Understanding Airborne Weather Radar

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The objective of this guide is to re-enforce and add to the Aviation students' knowledge of weather (Meteorology) and Weather Radar systems to enable them to interpret and utilize, intelligently, the Weather Radar display onboard their aircraft.

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On April 4, 1977, a Southern Airways DC-9 crashed killing 62 people onboard and eight people on the ground. The factual cause of the crash was that the crew misinterpreted a radar shadow as a hole in a line of thunderstorms. They inadvertently flew the aircraft into the heart of the storm and encountered such heavy precipitation, turbulence and hail that both engines failed, and the aircraft crashed. These were two well-trained, experienced and capable pilots who like many of us simply didn't understand or know of the many limitations of Airborne Weather Radar.

On June 9, 2006, Asiana flight 8942, an Airbus 321 en route from Jeju International Airport to Gimpo International Airport, encountered a thunderstorm accompanied by hailstones around 20 miles southeast of Anyang VOR at an altitude of 11,500 ft during descending to approach Gimpo Airport. The radome of the aircraft was detached and the cockpit windshield was cracked due to impact with ice stones carried by the thunderstorm.

In the thirty years between these two incidents – and hundreds of other incidents in between - Weather Radar remains a mystery to many of us.

This guide contains a collection of information and recommendations from official Airbus, Boeing and other aircrafts manufacturers FCOM's and POH's, several weather service providers and NASA. Although most of the references in this guide refer to the Airbus, all other types of weather radar equipment on aircraft are very similar and operate in the same manner with only the controls and some "points" of technology being different.

This guide covers and introduces the reader to;

- Conventional Weather Radar Systems
- Auto-Tilt Radar Systems, and
- Some of the functions of the MultiScan Fully Automatic Weather Radar System (Multi-Scan).

> *MultiScan is a radar/ turbulence emulator which scans multiple levels into it's computer memory, then considers temperature, altitude, terrain, wind and other factors, and finally displays turbulence predications onto the ND in the form of green, amble and red 'radar returns'.*

In addition to the official Airbus data, supplemental information from each Weather Radar manufactures' (Bendix & Collins) documentation is included. All the technical data and recommendations contained herein are directly quoted from those official sources.

I've enjoyed over 30 years of in-flight experience in a variety of different aircraft including Airbus, Boeing and Douglas as well as several medium-sized Turbojet, Turboprop and various small and large Piston Aircraft. I'm an experienced Flight and Ground Instructor; certified under the Canadian Aviation Regulations as a Flight Operations Manager, and have been qualified as an Aircraft Maintenance and Structures Engineer. I hold ATPL licenses in 7 different countries

> *I will use the official aircraft manufacture's information, recommendations and procedures as contained in their manuals. However, when my own experience or personal opinions are included, those statements will be written in italic, so as to differentiate those comments from the manufactures official recommendations.*

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This manual is <u>not</u> a complete Aviation Weather course. The material in this guide <u>only scratches the surface</u> of the total meteorological and Weather Radar Systems subject.

Because English is the second language of a great number of the pilots that I come into contact with, and in an effort to keep this guide as concise and simple as possible, if a specific item is "…not recommended…" or "…recommended…" by the manufacture, no further explanation will be offered. Simply, do as "recommended" without second guessing the WXR systems designers and manufactures' instructions. They really do know what's best; after all, they build the darn things.

Regarding copyrights and material ownership; as stated earlier, this guide is a collection of information available from various companies and sources, and it is compiled and offered free of charge in the interest of flight safety.

<u>The liability disclaimer:</u>

The reader should be FULLY knowledgeable with their specific aircrafts' operating manuals, systems and limitations. Although (as mentioned several times previously) this guide is a collection of various manufactures procedures, recommendations and support data, I cannot be held liable for any consequences resulting from the use of this guide whatsoever.

Finally, my employer is/was not involved in the publication of this guide and this guide shall not in any way be associated with my present, or any past, employer(s).

This is NOT an official publication; it is not subject to any revision control and may or may not, be updated or revised.

General information from the Airbus and Boeing Manuals

Weather Radar (WXR) provides the pilot with a tool for detecting hazardous weather during flight. WXR is nothing more than a precipitation detector. How much precipitation it detects depends upon the raindrops; their size; composition; and quantity*.

> **Actually, it depends on the precipitation's molecular structure which changes depending on its various states, i.e.: Dry, Wet, or a little of both.*

Although more and more aircraft are equipped with one or two weather radar systems, flight into moderate or severe turbulence associated with CB's still occurs, resulting in injuries, aircraft damage and deaths.

Regardless of the type and amount of safety equipment installed in an aircraft, if the pilots don't know how to properly use that equipment, it's not worth having it in the first place.

It's also a fact, that decisions made based on the weather images on the display will vary depending upon the pilots interpretation of those images; thus on the crews experience, meteorological knowledge and their knowledge of what a WXR system can and cannot do.

What WXR does not detect;

- Cirrus type clouds, fog or wind (small or no precipitation droplets),
- Clear Air Turbulence (CAT) or Windshear,
- *Sandstorms, or*
- *Lightening.*

What WXR does detect:

- Rain,
- Wet hail and wet snow,
- Ice crystals, dry hail and dry snow but above 30,000 feet these will only give VERY small reflections, therefore they do NOT provide an accurate representation of the actual weather conditions.

Note:
The reflection of water particles (Rain) is 5 times greater than ice particles of the same size.

> *This is due to the differences in the atomic structure of the molecules when in their different forms (Liquid or Frozen). Obviously, this implies that knowing the location of the freezing level is one of the first requirements for effectively detecting weather in flight.*

Operational Functions

The three Weather Radar System functions that pilots must understand in order to take full advantage of the WXR are:

- **Tilt:**
  - The angle between the radar antenna and the horizon, irrespective of the aircraft pitch and bank angles,
    - The antenna is stabilized by IRS data.
  - It is appropriate*, and generally necessary;* to tilt the radar to a value that provides a ground return on the top of the display (ND).
    - If AUTO TILT or MULTISCAN in installed, selecting AUTO ensures proper tilt management along the flight, *although the displayed tilt values may NOT correspond to the tilt values recommended for Conventional Weather Radar Systems.*

- **Range control:**
  - Which in co-ordination with tilt governs the range of the navigation display.

- **Gain Control:**
  - Which adjusts the sensitivity of the receiver and should be set to AUTO or CAL.
    - Manually adjusting gain can provide details not otherwise obvious by providing information that may help in determining the **LEAST WORST** path through an area of hazardous weather.
    - Manipulating the gain will, more often than not, be hazardous since the threatening weather will now be understated when GAIN is used incorrectly.
  - The sensitivity may vary from one type of radar system to another.

Colour Code

- Black
  - The lowest intensity level (nothing appears on the display)
- Green
  - Light Turbulence and/precipitation
- Amber
  - Moderate Turbulence / Precipitation
- Red
  - Severe Turbulence / Precipitation
- Magenta
  - Severe Turbulence and horizontal Shears (WXR & TURBO mode)

Split Control Feature (Optional)

The dual-mode control panel (Figure 1) has split control that allows for different gain and tilt settings to be individually selected for left and right HSl's. If different tilt settings are selected, the antenna scans left to right at the tilt angle selected by the left mode, adjusts to the tilt angle selected by the right mode, and scans right to left at that angle.

Detection and Interpretation

The pilots should monitor the weather at long range (80 – 160 miles), as well at shorter ranges (40-80 miles), in order to effectively plan course changes, and to avoid weather-defined blind alleys and box canyons *(the black areas that killed those people on the Southern Airways Flight mentioned earlier).*

Gradient and Contour

The steeper the 'gradient of rainfall' rate, the stronger the turbulence and the greater possibility of Hail *(we'll talk more about this later).*

To use the radar effectively, the pilots should select the following ranges on the displays (ND's).

- 160 NM (80 NM) on the Pilot Not Flying (PNF)
- 80 NM (40 NM) on the Pilot Flying (PF)

Pilots need to remember that CRM is paramount when evaluating weather. Each ND is a tool for the purpose of conducting the safest flight possible. It's not a case of "...your ND and my ND," they must be used together.

To avoid dangerous weather conditions, the pilots must make decisions while still 40 NM from large storms.

Therefore, the pilots should:

- Avoid Red areas and fringes by at least;
  - 20 NM when flying above FL230, and
  - 10 NM when below FL230,

- Re-adjust Tilt appropriately in order to accurately monitor storm development and to see the best cell echo (the most accurate return), and remember that failure to accurately tilt the radar will cause the target to disappear.

Pilots should not attempt to penetrate a CB, or clear its top, by **less than 5000 feet;** otherwise the aircraft may likely encounter severe turbulence. If the CB top is above 25,000 feet, overflying should be avoided due to the possibility of encountering severe turbulence above the CB. In the same way, pilots should avoid flying under a thunderstorm because of possible Windshear, microburst's, severe turbulence, or hail.

This is the end of the information from Airbus and Boeing.

Understanding Airborne Weather Radar

General

Modern Weather Radar Systems consist of;

- A receiver / transmitter (RT) unit,
- A flat plate antenna, and a
- A mode control panel.

The radar system displays weather and ground targets on the pilot's ND (Navigation Display) or HSI (Horizontal Situation Indicator).

Antenna

The antenna scans 90 degrees to either side of the airplane's heading (not its track) and can tilt from **15 degrees above to 15 degrees below** the horizon (regardless of the aircraft pitch). Stabilized electric stepper motors that provide precise control of the antenna's azimuth and elevation drive the antenna. Antenna stabilization corrects for pitch and roll of the airplane, with some limitations. Normally, one of the Inertial Reference Units (IRU's) provides stabilization (The Left IRU on the Boeings, and IR 1 on the Airbus).

The Weather Radar determines turbulent areas by measuring precipitation size and velocity, which it can only do in the presence of precipitation. Consequently, the system is not capable of detecting clear air turbulence (CAT).

