# Airborne Weather Radar

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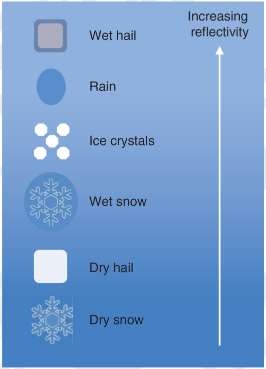
# Introduction

Airborne Weather Radar (AWR) fitted in the nose has become standard equipment on commercial transport aircraft and has led to a significant improvement in safety and passenger comfort as it **allows pilots to go around or over storms**.

Primarily the radar detects precipitation by the backscattering of radio waves by water droplets or ice crystals.

The hierarchy of reflectivity by various types of precipitation is illustrated in Figure revealing that wet hail produces the strongest return and dry snow the weakest.

Essentially, the precipitation with the largest droplet sizes containing water gives the strongest reflection.



# Weather Radar Equation

A careful consideration of the intensity of the backscattered (reflected) radiation from precipitation enables quantitative information such as the rain rate to be determined.

The reflected intensity can be calculated by modifying the radar equation

$$P_{rx} = \frac{P_{tx} G^2 \lambda^2 \sigma}{(4\pi)^3 r^4} \tag{1}$$

which was derived for a single target with a cross-section $\sigma$.

The reflection from precipitation is due to a large number of raindrops distributed through the scanned volume $V$ with a range of cross-sections. The single cross-section of the basic radar equation is thus replaced by an average cross-section over all raindrops given by

$$\overline{\sigma} = V \sum_i \sigma_i \tag{2}$$

# Weather Radar Equation

The analytical evaluation of the backscattered radiation is beyond the scope of the present exposition.

It is dependent on:

- the raindrop (ice particle) diameter $D_i$
- the dielectric constant of water (or ice) $K$
- the number $n$ of particles in the scanned volume
- the size distribution of raindrops $N_D(D)$
- the radio signal wavelength $\lambda$

# Weather Radar Equation

In the literature, the quantity

$$\sum_{i=1}^{n} D_i^6 = \int_0^\infty D^6 N_D(D) dD = Z \tag{3}$$

is often called the radar reflectivity and is given the symbol $Z$.

The cross-section per unit volume

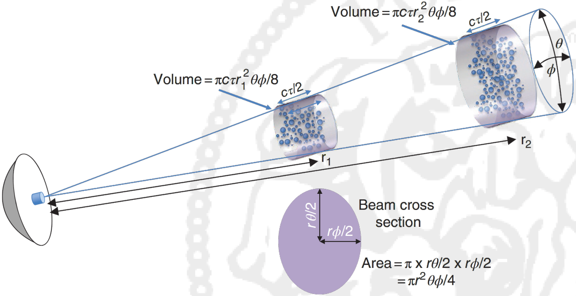
$$\frac{\overline{\sigma}}{V} \tag{4}$$

is denoted by the symbol $\eta$.

$$\eta = \frac{\pi^5}{\lambda^4} |K|^2 Z \tag{5}$$

# Weather Radar Equation

The volume of rain probed by the radar beam at one position in the scan depends on the distance $r$ from the antenna




and is given by the radial resolution (i.e. the distance that light travels during half transmission pulse of duration $\tau$) multiplied by the area of the beam at $r$ The radar beam cross-section is an ellipse with angular width $\phi$ and $\theta$ in orthogonal directions.

# Weather Radar Equation

Taking in consideration all factors it is possible to define an *average cross section* $\overline{\sigma}$

$$\overline{\sigma} = \left(\frac{\pi c \tau r^2 \theta \phi}{8}\right) \frac{\pi^5}{\lambda^4} |K|^2 \int_0^\infty D^6 N_D(D) dD \tag{6}$$

This average cross-section replaces the single target cross-section in (1) to give the power of the return signal for a given transmitted power

$$P_{rx} = \frac{P_{tx} G^2 c \tau \theta \phi \pi^3 |K|^2}{512 \lambda^2 r^2} Z \tag{7}$$

**Note**

In the case of reflection from raindrops the received power decays as $1/r^2$ as opposed to $1/r^4$ for a single target since the scanned volume increases as $r^2$

# Weather Radar Equation

(7) is known as the **weather radar equation** and can be written as

$$P_{rx} = C\frac{|K|^2}{r^2}Z \tag{8}$$

where $C$ is a constant for a specific weather radar transmitter and antenna.

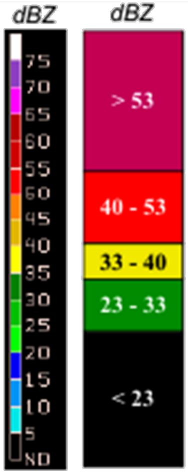
The return signal can be used to determine the intensity of weather phenomenon by solving (8) for $Z$ and comparing it to a standard scale of values.

To accomplish this, a standard reference $Z_0$ for reflectivity is defined evaluating (3) for a return of a 1 mm drop in a volume of a meter cube.

