Aviation Weather – White paper

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Contents

List of acronyms

Abbreviation	Full text
ACARS	Aircraft Communication Addressing and Reporting System
AMDAR	Aircraft Meteorological Data Relay
AOC	Airlines Operations Centre
ATIS	Automatic Terminal Information Service
CAT	Clear Air Turbulence
Cb	Cumulonimbus
EFB	Electronic Flight Bag
FL	Flight Level
FMS	Flight Management System
GPS	Global Positioning System
HAIC	High Altitude Ice Crystals
IP	Internet Protocol
LIDAR	LIght Detection And Ranging
METAR	METeorological Aerodrome Report
MSL	Mean Sea Level
ND	Navigation Display
NOTAM	NOTice to AirMen
PFD	Primary Flight Display
PIB	Pre-flight Information Bulletin
PIREPS	Pilot REPortS
PWS	Predictive WindShear
RVR	Required Visual Range
SATCOM	SATellite COMmunication
SIGMET	SIGnificant METeorological phenomenon
TAF	Terminal Area Forecast
TMA	Terminal Maneuvering Area
VAAC	Volcanic Ash Advisory Centres
VOLMET	Vol METeo
WAFC	World Area Forecast Center

Table 1 - Acronyms

1 Introduction

Weather continues to pose a challenge to aviation flight safety and flight economy. This paper spells out the problem statement and describes Honeywell's vision to address the current deficiencies.

2 The weather information needed for safe operations

The knowledge of the following weather information is needed when planning and executing a flight:

- Weather conditions en-route
  - Winds and temperatures at various Flight Levels
  - Convective weather (Cb) top, location, intensity, trend
  - Precipitation nature and intensity (snow, rain, hail)
  - Convective turbulence
  - Lightning
  - Icing (High altitude ice crystals, super-cooled droplets)
  - Clear Air Turbulence, Mountain wave
  - Volcanic ash

- Weather conditions at and around airports (take-off / initial climb, approach and landing)
  - Sky cover
  - Precipitation nature and intensity
  - Ceiling
  - Visibility/RVR
  - Wind direction and speed
  - Wake vortex
  - Microburst/low level windshear
  - Lightning

Both observations at the present time and forecasts of future weather conditions are required. The information is needed for strategic decision-making (pre-flight and in-flight) and for tactical weather identification and avoidance (in-flight):

- Tactical weather identification and avoidance must rely on real-time observations.
- Strategic decision-making relies on a combination of observations, observations trend and forecasts.

Sources

There are 4 types of weather observations: surface, upper air (balloons, pilot reports, and aircraft automated reports), radar (airborne and ground) and satellite.

Data gathered from surface and upper air observations allow the computation of weather forecast by ground systems through complex weather models.

World Area Forecast Centres publish Significant Weather Charts (including Cbs), Winds & Temperatures forecast, Clear Air Turbulence forecast, Icing forecast, SIGMETs.

Airports publish TAF/METAR/ATIS.

Volcanic Ash Advisory Centres issue warnings in the form of NOTAM, SIGMET messages and volcanic ash advisory messages from the Volcanic Ash Advisory Centres identifying areas of volcanic ash and their predicted movement.

Airborne weather radar provides detection and prediction capabilities for precipitation-related phenomena.

Pilot reports (PIREPS) are a source of observations for all weather phenomena.

The table below summarizes the sources available today and in the foreseeable future for all this weather information.

