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Phase I—Aviation Weather Communication Requirements

Foreword

The purpose of this study is to support NASA efforts to assure the availability of communication technology and systems for providing future weather related information to planes in-flight to make air travel safer under all weather conditions.

The study is to be completed in two phases. This phase, *Aviation Weather Communication Requirements,* is to determine the requirements for ground-to-air data communications that will be needed to support present and future aviation weather tools and products. The next phase will evaluate the requirements against current and planned communication systems to determine where to invest manpower and monetary resources for new technology development.

This phase I report is submitted to NASA John H. Glenn Research Center at Lewis Field by Lockheed Martin Aeronautical Systems as a contract deliverable.

The Lockheed Martin Program Manager for this study is:

Mr. John W. Ball
Lockheed Martin Aeronautical Systems
86 South Drive
Marietta, GA 30063–0670
Voice: 770–494–5531
FAX: 770–494–0970
email: jack.ball@lmco.com

The Lockheed Martin Team consists of the following organizations and individuals:

Company	Name	Contribution
Lockheed Martin Aeronautical Systems	John W. Ball Roger G. Herron E. T. Nozawa	Program Manager Technical Lead Weather Information Systems, Sources and Distribution
AvCS Inc.	Edwin A. Thomas Raoyd D. Witchey	Aviation Weather Research and User Requirements

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APPENDICES

1 Introduction

In 1997 the White House Commission on Aviation Safety and Security recommended the establishment of a national goal of reducing fatal aviation accident rate by 80 percent by 2007. As a result of this recommendation, NASA formed the Aeronautics Safety Investment Strategy Team (ASIST), and weather concerns were identified as a sub-element within this team. Weather is one of many factors impacting aviation accidents as well as responsible for approximately two-thirds of air carrier delays- a four billion dollar cost, of which 1.7 billion dollars are considered avoidable. NASA started the Aviation Weather Information (AWIN) program to address the weather aspects of aviation safety.

The goal of the AWIN program is to provide improved weather information (not simply data) to users in the National Airspace System, and to foster the improved usage of this information. The emphasis of the AWIN project is to provide this information to the flight deck. NASA envisions a futuristic system that would allow aircraft to be both a source and user of weather information. Airborne sensors would provide data for weather systems on board the plane, on the ground and in other aircraft. In the cockpit would be easy-to-read, real-time displays that can show weather across the country, not just a limited number of miles ahead. That way pilots could more easily monitor possible trouble spots and make better, more cost-efficient routing decisions.

It is envisioned that many of the new weather tools will present severe demands and challenges to the ground-to-air communications channels. This is due to the anticipated increased quantity of weather data required to be transported over the various channels for safety and regularity of flight. Aeronautical communications will thus need to be able to accommodate the increased traffic associated with the dissemination of tactical and strategic weather information to the cockpit. This study focuses on the current and future aeronautical weather communication requirements and explores systems and technologies that are available or will be needed to meet those requirements.

2 Scope

The scope of the first phase of the study is to explore all types of weather products that are available or envisioned for the future that must be transmitted to the cockpits of all types of aircraft. The second phase of the study will address communication systems and technology to support the necessary upgrades to weather information in the cockpit that are required to meet the aviation safety enhancement goals. The focus is on data communications (text, graphics and digitized voice) rather than analog voice transmissions as are common today with the expectation that future air-to-ground communications will be dominated by various forms of aeronautical data link. The study concentrates on weather and communication systems in the United States.

3 Data Communication Requirements for Aviation Weather

3.1 General Considerations

3.1.1 Characterizing Future Cockpit Weather Information

3.1.1.1 Text / Voice Weather

Text messages and voice are an indispensable part of today's weather information flow, and will continue to be into the foreseeable future. They are well established, immediate, familiar, and useful, suggesting no reason to believe they will become obsolete. In fact, METAR and TAF text sequences communicate the most fundamental of all weather information—ceiling and visibility—providing the legal (regulatory) basis for filing a flight plan, for designating an alternate airport, and for starting an instrument approach. In the future, graphical weather products will augment and supplant some text and voice usage in the cockpit. It seems likely, therefore, that text and voice exchanges will continue to increase with air traffic volume, though not at the same rates we see today.

3.1.1.2 Graphical Weather

A significant safety argument for graphical weather is its immediacy and impact. This is literally a case where a "picture is worth a thousand words." Studies have shown humans more quickly and completely comprehend a picture than they do written or spoken words, in addition, coded information such as weather data adds yet another level of complexity. Industry statistics indicate that in many weather-related aviation accidents, the appropriate weather was forecast and available, and often actually in the possession of the pilot. Even so, either the pilot did not fully regard the information available, misinterpreted it, or gave it less weight than it deserved.

As technology, communications, and weather prediction algorithms improve, graphical weather information has the power to reduce pilot judgment errors related to weather. It is logical to assume, and individual interviews confirm, that more accurate predictions confined to smaller areas will carry more weight with pilots. If the information is in the form of a picture, especially one quickly and easily available in the cockpit, the information becomes compelling enough to change behavior, thus making airborne decisions both safer and more economical. This process has already started in business aviation and at some commuter airlines.

The industry's current move toward graphical weather is likely to increase more rapidly than is commonly expected. Experience in the cellular, computer, and internet industries strongly suggest that as information becomes more accurate, accessible, and affordable, volume and demand increase very quickly. Historical increases in the use of ACARS data link in the aviation industry serve to reinforce this view.

3.1.1.3 A Global Solution

As aviation expands, a pilot may have to deal with globe-spanning weather on a single flight. Although some areas of the world will continue to be less accessible and feature correlatively less accurate data and forecasts than others, safety and economics dictate that the *transmission* and *presentation* of whatever information *is* available must be as seamless, world-wide, integrated, and timely as possible. U.S. aviation cannot afford a U.S.-only solution; we must work to provide a truly global data and communication network for aviation weather.

3.1.1.4 Information versus Data

As technology advances, more and more "data" becomes available to the pilot. One of the increasing concerns in the aviation industry is that the pilot may become so overloaded with data that s/he may delay a critical decision while sifting through multiple satisfactory options. In an effort to combat data overload, users, airframe manufacturers, data suppliers, and avionics suppliers are all striving to present integrated "information," rather than simply "data."

Weather *information* implies data that have been collected, analyzed, integrated, and placed into context before being presented to the pilot. In the future, weather *information* will likely grow hand-in-hand with artificial intelligence that anticipates what the pilot needs to know at a given moment in each particular phase of flight. As the industry grows into a Free Flight environment, weather will become one of many outside forces which shape pilot safety and efficiency decisions.

3.1.1.5 Integrated "Threats"

In a future which includes Free Flight, a pilot will face many "threats" to air safety. Besides hazardous weather, these include the state of the Air Traffic System (facilities status, congestion), location of terrain and obstacles, active Special Use Airspace, etc. A popular line of thinking anticipates integrating various airborne "threats" into a single presentation or display. Weather products represent one of the largest, most dynamic, future data sets and may, therefore, drive the communications requirements. While this study does not focus on hazards other than weather, it seems advisable to anticipate information on these other hazards will be competing for the same limited bandwidth. Another feature of integrated "threats" is that one condition might be hazardous enough for a given airplane to avoid, while hardly bothering another. Icing is a good example. A Cessna 152 pilot with no anti-icing equipment in Instrument Meteorological Conditions (IMC) may be in grave danger while a Boeing 777 pilot in the same conditions may hardly notice. To deal with this disparity, there are efforts underway to normalize, or index, hazards in an absolute manner so that they may be sent to a particular aircraft system where they are processed, then displayed in a relative context. This on-board processing will take into account equipment capabilities, mission requirements, pilot limitations, etc., then display the appropriate relative threat level for that particular aircraft and its occupants.

3.1.2 Characterizing Cockpit Weather Decisions

The industry generally recognizes two kinds of airborne weather-related decisions, "tactical", and "strategic." Reviewing what each entails, and combining that knowledge with current weather research, reveals some interesting insights.

3.1.2.1 Tactical Decisions

"Tactical" decisions are essentially reactive penetration decisions which need to be made quickly with whatever information is at hand, as the pilot tries to decide the safest way to negotiate an immediate hazard. For commercial carriers, pilots generally do not have the time or resources to coordinate these decisions with their dispatchers. On rare occasions they might not even coordinate with Air Traffic Control, invoking their emergency authority when extreme situations dictate. These tactical weather decisions are currently made on the basis of on-board sensors: what a pilot sees out the window, feels in the seat of his pants, hears on the radio, or views on the weather radar.

Tactical weather decisions are often safety related and time-critical, typically being forced when a pilot finds him or herself already in a potentially dangerous weather condition. Tactical decisions may include rapidly changing course to escape thunderstorms, wind shear, icing, or turbulence—time is of the essence as a pilot negotiates a hazard s/he probably wished to avoid to begin with. An arbitrary, but convenient dividing line between "tactical" and "strategic" decisions might be at approximately fifteen minutes ahead of the aircraft's present position, roughly corresponding to the useful range of on-board weather radar and human vision. (See the figure below)

3.1.2.2 Strategic Decisions

Strategic decisions, on the other hand, tend to be more pro-active, planning for avoidance rather than penetration. These decisions are characterized by the ability to identify a hazard early, collaborate on a plan to avoid it, and make relatively small, well-coordinated changes to the flight trajectory.

Strategic weather decisions are typically based on off-board sensor data, and information derived from that data. PIREPs, ARTCC advice, satellite imagery, updated forecasts, NEXRAD imagery, etc. are a few sources of the data and information that influence strategic decisions. In contrast to tactical decisions, the strategic decision arena begins beyond on-board sensor range and extends forward to the destination. In this arena, there is more time to collect new information, discuss it with dispatch, flight watch, and/or air traffic, plan a new course of action if needed, and implement that plan in a coordinated fashion.

Though tactical decisions can be critical, strategic decisions might be argued to be even more important. This is because a strong strategic decision process can avoid the need to face tactical decisions to begin with. In fact, this logic is at the core of the thrust to provide strategic weather information to the flight deck.

The strategic arena can be increasingly viewed in two segments, far-term and near-term. (See the figure below) This is primarily due to new forecasting capabilities and resulting weather products which are beginning to appear. In the near-term segment, these "nowcasts" are short-range forecasts targeted to provide accurate information of greater fidelity than formerly available for up to the next 60 minutes. For the purposes of this discussion, a "nowcast" can be considered to be an automatically generated, computer-produced product, synthesized from multiple sensors.

3.1.2.2.1 Far-term Strategic

Generally speaking, we currently have minimally adequate data and information to make *far-term* strategic weather decisions in today's commercial and military aviation environments. The extensive ground network designed to flight-follow these aircraft has time and resources dedicated to aid in making far-term strategic weather decisions which are based on long-range forecasts of sometimes volatile weather conditions. The resulting forecasts are understandably not precisely accurate, and therefore often serve as a warning, alerting a pilot that a future decision will have to be made at the appropriate time and location. Cockpit graphical information will greatly enhance a pilot's ability to visualize and avoid these upcoming hazardous situations. Moreover, on-board graphics in any arena will reduce already congested voice radio traffic, especially in the vicinity of bad weather conditions.

The general and business aviation communities, on the other hand do not always have a similar ground network in place and will benefit even more dramatically from *far-term* strategic graphical weather in the cockpit. Though they, too, can gather textual and/or audio information, it is not nearly as compelling or complete as a picture. Aviation statistics strongly imply that strategic graphical information in GA cockpits will be a compelling force to reduce weather-related accidents.

3.1.2.2.2 Near-term Strategic

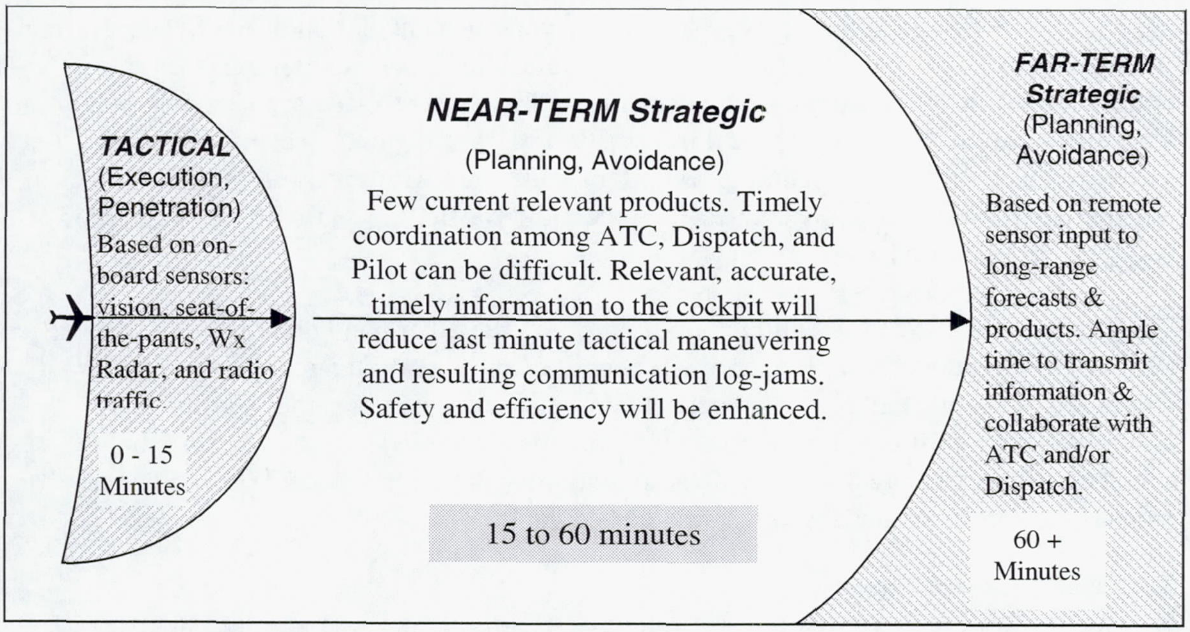
Perhaps the most promising arena for graphical weather in the cockpit lies between 15 minutes and 60 minutes ahead of the airplane's current position. This is the time frame when avoidance planning is reaching a crescendo. Pilots request and receive advice from ARTCC controllers while the controllers request and receive PIREPs. At the same time pilots are also often overwhelming dispatch or flight watch radio frequencies in a search for even more information. In the cockpit, pilots are doing their best to filter the resulting cascade of verbal information and construct a meaningful "picture" in their heads while not missing any flight-critical directions or data. If successful, a pilot can make a relatively small change in planned flight path and avoid an upcoming hazard, altogether.

In this *near-term* strategic arena, there is still time to make a strategic avoidance decision. Fortunately, the weather hazard in question is becoming mature and predictable enough to base a concrete decision on with a good degree of accuracy. Unfortunately, up to the present, almost no meaningful near-term weather hazard information is easily available to the flight deck, and certainly not in graphical form.

Current weather research promises to fundamentally alter the near-term strategic arena. Improved "nowcasts" promise to help pilots make earlier, smarter, safer decisions *in the immediate future*—15 to 60 minutes ahead of the aircraft. As a result, much of the last minute, relatively high-threat tactical maneuvering, and resulting radio traffic, can be avoided in the immediate vicinity of a major "hazard," such as a rapidly building line of thunderstorms.

With the advent of accurate nowcasts available to the flight deck in graphic form, the *near-term* strategic arena is likely to afford maximum safety and economic benefits. (See the figure below)

Three Weather-Related Decision Arenas



3.1.3 The Impact of Cockpit Certification Levels

Choosing how to display weather (and other previously mentioned "hazards") will have a profound effect on cockpit architecture. The current trend of certifying "advisory" or strategic information to level "D," and "regulatory" information to level "C" provides a solid basis for anticipating future requirements.

Barring a fundamental change in the certification methodology of flight software (Do 178-B), it seems likely that most near-term and far-term strategic weather and other hazards will be displayed for "informational purposes" only. Continuing the current trend in certifying such systems to Level "D" should ensure that cockpit graphical weather is affordable. Elevating certification requirements could almost certainly keep graphical weather out of the cockpit, defeating the entire AWIN concept.

3.1.4 Process Considerations in Decision Making

Weather prediction algorithms are improving while weather measurements are becoming more frequent, more wide-spread, more densely populated, and more accurate—leading to potentially new and useful weather products. Other than the considerations mentioned previously, a number of process considerations are likely to influence what weather products are displayed in the cockpit, as well as how they will be used.

3.1.4.1 Pilot – Dispatch – Air Traffic Managers

Today, any one of these three functions may posses information that at least one of the others do not have. For instance, the airplane's weather radar can detect thunderstorms a short distance ahead better than either ATC or Dispatch. ATC is often the only one who has a good idea of where turbulence is. Dispatch usually has the most accurate "big picture" about convective activity along a specific route of flight. Consequently, avoiding weather hazards often congests available voice radio frequencies as the three functions try their best to meet individual requirements.

The prospect of better weather information in the cockpit, leaves both controllers and dispatchers wary of being left "out of the loop." To fulfill their regulatory responsibilities, dispatchers believe they should have equal access to, perhaps even filtering, the information that goes to the airplane. ATC has similar concerns as they consider the implications of Free Flight and the changing roles of pilots and Air Traffic *Managers,* especially in the presence of weather. As a result, pilots are expressing concern that political maneuvering could leave them without cockpit access to the safety information technology is finally promising.

Ensuring equal access to information by all three groups of personnel is essential. Providing "parity of information," if not identical information where possible, will ensure both maximum cooperation and understanding, while operating in the safest, most efficient manner.

Dispatch and Air Traffic Controller political processes will certainly help shape the final character of future weather in the cockpit. Even so, the safety and efficiency benefits provided by graphical weather in the cockpit will eventually prevail. These general benefits include safely avoiding weather hazards, avoiding them more efficiently, reducing radio congestion, and improving pilot, dispatcher, and air traffic coordination.

3.1.4.2 Major Airlines

The major airlines have a significant ground support system and will initially resist equipping their cockpits with graphical weather. Their primary concerns will be extensive costs to upgrade cockpits with new equipment and communications capabilities. Doing so must show an early return on investment that cannot yet be proven.

Major carriers are most likely to equip new airplanes for weather in the cockpit with the capability already built-in. Within five to ten years, such equipment will probably become standard in the major airlines, as it is beginning to be on the regional jets some commuter airlines are now purchasing.

There are a variety of options for retrofitting older fleets. Problems include display location, adding communications capabilities, upgrading radios, etc. One of the most likely scenarios that will make a weather information retrofit attractive is one done in conjunction with applications destined for customers in the cabin.

3.1.4.3 Commuter Airlines

Commuter flights spend more time in the weather, since they generally fly a greater percentage of their flights at lower altitudes. Consequently, graphical weather in the cockpit can be more important to them than it is to the major airlines. Moreover, many commuters are in a convenient position of buying new Regional Jets at this time. Some have already capitalized on this opportunity by ordering planes that feature graphical weather in the cockpit, enabled by flexible air-to-ground communications and advanced avionics technology. In general, commuter airlines are in a more "nimble" marketplace and will, therefore, be earlier adopters of cockpit graphical weather than the major airlines.

3.1.4.4 Business Aviation

Some high-end business airplanes are also already equipped with first-generation weather in the cockpit. These airplanes sometimes blur the distinction between what external information is available to the cockpit versus to the cabin, since the cabin occupants are essentially both owner and customer. With the primary job of ferrying high-level executives whose time is critically expensive, business airplanes are often the first to equip with new capability designed for efficiency by enhancing cabin productivity with new technology. A significant by-product of the enhanced technology is improved safety. Look to business aviation to be the earliest adopters of equipment, products, and new communications—both here in the CONUS and internationally.

3.1.4.5 General Aviation

General aviation airplanes spend the most time at lower altitudes, and are therefore often the most highly threatened by weather. Predictably, however, they also have the least money to spend on graphical weather in the cockpit.

Currently about 3-4% of GA airplanes are equipped with weather radar that costs a minimum of roughly $15,000. Nearly 15% are equipped with a "stormscope," costing about $3,000 to $5,000. AOPA member surveys indicate that the low end GA pilots will spend money to avoid bad weather, but only about $1500 total for the purchase and installation of all the needed equipment. Considering the multi-functional nature of future weather product systems, it seems reasonable to assume that even the GA community will begin to equip for in-flight weather products. Fortunately, their slower flight speeds make smaller, regionalized broadcasts of relevant weather products more useful, effective, and affordable.

Another significant aspect of the GA world is the FAA's Flight Information Service (FIS) proposal to dedicate four VHF frequencies to uplink weather information. While this is a good start, this and other datalink schemes must also consider the continuing need to *downlink* current conditions to feed the ever-improving numerical models which generate the products future pilots will depend on.

3.1.4.6 Military Aviation

The requirements of military transport aircraft are generally very similar to civilian airline requirements. They will likely use the same products projected later in this document, probably even sharing some of the commercial third-party providers. They do, however, have additional tactical interests related to combat situations, hostile airspace or clandestine operations which will translate into specific classified products produced internally. While they will likely equip to share the civilian data "pipeline," they will also no doubt develop their own protected communications which will be secure and available during wartime. As they do, the civilian sector should stay alert for military methods, processes, and algorithms which civilian aviation could build on to improve their own systems.

3.2 Current In-Flight Weather Information, Tools and Products

Today, pilots have a wide variety of sources for getting the weather information they need to plan their flights. These include telephone access to flight service stations, special radio and television aviation forecast, face-to-face briefings from weather specialist, dedicated terminals at airports, and personal computer access to weather services as well as a multitude of web sites on the internet. The information available ranges from a printout of coded text to full color moving maps of local and national weather systems. While this vast array of information and tools is extremely useful in planning a flight to avoid dangerous weather situations, the sources of weather information available to the pilot during a flight are more limited.

Currently, almost all aviation weather information provided in-flight in the USA is in analog voice format or textual weather information via ACARS. While the focus of this study is the communication needs for *digital* weather data transmission to the cockpit, it is assumed that the current information will be provided over various forms of data link as soon as data link becomes operational and widely used by the aviation industry. For this reason the analog voice broadcast and weather resources available by radio from flight service stations are included in this investigation of current aviation weather systems.

3.2.1 In-Flight Weather Products and Delivery Systems

The "official" sources for in-flight weather information today include: sources available over voice radio, in-flight weather broadcast, and products accessible over ACARS. National and international standard weather products and formats have been defined and are used by in-flight delivery systems to provide the weather information pilots need under various conditions and circumstances. These products are introduced here for explanation of today's in-flight delivery systems and described in more detail in Appendix A for communication requirements analysis.

- **Aviation Routine Weather Report (METAR/SPECI)** - The METAR is an international standard code format for hourly surface weather observations. Weather related information provided includes: wind, visibility, weather type, obstructions to visibility, sky conditions, temperature, dewpoint, and altimeter setting.
- **Terminal Aerodrome Forecast (TAF) -** A Terminal Aerodrome Forecast (TAF) is an international standard format for providing a concise statement of the expected meteorological conditions at an airport during a specified period (usually 24 hours).
- **Area Forecast (FA) -** An area forecast (FA) is a forecast of Visual Flight Rules (VFR) clouds and weather conditions over an area as large as several states. It must be used in conjunction with the AIRMET Sierra bulletin for the same area in order to get a complete picture of the weather. The area forecast together with the AIRMET Sierra bulletin are used to determine forecast en route weather and to interpolate conditions at airports which do not have terminal forecasts (TAFs) issued. FAs are issued 3 times a day for each of 6 areas in the contiguous 48 states, one in Alaska and one in Hawaii. Each FA consists of a 12 hour forecast plus a 6 hour outlook.
- **Severe Weather Forecast Alerts (AWW)/ Severe Weather Watch (WW)** - These messages define areas of possible severe thunderstorms or tornado activity. The messages are unscheduled and issued as required by the National Severe Storm Forecast Center at Kansas City, Missouri.
- **Center Weather Advisories (CWA)** - A CWA is an unscheduled weather advisory issued by Center Weather Service Unit meteorologists for ATC use to alert pilots of existing or anticipated adverse weather conditions within the next 2 hours. A CWA may modify or redefine a SIGMET.
- **AIRMET (WA) -** AIRman's METeorological Information advises of weather of less severity than that covered by SIGMETs or Convective SIGMETs but which is of operational interest to all aircraft and potentially hazardous to aircraft having limited capability because of lack of equipment, instrumentation, or pilot qualifications. AIRMETs cover moderate icing (AIRMET Zulu bulletin), moderate turbulence (AIRMET Tango bulletin), and visibility conditions and/or extensive mountain obscurement (AIRMET Sierra bulletin). AIRMET items are issued for weather conditions affecting or forecast to affect an area of at least 3000 square miles at any one time. AIRMETs are routinely issued for 6 hour periods and are also amended as necessary due to changing weather conditions or issuance/cancellation of a SIGMET.
- **SIGMET (WS) / Convective SIGMET (WST) and International SIGMET**- A SIGMET (SIGnificant METeorological Information) is a weather advisory that covers severe and extreme turbulence, severe icing, and widespread dust or sandstorms that reduce visibility to less than 3 miles. A Convective SIGMET may be issued for any convective situation which the forecaster feels is hazardous to all categories of aircraft. Convective SIGMET bulletins are issued for the Eastern (E), Central (C), and Western (W) United States for regions affecting 40% or more of an area at least 3000 square miles. International SIGMETs are weather advisory covering flight

routes over US coastal waters. Bulletins are issued hourly. The text of the bulletin consists of either an observation and a forecast or just a forecast.

- **Winds Aloft -** Winds aloft are computer prepared and contain forecast wind direction and speed as well at forecast temperatures. Forecast winds and temperatures aloft are prepared for: 6,000, 9,000, 12,000, 18,000, 24,000, 30,000, 34,000, and 39,000 feet
- **Pilot Reports (PIREP) -** A PIREP is a report of meteorological phenomena encountered by aircraft in flight. Pilots report such information as: thunderstorms, icing, turbulence, windshear, cloud base, tops and layers; flight visibility; precipitation; visibility restrictions such as haze, smoke and dust; winds at altitude; and temperature aloft. This information is combined with other observations to present a complete picture of weather conditions.

The weather products packaged in the formats described above are transmitted to the cockpits of planes in a variety of ways. Initial weather information used in flight planning may be provided in textual format integral to the flight plan, via telephone, via special computer terminals or in face-to-face interviews with aviation weather experts at Flight Service Stations. In-flight, planes may obtain weather information through a variety of broadcast and radio accessible sources. For the most part these are over analog radios. The only *digital* communication system available today in the USA that allows access to in-flight weather information is ACARS. These three modes of distributing in-flight weather information are described below.

3.2.2 Aviation Weather Call-Up Services

3.2.2.1 Flight Service Stations / Automated Flight Service Stations (FSS/AFSS)

Flight Service Station are air traffic facilities which provide pilot briefing, en route communications and VFR search and rescue services, assist lost aircraft and aircraft in emergency situations, relay ATC clearances, originate Notices to Airmen, broadcast aviation weather and NAS information, receive and process IFR flight plans, and monitor NAVAIDs. In addition, at selected locations, FSSs provide En route Flight Advisory Service (Flight Watch), take weather observations, issue airport advisories, and advise Customs and Immigration of transborder flights.

There are two types of flight service stations in use today, the original FSS and the newer Automated Flight Service Station (AFSS). Most of the older FSSs have been consolidated and replaced with AFSSs. FAA flight service facilities in operation today include 61 AFSS, 3 Flight Service Stations, as well as 14 FSSs in Alaska operated on a rotational plan, and 17 Auxiliary FSSs.

The FAA Flight Service Station (FSS and AFSS) provides more aviation weather briefing service than any other government service outlet. The FSS or AFSS provide preflight and in-flight briefings, transcribed weather briefings, scheduled and unscheduled weather broadcast, and furnishes weather support to flights in its area.

Flight service station (FSS) can be contacted by pilots over voice radios on dedicated FSS frequencies. Often these frequencies are either 122.2, 122.4, or 122.6 MHz, although other frequencies are sometimes allocated to FSS/AFSS.

3.2.2.2 En route Flight Advisory Service (EFAS)

En route Flight Advisory Service (EFAS) also known as "Flight Watch" is a service designed to provide en route aircraft weather advisories pertinent to their type of flight, route and altitude. EFAS provides communication capabilities for aircraft flying at 5,000 feet through 17,000 feet on a common frequency of 122.0 MHz. Also, discrete frequencies have been established for altitudes between 18,000 and 45,000 feet. These discrete frequencies are sometimes useful for getting weather information below 18,000 feet but communication on the discrete frequencies at these altitudes is not always reliable.

EFAS is provided by specially trained aviation weather specialist in selected AFSSs controlling multiple remote communication outlets such that coverage is available throughout the US and Puerto Rico from 6:00 a.m. to 10 p.m. In addition to getting weather information, pilots provide information about the weather they are observing in-flight in form of PIREPs to the EFAS stations.

EFAS is intended for weather updates only. Pilots can use flight watch to keep track of such things as the surface conditions at their destination, learn of any pilot weather reports along their route, and follow the progress of any fronts or convective activity that may be coming their way.

3.2.3 Aviation Weather In-Flight Broadcast

3.2.3.1 Weather Advisory Broadcast

Air Route Traffic Control Centers (ARTCCs) broadcast a Severe Weather Forecast Alert, Convective SIGMET, SIGMET, or Center Weather Advisory (CWA) alert once on all frequencies, except emergency, when any part of the area described is within 150 miles of the airspace under their jurisdiction. These broadcast contain SIGMET or CWA identification and a brief description of the weather activity and general activity affected.

3.2.3.2 Hazardous In-flight Weather Advisory Service (HIWAS)

HIWAS is a continuous broadcast of recorded in-flight weather advisories, carried over selected VOR outlets defined as an HIWAS Broadcast Areas. Severe Weather Forecast Alerts (AWW), SIGMETs, Convective SIGMETs, Center Weather Advisories (CWAs), AIRMETs, and urgent PIREPs are all broadcast on HIWAS. As soon as one of the above statements is issued and/or updated and recorded, it's immediately broadcast on HIWAS and continues until an update is issued. HIWAS has been adopted as a national program and in areas where HIWAS is commissioned, Air Route Traffic Control Centers (ARTCC), tower facilities, and Flight Service Stations (FSS) will not broadcast in-flight weather advisories. They do, however, issue an alert announcement, once when it is received, that is broadcast on all except emergency frequencies, which will include VOR frequency instruction, number, and type of advisory; e.g., AWW, SIGMET, Convective SIGMET, or CWA.

3.2.3.3 Transcribed Weather Broadcast (TWEB)

Transcribed Weather Broadcast (TWEB) is a continuous broadcast of meteorological and aeronautical data that has been recorded on tapes for distribution over selected low-frequency (190-535 kHz) navigational aids (L/MF ranges or H facilities) and/or VORs(108.0 to 117.95 MHz). The TWEB is based on a route-of-flight concept.

Broadcasts are made from a series of individual tape recordings, and changes, as they occur, are transcribed onto tapes. The information provided varies depending on the type of equipment available. Generally, the broadcast contains route-oriented data with specifically prepared NWS data, forecast, in-flight advisories, and winds aloft plus preselected current information, such as weather reports (METAR/SPECI), NOTAM, and special notices. The order and content of the TWEB transcription as follows:

1. Introduction
2. Synopsis
3. Adverse Conditions
4. TWEB Route Forecast
5. Outlook (Optional)
6. Winds Aloft
7. Radar Report
8. Aviation Weather Observations (METAR/SPECI)
9. Pilot Reports (PIREP)
10. Notice to Airmen (NOTAMS)
11. Military Training Activity
12. Density Altitude
13. Closing Announcement

The TWEB route forecasts are prepared by National Weather Service Forecast Offices (WFOs) for more than 300 selected short-leg and cross-country routes over the contiguous U.S. WFOs prepare synopses for the routes in their areas. The Synopsis is a brief statement of frontal and pressure systems affecting the route during the forecast valid period. Forecast sky cover (height and amount of cloud bases), cloud tops, visibility (including vertical visibility), weather, and obstructions to vision are described for a corridor 25 miles either side of the route. Cloud bases and tops are always Mean Sea Level (MSL) unless noted. Ceilings are always above ground level.

The TWEB route forecasts and synopses are issued by the WFOs three times per day. Route forecasts are valid for 15 hours. This schedule provides 24-hour coverage with most frequent updating during the hours of greatest aviation activity.

3.2.3.4 Automated Weather Observing Systems

Automated Weather Observing Systems (AWOS) and Automated Surface Observation Systems (ASOS) consist of various sensors, processors, computer-generated voice subsystems, and a transmitter to broadcast local, minute-by-minute weather data directly to pilots.

The implementation, and commissioning of a large number of automated weather observing stations - Automated Weather Observing Systems (AWOS) and Automated Surface Observation Systems (ASOS) is nearing completion. While the two automated systems, AWOS and ASOS, are similar in their mission support to aviation, the standard configurations and weather products produced differ slightly.

There are four basic classifications of AWOS systems based on functionality. The classification levels are as follows:

AWOS-A	Only altimeter settings
AWOS-1	Same as AWOS-A plus wind, temperature, dew-point and density altitude
AWOS-2	Same as AWOS-1 plus visibility
AWOS-3	Same as AWOS-2 plus cloud/ceiling data

An enhanced AWOS-3 has been approved that will include the capability to report precipitation type (AWOS-3 P), thunderstorm/lightning occurrence (AWOS-3 T), or both (AWOS-3 P/T). The reporting of thunderstorms and/or lightning is determined from the occurrence of lightning within 30 nautical miles (rim) of the Airport Reference Point (ARP). If lightning is detected within 10 nm of the ARP the AWOS will report a thunderstorm and lightning either at the airport (within 5 nm) or in the vicinity (5 to 10 nm). If the lightning is between 10 and 30 nm the AWOS will report lightning distant and the appropriate octant or position.

The ASOS program will result in 1,700 systems being installed throughout the United States in a joint effort of the NWS, FAA, and Department of Defense (DoD). ASOS is designed to support aviation operations and, at the same time, support a variety of climatological, hydrological, and meteorological activities. Each ASOS contains the following basic set of sensors:

1. Cloud height indicator (one or possible three)
2. Visibility sensor (one or possible three)
3. Precipitation identification sensor
4. Freezing rain sensor (at selected sites)
5. Pressure sensor (two sensors at small airports, three at large airports)
6. Ambient temperature/Dew point temperature sensor
7. Anemometer (wind direction and speed sensor)
8 Rainfall accumulation sensor

Aviation weather services provided at ASOS sites varies from just the automated measurements of the ASOS (level D) to augmentation from other systems as well as human operators (level A). Table 3.2.4-1 provides a summary of weather elements provided by each AWOS/ASOS configuration.

Table 3.2.4-1. Weather Elements Provided by AWOS/ASOS

Element Reported	AWOS -A	AWOS -1	AWOS -2	AWOS - 3	AWOS - 3 P	AWOS - 3 T	ASOS
Altimeter	X	X	X	X	X	X	X
Wind		X	X	X	X	X	X
Temperature / Dew Point		X	X	X	X	X	X
Pressure		X	X	X	X	X	X
Visibility			X	X	X	X	X
Clouds / Ceiling				X	X	X	X
Precipitation					X		X
Thunderstorm / Lightning						X	X
Remarks							X

The information from both systems (AWOS/ASOS) are transmitted on discrete VHF radio frequency or the voice portion of a local NAVAID. AWOS/ASOS transmissions on VHF radio frequencies are designed to be receivable to a maximum of 25 nm from the AWOS/ASOS site and a maximum of 10,000 feet AGL. Each system transmits a 20 - 30 second weather message updated each minute. Most AWOS and ASOS systems have a dial-up capability so the weather information can be accessed by phone.

The weather information provided by AWOS/ASOS is formatted as an Aviation Routine Weather Reports (METAR/SPECI) (see Appendix A). A typical coded text is as follows:

0356 AM METAR KGRR 010856Z 32017G23KT 10SM BKN018 OVC024 00/M03 A2961 RMK AO2 PK WND 33028/0837 UPB39E42SNB07E25 SLP035 P0000 60000 T00001028 53010*f*

3.2.3.5 Automatic Terminal Information Service (ATIS)

ATIS is a continuous broadcast of recorded noncontrol information in selected terminal areas. The ATIS broadcasts are used by airports to notify arriving and departing pilots of the current surface weather conditions, landing and departing runways, runway and taxiway conditions, communication frequencies and other information of importance to arriving and departing aircraft. Its purpose is to relieve frequency congestion and controller workload by automating the repetitive transmission of essential but routine information.

The broadcasts are updated as weather and runway conditions change. Each broadcast is identified by a sequential letter of the alphabet and referred to using the phonetic alphabet pronunciation of that letter, i.e. Alpha, Bravo, Charlie.

ATIS broadcasts originate from most major airports. The frequency varies from airport to airport and can be found on any aeronautical chart next to the symbol for the airport. If an ATIS exists, the frequency will be shown next to the letters "ATIS". The ATIS frequency for Cleveland Hopkins ATIS frequency is 127.85 MHz. The format of ATIS and example data is provided in Table B-1.

Table B-1. ATIS Broadcast Format and Example Data

Topic	Example
ATIS information identifier letter	Information India
Time of Report	1755 Zulu
Wind Direction/Speed	260 at 15 gusting to 19
Visibility	6 miles, light snow
Ceiling	2,600 Scattered, 3,500 Overcast
Temperature	-5
Dew Point	-11
Altimeter	29.99
Instrument Approach and Runways in use	ILS (Instrument Landing System) runway 23 Left in use Landing 23 Left, Departing 23 Right
Notices to Airmen Taxiway/runway closures, lights, etc.	Runway 18 closed

3.2.4 In-Flight Weather Information over ACARS

While all the above delivery systems provide weather information to the cockpit in voice format, weather data is available in *digital* format for planes equipped with the Aircraft Communications Addressing and Reporting System (ACARS). As the aviation industry moves toward digital communications as a way to increase accuracy and optimize the use of the valuable RF spectrum, it is expected that systems like ACARS will find even greater roles in dissemination of all types of aviation information including weather.

ACARS is a VHF air/ground data link that uses nearly 600 VHF frequency locations throughout North and Central America, Hawaii, the Caribbean, and several U.S. territories. The VHF frequencies allocated for use by ACARS in the USA include: 131.550 (Primary Channel for USA and Canada); 130.025 (Secondary channel for USA and Canada); 129.125; 130.450; 131.125; 136.800 (Additional channels for use in the USA).

ACARS was originally developed by ARINC in the 1960s as a nationwide VHF voice network to allow pilots of ARINC member airlines to report Out/Off/On/In (OOOI) times to the radio operators of a local ARINC ground station. In 1979, ARINC switched from voice to data transmissions. While ACARS was initially used to transmit only OOOI events, today ACARS supports over 50 applications including weather.

ACARS is provided by ARINC in the USA. In other parts of the world, the French Societe-International de Telecommunications Aeronautique (SITA) provides an ACARS - compatible VHF data link service called VHF Aircom. SITA and ARINC have a cooperative arrangement whereby each handles the other's traffic in their respective geographic areas. In Canada, ACARS is operated by Air Canada, while in Japan the service is provided by Avicom Japan, under similar arrangements. Currently, however, ARINC is the major ACARS provider, carrying more than two-thirds of the total commercial air/ground data link traffic in the world. Today, more than 4,200 aircraft use ARINC's ACARS data link system, which now handles around nine million messages per month. With some exceptions, most major airlines of the USA, Canada, Europe and Asia have equipped all or part of their aircraft fleets with ACARS.

ACARS is primarily a VHF data link system, however, there are several ACARS data links available, including but not limited to, VHF, HF and satellite. ACARS is comprised of three main elements:

- The Airborne Subsystem onboard the aircraft, which consists of a Management Unit and a Control Unit (A VHF radio and, optionally a Satcom unit, are required but are not considered part of the ACARS avionics)
- The ARINC Ground System, which consists of all the ARINC ACARS remote transmitting/receiving stations, and the ACARS Central Processing System (CPS), located at ARINC headquarters in Annapolis, Maryland. It is connected to ground stations through direct communications circuits and the ARINC Data Network Service (ADNS®) and the ARINC Packet Network (APN).
- The Air Carrier Command and Control and Management Subsystem, which is basically all the ground based airline operations such as operations control, maintenance, crew scheduling and the like, linked into the ACARS system.

In-flight weather information currently available over ACARS includes: Terminal Weather Information for Pilots (TWIP), weather products included in the Digital - Automated Terminal Information Service (D-ATIS), and various products available from resources within the Airline Operation Centers (AOCs).

3.2.4.1 Digital Automatic Terminal Information Service (D-ATIS)

Digital Automatic Terminal Information Service (D-ATIS) is a digital format of the voice broadcast ATIS described above. D-ATIS is part of the Tower Data Link Services (TDLS). This system is a redundant computer hardware / software platform that supports D-ATIS with Automatic Voice Generation (AVG) as well as Pre-Departure Clearance (PDC) and Flight Input/Output Emulation capability at 57 Airport Traffic Control Towers (ATCTs). D-ATIS information is routed to the aircraft via a combination of external FAA and ARINC communications systems in conjunction with the Aircraft Communications Addressing and Reporting System (ACARS).

The D-ATIS provides the latest airport weather, runway status and field conditions. With D-ATIS controllers prepare ATIS messages with an automation tool which increases workload efficiency and Flight crews receive precise and timely information by voice or digital communications. Table 3.2.4.1-1 gives an example of a D-ATIS coded message with an explanation of the code.

Table 3.2.4.1-1. D-ATIS Message Format

Message Code	Explanation
KBDL ATIS INFO N 101753Z	HARTFORD/SPRINGFIELD D-ATIS message N at 10-17:53 Universal Time
35019G30KT	Winds 350 19 knots gusting 30 knots
5SM -TSRA	Visibility 5 statute miles light thunderstorms mist
BR BKN035CB BKN200	Broken layer 3,500 feet cumulonimbus broken layer 20,000 feet
36/22	Temperature 36 Celsius, 98 Fahrenheit dewpoint 22 Celsius 72 Fahrenheit
A3001	Altimeter 30.01
RMK PK WND 32030/50 WSHFT49 FRQ LTGICCG N-NE RAB47 TSB39 N-NE MOV E SLP161 60001 10393 20266 55000=	Remarks - peek winds 320 30 to 50 knots wind shift 49 frequent lightning in clouds to ground north to northeast moving east. Rain began 17:39 universal time. Thunderstorms began 17:47 universal time. Sea level pressure 1161.
...ADVS YOU HAVE INFO N.	D-ATIS Message N

3.2.4.2 Terminal Weather Information for Pilots (TWIP)

Terminal Weather Information for Pilots (TWIP) provides ground-based terminal weather information to pilots via ACARS. These products are specially tailored for pilots to furnish data on terminal weather phenomena such as microburst, gust fronts and precipitation. TWIP continually generates revised weather products which provide pilots with better "Nowcast" assessments and increase the opportunity for safe utility in flight planning and en route operations.

TWIP products are generated using weather data from the Terminal Doppler Weather Radar (TDWR) or the Integrated Terminal Weather System (ITWS) testbed. TWIP products are stored in the form of text and character graphic messages. These products can be accessed by pilots using ACARS or, alternatively, an airline (e.g., Northwest Airlines) can choose to send forced messages from its host to an aircraft whenever windshear activity begins or ends at an airport. For selected airports, TWIP messages will be generated based on TDWR data or the ITWS testbed. TWIP products include descriptions and depictions of the airport weather microburst alerts, wind shear alerts or significant precipitation, the present convective activity within 15 NM of the terminal area, and expected weather that will impact airport operations. TWIP products are updated and databased once each minute for text messages and once every five minutes for character graphic messages.

These products provide pilots strategic information to aid in flight planning prior to arriving in the terminal area. Pilots must frequently operate without full knowledge of the weather conditions that may impact their planned flight. ACARS allows pilots to receive TWIP messages and minimizes weather induced risk by affording them more time to prepare for changes to their planned flight.

Current pilot/controller voice radio communications frequently require multiple transmissions and read-backs to insure correct receipt of the intended information. With TWIP, flight crew misunderstandings are reduced because the message content can be verified during and after the data link transmission. By using printer hard copy or storage/retrieval, the crew can review the TWIP message at the least disruptive time. This allows the crew to better manage cockpit work flow.

