Technology transfer to U.S. industry was maximized by direct contact and through CRA programs between NASA and industry. Since industry is sharing the development costs in portion of these efforts, there is a high potential for significant transfer of this technology to commercial applications.

WINCOMM Overview

This Technical Memorandum will report on the NASA Glenn first- and second-generation WINCOMM aviation data link development, accomplishments, and conclusions (ref. 4). In this report, "General Aviation" aircraft generally refers to small propeller-powered aircraft with one pilot that carry several passengers and operate below 18 000 ft at speeds less than 200 mph. General aviation aircraft are not for hire and never charge passengers for transportation. "Regional" aircraft generally refer to jet-powered aircraft with at least two pilots that charge passengers for transportation and fly below 25 000 ft. "Commercial transport" aircraft are generally the same as regional aircraft and fly above 25 000 ft up to 600 mph. A list of the acronyms used throughout this report is provided in the appendix.

First-generation WINCOMM weather information systems developed from 1999 to 2002 contain ground-to-air weather-only data links that were commercially available in 2004. These weather data links provide current and near-term technologies to general aviation aircraft focusing on system solutions that validate system implementation over private networks. Terrestrial-based networks providing weather information to the cockpit include the Flight Information Services Data Link (FISDL) network developed by ARNAV Systems, Inc.[1] (Puyallup, WA) and NavRadio[2] and satellite-based networks developed by ViGYAN, Inc. (Hampton, VA) and WSI Corporation (Billerica, MA) with XM Satellite Radio (Washington, DC). Research performed by the WINCOMM project has been responsible for the commercial weather information being provided currently to airplane cockpits by providers such as the Honeywell FISDL (Honeywell International, Inc., Morristown, NJ), XM Satellite Weather, and WSI. These first-generation systems are excellent and improving safety now but are limited to a one-way broadcast capability to aircraft.

Second-generation systems were developed from 2003 to 2005 and investigated potentially significant benefits when implemented to the aviation community that include ground-to-air weather products and information, air-to-air data links, and air-to-ground data links for automatic meteorological dissemination. These second-generation systems are modified aircraft, ground networks, and equipment to enable exchange of weather information between ground providers and pilots via multi-use surveillance, air traffic, and airline operation communication services without impacting normal traffic. These data links utilize private networks for general aviation, regional, and commercial transport aircraft

[1]ARNAV was purchased by SAGEM Co.
[2]NavRadio Corporation has since been bought by AlliedSignal-Bendix/King and is now part of Honeywell.

weather information that include electronic pilot reports, aircraft weather sensors, and dynamic two-way communication with increased capacity over first-generation technologies that result in increased value. New second-generation technologies just demonstrated allow pilots to request specific weather products in flight and to receive and send automatic hazard information from or to other surrounding aircraft. It also enables the aircraft to be a weather sensor to create a more accurate picture of the atmosphere and improve the forecasting models. This will allow pilots to avoid or anticipate turbulence and icing weather events that have potentially damaging effects on passengers and airplanes. Whether in the air or on the ground, all people will benefit from improved weather forecasting.

First-Generation Weather Information Communications Aviation Data Link Development

A critical need has been identified for improved dissemination of graphical weather information to the general aviation and regional cockpits for weather accident prevention. This information needs to be delivered in a timely manner with comprehensive coverage at all altitudes and across the United States.

ViGYAN Satellite Broadcast Network for Graphical Weather Delivery to General Aviation and Regional Aircraft

In the early 1990s, a Pilot Weather Advisor (PWA) system was developed through a NASA Small Business Innovative Research Contract with ViGYAN. The PWA is a satellite-based aviation weather information system to broadcast text and graphical weather information to aviation users at any altitude and location. The PWA system provides a continuous satellite-based broadcast of weather information to aircraft cockpits that includes both radar and airport condition data graphically displayed on portable or panel-mounted displays.

A prototype PWA system was originally developed and patented by ViGYAN under Phase I and II Small Business Innovation Research (SBIR) sponsored and supported by NASA Langley. Although the PWA showed great potential, ViGYAN discovered that the technology was ahead of its time. The system could not become a reality until the cockpit displays and affordable satellite time needed to support it became available.

After investing its own money to keep the project afloat, ViGYAN saw another opportunity to complete the system in 1997 as satellite costs dropped and new cockpit multifunction displays appeared on the market. After more than a decade of work, the company completed its PWA in February 2002 through a Phase III SBIR contract with the NASA Glenn WINCOMM project.

The PWA weather system enables pilots to receive and view 1-nmi resolution weather information inside their aircraft cockpits, greatly enhancing aviation safety with respect to in-flight weather hazards. The PWA weather system provides a continuous, satellite-based broadcast of weather information to a portable or panel-mounted display inside the cockpit. With complete coverage and content for the continental United States (CONUS) at any altitude, the system is specifically designed for in-flight use.

The PWA satellite digital data modulator, the ground station, and the corresponding aircraft receiver and demodulator were designed with advanced turbocoding techniques that enable a signal to be received reliably with less signal power than was previously possible and delivered in a timely manner for all altitudes and across the United States. A composite mosaic Next-Generation Radar (NEXRAD) image for the entire United States is updated and broadcast every 5 min via a commercial geosynchronous satellite. A number of these images can be stored and animated to show weather trends. The system also sends graphical and textual weather information including observations, forecasts, and warnings. The PWA system consists of an aircraft antenna, a digital data receiver, and a third-party display (ref. 5).

A new company, WeatherStream, was formed to market and maintain the PWA satellite weather service across the entire CONUS from ground level to 40 000 ft. PWA was sold to WSI Corporation in

April 2002. WSI has developed and sold the production commercial weather product as WSI InFlight (ref. 5).

Data link weather in the cockpit received top press coverage at AirVenture Oshkosh, 2001 and 2002 with the ViGYAN–WSI Pilot Weather Advisor as one of many highlighted products. ViGYAN, Inc., received a 2003 R&D 100 award from R&D Magazine for its PWA system (ref. 5). The award recognizes the WSI InFlight system as "one of the 100 most technologically significant products introduced into the marketplace over the past year." Corecipients of the award include WSI, Langley, and Glenn.

