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RADIO NAVIGATION

CHAPTER 13 – AIRBORNE WEATHER RADAR

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THE PURPOSE OF AIRBORNE WEATHER RADAR

Primarily, airborne weather radar (AWR) is a means of avoiding turbulence by detecting and locating turbulent clouds and precipitation. A secondary function is the mapping of ground features as an aid to navigation.
To assist in the avoidance of turbulence, AWR distinguishes between safe and turbulent clouds and can determine the height of clouds relative to the aircraft.

PRINCIPLE OF OPERATION

AWR is an example of **primary radar**. The location of clouds relative to the aircraft is measured by beam direction finding and range by pulse technique. By a careful choice of wavelength, it is possible to maximise radar returns from convective cloud and precipitation and to minimise returns from stratus type cloud which pose no threat of turbulence. AWR cannot display clear-air turbulence, such as that associated with jet streams.

FREQUENCIES

Commercial AWR systems operate in two frequency ranges in the **SHF** band:

(G band)	4000 to 8000 MHz	example	5.44 GHz
(I band)	8000 to 12500 MHz	example	9.33 GHz

The terms G and I have replaced former references to C and X

As previously mentioned, the choice of frequency and hence wavelength is critically important. If wavelengths are too long (greater than 10 cm), weather would be transparent to the transmissions. If wavelengths are too short (1 cm or less) all types of precipitation and cloud will appear, including cloud with no risk of turbulence. Both G and I band radars are effective but have advantages and disadvantages. The longer wavelength of G band results in less attenuation but a weaker return. The shorter wavelength of I band gives strong returns (or an adequate return at long range) but greater attenuation.

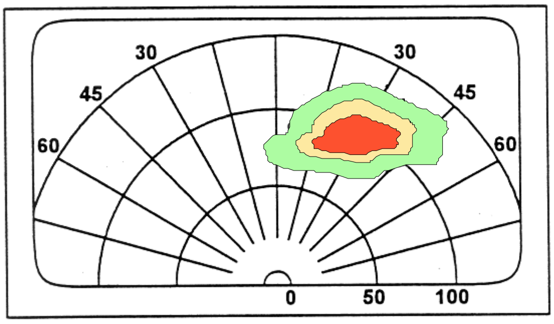
	G band	**I band**
Frequency (typical)	5.44GHz	9.33GHz
Wavelength	5.51cm	3.21cm
Beam width	5.4^{O}	3.5^{O}
Display Resolution	less	more
Attenuation by WX	less	more
Ability to penetrate to distant cloud	more	less

AERIAL SCANNER UNIT

Modern weather radars use flat-plate, slotted, phased-array antennas. Compared with the parabolic aerials that preceded them, flat-plate antennas produce a narrower beam with smaller side lobes and so are capable of detecting target clouds at longer range and with greater accuracy. The aerial is stabilised in pitch and roll, using as a vertical datum either a gyroscopic unit or the Inertial Reference System, so that the radar scans in the horizontal plane. The beam is made to scan up to 90^{O} each side of the fore/aft axis of the aircraft and a manual tilt control allows the beam to be tilted $\pm 15^{\circ}$

DISPLAY UNIT

A typical weather radar indicator is a colour CRT display presenting a 2-dimensional map of cloud and precipitation ahead of the aircraft.

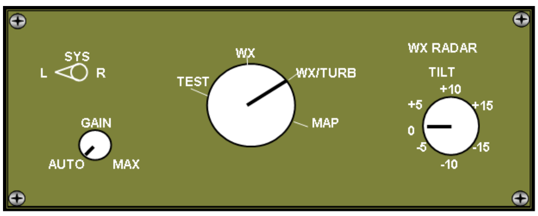


AWR showing
range markers
bearing lines
at 15^{o} intervals

The weather radar may also be integrated into EFIS displays so that the location of significant cloud is shown relative to the tracks between waypoints. The selected tilt angle may also appear on the EFIS display.

CONTROL PANEL

The weather radar control panel for an EFIS equipped aircraft is shown below. The range selection switch is not shown as it is located on the EFIS control panel.



The **L-R** switch allows selection of one of the two receiver/transmitter units.

The **GAIN** control affects the amplification of the radar echoes. When in the **WX** mode, **AUTO** should be selected so that the gain applied to returning signals is determined by the SENSITIVITY TIME CONTROL (STC) circuitry.

STC is an automatic device which progressively reduces the gain as the aircraft approaches a cloud. Without STC, clouds close to the aircraft would appear more significant than clouds further away because of normal radar attenuation. STC compensates for this effect so that targets of equal intensity, but occurring at different ranges, appear the same on the screen. To achieve this, STC applies less gain to returns occurring early in the radar cycle than to returns received later. In current AWR, STC operates to a range of about 60nm.