Flight phase	Information	Sources
En-route	Winds and temperatures at various Flight Levels	AMDAR observations WAFC Winds & Temp forecasts PIREPs
En-route	Convective weather (e.g. Cb) top, location, intensity, trend	WAFC SigWxcharts SIGMETs Airborne Weather radar observations Satellite observations Ground radar observations PIREPs METAR/TAF
En-route	Precipitation nature and intensity (snow, rain, hail)	Airborne Weather radar observations Airborne Weather radar (Predictive Hail) Ground radar observations SIGMETs PIREPs METAR/TAF
En-route	Convective turbulence presence	Airborne Weather radar turbulence observations Automated Turbulence reports SIGMETs PIREPs
En-route	Lightning	Ground systems-based Prediction Airborne Weather radar (Predictive Lightning) Lightning Sensor Systems
En-route	Icing (High altitude ice crystals, super-cooled droplets)	Airborne Weather radar HAIC detection (future) WAFC icing forecasts SIGMETs PIREPs
En-route	Clear Air Turbulence, Mountain wave	WAFC CAT forecasts No observations (future: LIDAR?) Automated Turbulence reports

Flight phase	Information	Sources
		SIGMETs PIREPs
En-route	Volcanic ash / Dust storm	SIGMETs NOTAMs
TMA	Sky cover	METAR observations TAF forecasts ATIS
TMA	Precipitation nature and intensity	METAR observations TAF forecasts ATIS Airborne Weather radar observations
TMA	Ceiling	METAR observations TAF forecasts ATIS
TMA	Visibility/RVR	METAR observations TAF forecasts ATIS
TMA	Surface contamination	METAR observations TAF forecasts ATIS
TMA	Wind direction and speed	Air Data sensors data displayed on PFD / ND METAR observations TAF forecasts ATIS
TMA	Wake vortex	ATC Advisories
TMA	Microburst/low level windshear	Airborne Weather radar (Predictive Windshear)
TMA	Lightning	Ground systems-based Prediction Airborne Weather radar (Predictive Lightning) Lightning Sensor Systems

Table 2 – Weather information

3 The current deficiencies / gaps

1/ While the knowledge of weather conditions around airports is pretty well covered via Surface observations (METARs, ATIS) and airborne weather radar (in particular PWS), it could be complemented by solutions for wake vortex detection / prediction.

2/ Airborne weather radar can only detect precipitation and certain hazards associated with precipitation. In particular, Clear Air Turbulence, wake vortex, cloud mist, volcanic ash cannot be detected. Airborne detection Clear Air Turbulence would require a different type of sensor but the cost/benefit over a good prediction model of CAT probability is not obvious.

3/ Weather forecasts from WAFC are published only every 6 hours. Forecast can be 6 hours old when flight departs!

4/ There is no aviation-approved short-term convection forecast (so-called nowcast) that could provide a 1-hour prediction of hazardous convective cells trend (growth and movement). Small but fast-growing cells can create a serious threat as some recent incidents indicate.

5/ Uplink weather solutions have a low adoption rate in Commercial Air Transport, while they are widespread in Business and General Aviation. Hence updated observations and forecast are not available to flight crews during the flight, or limited to textual messages.

6/ Automated reporting solutions such as AMDAR allow aircraft to automatically report Air temperature (static air temperature), Wind speed and direction, Pressure altitude (barometric pressure), Turbulence (Eddy Dissipation Rate or Derived Equivalent Vertical Gust). However contribution to such system is not mandatory and some airlines do not participate due to communication costs (ACARS).

7/ Sources of en-route weather observations bear certain limitations:

- Radiosondes: limited number of balloons
- PIREPs: voice or textual process, cumbersome
- Ground radar: only continental areas, not worldwide continental coverage and unequal quality
- Automated Turbulence reports: cannot differentiate convective turbulence from CAT
- Airborne weather radar: only serves the aircraft it is installed on

Having more weather observations would have a direct benefit for the in-flight aircraft and an indirect benefit in that the weather forecasts produced by ground models would be more accurate and reliable.

Making PIREPS easier to write and communicate would encourage pilots to report.

8/ ACARS communication costs hinder the deployment of reporting solutions such as AMDAR. Moving from ACARS to IP communication would allow to decrease communication costs and make AMDAR-like solutions more attractive to operators.

9/ Dedicated training for airborne weather is not widespread and quality is variable

4 Honeywell vision

Honeywell's vision is to provide more reliable, more accurate weather data to the flight crew allowing them to anticipate strategic-decision making as well as perform better tactical weather identification and avoidance.

