ARTIFICIAL CLOUD TARGET FOR RADAR (ACTR) TO SIMULATE GROWTH OR DECAY OF CUMULUS CLOUD

Dr. P. Kumar
Professor and Head
Dept. of Core Engg. and Engg. Sciences,
MIT College of Engineering,
Pune - 411029, India

ABSTRACT: *Micro scale details of growth and decay of cumulus cloud is indispensible for developing any software related to prediction of thunderstorm, duststorm, hailstorm and also downbursts, microburst, gust fronts etc. It is well known that despite favourable synoptic situation not all cumuliform clouds in the region grow into towering cumulus or cumulonimbus. Growth could be isolated (single cell storm) or localized in small region (multicell storm). It could be attributed to locally favourable topographical support, small scale low level humidity contrasts or local hot spots etc. Hence for a nowcaster it is extremely essential to predict which cell will grow into cumulonimbus and which will not. Further if any cell is likely to grow into cumulonimbus then it is important to determine its precise direction and speed of movement*

KEYWORDS: Artificial Cloud, Target Radar (ACTR) Simulate Growth, Decay of Cumulus Cloud

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INTRODUCTION

Micro scale details of growth and decay of cumulus cloud is indispensible for developing any software related to prediction of thunderstorm, duststorm, hailstorm and also downbursts, microburst, gust fronts etc. It is well known that despite favourable synoptic situation not all cumuliform clouds in the region grow into towering cumulus or cumulonimbus. Growth could be isolated (single cell storm) or localized in small region (multicell storm). It could be attributed to locally favourable topographical support, small scale low level humidity contrasts or local hot spots etc. Hence for a nowcaster it is extremely essential to predict which cell will grow into cumulonimbus and which will not. Further if any cell is likely to grow into cumulonimbus then it is important to determine its precise direction and speed of movement. During hail suppression operations, over and above nowcasters' input, one also needs to know the Reaction Time (Total or Available) and promptly disseminate it along with cloud location, speed and direction to sappers for quickly seeding the cloud. Total Reaction Time (TRT) may be defined as the time taken by any cumulus cloud with reflectivity 20 dBZ to grow till its reflectivity reaches 45dBZ. Available Reaction Time (ART) is the time actually available within the TRT for action against the threatening cumulus cloud growth. To develop any software for determining various cloud parameters, as discussed, actual cloud formation is needed, but as convective clouds may not form every day at any fixed place for repeated experiments on cumulus cloud growth, an artificial device at a fixed place is imperative for research purpose. Hence as an aid to hail suppression efforts an Artificial Cloud Target for Radar (ACTR) was designed and developed which could simulate the reflectivity of actually growing or decaying cumulus cloud.

As for design and development of Artificial Cloud Target for Radar (ACTR) one needs to thoroughly examine the range and variability of any convective cloud parameter in actual conditions hence initial sections of this paper are devoted to identifying these features from actual observation of growing or decaying convective clouds. Observed radar data is collected from three different radar sites – Nagpur, Mumbai and Patna. Growth or decay of reflectivity is discussed in section 2.1. Section 2.2 deals with the observed horizontal speed of cumulus cloud. In section 3.0 theory of ACTR to simulate growth or decay of cumulus cloud is described. In 4.0 various radio wave absorbing materials (RWAM) are described. Since to simulate artificial cloud must be with in the detectable limits of any radar hence prior to description of ACTR in section 5.0 radar specifications are presented. In section 6.0 artificial cloud target for radar (ACTR) is described.

Cumulus Growing into Hailstorm (CGH) and Cumulus Not Growing into Hailstorm (CNGH)

Table-1 shows 23 cumulus clusters from DWR data of Nagpur, Patna and Delhi DWR stations of India Meteorological Department. In the following subsections we discuss the reflectivity and speed of the cumulus clusters, respectively.