3.2.4.3 Airline Operation Centers Weather Data

In addition to the standard ACARS weather services, some airlines have implemented in-flight access to weather information over ACARS through host computers at the Airline Operation Centers (AOC). An example is the United Airlines implementation of ACARS. In their system, pilots have a weather menu on the ACARS that allows the pilot to select between METAR, TAF, Area Forecast, SIGMETs, PIREPs, or Winds Aloft. The ACARS network relays the request to the AOC host computer which prepares the necessary information specific to the requesting flight and transmits it back to the cockpit.

3.2.5 Current Weather Tools Communications Requirements

The communication systems required to delivery current weather products to the cockpit are summarized in figure 3.2.5-1. The different delivery systems are shown in relation to the phase of flight in which weather information is provided by each system.

In the terminal area, pilots can receive current and forecast weather from several systems, though not at all airports. These include the broadcast from AWOS/ASOS weather observation systems as well as from the Automated Terminal Information Service (ATIS). ACARS equipped aircraft can receive terminal weather information even before they get to the terminal area by requesting Digital Automatic Terminal Information Service (D-ATIS) data or Terminal Weather Information for Pilots (TWIP) data for terminals where those systems have been implemented.

In the domestic en route phase of flight, weather information can be obtained from Flight Service Stations (FSS/AFSS) directly or from their En route Flight Advisory Service (EFAS) if one is available. Pilots may also listen to broadcast from Transcribed Weather Broadcast (TWEB) facilities for weather information specific to their flight plan or get selected data by requesting weather information from their operation centers over ACARS. If moderate or severe weather conditions develop, pilots will be advised by en route controllers over radio broadcast and be advised to tune to the Hazardous In-flight Weather Advisory Service (HIWAS) broadcast for detailed information.

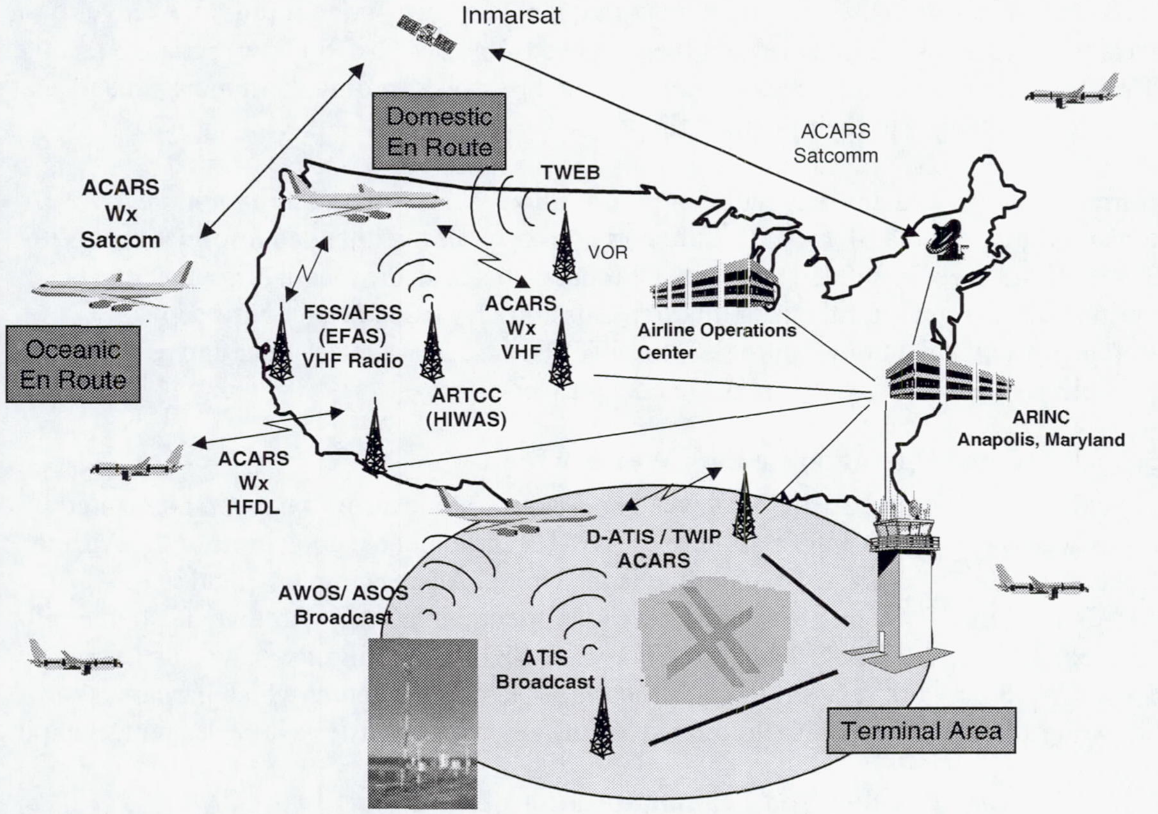


Figure 3.2.5-1. Current Ground-to-Air Weather Product Delivery

In the oceanic en route phase of flight, pilots with appropriate equipment on board can use ACARS Satcom or HF ACARS to request weather information.

3.3 Aviation Weather Planning and Tools in Development

Planning for future delivery of in-flight aviation weather tools involves a mix of government services and private sector provided value-added weather products. The products that will enhance or replace the current tools in the near future will come primarily from the private sector.

3.3.1 FAA Flight Information Services (FIS)

A FAA general aviation data link program known as Flight Information Services Data Link (FIS DL) has been established to coordinate and administer the development of the FIS DL system.

The development concept for the FIS DL system is to have private industry bid for the right to design, build and maintain a FIS DL system that is within the guidelines of the Airborne FIS Policy Statement. The FAA plans to petition for and obtain four 25 kHz bandwidth VHF channels from the FCC for use by the data link system.

The following are selected excerpts from the Airborne Flight Information Services Policy Statement that summarize the program:

- Definition – "Flight Information Services (FIS) are defined as the noncontrol, advisory information needed by pilots to operate more safely and efficiently in the National Airspace System (NAS) and in international airspace. Flight Information Services include information necessary for continued safe flight and for flight planning, whether in the air or on the ground."
- Goal – "The goal for FIS in the cockpit is to use digital data link to deliver information to the pilot, and in doing so, improve safety, reduce costs to users and the FAA, and increased the utility, efficiency, and capacity of the NAS."
- Initial FIS Products – "...include information on the status of the NAS (Notices to Airmen (NOTAMS), Special Use Airspace) and meteorological information, both in textual as well as graphical format."
- Voice Communications – "FIS...to complement, not replace, existing voice communications."
- Frequency of Operation – "...four 25 kHz radio frequency channels in the 136.0 – 136.9 MHz VHF spectrum..."
- Human Factors – "...develop a common set of human factors guidelines and standards for the display and training associated with use of FIS products in the cockpit;"
- Waveform Design – "The FAA intends to use VHF Data Link (VDL) Mode 2 capability for non-time-critical data link messaging and subsequently to transition to VDL Mode 3 data and voice capability as part of a multimode data communications architecture that uses the aeronautical telecommunications network and which will support future requirements for FIS."

3.3.2 Aviation Weather Data Sources

Under the FIS program the collection, production, distribution, and delivery of aviation weather products will be a joint effort between government and private sector. This concept will build on the current infrastructure of weather sensors and distribution.

3.3.2.1 NWS Family of Services

The primary collector and disseminator of U.S. Government obtained or derived weather information in the United States and certain parts of the international community is the National Weather Service Telecommunications Gateway (NWSTG) maintained by the NWS Office of Systems Operations (OSO) in Silver Spring, Maryland. The Gateway provides unaltered weather information services to NWS, FAA, DoD, FEMA, DoA, Commercial, and International customers. The weather information service is known as the NWS Family of Services (FOS) and is accessible via dedicated telecommunications access lines. The NWSTG Gateway provides six data streams of weather information as shown in Table 3.3.2.1-1.

Table 3.3.2.1-1. NWS Family of Services (FOS)

FOS Service	Product Description	Data Rate
Public Product Service	Provides users with forecasts and warning in easily read, plain language format.	9600 bits per second Asynchronous Character oriented
Domestic Data Service	Provides users with coded observations, reports, forecasts, and analyses.	9600 bits per second Asynchronous Character oriented
International Data Service	Provides users with worldwide coded observations, reports, and forecasts.	9600 bits per second Asynchronous Character oriented
High Resolution Data Service	Provides users with global model-derived forecasts and analyses, most of which are in the gridded binary (GRIB) format. (Was: Direct Connect Service)	56,000 bits per second X.25 transmission protocol
Digital Facsimile Service	About 300 facsimile charts distributed daily including analyses, prognoses, and observed data.	4800 bits per second 720 scans per minute Synchronous
AFOS Graphics Service	About 300 charts distributed including model guidance charts, national radar summaries, objective forecasts, manually prepared analyses, and forecast charts.	4800 bits per second asynchronous or 9600 bits per second synchronous

The aviation weather products are mainly available on the Domestic Data Service (DDS) channel. Aviation weather products includes:

- AIRMETs
- Aviation Area Forecasts
- Center Weather Advisories
- Convective SIGMETs
- FD Winds Aloft Forecasts
- Meteorological Impact Statements
- Offshore Aviation Area Forecasts
- PIBAL Observations
- PIREPs
- SIGMETs

- Surface Aviation Observations (i.e. METAR/SPECI)
- Hourly Observations
- Terminal Forecasts (i.e. TAF)
- Transcribed Weather Broadcasts
- Urgent PIREPs
- Wind and Temperature Forecasts

In addition to DDS, Commercial vendors may subscribe to as many as six additional services for a connection charge and an annual user fee. The vendors must provide the raw NWS weather information free of charge to the public, but are allowed to provide value-added information to their customers for a charge.

The NBS (NOAAPORT Broadcast System) is a new one-way satellite based broadcast system that provides environmental data and information in near-real-time to NOAA users and to external users in the United States. The NBS system came on line in November 1998. NBS will provide the following four (4) data streams:

- GOES East satellite imagery products
- GOES West satellite imagery products
- Non-GOES Imagery/DCP Data Channel
- NCEP/NWSTG
    - NCEP Model outputs
    - Observations, forecasts, watches, warnings from WFO
    - Observational data from all over North America

The primary source of the observational data is AWIPS (Advanced Weather Interactive Processing System). AWIPS weather products from the Weather Forecast Offices (WFO) are sent to the Network Control Facility in Silver Spring, MD, and then to the Master Ground Station (MGS) at Fort Meade, MD, for transmission to the Spacenet IV Communications satellite and broadcast. Currently NOAAPORT is for internal NWS use, but in the future aviation weather products may also be broadcast over NOAAPORT.

The NWS Headquarters office responsible for the "planning and development of efficient and effective external relations programs and policies related to NOAA commercial weather support" is the Industrial Meteorology Staff in Silver Spring, Maryland. The Chief of the Industrial Meteorology Staff acts as an ombudsman for the private sector and sees that the comments and concerns of the private sector are represented in NWS planning and evaluation.

The current private sector aviation weather subscribers to the NOAA Family of Services (FOS) Program are listed in Table 3.3.2.1 – 2.

Table 3.3.2.1–2. Aviation weather subscribers to the Family of Services. The companies also service industries outside of the aviation domain.

Company	Address	Point of Contact
AccuWeather	385 Science Park Road State College, PA 16803-2215 http://www.accuweather.com	Mr. Erik Bjalme 814-235-8600
Alden Electronics	40 Washington Street Westboro, MA 01581 http://www.alden.com	Mr. Jimmie Smith 800 225-9492
GTE/Contel Federal Sys	15000 Conference Center Drive Rm 131 Chantilly, VA 22021 http://www.gte.com	
Harris Corporation Government Information Division	505 John Rodes Blvd, Bldg R-3 Melbourne, FL 32935 http://www.harris.com	Mr. Mike Edwards 888 984-8801
Kavouras, Inc.	11400 Rupp Drive Burnsville, MN 55337-1279 http://www.kavouras.com	Mr. Phil Gilmer 612 890-0609
UNISYS Corporation	P.O. Box 1226 221 Gale Lane Kenneth Square, PA 19348 http://www.unisys.com	Mr. Mike Porreca 610 444-2433
Universal Weather and Aviation, Inc.	8787 Tallyho Road Houston, TX 77061 http://www.univ-wea.com	Mr. Paul Ryan 800 231-5600
WSI Corporation	4 Federal Street Billerica, MA 01821 http://www.wsicorp.com	Mr. Rick Ovender 978 670-5149

3.3.2.2 NWS Aviation Weather Center (AWC) Aviation Digital Data Services (ADDS)

A relatively new source of NWS aviation weather information is the Aviation Digital Data Service (ADDS). The ADDS is the data distribution element of the AGFS (Aviation Gridded Forecast System). The AGFS PDT (Product Development Team) is located at FSL (Forecast Systems Laboratory), but is a joint effort of Forecast Systems Laboratory (FSL), National Center for Atmospheric Research/Research Applications Program (NCAR/RAP), and the National Center for Environmental Prediction/Aviation Weather Center (NCEP/AWC). The AGFS consists of forecast tools and productivity tools that enable NWS forecasters to use the aviation impact variables generated at other locations.

The ADDS is maintained by the AWC in Kansas City, Missouri. The ADDS weather information is easily accessible through the AWC ADDS Web Page:

<http://adds.awc-kc.noaa.gov/>

ADDS makes available to the aviation community digital and graphical analyses, forecasts, and observations of meteorological variables. The weather products available on ADDS includes:

- PIREPs
- AIRMETs
- IFR
- METARs
- TAFs
- WINDS
- ICING
- TURBULENCE
- CONVECTIVE
- SATELLITE
- RADAR

The ADDS sends its weather product information to

- Vendors
- Internet
- NOAAPORT
- ITWS
- WARP
- OASIS
- DUATS

The inclusion of the Internet on the dissemination list makes the ADDS weather products available to anyone on the ground or *in the air* with a PC and access to a cellular or flight telephone connection.

3.3.3 Commercial Aviation Weather Product/Delivery

The principal service provided by the private weather providers is in offering user-friendly access to the large variety of free Family of Services products by way of telephone, fax, modem or the Internet. The services are offered to a broad array of different customers including the aviation community. The private sector provides tailored weather forecasts and, for special cases, climatological summaries, and weather extremes probabilities. The private sector develops and markets value-added products such as aviation weather workstations, software, observational systems, imaging systems, displays, communications, satellite down-link stations, charts, graphs, and maps.

3.3.3.1 National Weather Dissemination Policy

The commercial aviation weather product generation and delivery business was created by partitioning the weather dissemination process between the National Weather Service (NWS) and the Private Sector. The Private Weather Industry was permitted to add enhancements to the raw weather products received from NWS and to charge for the value added. The Private Weather Industry, however, was required to offer to the general public the Government derived weather information at no cost.

The policy was established in 1991 with the publication of the policy statement in the Federal Register. The statement was titled, "The National Weather Service (NWS) and the Private Weather Industry: A Public-Private Partnership". The statement defined the relationship and the roles of the NWS and the private sector.

The policy states as follows for the **National Weather Service** (Only the weather portions are extracted):

a. "The NWS shall collect and exchange hydrometeorological data on a national and international basis;
b. Issue warnings and forecasts of severe weather, hurricanes;
c. Issue weather forecasts and related guidance materials;
d. Provide climatological summaries;
e. Provide private weather access to near-real-time alphanumeric and graphical data and information through a variety of techniques;
f. Establish basic quality control for the observed and collected data, and provide the user community with sufficient information to evaluate data and forecast reliability and applicability;
g. Conduct and support research and development of atmospheric and hydrometeorological models;
h. Produce global, national, or general regional atmospheric models."

"The **private weather industry** provides:

a. Tailored weather forecasts, detailed hydrometeorological information, consultation, and data for weather sensitive industries and private organizations;
b. Value-added products such as weather computer hardware and software, observational systems, imaging systems, displays, communications, charts, graphs, maps, and images for clients;
c. Climatological summaries, probability values of weather extremes, and similar material for specific design and construction problems."

3.3.3.2 Commercial Aviation Weather Providers

Table 3.3.3.2 –2 gives a partial list of private weather companies that provide pre-flight briefing services and aviation weather information for the pilots.

Table 3.3.3.2-3. Summary of commercial weather provider products and capabilities

Company	Value Added Products	Web Site for General Weather and Aviation Weather	Weather Tools for Pre-Flight Briefings or Planning	Airborne Internet Service
Kavouras	Yes	http://www.kavouras.com	Weatherlink Vistas	No
WSI	Yes	http://www.wsicorp.com	PILOTbrief VECTOR	No
UNISYS	No	http://www.weather.unisys.com	Weather Processor	No
Alden	No	http://www.alden.com	WeatherWorks	No
Universal	Yes	http://www.univ-wea.com	Windstar Plus	Yes
Accu-Weather	Yes	http://www.accuweather.com	AMPS/AccuData	No
GTE	Yes	http://www.skycentral.com	Skycentral DUATS	No
Harris	No	http://www.hisd.harris.com	WeatherTAP – Aviation Weather WINGS – OASIS Work Station equivalent to DUATS WINDS – Part of WARP System	No

3.3.3.3 NEXRAD Information Dissemination System (NIDS)

Of the large variety of aviation weather products that are available today the single most wanted aviation weather product is weather graphics in the cockpit; more specifically, color NEXRAD radar graphics and NEXRAD radar mosaics. The large size of the NEXRAD database makes it the weather product that would require the largest bandwidth for transmission of weather graphics to the cockpit.

The NIDS Program is a National Weather Service program that called for private weather companies to receive the outputs of all NEXRAD radars (approximately 142 radars across the country) and provide the composite Unaltered NIDS products (18 products) to users in the public and private sectors. Any participating company was required to provide its own radar data collection network and provide for connections to the output port of each NEXRAD systems. The NIDS Program provided the output ports.

Today there are three private companies WSI, Kavouras, and UNISYS that are distributing NIDS products to the public (Alden Electronics was a participant and has dropped out). UNISYS is adding no value to their NEXRAD products; they redistribute Unaltered NIDS products. WSI and Kavouras, however, are adding value to the basic NIDS data and receive fees for the value added. There is no charge for the Unaltered NIDS Products but the companies receive fees for providing the service.

The NIDS companies provide the Unaltered NIDS Products to other private weather companies for their use and enhancement.

Table 3.3.3.3-1 lists the Unaltered NIDS Products data rate and Table 3.3.3.3-2 lists the NEXRAD products that are produced by each NEXRAD radar during each volumetric scan. There are four volume coverage patterns (VCP) and the update rate is different for each scan:

Table 3.3.3.3-1. NEXRAD WSR-88D Update Rates.

Volume Coverage Pattern (VCP)	NEXRAD UPDATE RATE
VCP11	5 MINUTES
VCP21	6 MINUTES
VCP31	10 MINUTES
VCP32	10 MINUTES

Table 3.3.3.3-2. **Unaltered NIDS Products received from each NEXRAD radar system. Data provided through the courtesy of the National Weather Service.**

	MODE	DATA SIZE	DISPLAY LEVELS
1	Precipitation Mode	Text	
2	Clear Air Mode	Text	
3	Base Reflectivity – 124 nmi range (Lowest Four Elevation Angles)	30 kB each elevation angle	16
4	Base Reflectivity – 248 nmi range (Lowest Elevation Angle)	21.25 kB	16
5	Composite Reflectivity (8 levels)	12.25 kB	8
6	Composite Reflectivity (16 levels)	13.50 kB	16
7	Layer Composite Reflectivity – Low Level	3.25 kB	8
8	Layer Composite Reflectivity – Middle Level	2.75 kB	8
9	Layer Composite Reflectivity –High Level	2.50 kB	8
10	Layer Composite Reflectivity with AP Removed	3.25 kB	8
11	Echo Tops	2.75 kB	16
12	Vertical Integrated Liquid	2.25 kB	16
13	Base Radial Velocity (Lowest four elevation angles)	29 kB	16
14	Storm Relative Mean Radial Velocity (Lowest two elevation angles)	29.50 kB each elevation angle	16
15	Velocity Azimuth Display (VAD) Winds	7.50 kB	30
16	Surface Rainfall Accumulation – One hr running total	14.74 kB	16
17	Surface Rainfall Accumulation – Three hour total	11.50 kB	16
18	Surface Rainfall Accumulation – Storm total	15 kB	16
19	Hourly Digital Precipitation Array	10.5 kB	256

The primary products that the private providers generate for use by the aviators are the NEXRAD radar mosaics with annotated overlays. Typically the radar mosaics are available for regional, national, and customized coverage. The NEXRAD radar produces 17 different types of data based on 3-Dimensional, 360 degree volumetric coverage of the atmosphere. A 3-Dimensional radar provides information in range, azimuth, and in elevation. The completeness of the NEXRAD radar coverage and the extensive amount of derived weather information makes it a generator of a highly desirable and useful weather product for display in the cockpit. The availability of near real time weather information that is updated regularly permits generation of time lapsed storm motion, and when combined with textual and graphical overlays further enhances the usefulness of the NEXRAD radar weather picture.

3.3.3.4 NLDN (National Lightning Detection Network)

The National Lighting Detection Network is a private system operated by lightning product contractor Global Atmospherics, Inc. The company is a spinoff of lightning research conducted at the University of Arizona in Tucson.

The NLDN provides cloud-to-ground lightning activity coverage of the 48 contiguous states. Detection reports are transmitted via satellite to a Network Control Center (NCC). The location, time, polarity, and amplitude of each strike is processed and is provided to NLDN subscribers for use on Windows or Unix-based platforms. Reports are also available via dial-up telephone.

3.3.3.5 ASOS/AWOS Lightning Detection System

Global Atmospherics manufactures a variety of lightning products. ASOS and AWOS observation systems include lightning detection systems that are independent of the NLDN. The ASOS/AWOS lightning detection system is also produced by Global Atmospherics. These lightning detectors provide lightning data to local users and are also transmitted to the NWS Gateway along with the rest of the ASOS/AWOS observations.

The lightning products produced by Global Atmospherics are the only proprietary weather products that are being transmitted along with NWS data streams.

3.3.4 Planned/Developmental Weather Tools Communications Requirements

The community, represented by AOPA (Aircraft Owners and Pilots Association), has surveyed its membership to determine their needs and preferences for in-flight weather information. The results show a strong desire to have weather graphics in the cockpit. The preference seems to be leaning towards a low cost (possibly a $1500 or less handheld system) Satellite Communications-based system rather than a ground based ground-to-air data link. The current trends in computing, communications, and internet technologies appear to be supporting the AOPA position.

The original systems analysis approach to determining the impact of commercial weather products to the ground-to-air data communications load was to identify and define value added weather products. The next step in the process was to determine the communications load for those value-added products. Then to add the value added commercial products to the basic NWS weather products and arrive at a final communications load that would establish the communications requirement for ground to air data communications.

That approach to determining ground to air communications requirements for general aviation has now become somewhat questionable with the advent of airborne cellular telephony and the lower usage costs of flight phones. The FCC granted a waiver to AirCell in late December 1998, to operate their patented airborne cellular telephone system in the 800 MHz band. AirCell claims to be able to provide cellular telephone service, fax service, and data transmission capability with a rate of 9600 bps. The system is able to interface with on-board displays, laptop PCs, or handheld computers.

The significance of this new communications link is that Internet Technology will now be available in the cockpit. With that the pilot will now able to access weather products in the cockpit. The same weather products that are normally obtained on the ground via telephone, fax, briefings, or the Web are now accessible in the cockpit through the Internet. Table 3.3.5-1 lists just some of the emerging communication options/alternatives becoming available to the aviation community.

Table 3.3.5-1. Examples of potential data communications vendors.

	Company	Technology	Operating Frequency	Notes
1	AirCell	Airborne Cellular Telephone (Analog)	800 MHz	a. FCC Approved. For general aviation. b. Reported to work in conjunction with Universal Weather Internet to provide Internet in the cockpit.
2	GTE Airfone	AirborneFlight telephone	a. Air-to-Grd: 849 to 851 MHz b. Grd-to-Air: 894 to 896 MHz.	a. Operational. Commercial airlines. b. 135 Ground stations in North America. c. Satellite connections for over water operation.
3	NavRadio	VDL	VHF	a. Candidate system for FIS DL. b. Designed to transmit weather graphics. c. Current AWIN contractor

3.3.4.1 Convergence of Computing, Communications, and Internet Technology.

In addition to the Human Factors and Safety issues, there are changes in technology that will further affect the final design of the graphical weather product and the ground to air data link. Today, there is a rapid convergence of technologies that will eventually merge into a single multidisciplinary technology. Computer technology has advanced in parallel with wireless and internet technology. Windows CE, GPS, moving maps, weather graphics, wireless, and internet capability for handheld computers will soon be available.

3.3.4.1.1 The Next Generation Internet (NGI) Initiative

The once separate and distinct technologies of Computing, Communications, and Internet are now being addressed together under the new White House Initiative, *The Next Generation Internet (NGI)* Initiative. The objective of NGI is to increase the speed of the Internet by a factor of 1000. The 1999 funding for NGI activities is reported to be $110 million.

3.3.4.1.2 Hand Held Computer Advances

Separately but simultaneously, computing technology has reached a point where handheld personal computers with Windows, wireless operation, and modems are now becoming available. An example, is the Palm VII handheld computer. This handheld unit has a special Windows operating system developed by Microsoft called Windows CE. It is a scaled down version of Microsoft Windows developed for a class of small computers with the code name: Jupiter. In the opinion of aviation weather experts, handheld Jupiter units with GPS and Moving Map will soon be available. The combination of weather graphics with GPS and a Moving Map is becoming realizable and will satisfy one of the safety needs of the General Aviation community.

3.3.4.1.3 Aviation Use of Cellular Telephones

Again, separately and simultaneously, cellular telephones have become available for use in the cockpit. AirCell received FCC approval to operate its airborne cellular telephones in December 1998. The AirCell units are designed to interface with onboard displays or to a computer with a modem.

The AirCell system is reported to be capable of transmitting data at a rate of 9600 bps with a goal of 19200 bps. Private weather provider, Universal Weather, has developed weather products for transmission over a system such as the AirCell system. Universal reports that the actual data rates are at about 2400 bps with the limitation being set by the ground systems.

3.3.4.2 Effects of Merging Technologies on Aviation Weather Information

The significance of these developments is that the capability will shortly be in place to allow en route general aviation pilots to access private weather provider Web sites from the air and also to access the NWS ADDS Web site from the air. In effect the general aviation community will soon have the ability to have weather graphics in the cockpit at a relatively low cost.

3.4 Aviation Weather Research and Potential New Weather Products

Looking at current needs and research can help predict future direction. The following current concerns and FAA research, combined with reasonable assumptions based on user needs and NASA's AWIN efforts, helps define the character of future on-board weather products.

3.4.1 General Flight-Deck Considerations

The future of specific weather information products in the cockpit will be shaped by a variety of forces that are already in play today. Examining current and planned products unveils the following considerations in projecting future products and their supporting communications requirements.

3.4.1.1 Types of "Graphical" Weather

Current thinking seems to group "graphical" weather information presentation into four main categories: text, icons, pictures, and objects. These four, listed according to their relative complexity, have different uses, depending on the phase of flight and decision-making arena.

3.4.1.1.1 Colored Text

Better than plain text, "Colored Text" can be used to present visual cues about the severity of a given condition. For instance, red text can describe "bad" conditions; yellow, "marginal"; green, "good." Pioneered by NASA's CWIN effort, colored textual weather forecasts and observations were quite popular with pilots. Since text is far too useful to disappear in the foreseeable future, color coding is a natural enhancement. Color coded text and icons are roughly the same file size, depending on the amount of information encoded and sent.

3.4.1.1.2 Icons

Some weather products reduce a variety of data and information down to a single, coded, "icon." For weather in the cockpit, this was also demonstrated in NASA's CWIN project which used colored icons to describe winds, ceiling, and visibility at stations across the country. Icons take up little file size for the amount of information conveyed, but are best at representing conditions at a single point in space and time, such as specific airports, runways, arrival gates, holding patterns, etc.

3.4.1.1.3 Pictures (Bit-Mapped, Gridded, Graphics)

In this context, "Pictures" include, but are not limited to, direct sensor output such as satellite photos or radar returns. A "picture" could also be a computer synthesized product. An example includes NCAR's experimental convection product which synthesizes information from weather radar returns and lightning strike data into an entirely new product. The defining requirement is that "picture" information is essentially information from a grid, bit-mapped in one of various formats. These files tend to be large, though they can be compressed with a variety of schemes, such as the MIT Lincoln Labs "Huffman" compression algorithm. In its basic form, a "picture" can be difficult to overlay with other information (waypoints, other aircraft, etc.) on a single display since the picture will hide portions of whatever was displayed previously.

3.4.1.1.4 Objects

"Objects" are more easily scalable and "smoother" than "pictures." In a basic sense, an object can be a "picture" with the relevant material reduced to polygons that exhibit a number of characteristics. One advantage of "objects" is that they can be more easily manipulated in three or four dimensions, allowing the pilot to visualize hazard avoidance by "virtually" examining projected hazards from any angle, altitude, or time desired. Another advantage is that objects are also more easily ranked in importance for merging with other information on a common display. Finally, the raw file size of a hazard described with objects can be smaller than its bit-mapped equivalent, though it may be harder to compress to the same degree.

3.4.1.2 On-Board Considerations

3.4.1.2.1 General Display Considerations

Pixel density, color depth, and screen size are important factors in determining how much detail can be viewed for any given product. These factors can also project how large a given bit-mapped product might be. Current trends tend toward displaying weather products (and other hazards) for informational purposes only. These products are appearing on displays ranging from 640x480 to at least 1024x768 pixels, from 2 to at least 16 colors, and from 4 to 10 inch diagonal screen sizes and beyond.

As mentioned earlier, it is anticipated that the screens which display future weather products will be multi-functional, including perhaps the ability to display terrain, obstacles, Special Use Airspace status, electronic approach plates, aircraft system schematics, maintenance write-up or electronic log books, etc. In order to do this, it seems likely future weather cockpit displays will display at least 1024x768 pixels and carry at least a four bit color depth (16 colors).

3.4.1.2.2 Cockpit Screen Location

Users and avionics suppliers tend to agree that these informational displays will be separate from current cockpit displays for all but the most advanced avionics suites. Thus, there appears to be a large *retrofit market* for cockpit graphical weather (and other information) displays. There are examples of displays being fixed into/on to instrument and side-wall panels, displays mounted on flexible/articulated supports, and wireless handheld displays that can be seated in a cradle. All of these examples are likely to survive into the near-term future at least. For the most part, the location may drive some certification requirements, and may even provide special human factors considerations, but do not seem to have a primary bearing on the communications required to deliver weather products.

3.4.1.2.3 On-board Processing Power

More on-board processing capability will lessen the demands on the communication "pipeline" to the airplane in a variety of ways.

Currently, many products being delivered to the flight deck are compressed pictures, bit-mapped to fit only a particular display. This occurs because cockpit hardware and software usually lags ground PC development due to certification issues. Therefore, unlike today's personal PCs, many current cockpit display systems require bit-mapped products to be specifically tailored. This means that for a given display pixel size and color palette, a different version of a weather product must be created on the ground and sent to the air. One manufacturer/supplier reports creating *36 separate versions* of their products for delivery to the various screens they currently supply. This is not a viable, long-term paradigm, as it consumes limited bandwidth and is prohibitively expensive for the information supplier.

In the future, many hazards may be normalized to an index in some fashion, as NCAR is now trying to do with turbulence. This would mean, for instance, that a future turbulence product would be transmitted to the airplane in normalized fashion that would require decoding to provide relevance. Sufficient processing power on-board would enable applying known aircraft, pilot, and mission conditions to an indexed hazard, displaying it in context. In this way, a highly wing-loaded cargo aircraft may see some turbulence ahead displayed as a "green" area, acceptable to penetrate. On the other hand, a lightly wing-loaded commuter airliner might see the same location displayed as a "red" area, one to be avoided.

Although adding processing power will drive up airborne equipment costs, computing power continues to drop in price and size. An added benefit of more airborne processing power is the ability to combine multiple hazards or other information into one display when desired, rather than simply viewing one "product" at a time. Doing so will gain functionality which will dilute equipment costs.

3.4.1.2.4 Cabin Connectivity

Another way to defray on-board computational equipage costs is to network the cockpit and cabin information systems. For major airlines and high-end business aviation, this seems a likely scenario. In fact, it may be that cabin communications drive the connectivity that will ultimately bring a weather data "pipeline" to the airplane. Unfortunately, this may also serve to compete for the bandwidth available for weather products.

3.4.1.3 Product Size Considerations

The file size of current and future weather products can be managed using a variety of tradeoffs. A given product might be a satellite photo, radar mosaic, numerical model, or combination of these and other inputs. In its raw form, a "initial" product could cover something as large as the entire globe. Obviously, a global product would have little use to most pilots; however, a portion of that product – the "final" product – could very well be useful. The eventual size of what is finally delivered to the airplane will depend on model grid sizes, desired/available fidelity, and desired/available area of regard.

3.4.1.3.1 Model Grid Sizes

The initial fidelity and area of regard for a specific product is a starting point to sizing future products. As algorithms, grid space resolution, and data input improve, current numerical models are getting more detailed and accurate. NCAR, for example, currently uses a grid size of roughly 40km x 40 km x 1000 ft for their icing and turbulence models and is planning to soon shrink this to 29km x 29km.

As the models get finer and more accurate, the initial product size will continue to climb. For a four dimensional product, one that includes time, doubling the accuracy in all axes will consume up to *16 times as much space* to describe, store, and send. The system may not be able to distribute such products in their entirety.

3.4.1.3.2 Product Fidelity

How much fidelity – or precision – is available or desired in a given product has a significant impact on file size.

Generally speaking, the more immediate the need for a product, the more fidelity will be required. The planned NCAR turbulence projections, for instance, model down to a roughly 29x29km grid that is 1000 feet deep. This may be sufficient for an airliner's far-term strategic decision making arena, but would have limited use for tactical penetrations decisions.

Since far-term strategic decisions are based on inherently less accurate future information, that information needn't be displayed as precisely. A pilot basing strategic decisions on a nationwide NEXRAD mosaic, for example, won't need the initially broadcast 2km resolution. In fact, for far-term strategic decisions, pilots are much more likely to accept the artificially smoothed lines or chunky graphics that can result from reducing pictures to polygonal representations. For example, MIT's Lincoln Lab's Huffman compression algorithm, specifically tailored to weather products, has demonstrated a 64:1 file size compression that still remains useful in a far-term strategic environment.

3.4.1.3.3 Area of Regard

How much geographic area a product covers, also has a direct impact on its file size. A "strategic" product will necessarily cover more area than a tactical one. However, not every segment of aviation is equal. What is "strategic" for the GA pilot (100 miles away) may be within the "tactical" threshold for the airline, military transport, or biz-jet pilot. In making terminal area, tactical decisions using the NEXRAD mosaic mentioned above, a pilot in Cleveland does not consider conditions in Los Angeles, Chicago, or even Cincinnati. As that pilot's area of regard is much smaller, the entire mosaic isn't needed. Tailoring the required geographic or time area of regard can help manage file sizes.

3.4.1.3.4 General Tradeoff Conclusions

Graphical strategic safety products are likely to focus on in-flight visibility conditions, convection, icing, and turbulence. These four may even be general enough in the far-term strategic decision making arena to be partially or completely combined. Thus, there will be relatively few products represented in a coarse manner. As projected in the tables which follow, far-term strategic file sizes will be smaller than the near-term files.

Near-term strategic products, as mentioned, will be the most actively pursued in the future. There is room and desire for significant growth in this area. Though the geographical area of regard is smaller than the far-term strategic arena, the information desired will be more dense, with the time element becoming critical to avoid last minute tactical maneuvering that will squander any safety and efficiency gains made in the strategic plan. Thus, near-term strategic products are likely to be the largest group, as well as the largest average file size.

Tactical maneuvering will continue to be done largely with the on-board sensors we have today. The time lag associated with sensing conditions, generating a product, transmitting it, receiving it, displaying it, and acting on that information makes useful, off-board tactical products difficult to produce. Even so, there is some desire for more products in the cockpit in this arena. Some of these products may not be graphical, and will be focused on a point sources, such as RVR, ceiling, microburst location, etc. A possible graphical weather product in the tactical arena might be a tightly focused, nearly continuously broadcast NEXRAD or TDWR-type picture. With such a tight focus (the terminal approach/departure area), no time component, and limited colors required, the tactical products are likely to be the smallest.

3.4.1.4 Bandwidth Required

The bandwidth required or desired to deliver given weather products will depend on four main factors: the number of products available, their sizes, how often they are needed, and immediacy of need for the product.

3.4.1.4.1 Broadcast versus Request-Reply

Bandwidth is already at a premium. Because of this, there is general agreement among avionics suppliers and users that weather products will generally follow a broadcast paradigm in the future. Though there will still be a requirement for addressed request/reply or “pushed” products, current feeling seems to be that 75% or more of cockpit weather product transmission will be in the broadcast mode.

3.4.1.4.2 Numbers and Sizes of Products

As pointed out earlier, and is evident in the product projections that follow, the main thrust of future weather products is likely to be in the near-term strategic decision arena, roughly 15 to 60 minutes in front of an aircraft. While many of the factors affecting product size have already been discussed, product size is ultimately highly variable, and will be adjusted to some degree to fit the constraints in the system. Products will no doubt be designed, in part, by appropriately adjusting the fidelity and area of regard to fit available bandwidth.

3.4.1.4.3 Product Delivery Frequency

A number of factors will determine how often it makes sense to transmit any given product. These factors include how much the given conditions affect flight, how rapidly those conditions change, and how often meaningful products describing those conditions can be created.

Currently, the update cycle for some existing and planned products is more limiting than the actual weather conditions. That is, there is a desire for a more rapid update cycle, but the models cannot be run more often due to current limits in computational power. This limitation is worsened by the immaturity of the associated numerical algorithms and/or the frequency and accuracy of the measurements that drive those algorithms. It seems highly likely as the computers, algorithms, and input data mature, product update cycles will shrink and the resulting communications demands will increase. The ultimate practical limit will be driven by the variability of a given weather phenomenon, and how much it can affect an airplane.

3.4.1.4.4 Time Sensitivity

Some phenomena, like microbursts, hail, or tornadic activity can be short lived, but have a potentially catastrophic effects. Generally speaking, the shorter lived and more dramatic a particular hazard, the more rapidly a pilot will want the product which describes it. Therefore, even a moderately sized product produced relatively infrequently may demand wide bandwidth to arrive in time to be useful.

3.4.1.4.5 General Bandwidth Requirements According to Decision Arenas

These four bandwidth drivers – product numbers, size, delivery frequency, and time sensitivity – can be generally related to the previously discussed weather-related decision arenas. The following table summarizes this relationship notionally.

Relative Bandwidth Requirements versus Decision Arenas

Decision Arena	Bandwidth Drivers				Relative Weight
	Relative # of Products	Relative size of Products	Delivery Frequency	Time Sensitivity	
Tactical	1	1	3	3	8
Near-term strategic	3	3	2	2	**10**
Far-term strategic	2	2	1	1	6

Legend: NB – the numbers used are *relative*, not absolute

1 – Least resource critical. I.E., few products, low delivery frequency, not time-sensitive
3 – most resource critical. I.E. many products, high frequency, time-critical

This relative projection indicates that the near-term strategic arena will demand the most communication bandwidth from the system, followed by the tactical arena, and finally the far-term strategic. With this in mind, looking at the bandwidth likely to be actually available can be instructive.

3.4.1.5 Bandwidth Available

There are already many communications schemes to choose from, and more are on the horizon. This can make a rigorous future analysis somewhat difficult; nevertheless, some general trends are apparent when considering phases of flight. These phases can be generally broken down into when the airplane is en-route, in the terminal area, or on the ground.

3.4.1.5.1 En-route

Available en-route bandwidth is, and will probably remain, the lowest among the three flight phases. Current data rates are capped at approximately 2400 bps, but improvements are on the horizon. Still, for the foreseeable future, the en-route segment of flight will continue to suffer from the least bandwidth available.

3.4.1.5.2 Ground

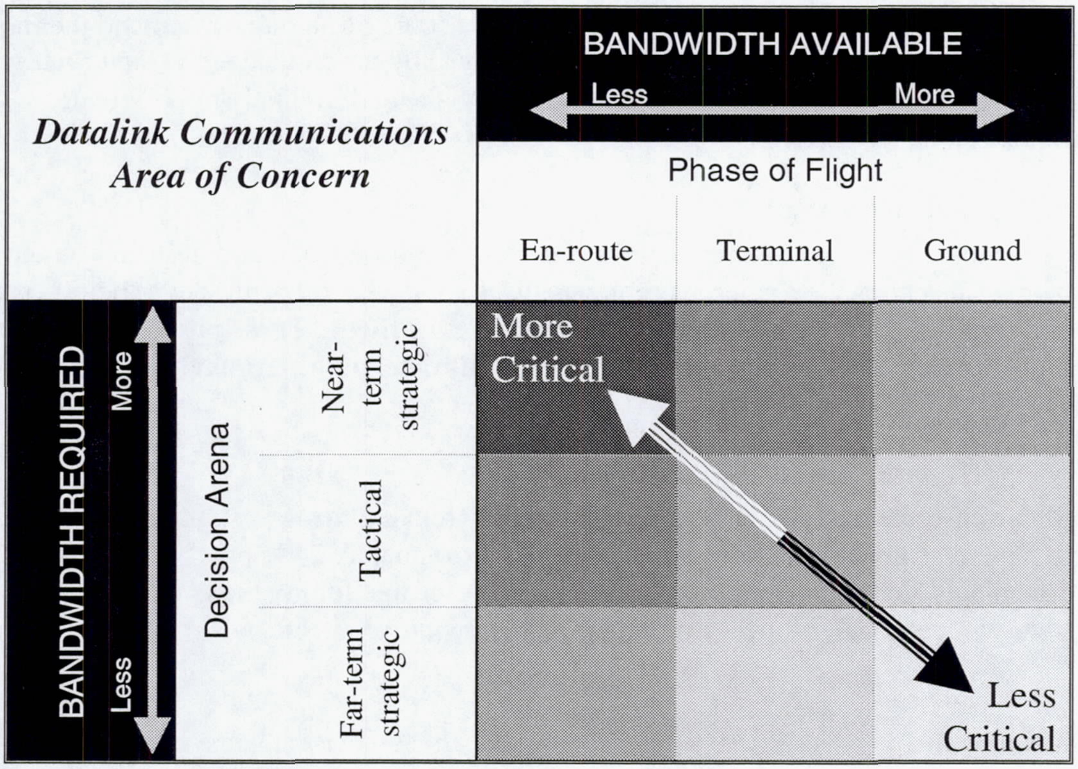
High bandwidth, ground-based, wireless networks already exist at some airports. These are demonstrating speeds of up to 3 Mb per second, far surpassing what is available en-route. It seems logical to assume that such networks will both expand and get faster in the future.

3.4.1.5.3 Terminal

The airborne terminal area is the next logical place for ground-based, wireless bandwidth to expand. The high-density traffic in the vicinity of an airline hub can be dramatically affected by weather phenomena such as wind shear, microbursts, Runway Visual Range, ceiling heights, turbulence, and icing. Providing real or near-real-time information about such hazards will enhance cockpit situational awareness, thereby reducing voice radio congestion, cutting back on unnecessary and expensive diversions, and raising airport arrival rates. In the vicinity of a major airline hub, there are many users and uses beyond cockpit weather information to help defray costs. It is, therefore, reasonable to anticipate the introduction of localized, higher bandwidth, wireless services in U. S. major terminal airspace.

3.4.1.6 Resulting Datalink Areas of Concern

A pilot in any given *phase of flight* (en-route, terminal, or ground) may be making tactical, near-term strategic, or far-term strategic decisions. As these phases of flight are related to bandwidth *available*, and the decision arenas are related to bandwidth *required*, the following notional matrix can be used to help focus on areas of concern. As shown, the most communication limited piece is an en-route, near-term strategic decision, while the least area of concern is a ground-based, far-term strategic decision.