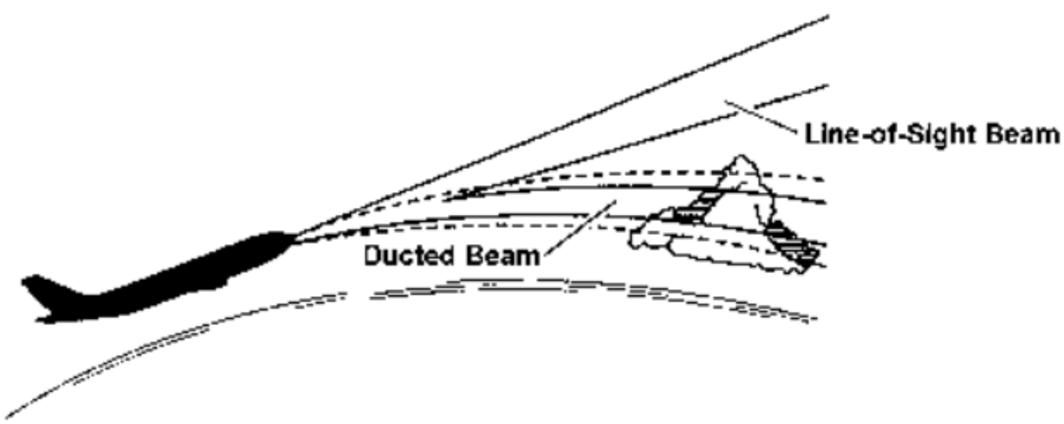
Other information from the aircraft's IRUs is available to the pilots, which allow them to somewhat accurately determine the location and likelihood of in-flight turbulence that is not associated with Thunderstorms. A discussion of this information is outside the scope of this tutorial.

Cloud Types:

- High-Level Clouds
  - Cloud types include: cirrus and cirrostratus.
- Mid-Level Clouds
  - Cloud types include: altocumulus, altostratus.
- Low-Level Clouds
  - Cloud types include: nimbostratus and stratocumulus.
- Clouds with Vertical Development
  - Cloud types include: fair weather cumulus and cumulonimbus.
- Other Cloud Types
  - Cloud types include: contrails, billow clouds, mammatus, orographic and pileus clouds.

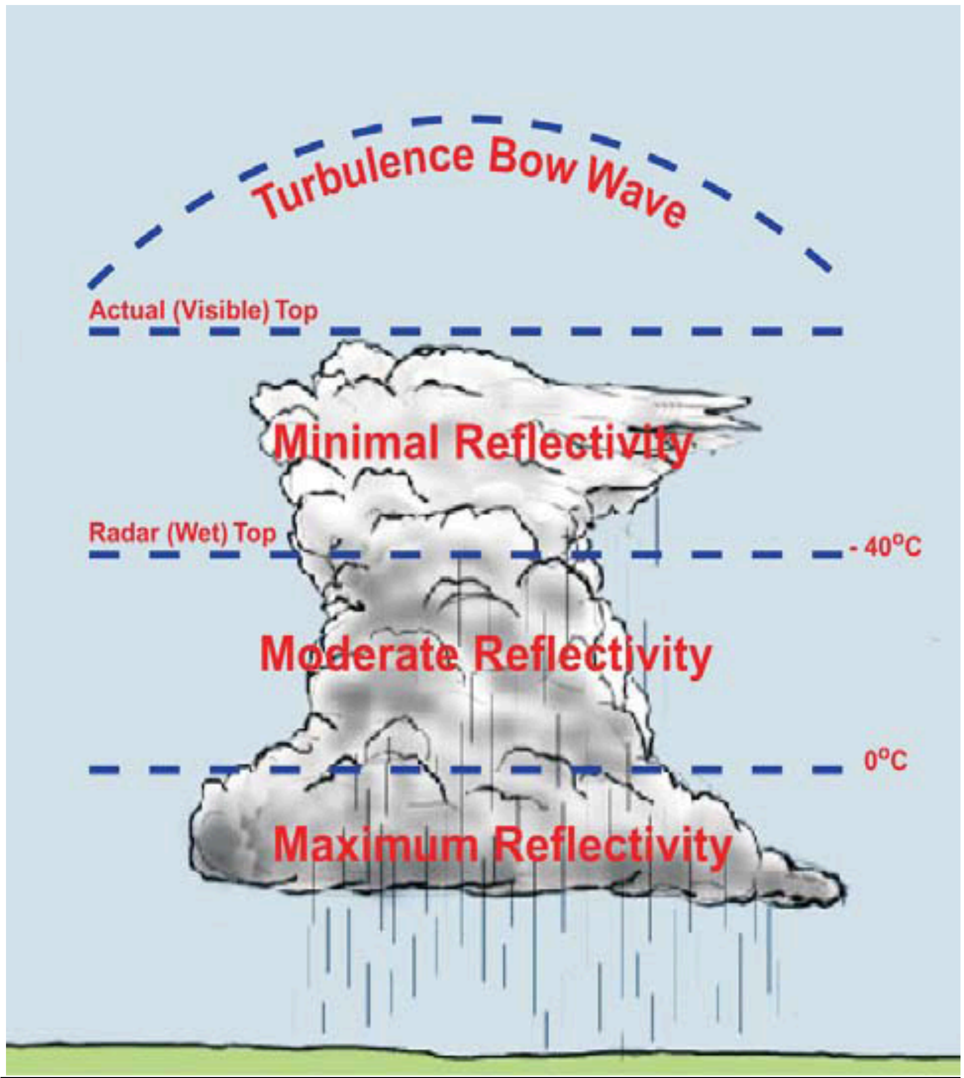
Some clouds, often of the cirrus, cumulus, and stratus types, do not contain sufficient moisture to reflect a detectable return; however, these clouds are not usually a hazard to flight.

> *A non-hazardous phenomenon that is occasionally encountered is ducting of radar signals. This occurs with certain temperatures and humidity conditions that cause targets to be detected at distances farther than normal. A duct, or broad-tunnel, that guides radar signals in a curving path, can be formed when temperature increases and humidity decreases with altitude. These gradients occur in inversion conditions and will likely not remain stable for a long period of time.*
>
> *The radar signals must be located in or close to the duct to be trapped. Signals at an angle one or two degree or more to the duct are not trapped. However, elevating the antenna a few degrees gets the beam out of the duct. With this technique, distant thunderstorms can be differentiated from ducted ground echoes that may be mistaken for cloud targets.*



<u>THUNDERSTORM REFLECTIVITY</u>

A thunderstorm (CB) is composed of three parts, each with different weather radar reflectivity characteristics as shown below.



The bottom portion of the storm, below the freezing level, is composed entirely of liquid precipitation (i.e. rain) and is the most reflective portion of the storm.

The middle portion of a thunderstorm occurs above the freezing level (0° C) and up to the altitude where the outside air temperature drops below –40° C. This section of the storm is composed of a combination of ice crystals and super cooled water. The super cooled water provides moderate reflectivity, but some reflective energy will be lost due to the presence of the ice crystals. The top of this section of the storm is often referred to as the wet top or radar top of the thunderstorm because the radar detects very little of the thunderstorm above this point.

The top of a thunderstorm is composed entirely of ice crystals and reflects very little radar energy.

Historically, pilots were trained to be believe that at temperatures lower than minus -40° C, only ice crystals were present which were of no consequence to airline operations. Recent studies and data show that "Ice crystal" icing conditions have been recognized as a hazard to turbofan engines, as ice has been found to build up deep in the engine core at temperatures well below –40° C, and have caused engine power-loss events

Further details regarding high-altitude icing are located in the appendix, or by contacting Jeanne Mason at jeanne.g.mason@boeing.com

The altitude at which this temperature occurs varies depending on the time of day, time of year, and on latitude.

The top of this section of the storm is referred to as the actual or visible top *(visible **only** to the naked eye, **not** to a WXR system)*.

Thunderstorms can grow as rapidly as 6,000 feet per minute, so any images or gleamed information will quickly become "old news". Developing thunderstorms have a turbulence bow-wave that may extend several thousand feet above the visible top of the storm. The bow-wave may cause severe turbulence but is completely invisible to radar. It is important to note that significant turbulence may exist well above the radar top of the thunderstorm. Most important, Pilots must evaluate hazardous weather not only with respect to what it is now, but what it may become.

Compare a thunderstorm to a small fire burning on the ground. Fires are always in a constant state of change, and no two fires are exactly the same. Thunderstorms are no different. First there's a spark that gets them started, then the fuel (wood) starts to burn and the fire develops more and more until the fuel (energy) begins to run out. Physically, you can see the fire's flames, and typically those flames will be visible to a height nearly proportional to the triple the diameter of the fire.

Thunderstorms are the same. First, there's a "spark" in the form of favourable atmospheric conditions (Cumulous Stage). Then, the fuel gets introduced in the form of released latent heat as the associated water vapour condenses (Mature Stage). When the fuel runs out, the thunderstorm begins to subside (Dissipating Stage).

Back to the fire.... Those <u>visible</u> flames can be considered as the reflective <u>"Precipitation"</u> in a thunderstorm. If you put your hand into those flames, you'd get burnt, but not all that badly as that part of fire's flame is considered a "cold flame," In the Thunderstorm it's where all the warm water is.

Raise your hand a little and touch the tops of the flames. In relation to our thunderstorm, you could consider this as the "freezing Level". In the fire this is the point where your hand is going to be badly burnt, as this is the hottest part of the fire, and in the Thunderstorm, is the freezing level. This is the area that you want to scan thoroughly, so that you can be sure that you are getting a good picture of the "Fuel" in this fire (the storms intensity).

Now move your hand about a meter above the visible flames in our imaginary fire. Remember, the tops of the visible flames in our fire equate to the "Freezing Level" in a thunderstorm, but the heat continues to rise with great intensity carrying with it particles of smoke, soot, ashes and burning cinders (i.e. Cold Rain, Ice Crystals and Hail).

Now raise your hand several meters above the fire. It's still very hot and you can feel the heat and rising air even several metres above the fire. You may even find some of the hot cinders (Hail) rising with this column of heated air. This is the area all the way up to the top of the thunderstorms Bow-Wave. There are no flames visible at this height, and on your Radar there are NO returns displayed, but there WILL be turbulence and its intensity will be relative to the heat in our fire that you're feeling as you raise your hand higher and higher above the visible flame, in other words, above the reflective area of the storm.

In fact, you'd have to raise your hand a significant distance (several meters or more) above the visible flames until you could no longer feel any heat, or until you could no longer feel any turbulence. Relative to the diameter of the fire, you'd be holding your hand at least 3 -5 times higher than the tops of the visible flames. Now imagine a thunderstorm cell that is only 2-3 NM in diameter. The altitude where the turbulence finally ceased would be from to 6 to 10 miles up (35000 – 60000 feet). Further up than some aircraft can fly.

To assess the possibility of overflying this thunderstorm cell you'd have to tilt your radar down considerably into the 'Reflective' part of the storm to see a return from which you could determine the amount of turbulence to expect at your flight level. Remember, that rising heat is the turbulence that you're trying to avoid. And, just as smoke rises above our fire, so rise the Hail, Ice and other stuff that thunderstorms are known for. Also remember, that super-cooled water does exist above the freezing level and causes sever in-flight icing and engine power loss.

