



Flight Operations Briefing Notes Adverse Weather Operations Optimum Use of the Weather Radar

I Introduction

Although more and more aircraft are equipped with one or two airborne weather radars, incursions into very active cumulonimbus still occur, annually resulting in injuries or substantial aircraft damage (**Figure 1**).



Figure 1

A320 Radome after Hail Encounter

The aim of this Flight Operational Briefing Note is to provide additional information about weather radar capabilities and limitations, in order to improve the flight crew's overall understanding of the system, and to help prevent such incidents from occurring.

II Background Information - Statistical Data

A weather radar is only helpful, if the flight crew is able to interpret the screen display. The image of radar returns on the Navigation Display (ND) is a representation of what is detected by the radar. Decisions that are taken, based on this information, will vary

depending on the flight crew's interpretation of the ND radar image, thus on the experience of the flight crew and their knowledge of the weather radar's limitations.

II.1 Cumulonimbus (Cb) Structure

In flight, cumulonimbus (Cb) structures can be a major source of danger, due to turbulence and heavy precipitation.

Hail

Hail represents a major threat, because of its effect and because it is impossible to positively detect. Only the knowledge of a Cb's structure and the observation of different clues can help. The presence of hail within a Cb, varies with altitude and wind (**Figure 2**):

- Below FL 100, hail is equally likely to be encountered under the storm, in the cloud or around it (up to 2 NM)
- Between FL 100 and FL 200, 60 percent of hail is encountered in the Cb and 40 percent is encountered outside the cloud, under the anvil
- Above FL 200, hail is most likely to be encountered inside the cloud.

Usually, the threat of hail is greater downwind of a Cb: indeed, moisture is driven upward by strong drafts. It then freezes and is transformed into hail, before being blown downwind. When possible, it is better to try to avoid a storm by flying on the upwind side of the Cb. Paradoxically, there is less risk of hail in humid air than in dry air. In fact, moisture in the air behaves as a heat conductor, and helps to melt the hail.

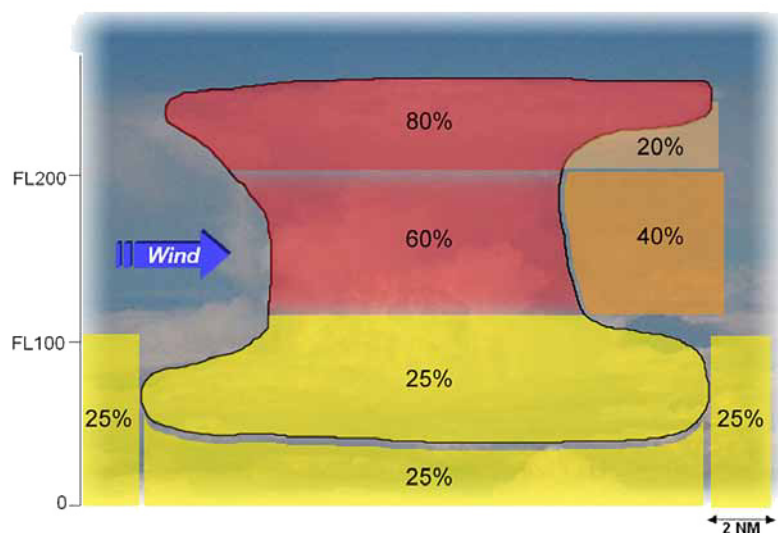


Figure 2

The Risk of Encountering Hail relative to Cb Cloud Position

Turbulence

Turbulence associated with a Cb is not limited to inside the cloud. Weather radars cannot detect turbulence in clear air, so it is therefore necessary to take precautionary measures. A Cb should be cleared by a minimum of 5 000 ft vertically and 20 NM laterally, to minimize the risk of encountering severe turbulence.

Lightning is a very strong indicator of severe turbulence.

Note:

A method to determine the altitude of the top of a Cb is presented in paragraph IV.1.

II.2 Weather Radar Principle

A knowledge of the radar principle is essential in order to accurately interpret the weather radar display.

Weather Radar Detection Capability

The weather radar only detects precipitation droplets (**Figure 3**). How much it detects depends upon the size, composition and number of droplets. Water particles are five times more reflective than ice particles of the same size.