The logarithmic reflectivity $L_Z$ is finally defined in dBZ as:

$$L_Z = 10log\frac{Z}{Z_0} \tag{9}$$

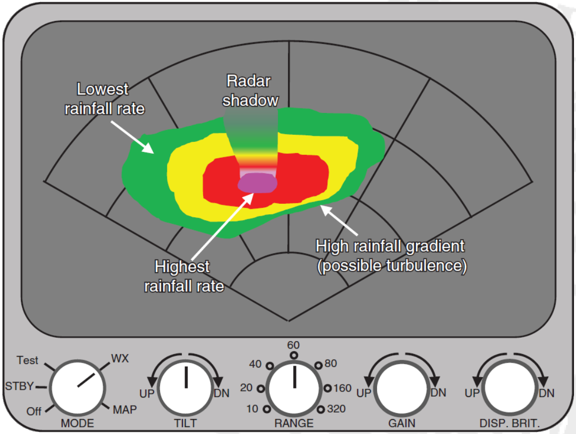
# dBZ vs Rainrate



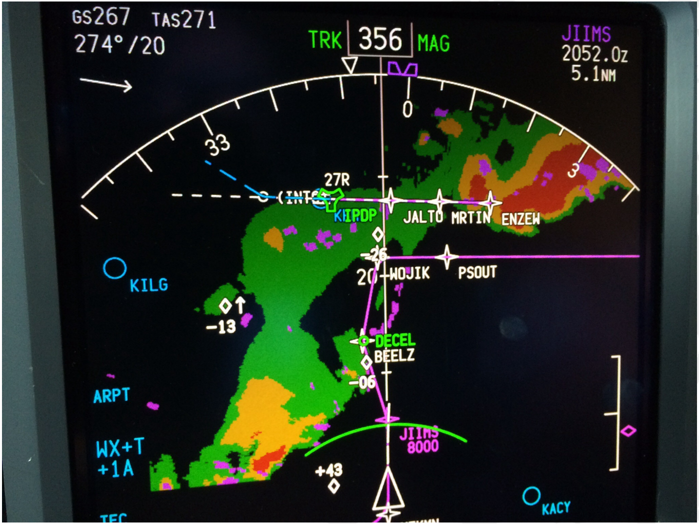

**Reflectivity in dBZ versus Rainrate**

| $L_Z$ (dBZ) | *R* (mm/h) | *R* (in/h) | Intensity |
|---|---|---|---|
| 5 | 0.07 | < 0.01 | Hardly noticeable |
| 10 | 0.15 | < 0.01 | Light mist |
| 15 | 0.3 | 0.01 | Mist |
| 20 | 0.6 | 0.02 | Very light |
| 25 | 1.3 | 0.05 | Light |
| 30 | 2.7 | 0.10 | Light to moderate |
| 35 | 5.6 | 0.22 | Moderate rain |
| 40 | 11.53 | 0.45 | Moderate rain |
| 45 | 23.7 | 0.92 | Moderate to heavy |
| 50 | 48.6 | 1.90 | Heavy |
| 55 | 100 | 4 | Very heavy/small hail |
| 60 | 205 | 8 | Extreme/moderate hail |
| 65 | 421 | 16.6 | Extreme/large hail |

# Human Machine Interface (HMI) (standalone)



# HMI On Electronic Flight Instrumentation System (EFIS) Navigation Display (ND))



# Installation

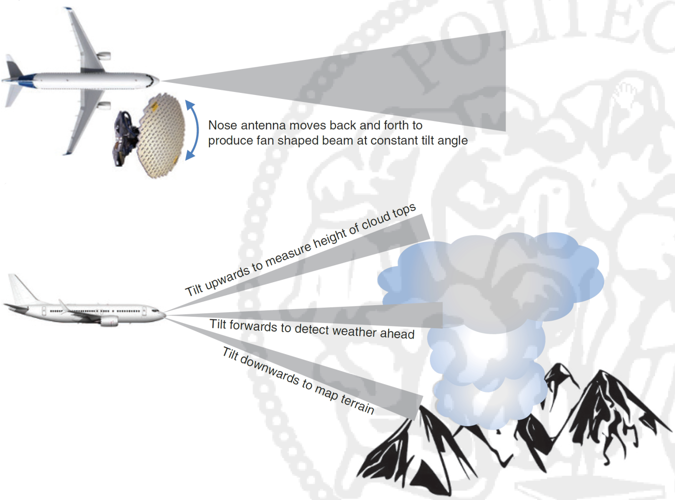
The nose cone in front of the antenna is plastic or glass fiber, which is transparent to *SuperHighFrequency*(SHF) band radio waves.

Older systems use a parabolic antenna and frequencies in the range 4-8 GHz ($\lambda = 3.8 - 7.5cm$) but newer systems use a slotted array antenna which has a higher azimuthal resolution and works in the frequency range 8-12.5 GHz ($\lambda = 2.4 - 3.8cm$).

# Installation

On single engine propeller A/C AWR radar is installed on wingtip

# Fan shaped beam and tilt control



# List of Acronyms

| | |
|---|---|
| **AWR** | Airborne Weather Radar |
| **EFIS** | Electronic Flight Instrumentation System |
| **HMI** | Human Machine Interface |
| **ND** | Navigation Display |
| **SHF** | Super High Frequency |