ARNAV and NavRadio Terrestrial Broadcast Network for Graphical Weather Delivery to General Aviation and Regional Aircraft

On July 30, 1999, the FAA announced that it would partner with two companies, ARNAV Systems and NavRadio, to work with NASA to develop capabilities for a terrestrial system to deliver graphical and textual weather information to national General Aviation and Regional aircraft; this would be called FISDL. The FAA's stated goal was to use digital data link to deliver strategic weather information to the pilot and to do this by using private-sector capabilities to bring services and products to the market place. The purpose of the NASA Langley and Glenn CRA is to conduct research and testing with the FAA, NASA, and industry that will address the near-term need and deliver the broadcast of textual and graphical weather products and information to the general aviation and regional aircraft cockpits. These CRAs will satisfy elements outlined in the NASA WxAP AWIN and WINCOMM subprojects. FISDL received no capital investment by the FAA.

The FISDL system is an FAA-sponsored program that provides broadcast weather information to aircraft over a very-high-frequency- (VHF-) based communication link. The FAA's FISDL system was developed by ARNAV and NavRadio to provide general aviation and regional flight crews of properly equipped aircraft with a cockpit display of textual and graphical aeronautical weather and flight operational information while en route. The contracted firms are responsible for building the ground infrastructure, providing a data radio, and delivering the free weather information. These systems will enhance the safety of general aviation and regional air travel by providing improved in-flight weather information and related situational awareness to pilots. To assure adequate bandwidth for the FISDL, the FAA granted each company two 25 KHz VHF frequency channels—from 136.425 to 136.500 MHz. FISDL utilized four frequencies in the VHF band employing Very High Frequency Digital Link (VDL) Mode 2 protocol, and the broadcast includes local and regional en route flight operations at 31.5 kbps. Broadcast FISDL allows pilots to passively receive weather data for review on a multifunctional display (MFD).

FAA's concept for FISDL is to have land-based transmitter sites distributed across the United States that broadcast weather and National Airspace System (NAS) status information to airborne receivers in the flight deck. A separate cockpit display called an MFD format and presents stored weather or flight advisory information on pilot demand.

The service provider running the FISDL network gets weather data from the FAA or a commercial vendor. Computer software adjusts the format and content to comply with FAA standards and inserts the resulting images and text into the distribution network. From a central computer hub, each remote transmitter gets an update of each data item every 5 min. The VHF transmitter broadcasts data to the receiving antenna aboard airplanes equipped with compatible receivers. The pilot selects any product he needs to see by pressing a button highlighted by a graphic or text menu topic. Software onboard the MFD unit keeps track of the age of each item, and suppresses display of pages too old to be useful in current decisionmaking.

In an agreement signed by private vendors and the FAA, it was agreed that basic weather products would be broadcast for free after meeting additional avionics requirements. The FAA and industry have defined the following weather products as basic: METAR, SPECI, TAF, AMEND TAF, SIGMET, Convective SIGMET, AIRMET, PIREPs, and Alert Weather Watches.

General aviation and regional pilots may augment the free basic weather products by purchasing value-added products that will uplink weather information. The following seven value-added products are available from the vendors on a paid subscription basis: NEXRAD map, Graphical METAR Ceilings & Visibility, SIGMET map, Convective SIGMET map, AIRMETs, and FISDL Transmitter Status.

FISDL is a method of disseminating strategic aeronautical weather and operational data, which augments pilot voice communication with Flight Service Stations, Air Traffic Control facilities, and Airline Operations Control Centers. General aviation and regional pilots will benefit from the FISDL by being able to make earlier decisions to divert or curtail a planned flight because of greater situational awareness of hazardous weather conditions ahead. FISDL does not replace pilot and voice communication for critical weather or operational information interpretation. FISDL, however, can provide the background information, which can abbreviate and greatly improve the usefulness of such communications. Loss or nonreceipt of FISDL service would not be considered flight critical. FISDL supports strategic weather decisionmaking such as route selection to avoid a weather hazard area in its entirety.

ARNAV Systems and NavRadio acted as service providers for FAA's weather information. Under a 5-yr agreement signed during the 1999 Experimental Aircraft Association's AirVenture, both ARNAV and NavRadio received two nationwide data link frequencies for the broadcast of basic aviation weather reports as well as additional information they provide by subscription. The ARNAV and NavRadio CRAs were each broken down into two phases with specific deliverables and accomplishments listed below:

- NavRadio Phase I CRA (ref. 6): WINCOMM specific accomplishments focused on the data links, display avionics technologies, and ground-based infrastructure elements for acquisition and dissemination of data for ground-to-air VDL Mode 2 broadcast. In Phase I the industry's first general aviation practical VDL Mode 2 airborne receiver was developed, proven, and inexpensive, as was a companion ground transmission station that was functional and robust. In addition, an operational system of acquiring weather information, processing it for ground-to-air broadcast, and efficiently distributing it to ground stations was constructed and demonstrated. This system provided the necessary weather data in an efficient and inexpensive manner suitable for general aviation and regional pilots and operators.
- NavRadio Phase II CRA (ref. 7): WINCOMM specific accomplishments focused on the development of a low-cost, single-chip, VDL Mode 2 receiver followed by a single-chip transceiver and studies to address bidirectional FIS implementation. In addition, an understanding of VDL propagation from ground-based transmitters to airborne receivers was performed with single transmitter tests, multiple transmitter tests, and computer simulations. While much of the testing was focused on low-altitude (5000 ft) flight scenarios, tests were also performed at high altitude (over 30 000 ft).
- ARNAV Phase 1 CRA (ref. 8): ARNAV developed methods for providing general aviation pilots with better, timelier weather information via VHF radio data link. Aviation weather products were developed and validated in both research and operational environments. The ARNAV Phase I accomplishments (ref. 9) included the development of new advanced weather products geared specifically for transmission to general aviation aircraft and a method to distribute Transmission Control Protocol/Internet Protocol (TCP/IP) of the same weather products for preflight use that will be available in flight. ARNAV established requirements for certification of weather products through the Radio Technical Commission for Aeronautics (RTCA) and obtained FAA certification of weather products on MFD, including weather sourcing, processing, and end-to-end transmission and validation of weather products. In addition, ARNAV obtained FAA certification for a low-cost electronic PIREPs (E-PIREPs) temperature and humidity aircraft sensor, flight tested weather products, and established business relationships that allowed the developed weather products to be transmitted on the Aircraft Communications Addressing and Reporting System, GLOBALink, and satellite distribution networks.