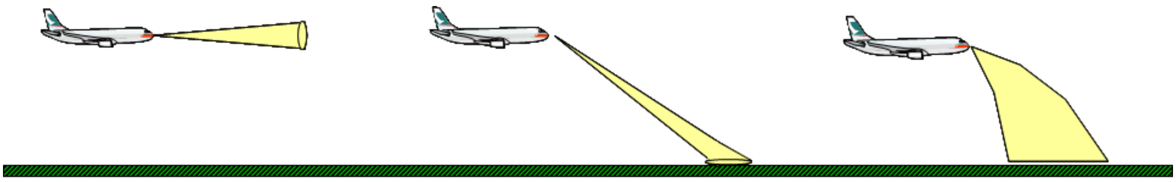
The **TEST** position on the mode selector switch verifies system operation before flight.

The **WX** position selects the weather beam and automatic gain (STC). The weather beam is a conical, pencil beam which directs the radar energy into a narrow stream. In the WX position, areas of strong return appear red, moderate returns appear yellow and light returns appear green.

The **WX/TURB** position selects the weather beam plus Doppler turbulence detection. This process depends on the wide variance of particle speeds that occur in turbulent cloud. By the Doppler principle, it can be predicted that returns from turbulent cloud will contain a wide spectrum of frequency shifts due to this variety of particle speeds. To measure this spectrum accurately, a large number of returns must be used so the radar PRF is increased accordingly. The high PRF shortens the listening period and so the maximum range of WX/TURB is about 50nm. Strong returns in turbulence mode appear magenta.

In the **MAP** mode, STC is deactivated and gain must be adjusted to highlight terrain features. In some systems, a fan-shaped mapping beam is used which is about 85^{O} deep and about $3^1/_2{}^{O}$ wide. To provide a uniform picture, the transmitted power density is varied at the antenna so that more power is directed to the ground further away and less to the ground below the aircraft. The result is called a COSECANT beam as the power is transmitted in accordance with the cosecant of the angle of depression. The cosecant beam achieves through the transmitter a result similar to that of STC through the receiver. Use of the MAP mode is limited in range to about 70 nm and in altitude to about 10.000 feet.
For mapping the ground beyond 50-60nm, the weather (conical) beam is used. On some control panels, there is a MAN (manual) switch position that provides the conical beam with manual gain control for this purpose.

MODE	**RANGE**	**BEAM TYPE**	**GAIN CONTROL**
Map	up to 70 nm	Cosecant	Manual
Man	Greater than 70 nm	Conical (pencil)	Manual
Wx	STC up to 60 nm	Conical (pencil)	STC
Wx/Turb	Doppler Turbulence Detection up to 50 nm	Conical (pencil)	STC

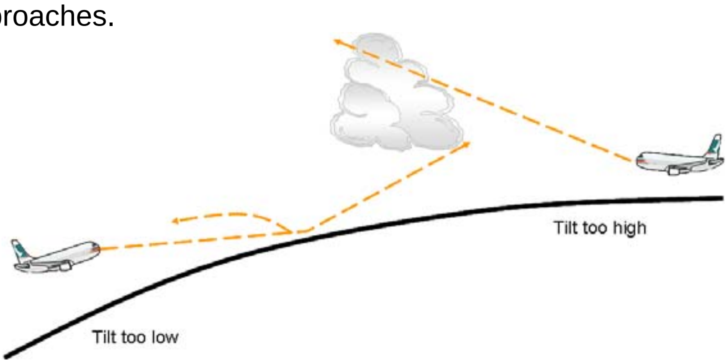


USE OF TILT

Careful adjustment of the tilt control is needed to avoid:-

a) Scanning too low so that ground returns become mixed with weather returns.

b) Scanning too high so that storms that are visible at long distance disappear as the aircraft approaches.

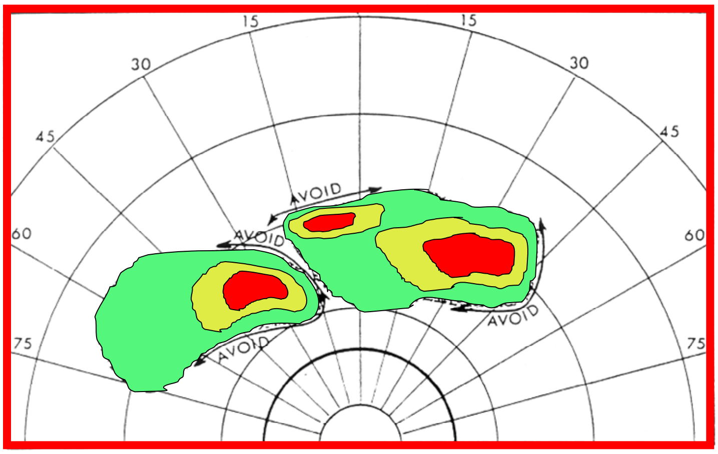


A significantly turbulent cloud may have little moisture at the aircraft's cruising level. If only the upper portion of the cloud is scanned, strong radar returns may not be produced. With tilt too high, this problem becomes worse as the cloud approaches.

