Weather Sensing Methodology
for
U.S. Commercial Aviation

Evan Farbstein
University of California Santa Barbara

Leila Carvalho, PhD
University of California Santa Barbara
Abstract

A literature review detailing weather sensing technologies and their utilization in commercial aviation. The report focuses on three categories of weather observations: ground-based and relayed observations, on-aircraft equipment, and pilot-reported weather observations. The scope of the report is air carrier service in the United States and the weather technology that is government mandated for use by these air carriers. This report is based in Federal Aviation Administration official publications and supplemented by published studies and interviews with a NWS weather forecaster and a commercial airline pilot.
Introduction

This literature review draws from various government and private publications, attempting to create a comprehensive and streamlined summary of the methods used in aviation weather sensing technology. The methods discussed have been set into three categories for ease of discussion; however, the categories are neither mutually exclusive nor isolated, and there are inter-category aspects to many of the technologies. The three categories discussed are ground sourced and relayed observations, on-aircraft observations, and pilot reports (PIREPs). Ground-sourced relayed observations are observations that are created on the ground, by ground-based technologies, and subsequently synthesized and relayed to the aircraft or the pilot. On-aircraft observations are observations generated from the aircraft’s own internal systems, independent of ground observations. Pilot reports are reports created by pilots when they observe phenomenon that is unobservable by, has failed to be observed by, or is supplemental to the other methods.

The scope of this literature review is commercial airline service in the United States, as defined under Federal Aviation Administration part 121 regulations. This includes all scheduled domestic and international air traffic entering, leaving, or passing through US airspace. The report examines only what is mandated for use by the FAA minimum requirements, though some airlines’ company standards may exceed these minimums. General aviation, light sport aircraft, rotorcraft, and private/corporate aviation are excluded from this report.

The majority of the literature synthesized into this report comes from FAA published documents, including the FAA Code of Federal Regulations (CFR), which contains the regulations relating to mandated weather sensing equipment. Other
sources include scientific research articles, aircraft technical publications, and interviews.

Sources of information in this subject area are available, but disparate. This report aims to compile and streamline the multitude of sources in the area of aviation weather sensing methodology into one comprehensive whole.

Part 1: Ground Based and Relayed Observations

a. Overview:

This report operationally defines ground based observations as observations that are produced from ground-based technologies and are subsequently relayed to the aircraft or dispatchers. These observations are the backbone of commercial aviation weather reporting. Observations are created and synthesized into standardized formats; for aviation, the standard current weather report is called a METAR (supplemented when necessary with special observations called SPECIs), and the standard forecasted weather report is called a TAF. In addition to text-based weather reporting such as the METAR and TAF, a variety of weather graphics are available.

The weather conditions determine which flight category a flight is allowed to operate under. There are four categories of flight; in descending order from most to least visibility the flight categories are: Visual Flight Rules (VFR), Marginal VFR, Instrument Flight Rules (IFR), and Low IFR. FAA part 121 mandates pre-flight familiarization with weather conditions through the use of weather briefing services\(^{(12)}\); these briefings may be obtained through government services, such
as the National Weather Service (NWS), or private services, such as airlines’ own weather report generating departments.

b. Weather Sensing Measurements:

A variety of measurements, both in situ and remote, are available from ground sources. An in situ measurement is a measurement that requires “direct contact between the sensor and the object whose properties are to be determined”\(^{(6)}\). This can result in the measure being influenced by its means of measurement; for instance, a thermometer used to measure a parcel of air will heat or cool the air parcel slightly during measurement. Examples of in situ measurements in aviation are atmospheric pressure, wind speed and direction, and temperature. Remote measures are, by contrast, measurements that “do not require direct contact between instrument and object”\(^{(6)}\). This makes repercussions from measurement unlikely, and also allows measurements of locations where in situ measurements would be difficult to obtain. Remote sensing includes satellite imaging and radar.

c. Means of Reporting:

METARs

Meteorological Terminal Routine Aviation Weather Reports, or METARS, are defined by the FAA Aeronautical Information Manual as *aviation routine weather reports*\(^{(1)}\). METARs report current weather and do not include forecasts. The METAR format is standardized throughout FAA accredited weather reporting sources, and fulfills the pre-flight current weather briefing required for operations under FAA part 121\(^{(1)}\).
METAR observations are recorded at airports or weather reporting stations, and are typically recorded at one-hour intervals. Special reports (SPECIs) are recorded between one-hour observations if the weather changes significantly. METARs are recorded digitally, and can be augmented by human input at some weather stations.

METAR KJFK 161551Z 14016G22KT 2SM BR BKN003 OVC065 18/16 A2996 RMK AO2 PK WND 14026/1537 SFC VIS 6 SLP144 T01830161

Figure 1.1: Sample METAR. Retrieved from wunderground.com 5-16-14

Decoding the sample METAR in figure 1.1

METAR: Describes the type of observation

KJFK: The location of the observation, given in International Civil Aviation Organization (ICAO) 4-letter format

161551Z: Date and time of observation. The first two numbers signify the day of the month. The following four numbers signify the time of the observation in UTC standard time.

14016G22KT: Wind direction and speed. The direction is given in magnetic heading by the first three numbers. The wind speed in knots is given by the next two numbers; “G” and the following two numbers denote the speed of wind gusts.

2SM: Visibility, given in statute miles

BR: This refers to weather phenomena. “BR” signifies mist.

BKN003 OVC065: Cloud cover and height above ground level, given in flight level.

18/16: Temperature/Dew Point
A2996: Barometric pressure in inches mercury. Referred to as “altimeter” in aviation

RMK: Everything that follows falls under the “remarks” category. These include clarifications, augmentations, and maintenance data.

TAFs

A Terminal Aerodrome Forecast (TAF) is defined by the FAA as a “a concise statement of the expected meteorological conditions significant to aviation for a specified time period within five statute miles (SM) of the center of the airport’s runway complex (terminal)” (2). TAFs are issued every six hours, and forecast the weather for a 24 to 30 hour time period; 24 hours at most airports, 30 hours at large international airports (13). TAFs are created at National Weather Service regional offices for a selection of airports in the NWS region. These reports are generated by on-ground human forecasters, who analyze a variety of graphics, models, and forecasts and synthesize the information into one brief TAF(13). TAFs open with the period for which they are valid, and contain as many lines of forecasted weather as necessary to accurately portray the period they forecast; the more dynamic the weather, the more TAF lines will be necessary. Forecasters determine how many lines of TAF are necessary, and also have the responsibility of issuing amendments to the TAF if it proves inaccurate(13).

Similar weather terminology is used for coding weather phenomena both in METAR and TAF formats. Due to the human input required, TAFs are less common than METARs, and not all stations that report METARs have a corresponding TAF. See figure 1.2 for a sample TAF.
Decoding the Sample TAF in Figure 1.2

<table>
<thead>
<tr>
<th>TAF</th>
<th>KLAX 161735Z 1618/1724 VRB05KT P6SM SCT250</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>FM162000 25010KT P6SM SKC</td>
</tr>
<tr>
<td></td>
<td>FM170300 25006KT P6SM SKC</td>
</tr>
<tr>
<td></td>
<td>FM170600 VRB03KT P6SM SCT005 SCT250</td>
</tr>
<tr>
<td></td>
<td>FM171700 22005KT 5SM BR SCT030</td>
</tr>
<tr>
<td></td>
<td>FM172000 25010KT 6SM HZ SKC=</td>
</tr>
</tbody>
</table>

**Figure 1.2: Sample TAF. Retrieved from wunderground.com 5-16-2014**

**Decoding the Sample TAF in Figure 1.2**

**TAF**: Type of report

**KLAX**: 4-letter ICAO station identifier

**161735Z**: Date and time of forecast generation; given in day of the month and UTC (Zulu) time.

**1618/1724**: Period forecast covers. The first two numbers denote the day of the month; the second two denote the hour in UTC time.