• ARNAV Phase II CRA (ref. 10):[3] ARNAV performed flight test evaluation of advanced weather products transmitted to the cockpit and actively participated in a NASA-lead activity to develop, test, and evaluate a concept of operations and architecture for E-PIREPs. The flight test teams verified the accuracy and precision of transmitted weather products to improve general aviation pilot decisionmaking and evaluated the weather products for eligibility for the FAA FISDL program.

ARNAV's general aviation data link air and ground systems and graphical display avionics were integrated with Global Positioning System (GPS) moving map navigators, including terrain warning, providing weather product generation and dissemination. Display avionics and experimental weather hazard data were developed to demonstrate and implement a weather data link system, which was used to verify the accuracy and precision of these new weather products. This system helped evaluate their effective use to improve general aviation pilot decisionmaking, for both single small aircraft pilots and two-pilot turbine aircraft crews, to reduce the rate of fatal weather-related accidents.

Rockwell Collins Satellite Digital Audio Radio Service (S–DARS) for Graphical Weather Product Delivery to General Aviation and Regional Aircraft

NASA Glenn WINCOMM and NASA Langley AWIN programs collaborated in a flight test and evaluation of a worldwide weather data link capability using satellites. Rockwell Collins, Inc. (Cedar Rapids, IA), was selected to provide S–DARS in-service evaluation of real time updated graphical weather to aircraft while en route to enable strategic flight decisions where there is no ground support infrastructure. The end solution is to improve flight safety, reduce fuel burn, and improve time en route while providing wide-area coverage for all classes of aircraft.

The Rockwell Collins Phase I CRA objective was to install and validate a fixed patch antenna that can receive satellite broadcasts reliably from geostationary orbit, determine link margin and determine limit of aircraft dynamics to reliably receive the signal without errors on single-engine aircraft. Flight test trials were conducted in Johannesburg, South Africa, in September 1999, with Cessna 182 aircraft using the WorldSpace geostationary Afristar satellite. The X-band uplink signal originated from WorldSpace Johannesburg Regional Operations Center and was sent to the satellite, which sent a Time Division Multiplex L-band downlink signal to the Cessna patch antenna. User data rate was successfully measured at 64 Kbps using a Rockwell Collins fixed patch antenna onboard the aircraft with bank angles up to 50 degrees. WINCOMM CRA with Rockwell Collins proved S–DARS for weather product delivery over AfriStar for general aviation aircraft (ref. 11).

Rockwell Collins Satellite Digital Audio Radio Service for Graphical Weather Product Delivery to International and Oceanic Aircraft

Rockwell Collins Phase II CRA activity is follow-on to the Phase I AfriStar activity conducted in September 1999 that utilized general aviation aircraft. Phase II objective is to transmit weather data to aircraft via WorldSpace AsiaStar geostationary satellite and develop ground network capability to rapidly move weather graphics files to airborne aircraft.

From September 2001 to February 2002, flights between Chicago and Tokyo using the Satellite Weather Information Service (SWIS) were flown on a series of American Airlines, Inc. (Fort Worth, TX), B777–200 commercial transport flights. SWIS utilizes geostationary S–DARS for relaying weather information received via a small patch antenna mounted on an aircraft. Graphical weather images were successfully received through the AsiaStar satellite and distributed on the aircraft through a file server and associated wired and wireless Local Area Networks (LANs). An in-service evaluation (ISE) of SWIS developed by Rockwell under a cost-share effort with the AWIN and WINCOMM elements was

[3]The provisions between ARNAV and the FAA for FISDL service were never implemented, and the agreement was terminated.

completed in February 2002, with favorable crew feedback and excellent technical performance demonstrated.

These aircraft elements included a patch antenna, satellite receiver, file server unit, avionics secure interface unit, wireless LAN, pilot laptop computers, and Jeppesen FliteStar Software (Jeppesen Sanderson, Inc., Englewood, CO). Data routing included weather graphics generated by Jeppesen at Los Gatos, CA, that were encoded and sent to the WorldSpace ISE ground Earth station (GES) in Melbourne, Australia, via Internet File Transfer Protocol (FTP). The Melbourne GES uplinked each file to the satellite three times at short intervals with broadcast data at 64 kbps. Aircraft satellite receiver recovered files, checked data validity, and transferred good files to the file server unit (FSU) for storage. The FSU managed data files and made files available to pilots on aircraft via wireless LAN that included aircraft position and time information. Time delay from Jeppesen to aircraft was less than 60 s. (ref. 12)

Weather graphics include winds and temperatures aloft from 5000 to 45 000 ft, surface weather (ceiling, winds, and visibility), high-level significant weather, visible and infrared satellite imagery, and surface analysis. Update rates varied from once per 30 min to once per 6 h. Update rates were dependent on the specific type of graphic used. Zoom capability was provided for all weather graphics track files and aircraft position overlays. Detailed geographic features and airport diagrams could be inserted by pilots as needed along with "time lapse" weather movement graphics as called for by pilot.

Team members included Rockwell Collins, WorldSpace, Jeppesen, American Airlines, and NASA. Rockwell Collins provided file servers, displays, receivers, antennas, wireless LAN, and integration. WorldSpace Corporation provided the satellite and satellite channel, receiver card, and ground station with feed. Jeppesen provided weather products and laptop software. American Airlines provided installation support, flight tests, and evaluation.

After the successful Rockwell Collins Phase I and Phase II CRA work, WINCOMM was the catalyst enabling XM Radio shared entertainment channel and Heads Up Technologies, Inc. (Carrollton, TX) (ref. 13) to offer graphical weather information over the XM S–DARS system. This led to a teaming with Baron Aviation for a general aviation national weather service commercial offering over XM in 2003.

GTE Airfone and Electronic Flight Bag Delivery of Graphical Weather Products to the Commercial Transport Cockpit

CRA between NASA Glenn and NASA Langley, Honeywell, and Boeing (Chicago, IL) recently leveraged off-the-shelf communication equipment and demonstrated the ability to send weather data via a GTE Airfone[4] to laptop computers for the display of graphical weather pictures. This system also demonstrated the related concept of the electronic flight bag (EFB).

Items that may constitute an EFB are personal electronic devices brought onboard aircraft such as laptops, rather than fixed equipment of the flight deck. These devices enable an application to assist in flight management and decisionmaking that is not currently part of that particular aircraft. Use of such applications can increase safety of flight through more informative, faster, and more accurate information retrieval as well as reduce the pilot's workload en route during operations.