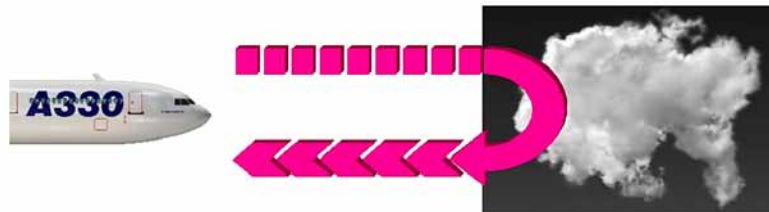


Figure 3
Weather Radar Principle

The radar **does** detect:

- Rainfall
- Wet hail and wet turbulence
- Ice crystals, dry hail and dry snow. However, these three elements give small reflections, as explained below.

The radar **does not** detect:

- Clouds, fog or wind (droplets are too small, or no precipitation at all)
- Clear air turbulence (no precipitation)

- Windshear (no precipitation except in microburst)
- Sandstorms (solid particles are almost transparent to the radar beam)
- Lightning.

Reflectivity

Radar echo returns are proportional to droplet size, and therefore, precipitation intensity. Droplets that are too small (fog droplets) will return no echo, whereas heavy droplets (thunderstorm droplets) will return the majority of radar waves (**Figure 4**).

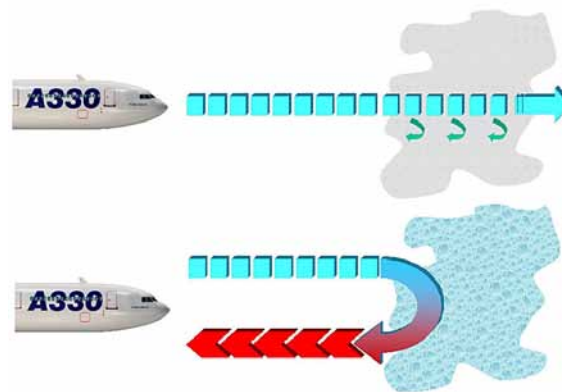


Figure 4

Reflectivity According to Droplet Size

Reflectivity of precipitation not only depends on the intensity of the precipitation, but also on the type of precipitation. Precipitation that contains water will return a stronger return than dry precipitation. Dry hail, for example, will reflect far less than wet hail (**Figure 5**). The upper level of a thunderstorm, that contains ice crystals, provides weaker returns than the middle part, that is full of water or wet hail.

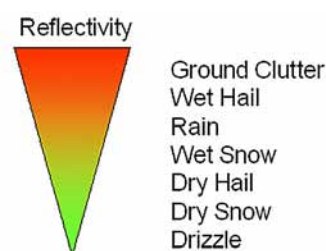


Figure 5

Reflectivity According to Droplet Type

It is important to note that reflectivity of particles is not directly proportional to the hazard that may be encountered in a cell. Air can be very humid, when close to the sea for instance. In this case, thermal convection will produce clouds that are full of water. These clouds will have a high reflectivity, but will not necessarily be a high threat. On the other hand, there are equatorial overland regions where converging winds produce large scale uplifts of dry air. The resulting weather cells have much less reflectivity than mid-latitude convective cells, making them much harder to detect. However turbulence in or above such clouds may have a higher intensity than indicated by the image on the weather radar display.

Similarly, snow flakes have low reflectivity, as long as they are above freezing level. As they descend through freezing level, snowflakes stick together and become water covered. Their reflectivity increases and the weather radar display may display amber or red cells, despite the fact that there is no threat.

Attenuation

Because the weather radar display depends on signal returns, heavy precipitation may conceal even stronger weather: The major part of the signal is reflected by the frontal part of the precipitation. The aft part returns weak signals, that are displayed as green or black areas. The flight crew may interpret these as a no/small threat areas.

Modern weather radars are now able to apply a correction to a signal when it is suspected to have been attenuated behind a cloud. This reduces the attenuation phenomenon. However, a black hole behind a red area on a weather radar display should always be considered as a zone that is potentially very active.

Despite this attenuation correction function, the weather radar should not be used as a tool to penetrate, or navigate around, areas that are displayed as severe. The weather radar should only be considered as a tool to be used for weather avoidance.