Serious injury and death have occurred due to inadvertent penetration of thunderstorm tops, or the turbulence bow wave, that an inexperienced radar user failed to detect.

It's important to note that reflectivity of the 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. The 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 then the mid-latitude convective cells, making them much harder to detect. However turbulence in or above such clouds may have a much higher intensity than indicated by the image on the weather radar display.

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

Pollution and high levels of water vapour have similar effects. Examples can be seen over places like: Beijing, Shenzhen, and several other developing cities.

CALIBRATED GAIN COLOUR SCHEME

At a basic level, weather radar measures the amount of moisture present in the atmosphere, ***in the area where the radar beam is focused***. Calibrated gain within the weather radar's circuitry associates these different amounts of moisture (or rainfall rates) with a particular colour level on a weather radar display. For instance, green represents a weak rainfall rate of 0.03 to 0.15 inches per hour (in/hr); while red represents a rainfall rate that is greater than 0.5 in/hr. Note that black is also a colour level. Black on a weather radar display does not mean that weather is not present (although this may be the case); it simply means that the rainfall rate is less than 0.03 in/hr.

Also note that each colour level represents a change of 10 dB (green is 20 dB, yellow is 30 dB, and red is 40 dB or greater). Therefore, changing the gain by 10 dB above or below the CAL setting will change the display by one colour level. Magenta represents turbulent airflow that, in essence, represents variations in raindrop movement of greater than 5 meters/second.

GAIN CONTROL SETTINGS

The Calibrated (CAL) position sets the radar sensitivity to the standard calibrated reflectivity levels <u>and is the recommended position for normal operation</u>.

If desired - and provided the WXR user has a <u>thorough</u> understanding - the radar gain may be adjusted to **<u>DECREASE</u>** sensitivity by rotating the GAIN control counter clockwise from the CAL position or, when operating over oceanic areas, to increase the sensitivity by rotating the GAIN control clockwise from the CAL position.

However, it is recommended by all WXR manufactures to leave the GAIN in CAL or AUTO.

> **<u>Note:</u>** Airbus specifically states in their Flight Operations Briefing Notes, "…if not used correctly *the displayed images* may mislead the crew when GAIN is left in a manual position…"

Depending on the specific WXR unit, selecting GAIN to any position other than CAL or AUTO, will turn off various safety features, such as:

- the Path Attenuation Compensator (PAC) or,
- the OverFlight protection.

OverFlight Protection (MultiScan Systems)

OverFlight protection is designed to prevent thunderstorms that are in the aircraft flight path from falling below the radar beam and off the radar display during high altitude cruising.

At extended ranges the upper radar beam scans the wet, reflective portion of a thunderstorm in the same manner that conventional radars scan weather. As the aircraft approaches the storm and the cell begins to fall below the upper radar beam; MultiScan utilizes 6,000 feet of bottom beam information to keep the reflective part of the storm in view.

Within approximately 25 NM of the aircraft, MultiScan compares the stored digital image of the thunderstorm with the latest sweep information and displays whichever return is greater. If a cell that is a threat to the aircraft begins to fall below the radar beam, MultiScan displays the stored digital image of the storm, thus ensuring that any threatening thunderstorm will remain on the display until it moves behind the aircraft.

OverFlight protection is operational above 22,000 feet MSL.

With conventional or Auto-tilt WX Radar systems the pilots must maintain a mental awareness of over- flight conditions and protect themselves and their aircraft from the consequences.

EFFECTS OF GAIN SELECTION

MAX gain is equivalent to an approximately 1.5x colour level increase. MIN gain is equivalent to an approximately 0.5 colour level decrease.

Other Controls

TURB: *This mode can detect turbulence under certain conditions but is also plagued with several limitations. Armed with correct knowledge, pilots can use turbulence mode to their advantage while avoiding the biggest operational problem - over-reliance. How turbulence is displayed varies by the various manufactures, which itself can cause confusion.*

MAP: *Terrain mapping should be done with the MAP mode selected, one of the shorter ranges selected, and the antenna tilted down. The gain may require adjustment to increase ground return in the display.*

The interpretation of terrain maps displayed on the indicator is largely a matter of experience and understanding of the factors involved when the radar beam strikes a ground target. The extent to which ground targets are displayed depends upon the selected range, antenna tilt, and airplane altitude and attitude.

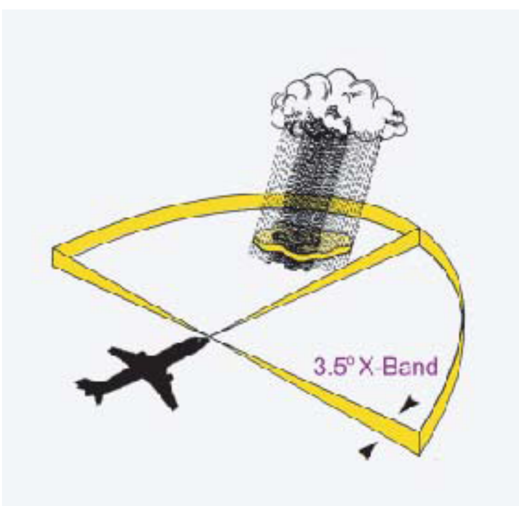
Proper interpretation of ground targets by the pilot make the weather radar system a valuable tool on the flight deck, performing not only the functions *from advance warning of thunderstorms, but also to a backup navigation system providing a geographic position fix. However, the capabilities and limitations of the radar system must be thoroughly understood and remembered.*

RADAR BEAM CHARACTERISTICS

Although antennas come is a variety of sizes, the typical Airbus/Boeing radar uses an approx 28-31 inches (71- 77cm) antenna that produces 2.8 to 3.5-degree wide beam. As the beam sweeps through a thunderstorm at close range (Less than 80 NM), it takes a "slice" out of the target and then displays that slice on the radar display. The displayed weather presentation can change significantly based on the selected radar tilt and from where in the storm the slice is taken from.

> ***Note:*** *There is an inverse relationship between antenna diameter and radar beam diameter.* ***Generally, a 30-inch antenna generates an approximate 3-degree beam****, where a 12-inch antenna would generate an approximate 20-degree beam.*

Weather Radar Beam "Slice" and Resulting Display example;



BEAM DIAMETER

A 28-inch flat-plate antenna produces a 3.5°-wide beam. At ranges less than 80 NM, this produces a fairly narrow and well-focused beam. Beyond 80 NM, the beam diameter increases until at 300 NM it is equal to 105,000 feet. To put this into perspective, at this distance, it would take a storm cell over 22 NM tall **and** equally as wide.

In other words, beyond 80 NM, WXR is not very accurate. MultiScan is the exception to this rule.

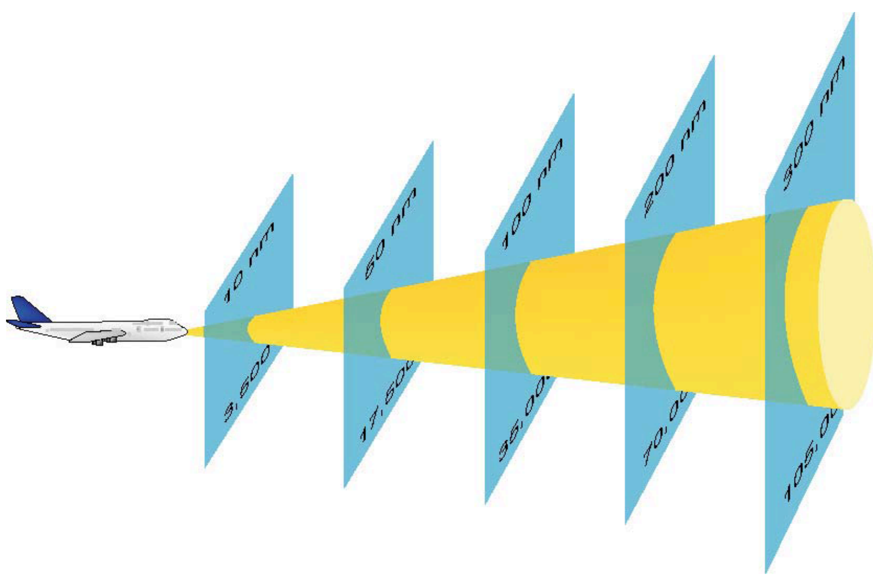
Because the beam remains fairly focused within 80 NM of the aircraft, it is recommended that weather evaluation be done only when the weather is within 80 NM of the aircraft. Beyond 80 NM, the radar should be used primarily for strategic planning and for weather avoidance.

The following formula can be used to calculate the approximate beam width at any range:

> Beam width (in feet) = (Distance in NM + “00”) x 3.5 For example, to determine the width of the radar beam at 50 NM out from the aircraft, take the 50 NM distance and then add “00” to it for a result of 5,000. Multiply this figure by 3.5 to yield an approximate beam width of 17,500 feet at 50 NM.

Weather Radar Beam Width Increases Over Distance

Fig 1.5

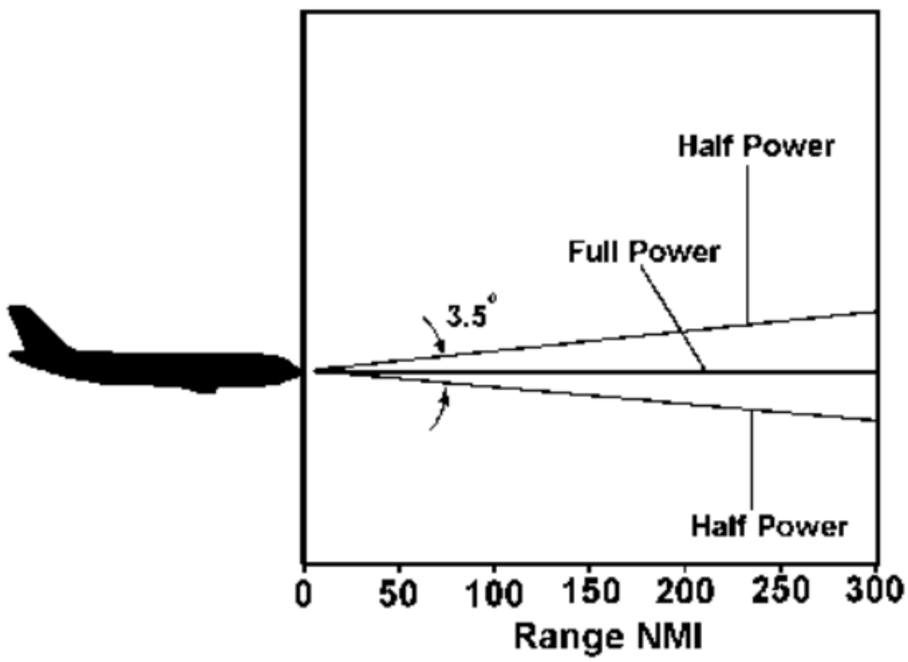


By using the range rings on the Airbus ND or Boeing HSI you can make a close approximation of Radar Beam diameter with the following. Simply triple each of the ranges and add ‘00’ (Approx 3 degrees), i.e.: 40NM Range Ring X 3 = 120 (12000 Feet), 80NM X 3 = 240 (24000 Feet) etc. This quick and dirty calculation will be…close enough!