3.4.2 General Aviation Weather Concerns

According to the FAA's Weather Joint Safety Analysis Team (JSAT), research indicates that weather-related GA fatal accidents are attributable to, in order:

- Instrument Meteorological Conditions
- Convection
- Icing
- Turbulence

Airlines have very similar concerns. IMC conditions at destination and alternate fields drive many flight planning and execution decisions, though they are not responsible for a correlative number of fatalities. Convection, icing, and turbulence are similarly important in the commercial world as in the GA world.

3.4.3 FAA Current Research Efforts

The FAA's Aviation Weather Research Program (AWRP) efforts are organized into eight Product Development Teams (PDTs). The PDTs are listed and briefly described below. Each PDT leader coordinates among multiple laboratories and agencies, serving to eliminate redundant efforts, and promote collaboration and leverage.
The PDTs are:

- Inflight Icing
- Aviation Gridded Forecast System

- Turbulence
- Winter Weather
- Convective Weather
- Ceiling and Visibility
- Model Development and Enhancement
- NEXRAD Enhancements

3.4.3.1 Inflight Icing

Inflight Icing is currently the FAA's top weather research priority, and is being led by NCAR. This PDT's goal is an hourly, gridded depiction of forecast inflight icing, based on operational model output combined with real-times sensor data, including icing severity and type.

3.4.3.2 Aviation Gridded Forecast System

This PDT is based on the assumptions that in the future, pilots and support staff will have to make more weather related decisions, particularly in a Free Flight environment. With limited bandwidth, an excellent way to customize products to a particular airplane will be to utilize computer systems that can extract from a larger data base the critical information that the pilot requires, and then format it in an appropriate fashion. To do so, this PDT proposes a service—the Aviation Gridded Forecast System (AGFS). The AGFS will be an official service of the National Weather Service originating from the Aviation Weather Center (AWC). The database and distribution portion of the AGFS is the Aviation Digital Data Service (ADDS), which became operational in February 1997. The goal of the AGFS will be to provide accurate, timely, detailed weather observations and forecasts which can be used to derive information for flight planning and operations. This will require observations and forecasts with details in the 10s of miles, spatial extent of the 1000s of miles, and vertical resolutions on the order of 1000s of feet. The AGFS PDT is led by the NOAA Forecast Systems Laboratory.

3.4.3.3 Turbulence

The Turbulence PDT, also led by NOAA's Forecast Systems Laboratory, hopes to provide an hourly, three-dimensional field of turbulence from objective, "in-situ" measurements. In this context, "in-situ" reporting refers to the use of measurements made by existing data on-board aircraft.

3.4.3.4 Winter Weather

The primary focus of this PDT is the capability called Weather Support to ground De-icing Decision Making (WSDDM). Past ground icing/de-icing accidents, as well as the monetary and environmental costs involved, make enhancing the de-icing decision attractive. The WSDDM approach is to develop an accurate, graphical description of the real-time, 30 minute nowcast, and four hour forecast of winter weather conditions for the 10km region surrounding an airport. These conditions include precipitation intensity, precipitation type and weather condition, temperature, and wind speed and direction. This is to be done through multiple sensors and enhanced algorithms. NCAR is leading this team.

3.4.3.5 Convective Weather

This PDT is split into two related components: forecasting and detection. The forecasting segment is designed to predict storm cell growth and decay from the current time up to six hours in advance. The detection portion is designed to automatically detect and extrapolate the location of hazardous convective weather. The Convective Weather PDT, therefore, aims to provide accurate, timely information which includes storm growth and decay, often currently ignored. In doing so, they are focusing on enabling reductions in air traffic delays and increased separation near weather. MIT Lincoln Laboratory is leading the Convective Weather PDT.

3.4.3.6 Ceiling and Visibility

MIT Lincoln Labs heads this PDT as well. Ceiling and Visibility conditions dictate much of the airlines' behavior, and account for the largest share of GA fatal accidents. Airports, especially those in the vicinity of the ocean, such as SFO, would dramatically benefit from improved ceiling and visibility forecasts, as safe capacity increases could be better planned and executed. The 50% of the GA populace without instrument ratings would also benefit from this improved ability. This PDT is focusing on providing accurate 1-2 hour forecasts using a column modeling system.

3.4.3.7 Model Development and Enhancement

This effort, led by the NOAA Forecast Systems Laboratory, consists of improving the accuracy of numerical models. To produce more timely and accurate forecasts, the PDT is focusing on taking advantage of new observations, properly defining the required wind and cloud features, and improving models' internal representation of cloud development. The two principal models they are working with are the Rapid Update Cycle (RUC) and Eta models run at NCEP.

3.4.3.8 NEXRAD Enhancements

NOAA's National Severe Storms Laboratory is focusing on enhancing NEXRAD performance. These enhancements should enable better definition, location, timing, and severity of convective weather hazards by improving NEXRAD algorithms, as well as storm growth and decay efforts relative to ITWS pre-planned product improvements.

3.4.4 Assumptions

In order to characterize the kinds of products that will populate the future aircraft flight deck, a number of assumptions have to be made. These assumptions are not intended to design a particular product, but to characterize the kinds and order of magnitude sizing of such products.

In the following section, representative classes of products are projected. Embedded in those representations are the following assumptions:

3.4.4.1 Airline Viewpoint

The products have been sized from mostly an airline viewpoint, assuming that airlines will have the need and resources to pay for more specific, sophisticated products which will tax the available bandwidth. Slower moving GA users are likely to get by with products covering smaller areas which consume less bandwidth.

3.4.4.2 Area of Regard

The assumed area of regard, based on airliner speeds, has been chosen to provide an equitable basis of comparison among products, as well as to roughly size them. Tactical products are assumed to be within 15 minutes of current position, or less than 125Nm away. For near-term strategic products, an area of 500Nm x 500Nm provides information to at least an hour from each boundary. For far-term strategic products, 1500Nm x 1500Nm could cover the CONUS with six overlapping areas as some providers have already done, providing information out to at least three hours from each boundary. Note that the time area of regard, for example 90 minutes, may be –30 to +60 as easily as 0 to +90 minutes, depending on user preference.

3.4.4.3 Broadcast Products

Users and suppliers expect both broadcast and addressed products to be available in the future, with the emphasis on broadcast. The final mix of these two, for example 75% to 25%, will depend on the operating paradigm of a user, frequency congestion, area of the world, etc. Though the final mix is not accurately predictable, it does seem certain that the basic foundation of future in-flight weather information will be built on broadcast products. With a given core of these available, pilots (and dispatchers) will likely fill in any informational gaps with specific, addressed products.

3.4.4.4 Addressed Products

Most addressed products are likely to be fairly specific, and perhaps, therefore, smaller in file-size than their broadcast cousins. Even so, a high demand for relatively small products in the vicinity of a weather hazard could easily tax future available bandwidth. Unfortunately, there are too many variables associated with addressed products to make a meaningful prediction about exactly how they might be used. Instead, the treatment that follows look at potential broadcast products with the knowledge that addressed products will add at least 25% to the bandwidth load.

3.4.4.5 "Pictures" vs. "Objects"

The future may hold products that have embedded weather "objects" that can be manipulated by on-board systems. Current research, however, is squarely aimed at a gridded system. Therefore, the projected products are assumed to be bit-mapped "pictures" in a multi-dimensional grid.

3.4.4.6 Compression

As mentioned earlier, the MIT Lincoln Labs Huffman compression, a weather-specific compression scheme, has produced up to 64:1 compressed file sizes which are useful for far-term strategic representations. Near-term strategic products, however, may require less "lossy" techniques to show the level of detail required to gain a pilot's confidence and change his or her behavior. As an order of magnitude estimate, the following tables assume that far-term strategic products can be compressed to 50:1, near-term strategic at 20:1, and tactical products at 10:1, and still remain useful.

3.4.4.7 Information, not Data

Future products will provide more meaning in less bandwidth by transmitting "information" versus "data." Most direct sensor data, such as a satellite photo, are bandwidth intensive, and do not contain as much information as a synthesized, integrated product does. It is assumed that the largest share, by far, of future broadcast weather products will be computer generated, synthesized, integrated information. This means, for instance, that a lightning strike product available today would be rolled into an integrated convective product in the future.

3.4.4.8 Timeframe

The classes of future products described below are projected to exist from five to ten years in the future. It must again be stressed that these products are generic projections, intended to be used for order of magnitude estimates, and not at all intended as an exhaustive list of all possibilities or a specific list of the exact future. There are many factors that could dramatically affect future outcomes.

3.4.5 Representative Future In-Flight Weather Products

The following described products are grouped by phase of flight: En route, Terminal, and Ground. Each includes both a short discussion and/or table which summarizes the projected product. In each case, the product described has been roughly sized near the high end of its anticipated requirement. Far-term strategic products, for example, are based on airline requirements with true airspeeds of roughly 500 Nm/Hr. As such, they are going to be larger than an equivalently sized GA far-term strategic product, based on a true airspeed of 200 Nm/Hr or less.

3.4.5.1 Projected En route Products

En-route products are the ones most often pictured when discussing weather products on the flight deck. For airlines, this information is sometimes already provided in a very diluted form, through various links to the dispatcher. Broadcast to the cockpit, these products will help enable more pro-active, quicker, smarter, more collaborative decisions. For non-dispatched traffic, including GA, these products represent information previously available only through fairly arduous searching.

3.4.5.1.1 En route Far-term Strategic

As noted earlier, the most likely path for depicting future weather hazards will be one of indexing or normalizing a hazard, up-linking it to an airplane, and having that aircraft's system decode and display the severity of the aircraft-specific hazard, depending on airplane type, mission, pilot capability, etc. With this in mind, there is likely to be a general hazard display, available someday on a common screen.

A general hazard display would integrate all known "threats," including weather. From there, a user may be able to filter some information out in order to look at either a chosen hazard class, or a particular hazard of interest. Though a single, thoroughly integrated hazard product is conceivable, the following treatment assumes discrete products, one of which is a general weather hazard product.

3.4.5.1.1.1 General Weather Hazards– En route Far-term Strategic

This product is eventually likely to be a portion of a more generic "hazard" product that displays other hazards as well, such as traffic, terrain, airspace limitations, etc.

The General Weather Hazard Display could actually be a combination of all the products rolled into one by an on-board system, or a product unto itself. In the latter case, the other products such as icing, turbulence, etc., would be a filtered out subset of the entire hazard display.

In this treatment, all products are assumed to be a product unto themselves to be conservative in comparing bandwidth requirements as well as to avoid single-point failures of the information flow.

En Route Phase of Flight	Far-Term Strategic Decision Arena	GENERAL HAZARD Product	Product Summary

Area of Regard:			
1500 NM	1500 NM	50,000 FT	300 Mins
Fidelity:			
25 NM	25 NM	2000 FT	30 Mins
Number of states (colors &/or symbols):	< 256		
Corresponding Bit Depth:	8		

Comments:

The CONUS would be covered in six sections with significant overlap.

It is possible that a higher level product might be produced which would span the entire CONUS or other general operating region.

The enhanced bit-depth is needed to handle all the other product information rolled into a single, general product.

RELATIVE ORDER OF MAGNITUDE SIZING COMPARISON AND IMPLICATIONS			
7,200,000 Bits	144,000 Bits	1.0 Mins	2.0 Mins
Approximate uncompressed data file size	Nominally compressed at 50:1	Single product Transmission Time at 2400 bps	Time spent transmitting this product each hour.

3.4.5.1.1.2 Turbulence – En route Far-term Strategic

Strategic turbulence information will become one of the most important future products. Currently, turbulence is basically avoided by word of mouth, and then on an almost exclusively tactical basis. Turbulence is a growing injury and liability concern for nearly all airlines and a primary safety concern for GA.

En Route Phase of Flight	Far-Term Strategic Decision Arena	TURBULENCE Product	Product Summary
Area of Regard: 1500 NM · 1500 NM · 50,000 FT · 300 Mins		*Comments:* The CONUS would be covered in six sections with significant overlap. If the models and measurements can support it, 30 minute increments may be desirable. Non-convective turbulence fields do not change as rapidly as convective weather, however, so a more rapid update rate than 30 minutes is unlikely.	
Fidelity: 25 NM · 25 NM · 2000 FT · 60 Mins			
Number of states (colors &/or symbols): < 8			
Corresponding Bit Depth: 3			

RELATIVE ORDER OF MAGNITUDE SIZING COMPARISON AND IMPLICATIONS			
1,350,000 Bits	27,000 Bits	0.2 Mins	0.2 Mins
Approximate uncompressed data file size	Nominally compressed at 50:1	Single product Transmission Time at 2400 bps	Time spent transmitting this product each hour.

Convection – En route Far-term Strategic

A future, integrated "convective" product will include a synthesis of many data, such as cloud tops, freezing level, lightning activity, projected decay, water content, etc. Thus, the "convective" product of the future will be much more than a simple radar mosaic, or lightning strike presentation. It will be a complex synthesis of that data and more, but will probably have that data available for viewing as needed. Thus, the higher bit depth anticipated for this product.

En Route (Phase of Flight)	Far-Term Strategic (Decision Arena)	CONVECTION (Product)	Product Summary

Area of Regard:				*Comments:*
1500 NM	1500 NM	50,000 FT	300 Mins	The CONUS would be covered in six sections with significant overlap.
Fidelity:				Because this is a far-term strategic product, it is conceivable that the update rate may be cut to 20 to 30 minutes. If 15 minute updates are available, however, it seems likely they will be expected.
25 NM	25 NM	2000 FT	15 Mins	
Number of states (colors &/or symbols):		*< 128*		Because there are more elements embedded in an integrated convective product than most others, it will require more bit depth to describe.
Corresponding Bit Depth:		7		

RELATIVE ORDER OF MAGNITUDE SIZING COMPARISON AND IMPLICATIONS			
12,600,000 Bits	252,000 Bits	1.8 Mins	7.0 Mins
Approximate uncompressed data file size	Nominally compressed at 50:1	Single product Transmission Time at 2400 bps	Time spent transmitting this product each hour.

3.4.5.1.1.3 Icing / Flight Conditions – En route Far-term Strategic

IMC and icing are two of GA's biggest concerns, though they are somewhat less critical for the airlines. Both icing and in-flight conditions fit conveniently into a single package as they depend on many of the same variables, and drive similar regulatory decisions.

En Route (Phase of Flight)		Far-Term Strategic (Decision Area)		'CING / FLT CNDTN (Product)	Product Summary
Area of Regard:				*Comments:* The CONUS would be covered in six sections with significant overlap. Flight conditions (IMC, VMC, visibility, etc.) would be included with the icing reports and forecasts. As for turbulence, 30 minute updates may be desirable if they are achievable.	
1500 NM	1500 NM	50,000 FT	300 Mins		
Fidelity:					
25 NM	25 NM	2000 FT	60 Mins		
Number of states (colors &/or symbols):		*< 32*			
Corresponding Bit Depth:		5			

RELATIVE ORDER OF MAGNITUDE SIZING COMPARISON AND IMPLICATIONS			
2,250,000 Bits	45,000 Bits	0.3 Mins	0.3 Mins
Approximate uncompressed data file size	Nominally compressed at 50:1	Single product Transmission Time at 2400 bps	Time spent transmitting this product each hour.

3.4.5.1.1.4 Winds/Temperature – En route Far-term Strategic

Changing en-route winds are always a potential factor for any flight. Armed with sufficient computing power, it is even conceivable that this product (and others) could feed into an in-flight flight planning system. This would enable a pilot to much more easily coordinate proposed flight trajectory changes with dispatch and/or ATC.
As airspace over the former Soviet Union opens up, polar routes are going to become more and more common. As they do, in-flight temperatures will become increasingly important as they affect performance through a variety of means, including fuel temperatures.

En Route Phase of Flight	Far-Term Strategic Decision Arena	WINDS / TEMP Product	Product Summary

Area of Regard:				*Comments:*
1500 NM	1500 NM	50,000 FT	300 Mins	The CONUS would be covered in six sections with significant overlap. This could be one or two products, depending on implementation. Current use suggests they will be combined. Temperatures will be especially desirable for increasingly common polar flights.
Fidelity:				
25 NM	25 NM	2000 FT	60 Mins	
Number of states (colors &/or symbols):		*< 64*		
Corresponding Bit Depth:		6		

RELATIVE ORDER OF MAGNITUDE SIZING COMPARISON AND IMPLICATIONS			
2,700,000 Bits	54,000 Bits	0.4 Mins	0.4 Mins
Approximate uncompressed data file size	Nominally compressed at 50:1	Single product Transmission Time at 2400 bps	Time spent transmitting this product each hour.

3.4.5.1.1.5 Surface Conditions – En route Far-term Strategic

Surface conditions affect long-term contingency planning for potential diversions stations for weather or emergencies. They also can serve to enhance overall situational awareness.

There is no difference between this product and its near-term strategic or tactical equivalent. The same product will be used for all three kinds of decisions.

En Route Phase of Flight		(All) Decision Arena		SFC CONDITIONS Product	Product Summary
Area of Regard:				*Comments:*	
1500 NM	1500 NM	-Surface- FT	300 Mins	The CONUS would be covered in six sections with significant overlap.	
Fidelity:				This will probably be a combined Graphic, Icon, and Text product – growing out of the current CWIN-AWIN effort. It would, most likely, focus on reported and forecast airfield conditions and not be as compressible as the rest of the far-term strategic products.	
25 NM	25 NM	N/A FT	15 Mins		
Number of states (colors &/or symbols):		*< 32*		The 25Nm grid is included for approximate sizing purposes only. – reporting points will be wherever airfields of interest are located.	
Corresponding Bit Depth:		8			

RELATIVE ORDER OF MAGNITUDE SIZING COMPARISON AND IMPLICATIONS			
576,000 Bits	28,800 Bits	0.2 Mins	0.8 Mins
Approximate uncompressed data file size	Nominally compressed at 20:1	Single product Transmission Time at 2400 bps	Time spent transmitting this product each hour.

3.4.5.1.2 En route Near-term Strategic

3.4.5.1.2.1 General Weather Hazards– En route Near-term Strategic

As in the far-term case, near-term strategic products will probably feature a combined threat analysis. The same considerations apply:

The General Weather Hazard Display could actually be a combination of all the products rolled into one by an on-board system, or a product unto itself. In the latter case, the other products such as icing, turbulence, etc., would be a filtered out subset of the entire hazard display.

In this discussion, all products are assumed to be a product unto themselves to be conservative in comparing bandwidth requirements as well as to avoid single-point failures of the information flow.

En Route Phase of Flight	Near-Term Strategic Decision Arena	GENERAL HAZARDS Product	Product Summary
Area of Regard: 500 NM, 500 NM, 50,000 FT, 70 Mins		*Comments:* The enhanced bit-depth is needed to handle all the other product information rolled into a single, general product. It is possible that the near-term and far-term general strategic hazard product could be the same.	
Fidelity: 10 NM, 10 NM, 1000 FT, 10 Mins			
Number of states (colors &/or symbols): *< 256*			
Corresponding Bit Depth: 8			
RELATIVE ORDER OF MAGNITUDE SIZING COMPARISON AND IMPLICATIONS			
7,000,000 Bits	350,000 Bits	2.4 Mins	14.6 Mins
Approximate uncompressed data file size	Nominally compressed at 20:1	Single product Transmission Time at 2400 bps	Time spent transmitting this product each hour.

3.4.5.1.2.2 Turbulence – En route Near-term Strategic

Successful turbulence nowcasts will be highly prized products for the airlines. If they reach a sufficient level of detail and accuracy, they will be able to help enhance safety, comfort, and efficiency.

Even the best nowcasts will probably have difficulty in reaching the frequency and fidelity that will be desired for near-term strategic decisions. Nevertheless, such a product may be created by beginning with currently reported turbulence, and interpolating out to the nearest nowcast.

En Route Phase of Flight	Near-Term Strategic Decision Arena		TURBULENCE Product	Product Summary
Area of Regard:				
500 NM	500 NM	50,000 FT	70 Mins	
Fidelity:				*Comments:* Turbulence models will probably not run every ten minutes. Therefore, this product will likely be some kind of interpolation between a modeling forecast and reported conditions.
10 NM	10 NM	1000 FT	10 Mins	
Number of states (colors &/or symbols):			< 8	
Corresponding Bit Depth:			3	

RELATIVE ORDER OF MAGNITUDE SIZING COMPARISON AND IMPLICATIONS			
2,625,000 Bits	131,250 Bits	0.9 Mins	5.5 Mins
Approximate uncompressed data file size	Nominally compressed at 20:1	Single product Transmission Time at 2400 bps	Time spent transmitting this product each hour.

3.4.5.1.2.3 Convection – En route Near-term Strategic

Convection products may be generated more often than turbulence products because of the nature of the data and algorithms. Even so, the desire for frequency and fidelity may outstrip the ability of the models.

En Route Phase of Flight	Near-Term Strategic Decision Arena	***CONVECTION*** Product	Product Summary

Area of Regard:

500 NM	500 NM	50,000 FT	70 Mins

Fidelity:

10 NM	10 NM	1000 FT	10 Mins

Number of states (colors &/or symbols): *< 128*

Corresponding Bit Depth: 7

Comments:

Like turbulence models, convection models will probably not run every ten minutes, though they may get closer. Therefore, this product may also be an interpolation between a modeling forecast and reported conditions.

RELATIVE ORDER OF MAGNITUDE SIZING COMPARISON AND IMPLICATIONS			
6,125,000 Bits	306,250 Bits	2.1 Mins	12.8 Mins
Approximate uncompressed data file size	Nominally compressed at 20:1	Single product Transmission Time at 2400 bps	Time spent transmitting this product each hour.

3.4.5.1.2.4 Icing / Flight Conditions – En route Near-term Strategic

IMC and icing are two of GA's biggest concerns, though they are somewhat less critical for the airlines. Both icing and in-flight conditions fit conveniently into a single package as they depend on many of the same variables, and drive similar regulatory decisions. Again, for the near-term strategic arena, it may be some time before data, algorithms, and computing power can deliver the desired fidelity and frequency.

En Route Phase of Flight	Near-Term Strategic Decision Arena	'CING / FLT CNDTN Product	Product Summary
Area of Regard: 500 NM, 500 NM, 50,000 FT, 70 Mins		*Comments:* Icing models will probably not run every ten minutes. Therefore, this product will likely be some kind of interpolation between a modeling forecast and reported conditions. Flight conditions (IMC, VMC, visibility, etc.) would be included with the icing reports and forecasts.	
Fidelity: 10 NM, 10 NM, 1000 FT, 10 Mins			
Number of states (colors &/or symbols): < 32			
Corresponding Bit Depth: 5			
RELATIVE ORDER OF MAGNITUDE SIZING COMPARISON AND IMPLICATIONS			
4,375,000 Bits	218,750 Bits	1.5 Mins	9.1 Mins
Approximate uncompressed data file size	Nominally compressed at 20:1	Single product Transmission Time at 2400 bps	Time spent transmitting this product each hour.

3.4.5.1.2.5 Winds/Temperature – En route Near-term Strategic

Changing en-route winds are always a potential factor for any flight. Armed with sufficient computing power, it is even conceivable that this product (and others) could feed into an in-flight flight planning system. This would enable a pilot to much more easily coordinate proposed flight trajectory changes with dispatch and/or ATC.

As airspace over the former Soviet Union opens up, polar routes are going to become more and more common. As they do, in-flight temperatures will become increasingly important as they affect performance through a variety of means, including fuel temperatures.

En Route Phase of Flight	Near-Term Strategic Decision Arena	***WINDS / TEMP*** Product	Product Summary
Area of Regard: 500 NM | 500 NM | 50,000 FT | 70 Mins		*Comments:* Winds and temp models will probably not run every ten minutes. Therefore, this product will likely be some kind of interpolation between a modeling forecast and reported conditions.	
Fidelity: 10 NM | 10 NM | 1000 FT | 10 Mins			
Number of states (colors &/or symbols): *< 64*			
Corresponding Bit Depth: 6			
RELATIVE ORDER OF MAGNITUDE SIZING COMPARISON AND IMPLICATIONS			
5,250,000 Bits	262,500 Bits	1.8 Mins	10.9 Mins
Approximate uncompressed data file size	Nominally compressed at 20:1	Single product Transmission Time at 2400 bps	Time spent transmitting this product each hour.

3.4.5.1.2.6 Surface Conditions – En route Near-term Strategic

There is no difference between this product and its far-term strategic or tactical equivalent. The same product will be used for all three kinds of decisions.

En Route Phase of Flight		(All) Decision Arena		***SFC CONDITIONS*** Product	Product Summary
Area of Regard:				*Comments:*	
1500 NM	1500 NM	-Surface- FT	300 Mins	The CONUS would be covered in six sections with significant overlap.	
Fidelity:				This will probably be a combined Graphic, Icon, and Text product – growing out of the current CWIN-AWIN effort. It would, most likely, focus on reported and forecast airfield conditions and not be as compressible as the rest of the far-term strategic products.	
25 NM	25 NM	N/A FT	15 Mins		
Number of states (colors &/or symbols):		*< 32*		The 25Nm grid is included for approximate sizing purposes only. – reporting points will be wherever airfields of interest are located.	
Corresponding Bit Depth:		8			

RELATIVE ORDER OF MAGNITUDE SIZING COMPARISON AND IMPLICATIONS			
576,000 Bits	28,800 Bits	0.2 Mins	0.8 Mins
Approximate uncompressed data file size	Nominally compressed at 20:1	Single product Transmission Time at 2400 bps	Time spent transmitting this product each hour.

3.4.5.1.3 En route Tactical

Hopefully, a strong strategic set of weather information and processes will avoid the need for most tactical weather decisions and products.

Tactical products in an en-route environment are highly likely to be addressed and either "pushed" to an aircraft, or requested by the pilot and/or aircraft system. Due to their required accuracy and timeliness, they are considered to be centered around the aircraft and compressed to only $1/10^{th}$ of their original size.

Most of the en route tactical issues are now addressed by consulting on-board sensors, and this will probably remain the case. Using off-board sensors to make short-term penetration decisions usually requires a fidelity and update rate that cannot currently be achieved. For these reasons, as well as probable elevated software certification levels, en route tactical products may be sparse. A few potential examples are listed in the following treatment.

It should be noted that there is also a need for non-weather tactical information. Such information might include medical needs or emergency field locations and status. In short, any non-weather related information that can aid a tactical decision will necessarily come from off-board sensors and compete for bandwidth.

3.4.5.1.3.1 Field Conditions – En route Tactical

This product is identical to the one used for far-term and near-term strategic decisions. In this context, it would probably be used to help select an immediate divert location due to some unforeseen problem.

En Route Phase of Flight		(All) Decision Arena		SFC CONDITIONS Product		Product Summary
Area of Regard:				*Comments:* The CONUS would be covered in six sections with significant overlap. This will probably be a combined Graphic, Icon, and Text product – growing out of the current CWIN-AWIN effort. It would, most likely, focus on reported and forecast airfield conditions and not be as compressible as the rest of the far-term strategic products. The 25Nm grid is included for approximate sizing purposes only. – reporting points will be wherever airfields of interest are located.		
1500 NM	1500 NM	-Surface- FT	300 Mins			
Fidelity:						
25 NM	25 NM	N/A FT	15 Mins			
Number of states (colors &/or symbols):		*< 32*				
Corresponding Bit Depth:		8				

RELATIVE ORDER OF MAGNITUDE SIZING COMPARISON AND IMPLICATIONS			
576,000 Bits	28,800 Bits	0.2 Mins	0.8 Mins
Approximate uncompressed data file size	Nominally compressed at 20:1	Single product Transmission Time at 2400 bps	Time spent transmitting this product each hour.

3.4.5.1.3.2 Icing / Flight Conditions – En route Tactical

As noted earlier, locating and avoiding IMC is a top GA issue, more than an airline issue. Once in unacceptable IMC and/or icing conditions, GA pilots may well be facing a life or death struggle that requires them to efficiently and immediately exit the condition.

En Route Phase of Flight	Tactical Decision Arena	ICING / FLT CNDTNS Product	Product Summary
Area of Regard: 125 NM · 125 NM · 20,000 FT · 5 Single Picture		*Comments:* A tactical product like this may never be feasible for a variety of reasons, including model accuracy and software/process certification. Immediately exiting IMC and/or icing can be one of the most critical things a GA pilot must do. Fidelity is based on +/- 10,000 feet of current altitude, blocks less than 1 minute in length (5Nm), and at least three updates within the area of regard.	
Fidelity: 5 NM · 5 NM · 1000 FT · 5 Mins			
Number of states (colors &/or symbols):	*< 32*		
Corresponding Bit Depth:	5		

RELATIVE ORDER OF MAGNITUDE SIZING COMPARISON AND IMPLICATIONS			
62,500 Bits	6,250 Bits	0.04 Mins	0.5 Mins
Approximate uncompressed data file size	Nominally compressed at 10:1	Single product Transmission Time at 2400 bps	Time spent transmitting this product each hour.

3.4.5.1.3.3 Turbulence – En route Tactical

It is unlikely that a true, tactical turbulence product will be created. With current projections, the best the industry could hope for is an interpolated grid that combines current sensed conditions with the next available nowcast.

En Route Phase of Flight		Tactical Decision Arena		***TURBULENCE*** Product	Product Summary
Area of Regard:				*Comments:* A tactical product like this may never be feasible for a variety of reasons, including model accuracy and software/process certification. Fidelity is based on +/- 10,000 feet of current altitude, blocks less than 1 minute in length (5Nm), and at least three updates within the area of regard.	
125 NM	125 NM	20,000 FT	5 Single Picture		
Fidelity:					
5 NM	5 NM	1000 FT	5 Mins		
Number of states (colors &/or symbols):			*< 8*		
Corresponding Bit Depth:			3		

RELATIVE ORDER OF MAGNITUDE SIZING COMPARISON AND IMPLICATIONS			
37,500 Bits	3,750 Bits	0.03 Mins	0.3 Mins
Approximate uncompressed data file size	Nominally compressed at 10:1	Single product Transmission Time at 2400 bps	Time spent transmitting this product each hour.

3.4.5.1.4 En-route Backup Strategic General Imagery

With sufficient faith in new, integrated, synthesized weather products, need for direct imagery should reduce. It seems likely, however, that there will always be some desire for direct imagery, especially as a backup for integrated products, in a degraded weather information operations mode. (Provider communications failure, product-creating computers temporarily down, bad inbound datalink to those computers, etc.) The table below assumes up to ten different general images broadcast each 15 minutes.

Examples of general imagery might include satellite photos, lightning strike data, hand drawn Surface Analysis, SIGWX, etc. There may be one or more of these "back-up" general images broadcast at all times, or all ten may be broadcast only when the primary synthesized products are not available. General imagery could be standard, or situationally dependent.

This type of product also makes a good candidate for addressed products that are either requested or "pushed" by a ground based flight monitor. As such, in a non—backup (primary) role, they may be more directly useful in the near-term strategic arena than in the far-term.

En Route Phase of Flight	Backup Strategic Decision Arena	*GENERAL IMAGERY* Product	Product Summary

Area of Regard:				*Comments:* The CONUS would be covered in six sections with significant overlap. Imagery would likely be archived, but would not project into the future. To save bandwidth, the same products would likely be used in far-term and near-term strategic situations. To do so, the fidelity is set to 5nm and compression to 10:1. Although space is estimated for up to ten products, all ten would not necessarily be broadcast each 15 minutes.
1500 NM	1500 NM	1 Single Alt	10 Pictures	
Fidelity				
5 NM	5 NM	1 Single Alt	15 Mins	
Number of states (colors &/or symbols):		*< 256*		
Corresponding Bit Depth:		8		

RELATIVE ORDER OF MAGNITUDE SIZING COMPARISON AND IMPLICATIONS			
28,800,000 Bits	2,880,000 Bits	20.0 Mins	80.0 Mins
Approximate uncompressed data file size	Nominally compressed at 10:1	Single product Transmission Time at 2400 bps	Time spent transmitting this product each hour.

3.4.5.2 Projected Terminal Products

3.4.5.2.1 Terminal Strategic

Most decisions in the terminal area will be tactical in nature.
In the terminal area, there are two basic cases: arrival and departure. In either case, the products that address near-term and far-term strategic decisions are the same as in the en route phase of flight.

When *arriving* the need for strategic products is almost nil. One of the only cases would be for a diversion. This essentially becomes a departure.

When *departing* a terminal area, the infrastructure may allow quicker downloading of strategic products than in the en route phase of flight due to higher bandwidth available. Typical near-term strategic decisions in a Free Flight environment that may be made in the terminal area might include diverting, holding, sequencing, etc.

3.4.5.2.2 Terminal Tactical

Even in the terminal area, most tactical decisions will continue to be made with on-board sensors. However a few broadcast products may be appropriate. These will probably be tailored for individual terminal airspace and traffic flow. Additionally, due to the time sensitivity of the information, these products will also tend toward "data" rather than the more time-consuming to produce, synthesized, information.

3.4.5.2.2.1 Radar Mosaic

Real-time broadcasts of NEXRAD or TDWR-type radar pictures could be highly useful in the terminal area. They would provide non-radar equipped pilots with a good, current look into current weather conditions. Even pilots with radar could successfully see parallel to their flight paths and behind them, anticipating what to expect when turning to base and final from a long, instrument downwind leg. In extreme cases where radar attenuation is a factor, these pictures can also help see into the on-board radar cloud "shadow". Finally, anticipated NEXRAD improvements might help depict localized, short-lived phenomena such as microbursts, hail, and tornadoes.

Bandwidth should not be a problem in most hub locations. The table below assumes the worst case scenario of 2400bps broadcasting in a non-hub terminal location.

Terminal Phase of Flight	Tactical Decision Arena	RADAR MOSAIC Product	Product Summary
Area of Regard: 35 NM; 35 NM; 15,000 FT; 1 Single Picture		*Comments:*	
Fidelity: 1 NM; 1 NM; 1000 FT; 1 Mins			
Number of states (colors &/or symbols):	*< 16*		
Corresponding Bit Depth:	4		
RELATIVE ORDER OF MAGNITUDE SIZING COMPARISON AND IMPLICATIONS			
73,500 Bits	7,350 Bits	0.1 Mins	3.1 Mins
Approximate uncompressed data file size	Nominally compressed at 10:1	Single product Transmission Time at 2400 bps	Time spent transmitting this product each hour.

3.4.5.2.2.2 Icing

A terminal, tactical icing product would be useful, but does not appear very practical at this point. To work, it might be based on automatic reports from aircraft in flight to a central ground location which was constantly plotting, updating, and reporting.

Terminal Phase of Flight		Tactical Decision Arena		ICING Product	Product Summary
Area of Regard:				Comments: A potentially useful product, but difficult to implement.	
35 NM	35 NM	15,000 FT	1 Single Picture		
Fidelity:					
1 NM	1 NM	1000 FT	1 Mins		
Number of states (colors &/or symbols):		< 8			
Corresponding Bit Depth:		3			

RELATIVE ORDER OF MAGNITUDE SIZING COMPARISON AND IMPLICATIONS			
55,125 Bits	5,512.5 Bits	0.04 Mins	2.3 Mins
Approximate uncompressed data file size	Nominally compressed at 10:1	Single product Transmission Time at 2400 bps	Time spent transmitting this product each hour.

3.4.5.2.2.3 Low Level Wind Shear

This is another product with good potential that may be difficult to implement. A wind shear product would identify those dangerous shearing winds caused by microbursts, frontal passage, or leeward structure/mountain rotors. Such a product might be embedded in the radar mosaic, or stand alone. For the sake of clarity and sizing, it is considered alone.

Although a wind shear product might eventually include various altitudes, the projected product here is assumed to be generated by ground-based sensors, fused with NEXRAD or TDWR data that will create a near ground-level view.

Terminal Phase of Flight	Tactical Decision Arena	*WIND SHEAR* Product	Product Summary
Area of Regard: 10 NM, 10 NM, Surface Single Slice, 1 Single Picture			
Fidelity: .25 NM, .25 NM, 1000 FT, 1 Mins		*Comments:* A potentially useful product, but difficult to implement.	
Number of states (colors &/or symbols): < 8			
Corresponding Bit Depth: 3			

RELATIVE ORDER OF MAGNITUDE SIZING COMPARISON AND IMPLICATIONS			
4,800 Bits	480 Bits	0.20 Secs	0.2 Mins
Approximate uncompressed data file size	Nominally compressed at 10:1	Single product Transmission Time at 2400 bps	Time spent transmitting this product each hour.

3.4.5.2.2.4 Destination Field Conditions

This is a product that has current availability. It will probably grow to be a combination of text, icons and graphics, potentially describing NOTAM information, RCR readings, ramp snow conditions, de-icing necessity, , arrival rates, etc. Some have even predicted including local weather and traffic information for display to the arriving passengers.

Terminal Phase of Flight	Tactical Decision Arena		**FIELD CONDITIONS** Product	Product Summary
Area of Regard:				*Comments:* This product would eventually incorporate much more than simply weather. It is meant to help plan for post-landing considerations. This product will probably be a combination of text, graphics, and icons.
5 NM	5 NM	Surface Single Slice	1 Single Picture	
Fidelity:				
.1 NM	.1 NM	Surface Single Slice	1 Mins	
Number of states (colors &/or symbols):			*< 64*	
Corresponding Bit Depth:			5	

RELATIVE ORDER OF MAGNITUDE SIZING COMPARISON AND IMPLICATIONS			
12,500 Bits	1,250 Bits	0.5 Secs	0.5 Mins
Approximate uncompressed data file size	Nominally compressed at 10:1	Single product Transmission Time at 2400 bps	Time spent transmitting this product each hour.

3.4.5.2.2.5 Runway Conditions

Runway condition products may eventually be used, although some groups have suggested that they do not wish to incorporate such information into the flight deck. The current RVR, RCR, lighting, or ceiling conditions are all factors that help a pilot both decide whether s/he is allowed to attempt an approach, as well as his or her chances of successfully completing it. If such products are ever developed to cover these approach issues, they likely to be one dimensional, and constantly broadcast. They might be displayed on the flight deck as analog bars against a threshold setting, or simply lights or aural warnings. In any case, they will not be large enough to affect the overall terminal area bandwidth availability.

3.4.5.3 Projected Ground Products

Some weather products will be wirelessly delivered to the flight deck while still on the ground, preparing for flight. While technically not "in flight," there are still valid products that can enhance upcoming tactical or strategic decisions. For that reason, some weather products delivered wirelessly to the flight deck are considered here.

3.4.5.3.1 General Weather Updates – All Decision Arenas, Ground

On the ground preparing for departure, the most recent in-flight tactical and strategic weather products will be loaded via the high-speed wireless links now becoming available. Barring any high-bandwidth cabin needs, all foreseen weather products will have no trouble being downlinked. Although not a factor from a bandwidth perspective, two weather-related cases merit special mentioning.

3.4.5.3.2 Field Conditions – Tactical Ground

As in the terminal area, general field conditions will be of interest to the planes on the ground. Taxiway condition, RCR, RVR, de-icing requirements, and de-icing wait times will all calculate into a pilot's decision about when and where to taxi, especially during any irregular operations due to weather.

3.4.5.3.3 De-icing Effectiveness – Tactical Ground

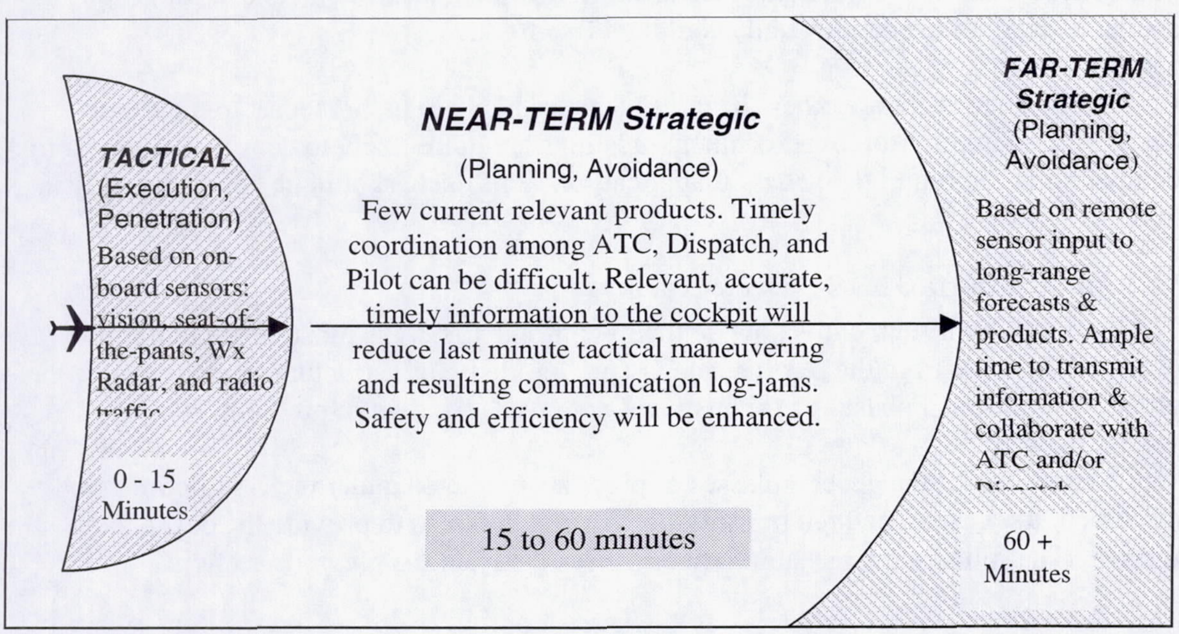
One possible outgrowth of the WSDDM PDT is a more accurate de-icing holdover time calculation. This information, combined with taxi-out delays would help plan de-icing and departures in heavy winter weather with greater safety and efficiency.

3.4.6 Communications Requirements for Potential New Weather Products

3.4.6.1.1 General

It seems likely that future in-flight weather products will be broken down by both phase of flight, and the character of the decision being made. The industry has characterized these decision arenas as tactical (penetration) and strategic (avoidance). For anticipated future use, the strategic arena can be further sub-divided into *near-term* and *far-term*. The near-term strategic decisions will be enabled by new and more accurate nowcasts currently in development, and will greatly reduce the amount of tactical maneuvering required, thus enhancing safety while reducing operating costs.

Three Weather-Related Decision Arenas



3.4.6.1.2 Information vs Data

"Information" implies data that are contextualized to empower faster, smarter decisions. In the future, artificial intelligence, improved algorithms, better measurements, airborne feedback loops, and improved computing power will enable multiple data sources to be synthesized into a single, more meaningful, informational product. This process has the added value of shrinking bandwidth requirements by reducing the total number of raw products a pilot would otherwise desire to see.

3.4.6.1.3 Broadcast Products

As previously stated, the above treatment assumes that the broadcasting is the general delivery paradigm. Users, avionics suppliers, and third party providers generally agree that broadcasting is the most efficient way to supply weather information to thousands of airborne airplanes at the same time. It is highly likely that broadcast products will form the basis for future weather information in the cockpit.

3.4.6.1.4 Addressed Products

Addressed products, in the form of either request-reply or "pushed" information, will be important as well. However, there are too many variables associated with addressed products to meaningfully and accurately predict how and when they will be used. As well as bandwidth available, these variables include a specific airline's operating paradigm, cost of the product, cost of transmission, time sensitivity and latency, accuracy of the information, etc. Under certain conditions, it seems likely that addressed products will consume at least 25% of the available weather-product bandwidth.

3.4.6.1.5 Downlinking and Other Bandwidth Drains

Embedded in the concept of improving weather products, is the important assumption that airplanes will automatically downlink current conditions. This will be done to validate and tweak past forecasts, as well as to provide input for future forecasts and nowcasts. Though not specifically treated here, downlinking these data is already being done by the airlines over ACARS. As this program expands, it will also consume available datalink bandwidth, and should not be forgotten.

Besides weather, there are other "hazards" that are likely to be broadcast to the flight decks of the future. Moreover, cabin applications are quire likely to consume much more bandwidth in the future than cockpit application. This, also, should be kept constantly in mind.

3.4.6.1.6 Summarized Bandwidth Projections

The en-route flight segment is now, and will continue to be, the most bandwidth limited phase of flight. Within the next decade, assuming likely infrastructure improvements, the ground and terminal phases of flight should not pose a bandwidth problem.