The vision builds on the following pillars:

1/ **Airborne weather radar**: Continuous improvements to detect a wider scope of phenomena, at a higher range, more accurately. This is to better support the pilots' task to identify and avoid adverse weather in a tactical manner.

2/ **Uplink weather**: In-flight updates of graphical and textual weather forecast / reports from ground systems to the flight deck. This allows the flight crew to build a mental picture of the weather situation both pre-flight and in-flight ahead of time, anticipating strategic decisions such as flight path deviation or Flight Level change. The synchronization / sharing of information between flight crews and their Airlines Operations Center is also key.

3/ **Aviation source data**: Drive improvements by more frequent forecast updates, worldwide coverage, nowcasting, new sources of weather observations.

5 Airborne Weather radar

5.1 Airborne Weather Radar - Introduction

The primary purpose of weather radar is the facilitation of tactical hazardous weather avoidance.

The Honeywell airborne weather radar product line stretches back to the 1950s and includes a legacy of RCA, Bendix, Allied Signal, King Radio and Sperry weather radars, as well as the current line of Honeywell and Bendix/King weather radars.

The product line finds applications in general aviation, business aircraft, regional aircraft, air transport, rotary wing and military transport aircraft.

Honeywell continues to advance weather radar technologies which have led to innovations such as turbulence detection, predictive windshear detection, 3D weather, and smaller and lighter equipment.

Honeywell's flagship Airborne Weather Radar system is the IntuVue® RDR-4000 Weather Radar. IntuVue® brings unprecedented levels of automation, usability enhancements, performance, growth and reliability.

5.2 Airborne Weather Radar Capabilities: Current and Near Future State

5.2.1 General Capabilities and Limitations of Airborne Weather Radars

Weather radar receives and processes radar returns from precipitation. Most fielded radars operate at X-band frequencies (in the range of 9.3 to 9.5 GHz), although there are still a few in the C-Band frequency range (around 5 GHz). At such frequencies, the wavelengths are large (on the order of 1.5 inch for X-band, 3 inches for C-band) compared to "scatterers" (individual raindrops or ice crystals). This is known as Rayleigh conditions, and means that energy in the returns are a strong function of scatterer size. (The opposite condition, where wavelengths are small compared to the size of scatterers, is known as "optical" conditions where the return energy is largely independent of scatterer size)

Because of operation at these wavelengths and the practically achievable transmitter power levels and receiver sensitivities, airborne weather radar generally requires a fair amount of precipitation to yield detectable returns.

As a result, weather radar is not generally capable of measuring clear air phenomenon, ice crystals, or mist associated with clouds. The advantage of using this frequency is that the radar is not impeded by these conditions and can see weather behind intervening weather.

Many modern airborne weather radars, in addition to measuring radar return power levels, are also able to make Doppler measurements. Doppler measurements provide information related to the velocity and velocity statistics of scatterers.

The basic return power measurement that all weather radars are capable of provides a measure of "reflectivity" and in rough terms corresponds to rainfall rate. (Reflectivity is essentially a measure of the percentage of the power incident on a target returned, normalized for range).

If so capable, Doppler measurements can be used to measure turbulence, windshear threat levels. So, airborne weather radar generally excels detecting weather phenomenon producing precipitation; the two broad classes of such being stratiform and convective systems.

Of these two types, convective weather systems by far present the most types of hazards, including:

- Turbulence
- Lightning
- Hail
- Low-Level Windshear (Microbursts)
- High-Altitude Crystal icing.

Honeywell's IntuVue® Automatic Operation radars will be discussed in the next section ; the discussion in the remaining part of this section will be based on radars without automated operation.

Figure 1: Microburst

The following sections survey the general capabilities of currently fielded weather radars.

5.2.2 Basic "Tilt-Based" Weather Radar

The original airborne weather radars introduced in the 1950's were non-Doppler systems capable only of measuring reflectivity.