Incidentally, this same calculation can be used to determine the height of the centre of the Radar beam above or below the horizon. Again, it's a quick and dirty calculation, but it will be pretty darn close.

The transmitted radar beam and the returned signals from precipitation targets provide the weather information to the display. To interpret the display, it is necessary to understand how well the radar sees precipitation targets.

The radar beam covers an area ahead of the airplane as shown in the diagram below. The beam width of the antenna is determined by the width of the beam at the half-power points (antenna has a beam width of 3.5 degrees). The diameter of the beam cross-section becomes very large as the range increases. Therefore, the resolution of the radar is much less at longer distances than at shorter distances.



Once again, beyond 80 NM, the ability of the weather radar to accurately portray weather information becomes weaker and weaker.

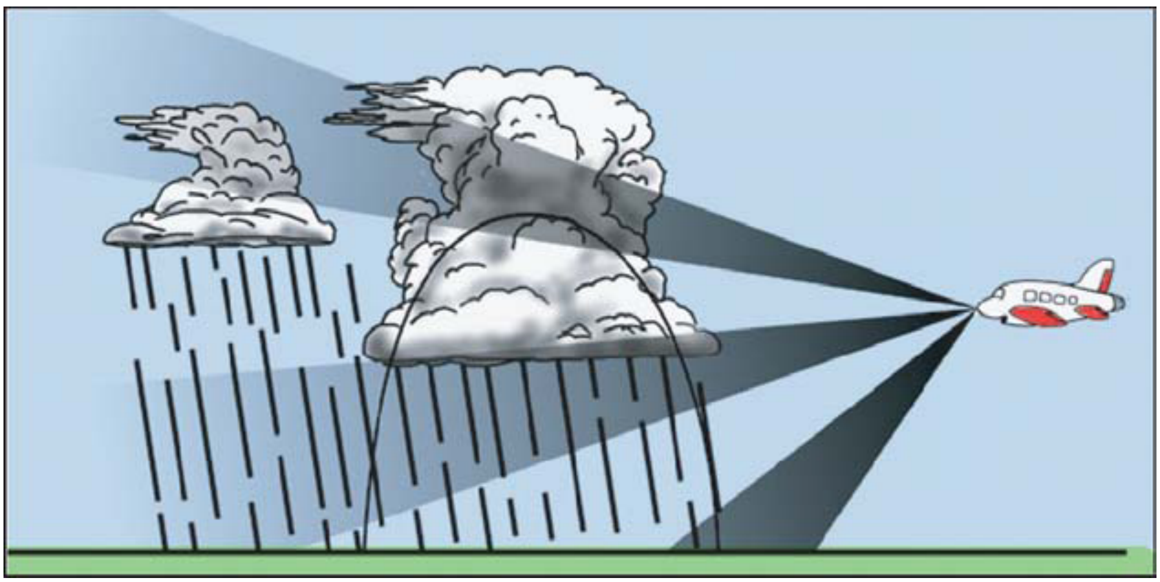
Range and Azimuth resolution & Attenuation

The length of the pulse width and the width of the radar beam affects range and azimuth resolution, respectively. For long-range weather detection, the radar uses a longer pulse width to put more energy on the target.

The longer pulse can cause targets to merge into a single target due to the fact that the front of the pulse may already be in contact with the next target before the trailing edge of the pulse leaves the previous target.

Thus, the pulse appears to be painting one continuous target. Shorter pulse widths are used for close range targets and are thus able to distinguish more precisely between the different weather targets.

Often on the display, more "blocky" looking weather at extended ranges and a more refined weather picture at shorter ranges manifest this.



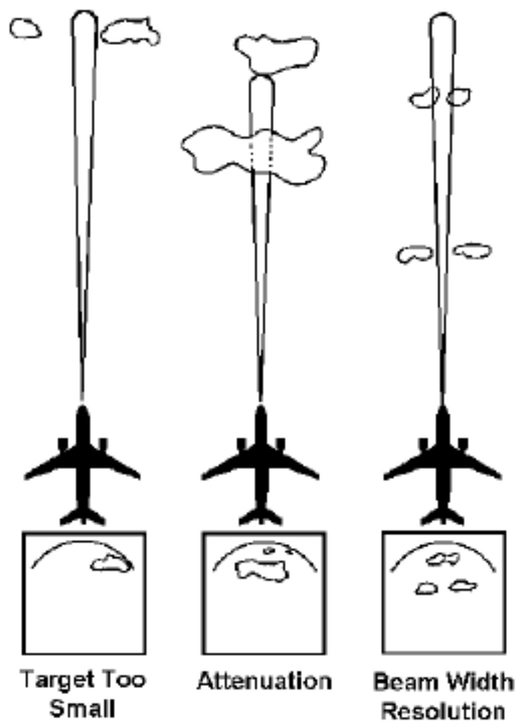
Because the weather radar display depends on signal returns, heavy precipitation may conceal stronger weather. This is because the signal is reflected by the frontal part of the precipitation. The aft part returns weak signals that are displayed as green or black areas. The pilots may interpret these as a weak threat area, when in fact, they would be wrong. <u>This is EXACTLY what happened with the Southern Air flight described earlier in the introduction to this book.</u>

Modern weather radar systems are able to apply a correction to a signal when it is suspected to have 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 an area of hazardous weather.

<u>The attenuation correction function only operates correctly when the GAIN is set to AUTO or CAL</u>.

Attenuation (induced by either range or intervening precipitation) also affects the targets displayed or not displayed on the indicator. It should also be remembered that as the tilt control is used to sweep a storm target, the cell might change in color, not due to a change in precipitation rate, but in the type of precipitation targets encountered.

The important thing to remember is that the targets displayed on the weather radar indicator are large enough and/or intense enough to provide a processable return signal. Return signals from targets beyond a large storm cell are attenuated, and the displayed target does not accurately represent the real storm cell. Two small intense targets may appear to be one, if the beam width is not smaller than the gap between the two targets. The illustration below demonstrates these points:

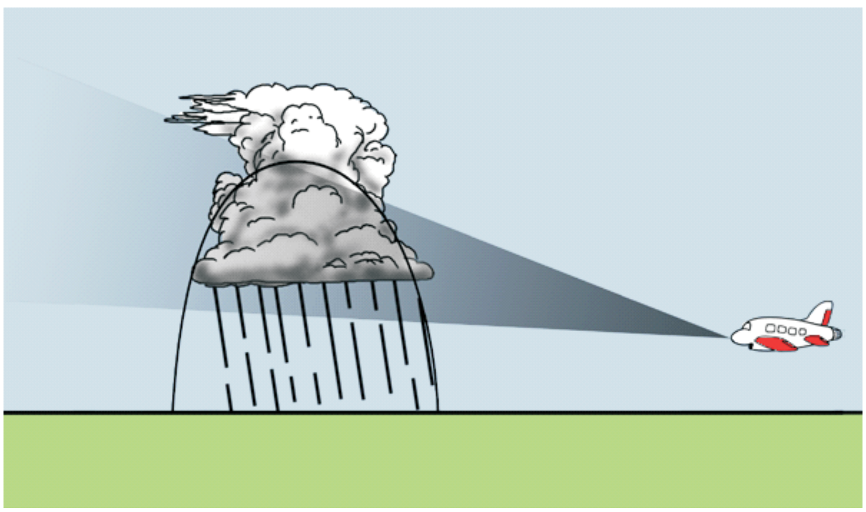


In-flight Operations

LOW ALTITUDE TILT SETTINGS (10,000 FT AND BELOW)

Below 10,000 feet, a tilt setting of between +2° and +7° is recommended with +5° being a good compromise setting. Below 10,000 feet, the flight crew is busy with a variety of tasks from completing checklists to talking with approach/departure control. Setting a +5° tilt and leaving it set through 10,000 feet reduces cockpit workload. The +5° setting will eliminate most ground clutter and detect the majority of the weather in the immediate vicinity of the aircraft. The two topics that follow (Climb and Descent) explain the logic behind these guidelines, and when a +2° tilt setting and a +7° tilt setting might be appropriate.

Recommended Tilt For Low Altitude flight



CLIMB

It is typical for a two, three or four engine transport category aircraft to climb out after takeoff at approximately 240 knots with a 3000 fpm rate of climb. This equates to a 7° climb angle from the horizontal. Therefore, a +7° tilt setting keeps the radar aligned along the aircraft flight path; alerts the crew to potential penetration of vaulted thunderstorm areas; and eliminates ground clutter.

The drawback to a +7° tilt is that weather detection is limited to the general vicinity of the aircraft. This can be shown using the general formula that says 1° of tilt gives you 100 feet per NM of beam position change. For instance, with a +7° tilt the centre of the beam is at 24,500 feet at 35 NM.

> *1° of tilt at 35 NM yields 3,500 feet of beam position change. Multiply 3,500 by 7 (due to the 7° of tilt). The result is the 24,500 feet used in the above paragraph. This means that if the radar top of the thunderstorm is less than*

24,500 feet, it may not be displayed on the radar. At 50 NM, the centre of the beam is at 35,000 feet, and the majority of the weather at this range will not be visible due to the fact that the radar is looking at the top of storms at this range. Since the radar beam is approximately 3.5° wide, a +5° radar tilt angle provides a good compromise because it keeps the outer edge of the radar beam pointed close to the aircraft flight path and provides marginally better weather detection ranges.

CAUTION
If the tilt setting is too high, the radar beam may scan above the tops of thunderstorms that are a threat to the aircraft. If the tilt is too low, the radar may not detect vaulted thunderstorm energy.

THUNDERSTORM VAULTING

Thunderstorm "vaulting" occurs when thunderstorm updrafts are so strong that large amounts of moisture are trapped high in the thunderstorm cell and an area of potential energy is formed.

Little precipitation occurs at the bottom of the cloud due to the fact that downdrafts are all but eliminated. This is especially possible as thunderstorms transition from the towering cumulous stage to the mature stage of development.