While en route, for the general classes of products predicted under the assumptions discussed, there is not enough transmission time at 2400pbs to provide the desired service. The following table summarizes the results from the previous section:

EN ROUTE DECISION ARENA	TRANSMISSION TIME REQUIRED PER HOUR
Near-term strategic:	53 minutes
Far-term Strategic:	11 minutes
Tactical:	1 minute
Total:	65 minutes

Available bandwidth is already over-committed, despite the futuristic assumptions that products are pre-processed into "information" rather than simply data, and that they have been optimistically compacted,. Other assumptions (addressed products likely to consume at least 25% more bandwidth, flight condition downlinking not taken into account, other non-weather hazards being broadcast to the airplane) make this over-committal even more critical. *Historical precedent indicates that these and other considerations are likely to raise bandwidth requirements from a factor of two to ten.*

As noted earlier, any airborne cabin products would also dramatically increase bandwidth requirements.

3.5 Aviation Weather Data Communication Requirements Summary

3.5.1 Current Systems

The weather products communicated to the cockpit by the in-flight weather deliver systems in use today are summarized in table 3.5.1-1.

Table 3.5.1-1. Aviation Weather Products Delivered to the Cockpit by Current Delivery Systems

Delivery System	METAR/ SPECI	TAF	Area Forecast	AIRMET	SIGMET	Winds Aloft	PIREP
FSS/AFSS/ EFAS	X	X	X	X	X	X	X
Wx Advisories				X	X		
HIWAS				X	X		
AWOS/ ASOS	X						
TWEB				X	X	X	X
ATIS	X						
D-ATIS	X						
TWIP	TWIP						

Table 3.5.1-2 combines the information content of the data products expressed in coded format with the characteristics of the current delivery systems to present a summary of the *data* communication requirements of current weather products.

Table 3.5.1-2 Current In-Flight Weather Product Data Communication Requirements

Delivery System	User	Flt Phase	Delivery Mode	Format	Freq Band	Xmit Rate	No. of Stations	Coded No. of Bytes
FSS/AFSS/ EFAS	All	En route / Terminal	Radio call	Analog voice	VHF	As req'd from pilots	64	5,000 - 10,000
Wx Advisories	All	En route	As Req'd Broadcast	Analog voice	VHF	As req'd by weather	20+	5,000 - 10,000
HIWAS	All	En route	Broadcast	Analog voice	VHF (VOR)	Contin	20+	5,000 - 10,000
AWOS/ ASOS	All	Terminal	Broadcast	Synth. Voice	VHF	Contin	1700+	500 - 1000
TWEB	All	Terminal	Broadcast	Analog voice	LF VHF (VOR)	Contin	300	5,000 - 10,000
ATIS	All	Terminal	Broadcast	Synth. Voice	VHF	Contin	1000+	500 - 1,500
D-ATIS	Major Carrier	Terminal / En Route	Addressed	Digital ACARS	VHF HF Satcom	As req'd from pilots	600 ACARS 57 A/P	500 - 1,500
TWIP	Major Carrier	Terminal / En Route	Addressed	Digital ACARS	VHF HF Satcom	As req'd from pilots	600 ACARS 15+ A/P	500 - 1,500

3.5.2 Near Term Systems

Most of today's cockpit weather is delivered in voice format. The weather products becoming available over ACARS represents an initial move toward providing in-flight weather information in digital format along with the various voice radio sources. The near term planning calls for the current systems to be augmented further with digital information using the VHF Datalink (VDL). The planned products will be provided by commercial venders over a data link provided by the government called the Flight Information Services Data Link (FIS DL). Under this arrangement, the government will provide raw weather data to the commercial providers who will supply a standard set of products free to users along with value added products on a fee basis. A number of commercial providers already subscribe to the government provided weather data sources and provide "flight planning" services to the aviation community. The companies and current products include: Kavouras, Inc. (Weatherlink Vistas); WSI Corporation (PILOTBrief, VECTOR); UNISYS Corporation (Weather Processor); Alden Electronics (WeatherWorks); Universal Weather and Aviation Inc. (Windstar Plus); Accu-Weather

(AMPS/AccuData); GTE Contel Federal Systems (Skycentral DUATS); and Harris Corporation (WeatherTAP - Aviation Weather). Any or all of these products are candidates for in-flight weather products under the FIS DL program.

While the FIS DL is being established, advances in internet technology, small powerful handheld portable computers and cell phone approval for aviation applications could cause many aviation weather products currently accessible by phone, FAX or the internet to become "in-flight" weather products.

3.5.3 Future Systems

Aviation weather research aims toward products that provide decision aiding information in graphic format rather than just more weather data. Combining on-going research projects with user needs for weather related information points to potential products that address decision support in three time frames: Far-Term Strategic, Near-Term Strategic and Tactical. Tables 3.5.3-1, 3.5.3-2, and 3.5.3-3 list potential future products for each of these decision time frames and summarize the data requirements that will need to be supported by future communication systems. Table 3.5.3-4 provides summary data for future weather products for terminal area operations.

Table 3.5.3-1 En Route Far-Term Strategic Weather Products

Product	Area of Regard (Area, Altitude, Time)	Fidelity	States/ Bit Depth	Bits	Bits/ Comp	Xmit Time @2400 Bits/ sec	Xmit Min per Hour
General Hazard	1500nm^2 50 k ft 300 min	25 nm^2 2 k ft 30 min	<256 / 8 bits	7.2 meg	144 k @ 50:1	1 min	2 min
Turbulence	1500nm^2 50 k ft 300 min	25 nm^2 2 k ft 60 min	8 / 3 bits	1.35 meg	27 k @ 50:1	0.2 min	0.2 min
Convection	1500nm^2 50 k ft 300 min	25 nm^2 2 k ft 15 min	<258 / 7 bits	12.6 meg	252 k @ 50:1	1.8 min	7.0 min
Icing / Flight Conditions	1500nm^2 50 k ft 300 min	25 nm^2 2 k ft 60 min	<32 / 5 bits	2.25 meg	45 k @ 50:1	0.3 min	0.3 min
Winds/Temperature	1500nm^2 50 k ft 300 min	25 nm^2 2 k ft 60 min	<64 / 6 bits	2.7 meg	54 k @ 50:1	0.4 min	0.4 min
Surface Conditions	1500nm^2 Surface 300 min	25 nm^2 N/A 15 min	<32 / 8 bits	576 k	28.8 k	0.2 min	0.8 min
En-route Backup Strategic General Imagery	1500nm^2 Single alt 10 pict	5 nm^2 1 k ft 15 min	<256 / 8 bits	28.8 meg	2.8 meg	20 min	80 min

Table 3.5.3-2 En route Near-term Strategic Weather Products

Product	Area of Regard (Area, Altitude, Time)	Fidelity	States/Bit Depth	Bits	Bits/ Compr Ratio	Xmit Time @2400 Bits/ sec	Xmit Min per Hour
General Weather Hazards	500nm² 50 k ft 70 min	10 nm² 1 k ft 10 min	<256 / 8 bits	7 meg	350 k @	2.4 min	14.6 min
Turbulence	500nm² 50 k ft 70 min	10 nm² 1 k ft 10 min	8 / 3 bits	2.625 meg	131 k	0.9 min	5.5 min
Convection	500nm² 50 k ft 70 min	10 nm² 1 k ft 10 min	<128 / 7 bits	6.125 meg	306 k	2.1 min	12.8 min
Icing / Flight Condition	500nm² 50 k ft 70 min	10 nm² 1 k ft 10 min	<32 / 5 bits	4.375 meg	219 k	1.5 min	9.1 min
Winds/Temperature	500nm² 50 k ft 70 min	10 nm² 1 k ft 10 min	<64 / 6 bits	5.25 meg	263 k	1.8 min	10.9 min
En-route Backup Strategic General Imagery	1500nm² Single alt 10 pict	5 nm² 1 k ft 15 min	<256 / 8 bits	28.8 meg	2.8 meg	20 min	80 min

Table 3.5.3-3 En route Tactical Weather Products

Product	Area of Regard (Area, Altitude, Time)	Fidelity	States/Bit Depth	Bits	Bits Compr	Xmit Time @2400 Bits/ sec	Xmit Min per Hour
Surface Conditions	1500nm² Surface 300 min	25 nm² N/A 15 min	<32 / 8 bits	576 k	28.8 k	0.2 min	0.8 min
Icing / Flight Conditions	125 nm² 20 k ft 5 pict	5 nm² 1 k ft 5 min	8 / 3 bits	1.35 meg	27 k	0.2 min	0.2 min
Turbulence	125 nm² 20 k ft 5 pict	5 nm² 1 k ft 5 min	<258 / 7 bits	12.6 meg	252 k	1.8 min	7.0 min
En-route Backup Strategic General Imagery	1500nm² Single alt 10 pict	5 nm² 1 k ft 15 min	<256 / 8 bits	28.8 meg	2.8 meg	20 min	80 min

Table 3.5.3-4 Terminal Strategic Weather Products

Product	Area of Regard (Area, Altitude, Time)	Fidelity	States/Bit Depth	Bits	Bits Compr	Xmit Time @2400 Bits/sec	Xmit Min per Hour
Radar Mosaic	$35 nm^2$ 15 k ft 1 pict.	$1 nm^2$ 1 k ft 1 min	<16 / 4 bits	73.5 meg	7.4 k	0.1 min	3.1 min
Icing	$35 nm^2$ 15 k ft 1 pict.	$1 nm^2$ 1 k ft 1 min	< 8 / 3 bits	55.1 meg	5.5 k	0.4 min	2.3 min
Low Level Wind Shear	$10 nm^2$ surf. 1 pict	$.25 nm^2$ 1 k ft 1 min	<8 / 3 bits	4.8 k	480	0.2 sec	0.2 min
Destination Field Conditions	$5 nm^2$ surface 1 pict	$0.1 nm^2$ surface 1 min	<64 / 5 bits	12.5 k	1.3 k	0.5 sec	0.5 min

The future weather products summarized in the above tables may never completely replace all the voice and text messages available in today's aviation weather systems. In the future though, these graphical weather products will be able to augment and enhance text and voice usage in the cockpit to allow all types of aircraft to operate more safely in spite of adverse weather conditions. The challenge is to provide the necessary communication systems so products like these can be available to make flight operation in all types of weather conditions safer and more predictable.

4 Symbols and Abbreviations

ADAS	AWOS/ASOS Data Acquisition System
ADDS	Aviation Digital Data Service
AGFS	Aviation Gridded Forecast System
AIV	Aviation Impact Variable
ALRDS	Automated Lightning Reporting and Detection System
ARTCC	FAA Air Route Traffic Control Center
ASOS	Automated Surface Observation System
AWIPS	Advanced Weather Interactive Processing System
CPDLC	Controller Pilot Data Link Control
CTAS	Center/TRACON Automation System
DLP	Data Link Processor
DSR	Display System Replacement
DUAT	Direct User Access Terminal
FOS	Family of Services
FSL	Forecast Systems Laboratory
GOES	Geostationary Operational Environmental Satellites
IF	In-flight
ITWS	Integrated Terminal Weather System

MD&E	Model Development and Enhancement
NCAR	National Center for Atmospheric Research
NADIN	National Airspace Digital Interchange Network
NCEP	National Centers for Environmental Prediction
NCF	Network Control Facility
NEXCOM	Next-Generation Air/Ground Communications
NEXRAD	Next Generation Weather Radar (WSR-88D)
NIDS	NEXRAD Information Dissemination System
NLDN	National Lightning Detection Network
NPN	NOAA Profiler Network
NSSL	National Severe Storms Laboratory
NWS	National Weather Service
NWSTG	National Weather Service Telecommunications Gateway
OASIS	Operational and Supportability Implementation System
PDT	Product Development Team
RAP	Research Applications Program
RUC	Rapid Update Cycle
SARP	Standards And Recommended Practices
TDWR	Terminal Doppler Weather Radar
TRACON	Terminal Radar Approach Control Facility
UCAR	University Center for Atmospheric Research
VDL	VHF Data Link
WARP	Weather and Radar Processor
WMSCR	Weather Message Switching Center Replacement
WSDDM	Weather Support to Ground De-icing Decision Making
Wx	Weather
Xmit	Transmit

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5.2 Telephone Or Face-To-Face Interviews

[1] Mr. Gary Beeley, Science Officer
NWS Peachtree City WFO
Altanta, GA

[2] Mr. Mike Carelli
NOAA/NWS Office of Systems Operations
Silver Spring, MD

[3] Mr. Donald R. Carver, Assistant Federal Coordinator for DOT/FAA Affairs
Office of the Federal Coordinator Meteorology
Interviews and communications with OFCM personnel

[4] Dr. Russell Chadwick, Division Chief
Demonstration Division
Forecast Systems Laboratory
Boulder, CO 80303

[5] Mr. Tom Cuff, Deputy Director
Office of the Oceanographer of the Navy
U.S. Naval Observatory
Washington, D.C.

[6] Mr. Ernie Dash
FAA Office of Communications, Navigation, and Surveillance Systems (AND)
Hampton, VA

[7] Mr. Marvin Dubbin, Program Manager
U.S. Army Integrated Meteorological System (IMETS) Program
Army Research Lab
White Sands Missile Range, NM

[8] Dr. Allan Eustis, Industrial Meteorology Staff (W/IM)
NOAA National Weather Service
Silver Spring, MD

[9] Mr. Thomas Fraim, Meteorologist
Office of the Federal Coordinator Meteorology
Interviews and communications with OFCM personnel

[10] Mr. Douglas S. Helton, Vice President
AOPA (Aircraft Owners and Pilots Association)
Frederick, MD 21701-4798

[11] LCDR Tom Millman
NAVAIR METOC
Washington, D.C.

[12] Mr. Dean Resch, Program Manager
FIS DL Program Office
FAA Office of Communications, Navigation, and Surveillance (AND)
Washington, D.C.

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Appendix A
Aviation Weather Products/Codes

Table of Contents

1 Introduction

Aviation weather information available in the USA is packaged in various product formats that serve the needs of different planning and decisions involving flights. Without getting into the various weather sensors and tools used to collect and organize weather information for aeronautical users, the products available for in-flight use are discussed in this appendix to allow analysis of the current and future air-ground communications required for their delivery.

2 International Standard Products

Beginning 1 July 1996, the United States transitioned from Surface Aviation Observation (SA) code, and Terminal Forecast (FT) codes to the international standards *Aviation Routine Weather Reports* (METAR/SPECI) and *Terminal Aerodrome Forecast* (TAF) respectively. The METAR/SPECI reports weather observed at the time of the report and the TAF provides a forecast for weather in the reporting area over the next 24 hours.

2.1 Aviation Routine Weather Reports (METAR/SPECI)

METAR is the international standard code format for hourly surface weather observations. The acronym roughly translates from French as Aviation Routine Weather Report. SPECI is merely the code name given to METAR formatted products which are issued on a special non-routine basis as dictated by changing meteorological conditions. The SPECI acronym roughly translates as Aviation Selected Special Weather Report. METAR are taken manually by NWS, FAA, contractors, or supplemental observers. METAR reports are also provided by ASOS and AWOS systems

A METAR report contains the following sequence of elements:

- Type of report (METAR or SPECI)
- Station designator (4 LETTER ICAO station identifier)
- Time of report
- Wind
- Visibility
- Weather and obstructions to visibility
  - Intensity or Proximity (light, moderate, heavy or vicinity)
  - Descriptor (thunderstorm, low drifting, showers, shallow, freezing, patches, blowing, partial)
  - Precipitation (rain, drizzle, snow, hail, small hail, ice pellets, snow grains, ice crystals, unknown)
  - Obstructions to Visibility (fog, haze, smoke, spray, mist, sand, dust, volcanic ash)
  - Other (squall, sandstorm, duststorm, dust/sand whirls, funnel cloud. tornado / waterspout)
- Sky conditions
  - Amount of clouds (clear, few, scattered, broken, overcast, cumulonimbus, towering cumulus)
  - Height

- Type or indefinite ceiling height (cumulonimbus, towering cumulus, altocumulus castellanus, etc. METAR has no explicit ceiling designator; the first broken or overcast layer aloft is inferred to be the ceiling)
- Temperature and dewpoint
- Altimeter setting
- Remarks

A sample observation in the U.S. METAR code appears as follows:

METAR KIAD 081055Z AUTO 21019G27KT 1/2SM R04R/3000FT -SN FG SCT011 OVC015 01/M02 A2945 RMK PK WND 19029/16 SLP045 T00081016

2.2 Terminal Aerodrome Forecast (TAF)

A Terminal Aerodrome Forecast (TAF) is a concise statement of the expected meteorological conditions at an airport during a specified period (usually 24 hours). Each country is allowed to make modifications or exceptions to the code for use in each particular country. The TAF format, as described here, is the one used in the United States. TAFs use the same weather code found in METAR weather reports.

A TAF report contains the following sequence of elements in the following order:

- Type of Report: (TAF, TAF AMD, TAF COR, TAF RTD)
- ICAO Station Identifier: (KSEA, KATL etc.)
- Date and Time of Origin: (TAFs are scheduled for issuance four times daily at 0000Z, 0600Z, 1200Z, and 1800Z)
- Valid Period Date and Time: (Routine TAFs are valid for 24-hours. In the case of an amended forecast, or a forecast which is corrected or delayed, the valid period may be for less than 24 hours)
- Forecast Meteorological Conditions:
    - Wind (forecast surface wind direction and speed)
    - Visibility (forecast of expected prevailing visibility in statute miles and fractions of statute miles)
    - Weather
        - Intensity or Proximity (light, moderate, heavy or vicinity)
        - Descriptor (thunderstorm, low drifting, showers, shallow, freezing, patches, blowing, partial)
        - Precipitation (rain, drizzle, snow, hail, small hail, ice pellets, snow grains, ice crystals, unknown)
        - Obstructions to Visibility (fog, haze, smoke, spray, mist, sand, dust, volcanic ash)
        - Other (squall, sandstorm, duststorm, dust/sand whirls, funnel cloud. tornado / waterspout)
    - Sky conditions

    - Amount of clouds (clear, few, scattered, broken, overcast, cumulonimbus, towering cumulus)
    - Height
    - Type or indefinite ceiling height (cumulonimbus only, ceiling layers are not designated in the TAF code. For aviation purposes, the ceiling is the lowest broken or overcast layer or vertical visibility into a complete obscuration)
- Optional Data (Wind Shear is omitted if not expected to occur)

In addition to the standard format used to describe forecast weather, information is provided in TAF reports that indicate the probability of weather events occurring and how weather is forecast to change. This information is given as:

Probability Forecast - The probability or chance of thunderstorms or other precipitation events occurring, along with associated weather conditions (wind, visibility, and sky conditions).

Forecast Change Indicators - The following change indicators are used when either a rapid, gradual, or temporary change is expected in some or all of the forecast meteorological conditions. Each change indicator marks a time group within the TAF report.

- FROM Group - The FM group is used when a rapid change, usually occurring in less than one hour, in prevailing conditions is expected. Typically, a rapid change of prevailing conditions to more or less a completely new set of prevailing conditions is associated with a synoptic feature passing through the terminal area (cold or warm frontal passage). Appended to the FM indicator is the four-digit hour and minute the change is expected to begin and continues until the next change group or until the end of the current forecast. A FM group will mark the beginning of a new line in a TAF report. Each FM group contains all the required elements -- wind, visibility, weather, and sky condition. Weather will be omitted in FM groups when it is not significant to aviation.
- BECOMING Group - The BECMG group is used when a gradual change in conditions is expected over a longer time period, usually two hours. The time period when the change is expected is a four-digit group with the beginning hour and ending hour of the change period which follows the BECMG indicator. The gradual change will occur at an unspecified time within this time period. Only the conditions are carried over from the previous time group.
- TEMPORARY Group - The TEMPO group is used for any conditions in wind, visibility, weather, or sky condition which are expected to last for generally less than an hour at a time (occasional), and are expected to occur during less than half the time period. The TEMPO indicator is followed by a four-digit group giving the beginning hour and ending hour of the time period during which the temporary conditions are expected. Only the changing forecast meteorological conditions are included in TEMPO groups. The omitted conditions are carried over from the previous time group.

The international TAF also contains forecast temperature, icing, and turbulence. These three elements are not included in National Weather Service (NWS) prepared TAFs. The U.S. has no requirement to forecast temperatures in an aerodrome forecast and the NWS will continue to forecast icing and turbulence in AIRMETs and SIGMETs. These products are described below.

Aerodrome Forecast are prepared by approximately 100 Weather Forecast Offices (WFOs). These offices prepare and distribute approximately 525 TAFs four times daily for specific airports in the 50 states, Puerto Rico, the Caribbean and Pacific Islands. These forecast are valid for 24 hours and amended as required.

An example of a TAF report is given below:

```
TAF
KOKC 051130Z 051212 14008KT 5SM BR BKN030 TEMPO 1316 1 1/2SM BR
FM1600 16010KT P6SM NSW SKC
BECMG 2224 20013G20KT 4SM SHRA OVC020 PROB40 0006 2SM TSRA OVC008CB
BECMG 0608 21015KT P6SM NSW SCT040=
```

3 USA Standard Aviation Weather Products

While the METAR and TAF reports are international standards, there are provisions within the standards for different countries to customize these reports to meet their specific needs. For instance, the reports given in the USA use English units rather than metric for certain measurements. In addition to the two international standard weather products, other aviation weather products available in the USA include Area Forecast (FA), In-Flight Advisories, Winds Aloft and Pilot Reports.

3.1 Area Forecast (FA)

An area forecast (FA) is a forecast of Visual Flight Rules (VFR) clouds and weather conditions over an area as large as the size of several states. It must be used in conjunction with the AIRMET Sierra bulletin (see In-Flight Advisories below) for the same area in order to get a complete picture of the weather. The area forecast together with the AIRMET Sierra bulletin are used to determine forecast en route weather and to interpolate conditions at airports which do not have terminal aerodrome forecasts (TAF's) issued. FAs are issued 3 times a day by the Aviation Weather Center in Kansas City for each of 6 areas in the contiguous 48 states. In Alaska, FAs are issued by the Weather Service Forecast Office (WSFO's) in Anchorage, Fairbanks, and Juneau for their respective areas. The WSFO in Honolulu issues FAs for Hawaii.

Each FA consists of a 12 hour forecast plus a 6 hour outlook. All times are Coordinated Universal Time (UTC). All distances except visibility are in nautical miles. Visibility is in statute miles. The breakdown may be by states, by well known geographical areas, or in reference to location and movement of a pressure system or front. A categorical outlook, identified by OTLK, is included for each area breakdown. Amendments to the FA are issued as needed. An amended FA is identified by AMD, a corrected FA by COR, and a delayed FA is identified by RTD.

The FA consists of a:

- Synopsis section which is a brief summary of the location and movement of fronts, pressure system, and circulation patterns for an 18 hour period.
- VFR clouds and weather section which is a 12 hour forecast, in broad terms, of clouds and weather significant to flight operations plus a 6 hour categorical outlook. This section is usually several paragraphs. AIRMET Sierra supplies information regarding Instrument Flight Rule (IFR) conditions.

3.2 In-Flight Advisories

The Aviation Weather Center in Kansas City, Missouri issues in-flight advisories that serve to notify en route pilots of the possibility of encountering hazardous flying conditions which may not have been forecast at the time of their pre-flight briefing. These weather products are designated as: Airmen's Meteorological Information (AIRMET); Significant Meteorological Information (SIGMET); Severe Weather Forecast Alerts (AWW); and Center Weather Advisories (CWA).

3.2.1 Airmen's Meteorological Information (AIRMETs)

An AIRMET (AIRman's METeorological Information) advises of weather that may be hazardous, other than convective activity, to single engine, other light aircraft, and Visual Flight Rule (VFR) pilots. However, operators of large aircraft may also be concerned with these phenomena. Three types of bulletins are issued including AIRMET Sierra, AIRMET Tango, and AIRMET Zulu. The items covered are:

In the AIRMET Sierra bulletin:
- Ceilings less than 1000 feet and/or visibility less than 3 miles affecting over 50% of the area at one time.
- Extensive mountain obscuration

In the AIRMET Tango bulletin:
- Moderate turbulence
- Sustained surface winds of 30 knots or more at the surface

In the AIRMET Zulu bulletin:
- Moderate icing
- Freezing levels

AIRMET items are considered to be *widespread.* They must be affecting or be forecast to affect an area of at least 3000 square miles at any one time. AIRMETs are routinely issued for 6 hour periods beginning at 0145 UTC during Central Daylight Time and at 0245 UTC during Central Standard Time. AIRMETs are also amended as necessary due to changing weather conditions or issuance/cancellation of a SIGMET.

AIRMET text bulletins are issued from seven different area of the US including one from Alaska. These include:

- Boston Area
- Chicago Area
- Ft. Worth Area
- Miami Area
- Salt Lake City Area
- San Francisco Area
- Alaska AIRMETs

Example text bulletins published by the Aviation Weather Center for the Boston area are given below:

Boston AIRMET Sierra
12 Apr 1999 - 19:33:57 UTC

```
ZCZC MKCWA1S
WAUS1 KBOS 121945
BOSS WA 121945
AIRMET SIERRA UPDT 4 FOR IFR AND MTN OBSCN VALID UNTIL 130200
.
AIRMET IFR...WV
FROM EKN TO 40E EKN TO 40ESE BKW TO 40WSW BKW TO EKN
OCNL CIG BLW 010/VIS BLW 3SM PCPN/FG/BR.  CONDS ENDG 00-02Z.
.
AIRMET MTN OBSCN...WV VA
FROM 40SW AIR TO 40E EKN TO PSK TO HMV TO HNN TO 40SW AIR
MTNS OCNL OBSC CLDS/FG/BR.  CONDS CONTG BYD 02Z THRU 08Z.
....=
```

Boston AIRMET Tango Example
12 Apr 1999 - 19:34:01 UTC

```
ZCZC MKCWA1T
WAUS1 KBOS 121945
BOST WA 121945
AIRMET TANGO UPDT 5 FOR TURB VALID UNTIL 130200
.
...SEE SIGMET OSCAR SERIES FOR POSS SEV TURB...
.
AIRMET TURB...ME NH VT MA RI CT NY PA NJ MD DC DE VA AND CSTL
WTRS
```

FROM YSC TO ACK TO HTO TO ECG TO JST TO MSS TO YSC
LGT OCNL MOD TURB BLW 080 DUE TO NLY WNDS. CONDS CONTG BYD 02Z
THRU 08Z.
.
AIRMET TURB...PA WV MD VA
FROM JST TO ECG TO HMV TO JST
OCNL MOD TURB BLW 120 DUE TO MOD NWLY WNDS. CONDS CONTG BYD 02Z
THRU 08Z.
....=

Boston AIRMET Zulu Example
12 Apr 1999 - 19:34:02 UTC

ZCZC MKCWA1Z
WAUS1 KBOS 121945
BOSZ WA 121945

AIRMET ZULU UPDT 4 FOR ICE AND FRZLVL VALID UNTIL 130200
.
AIRMET ICE...ME
FROM 70NW PQI TO PQI TO HUL TO YSC TO 70NW PQI
LGT OCNL MOD RIME/MXD ICGICIP BLW 100. CONDS DVLPG 00Z AND CONTG
BYD 02Z THRU 08Z.
.
AIRMET ICE...VA AND CSTL WTRS NC
FROM 160ESE SBY TO 200ESE ECG TO 150ESE ILM TO 70SE ECG TO ORF TO
160ESE SBY
LGT OCNL MOD RIME/MXD ICGICIP BTN 060 AND 100. CONDS MOVG SEWD
AND ENDG 22-00Z.
.
FRZLVL...SFC-040.
....=

3.2.2 Significant Meteorological Information (SIGMET)

A SIGMET is a weather advisory that covers weather that is potentially hazardous to all aircraft. Three types of SIGMETs are issued in the US: Domestic SIGMETs, Convective SIGMETs and International SIGMETs. SIGMET items are considered to be widespread, they must be affecting or be forecast to affect an area of at least 3000 square miles. However, only a small portion of this total area may be affected at any one time.

3.2.2.1 Domestic SIGMETs

Domestic SIGMETs are issued for potentially hazardous conditions other than convective activity. Items covered are:

- Severe icing
- Severe or extreme turbulence
- Duststorms and sandstorms lowering visibilities to less that three (3) miles.
- Volcanic Ash

In Alaska and Hawaii, SIGMETs are also issued for the following events:

- Tornadoes
- Line of thunderstorms
- Embedded thunderstorms
- Hail greater than or equal to 3/4 inch in diameter

3.2.2.2 Convective SIGMET

A Convective SIGMET may be issued for any convective situation which the forecaster feels is hazardous to all categories of aircraft. Convective SIGMET bulletins are issued for the Eastern (E), Central (C), and Western (W) United States for regions affecting 40% or more of an area at least 3000 square miles. The areas separate at 87 and 107 degrees west longitude. Bulletins are issued hourly and are valid for up to 2 hours. The text of the bulletin consists of either an observation and a forecast or just a forecast. Convective SIGMETs are issued for any of the following:

- Severe thunderstorm due to
  - surface winds greater than or equal to 50 knots
  - hail at the surface greater than or equal to 3/4 inches in diameter
  - tornadoes
- Embedded thunderstorms
- Line of thunderstorms
- Thunderstorms greater than or equal to VIP level 4 affecting 40% or more of an area at least 3000 square miles.

An example of a Convective SIGMET is provided below:

NCEP/AWC - Central U.S. Convective SIGMET
13 Apr 1999 - 22:50:19 UTC

```
ZCZC MKCWSTC
WSUS41 KMKC 132255
MKCC WST 132255
CONVECTIVE SIGMET 56C
VALID UNTIL 0055Z
TX
FROM 40ESE LBB-40E FST
LINE SEV TS 20 NM WIDE MOV FROM 26025KT. TOPS ABV FL450.
TORNADOES...HAIL TO 3 IN...WIND GUSTS TO 70 KT POSS.

CONVECTIVE SIGMET 57C
VALID UNTIL 0055Z
KS OK TX
FROM 70W BUM-10SSW OSW-20NE LBB-40SE GCK-70W BUM
AREA SEV TS MOV FROM 25035KT. TOPS ABV FL450.
```

TORNADOES...HAIL TO 3 IN...WIND GUSTS TO 70 KT POSS OVR TX.
HAIL TO 1 IN...WIND GUSTS TO 50 KT POSS OVR OK/KS.

CONVECTIVE SIGMET 58C
VALID UNTIL 0055Z
CO NM
FROM 10SSW DEN-40E ALS-40E CIM
LINE TS 20 NM WIDE MOV LTL. TOPS TO FL300.

OUTLOOK VALID 140055-140455
FROM 40ESE OBH-UIN-FSM-ADM-SJT-MRF-LAA-40ESE OBH
REF WW 148 149.
SFC LO MOVG E TO BTN LBB-AMA TRAILS A DRYLN SWD THRU W TX. A
WRMFNT ARCS FM THE LO THRU W CNTRL OK - W CNTRL AR. TS...SOME
SEV...TO CONT ALG THE DRYLN WITH LTLCG. OVRRNG TS ACT OK-KS
ALSO TO CONT WITH LTLCG.

MJW
=

NNNN

3.2.2.3 International SIGMETs

International SIGMETs are issued for oceanic areas adjacent to the United States. Criteria for Domestic and International SIGMETs are similar, however the format, contractions, and wording used are different. International SIGMETs are issued by a Meteorological Watch Office (MWO). The National Weather Service has MWOs at Anchorage, AK, Guam Island in the Pacific Ocean, Honolulu, HI, Kansas City, MO, and the Tropical Prediction Center in Miami, FL. International SIGMET criteria are:

- Thunderstorms
- Lines of thunderstorms
- Embedded thunderstorms
- Large areas of thunderstorms
- Tornadoes
- Large hail
- Tropical cyclone
- Severe icing
- Severe or extreme turbulence
- Duststorms and sandstorms lowering visibilities to less that three (3) miles.
- Volcanic Ash

International SIGMETs are issued for 12 hour periods for volcanic ash events, 6 hours for hurricanes and tropical storms and 4 hours for all other criteria. If conditions persist beyond the forecast period, the SIGMET is updated and reissued.

An example code for an International SIGMET is given below:

NCEP/AWC - Atlantic International SIGMET Alpha
12 Apr 1999 - 22:26:49 UTC

```
ZCZC MKCSIGA0A
WSNT01 KMKC 122230
KZNY SIGMET ALFA 4 IS CNL WEF 2230 UTC.
NEW YORK OCEANIC FIR. TURB HAS DMSHD.
HLF
NNNN
```

NCEP/AWC - Atlantic International Sigmet Bravo
12 Apr 1999 - 21:27:44 UTC

```
ZCZC MKCSIGA0B
WSNT01 KMKC 122125
KZNY SIGMET BRAVO 2 VALID 122125/130125 KMKC-
NEW YORK OCEANIC FIR FRQ TS OBS WI 20 NM EITHER SIDE OF A LINE
40.5N60.5W 36.3N63W. TOPS TO FL380. MOV E 25 KTS. WKN. BASED ON
SATELLITE OBS.
HLF
NNNN
```

3.2.3 Severe Weather Forecast Alert (AWW)

Severe Weather Forecast Alerts define areas of possible severe thunderstorms or tornado activity. The messages are unscheduled and issued as required.

3.2.4 Center Weather Advisory (CWA)

A CWA is an unscheduled weather advisory issued by Center Weather Service Unit meteorologists for ATC use to alert pilots of existing or anticipated adverse weather conditions within the next 2 hours. A CWA may modify or redefine a SIGMET.

3.3 Winds Aloft

Winds aloft are computer prepared forecast of wind direction and speed as well at forecast temperatures for different flight levels above specific navigation reference points.

Each report contains:

- The valid time of the forecast (day and valid time range)
- Forecast location (i.e., MKC - Kansas City, MO)
- Forecast winds for 3,000 feet
- Forecast winds (heading and speed) and temperature data at other flight levels (i.e., 6,000, 9,000, 12,000, 18,000, 24,000, 30,000, 34,000, 39,000 feet)

All heights are above Mean Sea Level. Wind directions are true directions. Temperature is in whole degree Celsius for each forecast point. Temperatures are assumed to be negative above 24,000 feet. Wind direction is coded to the nearest 10 degrees. A calm or light and variable wind is indicated by 99.

Winds Aloft forecast are provided for 176 locations in the contiguous states and 21 locations in Alaska (Winds Aloft for Hawaii are prepared locally). Forecast are updated two times each day and include a 6 hour forecast, a 12 hour forecast and a 24 hour forecast.

This is an example of a winds aloft text message:

```
DATA BASED ON 010000Z
VALID 010600Z   FOR USE 0500-0900Z.  TEMPS NEG ABV 24000
FT  3000    6000    9000    12000   18000   24000   30000   34000   39000
MKC 2426 2726-09 2826-14 2930-21 2744-32 2751-41 275550 276050 276547
```

In the above example, the forecast data was generated the first day of the month at 0000 UTC. The valid time of the forecast is the first day of the month at 0600 UTC. The forecast winds and temperature are to be used between 0500 and 0900 UTC. The forecast winds and temperature data are for MKC, Kansas City, MO. For flight planning, a winds aloft forecast would be acquired for each waypoint along the route.

3.4 Pilot Reports (PIREP)

Pilots that encounter severe weather conditions while in flight will often report them to air traffic controllers. These pilot reports, or "PIREPs", provide valuable information about aircraft encounters with icing, turbulence and other weather phenomena. Data included in the PIREPs include the location and altitude of the icing or turbulence encounter, it's intensity and type, winds, temperature and more.

FAA air traffic facilities are required to solicit PIREPs when the following conditions are reported or forecast: Ceiling at or below 5,000 feet; Visibility at or below 5 miles (surface or aloft); thunderstorms and related phenomena; icing of light degree or greater; turbulence of modest degree or greater; windshear and reported or forecast volcanic ash clouds.

Pilots are urged to cooperate and promptly volunteer reports of these conditions and other atmospheric data such as: Cloud base, tops and layers; Flight visibility; Precipitation; Visibility restrictions such as haze, smoke and dust; Winds at altitude; and Temperature aloft.

PIREPs are given to the ground facility with which communication is established; i.e., EFAS, AFSS/FSS, ARTCC, or terminal ATC. One of the primary duties of EFAS facilities, radio call "FLIGHT WATCH," is to serve as a collection point for exchange of PIREPs with en route aircraft. In addition to being available to in-flight aircraft through Flight Watch, PIREPs are plotted on maps of the US and made available to over the internet through the Aviation Digital Data Service (ADDS), Table 3.4-1 list the types of information provided by PIREPs and the codes used to record and distribute the information.

Table 3.4-1. PIREP Information and Codes

	PIREP Elements	PIREP Code	Contents
1	3 letter station ID	XXX	Nearest weather reporting station to the reported phenomenena
2	Report type	UA or UUA	Routine or Urgent PIREP
3	Location	/OV	In relation to VOR
4	Time	/TM	Coordinated universal time
5	Altitude	/FL	Essential for turbulence and icing reports
6	Type Aircraft	/TP	Essential for turbulence and icing reports
7	Sky cover	/SK	Cloud height and coverage (sky clear, few, scattered, broken, or overcast
8	Weather	/WX	Flight visibility, precipitation, restrictions to visibility, etc.
9	Temperature	/TA	Degrees Celsius
10	Wind	/WV	Direction in degrees and true speed i knots
11	Turbulence	/TB	
12	Icing	/IC	
13	Remarks	/RM	For reporting elements not included o to clarify previously reported items

4 Other Aviation Weather Products

The weather products described above represent a small sample of products being produced today that support flight planning. The list includes telephone call-up services, charts and graphs available via FAX, and a host of web sites on the internet providing all types of textual and graphic material. In addition, there are commercial venders that provide aviation weather services, some through ground-to-air data link connections. The list is changing rapidly and many of these may become "approved" sources of in-flight weather information in the near future (most web sites have disclaimers warning that the data provided is not approved for flight planning). However, the products listed above do find their way into the cockpit through current ground-to-air communications and represent the official sources for obtaining weather information for in-flight decision making.

5 Weather Products / Formats Summary

The weather elements provided by the products described above are summarized in Table A5-1. When these products are currently made available to planes in the air they are generally formatted for voice broadcast or voice response to radio requests.

Table A5-1. Weather Elements Information Provided To In-Flight Planes By Current Aviation Products

Wx Element	METAR	TAF	Area Forecast (FA)	AIRMET - Sierra - Tango - Zulu	SIGMET - Domstc - Conv - Intern	Winds Aloft	PIREP
Wind, surface	Obs	FC		FC	FC		
Wind, aloft						FC	Obs
Visibility	Obs	FC		FC			
Obstructions to visibility		FC					
Precipitation	Obs	FC	FC				Obs
Squall	Obs	FC	FC				Obs
Sandstorm	Obs	FC	FC		FC		Obs
Duststorm	Obs	FC	FC		FC		Obs
Dust/sand whirls	Obs	FC	FC				Obs
Funnel cloud	Obs	FC	FC				Obs
Tornado / waterspout)	Obs	FC	FC		FC		Obs
Cloud ceilings / Types	Obs	FC	FC	FC			
Sky conditions	Obs	FC					Obs
Temp / dewpoint, surface	Obs	FC					
Temperature, aloft						FC	Obs
Altimeter setting	Obs	FC					
Wind Shear		FC (opt)					
Mountain Obscuration				FC			
Turbulence				FC (mod)	FC (sev)		Obs
Icing				FC (mod)	FC (sev)		Obs
Freezing levels				FC			
Thunderstorms					FC		Obs
Lines of thunderstorms					FC		
Embedded thunderstorms					FC		
Hail, surface					FC >3/4"		
Tropical cyclone					FC		
Volcanic Ash					FC		
Fronts (location/ Movement			FC				
Tropopause Height							
Jet Stream							
Pressure System			FC				
Circulation Patterns			FC				
Microburst							
Remarks	Yes	Yes	Yes				Yes

The weather elements as well as product message identifiers are coded for distribution to ground based aviation weather service providers to minimize the bandwidth needed for ground communication systems. The service providers decode the weather messages and present descriptions of observations or forecast in verbal messages that can be understood by airborne users. The coded formats used for ground based distribution can be used to estimate the data communication capability that would be required to provide the same information over a digital air/ground network. Table A5-2 summarizes the amount of data produced and distributed for the weather products described above. This data provides a high level reference that may be used to determine requirements for future ground-to-air data link system designed to provide the information in digital format in addition to (or instead of) the current delivery systems.

Table A5-2. Aviation Weather Products Data Summary

Products	Area Covered	No. of Product Zones for USA (lower 48 states only)	No. of Products produced per Day	Product Life	Bytes per message (coded)
METAR/SPECI	Terminal	1700 +	24	1 hr	500 - 1,000
TAF	Terminal	526	4	24 hr	500 - 1,000
Area Forecast	Several States	6	3	12 hrs	3000 - 10,000
AIRMET - Sierra	3000 square miles	6	as required by weather	6 hrs	500 - 1,000
AIRMET - Tango	3000 square miles	6	as required by weather	6 hrs	500 - 2,000
AIRMET - Zulu	3000 square miles	6	as required by weather	6 hrs	500 - 2,000
Domestic SIGMET	3000 square miles	6	as required by weather	4 hrs	500 - 1,000
Convective SIGMET	3000 square miles	3	up to 24 as required by weather	2 hrs	1000 - 5,000
International SIGMET	Atlantic/Pacific oceans	2	as required by weather	4 hrs	500 - 2,000
Winds Aloft	200 square miles	176	2	6/12/24 hrs	250 - 500
PIREP Distributed	1 - 5 miles	1	173	1 hr	250 - 500

6 References

[1] Aviation Weather Services, AC 00-45D, U.S. Department of Commerce National Oceanic and Atmospheric Administration National Weather Service and U.S. Department of Transportation Federal Aviation Administration, Revised 1995.

[2] Federal Aviation Regulations / Aeronautical Information Manual - FAR/AIM99, Jeppesen Sanderson, Inc. 1998.

[3] National Airspace System Architecture, Version 2.0, Federal Aviation Administration, Office of Systems Architecture and Program Evaluation (ASD).

In addition to the above references, the following World Wide Web sites and associated links were used as references:

[4] Aviation Weather Center, World Wide Web page, located at http://www.awc-kc.noaa.gov/awc/Aviation_Weather_Center.html

[5] AirNav, World Wide Web page, located at http://www.airnav.com/

[6] Macon Automated Flight Service Station, World Wide Web page, located at http://www.faa.gov/ats/mcnafss/

[7] The National Center for Atmospheric Research, World Wide Web page, located at http://www.ncar.ucar.edu/

Phase II—Aviation Weather Communication Technology and Solutions

Foreword

The purpose of this study is to support NASA efforts to make air travel safer under all weather conditions by assuring the availability of communication technology and systems for providing future weather related information to planes in-flight.

This is the second phase of a two part study. The first phase, *Aviation Weather Communication Requirements,* identifies present and future aviation weather tools and products that will need ground-to-air data communication support. This phase, *Aviation Weather Communication Technology and Solutions,* evaluates the requirements against current and planned communication systems to determine where to invest manpower and monetary resources for new technology development.

This phase II report is submitted to NASA John H. Glenn Research Center at Lewis Field by Lockheed Martin Aeronautics Company - Marietta as a contract deliverable.

The Lockheed Martin Program Manager for this study is:

Mr. John W. Ball
Lockheed Martin Aeronautics Company - Marietta
86 South Cobb Drive
Marietta, GA. 30063-0670
Voice: (770) 494-5531
FAX: (770) 494-0970
email: jack.ball@lmco.com

The Lockheed Martin Team consists of the following organizations and individuals:

Company	Name	Contribution
Lockheed Martin Aeronautics Company - Marietta	John W. Ball Roger G. Herron	Program Manager Technical Lead
Aviation Concepts Inc.	Edwin A. Thomas R. David Witchey	Aviation Communication Systems, Weather Applications and User Requirements

Table of Contents

1 Introduction

In 1997 the White House Commission on Aviation Safety and Security recommended establishing a national goal of reducing the fatal aviation accident rate by 80 percent by 2007. As a result of this recommendation, NASA formed the Aeronautics Safety Investment Strategy Team (ASIST), and weather concerns were identified as a sub-element within this team. Weather is one of many factors impacting aviation accidents as well as being responsible for approximately two-thirds of air carrier delays—a four billion dollar cost, of which 1.7 billion dollars are considered avoidable. NASA started the Aviation Weather INformation (AWIN) program to address the weather aspects of aviation safety.