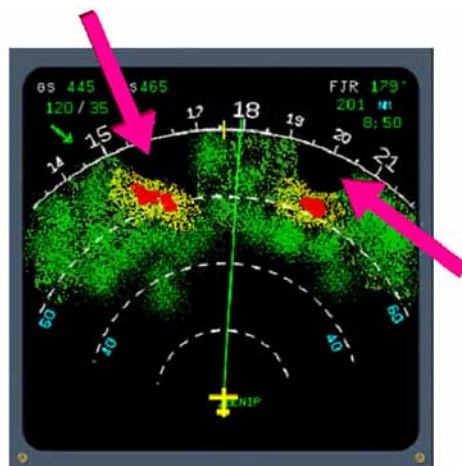


Figure 6

Attenuation Behind Two Very Active Cells

Weather Shapes that should attract the Flight Crew's Attention

Some displays contain cues that should alert the flight crew:

- **Shapes**

Shapes, more than colors, should be observed carefully in order to detect adverse weather conditions.

Closely spaced areas of different colors usually indicate highly turbulent zones (**Figure 7**).

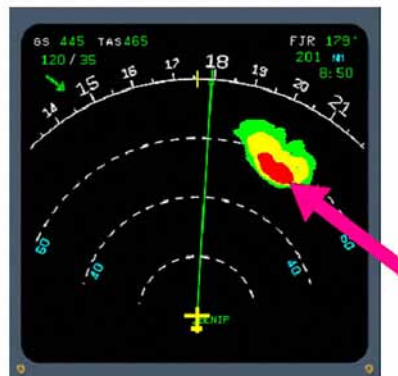


Figure 7

Closely Spaced Areas of Different Colors

Some shapes are good indicators of severe hail and signify strong vertical drafts (**Figure 8**). Fast changing shapes, whatever form they take, also indicate high weather activity.

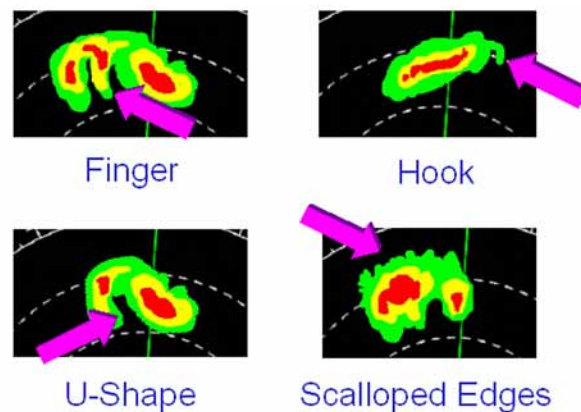


Figure 8

Shapes Indicating Adverse Weather

At cruise altitude, ice replaces water in clouds, and ice is not detected as easily as water by weather radars. High vertical expansion clouds are representative of high-energy air movements. Therefore, any returns at cruise altitude should be considered turbulent. In cruise, all cells with green or stronger returns should be avoided by 20 NM at least.

- **Turbulence**

Some weather radars are fitted with a turbulence display mode. This function (the TURB function) is based on the Doppler effect and is sensitive to precipitation movement. Like the weather radar, the TURB function needs a minimum amount of precipitation to be effective. To help make safe flight path decisions, and especially when the weather ahead is represented as dense, the turbulence display mode should be used.

An area of light rainfall, depicted in green in normal mode, is shown in magenta when there is high turbulence activity.

The TURB function is only active within a range of 40 NM (Doppler measurement capability) and can only be used in **wet** turbulence.

Note:

Clear air turbulence and dry turbulence cannot be detected by the weather radar.

III Radar Technology

Previous generations of weather radars use parabolic antennae and C-band frequencies (4 000-8 000 MHz). Newer weather radars are fitted with flat antennae and use X-Band (8 000-12 500 MHz) frequencies, that offer the following advantages:

- Higher pulse energy
- A narrower beam, that significantly improves the target resolution
- Higher reflectivity, and therefore a higher total energy return
- Turbulence and windshear detection
- Low power consumption.

Note:

Care should be taken when using radar on ground: Radar can cause damage to the human body.

This new technology has higher attenuation, and therefore a decreased ability to determine if there are weather cells with high levels of precipitations. Consequently, the X band radars are intended to be used as weather avoidance tools and not as tools for penetrating adverse weather.