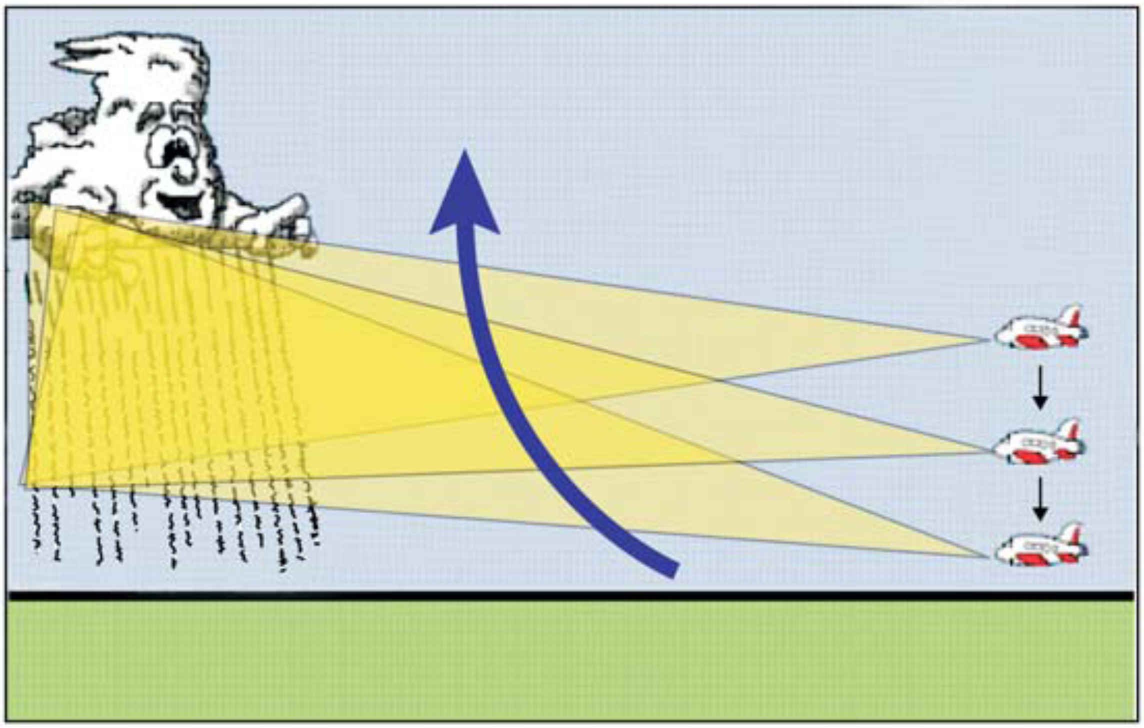
At lower altitudes during climb out, it is occasionally possible to miss the true extent of the thunderstorm threat due to the fact that the radar beam may scan below the high-energy area created by the vaulting of moisture high in the storm.

DESCENT

Below 10,000 feet, a +5° tilt angle remains the best compromise for descent if cockpit workload is heavy. This tilt angle will detect most weather while at the same time eliminating the majority of ground clutter.

The benefit to this method is that the tilt setting can be set and forgotten during the critical approach and landing phase of flight. However, it is still possible to descend into thunderstorms that are developing below the aircraft flight path and are under the radar beam. Therefore, an alternate tilt procedure for descent below 10,000 feet is to initially set a +2° tilt setting, then gradually raise it to +5° as the aircraft descends to lower altitudes.

Recommended Tilt Settings For Descent

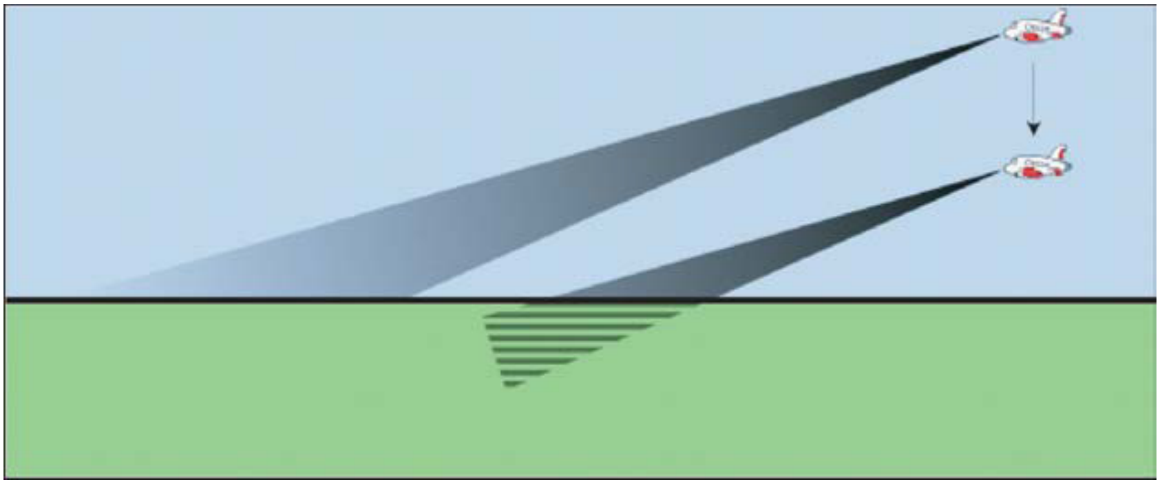


CAUTION

Even with a low tilt setting of +2°, it is possible for over-scanning to occur. Growing thunderstorms that are a threat to the aircraft may fall below the radar beam and fail to be shown on the radar display.

If the tilt is not raised as the aircraft descends, the radar beam will progressively “dig” deeper into the ground. The result is a very colourful display of ground clutter that may fully mask weather returns. In the next figure (Fig 1.11), the aircrew has failed to raise the radar tilt during descent. At lower altitudes the radar beam is totally immersed in the ground.

Result of Not Raising Tilt As Altitude Decreases



If the radar tilt is set to display clutter at the outer edge of the 80 NM range scale at a cruise altitude of 35,000 feet and the plane then descends to 5,000 feet without the tilt being adjusted, ground clutter completely masks all weather returns.

MID ALTITUDE TILT CONTROL (10,000 – 25,000 FT)

For **overland** operation at mid altitudes, the best general guideline is to tilt the antenna until a small amount of ground return appears at the outer edge of the display.

> *This technique may be worth considering; Decide which range scale you want to use (example, 80 NM in the Airbus). Then select the next highest range (160 NM), and on that 160 range put a strong ground return at 100NM. Then switch back to the 80 NM range to display the weather than you're interested in viewing. I mentioned earlier that CRM is paramount, so set the PF's ND to display the area of interest, and the PNF's ND set to the next higher range displaying the ground return so that you can be sure that you are scanning through the freezing level.*

NOTE: At mid altitudes, over-scanning of weather targets begins to become a problem. This is particularly true in high northern or southern latitudes.

Due to the nature of the earth's atmosphere, these regions are more likely to have high-energy thunderstorm cells at lower altitudes than equivalent storm systems closer to the equator.

HIGH ALTITUDE TILT CONTROL (25,000 FT AND ABOVE)

At higher altitudes thunderstorm tops can be invisible to radar. When outside air temperature falls below -40 °C (SAT or OAT), thunderstorm tops are formed entirely of ice crystals and reflect very little, if any, radar energy.

Significant down tilt is required to ensure that the radar beam is picking up the more reflective part of the storm that is at lower altitudes. Over land ground clutter can be used to determine proper tilt within 160 NM of the aircraft.

For longer-range targets, special procedures must be used. Within 160 NM, tilting the radar so that some ground clutter appears in the outer most range scale keeps the antenna pointed towards the reflective portion of the thunderstorms that are towards the outer edge of the selected range scale.

Note: Over-scanning of thunderstorms may be a problem at low and mid altitudes; the problem becomes a significant threat at high cruise altitudes. Many pilots INCORRECTLY use tilt settings based on the 80 NM range scale during high altitude cruise.

However, at high altitudes this setting only optimizes weather returns between approximately 50-80 NM. Significant weather may be present in the 0-50 NM area. Over-scanning and subsequent inadvertent thunderstorm top penetration is a significant concern.

Targets inside 50 NM may be over-scanned and disappear from the display but still cause significant turbulence. To view targets inside the 50 NM range, large down tilt settings are necessary. The large down tilt may prevent more distant storms from being detected, and in overland operations, will cause excessive ground clutter to appear.

WARNING:
Over-scanning and the resulting inadvertent thunderstorm top penetration is a significant threat during high altitude operations.

OVER-SCAN PREVENTION – PILOT TECHNIQUES

Method 1: One pilot technique that is used to judge which storms are a threat and which are not when using the 80 NM range scale is to use the 40 NM range (the mid point on the display) for a decision point criteria. If the storm stays in the radar beam (i.e., is painted on the display) through 40 NM, then it should be considered a potential threat and avoided. Thus, a storm cell that disappeared from the display at

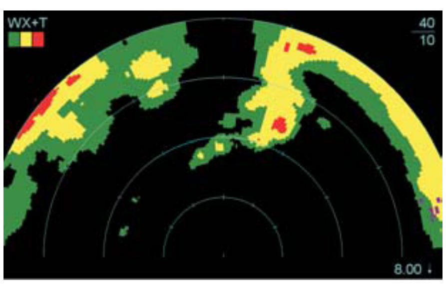
40 NM is still a potential threat. The position should be tracked mentally and avoided.

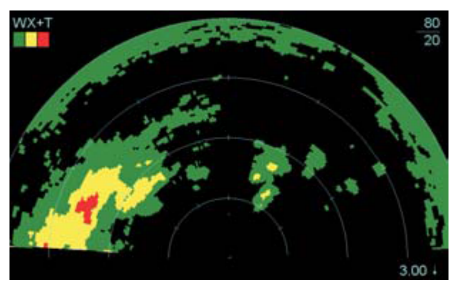
Method 2: For aircraft equipped with a split function control panel (Boeing), *or Auto-Tilt (Airbus)*, another technique can be used to reduce the threat of over-scanning significant weather.

In this case one pilot should utilize the 80 NM range scale (or higher) with a tilt setting that places ground clutter in the outer most range scale while the second pilot utilizes a 40 NM range (or less) with an increased down tilt that places clutter in the outer range scale of the 40 NM display. Use suggested mid and high altitude tilt settings over water when ground return is not present.

The 80 NM range is then available to help plan any required course changes and the shorter range can be used to prevent over-scanning and inadvertent thunderstorm top penetration.