**VRB05KT**: Wind direction and speed in knots

**P6SM**: Visibility. “P” means “greater than”; forecasts are often cautionary while reporting visibility, as it is heavily subject to change\(^1\).

**SCT250**: Cloud cover and altitude, in flight level above ground level.

**Weather Graphics:**

Aviation weather graphics provide visual representations of meteorological conditions. Government provided graphics are available through the Direct User Access Terminal (DUATS) website, which is accessible by any medically-current licensed pilot in the U.S.\(^1\) (for more information on DUATS,
see the “government weather services” section of this report). A variety of graphical representations are available through private companies, though these may not be certified in accordance with FAA regulations. Common weather graphics utilized in aviation include radar summaries, pressure charts, infrared satellite images, and visible satellite images.

![Weather Graphics](image)

*Figure 1.3: CSC Duats weather graphics. Captured 6 June 2014*

**Flight Categories**

The reported and forecasted weather determines which flight category flights must operate under. Flight categories include Visual Flight Rules (VFR), Marginal Visual Flight Rules (MVFR), Instrument Flight Rules (IFR), and Low Instrument Flight
Rules (LIFR). For the weather conditions associated with each category, see figure 1.4 below.

All scheduled air carrier service in the U.S. must file flight plans under the Instrument Flight Rules (IFR) condition\(^{(12)}\). However, the forecasted weather at the destination determines the fuel reserves the plane must have; for IFR forecast conditions, the plane must carry more fuel. For this reason, the a forecasted IFR flight category for an intended destination airport may be cause for an airline to seek alternate reports; see the “Commercial Weather Services” subsection below for more information.

<table>
<thead>
<tr>
<th>Category</th>
<th>Visibility</th>
<th>Ceiling</th>
</tr>
</thead>
<tbody>
<tr>
<td>VFR</td>
<td>&gt; 3 mi</td>
<td>and &gt; 500 ft (below), &gt; 1000 ft (above), &gt; 2000 ft (horiz) (^{(15)})</td>
</tr>
<tr>
<td>Marginal VFR</td>
<td>Between 3 and 5 mi</td>
<td>and/or Between 1,000 and 3,000 ft</td>
</tr>
<tr>
<td>IFR</td>
<td>1 mi or more but less than 3 mi</td>
<td>and/or 500 ft or more but less than 1,000 ft</td>
</tr>
<tr>
<td>Low IFR</td>
<td>&lt; 1 mi</td>
<td>and/or &lt; 500 ft</td>
</tr>
</tbody>
</table>

*Figure 1.4: Flight Categories*

d. Weather Briefing Services

**Government Weather Services:**

FAA part 121 states that all pilots and briefers must be thoroughly familiar with weather conditions before commencing the flight \(^{(12)}\). To satisfy this, the pilot or briefer must attain a briefing from an FAA authorized source. Observations of
weather are taken by the National Weather Service (NWS), and are relayed by to pilots and dispatchers by Flight Service Stations (FSS) and the Direct User Access Terminal System (DUATS).

To obtain a pre-flight briefing from a flight service station, the pilot must call the flight service station, and a report is relayed to the pilot over the phone by a briefer. Briefings and supplemental information are available in-flight from Flight Service Stations by radio. The briefers at flight service stations do not generate original forecasts, but translate and interpret forecasts along the route and at the destination.

There are three types of briefings available through flight service stations: Standard Briefings, Abbreviated Briefings, and Outlook Briefings. Standard briefings are the most in-depth and should be requested if the person requesting the briefing has not done recieved any other prior weather information(1). Abbreviated briefings supplement mass-disseminated data, or previous briefings(1). Outlook briefings are to be requested when the beginning of your flight is more than six hours from the time of the briefing, and are only to be used for planning purposes; another briefing should be completed before beginning a flight(1).