In the future, real-time interactive applications between the crew on the flight deck and the corresponding ground personnel and other systems are envisioned to alleviate the capacity and safety concerns associated with the currently saturated NAS. Applications useful to the flight operations will provide weather information, air traffic management tools, and situational awareness tools including EFB.

The EFB provides delivery of real-time graphical weather data to the flight deck via a laptop computer. United Airlines (UAL Corporation, Chicago, IL) performed 37 ISE flights of the EFB, which included the Honeywell Weather Information Network system, on an Airbus 319 flying routes in the CONUS (ref. 5) United participated in the EFB program and decided that in addition to weather data, the laptop could also store all the data existing in pilot carry-on black flight bags, thus saving the expense of paper distribution.

[4]GTE is now Verizon (Bedminster, NJ).

In addition to graphical weather information coming via the GTE Airfone System from Honeywell's Weather Data Center in Phoenix, AZ, the United pilots aboard two evaluation flights were able to pull up on a laptop all Jeppesen worldwide digital flight charts and United's newly created digital flight manual and documentation. The EFB unit for the evaluation flights had a GPS receiver built in and a window-mounted antenna. The GPS is used to overlay track and positioning information onto the weather map and show the aircraft's position geographically in relation to the airfield.

Initial Airborne Weather Reporting Data Link Concept Flights

Tropospheric Airborne Meteorological Data Reporting (TAMDAR, AirDat LLC, Morrisville, NC) is a low-cost weather sensor designed to collect and broadcast meteorological data on general aviation and regional aircraft. In 2002, two separate data link systems were flown in initial concept flights to test the movement of TAMDAR weather sensor data off aircraft. The purpose of these test flights was to finalize air-to-ground and air-to-air architecture technologies and prove that TAMDAR weather sensor messages can be transmitted off an aircraft using multiple data links.

Both nearby ground stations (air-to-ground) and aircraft (air-to-air) in the vicinity would ideally receive the data. The ground station would forward the information to a central processing facility, such as the National Weather Service, which would use the information for their forecasts. Additionally, nearby aircraft could receive hazard alerts about significant weather events from aircraft broadcasting TAMDAR. Another application of TAMDAR is as a tool for checking the validity of weather forecasts while engaged in flight operations. It is hoped that by sampling data with higher resolution, the accuracy of weather forecasting will improve and pilots will be able to operate more safely and efficiently. This application could be used by a variety of NAS users, such as pilots, controllers, dispatchers, and weather support agencies (ref. 14).

The first data link system flown was the EchoFlight system, which utilizes a number of mid-Earth orbit satellites for transmission of airborne weather data. In these system tests, TAMDAR data was transmitted once per minute as e-mail messages that were automatically forwarded to NASA Glenn through the Internet from the EchoFlight network operations center.

The second data link system flown was the Universal Access Transceiver (UAT) manufactured by Garmin International, Inc. (Olathe, KS), which is an air-to-air, air-to-ground, and ground-to-air data link, primarily intended for surveillance messages. The UAT is a multipurpose transmitter and receiver data link transceiver intended to support Automatic Dependent Surveillance-Broadcast (ADS–B), Flight Information Services-Broadcast (FIS–B), and Traffic Information Service-Broadcast (TIS–B). WINCOMM utilizes the UAT as a multipurpose data link and the exchange of weather information between aircraft (air-to-air) and the ground (air-to-ground). The UAT system utilized off-the-shelf Capstone equipment operating at 966 MHz.

TAMDAR messages were sent over the UAT as an extended version of the surveillance message every 5 s and recorded at the Glenn UAT ground station based in Mansfield, OH. For these tests, a series of arcs were flown at different altitudes and ranges from the ground station. The TAMDAR system requirements were not complete during the test, and no conclusions were drawn on the ability of the two tested links (air-to-ground and air-to-air) to meet system-level requirements (ref. 14).

First-Generation Conclusions

First-generation WINCOMM weather information systems developed from 1999 to 2002 contain ground-to-air weather-only data links that are commercially available today. These weather data links provide current and near-term technologies to general aviation and regional aircraft that focus on system solutions. These technologies can be implemented over private networks. ViGYAN Satellite Broadcast Network proved that graphical weather can be delivered to general aviation and regional aircraft over satellite. ARNAV and NavRadio developed the first national network that broadcast textual and graphical weather products and information to general aviation and regional aircraft. NASA Glenn WINCOMM

and NASA Langley AWIN programs collaborated in a flight test and evaluation of a worldwide weather data link capability proving that real-time updated textual and graphical weather information using S–DARS can be delivered to general aviation and regional aircraft over satellites. In addition, NASA Glenn and Langley proved and demonstrated that off-the-shelf communication equipment can be used to send weather data via a GTE Airfone to laptop computers for the display of graphical weather pictures in the cockpit. This system is commonly referred to as the EFB. Each of these systems provides more weather information to the cockpit, which increases the pilot's situational awareness and eventually decreases aircraft accidents.

Second-Generation Weather Information Communications Aviation Data Link Development

Second-generation system studies were performed for commercial transport aircraft as well as general aviation and regional aircraft. These studies indicated that weather not only was an aviation safety issue, but also had a negative impact on mobility. Weather is the number one source of flight delays in the United States. WINCOMM was tasked with generating technology to enable a safer, more secure, efficient, and environmentally friendly air transportation system that would move people and goods faster and farther with fewer delays. Current 2003 technology was not suitable for handling the size of weather data with the desired transmittal speed. WINCOMM successfully simulated, modeled, and developed aviation communication links that addressed the more stringent design requirements needed for the communication of weather information, including connectivity (ground-to-air, air-to-ground, and air-to-air), signal latency (<1 min), and bandwidth (>31.5 kbps) while costing less than the currently utilized product (<$17,000) (ref. 15). From April to June 2005, this technology was validated with flight demonstrations and actually achieved data rates that were 20 to 100 times greater than that which is operational in the 2005 NAS. As a result, this new communication approach provided higher quality and a more timely delivery of strategic digital weather advisory information. Data on turbulence, icing, and other adverse conditions are now shared with the pilot, air traffic controllers, and dispatchers resulting in a more robust en route system with the objective to optimize mobility for general aviation, regional, and commercial transport aircraft.