The left picture shows the radar display with the aircraft at 35,000 feet with 40 NM range selected. The picture on the right shows the radar display at the same altitude, but with 80 NM range selected. Note the cell directly in the aircraft path that has disappeared from the 80 NM range scale.





Method 3: The threat of over-scanning can be reduced by periodically selecting the 40 NM range scale and adjusting the tilt so that some clutter appears in the outer most range scale.

Observe potential target threats in this region. Then switch to the 80 NM range scale and adjust the tilt upwards until ground clutter is once again in the outer range scale only. Continue adjusting the range and tilt until the desired range scale is in use. Repeat the procedure periodically or when the location of thunderstorms within 40 NM of the aircraft needs to be determined.

THE TOTAL WEATHER PICTURE

In general, an experienced pilot mentally assembles the total weather picture by combining weather pictures taken at various tilt angles and with different gain settings. Scanning with various tilt angles allows the pilot to see weather at different ranges and varying the gain increases or decreases receiver sensitivity to best respond to the reflective nature of thunderstorms at the aircraft's altitude, but must always return the GAIN selector to AUTO or CAL.

Note: The above is not applicable to MultiScan systems, which are left in AUTO at all times.

RADIATION HAZARDS

To provide a practical safety factor, the American National Standards Institute has specified a maximum level of 10 mw/cam for personnel exposure of 6 minutes or longer to radar antenna electromagnetic radiation.

Collins engineering personnel measured the radiation emissions of an actual weather radar system on the flight line. A General Microwave radiation hazard meter (Model 481B) was used to measure the emitted radiation. It was placed less than a meter (0.5 Meter) in front of the radar's flat-plate antenna during normal operation with the radome removed. System range was set to 320 NM to provide the maximum pulse width. Under these conditions, the maximum power density meter reading was 0.3 mw/cm2.

The Collins radar system falls well below the 10 mw/cm2 standard. Microwave ovens represent a more public safety concern and their leakage standard has been set at 4 mw/cm2. The WXR power density is half or less than that of the microwave oven standard. Some handheld phones create a greater hazard.

In other words, a pilot sitting behind the WXR antenna is exposed to ZERO radiation from the Radar equipment

Note:

> Several years ago while waiting at an avionics shop for a headset repair I noticed a gentleman working on a noisy radar antenna. Amongst the several questions I asked him (a WXR Repair Technician) included a question to determine if there were any issues with turning a WXR unit "On" and "Off" during flight. His response was,
>
> "…The problem is with temperature cycling. The solder joints eventually fracture and lead to either intermittent or permanent failures. You can really stress electronics by letting them cold soak and then turning them on. It may not fail immediately, but you have shortened its life. It's best to turn it on

before take off, then leave it on until after landing…"

The bottom line. **Turn it on, and leave it on!**

Practically speaking - Airbus

Airbus has wavered several times regarding their recommendations about WXR use. In the past year alone they have changed their A330 and A320 Flight Crew Training Manuals (FCTM) twice in this regard.

Previously, they recommended the following:

FLIGHT PHASE	DETECTION AND MONITORING PROCEDURES	COMMENTS
TAXI	clear on parking area, set ND to lowest range, TILT DOWN then UP; Chek appearance/disappearance of ground returns.	TILT ANTENNA CHECK (away from people).
TAKEOFF	If weather is suspected, SLOWLY SCAN up to + 15°, then TILT + 4°.	Scanning along departure path.
CLIMB	To avoid OVERSCANNING, TILT DOWNWARD as the A/C climbs, and maintain GND RETURNS ON TOP OF ND.	TILT angle function of altitude and ND RANGE.
CRUISE	Use TILT slightly NEGATIVE to maintain ground returns on top of ND: Range 320 TILT≅1 DN Range 160 TILT≅1,5 DN Range 80 TILT≅3,5 DN Range 40 TILT≅6 DN In higher altitudes, closing weather: - Decrease ND - TILT down Use TURB to ISOLATE Turbulence - GAIN to AUTO.	No ground returns beyond line of view. $Dnm = 1,23\sqrt{ALT}$ ft FL 370 D 240nm Poor ground returns over calm sea / even ground.
DESCENT	During DES, TILT UPWARD approximately + 1° / 10000 ft in higher altitudes, then + 1°/5000 ft below 15000 ft.	
APPROACH	TILT + 4°.	To avoid ground returns.

Currently, they recommend:

Flight Phase	Detection and Monitoring	Comments
TAXI	Clear on parking area, set ND to lowest range. Tilt down then up. Check appearance/disappearance of ground returns.	Antenna tilt check (away from people)
TAKEOFF	If weather activity is suspected: slowly scan up to detect weather (Max 15 °up), otherwise: set tilt to 4 ° up	Enables to scan along the departure path
CLIMB	Adjust the ND range as required and decrease the tilt angle as the aircraft climbs	Avoids over scanning of weather
LEVEL FLIGHT/CRUISE	Depending on FL and detection requirement, adjust ND range. Maintain the ground return on the top of the ND Regularly scan the weather vertically by modifying the tilt Once the scan is done, adjust the ground return back on the top of the ND.	In cruise, for efficient weather awareness, the following ranges can be selected: - 160 nm on the PNF ND - 80 nm on the PF ND Shorter ranges can be used to track/avoid closing weather.
DESCENT	During descent, tilt upward to maintain the ground return on the top of the ND.	-
APPROACH	Tilt 4 ° up	Avoids ground return

It's interesting to note that with each revision to the FCTM regarding WXR, they have avoided explaining "why" they recommend a "Ground Return" on the upper edge of the display.

Also, in the previous version, they listed some down tilt recommendations that have been removed in the current version. However, those recommended settings were actually correct!

> *The problem with those setting is that the values that they published were only valid in the "standard atmosphere," and mid-latitudes, and the list of values for all temperature and latitude variations is too exhaustive to include in any useable manual.*
>
> ***The reason for the ground return is to ensure a scan THROUGH the Freezing Level to the area where the maximum signal return (Reflectivity) can be found (recall the earlier analogy using the fire).***

WXR units with "Auto Tilt" or "MultiScan" are capable of computing tilt values for all temperatures, latitudes and altitudes. Thus, they maintain the correct tilt to display expected "Turbulence" during flight, and are able to remove the ground return from the display. In fact, they are so good, that they are also able to predict turbulence at the "Bow Wave" of the Thunderstorm itself. That is the number one reason for many pilots commenting that "…MultiScan is too sensitive…" Oddly, those same pilots rarely comment on the fact that they actually DID encounter some turbulence at the exact place, and of the exact intensity, that the MultiScan system predicted.

As recommended in the various manuals, it is important to maintain a ground return on the upper part of the display. Since we are not always flying over "ground," some general tilt settings need to be committed to memory. Remember, the sea and oceans are lousy reflectors of WXR signals.

Generally, from take-off until landing your tilt management will look something like this, assuming that display range is set to between 40 and 80 NM:

- *Lined up on the runway*
  - *Scan from 1.5 up to 7.0 up pausing between each sweep*
- *Take-off until stable at climb speed (during acceleration)*
  - *4 degrees up*
- *Climb when speed is stable*
  - *5000 feet = 3.0 UP*
  - *10000 feet = 2.0 UP*
  - *15000 feet = 1.0 UP*
  - *20000 feet = 0.0*
  - *25000 feet = 1.0 down*
  - *+30000 feet = 2.0 down (min)*
- *Cruise (above 30,000 feet)*
  - *Range NM Tilt*
  - *320 0*
  - *160 1 DN*
  - *80 2.0 DN*
  - *40 4.0 DN*
  - *20 6.0 DN*
  - *10 8.0 DN*

- *Decent & Approach*
  - *Use climb data until deceleration to approach speed, then 4.0 UP.*

The information from Boeing is quite similar…(B757/767 Manual)

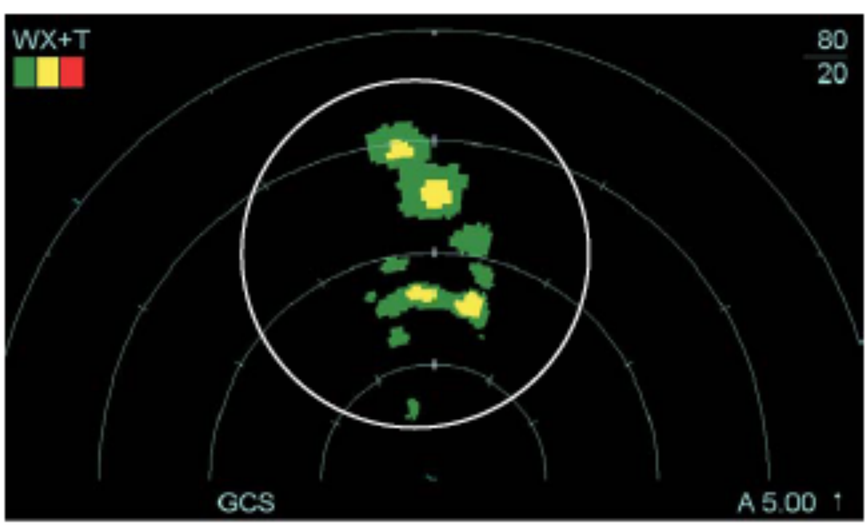
Tilt Operation		
Takeoffs and Landings	Below 10,000 ft	2 to 3 up tilt
Middle Altitudes	10,000 - 35,000 ft	0 or slightly down until a small amount of ground return appears
High Altitudes	Above 35,000 ft	
	Targets beyond 160nm	1 to 2 down tilt
	Targets 80 to 160nm	3 to 4 down tilt
	Targets 40 to 80nm	6 to 7 down tilt

Decision to avoid target should be made before the target is closer than 40 nm. (The flat plate antenna does not have significant side lobes, so targets may be overscanned at ranges less than 40 nm.)