Future weather radars will be fitted with:

- An auto-tilt function, that will set the radar antenna tilt automatically according to the altitude of the aircraft (see paragraph IV.1)
- An auto-scanning function, that will continuously scan both vertically and horizontally along the aircraft's intended trajectory, and will store and display a three-dimensional weather representation.

IV Operational Standards - Best Practices

Weather reports, provided at flight dispatch (e.g. SIGMET), as well as in flight (e.g. VOLMET, ATIS), inform the flight crew of potential in-flight weather. The best way to use a weather radar is to use it in conjunction with weather reports and weather forecasts. The weather radar can then be used in flight to detect, analyze, and to avoid significant weather.

The flight crew uses four features to operate the radar:

- **Antenna tilt**, that is the angle between the centre of the beam and the horizon
- **Range** control of the ND, that has an essential influence on the optimum tilt setting
- **Gain** control, that adjusts the sensitivity of the receiver (and should usually be set to AUTO). The sensitivity of the receiver may vary from one type of radar system to another
- **Radar modes**: weather (WX), weather + turbulence (WX + T).

IV.1 Antenna Tilt

On all weather radars, and more particularly on X-band/flat antenna weather radars, effective management of the antenna tilt, along with adequate selection of the ND range, will avoid over/underscanning, thus ensuring optimum detection and visualization of weather on the ND.

Indeed, the returns displayed on the ND are cells that are cut by the radar beam. The ND does not represent the cells at aircraft level. Antenna tilt should be taken into account in order to clearly understand the weather radar display (**Figure 9**).

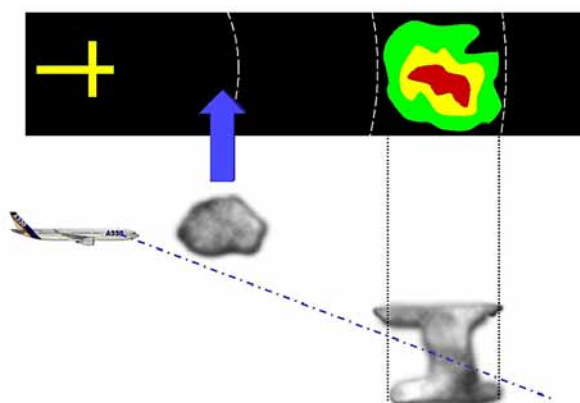


Figure 9

Display along Radar Beam

When flying towards a cell, the flight crew can get an estimate of the vertical expansion of the cloud above/below the aircraft altitude with the following formula:

$$h \text{ (feet)} \sim d(\text{NM}) \times \text{Tilt (degrees)} \times 100$$

Tilt represents the tilt selected so that the cell image disappears from the display.

For example, an echo disappearing at 40 NM with 1° tilt down has a top located 4 000 ft below the aircraft level (Figure 10).

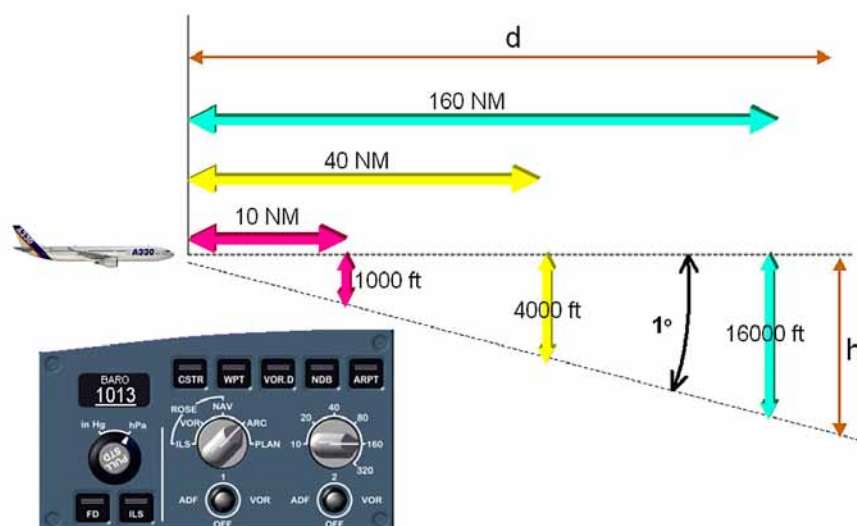


Figure 10

Relationship between Distance / Tilt / Height

Antenna tilt should be adapted to the ND range selection. In most cases in flight, the adequate antenna tilt setting shows some ground returns at the top edge of the ND. However, at takeoff, or in climb, the tilt should be set up if adverse weather is expected above the aircraft. The antenna tilt must be adjusted as the flight progresses, in relation to the aircraft's altitude, the expected weather and the ND range selection.