The goal of the AWIN program is to provide improved weather information (not simply data) to users of the National Airspace System, and to foster improved usage of this information. The emphasis of the AWIN project is to provide this information to the flight deck. NASA envisions a future that would allow aircraft to be both a source and user of weather information. Airborne sensors would provide data for weather systems on board the plane, on the ground, and in other aircraft. Easy-to-read, real-time displays in the cockpit would show weather across the country, not just a limited number of miles ahead. In this way pilots could more easily monitor possible trouble spots and make safer, more cost-efficient routing decisions.

NASA realizes that many of the new weather tools could present severe demands and challenges to the ground-to-air communications channels. This is due to the anticipated increase in quantity of weather data being transported over various channels for safety and regularity of flight. Aeronautical communications will thus need to accommodate the increased traffic associated with the dissemination of tactical and strategic weather information to the cockpit. This study focuses on the current and future aeronautical weather communication requirements, and explores systems and technologies that are available, or will be needed, to meet those requirements.

2 Scope

The scope of this second phase of the study is to explore various types of aviation and non-aviation communication technologies that offer the potential to address aviation safety enhancement goals by supporting the necessary upgrades to weather information in the cockpit. The focus is on data communications (text, graphics and digitized voice) rather than the analog voice transmissions that are common today. It is anticipated future air-to-ground communications will be dominated by various forms of aeronautical data link. The study concentrates on weather and communication systems in the United States but includes world wide consideration where appropriate.

3 Technical Analysis

3.1 Aviation Weather Data Communication Requirements Summary

Phase I of this study identifies numerous weather products that are currently made available to airborne flights as well as some products likely to emerge from on-going research. These products and the systems used to delivery them to the cockpit are summarized below.

3.1.1 Current In-flight Weather Product Delivery

Current aviation weather products are delivered to the cockpit using a combination of broadcasts, voice request/reply using aviation radios and text request/reply using ACARS. Figure 1 shows the delivery systems available for the different air space. The aviation weather products available from these systems to support different flight phases include:

- Terminal Area Specific: **METAR, TAF, ATIS, D-ATIS**
- Domestic En Route: **Area Forecast**, **Severe Wx Forecast Alerts, AIRMET, SIGMET, Convective SIGMET and Center Wx Advisory, Winds Aloft, PIREP**
- Oceanic En route: **International SIGMET**

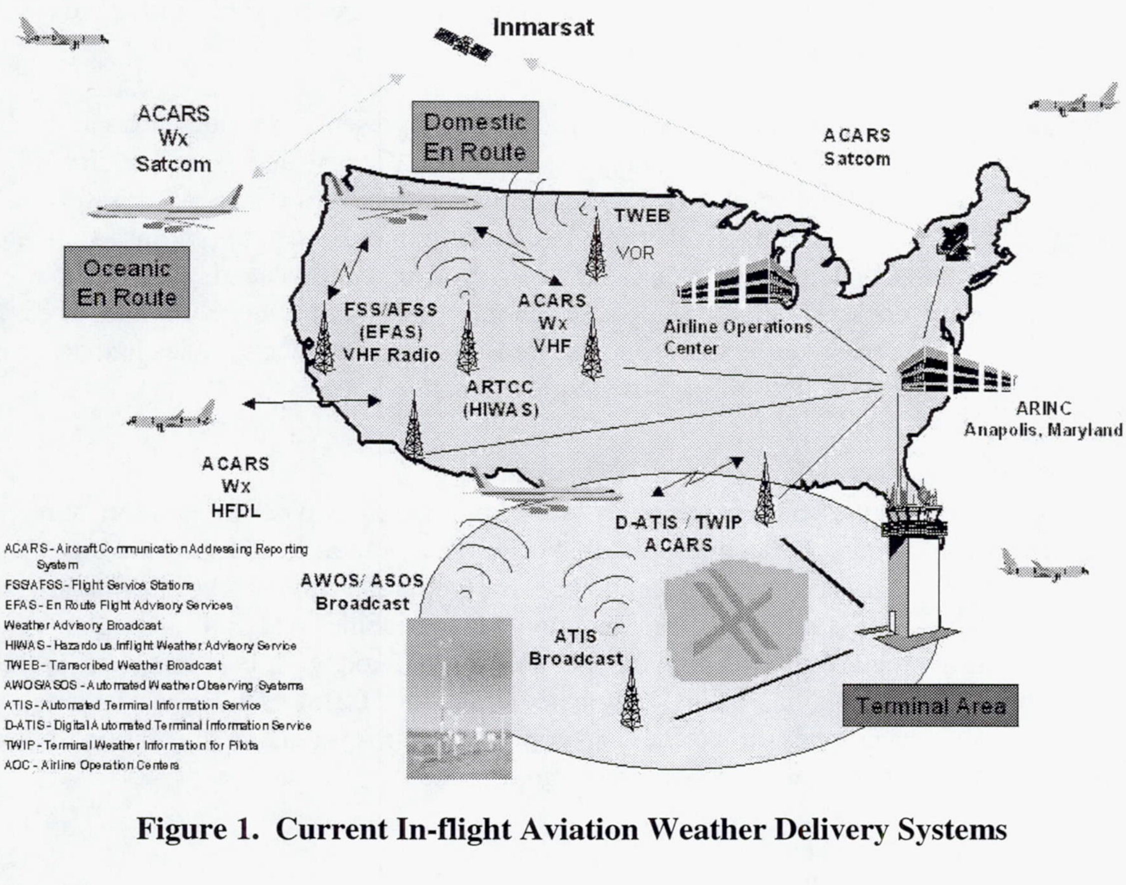

Figure 1. Current In-flight Aviation Weather Delivery Systems

There are three formats used for delivery of current in-flight weather products. These include:

- Voice Format Request / Reply: **FSS, AFSS, EFAS**
- Voice Broadcasts: **ARTCC, HIWAS, TWEB, AWOS, ASOS, ATIS**
- Text Format Request / Reply: **ACARS**

In the near future there will be a fourth format added, text broadcast. The Flight Information Services Data Link (FIS DL) is a cooperative effort between government and private industry that will broadcast aviation weather information in text format. FIS DL will complement, not replace, existing voice communications. The provisions for this addition to aviation weather delivery include:

- FAA: **Provide broadcast data link (four 25 kHz VHF channels)**
- Commercial Vendors: **Provide standard (free) and value added (fee based) weather products.**
- Standard Text Formatted Products: **METAR, TAF, SIGMET, AIRMET, Pilot Reports (PIREPs) and Aviation Watches (AWW)**
- Potential Value-added Products: **NEXRAD graphics, satellite imagery, icing maps, turbulence maps, winds aloft**

3.1.2 Future In-flight Products

Aviation weather research aims toward products that provide decision aiding information in graphic format rather than just more weather data. Phase I of this report provides a specific outline of likely future weather products derived from combining on-going research projects with user needs for weather related information. Potential future products are described that address weather related decision support in three time frames: Far-Term Strategic, Near-Term Strategic and Tactical. Figure 2 describes these decision arenas.

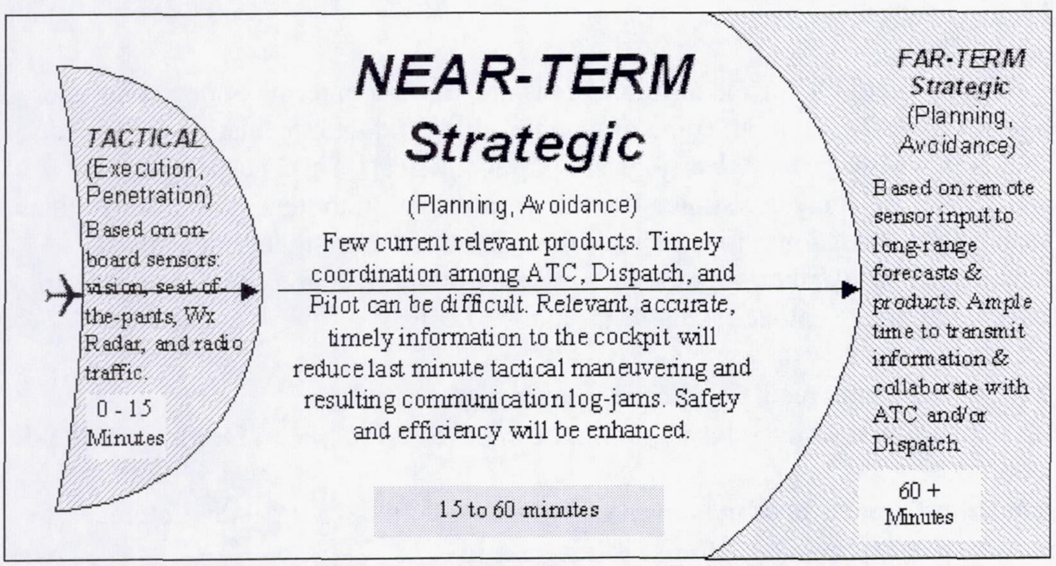

Figure 2. Three Weather Related Decision Arenas

The weather information and products needed for each of these decision arenas are identified and described in the Phase I Report and summarized as follows:

En Route Far-Term Strategic
- **Forecast information:** Includes sustained, long-term predictions
- **General hazard**: Integrates all known "threats," including weather
- **Discrete products**: Turbulence, Convection, Icing / Flight Conditions, Winds/Temperature, Surface Conditions
- **General area of regard:** 1500 $nm^{2,}$ 50 k ft, 300 min
- **Fidelity Needed**: 25 nm^2 - 2 k ft - 30 min
- **Backup Strategic:** General Imagery

En route Near-term Strategic
- **Nowcast information:** Includes short-lived, perishable predictions
- *Otherwise same as Far-Term - smaller area and higher fidelity*
- **General hazard**: Integrates all known "threats," including weather
- **Discrete products**: Turbulence, Convection, Icing / Flight Conditions, Winds/Temperature, Surface Conditions
- **General area of regard:** 500nm^2 - 50 k ft - 70 min
- **Fidelity Needed**: 10 nm^2 - 1 k ft - 10 min
- **Backup Strategic:** General Imagery

En route Tactical Weather Products
- **Real time information:** Includes directly sensed events as they occur
- **Mostly from on-board sensors**
- **Off-board products:** Surface Conditions (including visibility, ceiling, runway condition, wind components, etc.), Icing / Flight Conditions, Turbulence
- **Off-board products area of regard:** 125 nm^2 - 20 k ft - five 2d pictures
- **Fidelity needed**: 5 nm^2 - 1 k ft - 5 min

Future weather products for the terminal areas are similar, in terms of decision time frame, to En route Tactical but some unique weather product information is needed. Terminal area weather users' decisions are largely tactical. This is especially true of arrivals. Departures may use strategic weather information to plan operations such as long term routing decisions since most of their flight is before them but arrivals' decisions regarding weather are mostly centered around diversion or holding scenarios. Future terminal area weather products are likely to consist of:

- **Tactical decisions:** using on-board Wx sensors
- **Other products:** Radar Mosaic, Icing, Low Level Wind Shear, Destination Field Conditions
- **General off-board products area of regard:** 35 nm^2 - 15 k ft - 2d pictures
- **General fidelity needed**: 1 nm^2 - 1 k ft - 1 min

- **Area of regard for Low Level Wind Sheer**: 10 nm^2 - Surface - a 2d pictures
- **LLWS fidelity needed**: 0.1 nm^2 - Surface - 1 min

3.1.3 Requirements Levied by Future Products

Investigation of these products from a communications standpoint serves to outline the communications requirements to enable these products.

3.1.3.1 Background

As outlined in Phase I, it is useful to analyze communications requirements to support future weather products in two dimensions: Decision Arena and Phase of Flight. The three subsections of these two dimensions are represented graphically, below:

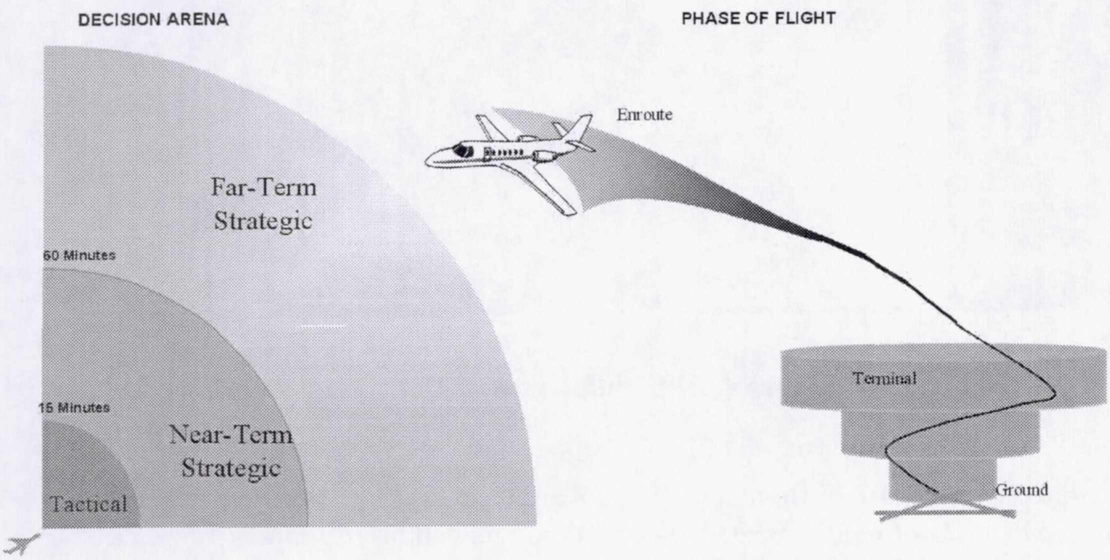

Figure 3. Decision Arenas and Phases of Flight

These two dimensions can be further related to one another according to bandwidth required to support the decision arena and bandwidth available in each phase of flight. The following diagram, repeated from Phase I, depicts this analysis graphically. For more detail on this chart, how it was derived, and more of its meaning, please refer to the Phase I report.

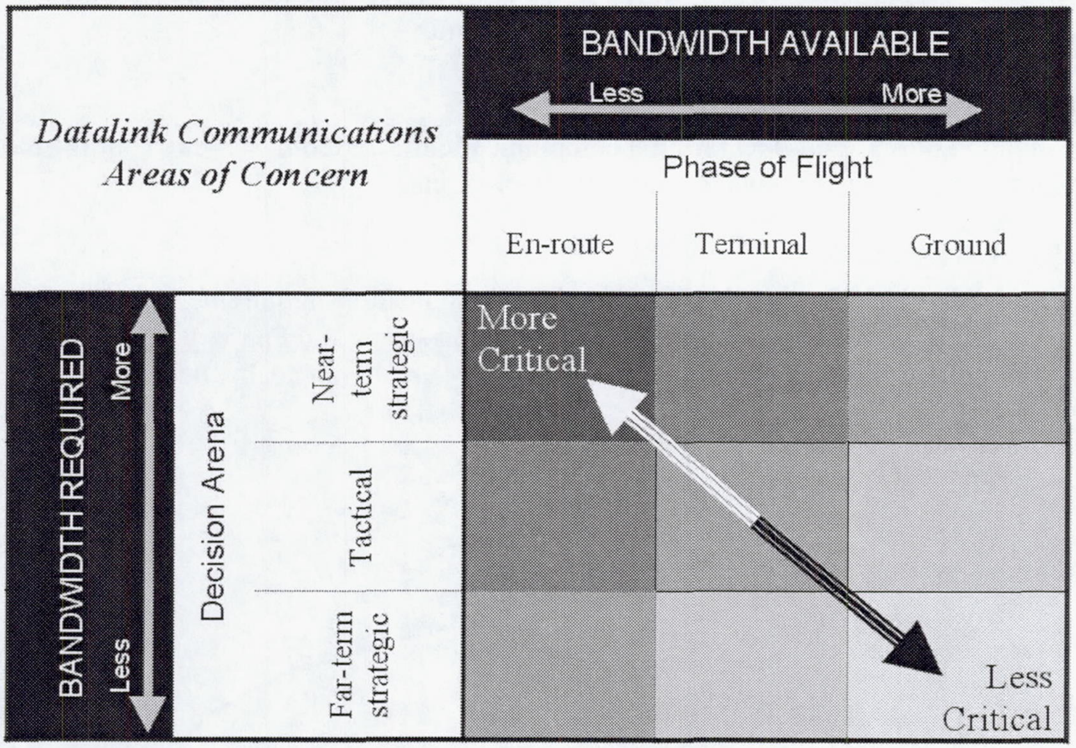

Figure 4. Datalink Areas of Concern

Cross-referencing phase of flight and decision arena yields nine specific areas that can be discussed in terms of requirements levied on communications to support future weather products. Many of these nine areas share the same restrictions and requirements, while some of the nine have very specific requirements. Both general and specific requirements are discussed below.

3.1.3.2 General Requirements

3.1.3.2.1 Open, Standard, Message Formatting

Extensive experience in technical areas (VCRs, computer operating systems, etc.) indicate the requirement for open architecture systems. Without open architecture, costs rise and utility diminishes dramatically because a proprietary architecture discourages creativity and competition.

Similarly, solid standards must be in place to ensure interoperability among providers, vendors, and users. Without a solid industry standard for message formatting, avionics manufacturers will be reluctant to build equipment, because users will be extremely reluctant to buy equipment with limited usefulness.

The standards set for message transmission will have a direct effect on available bandwidth in a number of ways. These effects include how much a message can be compressed, whether or not that compression is allowed to be "lossy," and how dense the information in the message was to begin with. As described later, there is good reason to carefully consider the need to "grid" and "index" future products, and create message formats that will skillfully handle compression of gridded and indexed data.

3.1.3.2.2 Adequate Bandwidth with the Proper Mixture of Addressed and Broadcast Products

Adequate bandwidth is an obvious concern. Not so obvious is the effect that the mixture of addressed and broadcast products will have on bandwidth. Currently there is little or no effort to predict the "correct" mixture of addressed weather products versus those that are broadcast. The theoretical "optimum" mixture of broadcast versus addressed products is likely to be dependent on a variety of factors such as the user's business model, aircraft type, mission, location, phase of flight, training and experience level of the crew, etc.

Conventional wisdom holds that broadcasting more weather information will increase both the level of situational awareness and the general level of safety, thereby decreasing the need for request/reply transactions, in turn lowering the demand for bandwidth. While this seems logical, there is also experience indicating that making information easily available can actually *increase* the amount of network traffic. This has been the case for many informational networks such as cell phones, the internet, and ACARS. It may be that broadcasting easily understood weather information could spark more request/reply transactions that look at very specific areas of concern. Thus, paradoxically, making more broadcast products available may well *increase* the addressed bandwidth required rather decreasing it.

3.1.3.2.3 Clearly Defined Product Boundaries

The products listed in the Phase I Report have suggested sizes, but are not specifically bounded. Specific 4D boundaries and overlap areas will be required in order to model, broadcast, and interpret these products. These boundaries will have to consider such factors as geography, topography, localized weather phenomena, typical aircraft routings, resulting product sizes, modeling, and capabilities of output media (screen sizes, dot pitch, printer capabilities, etc.). The boundaries that are adopted will also have an effect on how products are broadcast, e.g. transmitter locations.

3.1.3.2.4 Clearly Defined Media Boundaries

It is likely any future weather product broadcast system will depend on multiple broadcasting media. If the past is a guide, there will not be enough spectrum to allow every link to be available in every location.

Intelligent mixing of media and links can provide for both primary and backup sources, as well as seamless integration of ground, terminal, domestic enroute, and oceanic/remote sources. Defining the geographical as well as time boundaries will become essential, and may likely be interdependent on product boundaries. Maintaining the optimum media/link mixture requires well-located transmitters as well as a solid mutual-interference prevention methodology where more than one product or transmitter is available to a single aircraft.

3.1.3.2.5 Ground Bandwidth

As suggested in the Phase I report, the bandwidth available on the ground will generally not be restrictive. Most of the time an aircraft is on the ground, the crew will have access to either wired weather outlets, or high-bandwidth wireless outlets. Consequently, the three ground areas of concern are not considered to be sufficiently challenging to warrant further investigation.

3.1.3.2.6 Terminal Bandwidth

Terminal operations are primarily tactical in nature. This is because both "far-term" and "near-term" strategic planning would usually accompany a departure, a situation in which the crew had just completed extensive ground planning. Consequently, neither of the strategic situations adds to the terminal case and are not considered separately.

3.1.3.2.7 Enroute Bandwidth

Enroute operations are primarily strategic in nature. This is because enroute tactical planning will continue to be done via on-board sensors, including PIREPs, visual cues, on-board radar, The Enroute, Far-term Strategic area is currently served by a mixture of voice, paper products carried on board, ACARS, and a small but growing population of basic, datalinked, graphic and textual weather products. Future weather products will complicate the current situation in a number of ways, creating some unique requirements.

Weather is only one category of in-flight "hazard"; others include special use airspace, terrain, noise sensitive areas, traffic position, traffic density, etc. Multiple hazards, as well as the probable multiple *sources* of weather hazards, highlight an increasing demand to integrate a greater quantity of more complex information on the flight deck. Pilots cannot afford to simply ingest more and more data – they need to have it integrated with other operational information and presented only when it is needed. In other words, future flight decks will require "information," not simply data.

The industry is evolving to a point where it must agree on a method to integrate multiple data sources concerning a single phenomenon (such as icing), as well as multiple phenomenon (icing, turbulence, airspace available) into usable information. This strongly suggests the need to "grid" data and information into four (or more) dimensions. Such "gridded" data occupy a specific "location" and time and can, by nature, be more easily and directly compared, contrasted, and integrated with other data. Data integrated in this manner can then be manipulated more easily and presented in a more useable format.

Similar to "gridding," data can also be "indexed" to account for specific differences among aircraft facing the same hazard. For instance, a cargo carrier with a high wing loading can easily penetrate an area of turbulence that a general aviation aircraft with low wing loading would have to avoid. "Indexing" turbulence data would allow any aircraft to "decode" exactly what the turbulent area means to it, considering its specific wing loading, speed, business model, performance capability, crew training and experience, passenger complement, etc.

Finally, gridding and indexing data will have to be done across domestic and international boundaries to account for multiple inputs for multiple hazards. Although indexing and gridding is not a pure weather or communications issue, weather is currently the leading driver for such issues. Likewise, communications is at the heart of delivering such information to and from the cockpit.

*Requirement—**Index** and **grid** weather products to synthesize multiple hazard data from domestic and international sources into information.*

3.1.3.2.8 Terminal, Tactical: *Real-time weather and traffic integrated with Nav/PFD/HUD*

As described in Phase I of the report, "tactical" decision making is characterized by execution and penetration rather than the avoidance and planning of strategic decisions. As such, the FAA has indicated a higher level of certification would be levied on "tactical" products, software, displays, etc. which are intended for use as aircraft maneuver to avoid hazards. Additionally, in order to be useful, any kind of tactical information will have to be real-time, or very nearly real time. This may preclude indexing or gridding data, and also points to presenting more "data" than "information."

In the terminal area, for off-board weather products to be useful, they may have to be combined with traffic information on a single display. This data fusion may be further enhanced by other kinds of on-board processing that would allow a pilot to make routing, deconfliction, sequencing, and arrival spacing/timing decisions in the appropriate settings.

Since the terminal area is the most dynamic, traffic-dense, workload-intensive environment, any kind of tactical weather information would also have to be integrated with a nav display, PFD, and/or HUD to be fully exploitable. Cross-checking separate displays for navigation, flight parameters, traffic, and weather would be unacceptable from the standpoint of pilot workload.

Requirements—
Robust, broadband, broadcast of (not necessarily gridded) real-time, weather data.
Ability to integrate on and off-board weather data and traffic on a single display.
Ability to integrate this data with the nav display, PFD, and/or HUD.
Elevated certification of supporting products, displays, software, etc. is anticipated.

3.1.3.2.9 Enroute, Near-term Strategic: *Downlink and cross-link current conditions.*

Currently, the enroute, near-term, strategic area is not well supplied with useful weather products. Because of that, many certification questions remain open. As the FAA grapples with how to classify future weather products, their decision will probably have the largest, most immediate effect on this area.

Enroute, near-term, strategic products highly depend on "Nowcasting," which in turn assumes that automatic MDCRS-like products are constantly available from multiple sources, including aircraft in flight. These MDCRS reports serve to increase the accuracy of the nowcasting model in two primary ways: providing more accurate information for the model to use in calculations, and providing very accurate information to validate the nowcast's accuracy.

Another way to provide near-real time weather data to a flight deck is to get it delivered nearly directly from cockpit to cockpit. Air-to-air datalinking of "e-PIREPs," as the industry is beginning to refer to them, would allow trailing aircraft to become immediately aware of flight conditions 15 or more minutes ahead, then alter their routing as appropriate.

Requirements—
Downlinking of current in-flight conditions.
Potentially cross-linking current flight conditions to other nearby airborne aircraft.

3.2 Current & Future Communications Related Issues

There are a variety of peripheral issues that are influencing datalink to the cockpit, information management, and the use of graphical (and other) weather products in the cockpit. With the previous discussion in mind, characterizing these issues leads to explicit conclusions which, in turn, help generate specific recommendations. Though there are a wide variety of issues, they can be grouped into three general areas: harmonization, economic, and bandwidth.

3.2.1 Harmonization Issues

Bringing better weather – or *any* hazard information – to the cockpit involves a number of tradeoffs among organizations, standards, timeframes, etc. Harmonizing these necessary tradeoffs is now, and will continue to be, a notable technical and political problem. Some of the harmonization issues that must be faced are briefly describe below:

3.2.1.1 Airline vs. GA

Airlines have different regulations, concerns, and motivations than the general aviation community. The airlines, for instance, can afford to pay for air traffic or flight information services because they would pass the costs on to their customers by increasing the price of tickets. A GA pilot, on the other hand, may have to personally absorb every cost that comes along, whether it is a pay for services fee, or increased certification costs on weather-in-the-cockpit avionics.

What complicates this relationship even more is how much both groups can depend on each other, although they sometimes have what appears to be competing interests. This is apparent in the ADS-B link decision. It is in the airlines' best interests to have GA equip with ADS-B since that would both drive the costs of avionics down as well as ensure that most, if not all, of the traffic had an ADS-B transmitter on board. GA users, however, see little value in ADS-B since they already "free fly" by staying VFR. AOPA surveys indicate that GA are *very* interested in graphical weather on board their airplanes, however. Combining the airline hope that GA will equip with ADS-B and the GA desire for low-cost weather in the cockpit, one could easily make a case for using an ADS-B datalink that can also provide FIS data.

3.2.1.2 US vs. International

Standards are not really "standard" until they apply worldwide. Although weather is obviously a global issue, much of the work that has been done to date to bring real-time graphical weather to the flightdeck focuses on a US domestic market. "Standard" products, timing, gridding, compression, datalink, etc. will all have to be agreed upon in an international forum, not in a simple US policy decision.

3.2.1.3 Public vs. Private Information

Currently, the FAA will certify only products that spring from official US government sources. Third parties may "add value" to the products in various ways, but may *not* issue completely unique products of their own. Airlines do have limited authority to produce their own forecasts through a certificated process; however, even those forecasts must still be based on official government data collection sources. Who owns what data or information is not clear, nor is the liability associated with using particular products for specific purposes. As public versus private ownership and use of the data and information becomes more mature, unforeseen effects are likely to appear.

3.2.1.4 Broadcast vs. Request/Reply/Addressed Products

Most people active in pursing graphical weather in the cockpit assume there will be a large "broadcast" presence in the industry. Although no one is quite sure how this will evolve, most also expect there will still be a definite place for addressed/request/reply information as well. What is not understood, and has not been studied to any great degree, is the effect the mixture of broadcast versus request/reply will have on the industry. It seems likely the final mix of these two modes of communication will have a meaningful effect on fundamental decisions such as bandwidth required, displays, reaction times, costs, training, etc.

3.2.1.5 Strategic vs. Tactical Weather

This important issue must be well-harmonized if the industry is to avoid graphical weather delivery to the flightdeck that is excessively expensive. Currently, "strategic" weather is produced in the form of forecasts and can be used as supplemental information, implying low certification requirements and costs. "Tactical' weather, on the other hand, is usually described as currently observed conditions. Delivering this to the cockpit for the purposes of safely maneuvering through (as opposed to completely avoiding) bad weather implies higher certification requirements and costs. *Harmonizing the definitions of tactical and strategic weather, and identifying logical, useful, safe boundaries between them, may be the most important issue facing weather delivery to the flightdeck.*

3.2.1.6 Near-term Strategic… or Far-term Tactical?

Keeping "Near-term" *strategic* weather from becoming "Far-term" *Tactical* weather products in the eyes of the FAA and other certifying bodies will be a closely related issue. The Phase I report clearly identifies "Near-term" strategic weather as being characterized by avoidance, not penetration, and enabled by nowcasts, not observations. These important distinctions will have to be emphasized as the regulatory process matures. If the tactical/strategic line is drawn poorly, the entire class of products postulated for use in the 15 to 60 minute time window may become too expensive to produce and use.

3.2.1.7 On-board Sensors vs. External Information

The growing human factors issues on future flight decks appear in this harmonization issue. Will pilots be able to synthesize information from on-board systems with information from external sources? Will aircraft systems do this for the human, or will the human do it by consulting different sources and/or output devices and constructing the synthesis in his or her own mind? As more and more sources become available, will their addition to the flightdeck be limited by display space, processing power, communications links, or human capacity?

3.2.1.8 TIS vs. FIS

Harmonizing traffic and weather information is a critical issue. In a system growing toward "free flight," traffic information (TIS-B, ADS-B, TCAS, etc.) becomes more and more important. In fact, in true free flight, an aircraft can maneuver anywhere, without restriction, so long as there is no threat to safety. Obviously, traffic can be a threat, as well as weather. Moreover, weather dramatically affects the flow of traffic , and may often serve to funnel traffic into weather-free, "gaps" that become temporarily crowded. This strongly implies users will want weather and traffic on a single display as is currently the case in modern "glass" displays that share routes, TCAS traffic, and weather radar information. The ability to do this is by no means certain, however. Current traffic display (CDTI) development efforts have yet to directly address displaying weather from on-board or off-board sources.

3.2.1.9 Open vs. Proprietary Encoding/Compression

If vendors create avionics that employ proprietary encoding/compression schemes, they force a user to select and stay with that particular vendor, eliminating the advantages that competition brings. The absence of competition has historically slowed upgrades, limited flexibility, created interoperability problems, and strangled innovation. Without proper industry guidance from multiple groups such as NASA, FAA, RTCA, ATA, IATA, ALPA, IFALPA, SAE, etc., there is a definite risk of developing multiple, proprietary standards for encoding/compression that could then affect everything from displays to the weather products themselves.

3.2.1.10 Information vs. Data

Data is relatively easy to deliver, while "information" is more difficult to develop, deliver, and manipulate. The current trend in general aviation is to deliver weather "data" to a separate display – often to one that is not even mounted on the aircraft. These data are then shown individually in a variety of formats on the stand-alone display.

It is more useful, although more challenging, to integrate various data from multiple sources into a single product. Even more useful and challenging is the ability to present multiple products, synthesized into one. Deciding where these data and products are merged and synthesized into "information," has an effect on the bandwidth required to deliver information to the aircraft in flight. Sometimes, synthesizing data into information can result in less bandwidth required, sometimes more. Another complication arises from the fact that a system may be able handle "data" dropouts, but have much more difficulty with "information" dropouts since the "information" is so much more integrated and dependent.

3.2.1.11 Gridded vs. Unique

To place many sources of data into one, integrated product will require that the data are referenced in the same way to some space-time coordinate system. For weather data, this strongly implies some type of "gridding," most likely in at least four dimensions. Gridding, or its equivalent, will be required to combine and manipulate data from various sources and times into single products, though it may not always be clear whether the processing is done on the ground or in the air.

If the industry can agree on a single gridding system, then *any* party could create a weather product that could be easily integrated with any other weather product. Interestingly, this paradigm also fits neatly into modeling efforts, which tend to be gridded to begin with. In fact, it is quite likely that with a common gridding system for observed, nowcasted, and forecasted data, entirely new products might be developed using unique combinations and weightings of existing products. NCAR, for instance, has already begun such an effort by combining convective weather observations with lightning strike data to provide a dynamic and increasingly accurate nowcast for short term storm propagation.

3.2.1.12 Indexed vs. Raw

There are a number of data issues that could be "indexed" for easy use, transmission, and reference. Generally, normalized, or "indexed" data are smaller and therefore less of a strain on bandwidth. Turbulence and icing are good examples of weather data that might better be indexed than transmitted in raw form.

For instance, consider a Cessna 152 which has just experienced "moderate" turbulence near Colorado Springs. Other GA aircraft will avoid that area if at all possible for both safety and comfort, the PIREP creating the equivalent of a "no-fly" zone in the operators' minds. A cargo-carrying airliner, on the other hand, may have no trouble flying through the same area. His or her higher wing loading, greater experience and training, lack of passengers, and concern for schedule may all lead to a decision that flying through the area is both safe and desirable.

If an equivalent turbulence report, perhaps even "e-PIREP," can be normalized to a single number representing intensity at a given location, then that value can be efficiently transmitted or inserted into the weather/hazard grid described in the previous section. Interpreting this single, "indexed" value can be left up to a specific aircraft or dispatcher, or both – taking into account all the relevant factors for that plane at that time. Such factors might include aircraft type, avionics capability, hazardous weather capability (deicing capacity, etc.), airspeed, wing loading, mission requirements (passenger service, charter, cargo, etc.), training level of the crew, importance of schedule (or other economic factors), etc.

3.2.2 Economic issues

There are *always* a myriad of economic drivers in any business endeavor. How these economic forces are perceived and applied vary widely throughout any given industry, or even within a single organization. The aviation industry, with its historically small profit margins and great dependency on the relative of the economy, is often more sensitive to the economic pressures than other industries. Thus, it can be challenging to predict the effect of any given economic factor. The following are offered as recognized, major economic drivers that will have a definite effect on shaping the communications link(s) for bringing weather to the flightdeck. Exactly what that effect will be is highly dependent on the particular aviation segment, issues existent, and the culture(s) of the organization(s) faced with decisions at the time.

3.2.2.1 Liability Pressures

This is the most unpredictable, but arguably the potentially greatest economic pressure on flightdeck weather faced by the industry. In the US, especially, lawsuits have begun to exert enormous pressures on manufacturers, airlines, and the government. The results have been unpredictable.

Perhaps the best recent example is the work that Allied Signal did with their "Enhanced Ground Proximity Warning" system, a database-driven ground modeling system designed to warn crews *before* they encountered steeply rising terrain. It was viewed as a solid system, but generated little buying interest since it did not seem to provide a sufficient Return On Investment (ROI)—that is until the 757 accident at Cali, Columbia. After that accident, airlines succumbed to intense legal pressures and public perception, and nearly all immediately committed to equipping with the system. A similar weather-related accident would have the same effect on obtaining real-time weather to the flightdeck.

For instance, currently, passengers can establish an internet connection with a laptop over the wireless telephone system installed in many airline cabins. With such a connection, they can view a wide variety of graphical weather information (including NEXRAD pictures) that are not available to the flightdeck. This sets the stage for a disastrous combination where a passenger or group of passengers on a particular flight perceive a threat that the crew does not. If there is a weather-related accident or incident on that flight, the legal landscape will immediately and permanently change, much as it did for terrain awareness after the Cali accident.

The growing "liability gap" between the cabin and flightdeck should be considered in nearly all industry activity. Its ultimate effect is difficult to overstate. Past experience indicates that if the industry does not create progressive procedures, standards, etc., then whatever temporary conditions exist at the time a catastrophe occurs, dictate a de facto permanent standard. This could easily be the case for weather delivery, display, and use on the flightdeck. Often, such a short term reaction to a long term problem limits the potential of what might otherwise be done.

3.2.2.2 Certification Costs

Certification costs are steadily mounting, and it is frustrating manufacturers and users alike. In an effort to ensure "safety," increasing demands on accuracy, integrity, etc. are being levied. One of the collateral results is the cost of creating a system can rise so high as to be economically untenable. The ultimate, unfortunate result could be that system safety is actually compromised since the information that could have been presented with limited accuracy, integrity, etc., is not available at all.

Any effort to bring weather to the cockpit faces a number of certification issues that threaten to include the actual transmission of data as well as the more traditional areas of software development, displays, etc. Nearly all certification decisions in any arena will directly or indirectly affect how the information is transmitted to the aircraft. Any work that can be done to streamline the certification process could serve to simplify transmission of weather to the flightdeck, thereby potentially lowering costs and increasing the safety of the system as a whole.

3.2.2.3 Quantifying Safety

One of the reasons safety equipment and processes such as graphical weather in the flightdeck can be so difficult to implement is that it can be hard to "quantify" safety. In the business arena, the value of safety is typically gauged on parameters such as occupational time off, lawsuit costs, insurance premiums, changes in productivity, etc. If the industry can make inroads into quantifying the system-wide value of enhanced safety of flight operations, especially in the weather arena, it will be easier to justify buying flightdeck weather systems. If this were to happen, a number of other advantages appear relating to economies of scale and infrastructure development.

3.2.2.4 Economies of Scale

Anything that can be done to reduce unit costs will increase the numbers of systems purchased and installed. If only the airlines buy a particular system, then it is not as cost effective as it might be if business and commuter airlines purchased it as well. Likewise, if GA users buy in, costs reduce even further. Finally, if the aviation industry can piggyback on something another industry uses, or vice versa, costs are reduced even further. With flightdeck weather depiction systems, especially those that automate flight condition reporting to the ground and other aircraft, equipping more aircraft brings a system-wide increase in safety and efficiency.

3.2.2.5 Infrastructure Required for Paybacks

Simply installing equipment and trained crews into airplanes will not provide the safety and economic benefit required to make the economic decision to equip. Without a supporting infrastructure (i.e., antennas, frequency allocations, air traffic flexibility to accommodate reroutes and altitude changes, etc,) operators can expect little return for their investments. Airlines, in particular, are reluctant to equip large fleets that operate in geographically diverse areas without an indication they will be able to actually and fully use the equipment they are considering. Instead, airlines are quite content to allow the infrastructure to be put in place first, then purchase a new capability that uses that infrastructure. The FAA and their international counterparts, on the other hand, are likewise reluctant to build an infrastructure that no one is committed to using. This "chicken and egg" issue is closely related to economies of scale, certifications costs, quantifying safety, and liability pressures.

3.2.2.6 Measuring Paybacks

There are other benefits to equipping with graphical weather on the flightdeck, besides safety; however, these benefits are difficult to quantify as well. For instance, the original CWIN simulator study is fairly well known, but follow-on efforts have proved it is more difficult to measure actual payback in the real world. Users are wary of such open issues as how much flexibility truly exists in the current ATC system, or how often they might actually want to deviate for weather to begin with. The answers to both these questions are changing as the ATC system evolves, and new and better weather information becomes available. Other benefits might include passenger comfort, aircrew training and certification costs, etc. Keeping up with such changes, and quantifying them, enhances users' ability to analyze, afford, and acquire new technology.

3.2.3 Bandwidth Issues

As mentioned earlier, if past experience holds true, then the information will expand to fill the available pipeline. This general statement has some particular issues that frame it, discussed briefly in the following paragraphs.

3.2.3.1 Lossless Compression

Currently, SC-195 is writing technical standards for FIS-B weather product transmissions. One of the assumptions in their work is that any compression schemes used must be *lossless.* Not everyone on the committee agrees with this stance, and it does have a detrimental effect on the required bandwidth, should this requirement become the standard. Phase I of this report describes in more detail why a lossless compression scheme is not required for longer term decision arenas, thus conserving the bandwidth available for other uses.

3.2.3.2 Spectrum Management – Bandwidth or Frequency?

In much of the communications industry, the paradigm is beginning to shift from using specific *frequencies* to effectively using *bandwidth.* Currently, a specific portion of the VHF spectrum is allocated to aviation, and specific frequencies are assigned to given locations. As bandwidth becomes more and more scarce, spread-spectrum technologies are becoming more and more prominent. It is quite plausible that future users may be allocated and even charged for the bandwidth they consume, rather than told which particular frequencies they are allowed to occupy. As available RF bandwidth dwindles, the industry will have to respond in some fashion to reward efficient users and discourage inefficient ones.

3.2.3.3 ADS-B Link Decision

Currently, there are three standards vying for selection as the future ADS-B link. These three standards, described in the following sections, have a direct effect on delivering weather to the flightdeck of the future. There are a variety of possibilities, but two basic ones are illustrated below:

Bearing in mind the opening liability gap, a severe, weather-related accident could conceivably apply enough political pressure to force ADS-B to accommodate at least some weather information in the broadcast as well. This would immediately eliminate Mode S from consideration and vault the weather datalink community into the forefront of assisting with the ADS-B link decision.

In a second scenario, Europe would adopt VDL4 as their ADS-B solution while the US adopts Mode S. Avionics manufacturers would have to build systems that support both Mode S and VDL4 for operations into multiple environments. In the US, this would leave VDL4 available to be used for FIS and/or TIS information. A harmonized FIS/TIS broadcast from the ground could prove to be extremely useful in the new airspace structure that will support free flight.

3.3 Suitability of Current & Planned Aviation Communications

This section supports the requirement to "*evaluate and determine the feasibility of using the existing aviation communications infrastructure for supporting future weather tool implementation.*" This section of the report reviews the current NAS architecture and its aviation datalinks, in the context of future product requirements, considering present and future issues, draws specific conclusions concerning feasibility, and makes appropriate recommendations.

3.3.1 NAS 4.0

Currently "NAS 4.0" is the most recent version of the FAA's National Airspace Plan. It was published in January of 1999, and as such, is already out of date. The NAS 4.0 document, FAA interviews, and the unpublished web-based "CATS" tool were used to characterize this portion of the report.

Any reader who wishes to find the most current state of NAS funding and planning can consult the FAA's new tool, termed "CATS." CATS stands for **Compliance Activity Tracking System** and is an interactive web-based tool that allows users to see the interrelationships among different FAA modernization programs. Until recently CATS has only been available within the FAA on their internal network, but it should become available to the general public via internet in April, 2000.

3.3.1.1 General Outline

The NAS 4.0 plan, as currently conceived, is broken down into three main phases. These phases are intended to describe funding, programmatic, and functional milestones. The three phases are broken down by year as follows:

- Phase I 1998 – 2002
- Phase II 2003 – 2007
- Phase III 2008 – 2015

3.3.1.2 Communication Phases

Within these phases, certain communications capabilities are planned. In general, these can be summarized as:

- Phase I Free Flight Phase I Core Capabilities Demonstration, Safe-Flight 21, Demonstrated airborne link capabilities.
- Phase II Transition from analog to digital for all airborne communications.
- Phase III Integrate air and ground digital communications

Graphically, a few tables from the NAS 4.0 document can help picture communications transitions. For instance, Figure 5, repeated here from NAS 4.0, describes in general how domestic and oceanic communications systems for ATC communications are planned to evolve over the next fifteen years. Of particular note in this chart is the clear transition plan from analog to digital communications. Budget pressures, however, are expected to impact this schedule.