They are herein referred to as "Tilt-Based" to distinguish them from later systems which provide automation obviating the need for crew tilt control.

In this class, we include the original monochrome display radars and the later color digital systems, the latter of which were introduced circa 1970.

These systems required manual control by the flight crew of the antenna tilt (vertical) angle to analyze the radar returns.

The objectives of good tilt control are:

- Provide early detection of convective weather
- Discriminate convective weather from stratiform and ground returns.

Hence, the ability of the crew to detect hazards with these types of systems largely amounts to determining if the displayed returns are from convective weather; that is how well can convective activity be discriminated from stratus weather and ground returns.

With these systems, the discrimination of connective weather requires some crew interpretation, factoring in tilt angles (e.g., estimated radar tops), range, characteristic shapes, PIREPs and known weather conditions.

5.2.3 Tilt-Based with Turbulence Detection

In the 1980's several radar systems were outfitted with the capability to detect turbulence within precipitation using Doppler techniques.

This capability generally has limited range (40-50 nm depending on model), and so in those radars is generally used for terminal operations to discriminate between "bad" and "worse" weather cells.

Tilt-based turbulence detection also requires crew tilt management.

5.2.4 Tilt-Based with Turbulence and Predictive Windshear Detection

In this context, Predictive Windshear (PWS) refers to detection and alerting of low-level microbursts on departure and approach phases. The alerting threshold is based on an estimate of loss-of-aircraft performance resulting from both down drafts and loss of headwind.

PWS is fully automated, that is no requirement for crew to adjust any settings (display range, tilt angle etc).

5.2.5 Automatic Operation (Honeywell IntuVue®)

In the 2005 time frame, Honeywell introduced the RDR-4000 IntuVue® weather radar, which incorporated several innovations keyed on volumetric antenna scanning and 3D memory.

The tilt-based radars discussed previously all have the characteristic that the "update line" on the display is locked to the antenna scan; that is the radar only displayed radar returns collected in the instant (in the last 50 msec or so), with no memory of returns beyond that. The only memory was a 2D memory implemented inside the display system which memorized and displayed returns over one scan time.

By contrast, IntuVue® implements volumetric scanning and 3D memory, meaning that the antenna azimuth and tilt is a pre-programmed to sweep a volume of the atmosphere. One volumetric scan takes about 30 seconds. Motion compensation techniques ensure correct orientation of the display with respect to aircraft position and heading changes.

The returns collected during the volumetric scanning are processed to separate the return between weather reflectivity returns, turbulence returns and ground returns. The ground returns are stored in 2D memory, whereas the weather and turbulence information are stored in separate 3D memories.

As a result, at any given time IntuVue® has a pre-stored 3D representation of the radar ground, weather reflectivity and turbulence environment from 0 to 60,000 ft MSL and out to 320 nm.

This innovation provides numerous advantages over tilt-based radars:

- Automatic displays with discrimination between weather in proximity to anticipated aircraft path and other weather
- Manual modes based on intuitive altitude "cuts" of the weather at constant flight levels
- Vertical weather display at arbitrary azimuth angles, or even along arbitrary flight plans
- Correction for Earth curvature effects
- Simultaneous and independent right/left side displays (either side can display data in any mode and range; some automated radars have a limitation on this regard).

Some models of Honeywell IntuVue® radar are also available with a feature set known as Hazard 2.0 which automatically analyze the stored 3D reflectivity data integrated with other sensor information such as static air temperature to predict the presence of hail and lightning. Hazard 2.0 also extends Turbulence detection to 60 nm and includes Rain Echo Attenuation Compensation Technology (REACT), which compensates for signal attenuation and provides indications of severely attenuated areas. Lastly, it provides enhanced discrimination between convective and stratus weather.

5.2.6 Future Weather Radar Technology

Honeywell continues to invest in Weather Radar Technology. Technologies currently in development are discussed below

- More information about convective cells
- High Attitude Ice Crystal Detection

5.3 Summary of Airborne Weather Radar Capability and Limitations

As discussed above airborne weather radars can only detect precipitation and certain hazards associated with precipitation, but it remains the best source of tactical weather information for the flight crew.