INTERPRETATION OF WEATHER RADAR

The strength of radar returns depends on the concentration of cloud droplets or precipitation. Weather radar prediction of turbulence assumes that these concentrations of moisture indicate strong vertical currents. To aid in the identification of areas of turbulence, AWR is equipped with CONTOUR circuitry so that returns above pre-set levels are high-lighted. In the case of monochromatic radars, all returns above a predetermined (Iso-echo) level are blanked out so producing clouds on the radar screen with hollow centres. Similarly with colour radars, preset contour levels result in progressively stronger returns appearing green, yellow or red on the screen.

Strong returns indicate high water concentrations which in turn imply strong vertical currents. Clearly the blanked-out areas or red areas of the clouds should be avoided. However sharp edged echoes and close contours also indicate areas of intense turbulence. It should be noted that turbulence is associated with wind shear and in this case, changing vertical currents are indicated by the steepness of the contour gradients.



Weather targets that change shape rapidly or that exhibit protuberances such as hooks or fingers or have scalloped edges are associated with severe turbulence and /or hail, either of which can damage the aircraft. Weather radar is a tool for turbulence avoidance but if it is necessary to pass close to cumulonimbus, the following guidance is given as an annex to the UK AIC "The Effect of Thunderstorms and Associated Turbulence on Aircraft Operations."

Flight Altitude	**ECHO CHARACTERISTICS**			
(1000s of ft)	**Shape**	**Intensity**	**Gradient of intensity***	**Rate of Change**
0-20	**Avoid by 10 miles echoes with hooks, fingers, scalloped edges or other protrusions.**	**Avoid by 5 miles echoes with sharp edges or strong intensities.**	**Avoid by 5 miles echoes with strong gradients of intensity.**	**Avoid by 10 miles echoes showing rapid change of shape, height or intensity.**
20-25	**Avoid all echoes by 10 miles.**			
25-30	**Avoid all echoes by 15 miles.**			
above 30	**Avoid all echoes by 20 miles.**			

*Applicable to AWR with Iso-Echo or a colour display. Iso-Echo produces a hole in a strong echo when the returned signal is above a pre-set value. Where the return around a hole is narrow, there is a strong gradient of intensity.

Notes:

1. If storm clouds have to be over flown, always maintain at least 5000 ft vertical separation from cloud tops. It is difficult to estimate this separation but ATC or Met information on the altitude of the tops may be available for guidance.

2. If aircraft is not equipped with radar or it is inoperative, avoid by 10 miles any storm that by visual inspection is tall, growing rapidly or has an anvil top.

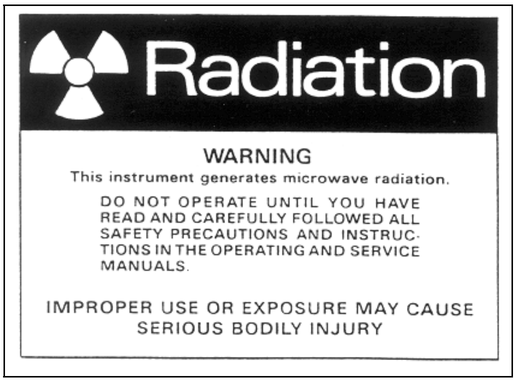
3. Intermittently monitor long ranges on radar to avoid getting into situations where no alternative remains but the penetration of hazardous areas.

4. Avoid flying under a cumulo-nimbus overhang. If such flight cannot be avoided, tilt antenna full up occasionally to determine, if possible, whether precipitation (which may be hail) exists in or is falling from the overhang.

SAFETY CONSIDERATIONS

Dangers from the operation of AWR on the ground include the possibility of human body damage and ignition of combustible materials by radiated energy. Operation on the ground is permitted but precautions must be taken to avoid danger to personnel and aircraft from harmful radiation. Radiation close to any of the following should be avoided:-

- Other aircraft, especially during refuelling
- Fuel tanks or tankers
- Hangars
- Persons or cargo