Growth or Decay of Reflectivity in Cumulus Clouds

45dBZ is the threshold value of reflectivity for locating hailstones in a thunderstorm (Witt et al 1998, Singh et al 2011 and Srivastava et al 2011). Out of them 13 Clusters Grew into Hailstorm (CGH) and 9 Clusters did Not Grow into Hailstorm (CNGH). One cluster's reflectivity (cluster no.7) rapidly grew from 26 dBZ to 44dBZ between 1810 to 1830IST but again weakened to 40 dBZ in next ten minutes at 1840IST. This cluster again grew and hail was reported after another 40 minutes at 1920IST. This was exceptionally faster growth wherein reflectivity grew at the rate 0.9 dBZ per minute (≈54 dBZ per hour). Excluding cluster 7 the average hourly growth of CGH clusters (refer table-1) was 19.1 dBZ per hour (Std Dev. ± 3.9) and that for CNGH it was 18.0 dBZ per hour (Std Dev. ± 8.1). It may be noted that for the sampled data average rate of growth for CGH is 1% faster and the standard deviation is more peaked than that of CNGH clusters. It may also be observed from table-1 that in both types of clusters' growth of reflectivity did not show any clear pattern and they are totally random. Random growth may be attributed to multiple factors interplaying together to push growth of a cumulus e.g. Convective Available Potential Energy (CAPE), strength of surface low pressure area or upper air cyclonic circulation or that of both, orographic support, surface temperature and dew point temperature and their values in upper levels up to the top of CAPE region, sustenance of upper level divergence.

Tabl-1: Reaction time and Speed of Cumulus

Radar Location	Image Date	Image Range in km/Azimuth in degree	Cluster No.	Time(UTC)	Actually observed Growth/Decay of reflectivity (dBZ) with time	Time of reflectivity reaching 45 dBZ for CGH clusters only	Average rate of growth of reflectivity per minute/per hour for CGH and CNGH clusters	Actual Speed (m/s)
NAGPUR	16-3-13	245/290	1	4:10	21	5:10	0.3/18	15.5
				4:20	23			
				4:30	27			
		75/135	2	3:30	26	No hailstorm	0.2/15	8.56
				3:40	28			
				3:50	30			
		160/85	3	4:10	22	No hailstorm	0.35/21	19.3
				4:20	26			
				4:30	29			
		100/225	4	3:30	28	No hailstorm	0.2/15	14.58
				3:40	33			
				3:50	32			
		240/270	5	4:10	28	No hailstorm	0.1/6	9.15
				4:20	33			
				4:30	30			
		240/274	6	3:50	22	No hailstorm	0.5/30	11.20
				4:00	28			
				4:10	32			
		220/315	7	6:10	26	Hailstorm	0.9/54	12.45
				6:20	28			
				6:30	44			
				6:40	40	7.20		
		220/315	8	3.30	26	No hailstorm	0.5.30	12.33
				3.40	37			
				3.50	36			
		145/350	9	3:30	26	No hailstorm	0.3/18	8.20
				3:40	30			
				3:50	32			
PATNA	1-5-12	230/345	10	9:22	33	No hailstorm	0.25/15	14.85
				9:32	36			
				9:42	38			
		230/345	11	10:12	26	11:20	0.3/18	11.75
				10:22	29			
				10:32	32			
MUMBAI	2-6-13	210/42	12	8:00	24	8:57	0.42/25	14.85
				8:19	32			
				8:38	40			
		175/48	13	8:19	29	No hailstorm	0.31/18.6	10.00
				8:38	37			

				8:57	41			
		200/33	14	8:19	29	9:35	0.16/9.6	6.00
				8:38	32			
				8:57	35156.00			
		230/345	15	9:35	26	10:32	0.39/23.4	6.00
				9:54	34			
				10:13	41			
		150/35	16	9:35	23	10:40	0.34/20.4	5.65
				9:54	29			
				10:13	36			
		210/142	17	8:57	22	10:13	0.36/21.6	10.00
				9:16	41			
				9:35	36			
		120/60	18	9:54	28	11:29	0.34/20.4	8.00
				10:32	32			
				10:51	41			
		200/90	19	16:33	23	18:27	0.29/17.4	9.00
				16:52	32			
				17:11	34			
	3-6-13	220/85	20	9:39	22	10:36	0.29/17.4	5.00
				9:58	23			
				10:17	33			
	6-6-13	240/45	21	9:35	23	10:51	0.29/17.4	18.00
				9:54	29			
				10:13	33			
	8-6-13	130/100	22	9:21	24	10:56	0.29/17.4	7.00
				9:40	29			
				9:59	35			
		210/85	23	12:50	24	13:47	0.3722.2	7.00
				13:09	32			
				13:28	38			