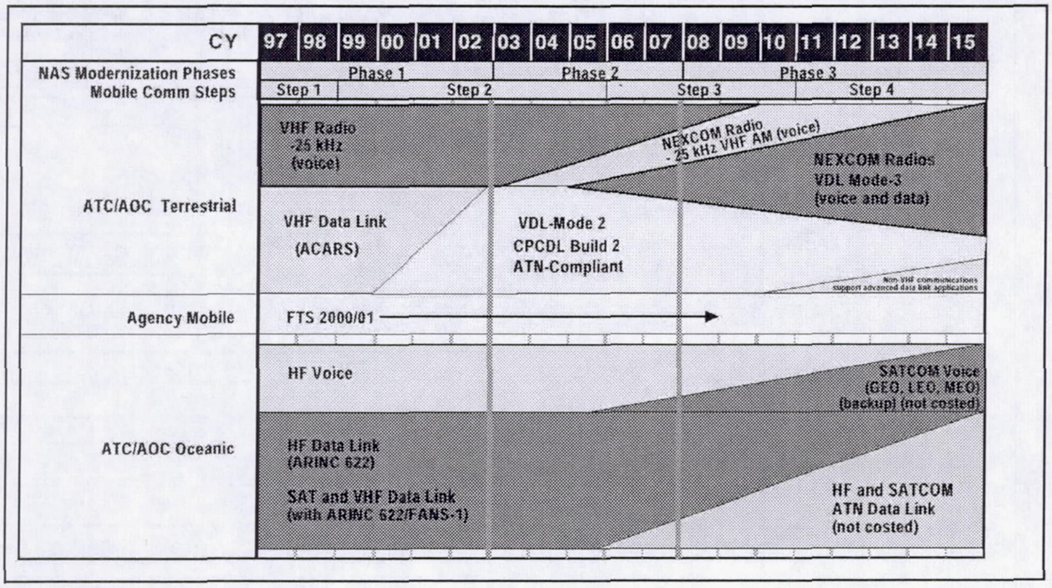

Figure 5. NAS 4.0 Mobile Communication Transition

Part of the evolution into digital communications depends on decommissioning some of the current VHF navigation aids. Though not quantitative in nature, the following chart from NAS 4.0 illustrates this trend. Note that ADS-B is shown coming onto the scene in 2001, that GPS capability replaces some basic Navaids, and LAAS capability supplants ILS.

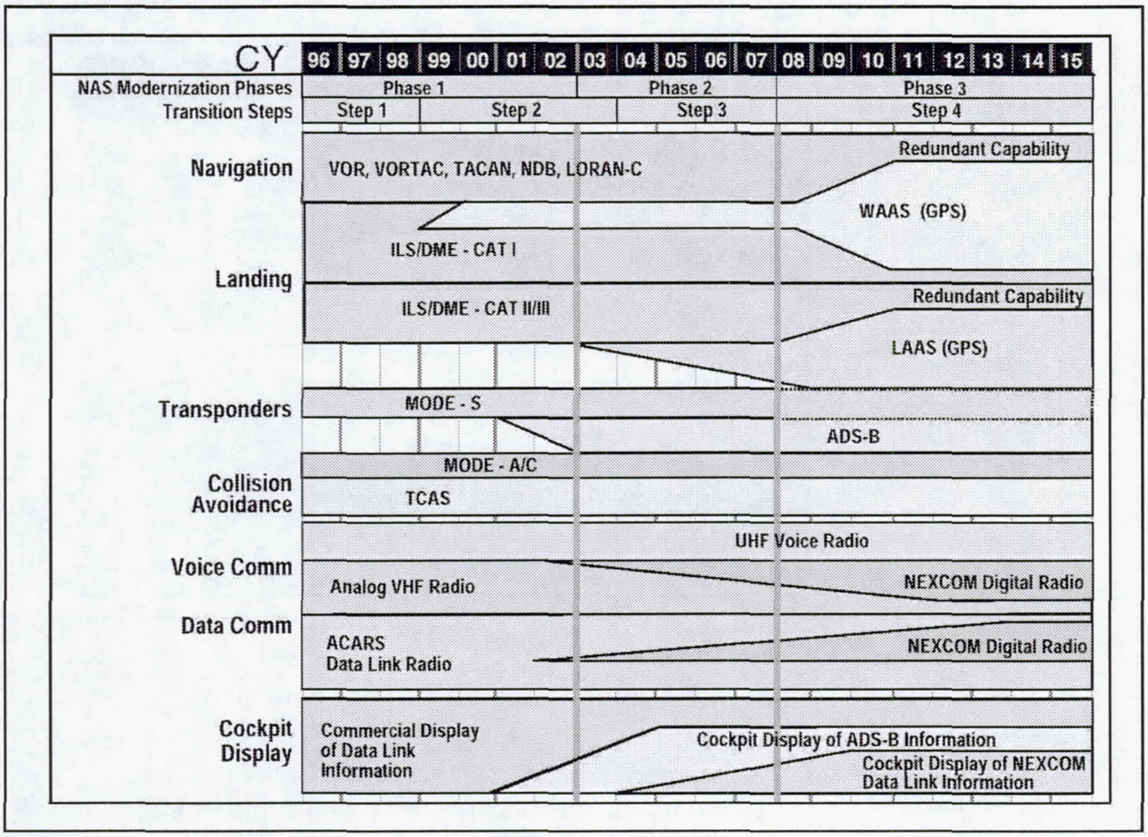

Figure 6. Ground Infrastructure Transition Supporting Avionics Equipage

Not only will communications systems change, but the weather information system is planned to evolve as well. This is shown graphically in the following chart, Figure 7, also repeated from NAS 4.0. Although the OASIS system is slated to replace two current systems, its future is uncertain due to a combination of budgetary and political issues within the FAA.

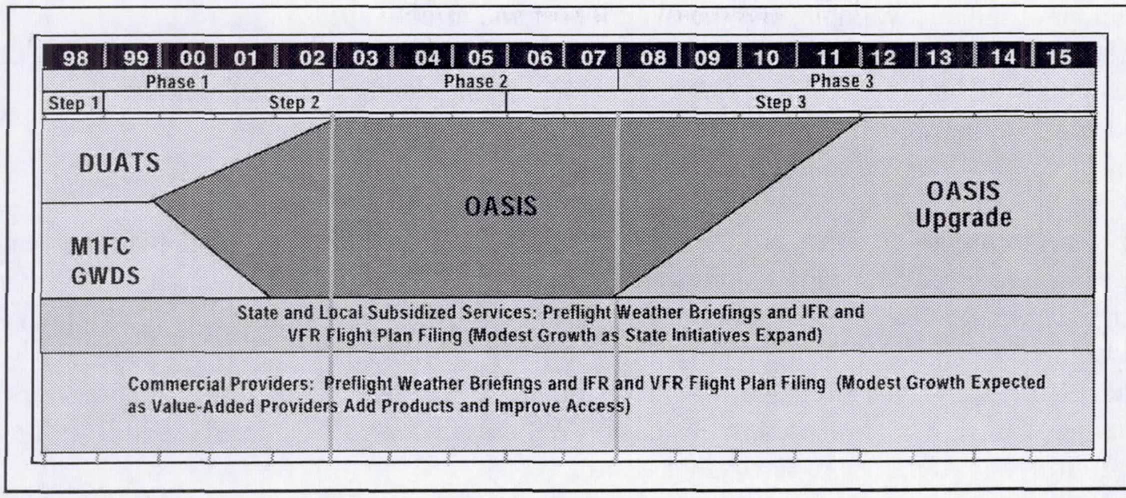

Figure 7. Flight Services Transition

3.3.1.3 Points of Interest

These charts, which outline the general FAA communication and weather plan for the next 15 years, raise some questions. Of general note are observations about the federal funding process that has historically hobbled planning and execution of FAA programs.

GENERAL NAS PLANS –The most current written version of the FAA's NAS plan was 4.0, released in January 1999. Unfortunately, NAS 4.0 is already obsolete due to actual and projected funding shortfalls. For example, the FAA expected a healthy funding boost in the FY 00/01/02 timeframe in a number of NAS 4.0 areas, a boost which has been cut or eliminated in many cases. Funding shortfalls such as these directly affect the viability of many datalink programs and issues. Moreover, the constant, unpredictable flux of appropriated dollars contributes to the FAA's inability to apply new technical capability, and degrades their ability to effectively manage and regulate that technology. While technology rapidly advances in the commercial sector, the FAA's modernization programs often languish in an un/under-funded program until the situation reaches crisis proportions.

FAA FUNDING – As currently structured, no FAA related activities can properly be viewed as "funded" unless they are operating in the current fiscal year. Funding has historically been an issue with FAA programs since, during the course of a fiscal year, funding priorities can change, with any given project being expanded, shrunk, or eliminated altogether. Nevertheless, the datalinks considered in the section are "funded" in the sense that they are planned in the current hard-copy version of NAS 4.0.

FAA BUDGET PROCESS – Due in part to the difficulties in predicting which programs will continue to receive Congressional support, there have been a variety of efforts to influence the way the FAA budget is administered. If some of these efforts achieve even partial success, they have the potential to significantly affect both the amount of money available, and the overall cost and effectiveness of projects for future datalink development. Two of these general efforts include releasing the FAA's "aviation trust fund" and taking the FAA "off budget" to varying degrees. It is anticipated that more stable funding will reduce the actual costs and development times associated with new programs by making them more predictable.

The uncertainty of the FAA budgetary process, and its effects on long range planning can be clearly inferred from figure 8, repeated here from NAS 4.0. This Research, Engineering, and Development projection shows a notable spike in the year 2002 which is required to support follow-on efforts in out-years. Unfortunately, even by 2000, this budget projection was already drastically behind and "realistic" 2002 projections were as much as half of what is shown in this chart. Without the up-front investment in R, E & D, follow-on programs are seriously jeopardized.

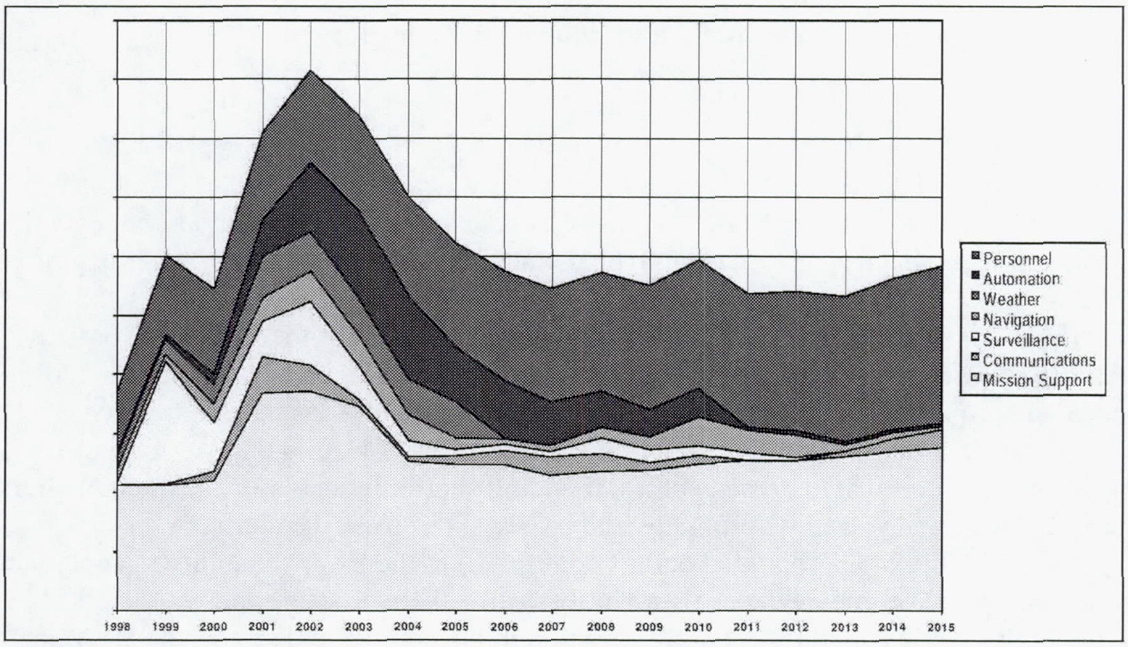

Figure 8. Estimated R,E&D Cost

Note – as this document was in final preparation, "Air 21," a bill to release the Aviation Trust Fund, was signed into law. AOPA reported "If the deal is finalized as reported, Congress would be required to spend all of the money that the trust fund takes in each year, plus the interest on the money already in the fund. Next, Congress would be required to provide the full amount authorized for programs such as the Airport Improvement Program Fund (AIP) and Facilities and Equipment (F&E). In total, funding for the AIP would increase from its current annual level of $1.9 billion to $3.4 billion, and F&E would see an increase from $2.04 billion to $3 billion." Although it remains to be seen how this money will be appropriated and invested, it bodes well for the budget projections in NAS 4.0. On the other hand, President Clinton has been quoted publicly as questioning such a large "increase" in FAA funding.

UNCERTAIN DEPENDENCIES – The FAA's future digital voice and data communications choice, "NEXCOM," is counting on using spectrum not only in the current voice range, but also from the VOR and ILS ranges (108-118 MHz). Current events and industry opinion indicate that reducing the current dependence on VOR and ILS frequencies is not a sure thing. Keeping current voice weather services available may be affected by this planned decommissioning; furthermore, budgetary and other factors threaten certain NEXRAD capabilities. In fact, NAS 4.0 specifically states "*Several items are critical to the aviation weather architecture. These include adequate radio spectrum for ASOS and AWOS, tri-agency (FAA, DoD, NWS) funding for NEXRAD upgrades, and implementation of private service provider FIS.*"

3.3.1.4 Flight Information Services Datalink Program

Near term planning to provide weather products to the cockpit in text and graphic format is being defined for the FAA's Flight Information Services (FIS) program. The *FAA Airborne Flight Information Services Policy Statement* defines Flight Information Services as "the noncontrol, advisory information needed by pilots to operate more safely and efficiently in the National Airspace System (NAS) and in international airspace."

Under the framework provided by this policy statement, the roles and responsibilities of the Government, industry, and users are defined as follow:

FAA:

- will make NAS status and existing Federal meteorological data equally accessible to all aeronautical users, including service providers;
- will work with industry to develop a joint petition to the Federal Communications Commission to assign four 25 KHz radio frequency channels in the 136.0-136.9 MHz VHF spectrum and select qualified vendor(s) on a competitive basis to be the providers of FIS services;
- will work with other Government agencies, users, and industry to develop a common set of human factors guidelines and standards for the display and training associated with use of FIS products in the cockpit;
- will lead and coordinate establishment of national and international standards and operational procedures for delivery of FIS via data link, ensuring interoperability between various FIS capabilities and service providers; and will conduct an investment analysis to determine the feasibility of establishing an electronic Pilot Report system in the same service volume as the uplink FIS in this policy.

Industry:

- will provide ground infrastructure (i.e., ground servers and data link transmitters) needed to get products to the aircraft as well as avionics needed to process and display products in the cockpit;
- will provide basic FIS products and services to all properly equipped users at no direct cost to Government and users;
- will provide value-added products for fee based on user demand.

Users:

- will acquire avionics at their own cost;
- will receive basic products at no cost; and
- will pay for value-added products.

The minimum products to be provided include: Aviation Routine Weather Reports (METAR), Terminal Area Forecast (TAF), Significant Meteorological Information (SIGMET), Convective SIGMET, Airman's Meteorological Information (AIRMET), Pilot Reports (PIREPs) - urgent and routine, and Aviation Watches (AWW).

The data format and content of the FIS/B broadcast channels are currently being determined by RTCA Special Committee 195 - Flight Information Services Communications (FISC). SC-195 is producing *RTCA Minimum Aviation System Performance Standards (MASPS) for FIS/B* and *RTCA Minimum Operational Performance Standards (MOPS) for FIS/B*. Together these two documents which are scheduled to be completed early in 2000, will define the characteristics of the broadcast channel for distributing weather in digital format for the FIS program. SC-195 also expects these standards to be applied across the board for *any* broadcast weather product.

The FAA has awarded two contracts to private companies to provide weather products for FIS. The two companies receiving FIS contracts are NavRadio Corp. of Golden, Colorado and ARNAV Systems, Inc. of Puyallup, Washington. Each company has received two of the four 25 KHz channels to distribute FIS products.

Ground-air communication coverage and user access to weather information is expected to be at least equivalent to the current FAA Enroute Flight Advisory Service (EFAS) voice service (Flight Watch).

En route Flight Advisory Service (EFAS) also known as "Flight Watch" is a service designed to provide en route aircraft weather advisories pertinent to their type of flight, route and altitude. EFAS provides communication capabilities for aircraft flying at 5,000 feet through 17,000 feet on a common frequency of 122.0 MHz. Below 17,000 feet, EFAS is accessible at 20 Flight Watch Control Stations and over 200 satellite stations (Figure 9).

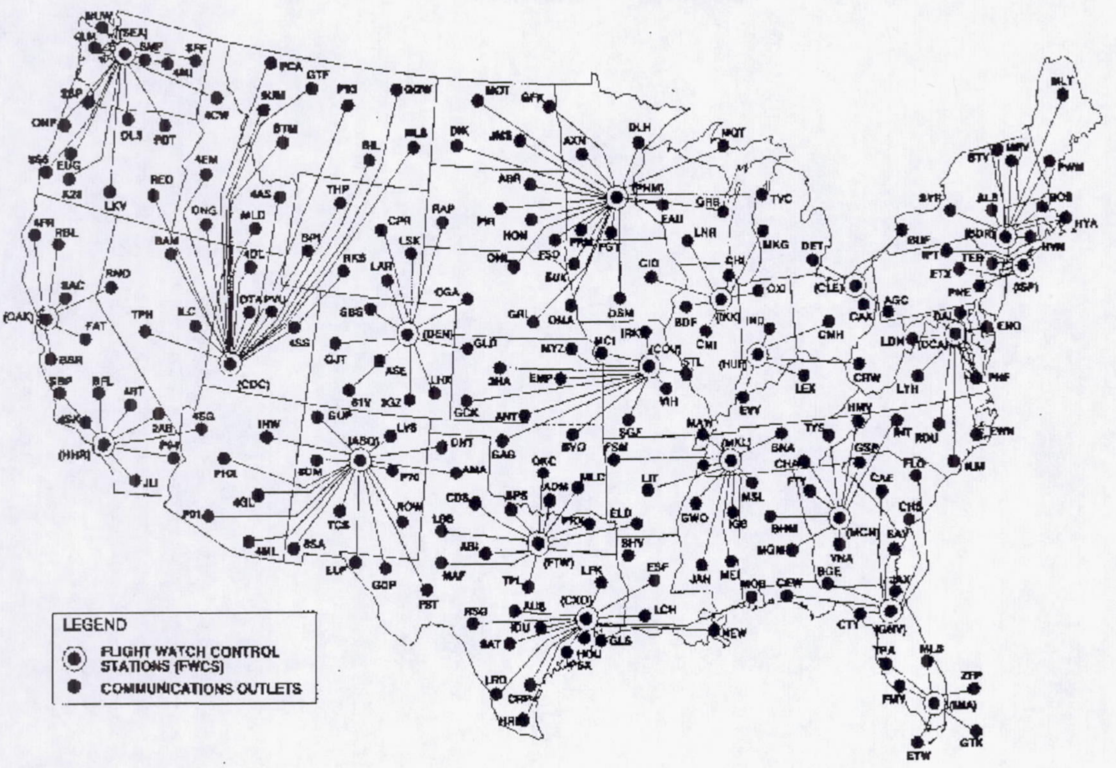

Figure 9. Distribution of EFAS Low Altitude Access Points

Discrete frequencies have been established for altitudes between 18,000 and 45,000 feet for EFAS. These discrete frequencies are sometimes useful for getting weather information below 18,000 feet but communication on the discrete frequencies at these altitudes is not reliable. Figure 10 shows the distribution of high altitude EFAS frequencies. Multiple frequencies are required for high altitude access to EFAS to avoid interference between ground stations.

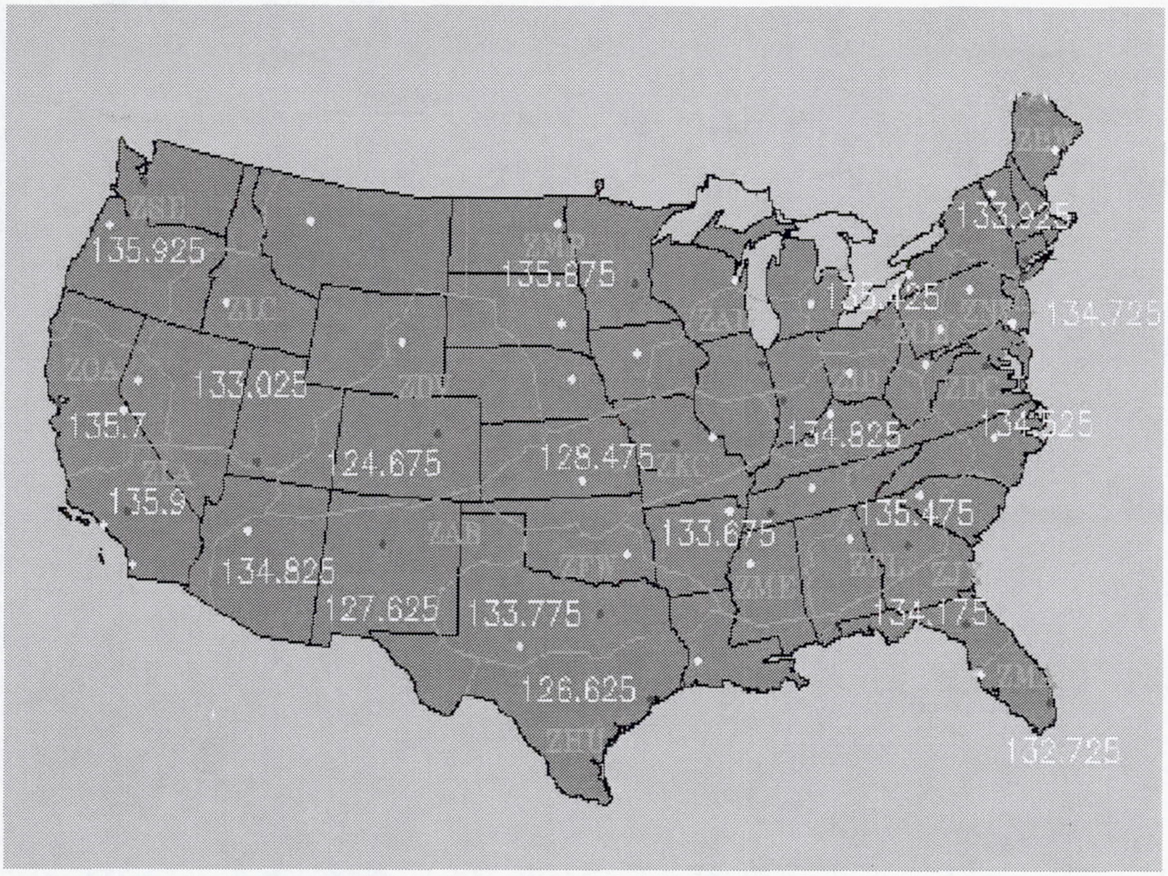

Figure 10. EFAS High Altitude Frequencies

If Flight Information Services (FIS) is to have the same level of distribution as EFAS, more than four frequencies will be required for distribution to high altitude flights.

3.3.2 Aviation Datalinks

NAS 4.0 and the CATS tool indicate the following "aviation specific" datalink associated frequencies, technologies, and protocols are ones that should be considered in this section of the report. (Note – the term "datalink" is often used to mean a variety of different wireless communications concepts within the industry.) What follows is *not* meant to be an exhaustive technical treatment, but instead intends to set the stage for a discussion of the appropriateness of each of these technologies to carry future weather products to the flight deck. For this report these concepts have been grouped in the following manner:

AVIATION FREQUENCIES / PHYSICAL LAYER

- VHF
- HF
- Mode S (1090 MHz)
- UAT
- Satcom (Specifically, Inmarsat)
- UHF

NETWORKS / PROTOCOLS

- ACARS
- ATN
- ADS-B
- FIS-B
- TCP (et al)

TRANSMISSION MEDIA / SUB-NETWORKS

- ATN: VDL2, VDL3
- ADS-B: Mode S, UAT, VDL4
- ACARS: Analog VHF, Satcom, HF, VDL2, VDL3

These technologies are well known in the aviation community, but a review of each is in order to support the analysis of future product requirements. The "advantages" and "disadvantages" are discussed solely from the point of view of communicating weather information to the cockpit.

Data transmission of weather information is the primary focus of this document. Weather information is also transmitted via voice, as described in the Phase I Report. Voice transmissions are an important part of the weather distribution system, but are not generally bandwidth restricted, although they have a definite effect on data bandwidth availability.

For the purposes of this section, the word "data" is meant to imply digitized information that is wirelessly transmitted to a flightdeck. It is not meant to imply only "raw" data, but also any variety of information that is both raw and processed such as drawings, pictures, icons, text, etc. It is recognized that there are other means of getting information to the aircraft, including various disk media, wired connections, and physically transported paper products. These other means are not considered in this report.

3.3.2.1 VHF Datalinks

In the US domestic, civil world, VHF is the predominant frequency band for aviation communications. There are various schemes proposed and currently in use for transmitting data in this spectrum. In the NAS 4.0, the following are included:

3.3.2.1.1 VHF ACARS

DESCRIPTION – The Aircraft Communications Addressing and Reporting System (ACARS) is an existing VHF air/ground data link that uses nearly 600 VHF locations throughout North and Central America, Hawaii, the Caribbean, and several U.S. territories. Although begun as a VHF datalink, ACARS messages can now be transmitted by HF or SATCOM as well.

FUNCTIONALITY – Initially used to transmit only Out/Off/On/In (OOOI) events for scheduled air carriers, ACARS today supports over 50 applications, including relaying Aircraft Operational Control (AOC), Airline Administrative Control (AAC), and Air

Traffic Control (ATC) messages between ground-based organizations and the cockpit. It has also been pressed into service for weather in the cockpit, including pseudo-graphical representations of detected microburst activities at selected airports under the "Terminal Weather Information Program (TWIP).

PROVIDERS – In the US, ARINC is the primary provider of ACARS services. In various locations of the globe, ARINC and other organizations, most notably SITA, have cooperative agreements that ensure messages are transmitted to aircraft that cross service boundaries. Multiple avionics vendors build ACARS capable receivers and displays.

USERS – Today over 4,800 aircraft from U.S. airlines, international airlines, regional airlines, corporate flight departments, and government agencies transmit and receive more than ten million messages per month via ARINC ACARS. Though most major US airlines use ACARS, not all airlines, or all fleets are equipped to use it.

IMPLEMENTATION – VHF ACARS datalink, as currently used, is a character-based system which has a maximum speed of roughly 2400 bps, but its effective throughput is usually much lower – sometimes on the order of 300 bps.

ADVANTAGES – ACARS is an existing system which is widely used, and growing in volume and capability. For instance, since 1991, ARINC reports that ACARS usage has grown more than 67%, and continues to grow, as one major airline reports, at a current rate of approximately 15% per year. ACARS equipment already exists on board many aircraft, and crews are trained in its use, therefore its costs are associated mainly with usage and maintenance.

DISADVANTAGES – Although there are upgrade plans to transition ACARS from a character to a digital transmission system, it still has limited potential to provide graphical weather in the cockpit. Existing cockpit ACARS displays are generally small, monochromatic, and character based. Additionally, the limited VHF frequency allocations are already overcrowded in major terminal areas. Retrofit costs associated with upgrading future versions of ACARS to a meaningful graphical weather depiction system will probably be prohibitive.

3.3.2.1.2 VHF Data Link Mode 2 (VDLM2, or VLD2)

DESCRIPTION – VDL2, as it is often abbreviated in the industry, transmits digitized data over current VHF 25kHz channels via a CSMA scheme. Good for data only, there are some VDL2 radios already in existence, and more slated for installation in future production transport aircraft.

FUNCTIONALITY – Designed as a sub-network for the ICAO Aeronautical Telecommunications Network (ATN), VDL2 represents a transition step from analog to digital radios that will eventually support both voice and data. VDL2 supports a connection-mode, addressable datalink with an ISO 8208 network interface, can operate at a 31.5kbps maximum data rate, and is expected to be used for AOC type functions for airlines. Besides AOC functions, VDL2 is expected to support other datalink applications, including AAC and eventually ATC via CPDLC. It is the first step into an ATN capable datalink. ARINC also plans to use VDL2 for ACARS transmissions as described previously.

PROVIDERS – Various vendors have committed to building VDL2 compatible radios which are expected to be used well into the future. VDL2 ground stations are scheduled to be deployed in the U.S. and Europe by 2001. Commercial airborne VDL2 radio equipment is also planned for introduction in 2001. The available spectrum will include at least 118-136.975 Mhz, and may reach as low as the low end of the aeronautical navigation band of the VHF spectrum. NAS 4.0 plans to decommission many current VOR stations, freeing up much of the lower end (112-117.975) of the VHF spectrum for VDL2 datalink (and VDL3 voice) usage in many areas. Ultimately, the FAA, FCC, and various world organizations will control how and where the spectrum is used.

USERS – The FAA will encourage all segments of aviation to use VDL2 capabilities, though costs may inhibit some from equipping with pure VDL2 radios. Instead, a variety of multi-mode radios are planned. This equipment is software programmable, and able to use standard VHF voice, VDL2, VDL3, and the new 8.33 KHz spacing recently implemented in Europe. GA probably will not equip with pure VDL2 radios unless their costs are significantly reduced, and there are adequate services available that make it beneficial to equip. AOPA indicates that this will likely not occur until NEXCOM (VDL3) is solidly in place. Additionally, ARINC is planning on using VDL2 for digital encoding and transmission of the character-based ACARS transmissions.

IMPLEMENTATION – VDL2 is a CSMA scheme that requires new receivers and transmitters, but no timing infrastructure. It is designed to support *only* data transmissions, and shares available bandwidth by listening prior to transmitting, then transmitting only when the selected channel is clear. Using VDL2 will require new avionics, new STCs for existing aircraft, and updated ground transmitters. Notably, a VDL2 radio *should be* upgradeable to a VDL3 radio through a software upgrade alone.

ADVANTAGES – VDL2 offers a data rate nearly an order of magnitude greater than ACARS or most other data links currently in use (31.5Kbps). Moreover, it is designed to be ATN compatible, which means it will be capable of supporting addressed, ATC messaging (CPDLC), any ACARS type messaging, and other datalinks. It also supports a pure broadcast mode, providing a basis for the current RTCA SC-195 efforts to define FIS-B formats.

DISADVANTAGES – VDL2 does not support voice, and like any broadcast medium, cannot tell for sure that a broadcast has been received. This may be further exacerbated in broadcasting weather data as the sensing scheme “listens” for 5ms, then declares a channel to be unoccupied at a 90% confidence level. Consequently, in-flight data collisions may occur, though some of these can be sorted out. This possibility is managed by such techniques as modularizing products (as called for in the FIS-B MASPS) into smaller “chunks,” repeating product broadcasts with a given frequency, the embedded forward error correction of the protocol itself, etc. CSMA will not work well when a channel is heavily loaded. Some experts indicate a CSMA scheme will become increasingly inefficient when transmissions occur on a channel more than 20 to 30% of the time. Recent tests with VDL2 transmitters have indicated problems with "spillage" into adjacent channels. Depending on how this problem is solved the cost of VDL radios could increase significantly or some adjacent spectrum will be lost.

3.3.2.1.3 VHF Data Link Mode 3 / NEXCOM (VDLM3 or VDL3)

DESCRIPTION – "NEXCOM" is the generic term used in NAS 4.0 to mean a future, digital radio capable of both voice and data transmission and reception. In current, common usage, NEXCOM and VDL3 are considered to be the same thing, although officially, that has yet to be declared. VDL3 plans to use the entire current VHF spectrum (112-136.975 MHz), split into four separate time slots for each 25kHz channel.

FUNCTIONALITY – The NEXCOM concept was intended to use as much of the allocated aviation spectrum as efficiently as possible. Thus – it supports both voice and data, and is poised to take advantage of spectrum that is released by the decommissioning of VOR Navaids. Like VDL2, it can support up to a 31.5Kbps; however this is the total for each 25kHz channel – each time slot will carry less than ¼ of that bandwidth.

PROVIDERS – Like VDL2 radios, VDL3/NEXCOM radios are being planned by major avionics manufacturers. Again – rather than a pure VDL3 radio, the industry seems to be leaning toward multi-mode, programmable transceivers that will be flexible enough to take advantage of multiple transmission schemes and frequencies. The FAA, FCC, and various other world organizations will ultimately continue to control how and where the spectrum is used.

USERS – The FAA will urge all segments of aviation to use NEXCOM radios for both voice and data. It seems quite likely that business aircraft and high-end GA will lead the way, as they are poised to take advantage of the extra capability that NEXCOM may provide. The airlines are also headed in this general direction, although the timing and their financial commitment are unclear. It also seems likely the US military will equip to some degree, as they have with VHF, to maintain some interoperability. It is even possible that lower end GA will support NEXCOM, according to AOPA. This will be a likely outcome only if, as is hoped, a single radio will be able to support both voice and data, will have relatively low acquisition and maintenance costs, and will provide enhanced capabilities not currently available – such as FIS/TIS in the cockpit.

IMPLEMENTATION – VDL3 radios have been demonstrated and are in the testing phase now. They use a straight TDMA scheme, splitting each existing 25kHz channel into four time slots using a GPS timing signal. These slots are tentatively planned to be shared for data and voice - two for each; however, they can be used differently, if desired – i.e. two for voice, two for data; three for voice and one for data; all for data; etc. To implement VDL3/NEXCOM, new airborne and ground transceivers will be required, but with the added complexity of a timing reference signal provided by GPS. Retrofitting older aircraft will require new avionics and new STCs, although upgrading from a VDL2 radio *should be* able to be accomplished through a software upgrade.

ADVANTAGES – VDL3 was designed for supporting digital voice and data communications while using available, assigned, aeronautical bandwidth efficiently. It has a generally agreed technical specification that AOPA tentatively supports, and thus seems decently positioned both technically and politically. It is ATN compatible and would be able to carry all manner of communications from weather information to flight-critical applications.

DISADVANTAGES – While it has potential advantages, VDL3 has significant disadvantages as well. One of the most critical technical problems is that VDL3 suffers from co-channel interference--much more so than VDL2. While VDL2 may need only a single "guard" channel on each side of the frequency being used, VDL3 may need as many as three to four "guard" channels to ensure data integrity as well as voice clarity. This may represent an unacceptable loss of spectrum. Additionally, moving to a VDL3 scheme would require a dramatic frequency adjustment across the entire country and carry with it the problems brought by such a paradigm shift. (This adjustment would be required due to the co-channel interference issue, use of old VOR frequencies for voice, and splitting each frequency channel into four parts.) Another potential disadvantage is that the industry track record for "software only" upgrades is poor, leading some to view this claim with suspicion if not outright skepticism.

Other arguments against VDL3 include VDL3's strict TDMA scheme which may not be the most efficient way to utilize assigned spectrum and that requires infrastructure that other schemes do not need. (i.e., – the timing signal). Moreover, splitting the channel into four parts reduces the data rate available for data-intensive applications such as weather in the cockpit. Finally, if ATN messaging is used in data transmissions there are two more distinct drawbacks: the ATN messaging overhead will significantly cut throughput, and ATN does not directly support a broadcast mode.

3.3.2.2 Inmarsat Satellite Data ACARS

Satcom datalinks are essentially telephone calls that put ACARS units in contact with an airline's operations center, using addressed communications over primarily geosynchronous satellites. There are a variety of current and planned implementations, including Aero H, H+, I, C, and mini-M – all with slightly differing schemes and target audiences that include other industries besides aviation. Typically relatively expensive, Satcom ACARS links usually need steerable airborne antennae and have been used primarily for oceanic/remote airspace.

As all current ACARS implementations are, Satcom ACARS is a character-based system that cannot support graphics. Most systems are limited to 2400 bps or less, though some upgrades will boost this to 4800 bps under certain conditions. Even so, the limitations of ACARS, the requirement for addressed communications, and the relative expense of the link relegate Inmarsat to proving occasional, text-based products in remote/oceanic areas.

3.3.2.3 HF Data

HF datalinks are currently operated by ARINC from eight stations throughout the world. They are long range, low speed links aimed at serving remote and oceanic aviation users. Like all current ACARS, HF ACARS datalink is a character based system. It typically operates at 300 bps or less, although 2400 bps is theoretically the highest speed available under perfect conditions.

There are currently no HF datalinks used or planned within the US civil aviation community, other than through ACARS. It is satisfactory for addressed, slow speed, character-based information delivery through ARINC, but not much more. Due to the nature of HF communications, an aircraft will hardly ever know in advance which HF station it might listen to, consequently, geographically-tailored broadcasts would be difficult to implement.

3.3.2.4 UHF Data

UHF datalink will continue to play a role for US armed forces. Since the aviation portion of UHF datalink is currently reserved for the military, however, little civilian use is likely. On the other hand, there is an identifiable, but remote possibility that the military might negotiate the use of other more desirable frequencies, using their current UHF assignments as a bargaining chip. If this unlikely scenario came to pass, civil aviation, at least here in the CONUS, could make very good use of the UHF band for datalink for all manner of information, including UAT and weather. If ILS transmitters are decommissioned with the advent of GPS LAAS, the UHF portion of the ILS that broadcasts glideslope information could conceivably also be used for a weather datalink.

3.3.2.5 ADS-B Datalink Contenders

3.3.2.5.1 VHF Data Link Mode 4 (VDLM4 or VDL4)

DESCRIPTION – VDL4 is a proposed ICAO standard, most popular in Europe, that includes a hybrid ground controlled TDMA scheme with a self-organizing capability designed primarily to enable ADS-B. It is one of the datalink candidates for ADS-B currently under consideration, along with UAT and Mode S, in the Safe Flight 21 activities. Although it is looked upon primarily as an ADS-B link, it has the potential to be used as a weather datalink, even if selected as the primary ADS-B link.

FUNCTIONALITY – VDL4 is designed to be a multi-channel ADS-B link, providing ground-to-air and air-to-air connections via ATN. It is capable of data sharing (no voice) up to a limit of approximately 19.2 Kbps per channel, and has demonstrated limited FIS-B functionality in various pre-production testing. It follows a cellular paradigm and can handle nearly unlimited message traffic by managing the size of the appropriate cells. Message transfer and broadcast uplink services will be provided on supplemental channels.

PROVIDERS – There are currently two producers of VDL4 radios, one based in Europe and one in the US; however, if VDL4 were to become the standard for ADS-B, it is assumed that nearly all avionics vendors would provide radios for the multiple applications that VDL4 allows. As in the other VHF Data Link schemes, ultimately, the FAA and FCC would regulate the use of the VHF aviation spectrum within this country.

USERS – Depending on the upcoming ADS-B data link decision, the users of VDL4 could vary widely. If VDL4 is selected as the ADS-B link, the aviation community can reasonably expect a large push from GA to make FIS-B available over the same link. Airlines, in turn, are likely to support such an effort since it will help populate the sky with ADS-B equipped aircraft, enhancing safety and efficiency.

IMPLEMENTATION – As currently envisioned, VDL4 runs in the 118.00-137 MHz band using a GFSK (Gaussian Fixed Shift Keying) approach, providing a maximum data rate of 19.2 Kbps per channel. While the prototype for ADS-B services is based on GPS-derived UTC for timing, the system is designed to accept other external timing and navigation sources for normal operations. Service areas are divided into "cells" of varying sizes, the size being determined by the required service density such that smaller cells would be used in heavy terminal areas. Aircraft transiting a cell "log on" to the cell, listening for a short time and develop a "user map" that allows each new user to efficiently share the spectrum.

ADVANTAGES – VDL4 can very efficiently use the available spectrum with its hybrid ground organized/self-organizing TDMA approach. Moreover, for air-to-air applications, it does not need any supporting ground infrastructure, depending on the GPS provided timing to do that instead. It has demonstrated limited FIS-B capability, and supports both broadcast and addressed communications. Ongoing efforts to update the "Surveillance" infrastructure of the NAS (along with Communications and Navigation) may result in weather information being included with ADS-B or other broadcasts. If this is so, VDL4 can provide a 19.2 Kbps channel to bring weather to the cockpit.

DISADVANTAGES – VDL4 is primarily an ADS-B datalink and FIS-B capabilities may not be heavily weighted in the upcoming ADS-B datalink decision. If FIS-B is included in the plan for ADS-B, heavy terminal airspace can be served through a dedicated broadcast channel with an appropriate cell size.

3.3.2.5.2 UAT

DESCRIPTION – The Universal Access Transceiver is a MITRE developed system that features an extremely wide bandwidth broadcast system that has been proposed as an ADS-B link. UAT has been demonstrated, and has the capacity to provide both ADS-B and FIS-B, but does not currently have an official set of RTCA supporting documentation or an official frequency allocation.

FUNCTIONALITY – UAT is not planned as a voice radio and is designed exclusively to be an ADS-B link, while allowing for other broadcast applications as well. It is broadcast only, and cannot carry addressed messages such as ATN or ACARS. Due to the digital nature of the radio, however, it could conceivably carry voice signals.

PROVIDERS – One vendor has shown an interest in UAT, and demonstration radios have been built, but no one can yet build a commercial version since the appropriate RTCA or ICAO standards do not exist. Few vendors are likely to spend resources to develop the UAT technology without broad domestic and international support. If UAT were to be selected as the ADS-B link, it is logical to assume that multiple vendors would build and sell UAT radios.

USERS – If UAT is selected as the ADS-B link, nearly all segments of aviation would be expected to equip. GA users, through the voice of AOPA, have indicated they are anxious for low cost, multi-purpose avionics, as well as weather in the cockpit. If UAT is selected as the ADS-B link, the aviation community can expect a large push from GA to make FIS-B available over the same link, since it is capable of providing this service. Airlines, in turn, are likely to support such an effort since it will help populate the sky with ADS-B equipped targets, enhancing safety and efficiency.

IMPLEMENTATION – UAT is currently working in the 960 MHz spectrum, and will occupying a bandwidth of approximately 2 MHz to obtain 1 Mbps raw throughput. Unlike many of the VHF datalink solutions, it will not be "tuned" to different frequencies, but would have access to various time slots within the operating frequency assignment by use of GPS-derived UTC. It uses a TDMA slotted scheme to manage various broadcasts, but also relies heavily on the high capacity of the link to allow for multiple collisions while still getting the message through to the intended receiver.

ADVANTAGES – UAT offers the greatest single-channel throughput, by far, of all the currently planned civil aviation datalinks. It has ample bandwidth to provide ADS-B messages as well as complex weather graphics.

DISADVANTAGES – UAT is a "newcomer" to the ADS-B scene, and is not yet well defined. While Modes S has a current RTCA Minimum Operating Procedures (MOPS) document and VDL4 has a European equivalent, UAT has not begun the process of standards development. Additionally, UAT does not yet have a permanent frequency allocation. Like Mode S, because of the higher operating frequency, UAT has problems with multi-path interference that may make the system unusable on the surface of an airport. While there is significant international interest in Mode S and especially VDL4, UAT is a "US-only" system at the present time. Development of required ICAO standards will likely be an expensive, time consuming (3 to 5 years) process. Additionally UAT has no air-to-air data link capability and no addressed ground-to-air capability.

3.3.2.5.3 Mode S or "1090"

DESCRIPTION – Mode S, or "1090" as it is sometimes referred to, uses the 1090 MHz "squitter" signal associated with the Mode S transponder to transfer other information. It is the third of the three proposed ADS-B links currently under consideration in the Safe Flight 21 link evaluation.

FUNCTIONALITY – Mode S is not planned as a voice radio and is designed to be an ADS-B link utilizing current antennae and wiring on board many of today's airplanes. It is broadcast only, and cannot carry addressed messages such as ATN or ACARS.

PROVIDERS – The airlines are expected to lean toward Mode S as the ADS-B link since they already have 1090MHz capable receivers and transmitters on their airplanes. Nearly any avionics vendor who produces transponder equipment will be well positioned to support a Mode S datalink radio. There is some question about whether the radios, as currently installed, have the power to transmit a signal of sufficient range to make the ADS-B messages useful in a true, high altitude, free flight environment.

USERS – If Mode S is selected as the ADS-B link, then any aircraft desiring to actively use the air traffic system will eventually have to be equipped with Mode S. Initially, this will include at least all IFR traffic, thus focusing on the major airlines, commuter airlines, and upper-end GA.

IMPLEMENTATION – Mode S will operate at 1090 MHz as it currently does for transponder applications. Although the higher frequency used would indicate a much higher throughput, Mode S, as planned, will continue to be tied to the sweep of the surveillance radar. The dwell time of about 5 seconds for each 12 second sweep leaves a throughput of only 300bps. Although adequate for ADS-B, this is not really enough for delivering graphical weather to the flightdeck.