The WINCOMM Team successfully addressed weather mobility and safety objectives by developing a system that automatically sends, receives, processes, and delivers valid turbulence warnings and atmospheric sensor weather data. This system has the ability to communicate ownship weather outside the aircraft with other aircraft (air-to-air), within 100 mi and ground users (air-to-ground), and can also receive FIS–B data (ground-to-air). The weather data can be displayed in four textual and two graphic FIS–B weather products. These FIS–B weather products and atmospheric sensor weather data are delivered to the cockpit to improve situational awareness, mobility, and safety operations with the objective to reduce the incidence of aircraft delays and accidents attributed to icing, turbulence, and other adverse weather-related conditions. The validation of the WINCOMM automated weather data links was accomplished through partnerships with the FAA, industry, and academia, leveraging existing East Coast and Ohio ground-station network infrastructure with the flight demonstrations being accomplished with two Learjets at NASA Glenn. The MITRE Corporation (McLean, VA), provided required network infrastructure changes and the uplink scheduling of FIS products and changes to the core switch software that supported routing of TAMDAR data messages.

For the commercial transport demonstration, two digital aviation data links were evaluated for their ability to carry weather data products. The first was the 1090 MHz extended squitter (1090ES) data link, which successfully exchanged automatic turbulence alerts between transport aircraft in real time while en route. The second was the VHF Digital Link Mode 3 data link, which successfully uplinked (ground-to-air) and downlinked (air-to-ground) automatic weather information between the aircraft and the ground.

The general aviation and regional flight tests were accomplished by leveraging the use of the UAT, a multipurpose aeronautical data link intended to support ADS–B, FIS–B, and TIS–B. The ADS–B is a system by which aircraft and certain equipped surface vehicles can share position, velocity, mobility, and weather with one another and also with ground-based facilities such as air traffic services via automatic radio broadcast techniques.

A weather sensor emulator was added to the UAT and ADS–B service to simulate the collection of weather data outside the aircraft. The weather sensor emulator was used in place of the TAMDAR sensor, which was programmatically unavailable during the 2005 flight test. The sensor emulator measures ownship aircraft winds, temperature, humidity, icing, and turbulence as well as location, time, and altitude and transmits this weather information to relevant aircraft within 100 mi and to ground-based weather service providers. This additional weather data will improve weather forecasting and positively impact mobility on land and sea and in air (ref. 16).

The WINCOMM Team achievements were possible only because of the excellent collaborative partnerships between Government, industry, and academia leveraging the best of what each had to offer. Johns Hopkins University Applied Physics Lab (JHU–APL) performed system engineering and communication architecture definition by conducting studies on future aviation communications data and requirements (ref. 17). Ohio Aerospace Institute (Lockheed Martin Management and Data Systems) created WINCOMM Concept of Operations and Requirements Documents (ref. 18). JHU–APL worked with government and industry to identify necessary changes for avionics and ground infrastructure equipment to support weather data transfer and dissemination. They also served in a coordinated function with the FAA Safe Flight 21 Office to ensure that proper procedures were developed for flight testing on the East Coast and Ohio networks. NASA Glenn, Ohio Aerospace Institute (OAI), and JHU–APL served as flight integration and test partners with the responsibilities of test director, systems engineering, and test conductor providing technical support, respectively. Despite daily challenges related to fiscal funding considerations, milestone schedules, and managerial pressures, the WINCOMM Team rallied and tackled the more demanding technology hurdles and complicated aircraft schedules to produce new communication technology that will greatly benefit mobility in the NAS.

General Aviation and Regional Aircraft

The JHU–APL and OAI previously conducted a study of the future aviation communications data and architecture requirements in order to support the NASA Glenn WINCOMM initiative to reduce aircraft accidents through high-quality and timely dissemination of the NAS weather and status information to in-flight aircraft (ref. 16). WINCOMM contains two distinct parts to accomplish this goal: (1) uplink of FIS–B information from the ground to the air, and (2) aircraft broadcast of ownship weather data from an onboard TAMDAR weather sensor to other aircraft (air-to-air) as well as to the ground (air-to-ground) infrastructure. Later, JHU–APL's involvement focused on general aviation and regional aircraft and supplying them with UAT avionics. Two types of testing have demonstrated this weather dissemination capability: lab tests (refs. 19 and 20) and flight tests (refs. 21 and 22).

Weather Information Dissemination.—Lab tests were performed in November 2004 at the Federal Aviation Administration Technical Center (FAATC) in Atlantic City, NJ, where the system modifications functioned as expected and were determined to pose no adverse effects on the currently deployed system. JHU–APL has worked with government and industry to modify ground infrastructure and avionics equipment in support of these test activities. The purpose of the tests identified in the UAT WINCOMM Flight Test Plan (ref. 21) is to verify architecture and equipment modifications for a system that can support data transfer of onboard aircraft weather sensor data and dissemination of an expanded weather information product set.

Flight testing for UAT WINCOMM was performed at NASA Glenn on June 13 and 14, 2005. Figure 1 illustrates the resulting test configuration of weather information dissemination for general aviation and regional aircraft. The purpose of the flight testing was to demonstrate a path to implementation in a relevant environment, verify a system that supports data transfer of onboard aircraft

weather sensor data from air to air and air to ground, and disseminate an expanded weather information product set to general aviation and regional aircraft from ground to air. All test activities were successful and proceeded as planned in the WINCOMM UAT Flight Test Plan and Report (refs. 21 and 22).

Conclusions.—All of the tests performed as expected, and successful results were obtained. Data logs verified the transmission and receipt of TAMDAR data and new FIS–B products by the appropriate transceivers. This includes (1) receipt and display of TAMDAR data by the modified avionics, (2) receipt of TAMDAR data by the modified ground-based terminal, and (3) display of new FIS–B product uplinks by the modified avionics.