Horizontal Speed of Cumulus clouds

The speed of the cumulus cloud depends on several factors e.g. resultant of the sum of all levels of wind vectors, height of cumulus, its vertical tilt and its cellular structure (single cell or multiple cells)- Kumar, 2010. Last column of Table-1 shows cluster wise speed of the cumulus clouds. As this sampled data is collected from different places of India under different synoptic conditions hence it could be taken as the representing cumulus speed range, in general. Highest speed of 19.3 m/s is recorded by cluster 3 and lowest speed of 5 m/s is recorded by cluster 20. Average speed of the sampled clusters are 10.6 m/s with standard deviation of 4.0 m/s.

Theory of ACTR to Simulate Growth or Decay of Cumulus Cloud

Based on the observed data analysis of DWR, as presented in section 2, following facts emerge about the reflectivity and horizontal speed of natural cumulus clouds.

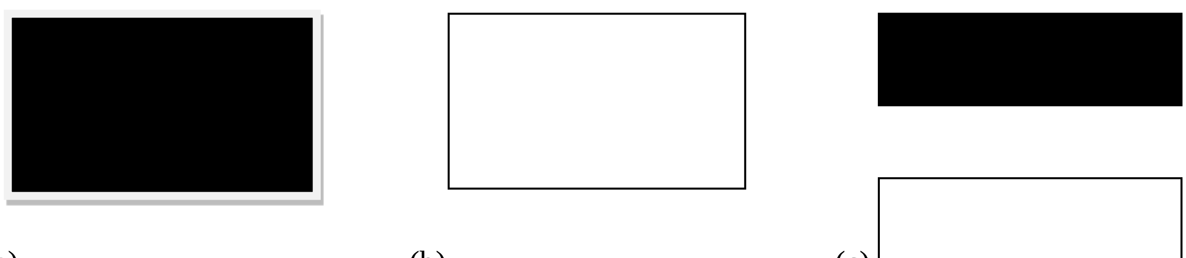
i. In any cumulus cloud reflectivity randomly changes.

ii. It may randomly increase or it may randomly decrease or in exceptional cases it may randomly increase then decrease and again increase.

iii. The average hourly growth of CGH clusters may be 19.1 dBZ per hour (Std. Dev. ± 3.9) and that for CNGH it may be 18.0 dBZ per hour (Std. Dev. ± 8.1). However, in exceptional cases reflectivity may grow as fast as 0.9 dBZ per minute (≈54 dBZ per hour).

iv. Horizontal speed of the cumulus shows wide variability. Normally average speed of the clusters could be 10.6 m/s (Std. Dev. ± 4 m/s). However speed could be as high as and as low as 5 m/s in exceptional cases.

To ensure random increase or decrease or both, one after the other, a prism with three faces of different reflectivity was taken. Refer fig. 1(a), 1(b) and 1(c). Each rectangular face of the prism is having different reflectivity as one face is fully pasted with Radio Wave Absorbing Material (RWAM), one face is fully pasted with shining white aluminum foil paper and one face is pasted with half shining white aluminum foil paper and half RWAM. White shinning aluminum is strong reflector of the radio waves.



(a) (b) (c)

Figure 1(a) to (c). It shows three different faces of prism. (a) has minimum reflectivity as it is pasted by Radio Wave Absorbing Material (RWAM) , (b) has maximum reflectivity as it is pasted with shining white aluminum foil and (c) is having moderate reflectivity – in between (a) and (b) - as it is pasted with half RWAM and half shining white aluminum foil

For Radio Wave Absorbing Material (RWAM) IR-K090 of TDK Corporation electromagnetic absorber sheet was used for X-band. Frequency vs Reflection Attenuation graph is shown in fig. 2. It is 2.5 mm thick flexible sheet and is composite of synthetic rubber and Ferrite material. Different RWAM are briefly discussed in section 4.