DUATS provides the same pre-flight briefing, but in an online format. In addition, DUATS has graphics and other complementary information. Any pilot who is medically current may access the DUATS system(1).

In the case of an accident, the FAA or NTSB can determine whether the pilot obtained a briefing from any government source, such as DUATS or an FSS(1).

Commercial (Non-governmental) Weather Services:
Airlines may have their own reporting services, or subscribe to other private, non-FAA reporting. The FAA tends to be conservative in their reporting, so airlines that generate their own weather reports often do so to sway reports that are close to IFR conditions to VFR. This allows the planes to carry less fuel under the flight rules of the better weather conditions, saving the airlines money. These private reports can be solicited on a case-by-case basis, when borderline weather conditions might cause delays or cancellations, or may be provided around-the-clock by airlines with weather departments. In addition, some airlines maintain their own data on headwinds and turbulence, which they use internally for flight planning and routing but do not share with other airlines.

To operate commercial aircraft under FAA part 121, the weather observations and forecasts must be obtained along the Enhanced Weather Information System (EWINS) guidelines, set forth in FAA General Technical Administration guidelines. To meet EWINS guidelines, the weather observations must come from an FAA or NWS authorized source. To combat “forecast shopping”, or airlines selecting the most favorable forecast, EWINS requirements mandate that the certificate holder or operator must be able to show that any combination of forecasts indicate that the weather will be above minimum requirements for the desired flight category.

Part 2: On-Aircraft Observations

a. Overview
On-aircraft observations are weather observations generated solely from the aircraft’s on-board equipment, with no input from outside sources. The FAA mandates radar systems for aircraft to be operating in the vicinity of thunderstorms, or the possibility of thunderstorms\(^{(12)}\). In addition, information on the temperature and dew point of the outside air can be taken by a plane’s on-board systems\(^{(10)}\). Wind shear warning systems are also required by the FAA\(^{(12)}\). The Aircraft Communications Addressing and Reporting System, or ACARS, provides a means for aircraft to relay their weather observations to ground bases.

b. Radar

Radar systems are required by the FAA on flights where “thunderstorms, or other potentially hazardous weather that can be detected with weather radar systems, may reasonably be expected along the path to be flown”\(^{(12)}\). In planes equipped with a glass flight deck (where traditional analog instrumentation is replaced by computer screen displays) the radar returns can be overlaid directly onto the projected flight path of the plane, allowing the course to be modified accordingly.

Airborne radar weather systems are capable of detecting rainfall, wet hail, wet turbulence, and ice crystals; however, radar does not detect clouds, clear-air turbulence, wind shear, sandstorms, or lightning\(^{(4)}\). Radar returns indicate the location and intensity of the precipitation.

c. Wind Shear

All turbine powered aircraft must have windshear warning systems prior to operating under FAA part 121\(^{(12)}\). Wind shear warning systems use radar to detect wind shear
events in the flight path of the plane, sounding warning alarms when wind shear is detected\(^3\). Some warning systems can project the area of wind shear onto the navigation computer\(^3\), allowing the pilot of the aircraft to navigate around the location of the occurrence. Wind shear warning systems use extremely high frequency Doppler radar to locate areas of air movement associated with wind shear\(^3\).

d. ACARS

ACARS (Aircraft Communications Addressing and Reporting System) is a digital system that allows the transmission of data and information between aircraft and ground stations, via satellite or radio\(^10\)\(^13\)\(^14\). While the ACARS does not record observations, it proves a useful tool in linking ground and on-aircraft observations, in a two way exchange: ACARS displays METARs and TAFs in text format on the flight management computer, and collects information about temperature, dew point, and humidity (if the aircraft is equipped with those collection capabilities) and relays the information to ground stations\(^10\)\(^14\). The ground systems use this upper-level atmospheric information to augment radiosonde data and create, amend, or enhance their forecasts\(^13\)\(^14\).