In order to avoid overscanning or underscanning, the antenna tilt should be changed periodically when changing altitude, unless the weather radar is fitted with an auto-tilt function (**Figure 11**).

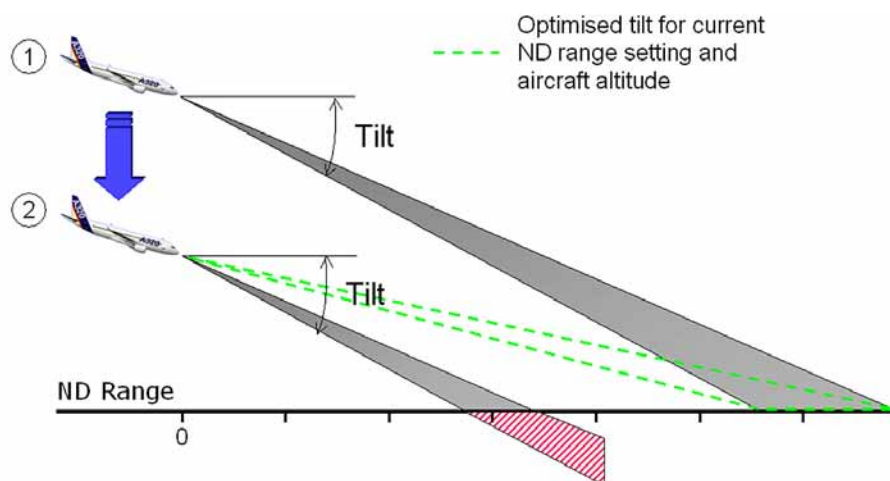


Figure 11

Level Change / Tilt adjustment

Weather echoes and ground returns are difficult to differentiate. A change in antenna tilt rapidly changes the shape and color of ground returns and eventually causes them to disappear. This is not the case for weather echoes. Some weather radars are fitted with a Ground Clutter Suppress (GCS) function that suppresses the ground return from the display, when turned ON.

Upper levels of a Cb may contain ice, and therefore may return radar images that do not represent the severity of its activity. In order to get a better weather detection, weather radar antenna should be pointed toward lower levels, where water can still be found, i.e. at levels that are below freezing (**Figure 12**). If a red area is found at a lower level, the antenna tilt should be reduced to scan the area vertically. Presence of yellow or green areas at higher altitude, above a red cell, is an indication of a very turbulent area. If such an area is detected above FL 250, no overflying should be attempted.

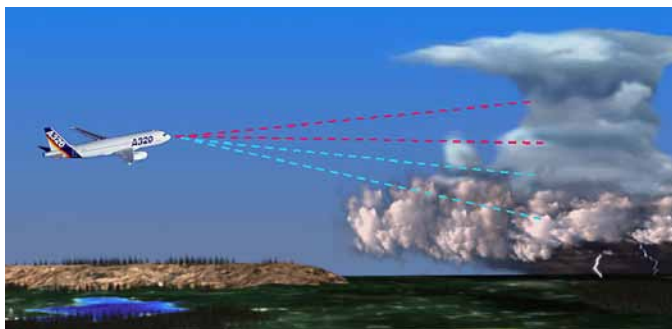


Figure 12
Storm Scanning

IV.2 Display Range

To avoid a large storm, the flight crew must make decisions while still 40 NM away from it. Therefore, the flight crew should select adequate ranges on the NDs:

- PNF adequate ranges to plan long-term weather avoidance course changes (in cruise, typically 160 NM and below)
- PF adequate ranges to tactically avoid adverse weather, and monitor its severity (in cruise, typically 80 NM and below).

Course changes to avoid adverse weather, should be determined using both higher and lower ranges. This technique prevents the “blind alley” effect: A course change that may seem safe when using a low range ND display may reveal a blocked passage when observed at a higher range (**Figure 13**).