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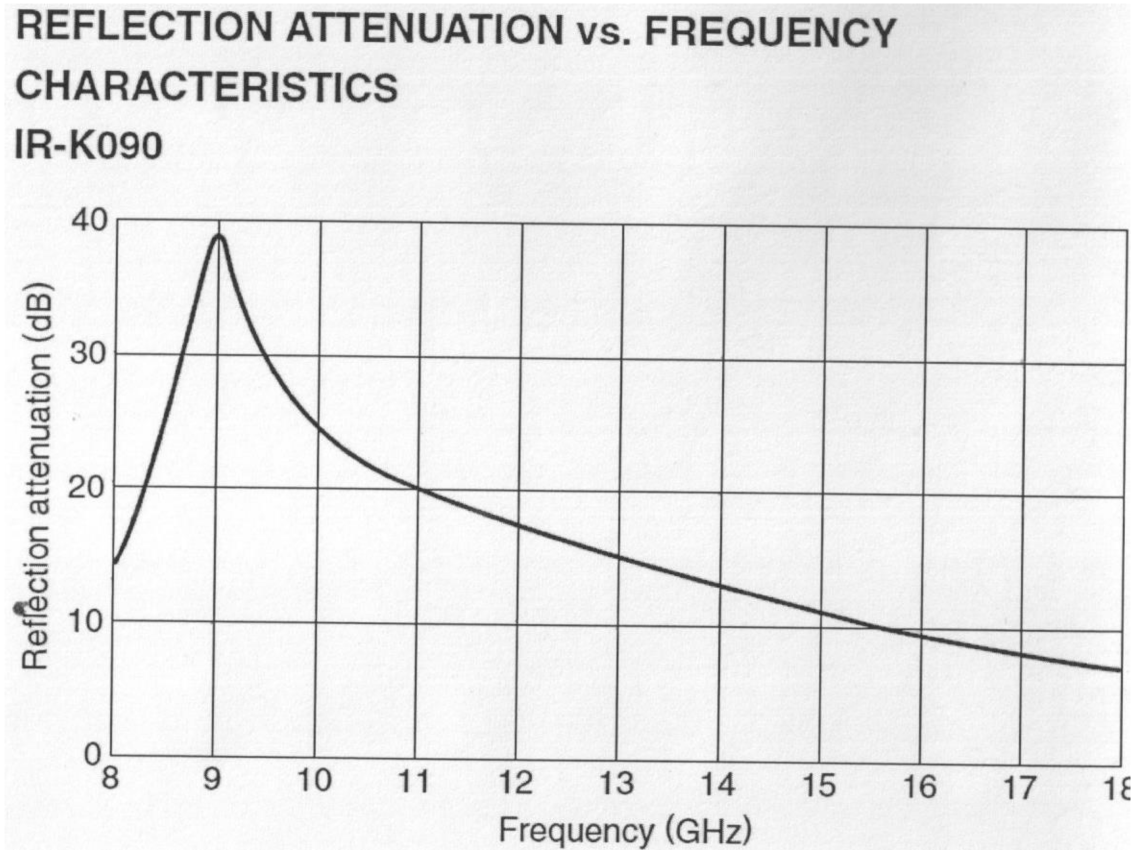


To enforce randomness in the reflectivity, as observed in cumulus clouds, the prism is made to rotate on its horizontal axis. Further to simulate horizontal motion of the convective cloud the prism is made to slide on horizontal axis with the help of a thin iron wire as shown in fig. 3.