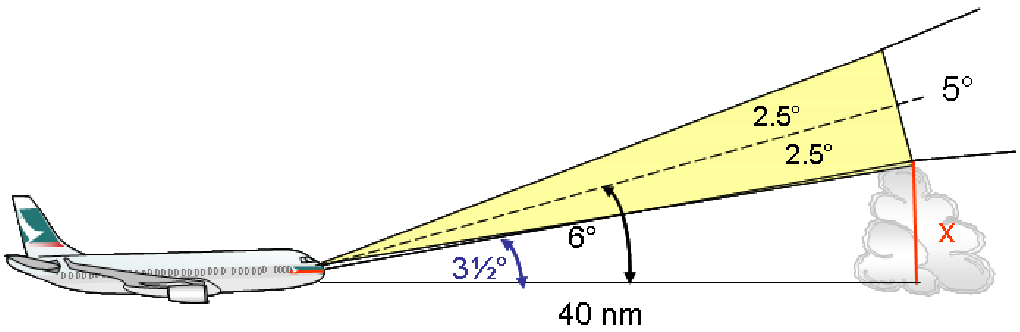
The aircraft's check list and the company operations manual will define safe procedures. These are likely to include:

- Do not transmit until the aircraft has moved clear of the terminal building.
- Do not use the mapping beam (MAP) on the ground. Use the weather beam (WX).
- Select tilt up e.g. +5°.
- After testing, select STBY until airborne.

FINDING THE APPROXIMATE HEIGHT OF CLOUDS

Cloud height relative to the aircraft can be found by changing the tilt setting until a cloud visible on the screen just disappears from view. Assuming beam width is known, cloud height can be calculated from the tilt setting and the range to the cloud by using the 1-in-60 rule or by trigonometry. It is important to note that the tilt setting is the angle from the horizontal to the centre of the beam.

Example:
A cloud at range 40 nm just disappears from view when the tilt setting is changed to 6° up. Stabilization is ON, beam width is 5° and the aircraft is flying at FL 120. Find the height of the cloud.



With the tilt set to 6° up, the lower edge of the beam is (6° - half beam width) 3.5° above the horizontal.

<u>By 1 in 60 rule</u>
1º equates to 1 foot in 60 feet
therefore 1º equates to 100 feet in 6000 feet (1 nm)
so 3.5º at 40 nm equates to 100 X 3.5 X 40 or 14000 feet and this is approximately the height of the cloud top (relative to the aircraft).
The height of the cloud is approximately 14000 + 12000 = 26000 feet

<u>By Tangent</u> (more exact but much less practical)

The height of the cloud top (relative to the aircraft) is 40nm X 6080 X Tan 3.5º which is equal to 14875 feet. The height of the cloud is 14875 + 12000 = 26875 feet

WORKSHEET - AIRBORNE WEATHER RADAR

1. AWR operates in the ___________ frequency band and uses________ radar techniques.

(a)	SHF	primary
(b)	UHF	primary
(c)	EHF	secondary
(d)	SHF	secondary

2. The detection of clear air turbulence by AWR :

(a) is only possible at short range
(b) is only possible when using doppler turbulence detection
(c) is an advantage when flying above active storm clouds.
(d) is not possible.

3. Doppler turbulence detection does not operate

(a) at high speeds
(b) at high altitude
(c) at long range
(d) at low altitude

4. The moisture content of clouds_________with increase in altitude. At cruising altitudes care must be taken to avoid____________significant clouds.

(a) increases/over-scanning
(b) decreases/under-scanning
(c) increases/under-scanning
(d) decreases/over-scanning

5. AWR antenna stabilization is referenced to the _______. A positive tilt setting positions the antenna________.

(a)	horizon	up-wards
(b)	horizon	down-wards
(c)	longitudinal axis	up-wards
(d)	longitudinal axis	down-wards

6. AWR operating in the WX mode predicts turbulence from the concentration of water droplets or precipitation. Dangerous turbulence ________ exist at higher altitudes above the top of detectable precipitation. Ice crystals in the upper levels_______ provide significant radar returns.

(a)	may	/	will not
(b)	will not	/	will
(c)	may	/	will
(d)	will not	/	will not

7. The prediction of turbulence by Doppler technique assumes that with turbulent cloud there will be:

(a) a difference between transmitted and received frequencies.
(b) stronger returns if wavelength is adjusted to droplet size.
(c) greater Doppler shift if there is significant wind shear.
(d) a wide spectrum of frequencies in the returning energy.

8. Some AWR control panels allow the selection of "MAN". With this selection the radar will transmit a ________ beam and STC circuits________provide correction for radar attenuation.

(a)	conical	will
(b)	fan-shaped	will
(c)	pencil	will not
(d)	cosecant	will not

9. STC circuits compensate for radar attenuation by:

(a) boosting receiver gain for returns received late in each radar cycle.
(b) increasing transmitter power for targets at long range.
(c) reducing signal strength of the radar beam directed towards closer targets.
(d) automatic gain control to apply equal amplification to returns irrespective of range.

10. An aircraft at FL210 is using an AWR with stabilisation ON . Beamwidth is 5º
An isolated cloud at 40nm range just ceases to paint when the tilt control is set to 2º up. The approximate altitude of the cloud top is:

(a) 12000
(b) 19000
(c) 23000
(d) 30000