The principal utilization is to determine location, severity and trend (growth) of convective areas. As noted, some radar models include features that facilitate this analysis, but in the main, airborne weather radars principal use is for convective weather avoidance so as to avoid the associated hazards, principally turbulence, hail and lightning.

Current airborne weather radars are not capable of providing information on clear-air phenomenon such as clear-air turbulence, cloud mist, gusts and wake vortex.

While airborne weather radar can detect stratiform rain, is not capable of discriminating stratiform conditions which can lead to wing surface icing (super cooled droplets).

There is also no foreseeable means of adapting airborne weather radar to measure temperature, humidity, general wind conditions, visibility volcanic ash or birds.

6 Uplink Weather

6.1 Uplink Weather- Introduction

The deployment of Electronic Flight Bags and broadband IP connectivity has opened the way to affordable in-flight updates of weather forecasts and reports. Uplink weather applications are expected to be classified as EFB Type B applications.

The main benefits of uplink weather are:

- Observations for weather phenomena that cannot be detected by on-board systems (outside the range of the WXR or not detectable)
- Real-time observations and updated forecast (as opposed to one-shot data set at pre-flight briefing)
- Graphical depiction of weather phenomena as opposed to legacy ACARS text messages
- Common data between flight crew and ground crews (dispatch, flight watch) for making operational decisions
- Flexibility to add new weather products as they become available
- At affordable communication costs (IP)

The benefits are particularly strong for long-haul flights as weather can evolve significantly between departure and arrival.

6.2 Uplink Weather - Current and Near Future State

Uplink weather solutions are not yet widespread. However mature solutions do exist and it is expected that they will be adopted as more aircraft are equipped with broadband SATCOM and in-flight WiFi connectivity solutions.

A typical strategic weather application provides the crew with weather observations and forecast, such as:

- Cb Tops forecast
- Clear Air Turbulence forecast
- Winds aloft forecast
- Icing forecast
- Ground radar observations
- Satellite observations
- SIGMETs
- PIREPs
- Airport weather (TAF/METAR/D-ATIS)

These graphical/textual weather products are usually depicted on a lateral map and a vertical situational display, with the ability to visualize the conditions at different Flight levels.

Regulatory-wise, as the intended function of such applications is strategic they are eligible as Type B applications and they are supplemental to existing sources of weather information (PIB, ACARS text messages, VOLMET, ATIS).

Such tools can also be used to automate and facilitate pilot reporting to ground systems.

6.3 Future State

It is expected that the initial adoption of such solutions will already bring a lot of operational improvements both pre-flight and in-flight.

Future improvements may include:

- introduction of new weather products
- more integration with airborne systems (GPS, FMS etc)
- For the most recent and future generation of aircraft, uplink weather may be ported onto the avionics displays to provide a more integrated user experience, while keeping a strategic-only intended function (note: this is already the case for some Business Jets)

From a regulatory perspective, uplink strategic weather applications may progressively replace the legacy sources of weather such as the weather portion of the Pre-flight Information Bulletin – while still meeting the criteria for EFB Type B applications.

7 Aviation Source data

The resolution, reliability and update frequency of weather source data is critical to the safety and economy of flight operations. While the current weather products from World Area Forecast Centers and other approved organizations do already provide an optimal level of service, it is possible to further improve the current products or offer new ones.

Areas of particular interest are:

- Frequency of forecast updates: 6 hours today, would benefit from faster rate
- Worldwide coverage: the quality of some products such as ground radar is highly dependent on the region of the globe.
- Nowcasting: while traditional forecast provide information for 3 hour-period, nowcast products provide a shorter-term prediction of the weather development (e.g. active convective cells growth and movement)
- New sources of weather observations. One specific improvement in this area is to better leverage flying aircraft as a network of weather data sources that can downlink their observations in real-time to ground systems