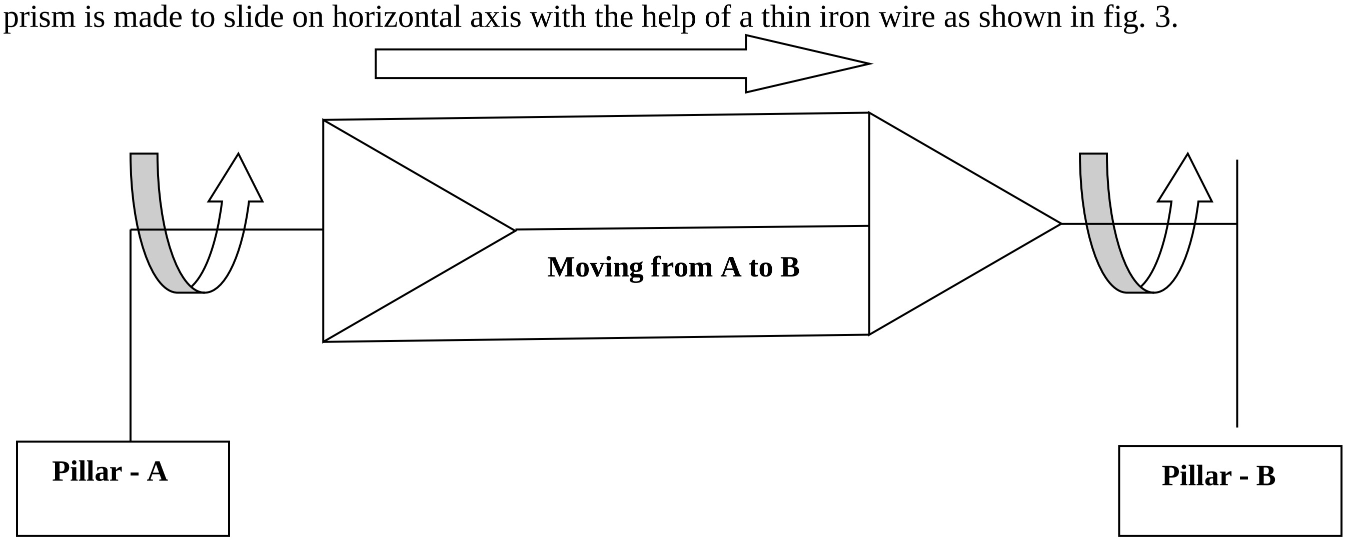


Fig: 3 Schematic description of artificial target hanging over a wire tied up on two pillers A and B.

Radio Wave Absorbing Material (RWAM)

When electromagnetic radiation interacts with radio-wave absorbing materials, the waves experience absorption (dielectric and magnetic losses), scattering (due to the structural inhomogeneities of the material), and interference. Nonmagnetic absorbing materials are subdivided into interference, gradient, and mixed types.

Interference materials are composed of alternate dielectric and conducting layers. Interference occurs between the waves reflected from the electrically conducting layers and the metallic surface of the object being protected. Gradient materials, which are the commonest type, have a layered structure in which the complex dielectric constant varies either in continuous or stepwise fashion throughout the thickness and is usually governed by a hyperbolic law. IR-K090 of TDK Corporation electromagnetic absorber sheet is Gradient type absorber. The thicknesses of these materials are relatively large and amount to more than 0.12 to 0.15Aλ_{max}, where λ_{max} is the maximum operating wavelength. The outer (matching) layer is made of a solid dielectric having a high content of trapped air, such as a foam plastic, and a dielectric constant close to unity; the other (absorbing) layers are made of dielectrics having high dielectric constants, such as fiberglass laminates, and an absorbing conducting filler, such as carbon black and graphite. Also among the gradient materials, by convention, are those with outer surfaces having such projections as pins, cones, and pyramids, that is, spiniferous materials. The multiple reflection of waves from the surfaces of the projections, with absorption of energy from the wave at each reflection, assists in reducing the reflection coefficient.

The mixed types of absorbing materials are composites of the gradient and interference types and are distinguished by their efficacy over a wide range of wavelengths. Ferrites form a group of magnetic absorbing materials in which the required thickness of the layer is characteristically small (1 to 10 mm).Refer Table-2. A distinction is made between broad-band ($\lambda_{max}/\lambda_{min}$ > 3 to 5), narrow-band ($\lambda_{max}/\lambda_{min}$ ~ 1.5 to 2.0), and those materials designed for a fixed (discrete) wavelength (bandwidth < 10 to 15 percent of λ_0), where λ_{min} and λ_0 are, respectively, the minimum and the operating wavelengths. Ordinarily, absorbing materials reflect between 1 and 5 percent of the electromagnetic radiation; some, however, reflect no more than 0.01 percent. They are capable of absorbing flux densities ranging from 0.15 to 1.5 watts/cm^2 and, in the case of foam ceramics, up to 8 watts/cm^2. The operating temperature range of the materials with air cooling is from - 60° up to 650°C, with some materials offering a range up to 1315°C. For X-Band refer Band number 10.