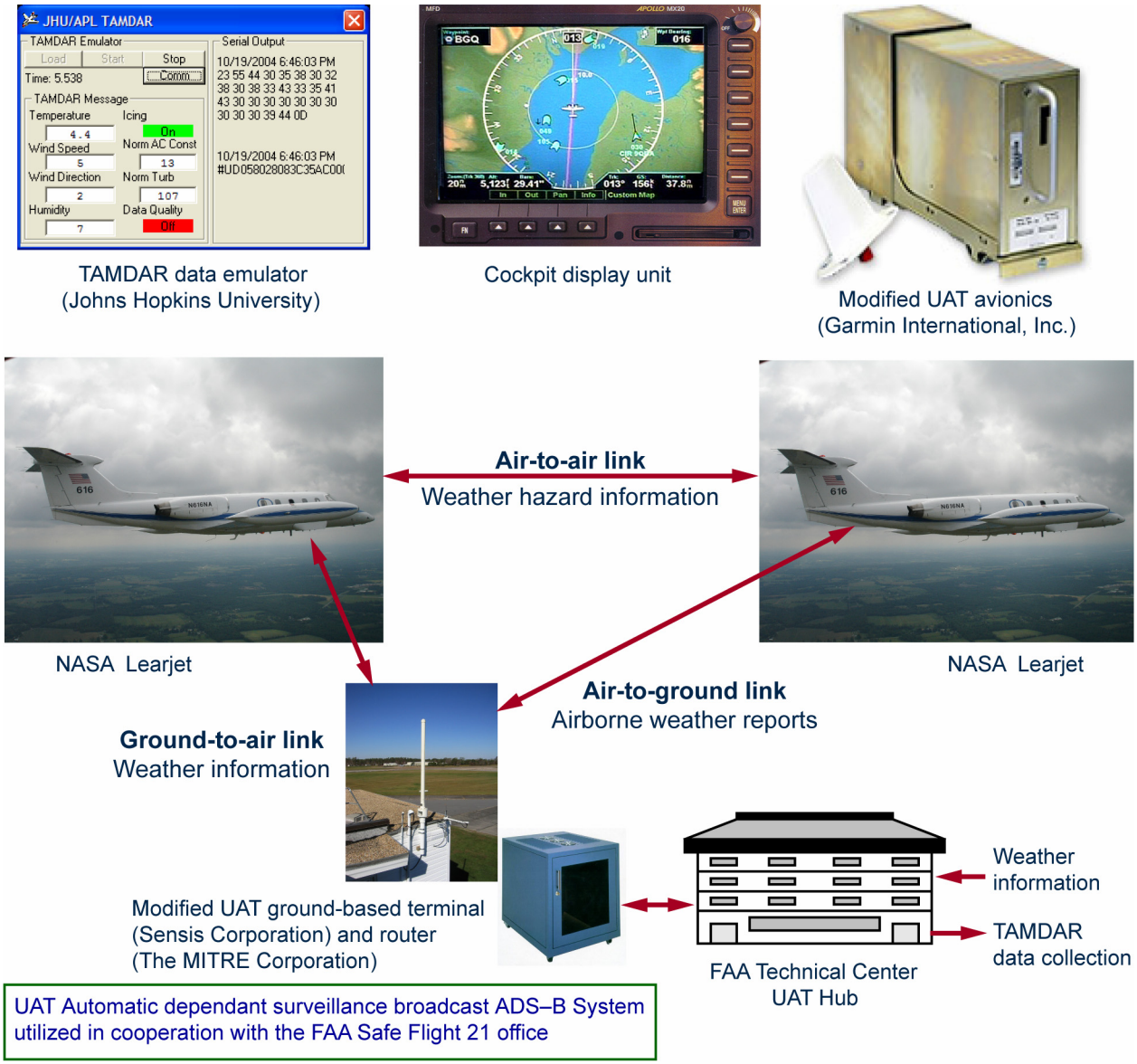

Figure 1.—General aviation and regional aircraft weather information final test configuration. TAMDAR is Tropospheric Airborne Meteorological Data Reporting, UAT is Universal Access Transceiver, ADS–B is Automatic Dependant Surveillance Broadcast, and FAA is the Federal Aviation Administration.

Commercial Transport

The specific goal of the commercial transport flight test was to develop a weather dissemination capability for commercial transport aircraft within a national network that included transmission of onboard sensed turbulence information to ground users (air-to-ground) and between aircraft (air-to-air) and broadcast graphical weather products to the pilot (ground-to-air) (ref. 23). Due to the near-term focus of the WINCOMM project it was necessary to select data links that already resided on commercial transport aircraft or were on a path for installation in the near future. No single data link can currently satisfy the project requirements for air-to-air, ground-to-air broadcast, and air-to-ground two-way communication to this class of aircraft. It was therefore necessary to design hybrid communication architecture to meet the project objectives.

The objective of the commercial transport subtask was to demonstrate a path to implementation in a relevant environment for the following value-added objectives: (1) disseminate data from ownship turbulence events to other aircraft (air-to-air) and ground users (air-to-ground), (2) receive, process, and deliver valid turbulence warnings to the cockpit from other equipped aircraft (air-to-air) and (3) receive and display FIS–B weather products from the ground (ground-to-air) (refs. 24 and 25).

Two near-term aviation communications technologies were selected for commercial transport and evaluated for delivering strategic weather information to aircraft. The 1090ES technology was selected for its ability to broadcast real-time 16-bit-long turbulence alert messages between aircraft (air-to-air) in flight, and VDL Mode 3 technology was selected for its ability to carry both voice and data simultaneously for air-to-ground and ground-to-air data links.

Test flights of the 1090ES and VDL Mode 3 data links were conducted to evaluate the performance characteristics of the two links in a relevant environment. For the testing of the 1090ES air-to-air data links, NASA Glenn equipped and flew two research aircraft. The details and results of the 1090ES and VDL Mode tests are documented in test reports (refs. 26 to 28).

Transport En Route Scenario 1090ES Test Results.—The 1090ES data link was chosen to send broadcast turbulence messages between commercial transport aircraft (refs. 26 and 27). In order to disseminate data from ownship turbulence events to other aircraft, an air-to-air data link is required to receive, process, and deliver valid turbulence warnings to the cockpit from other equipped aircraft. A logical match for air-to-air communication is one of the ADS–B links. On July 1, 2002, the FAA announced the ADS–B link decision, selecting the 1090ES link for air carrier and private/commercial operators of high-performance aircraft. The 1090ES data link was selected by WINCOMM to fulfill the air-to-air data link requirements for the transmission of turbulence alerts.

The turbulence alert message will consist of the following parameters:

(1) Time
(2) Latitude
(3) Longitude
(4) Altitude
(5) Processed normal load
(6) Processed aircraft constant

Standard ADS–B messages already contain the first four parameters, it is only necessary to broadcast two additional parameters. These two additional parameters are each 8 bits long, totaling an additional 16 bits to be transmitted. The additional parameters will be formatted as a payload to a standard ADS–B message, in compliance with the regulation RTCA DO–260.