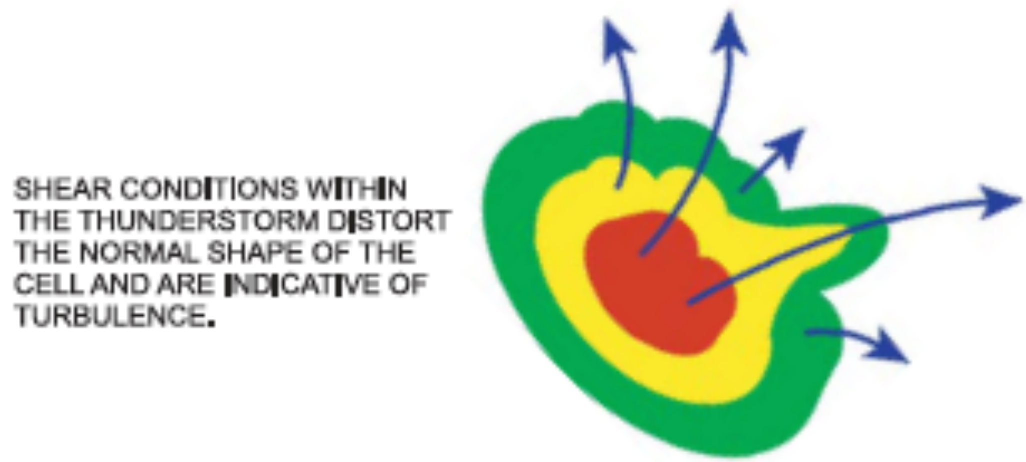
Hazardous Weather and associated Radar Images

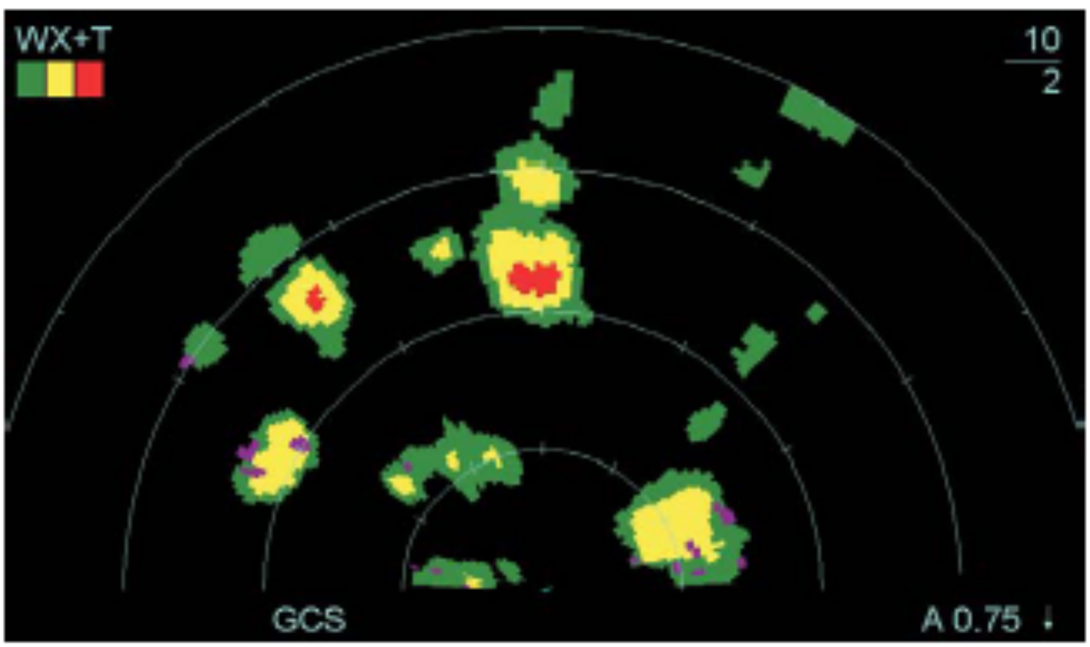
A typical thunderstorm is circular or oval in shape as shown below. Variations from this normal shape are indicative of a shear condition within the thunderstorm and can serve as clues to hazardous weather.

NORMAL THUNDERSTORMS ARE CIRCULAR OR OVAL IN SHAPE



Shear Conditions within Thunderstorm Shapes

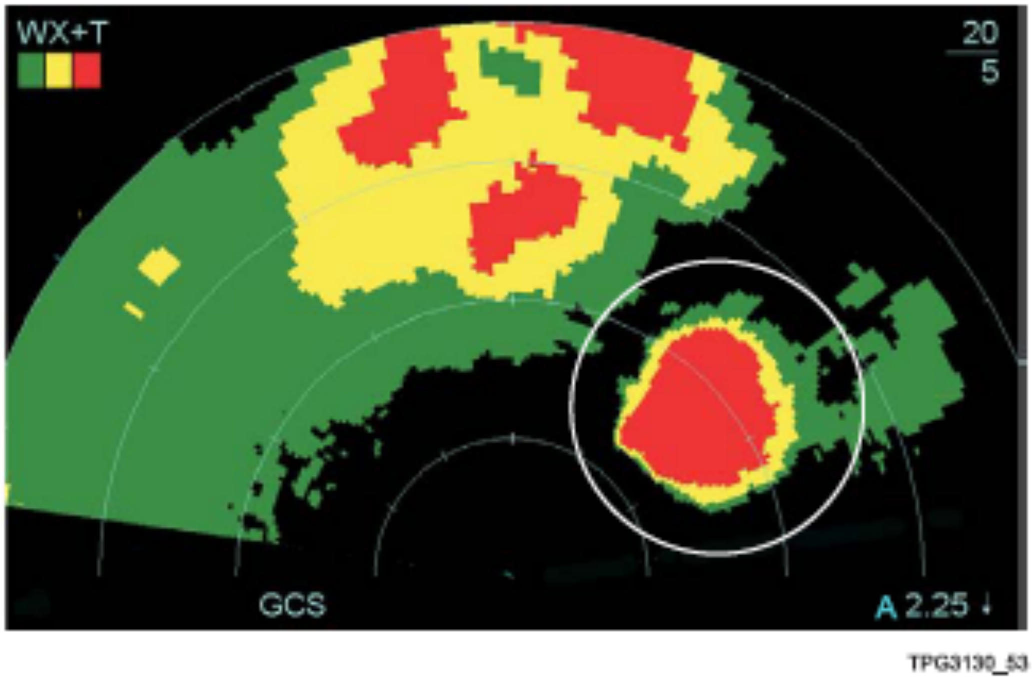




TPG3130_52

STEEP GRADIENT

A steep gradient occurs when the green and yellow portions of the thunderstorm shown on a weather radar display merge very rapidly into red as shown below. A steep gradient is indicative of significant convective activity and heavy turbulence.



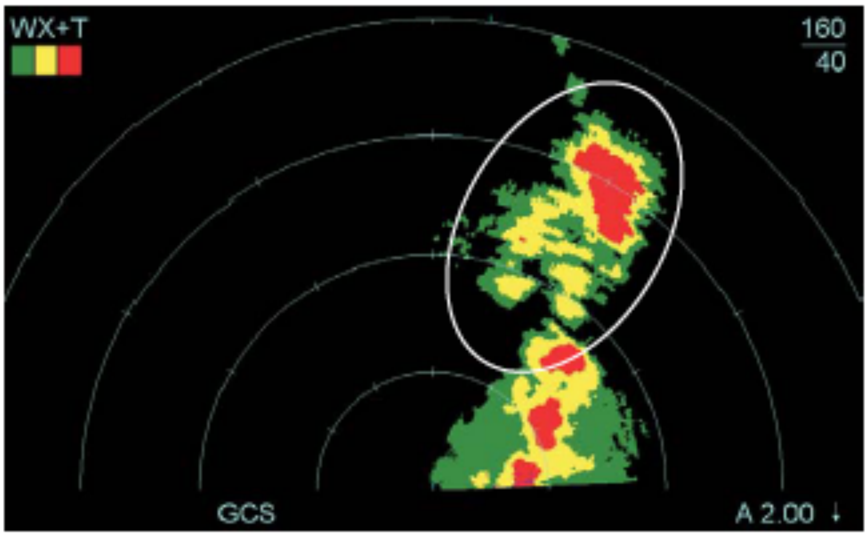
The circled thunderstorm shown above has a steep gradient because the green and yellow portions of the cell quickly move to red. A steep gradient is indicative of extensive convective activity, and severe turbulence would more than likely be encountered if the aircraft penetrated the thunderstorm.

SCALLOPED EDGES, PENDANT, FINGER, HOOK, and U-SHAPE

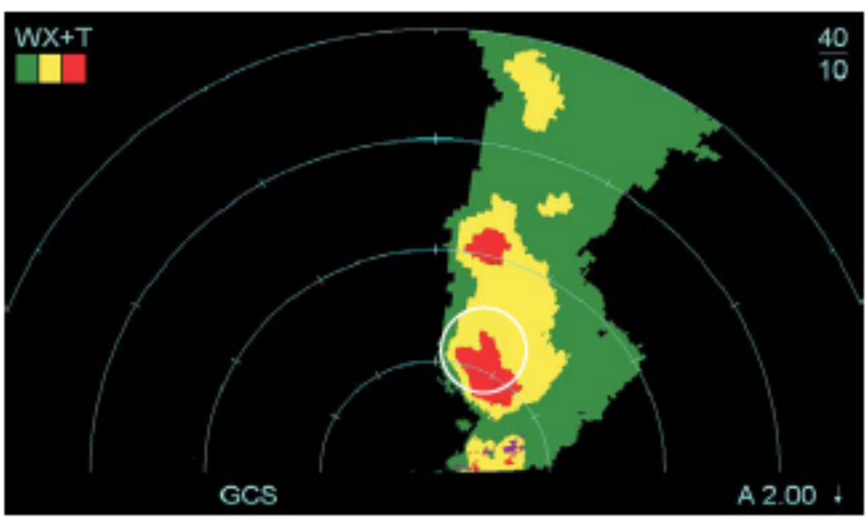
Scalloped or roughened edges, pendants, fingers, hooks, and U-shapes on weather radar thunderstorm displays all indicate the presence of sheer forces and turbulence. They may also indicate the presence of hail.

WARNING:
Increase the avoidance distances by 50 percent for echoes that are changing shape rapidly or are exhibiting hooks, fingers, or scalloped edges.