Table 2. Band classification of radio waves

Band number	***Designation in terms of frequency***	***Frequency range[1]***	***Designation[2] in terms of wavelength***	***Wavelength range[3]***
1	Extremely low frequency (ELF)	3–30 Hz	Decamegameter waves	100–10 Mm
2	Superlow frequency (SLF)	30–300 Hz	Megameter waves	10–1 Mm
3	Infralow frequency (ILF)	0.3–3 kHz	Hectokilometer waves	1,000–100 km
4	Very low frequency (VLF)	3–30 kHz	Myriameter waves	100–10 km
5	Low frequency (LF)	30–300 kHz	Kilometer waves	10–1 km
6	Medium frequency (MF)	0.3–3 MHz	Hectometer waves	1–0.1 km
7	High frequency (HF)	3–30 MHz	Decameter waves	100–10 m
8	Very high frequency (VHF)	30–300 MHz	Meter waves	10–1 m
9	Ultrahigh frequency(UHF)	0.3–3 GHz	Decimeter waves	1–0.1 m
10	Superhigh frequency (SHF) (It includes X-Band)	3–30 GHz (8 – 12.5 GHz)	Centimeter waves *This was used in the Portable radar described in next section*	10–1 cm (3.75 – 2.4 Cm)
11	Extremely high frequency (EHF)	30–300 GHz	Millimeter waves	10–1 mm
12	Hyperhigh frequency (HHF)	0.3–3 THz	Decimillimeter waves	1–0.1 mm

Note: [1]Upper limit inclusive, tower limit exclusive [2]In English, forms in -ic are often used, for example, “myriametric waves” [3]Lower limit inclusive, upper limit exclusive

Radar Specifications

ACTR’s dimension, speed and distance must be within the tracking limits of any radar. Hence X-Band radar was selected for the purpose. Refer fig.4. This small radar is foldable and can be carried on shoulders. For tracking targets it looks only in selected directions – horizontally and vertically. Its tracking Range is 70-200 meter. It has mounting tripod.