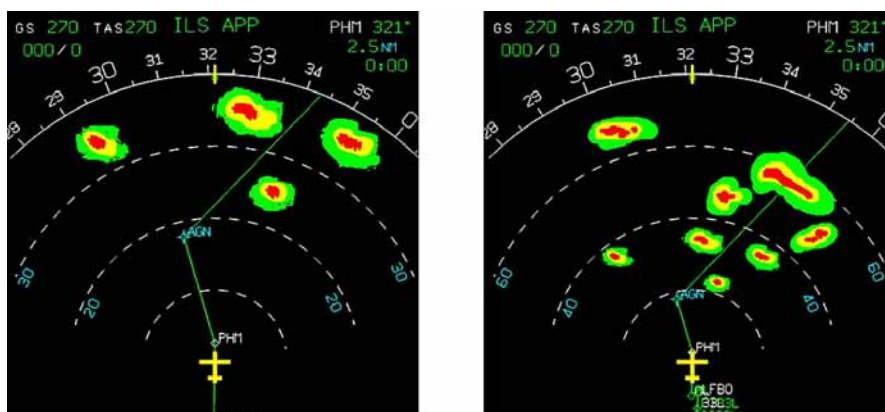


Figure 13
Blind Alley Effect

As indicated in paragraph IV.1, antenna tilt should be adapted to range selection. To cover the whole area shown on the ND, the weather radar must have a slightly negative antenna tilt in order to avoid overscanning. A correct setting will show some ground return at the top edge of the ND.

IV.3 Gain

The GAIN knob on the weather radar panel adjusts the receiver sensitivity. In the AUTO position, the gain is in the optimum position to detect standard thunderstorm cells.

A manual setting is available and can be used to analyze the weather.

In general, the AUTO position should be used, except for cell evaluation. If gain is used manually for in-depth weather analysis, it must be reset to CAL (AUTO) when analysis is complete.

Gain Reduction

At lower altitudes, cells are more reflective and the weather radar display may have a tendency to show a lot of red spots. This can also be the case at higher altitude with severe Cbs. In this case, decreasing gain:

- Can help to judge the relative intensity between two cells
- Can help to highlight turbulent cells, because the turbulence display is not affected by gain in turbulence display mode
- Can be useful for finding embedded cells, in heavy stratus rain
- Can render attenuation more visible, helping to identify very active cells.

Gain reduction allows the detection of the strongest part of a cell, displayed in red on the ND. By slowly reducing the gain, most red areas slowly turn yellow, the yellow areas turn green and the green areas slowly disappear. The remaining red areas, the red areas that are the last to turn yellow are the strongest parts of the cell and **must be avoided at the greatest distance possible** (Figure 14).

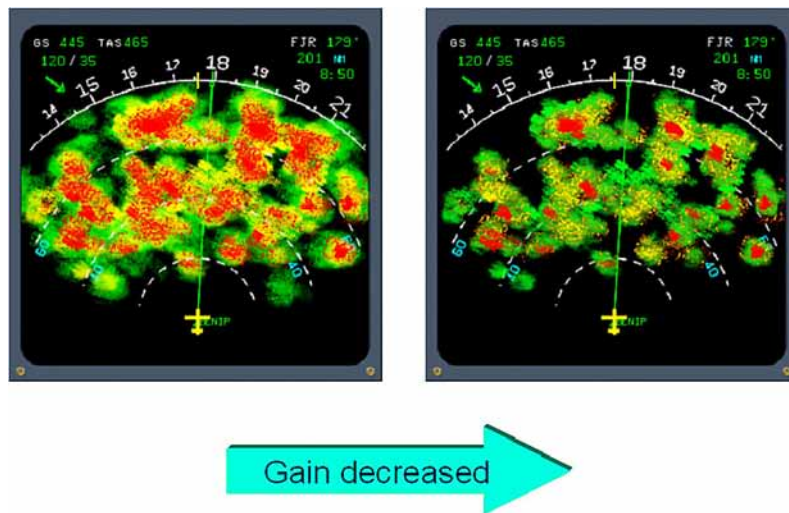


Figure 14

Effect of Gain Reduction

Note:

In MAP mode, the gain should always be reduced because of the high reflectivity of the ground.

Gain Augmentation

At high altitudes, water particles are frozen and clouds are less reflective. Gain may be increased for storm evaluation purposes.