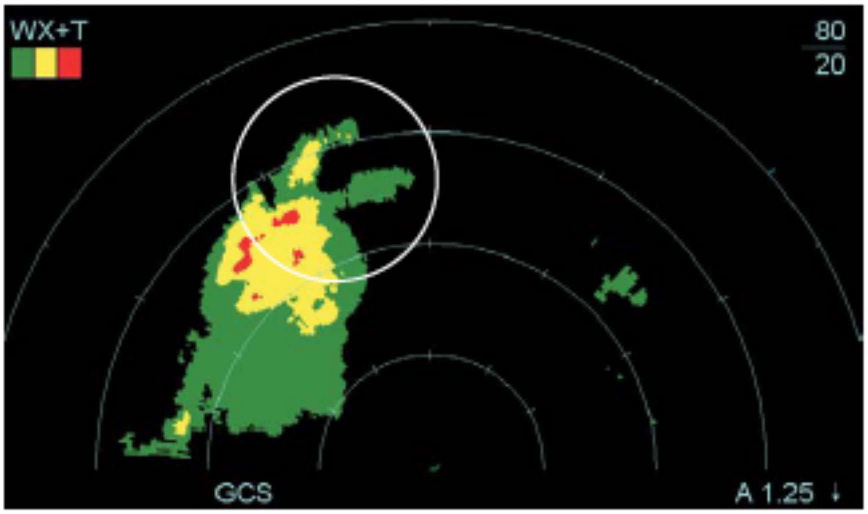
Thunderstorm Showing Scalloped Edges…



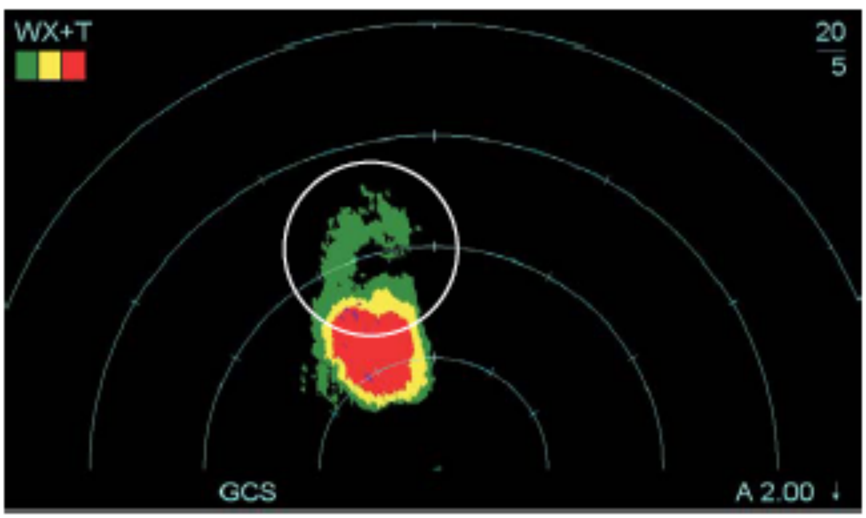
Thunderstorm showing pendants…



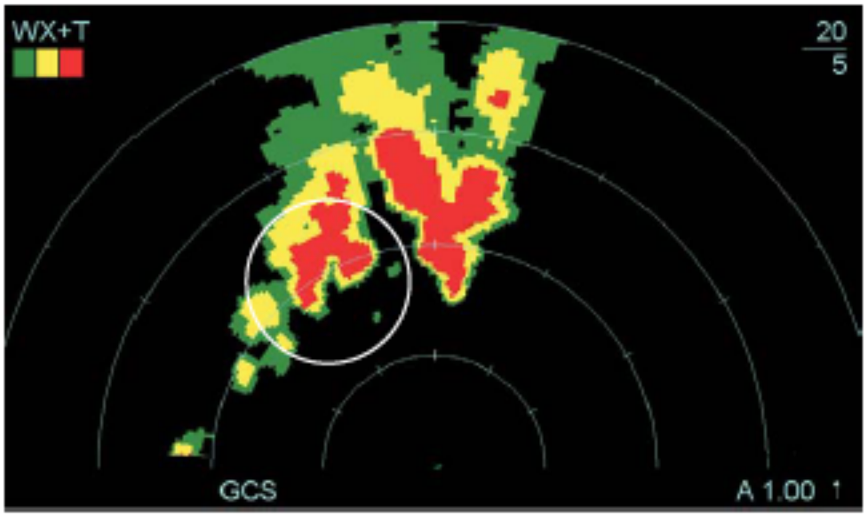
Thunderstorm showing fingers…



Thunderstorm showing a hook…



Thunderstorm showing a "U" shape….



Because the overall idea behind learning how to properly use Airborne Weather Radar is to avoid turbulence, it would probably be a good idea to review some information about turbulence.

When Pilots report "severe turbulence," technically, such a report would close the associated airspace to commercial traffic, and cause concern for other pilots in the vicinity.

> *A few years ago while approaching Singapore with a 744 just 1000 feet above me and converging when he reported that he was in "Severe Turbulence." After he made that very long-winded report, ATC asked why we turned slightly off our course. I explained that since the 747 above was in Severe Turbulence; his aircraft was - according to the Severe Turbulence definition – "Out of Control" and I didn't want an "out of control" 747 encroaching on me. The crew of the 747 responded that they had good control, but were in severe turbulence. An ATC investigation was conducted and it was disclosed that the pilot who made the report was only experiencing light turbulence; was inexperienced; and had no definitive turbulence reporting information to draw his conclusion from. Incidentally, in some parts of the world a "Severe Turbulence Report" could cause ATC to close the effected airspace or airway.*

All of us are familiar with the definitions of turbulence which the FAA and other authorities have provided…"Occupants feel a slight strain…. walking difficult…aircraft control difficult, etc, etc." These definitions are very subjective to individual pilot experience. In fact, I have a difficult time believing that any aircraft designer could use *those criteria in building a safe aircraft. Somewhere, there has to be a more scientific and credible definition.*

Fortunately…

The UK CAA publishes the UK AIP, *which is one of the more informative AIP's written.* Their weather section contains the following definitions (note the references to IAS and "g" loads):

<table>
<tr><th colspan="4">Table 3.5.6.1 — TURB and other Turbulence Criteria Table</th></tr>
<tr><th>Incidence</th><th>Occasional — less than 1/3 of the time</th><th>Intermittent — 1/3 to 2/3</th><th>Continuous — more than 2/3</th></tr>
<tr><th>Intensity</th><th colspan="2">Aircraft Reaction (transport size aircraft)</th><th>Reaction Inside Aircraft</th></tr>
<tr><td>Light</td><td colspan="2">Turbulence that momentarily causes slight, erratic changes in altitude and/or attitude (pitch, roll, yaw)
IAS fluctuates 5 - 15 kt. (<0.5 g at the aircraft's centre of gravity)
Report as 'Light Turbulence'. or;
turbulence that causes slight, rapid and somewhat rhythmic bumpiness without appreciable changes in altitude or attitude.
No IAS fluctuations. Report as 'Light Chop</td><td>Occupants may feel a slight strain against seat belts or shoulder straps. Unsecured objects may be displaced slightly. Food service may be conducted and little or no difficulty is encountered in walking.</td></tr>
<tr><td>Moderate</td><td colspan="2">Turbulence that is similar to Light Turbulence but of greater intensity. Changes in altitude and/or attitude occur but the aircraft remains in positive control at all times. IAS fluctuates 15 - 25 kt. (0.5-1.0g at the aircraft's centre of gravity). Report as 'Moderate Turbulence'. or;
turbulence that is similar to Light Chop but of greater intensity. It causes rapid bumps or jolts without appreciable changes in altitude or attitude. IAS may fluctuate slightly.
Report as 'Moderate Chop'.</td><td>Occupants feel definite strains against seat belts or shoulder straps. Unsecured objects are dislodged. Food service and walking are difficult.</td></tr>
<tr><td>Severe</td><td colspan="2">Turbulence that causes large, abrupt changes in altitude and/or attitude. Aircraft may be momentarily out of control.
IAS fluctuates more than 25 kt. (>1.0 g at the aircraft's centre of gravity). Report as 'Severe Turbulence'</td><td>Occupants are forced violently against seat belts or shoulder straps. Unsecured objects are tossed about. Food service and walking impossible.</td></tr>
</table>

Finally, a few safety reminders from the good people at Honeywell…

General safety rules

Don't accept a vector from ATC into convective weather. Always ask for an alternate route. When you do refuse a vector, always try to give them adequate warning time so they can plan for aircraft-spacing adjustments. That is, try to avoid last-minute decisions.

Don't plan a course between two closely spaced thunderstorms (storms with less than 40 NM between them).

Don't land or takeoff in the face of a thunderstorm that is in the projected flight path. A sudden wind shift or low-level turbulence could cause loss of control.

Don't attempt to fly under a thunderstorm even if you can see through to the other side. Turbulence under the storm could be severe.

Don't fly over thunderstorms. Turbulence above a storm can be severe.

Do avoid by at least 20 NM any thunderstorm identified as severe or giving an intense radar echo. This distance rule includes the anvil of a large cumulonimbus cloud.

Do clear the visual top of a known or suspected severe thunderstorm by at least 10,000 feet. If that exceeds the capability of the aircraft, go around the storm by a wide safety margin on the upwind side.

Do remember that vivid and frequent lightning indicates a severe thunderstorm.

Do regard as severe any thunderstorm with tops 35,000 feet or higher regardless of how you locate it--visual, radar or from a report.

Do evaluate weather scenarios from a distance and always plan an escape route at the top of a descent.

Appendix 1 (High Altitude Icing – Engine Power Loss)

Researchers have identified several conditions that are connected to engine ice crystal icing events.

The most important factors are:

■ High altitudes and cold temperatures. Commercial airplane power-loss events associated with ice crystals have occurred at altitudes of 9,000 to 39,000 feet, with a median of 26,800 feet, and at ambient temperatures of –5 to –55 degrees C with a median of –27 degrees C. The engine power loss events generally occur on days when the ambient temperature is warmer than the standard atmosphere.

■ The presence of convective clouds. Convective weather of all sizes, from isolated cumulonimbus or thunderstorms to squall lines and tropical storms, can contain ice crystals. Convective clouds can contain deep updraft cores that can lift high concentrations of water thousands of feet into the atmosphere, during which water vapor is continually condensed and frozen as the temperature drops. In doing so, these updraft cores may produce localized regions of high ice water content that spread downwind. Researchers believe these clouds can contain up to 8 grams per cubic meter of ice water content; by contrast, the design standard for super cooled liquid water for engines is 2 grams per cubic meter.

■ Areas of visible moisture above the altitudes typically associated with icing conditions. This is indicated by an absence of significant airframe icing and the ice detector (when installed) not detecting ice, due to its ability to detect only super cooled liquid, not ice crystals.

These additional conditions are also typically found during engine ice crystal power-loss events.

■ No pilot reports of weather radar returns at the event location.
■ Temperature significantly warmer than standard atmosphere.
■ Light-to-moderate turbulence.
■ Areas of heavy rain below the freezing level.
■ The appearance of precipitation on heated windshield often reported as rain, due to tiny ice crystals melting.
■ Airplane total air temperature (TAT) anomaly reading zero, or in error, due to ice crystal buildup at the sensing element.
■ Lack of observations of significant airframe icing.

I hope you have found this guide informative and useful. If you have any questions or comments, please email pjeeves13@me.com

Cheers and safe flying.

Credit and thanks to:

Rockwell / Collins
Boeing
Airbus
UK CAA
NASA