Part 3: Pilot Reports (PIREPS)

a. Overview:

**Pilot reports** (PIREPs) are unscheduled reports of weather experienced in-flight, typically describing weather phenomena that cannot be observed easily by other methods\(^15\). These observations are radioed by the pilot to a ground station, where
the report is processed, and incorporated into weather observing and forecasting systems.

b. Usage

The issuance of pilot reports is at the discretion of the pilots. Typically, PIREPS are reserved for observations that are difficult to observe by other methods, in an effort to avoid redundancy. A frequent subject of PIREPS are cloud ceilings. Satellite imaging can determine the tops of clouds, but it is harder to tell the “ceiling”, or the base of clouds relative to the ground\(^5\). Clear air turbulence is also frequently reported\(^{14}\).

In addition, air traffic facilities are required to solicit PIREPs when the following weather conditions occur or are forecast to occur: cloud ceilings at or below 5,000 feet, visibility reported on the surface or aloft of 5 miles or less, thunderstorms and related phenomenon in the vicinity, turbulence of moderate degree or greater, icing of light degree or greater, and wind shear\(^{11}\).

c. The Format of a PIREP

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LAS UA /OV LAS245020/TM 0348/FL110/TP B733/TB MOD CHOP
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Figure 3.1: Sample PIREP. From aviationweather.gov. Retrieved 5-20-14

The format of a pilot report is standardized. Each report must contain\(^{11}\):

- A statement of severity. “UA” prefaces routine observations; “UUA” prefaces urgent observations.
● Location of the observation.
● Time of the observation
● Altitude. Given in Flight Level above sea level.
● Aircraft type.

Once the mandatory information has been given, the report then describes the weather phenomena. These phenomena include sky cover, temperature, wind speed, turbulence, icing, flight visibility, or anything else of interest\(^{(1)}\). The formal language used for reporting weather phenomena in PIREPs is similar to the one used for METARS and TAFs(See PIRED code chart in “Tables and Charts” for more).
Conclusion

The core of aviation weather sensing for commercial airliner service in the United States is done from ground-based observing systems and services. The Federal Aviation Administration and the National Weather Service work in tandem to collect, analyze, synthesize, and disseminate these ground-based observations, in the form of standardized text observations (METARS), standardized text forecasts (TAFs), and graphical representations. These disseminations are available through government-funded sources such as briefings from Flight Service Stations and the online Direct User Access Terminal. Pilots and airline dispatchers are required to obtain this information on the weather before departing.

The plane’s on board weather systems supplement the ground sources by providing the pilots with real-time weather information. The on-board systems are minimal, and include radar, wind-shear warning systems, and rudimentary temperature and dew point readings. The information collected on the plane’s on-board systems is sent to ground-based stations by a satellite data-link, to help improve accuracy of further observations and forecasts.

Pilot reports provide a means for pilots to describe weather phenomena that other means of weather reporting may not capture. Pilot reports are typically volunteered by pilots when they come across phenomena hazardous or disruptive to the safe and timely operation of their aircraft. These phenomena include clear air turbulence and icing. In addition, certain circumstances require air traffic controllers to request pilot reports.
### Tables and Charts:

**METAR “Remarks” codes: (Courtesy of WikiCommons)**

<table>
<thead>
<tr>
<th>Type</th>
<th>Abbreviation</th>
<th>Meaning</th>
<th>Abbreviation</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intensity</td>
<td>-</td>
<td>Light intensity</td>
<td>blank</td>
<td>Moderate intensity</td>
</tr>
<tr>
<td>Intensity</td>
<td>+</td>
<td>Heavy intensity</td>
<td>VC</td>
<td>In the vicinity</td>
</tr>
<tr>
<td>Descriptor</td>
<td>MI</td>
<td>Shallow</td>
<td>PR</td>
<td>Partial</td>
</tr>
<tr>
<td>Descriptor</td>
<td>BC</td>
<td>Patches</td>
<td>DR</td>
<td>Low drifting</td>
</tr>
<tr>
<td>Descriptor</td>
<td>BL</td>
<td>Blowing</td>
<td>SH</td>
<td>Showers</td>
</tr>
<tr>
<td>Descriptor</td>
<td>TS</td>
<td>Thunderstorm</td>
<td>FZ</td>
<td>Freezing</td>
</tr>
<tr>
<td>Precipitation</td>
<td>RA</td>
<td>Rain</td>
<td>DZ</td>
<td>Drizzle</td>
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<td>Precipitation</td>
<td>SN</td>
<td>Snow</td>
<td>SG</td>
<td>Snow Grains</td>
</tr>
<tr>
<td>Precipitation</td>
<td>IC</td>
<td>Ice Crystals</td>
<td>PL</td>
<td>Ice Pellets</td>
</tr>
<tr>
<td>Precipitation</td>
<td>GR</td>
<td>Hail</td>
<td>GS</td>
<td>Small Hail and/or Snow Pellets</td>
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<tr>
<td>Precipitation</td>
<td>UP</td>
<td>Unknown Precipitation</td>
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<td></td>
</tr>
<tr>
<td>Obscuration</td>
<td>FG</td>
<td>Fog</td>
<td>VA</td>
<td>Volcanic Ash</td>
</tr>
<tr>
<td>Obscuration</td>
<td>BR</td>
<td>Mist</td>
<td>HZ</td>
<td>Haze</td>
</tr>
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<td>Obscuration</td>
<td>DU</td>
<td>Widespread Dust</td>
<td>FU</td>
<td>Smoke</td>
</tr>
<tr>
<td>Obscuration</td>
<td>SA</td>
<td>Sand</td>
<td>PY</td>
<td>Spray</td>
</tr>
<tr>
<td>Other</td>
<td>SQ</td>
<td>Squall</td>
<td>PO</td>
<td>Dust or Sand Whirls</td>
</tr>
<tr>
<td>Other</td>
<td>DS</td>
<td>Duststorm</td>
<td>SS</td>
<td>Sandstorm</td>
</tr>
<tr>
<td>Other</td>
<td>FC</td>
<td>Funnel Cloud</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time</td>
<td>B</td>
<td>Began At Time</td>
<td>E</td>
<td>Ended At Time</td>
</tr>
<tr>
<td>Time</td>
<td>2 digits</td>
<td>Minutes of current hour</td>
<td>4 digits</td>
<td>Hour/Minutes Zulu Time</td>
</tr>
<tr>
<td>PIREP ELEMENT</td>
<td>PIREP CODE</td>
<td>CONTENTS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>------------------------</td>
<td>------------</td>
<td>--------------------------------------------------------------------------</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. 3-letter station identifier</td>
<td>XXX</td>
<td>Nearest weather reporting location to the reported phenomenon</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Report type</td>
<td>UA or UUA</td>
<td>Routine or Urgent PIREP</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Location</td>
<td>/OV</td>
<td>In relation to a VOR</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Time</td>
<td>/TM</td>
<td>Coordinated Universal Time</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Altitude</td>
<td>/FL</td>
<td>Essential for turbulence and icing reports</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. Type Aircraft</td>
<td>/TP</td>
<td>Essential for turbulence and icing reports</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. Sky cover</td>
<td>/SK</td>
<td>Cloud height and coverage (sky clear, few, scattered, broken, or overcast)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8. Weather</td>
<td>/WX</td>
<td>Flight visibility, precipitation, restrictions to visibility, etc.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9. Temperature</td>
<td>/TA</td>
<td>Degrees Celsius</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10. Wind</td>
<td>/WV</td>
<td>Direction in degrees magnetic north and speed in knots</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11. Turbulence</td>
<td>/TB</td>
<td>Intensity, duration, proximity to clouds</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12. Icing</td>
<td>/IC</td>
<td>Severity and location</td>
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<td>13. Remarks</td>
<td>/RM</td>
<td>For reporting elements not included or to clarify previously reported items</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
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