V Operational and Human Factors Affecting Optimum Use of Weather Radar

The weather radar display may be wrongly disregarded by the flight crew (who may decide to enter clouds) in the following conditions:

- Near the destination airport
- When following an other aircraft
- When more than 15 minutes behind schedule
- At night.

On the other hand, and as explained before, the weather radar, if not correctly used or interpreted, may mislead the flight crew when:

- An area of strong activity is hidden behind heavy rain
- A small ND range is not sufficient for the flight crew to determine if an elected trajectory between clouds is blocked by adverse weather further ahead
- Dry hail precipitation returns a weaker echo than water droplets
- The antenna tilt is not correctly adjusted
- Gain is left in a manual position.

VI Prevention Strategies

A weather radar is a tool for detecting and avoiding adverse weather and turbulence. As with any other tool, adequate skills are needed in order to use it efficiently. Each type of radar has its own particularities, and does not display a given weather situation in the same way as another type of weather radar. These particularities are outlined in the weather radar user guide. It is therefore necessary to study the manufacturer's user guide, in order to gain a good knowledge of the weather radar capabilities and limitations.

The shape of radar echoes, as well as their color, should be observed to identify storms containing hail. The gain function should be used for deeper analysis, but should then be reset to the CAL or AUTO position. The TURB function can be used when closing in on active weather to identify the most turbulent area.

The flight crew should periodically scan:

- Vertically, using the antenna tilt function
- Horizontally, using the range change.

As a general rule, the following prevention strategies apply:

- Use the weather radar to detect/analyze/avoid significant weather
- The shape/colour/size of returns are factors that should be considered to interpret the weather
- Effective management of the antenna tilt along with an appropriate ND range selection, are key tools to obtaining an informative weather radar display on the ND
- Gain is used in CAL/AUTO mode for detection and initial evaluation of displayed weather: Manual gain control is used to analyze the weather
- Wet turbulence can be detected up to 40 NM with the TURB function.

Airlines should provide information and recommendations on the use of radar to their flight crews for each flight phase. A typical example of recommendations that could be provided is as follows:

Phase	Recommendations	Remarks
Taxi	Set ND to 10 NM range Tilt down, then up: Check appearance / disappearance of ground returns	<i>Radar check must be performed away from people</i>
Takeoff	Scan up to 15° UP for weather return, if significant weather is suspected Select tilt at 4° UP for takeoff	<i>Scan along the departure path</i>
Climb	Select negative tilt, maintain ground returns on top of ND as the aircraft climbs	<i>Change tilt according to altitude and ND range.</i>
Cruise	Select negative tilt and maintain ground returns on top of ND. As a rule of thumb: Range 320: tilt 1 DN Range 160: tilt 1.5 DN Range 80: tilt 3.5 DN Range 40: tilt 6 DN When approaching weather: - Decrease ND range - Tilt down - Use TURB to isolate turbulence - GAIN to AUTO	<i>No ground returns beyond line of sight</i> <i>FL370 => 240 NM</i> <i>FL250 => 200 NM</i>
Descent	<u>Above FL150</u> Every 10 000 ft: Adjust tilt upward to maintain ground returns on top of ND (~ +1°/10 000 ft) <u>Below FL150</u> Every 5 000 ft: Adjust tilt upward to maintain ground returns on top of ND (~ +1°/5 000 ft)	
Approach	Select tilt at 4° UP	<i>To avoid ground returns</i>

VII Summary of Key Points

The following key points should be emphasized:

- Weather radars are designed for active weather detection
- Antenna tilt, range management and gain function need to be fully understood to use the weather radar effectively
- Radar display colors reflect humidity in the air and not necessarily turbulence intensity: A red cell in a humid atmosphere may be less turbulent than a yellow one in dry air
- The TURB function should be used to identify the most turbulent cells within 40 NM.

VIII Additional Reading Material / Website References

- Honeywell (RDR-4B) User's Manual with Radar Operating Guidelines
http://www.flwsradar.com/Tech_Lit/Pilots_Guide/Pguide_main.htm
- Rockwell Collins Weather Radar Pilot's Guide

This FOBN is part of a set of Flight Operations Briefing Notes that provide an overview of the applicable standards, flying techniques and best practices, operational and human factors, suggested company prevention strategies and personal lines-of-defense related to major threats and hazards to flight operations safety.

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