ADVANTAGES – Nearly every airliner in the world is equipped with a Mode S transponder system. Consequently, many airlines hope that if Mode S is selected as the ADS-B link, equipment costs will be minimal. Mode S also has an approved MASPS through the RTCA forum, something neither UAT nor VDL4 share. Although it has limited throughput, if not selected for the ADS-B link, mode S could be useful for downlinking or cross-linking current "in-situ" weather conditions to the ground or other aircraft.

DISADVANTAGES – Mode S, although it has adequate bandwidth to serve ADS-B purposes, does not have the available bandwidth to also provide FIS services if it remains tied to the sweep of the radar. GA does not favor Mode S as the ADS-B link due to its high cost and high power requirements. Additionally, Mode S's high frequency range gives it multi-path problems on the airport which would limit its usefulness for ground traffic management and preventing critical runway incursions.

3.3.3 Voice

As mentioned previously, data is the primary focus of this document. Nevertheless, both digital and analog voice communications will continue to play a vital role in delivering weather to the cockpit. How voice communications are handled as the NAS is upgraded will impact both the frequencies and bandwidth available for data.

3.3.3.1 VHF Voice

VHF is by far the most widely used portion of the spectrum for voice broadcast. It is predicted to remain so in the foreseeable future.

3.3.3.1.1 Navaid Broadcast

Currently, many VORs broadcast weather information via the HIWAS program (See the Phase I report); however, the current NAS calls for decommissioning many VORs over the next 15 years. As this occurs, the HIWAS outlet for AWW, SIGMET, convective SIGMET, CWA, urgent PIREP, etc. information will be replaced. Currently, this information is transmitted on the navigational portion (108-117.975 MHz) of the VHF spectrum.

3.3.3.1.2 VHF Voice Spectrum Broadcast

Some broadcasts, such as ATIS, AWOS, etc. are transmitted on regular voice frequencies (118-136.975 MHz). While many of these products are being digitized, synthetic voice broadcast of the digitized information seems likely to be required beyond the 15 year horizon described in NAS 4.0 due to projected aircraft equipage, especially among GA.

3.3.3.1.3 VHF two-way radio

PIREPs, controller-provided information, contact with airline operations centers, requests to Flight Service Stations, etc. will also continue into the foreseeable future. In many areas the frequencies are already overloaded with such radio traffic which is part of the justification for sending future information via datalink.

3.3.3.1.4 NEXCOM

NAS 4.0 indicates that VDL3/NEXCOM is programmed to occupy the bandwidth made available as VORs are decommissioned. The combination of splitting each 25KHz frequency into two voice and two data channels, combined with using more of the VHF spectrum for voice could nearly, effectively double the available voice channels over the next 15 years, however the effect of co-channel interference is problematic and may severely limit that theoretical maximum.

3.3.3.1.5 VHF Voice Observations

VOR navaids are scheduled to be decommissioned, although they currently serve a vital voice broadcast need. If voice broadcast is continued as a means to disseminate aeronautical information such as ATIS, and SIGMETs, the current VHF voice spectrum will continue to be heavily taxed.

As VDL3 radios come into common usage – especially if and when they do among GA aircraft – the extra voice channels available should help alleviate channel congestion. Moreover, if VDL3 radios do come into common usage, the information that is currently broadcast by voice should be carried almost exclusively by datalink. However, it is by no means clear at present that VDL3 will become widespread enough to eliminate many voice broadcasts. Two-way voice conversations, however, will still be required to perform many of the non-routine communications required today.

3.3.3.2 UHF Voice

UHF voice is primarily a military issue, and it will likely remain so. Generally the military is likely to face the same congestion and allocation issues with UHF as the civilian world faces with VHF

3.3.3.3 HF Voice

Because HF voice is so widespread and relatively inexpensive, it will likely remain in use for some time. As satellite communications become less expensive, and more common, it appears HF voice will go through a protracted, but steady decline. HF datalink has usefulness, but is slow and will probably not grow in the future. Consequently, there appears to be no significant forced tradeoff between voice and data in the HF spectrum in the future.

3.3.3.4 Other Voice

There are a variety of other voice communications theoretically available to the cockpit in the future. At present, only UAT and Inmarsat Satcom are generally recognized as aviation-specific in that they are mentioned in NAS 4.0. Other options are considered in the non-aviation segment of this report.

3.3.3.4.1 UAT

If UAT becomes a viable radio choice, as noted above, conceivably there could be enough bandwidth for voice and data to co-exist, although UAT has been designed specifically for data transmission. As in the VDL3 case, if enough aircraft, especially GA users, equip with UAT radios, datalink will likely become the leading method of broadcasting information. UAT could technically be forced into supporting only broadcast voice, but interactive voice conversations will still be required and performed, though not supported by UAT.

3.3.3.4.2 Inmarsat Satcom

Again, as noted in the datalink portion, Inmarsat enjoys a unique place in the aviation world. With an aviation certified system, they provide a critical link in remote areas of the globe. Even so, the directional nature and relatively higher costs of these established GEO systems will likely minimize their impact on future voice weather dissemination. Inmarsat does not support a broadcast voice mode.

3.3.4 Current & Planned Aviation Communication Conclusions

Combining the concepts and products proposed in Phase I of this report with the plans for the NAS, the capabilities of available aviation datalinks, the requirements levied by future weather products, and the pressure of industry issues leads to a number of conclusions. These are presented here as general conclusions and as specific conclusions that accompany a particular link or mode of operation.

3.3.4.1 General Conclusions

3.3.4.1.1 Data Will Expand to "Fill the Pipeline"

For nearly any communications system that humans have created, the amount of information has nearly always expanded to fill the bandwidth available. In other words, communication bandwidth has historically been the limiting factor in any remote information transmission system from smoke signals to the internet. This trend will almost certainly continue into transmitting any hazard information to the cockpit, including weather.

3.3.4.1.2 Communications ~ the Heart of the Process

Precisely *because* data has historically expanded to fill whatever pipeline has been available, communications becomes the very heart of any information management issue on the flight deck. If we cannot communicate over available pipeline(s) – then there will be no information to manage.

Since communication is the single largest limiting factor, it stands to reason that it *must* play a central role in creating any kind of hazard (including weather) information management system on an aircraft. In other words, communications issues should be a primary consideration in the entire structure of the system, including message formats, compression schemes, product sizing, and multiple other standards.

3.3.4.1.3 Weather ~ the Biggest Drive

Weather is by far the biggest current "hazard" fighting for a place on the flightdeck. Everyone – passengers and pilots alike – has experience with weather. It is in the news every night and has been related to multiple crashes, such as the recent, highly-publicized accident at Little Rock, caused in part by a severe thunderstorm. As the existing popular and political pressure widens the "liability gap," *AWIN activities become the single best place to drive many of the other safety, capacity, and efficiency related datalink issues facing NAS modernization.*

3.3.4.1.4 "Cross-pollination" is required

No one organization or industry activity can stand alone. There is an *urgent need* to recognize the startling information management/human factors issues pilots are about to face. Too many sources, too much data, too many displays and controls, and not enough "information" threaten to overload crews at critical times.

For this "information overload" to be attacked in a systemic manner, a number of cross-pollination" efforts must be started. Weather products, for instance, cannot be developed without consideration of compression schemes, display limitations, geographic locations of transmission antennae, crew training, third party uses, new scientific abilities, certification requirements, users' intentions, etc. All of this points to the necessity for the industry to move positively and quickly away from narrow, "stove-piped," programmatic approaches to a vigorous, "cross-pollinating," functional approach to standards development, building, testing, and implementation.

3.3.4.1.5 Liability ~ an Unpredictable, but Strong Force

As mentioned earlier, *liability is the most unpredictable, but arguably the greatest economic pressure on flightdeck weather that the industry faces.* Every activity designed to bring weather to the flightdeck probably considers the safety, capacity, and efficiency aspects of the effort, but does not give liability its proper consideration. Through a lawsuit, a weather-related accident/incident is likely to propel the lack of weather on the flightdeck into the spotlight. The industry should specifically prepare for this eventuality, otherwise the accelerated interest is likely to have a long term detrimental effect on safety due to the imposition of de facto standards to show "immediate" progress.

3.3.4.1.6 Voice Will Always Remain Important

The best, most recent data and pictures imaginable will never obviate the need for voice contact. In fact, voice will probably eventually compliment real-time and near real-time weather information in the form of a video conference with airline operations or Flight Service Stations. Any development effort that minimizes or forgets about both broadcast and interactive voice will be doomed.

3.3.4.1.7 We Will Have Multiple Datalinks

Multiple missions, histories, geographies, and business models will result in multiple weather datalinks. Users, avionics manufacturers, standards organizations, and providers should all anticipate this.

3.3.4.1.8 Information Parity Among AOC, ATM, and Aircraft is Critical

As now, the future NAS will be built on a triad consisting of the ATM system, an airline's operations center (or GA's FSS), and the aircraft crew. Past experience strongly indicates that when one of these three possesses information not available to the others, misunderstanding and even frustration leads to increased communications requirements and reduced safety, capacity, and efficiency. Information is power, and human nature dictates information parity for maximum organizational effectiveness.

3.3.4.2 Datalink Specific Conclusions

3.3.4.2.1 FIS-B

The FAA's FIS-B datalink concept is useful, but may be limited by its business model. Presently, it is questionable whether there is sufficient motivation for enough users to purchase the value added products that the third parties are able to produce. Another factors is that this effort is aimed primarily at the GA market, and may have limited utility for the airlines. Furthermore, the growing proprietary nature of the FIS-B products may promulgate non-standard, standalone solutions. On the other hand, the standards efforts that the FAA's FIS-B program has begun may ultimately prove useful to the industry.

3.3.4.2.2 ACARS

ACARS is useful, and will remain useful, for limited, addressed, text-based, products to high-end customers. It may provide an eventual growth path for flightdeck weather if the digitized, character-based, transmission, interim standard for VDL2 is dropped and the system migrates to a truly pure digital mode. ACARS and its use will probably remain closely tied to airline operations which will limit its usefulness.

3.3.4.2.3 Inmarsat

Inmarsat's remote connectivity is useful, and will continue to be so; however, its usefulness is limited to that which can be supported by a telephone-type connection. This holds true for both voice and data. The low data rate and non-support of broadcast capability will limit it in delivering future weather products to the flightdeck. It will remain useful for oceanic/remote areas and continue to serve both AOC and ATM functions. Although it is subject to growing competition, Inmarsat's planned speed increases and installed base should keep it viable for this limited aviation use for the foreseeable future.

3.3.4.2.4 ATN

ATN is a robust system designed specifically to support addressed messaging in a complex, mobile-user environment. While it does this well, it will probably be too expensive for the airlines (or other users) to employ for more mundane tasks. This indicates that users or suppliers will carefully choose which products to route over ATN. Its required message overhead, likely usage cost, and non-support of broadcast capability make it an unlikely choice for supporting future weather products on the flightdeck.

3.3.4.2.5 VDL2

VDL Mode 2 is useful for delivering current and future weather products to the flightdeck. It is appearing now, has good speed, supports broadcast, and supports multiple protocols. It does need some frequency planning, however, due to the need for a clear guard channel on either side of a high speed datalink connection. Additionally, weather uses for VDL2 are in competition for other uses of this link, such as ATM messaging, ACARS, etc.

3.3.4.2.6 VDL3

VDL Mode 3 could be useful for future weather product delivery to the flightdeck, with major caveats. Attractive because it supports both voice and data, it has decent speed, especially if data lines are "trunked," but needs fairly extensive frequency planning as now being demonstrated due to the requirement for 3 to 4 clear "guard" channels. Although the intent is that a VDL3 radio will be just a "software update" from a VDL2 radio, history shows that this is not always so.

3.3.4.2.7 Mode S

Mode S is probably not useful for delivering future weather products to the flightdeck. Mode S does have an official MOPS and appears to be the current front-runner in some circles for selection as the ADS-B link; however, when tied to the radar sweep, Mode S has too low an effective rate to do both ADS-B and FIS type services. If Mode S is *not* selected as an ADS-B link, it would be available under certain circumstances for broadcasting weather products to the flightdeck.

3.3.4.2.8 UAT

UAT is potentially very useful for delivering future weather products to the flightdeck, with major caveats. Since UAT was designed from scratch to support ADS-B and other broadcast applications, it has the theoretical bandwidth to support the future products proposed in Phase I of this report. However, it does not yet have an officially assigned frequency and is far behind in the technical development for standards as compared to VLD4 or Mode S. If UAT can overcome these significant hurdles, it would be an attractive source for delivering future weather products to the flightdeck.

3.3.5 Current & Planned Aviation Communication Recommendations

Although this report primarily considers weather transmission, it also recognizes that weather is only one specific manifestation of a "hazard." Consequently, although the following recommendations specifically apply to transmitting weather to the flightdeck, they also apply to doing the same to nearly any hazard an aircraft faces.

Specific recommendations are split into five major categories:

- General Recommendations Affecting All Communications
- Setting progressive Standards using Communications Leverage
- Constructing an Information Datalink Paradigm
- Safely Conserving Bandwidth
- Improving Certification

3.3.5.1 General Communications Recommendations

Some recommendations are pervasive and do not easily fall into categories. These are termed "general." This is not to say they are not important, in fact, they may be the most important as they embody the widest raging impacts.

> ***Promote the concept that human factors issues surrounding information synthesis/integration/management is a large, if not the largest, safety aspect of the flightdeck in the near future.***

As in other areas of our society, the flightdeck faces an information "explosion." Managing that information in a safe, effective manner is rapidly becoming a major issue. Multiple screens, symbols, sources, colors, aural alerts, etc. all threaten to overload pilots at critical times. Data *must be integrated* into information, filtered, displayed, packaged, and transmitted with this understanding in mind.

Promote the concept that the heart of handling these human factors issues is communications.

Communicating the data and information that the flightdeck requires is at the very core of the information management problem. If the data is not packaged and transmitted in a manner conducive to easy and rapid integration and manipulation, it may be rendered useless. Similarly, if data is not packaged and transmitted in a way conducive to further integration, the flightdeck may be inundated with data, but unable to access meaningful *information*.

Work closely with other appropriate organizations including RTCA, SAE, ALPA, AOPA, etc., and their international equivalents.

The communication/information management problem has a political dimension at least as large as the technical one. There are multiple organizations representing many stake holders in the national and international arena. NASA should promote the necessary coordination required to bring both a political and technical solution to fruition.

Anticipate that severe liability issues will unpredictably accelerate or otherwise affect all weather (and other hazards) on the flightdeck programs.

Exact predictions are difficult; nevertheless it seems likely that specific events could trigger lawsuits that have a dramatic effect on information flow to the flightdeck – especially hazard information such as weather. The effect might be a hurried certification of a particular display solution, compression technique, datalink, area of regard, required resolution, specific product, etc. Every single activity that is undertaken should bear in mind the constant threat of the current "liability gap" that threatens commercial operations as long as graphical weather information is not available, or is limited, on the flightdeck.

3.3.5.2 Setting progressive Standards using Communications Leverage

As the industry comes to grip with the wide-ranging general recommendations, the next logical step is to narrow the focus. Standards affect *everything* that has to do with transferring, and therefore, archiving, manipulating, displaying, and using weather (and other hazard information) on the flightdeck.

Precisely because communications is at the heart of the human factors issues surrounding the explosion of information that must be managed, NASA should use their leverage to instigate the setting of progressive standards in *all areas* concerning hazard information on the flightdeck.

Promote the concepts in Phase I to help focus and direct the setting of standards.

Defining exactly the line between "tactical" and "strategic" weather information is a key standard for weather on the flightdeck, and it may even have ramifications concerning other hazard information. Furthermore, promoting the concept of "near-term" strategic versus "far-term" strategic requirements and uses will help focus industry activities, development, etc. Finally, maturing the concepts from Phase I of this report will have profound impacts on where, when, and how weather information is transmitted from the ground to the air, and vice versa.

Aggressively promote industry and world-wide standards for Open Architecture weather/hazard systems, including:

Synthesizing and processing data into information: Current and future flight decks are in increasing need of *information,* not data. Creating information from data can be a difficult and complex process; displaying it is even more difficult. Embedded in integrating, synthesizing, and contextualizing facts into decision-aiding information are assumptions concerning that processing. These assumptions include where it is done, how often it is accomplished, how much is displayed, and how often it is updated. *Every single one* of these and other background assumptions has an impact on the transmission of data/information to and from the aircraft. Constantly, in every step of maturing weather information on a flightdeck, the industry must consider its need to furnish information, and not simply more data, to flight crews.

Data / information gridding: In order to synthesize weather data to produce information, the data need to be gridded in some fashion. Looking beyond simply integrating weather requirements, *all hazard* data should be gridded in a consistent way so they can be integrated into new, synthesized products. Although gridding can locally increase the amount of data to be sent, in a more global perspective, it will actually reduce the strain on communications by allowing common referencing, compression, etc.

Data / information indexing: Indexing is also on the critical development path from supplying facts to providing a flight crew with information. Moreover, it can also serve as a kind of compression for those items that lend themselves to indexing, as it reduces the amount of information that must be transmitted.

The formatting of messages carrying gridded, indexed information: This is perhaps the fulcrum of the communications lever that can help set progressive industry standards. Without delivering data and information to the aircraft, there will be none to synthesize and display. As the issues above are being resolved, a common, open format for weather (and other hazard information) will help foster competition, keep prices down, and maximize usefulness. Intelligent formatting will provide the ability to compress the data to the maximum amount possible.

Consider influencing the industry to move toward a system that efficiently manages "bandwidth," not just "frequencies."

World spectrum management bodies have proven to be no friend of aviation in recent times. Extreme pressure from the mobile communications industry has successfully encroached on aviation frequencies internationally, and even here in the US. It has become evident that aviation has all the spectrum it will be assigned – and even the frequencies for some basic items like ILS and VOR are under siege in some arenas. This makes it imperative that our own industry manage the frequencies we are allocated very effectively. Multiple "spread spectrum" technologies are available to use assigned spectrum more efficiently than we do today. As the industry gravitates toward these new techniques and methods, there will be a subtle, but abiding shift from our current "frequency" mentality to a "bandwidth" one. NASA should play a key role in helping the aviation industry move solidly in that direction.

3.3.5.3 Constructing an Information Datalink Paradigm

As the general foundation is being established, and proper common, open standards are being set, attention can finally be turned to the datalink itself. Without the preliminary work, however, the following datalink issues will be difficult if not impossible to solve:

> ***Study, predict, and promote the appropriate mixture of "broadcast" and "request/reply" products for given aviation segments, missions, conditions, arenas, flight regimes, etc.***

Currently, there is little understanding of the interplay between broadcast and addressed products. There is little to no research upon which to base a business model for developing a network that includes both. There are opinions, but no evidence to suggest how differing mixtures affect the financial, safety, flexibility, capacity, etc. of any operation. This area represents, perhaps, the best opportunity for future research.

> ***Research and promote the thoughtful integration of voice with datalinked information.***

It seems certain that voice will always be important in *any* human communications system. Given that, the integration of datalinked information with voice is still an open issue. One has a clear and definite impact on the other, and is, again, an area available for research.

> ***Research and promote the appropriate use of TCP protocols for non-critical weather products.***

TCP is a growing juggernaut. Ten years ago, few knew what the internet was, and even fewer used it. Today, nearly everything we do is touched by the internet in some way – and it has dramatically changed the way our information is formatted throughout society. Not surprisingly, weather information is easily available and transmitted via the web.

There is already growing pressure to use TCP protocols to deliver both broadcast and addressed information to the flightdeck even though there is little knowledge describing when and how this is appropriate.

Develop and promote appropriate, progressive boundaries concerning:

"Boundaries" are important. They imply all manner of integration issues in the interface between and among areas. These include boundary shapes, repeated or missing data, multiple station reception, data update rates within specific areas, conflicting resolutions at the dividing line, areas of overlap in geography and/or time, certification issues, etc. All these and more are endemic in describing and setting the boundaries listed below.

- Enroute, Far-term strategic boundaries
- Enroute, Near-term strategic boundaries
- Terminal, Tactical boundaries

Develop and promote standard, hazard broadcast communications methods to deal with:

Remembering that weather is only one manifestation of a hazard that can affect an aircraft, there are a number of standard issues that will have to be resolved in delivering that hazard information to the flightdeck. These include:

- The potential of receiving multiple broadcasts in a single location
- Anticipating, handling, and preventing data dropouts
- Notifying users that data dropouts have occurred
- Allowing formerly missing data to be filled in during subsequent transmissions

Consider other methods of combining Near-term Strategic, Far Term strategic, and Tactical information, such as varying the fidelity of a single product centered at the transmission location.

If the industry is successful at gridding and indexing all weather information, the need for discrete products may wane. For instance, if the nation or planet can be described in a multi-dimensional grid (at least four dimensions), then it should be possible to transmit a unique product at each transmission location. Such a product might have very high fidelity in the vicinity of the transmission, and gradually lose fidelity with increasing range from the point of observation or transmission. As an aircraft flew it would always have the needed fidelity to make near-term and far-term strategic decisions. Obviously, this is just one of many methods to take advantage of a fully integrated, gridded, indexed hazard observation and prediction system.

3.3.5.4 Safely Conserving Bandwidth

No matter what datalink issues are addressed and resolved, it will be imperative to conserve bandwidth, our fundamental limiting factor. Efforts to do so, however, must always include safety considerations first.

> ***Aggressively work to allow "lossy" compression in appropriate arenas and regimes.***

The proposed MASPS from SC-195 will not allow lossy compression for FIS products. This seems overly conservative, since far-term strategic decisions do not need a great deal of fidelity. The NEXRAD pictures that are being proposed for broadcast are essentially *already* compressed before they are sent. If this "no lossy compression" restriction is not eased, it may squander valuable bandwidth while providing no added value.

> ***Aggressively work to define the appropriate degree of "lossy" compression in various arenas and regimes.***

Simply allowing lossy compression in certain areas is not enough. The industry must support research into when and how compression can be used in a lossy manner – safely and effectively.

> ***Develop maximum compression techniques for the standardized message format and datalink used.***

After deciding what the message format is, and to what degree, if any, it can be "lossy," maximum compression techniques should be brought to bear.

> ***Promote the creation of products, grids, and indices that integrate and compress well.***

Part of deciding how to create the messages, grids, and indices ought to take into account the need for compression. There will likely be tradeoffs in specific products, boundaries, grids, indices, etc. in order to archive higher compression techniques to maximize safety and throughput.

> ***Consider promoting an official "piggyback bandwidth tax" for passenger entertainment services to provide a pipeline to the flightdeck.***

The largest *direct economic* motivation for supplying information to the aircraft is centered in passenger entertainment and business communications. NASA should work with the FAA, FCC, and others to reserve some of the bandwidth that is ultimately destined for these applications to allow for a "safety" pipeline to the flightdeck. If, for instance, 10% of the passenger bandwidth dedicated to an airplane is reserved for the flightdeck, bandwidth for safe efficient operation of the flight would always be available.

Studies would be required to determine how much bandwidth is needed, how it could be reserved, etc.

3.3.5.5 Improving Certification

All certification issues affect communications to and from the aircraft either directly or indirectly, and even with a solid set of standards and technical solutions in place, problems remain. The single largest factor involved in deciding whether to increase safety through upgrading ground and air infrastructure is the pure cost of doing so. The lion's share of that cost lies in certifying new processes and equipment. It is arguable that safety has actually been compromised by the cost and complexity of the certification process itself. The net result has been that some useful information is completely unavailable to the flightdeck in the name of improving the accuracy or integrity of the data to be used in making decisions. The public and air crews are finding it more and more unacceptable that information widely available to laymen on the ground, *and even in the cabin of an aircraft,* is not available to the flightdeck. This can be addressed in the following manner.

> ***Aggressively work with the FAA and RTCA on updating, improving, and streamlining the certification process for communications and software. Focus on:***

Eliminating inconsistent practices among offices: FAA offices differ in their interpretations among themselves, and even among the people within a single office. Vendors, airframe manufacturers, avionics suppliers, etc. should be able to get consistent answers to certification questions no matter whom they speak with – and certainly should not have well-researched decisions reversed at a later date when another office/person reviews the same or a similar question.

Improving questionable decisions that make increases in safety unaffordable in the name of safety, itself. Safety should be viewed from a system level. This implies that a system of any kind that raises the level of safety should be very strongly considered for certification. If, for instance, the weak link in a weather delivery system is a communications link that has data dropouts at random intervals, *this is not a reason to prevent certification.* Some correct weather information is better than no weather information in most instances.

Setting solid, but flexible precedents: As we mature new standards, such as developing and delivering weather products to the flightdeck, we explicitly and implicitly set precedents. These precedents often evolve into desired practices and ultimately into requirements. The industry must take care to set solid, deliberate, and flexible standards that will be able to grow with time. This is one area of great risk in the event a lawsuit forces the rapid deployment of an immature system.

> ***Aggressively work with the FAA, RTCA, etc. to logically and effectively define "Strategic" and "Tactical" weather information in the context of this report.***

This is a specific precedent that has a fundamental influence on the way weather (and possibly other hazard information) is integrated, synthesized, delivered, managed, and presented on the flightdeck. The line between tactical and strategic is fraught with certification implications. Also, it stands to reason that the terminal, tactical boundary should be drawn as close to the destination airport as practical.

> ***Aggressively work with the FAA, RTCA, etc. to logically and effectively define "Near-term Strategic" and "Far-term Strategic" weather information in the context of this report.***

Assuming that the line between tactical and strategic can be drawn in a reasonable and useful manner, a similar line may have to be fashioned between the near-term and far-term strategic arenas. Again, placing this boundary sets a precedent the industry will live with for the foreseeable future.

> ***Anticipate and work to avoid excessive certification requirements for the datalink of graphical hazard (weather) information, especially in the "Near-term Strategic" arena.***

Once the near-term strategic area is defined, the FAA will be faced with related certification decisions. If these requirements are too strict, the products and resulting capabilities may become too expensive.

> ***Anticipate the growth of personal (versus mounted) displays. Prepare to help develop and certify:***

Due to a number of pressures, primarily cost, personal displays separate from the aircraft are appearing in all areas of aviation. This has already begun to create some unique challenges, such as those listed below. These require special and nearly immediate consideration.

- Reception of wireless signals for stand-alone units that include both FIS and TIS.
- Wireless communications among personal units on the flightdeck and in the cabin.
- Wired communications among personal devices that are independent of the aircraft.
- Varying levels of interaction with flightdeck communication systems.

3.3.5.6 Aviation Solution Recommendation Summary

Weather is only one specific manifestation of a "hazard" to an aircraft. Creating, transmitting, manipulating, and displaying hazard information is a growing human factors issue that has communications at its heart. Since transmitting weather hazard information enables all the other areas, it is the *sine qua non* of the entire hazard-display-on-the-flightdeck issue. NASA should use the communications aspect of weather on the flightdeck to drive general improvements, progressive standards, an information datalink paradigm, the safe conservation of bandwidth, and improved certification for required systems.

3.4 Potential Solutions from Non-Aviation Communications

As seen above, current aviation communication systems and those planned for the future offer a variety of methods for getting weather information to the cockpits. It is also apparent that there is no one-size-fits-all solution. Some products are well served by current and emerging communication systems but other products that are needed now and are likely to result from on-going weather research will overload even the most capable aviation communication systems. The solution may be to look outside the aviation industry for technologies to augment aviation communications in supporting weather information distribution. This portion of the study was performed to *"identify and evaluate specific existing communications technologies, techniques and services which are not currently applied to aviation but could offer potential technical solutions enabling the efficient delivery and use of tactical and strategic weather data and tools."*

The specific systems and technologies that were investigated include:

- Cellular / PCS Telephone Technology
- MMDS / LMDS
- Satellite - Digital Audio Radio Services (S-DARS)
- Satellite Based Data Communications
- Software Defined Radios

3.4.1 Cellular / PCS Telephone Technology

The cell phone industry has grown significantly since the introduction of mobile hand held telephone systems in the late eighties. Initially, these systems were analog voice modulated carriers but are rapidly transitioning to digitized voice systems that utilize complete digital processing and routing techniques.

Two distinguishing characteristics of a cellular telephone system that are different from earlier mobile radio phones are the Cell and Tracking / Hand-off techniques. These two concepts allow mobile users to move beyond the basic range of the radio link without interruption of service. These two concepts and the essential elements are shown in Figure 11.

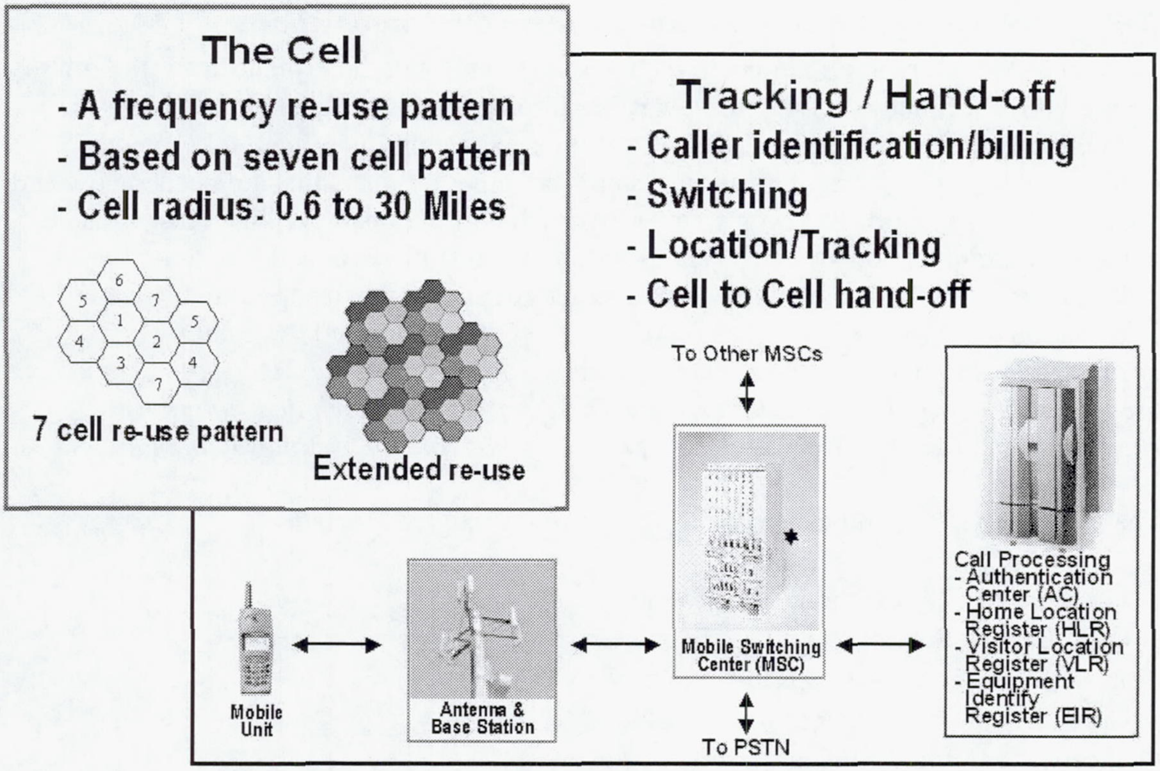

Figure 11. Essential Elements of a Cell Phone System.

The basic cell arrangement is a seven cell pattern which allows frequencies to be re-used without interference between adjacent cells. This basic pattern is repeated as often as necessary to cover the defined area using the frequency spectrum allocated for the type of telephone service.

The Tracking and Hand-off functions allow mobile users to be identified and served throughout the service area. These essential functions include: the Mobile Unit (cell phone), the Antenna and Base Station (at least one per cell); the Mobile Switching Center and the Call Processing Center. The Antenna and Base Station provide the radio link to mobile units within the cell and route information to the Mobile Switching Center. The Mobile Switching Center routes call initiation information to the Call Processing Center for user identification, billing, etc. then to the called party either through the public telephone switching system (PSTN) of another mobile switching center.

3.4.1.1 Cellular or PCS?

The original allocation of frequency bands for PCS was distinct from the cell phone industry and intended to create new technology to support personal communications of all types. The distinction between the terms *Cellular Phones* and *Personal Communication Systems (PCS)* is becoming somewhat blurred however. Generally, mobile phone system operating in the 800/900 MHz band are considered cellular phone systems while Personal Communication Systems (PCS) are mobile phone systems operating in the 1.9 GHz band. The distinction between the two terms is more than just semantics since the FCC has restricted the sale of spectrum and service areas based on a complicated set of rules designed to foster competition. Cellular and PCS services areas cover overlapping geographical regions.

3.4.1.2 Cellular Phone Systems

The Cell phone industry began in the United States in 1981 when the FCC adopted rules creating a commercial cellular radio telephone service. Geographical regions were identified and two 25 MHz bands for each region were allocated for cell phone service. One 25 MHz band was allocated for wireline (phone companies), and one for non-wireline to stimulate competition. The first commercial cell service began in Chicago in 1983.

3.4.1.3 Personal Communication Systems (PCS)

The FCC allocated PCS RF spectrum and began auctioning space in the band on December 5, 1994 - *to foster creation of new radio communication services that allow individuals to communicate anywhere at anytime*. Two PCS types were defined: narrowband and broadband. Three one MHz bands were allocated at 901-902, 930-931, and 940-941 for PCS narrowband to support advanced paging services. Six broadband PCS bands in the 1850 - 1990 GHz range were allocated for voice, data, and video services. The allocation consisted of three 120 MHz blocks and three 10 MHz blocks.

The type of communication service was not specified in the FCC ruling in an attempt to stimulate new technology. Winning bidders were free to decide how to use the spectrum in the regions they had purchased. The spectrum has been used primarily for higher performance voice phone system, however. Some of the cell phone like systems that have been established using the new spectrum allocation include, PCS1900, a USA version of GSM operating in 1.9 GHz band as well as upbanded AMPS, N-AMPS, D-AMPS, and CDMA.

The first commercial PCS service began in Washington DC in November 1995.

3.4.1.4 Cellular / PCS Mobile Phone Standards

Today there are numerous standards being used to provide cell phone service. These are generally considered first generation if they are based on an analog standard and second generation if they are all digital.

The dominate standards representative of each generation include:

<u>First generation:</u>

- **AMPS** (Advanced Mobile Phone Service): Analog system introduced in 1983. TIA Standard IS-41.
- **N-AMPS** (Narrowband AMPS): 1/3 bandwidth, 3x channels

<u>Second generation</u>

- **D-AMPS** (Digital AMPS) : TDMA implementation using same frequency and control system as AMPS. TIA Standard IS-54.

- **CDMA** (Code Division Multiple Access): TIA Standard IS-136
- **GSM** (Global System for Mobile Communications): Standard used throughout Europe.

3.4.1.4.1 Advanced Mobile Phone Service (AMPS)

AMPS is an analog system introduced by AT&T in 1983. It is based on a 25 MHz chunk of spectrum in the 824-849 band. The 25 MHz is divided into 30 KHz sub-bands with send/receive on separate sub-bands separated by 45 MHz to avoid interference between send / receive channels. FM modulation and FDMA Multiple Access are used to allocate 416 channels in a seven (7) cell re-use pattern. This allows up to 59 simultaneous calls per cell. The cell sizes used in AMPS systems range from 0.6 to 30 Miles.

Variations in the AMPS system include Narrowband AMPS (N-AMPS) which divides the 30 MHz band into 10 KHz sub-bands to increase the number of users supported. Digital AMPS (D-AMPS) is a digital version of AMPS that uses the same frequency band but uses FDMA and TDMA for multiple access within a cell. D-AMPS systems are also called "TDMA" for this reason. The 30 KHz sub-bands are divided into 3 or 6 TDMA slots as another way to increase the number of users supported.

E-TDMA is a system which uses dynamic time slot allocation to take advantage of the "dead time" on half the channel when a user is listening. Through dynamic allocation of time slots, this time is reused for other conversations. However, this only improves throughput for "polite conversations" where only one person talks at a time.

3.4.1.4.2 Code Division Multiple Access (CDMA)

CDMA, also known as CDMAOne™ is a cell phone system that uses spread-spectrum technology to allow multiple users to share the same spectrum. The standard for CDMA (IS-95) was adapted in 1993 and first commercial service began in 1995.

CDMA uses the same frequency band as AMPS (800 MHz). Unlike AMPS which divides the spectrum into different subbands for individual call, CDMA systems spread each call over a 1.28 MHz band using a Direct Sequence (DS) form of spread spectrum. The number of users that can be supported by a given bandwidth of spectrum is about 8 times that for a typical AMPS system though the actual number of calls support is a dynamic trade-off between system noise and voice quality. As the ambient noise increases, the system has the option of lowering voice quality by using fewer resolution bits or limiting user access.

In CDMA systems, both timing and power control are critical. Stations are synchronized using GPS timing and mobile units get their timing references from the stations. Power in mobile units is precisely manage by a closed-loop feedback system from cell stations.

An advantage claimed by proponents of CDMA is the provision for soft handoff. Mobile units can receive from multiple stations at the same time and select the best signal. As the mobile unit moves between cells it constantly selects from the best of several signals. The result is a smooth transition from cell to cell.

Variations of CDMA are being used in the higher frequencies of PCS and are under development for so called 3rd generation cellular. CDMA2000 and W-CDMA are implementations being developed for the next generation of cell phones.

3.4.1.4.3 Global System for Mobile Communication (GSM)

GSM is fast becoming the de facto European digital cell phone standard. In fact it was designed to be just that. GSM began commercial service in 1991. In addition to voice telephony, GSM supports FAX and Short Message Services (SMS).

GSM uses 890-915 MHz for uplink and 935-960 for downlink. Both TDMA and FDMA are used for multiple access. 124 carriers frequencies spaced 200 KHz apart are each divided into 208 TDMA channels or 0.577 ms *burst periods* as they are called.

Mobile units exercise power management to reduce interference and to conserve battery power. Bit-Error-Rate (BER) is monitored to increase or decrease power as necessary.

A distinguishing feature of GSM is the separation of network and subscriber information. Both the mobile unit and the user have a distinct identification number. The user ID is contained in a Subscriber Identification Module (SIM) which can be moved from handset to handset as well as to computers and pagers.. The SIM contains the user identification code and provides for authentication and billing.

Variations of GSM include DCS1800 which is a 1.8 GHz version used in Europe and PCS1900, a 1.9 GHz version used in the USA.

3.4.1.5 LEO/MEO Satellite Extension to Cellular

The emerging voice telephone satellite systems such as Iridium and GlobalStar offer services very similar to cell phone. In fact they are becoming extensions to the cell phone communication systems that allow world wide roaming.

Iridium is a Low Earth Orbit (LEO) system of 66 satellites providing digital voice as well as FAX and pager communication services. Handheld mobile units communicate directly to satellites using the 1616 - 1626 MHz band. In Iridium, the frequency reuse function of the cell is replaced by spot-beams and switching and handoff is performed by processing on-board the satellite. Some Iridium mobile units allow GSM customers to use their SIM modules in Iridium handsets to gain access to the Iridium system. The SIM provides for authentication and billing through the user's GSM account.

GlobalStar is a constellation of 48 LEO bent-pipe satellites that operate in the 1610-1626.5 MHz band for uplink and 2483.5-2500 MHz band for downlink. GlobalStar is a CDMA system compatible with the IS-95 standard. User-terminals for the GlobalStar system are dual or multi-mode, allowing interoperability between satellites and terrestrial systems such as AMPS, GSM and PCS1900. Mobile units first try to connect through existing cellular networks and, failing that, connect through the satellite system.

3.4.1.6 Future Cell Phone Systems - Universal Mobile Telephone System (UMTS)

A future cell phone technology system called the Universal Mobile Telephone System (UMTS) aims to expand the capabilities of mobile telephony into high speed data and video media as well as voice. UMTS is a European led initiative to define the next (third) generation of global cellular. The UMTS forum was created in 1996 for defining standards and procedures and to encourage industrial cooperation. The forum has over 190 members representing "who's-who" in mobile communications.

The UMTS system will utilize part of the International Telecommunication Union (ITU) IMT-2000 family of bands (1885-2025 MHz and 2110-2200 MHz) allocated by the World Radio Conference (WRC) in 1992 for high capacity, high data rate terrestrial and satellite mobile telecommunications. The 1980-2010 and 2170-2200 MHz bands were set aside for satellites communications. Europe and Japan are using 1920-1980 MHz paired with 2110-2170 MHz for UMTS terrestrial.

UMTS will employ multi-mode/multi-band audio/visual terminals with voice and packet data communication (DETC, AMPS, GSM, DCS1800, PCS1900, UMTS, GlobalStar). W-CDMA will be used for multiple access.

A family of cell types are being defined to support different data rates as allowed by available spectrum and technology. As shown in Figure 12, these include: Home-cell, Pico-cell (in-building), Micro-cell (urban), Macro-cell (suburban), and Satellite (global). The transmission rate that will be supported based on the type of communication cell is: 2,048 Mbit/s (home/pico/micro), 384 Kbit/s (micro/macro), 144 Kbit/s (full mobility).

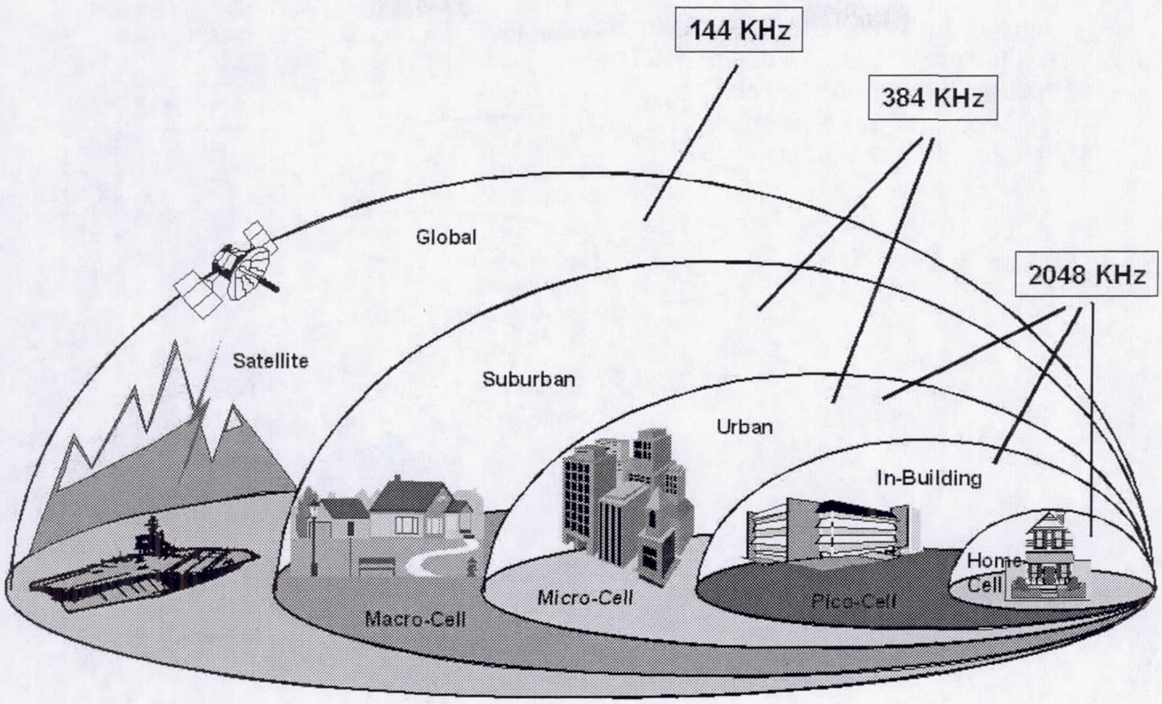

Figure 12. Universal Mobile Telephone System Cell Definitions

The UMTS is expected to be in place by 2004 and spectrum is currently being auctioned off to service providers throughout Europe.

3.4.1.7 UMTS Applied to Aviation Communication

Based on the list of members of the UMTS Forum, there seems to be very little interest from the aviation community in UMTS for air-ground communications. The performance anticipated for the system would provide for weather information to the cockpit and an effort should be made to assure that aviation is included in the development and planning of the system. Figure 13 shows a potential aviation extension to the structure and definition of cell types.