Laboratory testing for 1090ES was conducted at Sensis Corporation (East Syracuse, NY) and NASA Glenn. Testing utilized the Honeywell KT 73 transponder, connected to an altitude encoder test device, and to a computer interface for transmitting the turbulence alert messages. Sensis 1090ES receiver equipment was mounted in a flight rack and cabled to the KT 73. Messages were successfully transmitted between the KT 73 and the 1090ES remote unit, under multiple attenuation levels.

Commercial transport turbulence alert flights were flown out of Cleveland and no turbulence encounters were sought out. Test turbulence alert test messages were transmitted in order to effectively utilize flight time. The flights consisted of flying two aircraft at various ranges in order to perform limited testing of effective reception of turbulence alert messages. Data files were successfully collected on both aircraft racks and verified transmission and reception of turbulence alert messages (refs. 26 and 27).

Weather Information Dissemination VHF Digital Link Mode 3 Data Link.—The second commercial transport objective is to disseminate data from ownship turbulence events to ground users and receive and display FIS–B ground-to-air weather products. WINCOMM's experiments will also include an air-to-ground request message, in order to facilitate the broadcast of additional value-added weather products, and a reliable air-ground turbulence alert message. With the additional requirements, a bidirectional air-to-ground data link is now needed.

VDL Mode 3 was the data link chosen (refs. 24, 25, 27, and 28) to meet WINCOMM's commercial transport requirement of a reliable air-to-ground link. For these tests, two voice and two data channels were configured with one data channel utilized for weather information communication. A voice channel was utilized during flight testing to enable air-to-ground coordination. TCP/IP was utilized over this link, as the network and transport mechanisms for data transfer. The precedence field within the IP header was mapped to VDL Mode 3 priority levels, to give the weather messages lower priority than other traffic over the link. VDL Mode 3 messages provided reliable air-to-ground turbulence messages and messages for requesting additional graphical weather products. In addition, VDL Mode 3 provided reliable broadcast of ground-to-air FIS–B weather products to the cockpit that conform to RTCA DO–267. The standard weather products that the pilot requests will be transmitted as the channels are available.

VDL Mode 3 uses a time division multiple access (TDMA) scheme, which allows a number of users to access a single RF channel by dividing a 25 KHz channel into four time slots and allocating each time slot to one user and/or application. The channel separation can be utilized to effectively separate noncritical data, like weather information, from critical data such as that from Controller Pilot Data Link Communications.

The turbulence message will consist of the following parameters:

(1) Time
(2) Latitude
(3) Longitude
(4) Altitude
(5) Aircraft weight
(6) Airspeed
(7) Mach number
(8) Processed normal load
(9) Processed aircraft constant

Additional parameters are required beyond those in the turbulence alert message, to allow ground processing of the downlinked messages to be assimilated into weather prediction models and a future national turbulence weather product.

In order to allow pilots to request graphical weather products that may not be part of the standard weather product set, a request message will be transmitted (air-to-ground) to schedule the uplink (ground-to-air) of the desired product. This requested product will be transmitted as the channel is available.

VDL Mode 3 testing was undertaken by NASA Glenn with the cooperation, technical support, and facilities of the FAATC in Atlantic City, NJ, and Rockwell Collins personnel from Cedar Rapids, IA. The research aircraft were equipped and flown by NASA Glenn. Included in the airborne equipment was VDL Mode 3 avionics produced by Rockwell Collins. The FAA supplied the ground station. NASA Glenn additionally supplied the ground-based server that managed the uplink and downlink message traffic. A series of five flights were made during the 3-day period from April 11 to 13, 2005. In the months leading up to the flight tests, NASA Glenn, the FAA, and Rockwell Collins separately conducted extensive laboratory testing at the subsystem level and then jointly participated in two successful ground tests of the integrated system.

The VDL Mode 3 flight tests were conducted in accordance with the requirements and objectives set forth in the Test Requirements Document (ref. 24) and Test Plan (ref. 25) for the WINCOMM Transport En Route Scenario (ref. 28). In addition, written test procedures were developed and followed in the execution of the test flights.

Conclusions.—All equipment modifications were software based in order to allow the reception and transmission of additional messages. All modifications were made within the accepted standards or in a manner consistent with the standards. These changes were made working closely with industry partners with a path toward certification. All VDL Mode 3 weather information messages were successfully transmitted between the aircraft to ground and ground to aircraft, and all 1090ES turbulence alert messages were successfully transmitted between test aircraft (air-to-air). WINCOMM flight tests validate and prove that 1090ES is a viable data link for transmitting turbulence alerts and VDL Mode 3 is a viable data link for both broadcast and two-way weather product dissemination. Figure 2 illustrates the final test configuration of weather information dissemination for commercial transport aircraft.