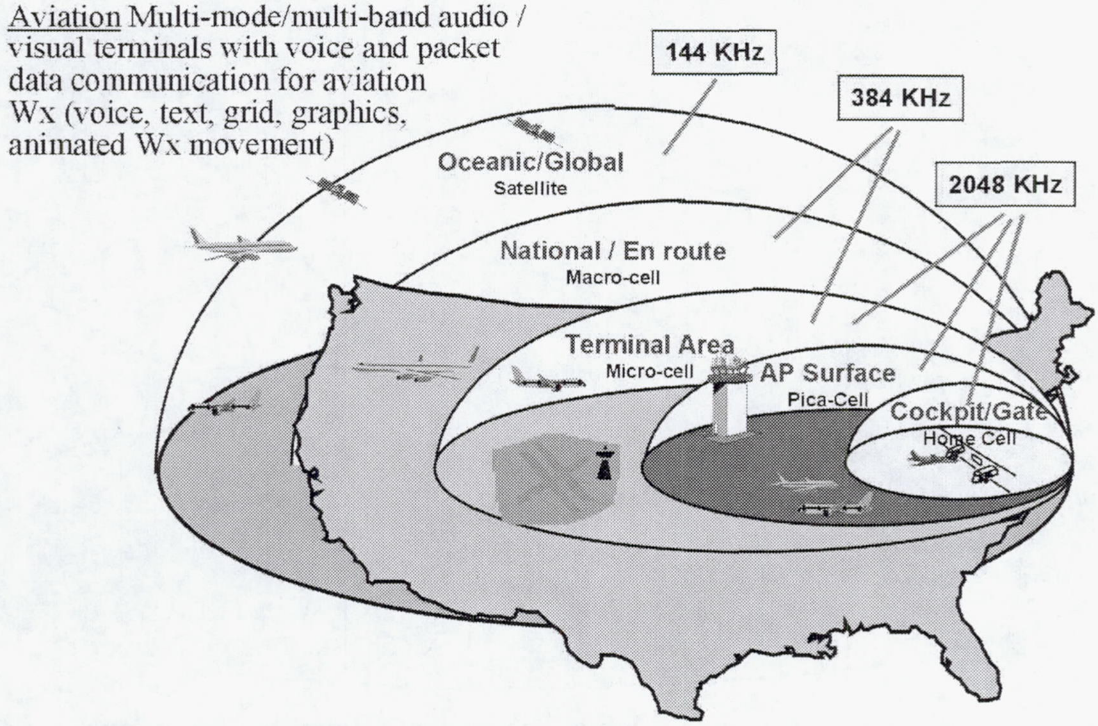

Figure 13. UMTS Cell Definitions Applied to Aviation

3.4.1.8 Aviation Weather Applications for Cell / PCS Phone Technology

If cell phone technology was available in the cockpit a number of sources of weather information would be made available. These include all the sources that a pilot currently has for getting information over the terrestrial telephones such as FSS/AFSS and some ASOS installations. In addition, those sources of weather graphics currently available via FAX would be accessible. With a lap top and a modem attached to a cell phone, a wide variety of internet sites that provide aviation weather would be available to pilots.

Having available computer/modem/cell phone combination opens up many possibilities for enhancing weather information for pilots. An example might be a software system aware of the flight plan that periodically retrieves weather information along the route. The process could be automated to get weather updates much like most e-mail systems are designed to contact the mail server for new e-mail on a regular basis. Such a system could check for changes to forecast weather in the flight plan and alert the crew if there is potential danger ahead. Weather databases could be designed to update a revision code if there are major changes so airborne systems would not have to download new weather files if the forecast revision has not changed since the last download.

Automated dialing and canned messages have been used in telephone advertising for years. Weather warning systems could be designed to automatically call each plane in a danger zone to provide weather condition alerts.

3.4.1.9 Cell Phones in the Cockpit

Cellular phone systems are already finding their way into the cockpit. The Allied Signal AIRSAT™ system is a low cost cell-like system for accessing the Iridium network of satellites from the cockpit. Another cockpit telephone system that is actually a cell phone in the cockpit is the AirCell system.

3.4.1.9.1 Airborne Cellular Telephone - AirCell™

In December, 1998 the FCC approved a "*waiver*" to allow operation of specially designed airborne cellular telephones in the same 800 MHz band as terrestrial cellular systems - but on a secondary basis. The FCC made their decision in spite of much opposition from ground-based operators because of the potential safety benefits of the airborne system. The safety aspects were supported by recommendations from the NTSB, FAA, NBAA, AEA, AOPA.

In the FCC decision, the waver is actually granted to terrestrial cell phone operators rather than AirCell. AirCell must *partners* with these service providers to support airborne cell phones and partnerships are being established across the US.

The types of services offered include voice telephony, FAX and digital data (Internet). The airborne units cost from to $3k to $7k and weigh from 2.9 to 5.6 pounds. There is a monthly fee of $39.95 and a $1.75/min air time charge.

The AirCell system differs from regular ground based cell systems in several ways to avoid interference from high altitude transmissions.

- Airborne cell phone signals can only be received at sites with specialized antennas.
- AirCell antennas must be located in rural areas with low background noise.
- Power levels are dynamically controlled and must be lower than the noise floor specification for primary service.
- The antennas use horizontal polarization instead of vertical polarization used by ground cell systems.

The following conditions are summarized in the December 24, 1988 FCC order regarding the AirCell Inc. request for a waver:

<u>GROUND STATIONS</u>

- located in rural, low-noise areas
- use of low-loss components to maximize receive sensitivity
- transmitter effective radiated power does not exceed 500 Watts
- typical service range to airborne terminals is 135 kilometers (84 miles)
- uptilted antenna is employed
- electromagnetic waves emitted are horizontally polarized

AIRBORNE MOBILE TERMINALS

- transmitter is permanently installed in the aircraft
- installation is inspected by authorized representative of manufacturer
- transmits only when in communication with a ground station
- unintended interoperation with co-block cellular base stations is prevented
- transmitter output power is dynamically controlled by ground station
- transmitter output power never exceeds 19 dBm (80 mW)
- transmitter output power rarely exceeds 11 dBm (12.5 mW)
- uses external permanently installed antenna
- antenna is essentially omnidirectional in the horizontal plane
- antenna exhibits conical null directly below aircraft
- electromagnetic waves emitted are horizontally polarized during normal flight
- incorporates standard cellular telephone for use only when aircraft on ground

3.4.1.10 Needed Technology and Recommendations

The safety and economic benefits of having cell phone technology available in the cockpits of G/A aircraft has been demonstrated by the success of the AirCell system and the overwhelming support received from the FAA and NTSB among others to get approval for the system. As analog cell phones gradually get replaced with digital systems, though, the future of cell phones for airplane use remains uncertain. To assure that mobile communication will be as readily available to airborne users as it is for ground mobile users, research is needed in airborne applications of digital cellular phones and PCS systems, particularly systems using CDMA.

Another area of aviation cell technology research that would help to extend cell phone benefit to aviation users is the development of aviation approved multi-mode, multi-band mobile units that interoperate between ground cellular and LEO/MEO satellite systems. A major limitation of cellular use in the cockpit is the lack of availability of ground stations under certain circumstances. Having the alternative of using ground cellular when it is available and going to satellites when it is not would greatly increase the safety and economic value of this communication option to aviation users.

Based on the investigation of cellular and PCS, the areas where opportunities for NASA to perform research to benefit aviation safety through improved communications include the following:

- Coordinate USA involvement in the Universal Mobile Telephone Systems (UMTS) development to assure aviation opportunities are realized.
- Fund research in digital cell phone technology for aviation applications (interference, power levels, CDMA airborne applications)
- Develop aviation multi-mode receiver technology to interoperate between cell and satcom, voice and digital applications (GSM, PCS1900, LEO/MEO).

3.4.2 Microwave Distribution Systems

Several systems have been used to distribute television and provide interactive services to business and residences using microwave links rather that cable or fiber optics. Two of these evaluated for their potential for aviation weather applications are the Multi-channel, Multi-point Distribution System (MMDS) and the Local Multi-point Distribution System (LMDS).

3.4.2.1 Multi-channel, Multi-point Distribution System (MMDS)

Multi-Channel Multipoint Distribution Service (MMDS) is a digital wireless communication system designed primarily as a distribution system for cable television. It operates in the 2.2 - 2.4 GHz band. At this frequency, line-of-sight between antennas is required and repeaters are implemented to work around obstructions such as buildings and terrain. Antennas are usually about 15 miles apart.

MMDS was a predecessor to Direct Broadcast Satellite (DBS).

3.4.2.2 Local Multi-point Distribution System (LMDS)

Local Multipoint Distribution System (LMDS) is a broadband fixed wireless point-to-multipoint communication system that operates in the 28 GHz band. It uses a cellular like implementation to provide line-of-sight internet access, videophone, video conferencing and Pay-Per-View cable television. It uses cells sizes with a 2-4 mile radius. It offers potential data rates of up to 1.5 Gbps. Figure 14 shows the components of a LMDS system.

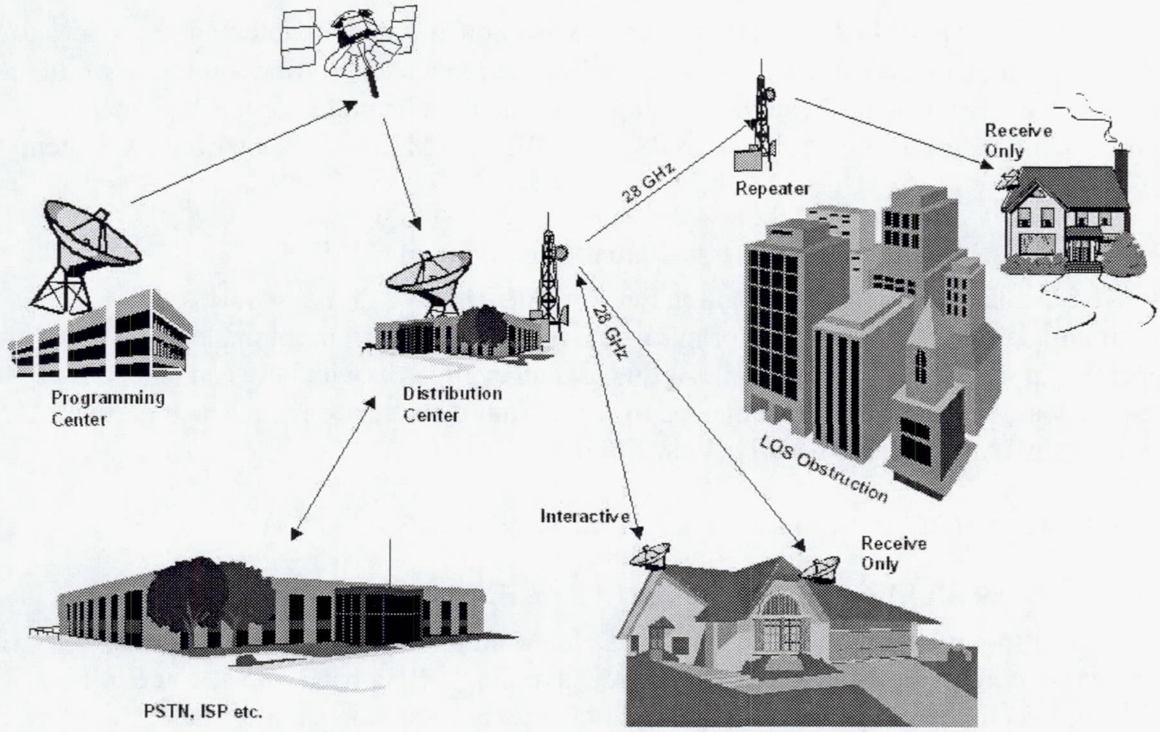

Figure 14. Local Multipoint Distribution System (LMDS) Implementation

The FCC allocated spectrum for LMDS In July 1996. The spectrum allocated includes:

- 850 MHz (27.5 - 28.35 GHz band) Primary basis
- 150 MHz (29.1-29.25 GHz band) Secondary basis
- Proposed 300 MHz (31-31.3 GHz band)

Early developments of applications for LMDS were made by CellularVision - under *Pioneer Preference* licenses. Cellular Vision provided 49 channels of cable vision services to parts of New York City in a unidirectional system. Their development included plans for interactive services to be provided later.

Other companies proposing systems for interactive services using LMDS include Hewlet Packard and Texas Instrument. The TI product segment established to develop LMDS, initially named MulTIpoint, is now SpectraPoint Wireless LLC.

3.4.2.3 Potential for Using MMDS/LMDS for Aviation Wx Distribution

The technology used for MMDS and LMDS have several characteristics that would limit their use for ground-to-air communication. These include:

- Current systems are for fixed services only
- No tracking and handoff capability is implemented
- Sectorized polarization favors fixed rather than mobile service

- Short distances - 2 to 3 miles
- Systems are not likely to be widely distributed - they are most useful where fiber and cable systems are expensive to implement
- Airborne systems would require tracking systems that would be very expensive and limited in application

The conclusions are that MMDS and LMDS are not likely candidate systems for distributing aviation weather.

3.4.3 Satellite - Digital Audio Radio Service (S-DARS)

Digital Audio Radio Service (DARS) is a revolutionary update to the existing AM/FM radio bands. The idea is to broadcast digitized audio rather than modulating the carrier with analog audio signals. The resulting signals received and processed have potentially much higher quality audio. S-DARS is Digital Audio Radio Service broadcast from satellites.

In 1991, the FCC awarded Worldspace Management Corp. experimental licenses to launch a S-DARS satellites over Africa. In 1992, the FCC allocated spectrum in "S" band (2.3 GHz) for nationwide broadcasting of satellite-based Digital Audio Radio Service. Licenses were awarded to American Mobile Radio Corp. (AMRC) and CD Radio in 1997 to build and operate S-DARS in the United States.

3.4.3.1 XM™ Satellite Radio

American Mobile Radio Corp. (AMRC) was renamed XM™ Satellite Radio in 1998. XM™ Satellite Radio plans to offer S-DARS broadcast of 100 channels available anywhere in the lower 48 states. Programming consisting of music, news, weather, and sports will be uplinked from Washington D.C. Services are scheduled to begin in the first half of 2001.

XM™ Satellite Radio will use two satellites in GEO orbit (115° and 85° West Longitude). The 100 channels will take up 12.5 MHz in the 2332.5 to 2345.0 MHz band. In addition to the satellite broadcast, a terrestrial repeater network will be used to fill in gaps in coverage caused by obstructions (buildings, mountains, etc.).

Users will be able to receive the digital audio on a receiver that includes the current AM and FM bands as well as the XM band. The AM/FM/XM radios will replace the traditional AM/FM radios. Unlike the AM/FM signals however, users will be charged a $9.95/month fee to receive the new XM digital channels.

3.4.3.2 Sirius Satellite Radio

The other winner of S-DARS licenses, CD Radio, became *Sirius Radio* in 1999. Sirius Radio plans to offer 50 music channels and up to 50 channels of news, weather, and sports w/ display of information about the channel/programming beginning the fourth quarter of 2000. Programming will be uplinked from Rockefeller Center in Manhattan, NY. to satellites - covering the lower 48 states coast-to-coast.

Unlike the GEO satellites used by XM Radio, Sirius Radio uses three *bent-pipe* satellites in inclined orbits such that each satellite spends at least 16 hours above the equator and allows for complete coverage of the lower 48 states. Sirius Radio will broadcast in the 2320-2332.5 MHz band, to receivers identified as AM/FM/Sirius radios. Sirius will also require terrestrial repeater networks to fill in gaps in coverage due to obstructions. (buildings, mountains, etc.). AM/FM Sirius radios are expected to sell for $199-$499 and a monthly subscription fee 0f $9.95 will be charged to receive the service.

3.4.3.3 Potential Aviation Wx Application of S-DARS

As a broadcast system covering the entire lower 48 states, there is limited opportunity for use of S-DARS to deliver aviation weather. Dedicated Programming for Aviation Wx products could be provided in voice format on one or more of the 100 channels. A more limited approach would be to get the Weather Channel to include national aviation weather products and alerts. Since both S-DARS systems are national broadcasts (lower 48 states), aviation weather products best supported would be those defined for large areas such as:

- Area Weather Forecast
- AIRMETS / SIGMETS
- Other Weather Alerts / Warnings

3.4.3.4 Needed Technology / Recommendations

To make S-DARS available for aviation weather communications, Sirius and/or XM compatible radios would have to be certified for aviation use. This could be done as a dual use systems to support passenger entertainment as well as cockpit Wx information. The installation cost for putting S-DARS systems on aircraft could be supported by charging passenger entertainment fees to access the non-aviation channels.

There is also the possibility of NASA working on the standardization efforts for S-DARS to include data transmission of Aviation Wx products. On February 17, 2000, Sirius Radio and XM™ Radio announced a joint effort to develop common standards for S-DARS such that a common receiver could be used for both systems.

An aviation weather distribution system using S-DARS would require little or no ground system maintenance by the FAA but would also be much more limited for weather product distribution.

3.4.4 Internet In/From the Sky

Other satellite systems offer greater potential for aviation weather aviation communications. Two in particular include Teledesic and DirectPC™.

3.4.4.1 Teledesic: Internet-in-the-Sky™

The Teledesic system referred to as the Internet-in-the-Sky™ promises a broadband satellite network to provide "fiber-like" access to telecommunication services worldwide. Applications will include broadband internet access, interactive multimedia, and high quality voice at cost that are expected to be competitive with wireline/fiber optic systems. Service is scheduled to begin in 2004.

Teledesic uses 288 satellites in Low Earth Orbit (LEO) to provide data rates of 2 mbps uplink and 64 mbps downlink direct to home/office computers. The system is designed for Fixed Satellite Services (FSS) but expects to serve marine and aviation customers as well.

With the expected data rates, Teledesic could address communication requirements for all aviation Wx products including voice, text, graphics and gridded data. To make Teledesic available for aviation use, components designed for fixed based system operation would have to be adapted for flight deck application. This would include low cost tracking antennas for Ka band: 28.6-29.1 GHz Uplink, 18.8-19.3 GHz Downlink.

3.4.4.2 DirectPC™ Internet-from-the-Sky

Another satellite system supporting internet applications is DirectPC™ from Hughes Network Systems. DirectPC™ is like a normal internet service via modem but with high speed download (up to 400 kbps) via satellite (see figure 15).

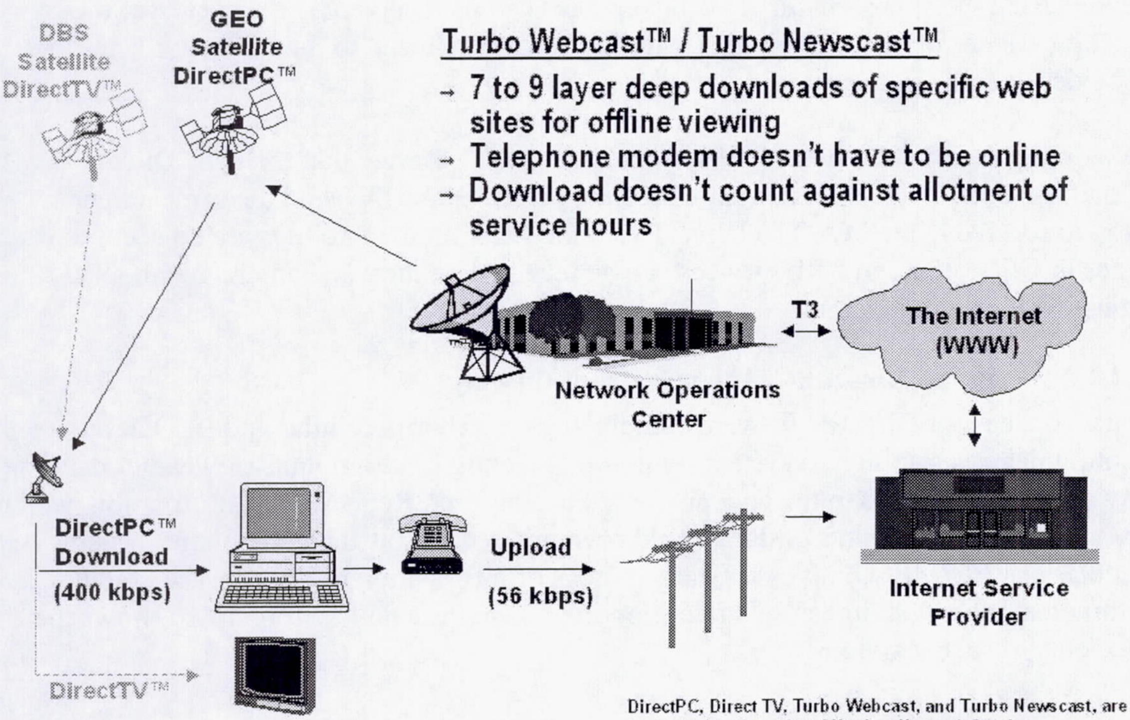

Figure 15. High Speed Internet Service Via Satellite Using DirectPC™

DirectPC™ is a product and service of Hughes Network Systems. Services are currently available in the United States using the Galaxy III-R - GEO satellite located at Longitude -96° but are expected to be available worldwide over other satellites by 2002.

The system appears to the user like any other modem internet service but with much faster downloads of large blocks of data. A request for URL has a "tunneling code" attached which directs the request to the DirectPC™ Network Operations Center (NOC). The NOC retrieves information via multiple T-3 lines then beams the data to the user system via satellite using the Ku Band.

The components required to receive the service include: a personal computer with a modem and an internet service provider (ISP) plus a DirectPC™ antenna, a satellite modem, and satellite access software. The equipment & software sells for around $299 and monthly fees range from $29.99-$129.00 depending on usage.

Two services offered by Hughes that are unique to DirectPC™ are Turbo Webcast™ and Turbo Newscast™. These two services take advantage of the one way high speed data characteristics of the satellite system by pre-packaging large amounts of data for bulk download to the subscribing user. Turbo Webcast™ combines multiple layers of user selected web sites (7 to 9 layers deep) for download all at once. The user can then browse the data offline. Turbo Newscast™ is a similar service that delivers regular updates of news related web sites. In this case the updates can be received by the user over the satellite system without the computer having to be connected to the internet service provider over the phone system.

A selling point of the DirectPC™ system is a package service that includes Direct Broadcast Satellite (DBS) television reception from DirectTV™ on the same antenna used to receive DirectPC. The DirectTV™ and DirectPC™ satellites are adjacent to each other in GEO orbit and both services can be received on the same antenna without adjusting the antenna.

3.4.4.3 Aviation Direct PC: Internet-from-the-Sky

If the concepts of DirectPC™ were combined with airborne cellular and LEO/MEO communication satellites, a system for communicating large amounts of weather data (or any other information) to the cockpit could be achieved. Requests for information, which are usually small amounts of data, could be supported by low data rate phone systems (via cellular or LEO/MEO links). The large blocks of information to be retrieved could be returned at the much higher data rate supported from the satellite. Figure 16 shows the elements of such a system.

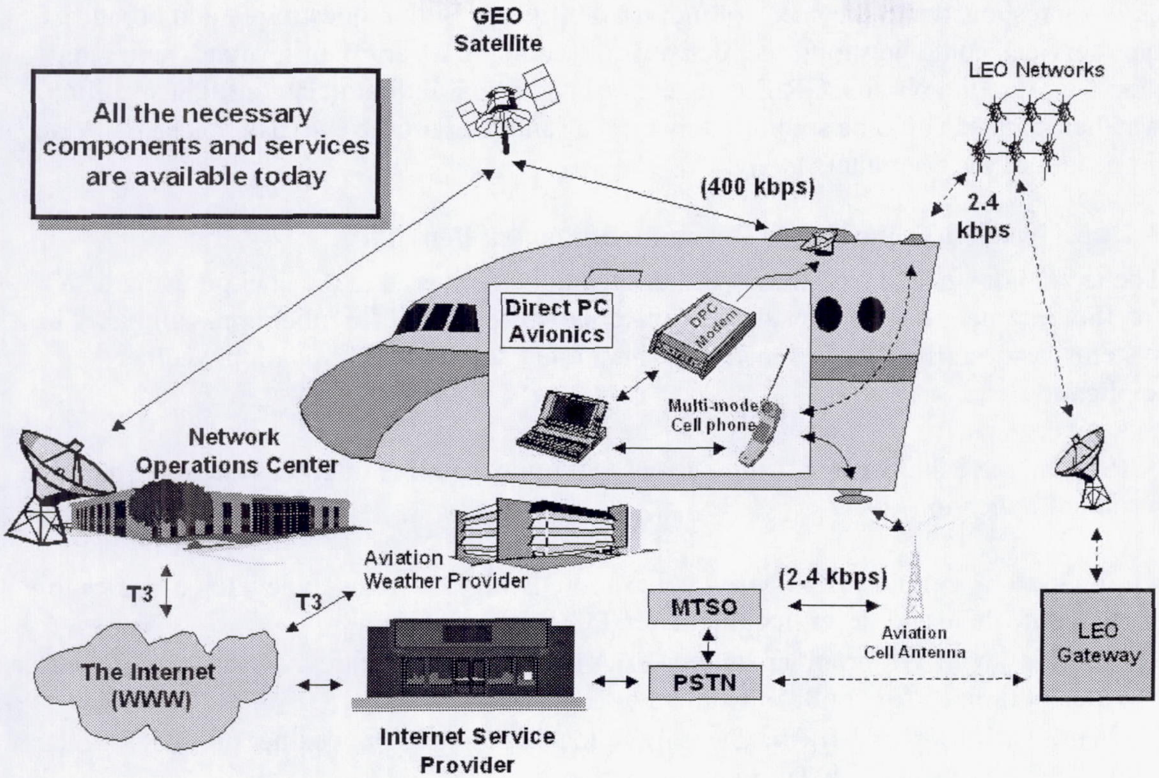

Figure 16. Aviation Direct PC

Using DirectPC™ for aviation data communications differs from fixed ground systems in the type of antenna required to track the fixed satellite in relation to the movement of the plane. Tracking antennas for airborne satellite communications have been used for some time but are very expensive because they have to be both high power and high gain to communicate with satellites in GEO orbit. Since the Ku band antennas used for DirectPC™ are "receive only" the requirements placed on the antenna and receiver are less stringent.

A potential solution for airborne tracking antennas to implement Aviation Direct PC may already exist in systems designed to provide DirectTV™ for in-flight entertainment systems. Two such systems are available from LiveTV™ and Datron.

The LiveTV™ DBS IFE is part of an in-seat DBS television entertainment system that is compatible with DirectTV™. Systems are already installed on A320s and 737-400s.

The Datron systems are also part of IFE based on DBS television, especially DirectTV™. Datron offers the DBS 2400 system for large air carriers and the DBS 2100 system for smaller planes.

3.4.4.4 Potential Aviation Wx Applications

A low cost data link system capable of delivering high volumes of information to the cockpit would address many of the emerging needs for better weather information delivery responsive to the needs of individual flights. Both request/reply and broadcast type services could be supported, delivering weather in a variety of formats (text, radar graphics, satellite photos, GRiB data, etc.). In addition, individualized, flight specific, weather updates could be supported much the same as Turbo Newscast™ is provided to home and office computers today.

3.4.4.5 Needed Technology / Recommendations / Benefits

The technology needed to allow weather data to be delivered to the cockpit using data satellite internet systems may already exist but is being used for other applications. These systems, as described above, need to be integrated and tested for aviation weather applications.

NASA can pave the way for using current and future satellite internet system for aviation weather applications by:

- Integrating, cellular, LEO/MEO voice and DBS IFE systems to develop avionics to evaluate the use of a service like DirectPC™ in the cockpit.
- Working with Wx providers and/or FAA (ADDS) to structure aviation weather web sites optimized for "bulk" download to flight deck.
- Work with *Hughes Network Systems* to "package" aviation weather products similar to Turbo Webcast™ & Turbo Newscast™.
- Implementing and testing the system under various flight conditions.

An aviation data communication system combining cell technology with LEO/MEO voice communications and satellite data delivery could address many of the requirements for aviation weather delivery.

Volume: The high data rate for data download would provide a practical solution for flight specific weather in all formats (text, graphics, grid, etc.)

Reliability: Combining three systems provides three levels of redundancy with graceful degradation. If the DirectPC™ satellite system is unavailable, the cellular link provides a low speed backup source for information. If the cellular link is unavailable the LEO/MEO system also provides a complete link.

Accessibility: The satellite internet link is available throughout the conus today and will be available around the world by 2002. In oceanic and polar regions where the aviation cellular system in not available the LEO/MEO satellites can be used.

Cost: DBS television systems and LEO/MEO phone services are already being installed on aircraft. The addition of internet services for passengers is just a matter of time and a DirectPC™ like system is likely to be the method of providing internet services. The cost of providing a system for cockpit access to ground based sources of aviation weather information could be offset by sharing the cost with passenger service and entertainment systems.

3.4.5 Software Defined Radios (SDR)

A communication technology rather than a communication system, Software Defined Radios (SDR) have the potential to revolutionize communications in ways that make the current method of allocating portions of the frequency spectrum obsolete. Software Defined Radios are wide band transceivers that implement transmit/receive functions in software rather than hardware. The SDR processes complete "waveforms" rather than just filtering, and demodulating signals from a carrier frequency. The concept of radios defined as AM, FM, FSK, or phase modulation types no longer apply to SDRs. An SDR becomes the "type" radio it is programmed to emulate and can change characteristics on-the-fly to support any new waveforms programmed into its memory.

3.4.5.1 Department of Defense SDRs

Some point to lessons learned in Grenada Operations where Army troops used personal calling cards to call in air support as the genesis of Software Defined Radios. Whether that is true or not, the DoD initiated the Joint Tactical Radio System (JTRS) to address the incompatible between different communication systems within the military.

The requirement for JTRS is a joint services, family of radios that are interoperable, affordable, & scaleable - with a common open architecture - and the ability to share waveform software between radios from man portable to aircraft carrier. JTRS has been defined as the DoD radio of the future. The plan is to migrate all legacy systems, including over 45 different radios, to the JTRS open systems architecture.

The Mission Needs Statement for JTRS identifies a need for a common system that will:

- Provide both line-of-sight and beyond-line-of-sight C^4I
- Cover operating spectrum from 2 to 2000 MHz
- Support voice, video, and data
- Make maximum use of commercial technology

3.4.5.2 FCC Notice of Inquiry

The FCC Technological Advisory Council (TAC) is exploring ways to facilitate experimental and commercial deployment of SDR. In March 2000 the FCC began an inquiry regarding Software Defined Radios to determine if the use of SDRs could improve the ability of public safety and emergency agencies to communicate across multiple frequency bands. The FCC is asking:

- How SDR could effect:
  - spectrum allocation
  - spectrum assignments
  - equipment approval
- Could SDR result in improved spectrum efficiency and spectrum sharing?
- What are the potential interference problems from programmable operating frequencies and output power?

3.4.5.3 Potential Aviation Applications of SDR

SDRs have the potential to provide the same benefit to civil aviation as is needed for military communications. In the air, aviation SDRs could provide multi-band, multi-mode, multi-function radios able to adapt to all existing and future voice and datalink aviation communication systems, around the world, through software programming.

On the ground, SDRs could allow nationwide management of aviation frequencies. A centralized optimization system could change assigned aviation frequencies as required to balance load and optimize spectrum usage - across the nation. Airborne systems using SDRs would be able to adapt in real-time to re-allocated spectrum.

With Software Defined Radios, there would no longer be a need to satisfy all types of communication requirements using a single waveform (like VDL Mode 3). Frequency, bandwidth, modulation type, multiple access techniques, etc. could be defined to optimize for the information type rather than trying to force-fit all media types (voice, data, video) into the same communication system.

3.4.5.4 Recommendations

In preparation for the revolution taking place in radio communications, NASA should evaluate SDRs for their potential to address aviation communications in general and weather communications in particular. The potential is a system able to adapt in real-time to constantly changing aviation needs. Ultimately, a range of spectrum may be set aside for aviation where users are free to select the frequency, bandwidth and waveform that best meets their needs under different circumstances. The resulting system would be the communication equivalent of Free Flight - *Free Communications.*

3.4.6 Summary of Solutions Available from Non-Aviation Comm Systems

Voice Wx Products:

Cellular and LEO/MEO satellite phone systems could provide request/reply capabilities in the cockpit to access weather services from the air as is done on the ground today using terrestrial telephones. Research is needed to expand the availability of Cell/SAT technology to all category of flights and all airspace.

S-DARS is a system for broadcasting digitized voice and music and has wide coverage but has been narrowly defined around the entertainment industry in the United States. Opportunities for aviation Wx application are very limited.

Text Wx Products:

FAX, and Internet access over cellular and LEO/MEO satellite phones could provide access to text and some graphic products from FSS / AFSS and the World Wide Web.

Graphics / Gridded Data:

Limited request/reply capability is possible using Cell/Sat phone access internet aviation weather sites. Bandwidth over voice grade communication systems is limited, however, and this could prevent widespread usage. Future cell phone technologies being developed could address flight deck weather needs if aviation is included in the definition of the using community.

Large graphic & gridded files could be delivered using a combination of Cell/Sat phone technology and DirectPC™ like download of large data files. The technology already exists for ground based applications and airborne adaptations seem feasible. Future Internet-in-the-Sky™, could address a wide range of aviation communication needs if the system designed for Fixed Satellite Service (FSS) can be extended to airborne mobile. The technology needs further development.

Software Defined Radios (SDR) may change the way RF spectrum is allocated and used in the future. Opportunities exist for adapting SDRs to solve the wide range of communication needs resulting from the transition to CNS/ATM and free flight.

3.4.7 Non-Aviation Comm Wx Solutions Recommendation Summary

To allow the aviation community to benefit from the explosion of technology in non-aviation mobile communication systems, NASA should:

- Develop digital cell phone technology for aviation applications (interference, power levels, multiple access)
- Develop aviation multimode receiver technology to interoperate between cell and satcom, voice and digital applications
- Work with S-DARS standardization efforts to include data transmission of Aviation Wx products where appropriate
- Develop Aviation Direct PC avionics system, integrate, test, and certify
- Work with Wx providers and/or FAA (ADDS) to structure aviation weather web site optimized for "bulk" download to flight deck.
- Investigate civil aviation applications for Software Defined Radios (SDR)

3.5 General Conclusions

Sections 3.3 and 3.4 above include conclusions and recommendations resulting from analysis of aviation and non-aviation communications for aviation weather support. The technologies needed to assure that communication systems are available to meet the future weather information delivery requirements are described along with the cost, performance and safety benefits to justify the investment. The study also leads to some general conclusions that apply equally well to all forms of communications used to deliver weather.

Not all weather information has the same level of urgency to safety-of-flight and some information is more critical to one category of flight than another. Specific weather products need to be matched with communication systems with appropriate levels of reliability to support the criticality of the information. Available bandwidth for highly critical information should be preserved and dedicated to safety. Meanwhile, systems designed for in-flight-entertainment and other passenger/crew services could be used to support less critical information that is used only for planning and economic decision support. Bandwidth required for "cockpit" applications will be dwarfed by demand for passenger entertainment and services. We should take advantage of the available resources where possible and include provision for cockpit weather information delivery.

There is a huge opportunity for timely investment in moderate-risk/high-payoff research to include aviation considerations in various mobile and data communication systems being developed. Wide-band systems may make the notion of frequency allocation obsolete and civil aviation needs to get involved. AWIN is the right application to stimulate initial development of the modern digital systems needed for all aviation applications.

4 Symbols And Abbreviations

AAC	Airline Administrative Control
ACARS	Aircraft Communications Addressing and Reporting System
ADAS	AWOS/ASOS Data Acquisition System
ADDS	Aviation Digital Data Service
ADS-B	Automatic Dependent Surveillance - Broadcast
AEA	Aircraft Electronics Association
AGFS	Aviation Gridded Forecast System
AIRMET	Airmen's Meteorological Information
AIV	Aviation Impact Variable
ALPA	Air Line Pilots Association
ALRDS	Automated Lightning Reporting and Detection System
AMPS	Advanced Mobile Phone System
AMRC	American Mobile Radio Corp
AOC	Airline Operation Centers
AOPA	Aircraft Owners and Pilots Association
ARINC	ARINC Inc.
ARTCC	FAA Air Route Traffic Control Center
ASIST	Aeronautics Safety Investment Strategy Team
ASOS	Automated Surface Observation System
ATA	Air Transport Association
ATC	Air Traffic Control
ATIS	Automated Terminal Information Service
ATN	Aeronautical Telecommunication Network
AWIN	Aviation Weather Information
AWIPS	Advanced Weather Interactive Processing System
AWOS	Automated Weather Observing Systems
AWW	Severe Weather Forecast Alerts
BER	Bit Error Rate
CATS	Compliance Activity Tracking System
CDMA	Code Division multiple Access
CDTI	Cockpit Display of Traffic Information
CNS/ATM	Communication, Navigation and Surveillance/Air Traffic Management
CONUS	Continental United States
CPDLC	Controller Pilot Data Link Control
CSMA	Carrier Sense Multiple Access
CTAS	Center/TRACON Automation System

CWIN	Cockpit Weather Information
D-AMPS	Digital-AMPS
D-ATIS	Digital Automated Terminal Information Service
DBS	Direct Broadcast Satellite
DECT	Digital Cordless Telephone Standard
DLP	Data Link Processor
DME	Distance Measuring Equipment
DoD	Department of Defense
DSR	Display System Replacement
DUAT	Direct User Access Terminal
EFAS	En Route Flight Advisory Services
E-PIREPS	Electronic PIREPS
FAA	Federal Aviation Administration
FCC	Federal Communication Commission
FDMA	Frequency Division Multiple Access
FIS	Flight Information Services
FISDL	FIS Data Link
FOS	Family of Services
FSK	Frequency Shift Keying
FSL	Forecast Systems Laboratory
FSS/AFSS	Flight Service Stations/Advanced Flight Service Station
GA	General Aviation
GEO	Geosynchronous Earth Orbit
GFSK	Gaussian Fixed Shift Keying
GOES	Geostationary Operational Environmental Satellites
GPS	Global Position System
GRiB	GRIdded Binary
GSM	Global System for Mobile Communications
GWDS	Graphic Weather Display system
HF	High Frequency
HFDL	High Frequency Data Link
HIWAS	Hazardous Inflight Weather Advisory Service
HUD	Head Up Display
IATA	International Air Transport Association
ICAO	International Civil Aviation Organization
IF	In-flight
IFALPA	International Federation of Air Line Pilot's Association
IFE	In-flight Entertainment
ILS	Instrument Landing System
ISP	Internet Service Provider
ITU	International Telecommunication Union
ITWS	Integrated Terminal Weather System
JTRS	Joint Tactical Radio System
LAAS	Local Area Augmentation System
LEO	Low Earth Orbit
LLWAS	Low Level Windshear Alert System
LMDS	Local Multi-point Distribution System
LORAN-C	Long Range Navigation-C System
M1FC	Model 1 Full Capacity
MASPS	Minimum Aviation System Performance Standards
MD&E	Model Development and Enhancement
MDCRS	Meteorological Data Collection and Reporting System
MEO	Medium Earth Orbit
METAR	Aviation Routine Weather Report
MMDS	Multi-channel, Multi-point Distribution System

Mode S	Mode Select (secondary radar discretely addressable mode with data link)
MOPS	Minimum Operation Performance Standards
NADIN	National Airspace Digital Interchange Network
N-AMPS	Narrowband-AMPS
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NAV	Navigation
NBAA	National Business Aviation Association
NCAR	National Center for Atmospheric Research
NCEP	National Centers for Environmental Prediction
NCF	Network Control Facility
NDB	Nondirectional Beacon
NEXCOM	Next-Generation Air/Ground Communications
NEXRAD	Next Generation Weather Radar (WSR-88D)
NIDS	NEXRAD Information Dissemination System
NLDN	National Lightning Detection Network
NPN	NOAA Profiler Network
NSSL	National Severe Storms Laboratory
NTSB	National Transportation Safety Board
NWS	National Weather Service
NWSTG	National Weather Service Telecommunications Gateway
OASIS	Operational and Supportability Implementation System
OOOI	Out/Off/On/In
PCS	Personal Communication System
PDT	Product Development Team
PFC	Passenger Facility Charge
PIREP	Pilot Reports
PSTN	Public Switch Telephone Network
RAP	Research Applications Program
RE&D	Research, Engineering & Development
RTCA	RTCA, Incorporated
RUC	Rapid Update Cycle
SARP	Standards And Recommended Practices
S-DARS	Satellite Digital Audio Radio Service
SDR	Software Defined Radio
SIGMET	Significant Meteorological Information
SIM	Subscriber Identification Module
SMS	Short Message Service
STC	Supplementary Type Certificate
TAC	Technical Advisory Council
TACAN	Tactical Air Navigation
TAF	Terminal Aerodrome Forecast
TCAS	Traffic Alert and Collision Avoidance System
TCP	Transmission Control Protocol
TDMA	Time Division Multiple Access
TDWR	Terminal Doppler Weather Radar
TIS	Traffic Information Service
TIS-B	Traffic Information Service - Broadcast
TRACON	Terminal Radar Approach Control Facility
TWEB	Transcribed Weather Broadcast
TWIP	Terminal Weather Information for Pilots
UAT	Universal Access Transceiver
UCAR	University Center for Atmospheric Research
UHF	Ultra High Frequency
UMTS	Universal Mobile Telephone System

VCR	Video Cam Recorder
VDL	VHF Data Link
VDL4	VDL Mode 4
VFR	Visual Flight Rules
VHF	Very High Frequency
VOR	VHF Omnidirectional Range
VORTAC	VOR Co-located with TACAN Facility
WAAS	Wide Area Augmentation System
WARP	Weather and Radar Processor
W-CDMA	Wide Band - Code Division Multiple Access
WMSCR	Weather Message Switching Center Replacement
WSDDM	Weather Support to Ground De-icing Decision Making
Wx	Weather
Xmit	Transmit

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Weather Research Scientist
National Center for Atmospheric Research

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AOPA (Aircraft Owners and Pilots Association)
Frederick, MD 21701-4798

[4] Mr. Steve Henley
Rockwell-Collins
Co-Chairman, RTCA SC-195

[5] Mr. Rick Heuwinkel
Federal Aviation Administration
RTCA SC-195 Co-Chairman

[6] Mr. Peter Hibson
AWIN Product Team
Boeing Aircraft Company, Inc.

[7] Mr. Ajai Kaul
Product Specialist
Comsat Corporation

[8] Dr. John McCarthy
Senior Weather Scientist
Navy Research Laboratory

[9] Mr. Dean Resch, Program Manager
FIS DL Program Office
FAA Office of Communications, Navigation, and Surveillance (AND)
Washington, D.C.

[10] Mr. Paul Ryan
Senior Manager Technical Product and Service Development
Universal Weather and Aviation, Inc.

[11] Dr. Serdar Uckum
Datalink Specialist
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J.W. Ball, R.G. Herron, E.T. Nozawa, E.A. Thomas, and R.D. Witchey

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Lockheed Martin Aeronautics Company
86 South Drive
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J.W. Ball, R.G. Herron, and E.T. Nozawa, Lockheed Martin Aeronautics Company, 86 South Drive, Marietta, Georgia 30063–0670; and E.A. Thomas and R.D. Witchey, Aviation Concepts, Inc., Kennesaw, Georgia. Project Manager, Gerald J. Chomos, Communications Technology Division, NASA Glenn Research Center, organization code 5640, (216) 433–3485.

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This two part study examines the communication requirements to provide weather information in the cockpit as well as public and private communication systems available to address the requirements. Ongoing research projects combined with user needs for weather related information are used to identify and describe potential weather products that address decision support in three time frames: Far-Term Strategic, Near-Term Strategic and Tactical. Data requirements of these future products are identified and quantified. Communications systems and technologies available in the public as well as private sector are analyzed to identify potential solutions. Recommendations for further research identify cost, performance, and safety benefits to justify the investment. The study concludes that not all weather information has the same level of urgency to safety-of-flight and some information is more critical to one category of flight than another. Specific weather products need to be matched with communication systems with appropriate levels of reliability to support the criticality of the information. Available bandwidth for highly critical information should be preserved and dedicated to safety. Meanwhile, systems designed for in-flight-entertainment and other passenger/crew services could be used to support less critical information that is used only for planning and economic decision support.

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