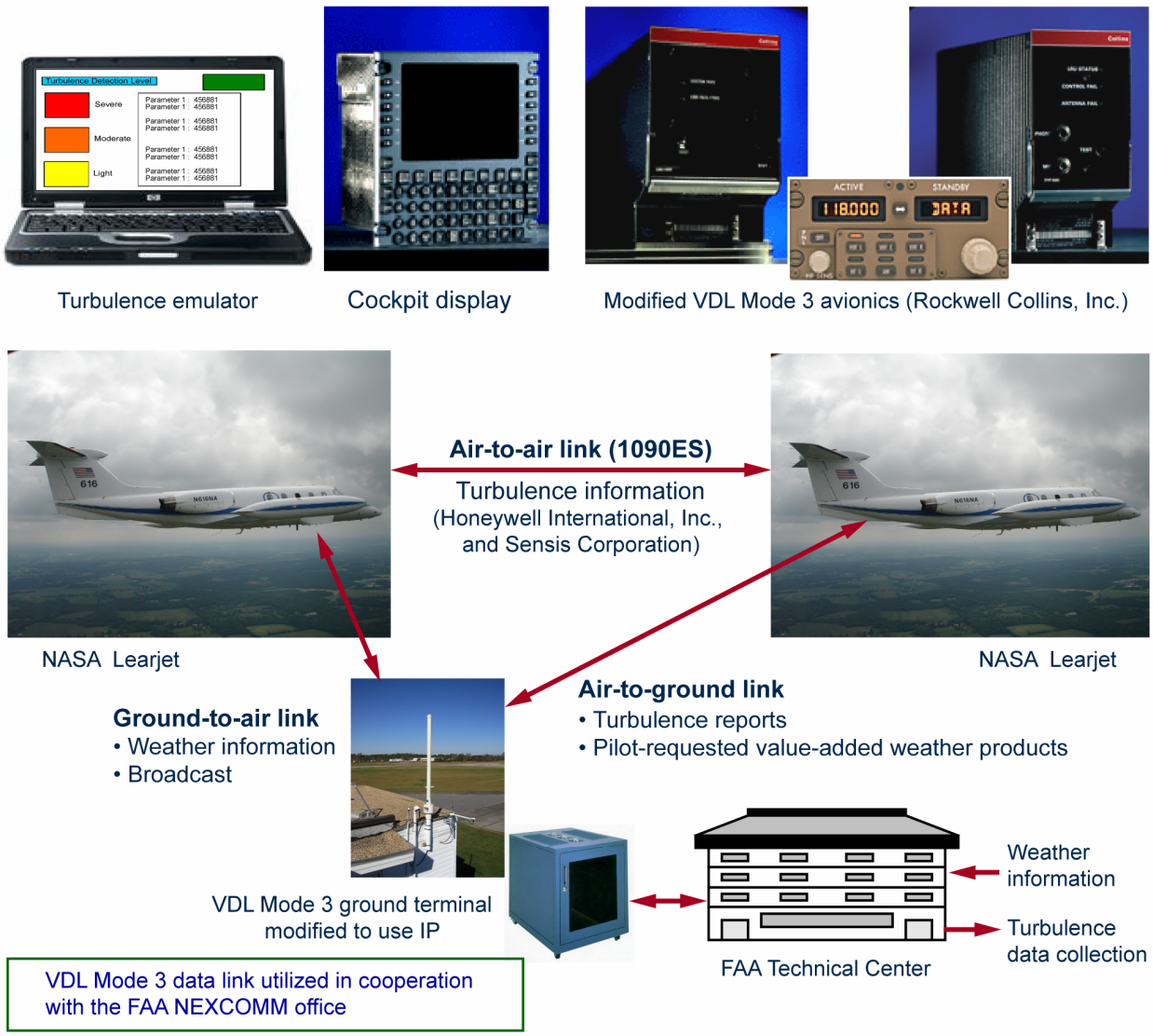

Figure 2.—Commercial transport weather information dissemination final test configuration. VDL is VHF Digital Link (VHF is very high frequency), 1090ES is the 1090 MHz extended squitter, IP is Internet Protocol, and FAA is the Federal Aviation Administration.

Conclusions

The WINCOMM element successfully developed a knowledge base and technologies to a mature technology readiness level (TRL) 6 and validated them in a relevant system environment. When implemented in the National Airspace System (NAS), WINCOMM will be part of the Aviation Safety and Security Project and will contribute to the national goal of reducing the fatal aviation accident rate 80 percent by year 2007. WINCOMM data links have not been implemented in the NAS as of the year 2005. NASA Glenn and the WINCOMM Project encourage government, industry, and academia to develop the knowledge base and technologies from TRL 6 to 9 and implement them in the NAS.

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Appendix—Acroynms

1090ES	1090 MHz extended squitter
ADS–B	Automatic Dependant Surveillance-Broadcast
AIRMET	Airman's Meteorological information
ASIST	Aeronautics Safety Investment Strategy Team
ATC	Air Traffic Control
AvSSP	Aviation Safety and Security Program
AWIN	Advanced Weather Information
CPDLC	Controller-Pilot Data Link Communications
CONUS	continental United States
CRA	Cooperative Research Agreements
EFB	electronic flight bag
E-PIREP	electronic pilot report
FAA	Federal Aviation Administration
FAATC	Federal Aviation Administration Technical Center
FIS	Flight Information Services
FIS–B	Flight Information Services-Broadcast
FISDL	Flight Information Services Data Link
FSU	file server unit
FTP	File Transfer Protocol
GES	ground Earth station
GPS	Global Positioning System
IP	Internet Protocol
ISE	in-service evaluation
JHU–APL	Johns Hopkins University Applied Physics Laboratory
LAN	Local Area Network
METAR	Meteorological Aerodrome Report
MFD	Multifunctional Display
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NEXRAD	Next-Generation Radar
OAI	Ohio Aerospace Institute
PIREP	pilot reports
PWA	Pilot Weather Advisor
RTCA	Radio Technical Commission for Aeronautics
SBIR	Small Business Innovation Research
S-DARS	Satellite Digital Audio Radio Service
SIGMET	Significant Meteorological information
SPECI	Aviation Selected Special Weather Report
SWIS	Satellite Weather Information Service
TAF	Terminal Area Forecast
TAMDAR	Tropospheric Airborne Meteorological Data Reporting
TCP/IP	Transmission Control Protocol/Internet Protocol
TDMA	Time Division Multiple Access
TIS–B	Traffic Information Service-Broadcast
TRL	technology readiness level
UAT	Universal Access Transceiver

VDL	VHF Digital Link
VHF	very high frequency
WINCOMM	Weather Information Communications
WxAP	Weather Accident Prevention

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13. ABSTRACT ***(Maximum 200 words)***

The purpose of the NASA Glenn Research Center Weather Information Communications (WINCOMM) project was to develop advanced communications and information technologies to enable the high-quality and timely dissemination of strategic weather information between the flight deck and ground users as well as tactical turbulence hazard information between relevant aircraft and to the ground. This report will document and reference accomplishments on the dissemination of weather information during the en route phase of flight from ground-based weather information providers to the flight deck (ground-to-air), from airborne meteorological sensors to ground users (air-to-ground), and weather turbulence and icing hazard information between relevant aircraft (air-to-air). In addition, references in this report will demonstrate the architecture necessary to implement and perform successful transmission and reception of weather information to the cockpit, show that weather information flow does not impact "normal" traffic, demonstrate the feasibility of operational implementation, and lay foundation for future data link development.

14. SUBJECT TERMS
Data links; General aviation; Broadcasting; Turbulence; Messages; Flight tests; Cockpit; Aircraft safety; Flight safety; Ground stations; Commercial aircraft; Avionics; Mobility; Forecasting; Transport aircraft; Safety; Communication networks; Situational awareness

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