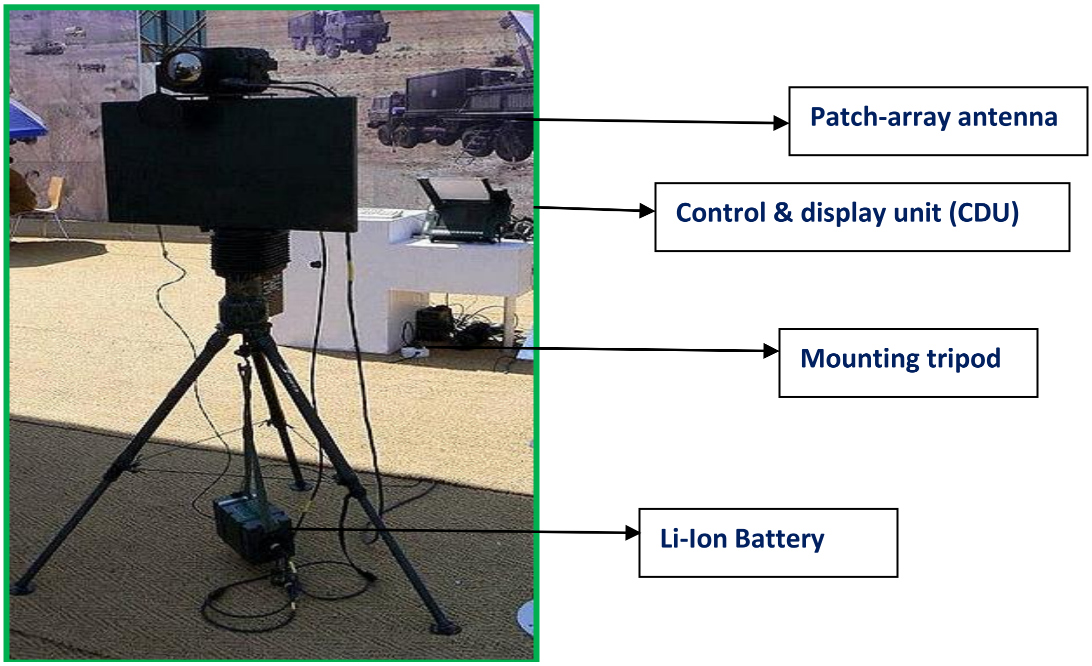


Fig. 4 Portable X-band short range Radar

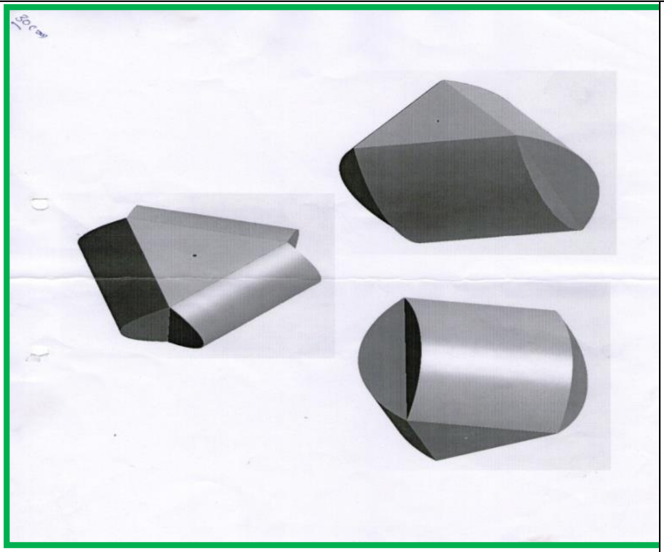
The radar operates on two rechargeable 24 V batteries, which are carried separately. The radar can also be operated from AC supply. The batteries are usually suspended from the tripod to provide extra stability to the radar, although they can be kept separately. Its display unit can be connected to any computer. At 100 m it can resolve a target of 1 m width and 50 cm height. Radar's general tracking specifications are mentioned below.

i. Elevation Coverage: -40 to +15° (remotely settable)
ii. Azimuth sector scan: Sector scanning
iii. Azimuth accuracy: 0.5° rms
iv. Azimuth resolution: better than 4°
v. Track while Scan**:** Multiple targets

Other hardware details of the radar are mentioned in appendix-A to this paper.

Artificial Cloud Target for Radar (ACTR)

Design of Prism. For receiving optimum back scatter at the fixed point, where radar antenna is located, the each reflecting surface of the prism are given with minor convexity. This is to ensure that incoming radar beam towards the surface of moving prism makes least possible angle with the normal to the surface of prism. The lesser is the angle to the normal the higher is the back scatter towards the radar antennae. The prism design is shown in the fig. 5.



(a) Left is the side view of the prism. Right (above) is the side and bottom view of the prism and right (below) is the top view of the prism.	(b) ACTR on wire. By a motor it moves left to right or right to left with controlled speed and also it rotates on horizontal axis in steps of 120^0 each.

Fig. 5 It shows the convexity of each surface of prism and hung ACTR on wire.

Each rectangular face of the target is of dimension 1.25m /1m in length and breadth respectively and the total weight is about 25-30 KG. Each face is made in such a manner so that it forms a convex plane with central bulging.

Support system. Entire ACTR with support system is shown in fig. 6.

Fig: 6. A live picture of the Artificial Cloud Target for Radar (ACTR) on wire supported by two yellow pillars on either side.

Configurations of the Artificial Cloud Target for Radar (ACTR) are described below. Entire arrangement consists of two pole of height 10 m and 50 m apart. A triangular prism is hanging on two wires through it. These wires are fixed on two pulleys – one on either pole. Each rectangular convex face of the prism is of dimension 1.25m x 1m. These pulleys are made to rotate by 2 HP motor to turn the prism on horizontal axis. Each rotation is in the steps of 120^0, so that after every one step different face of the prism faces radar antenna. Either end of the prism is also hooked up to separate wires; other ends of these wires are connected to geared pulley devices attached on the pole facing the side. If prism has to move to right then right side pulley pulls it and left side pulley leaves the rope similarly if prism has to move to left then left side pulley pulls it and right side pulley leaves the rope. To avoid the impact by the prism on extreme ends there are sensors installed on either side so that motor will switch off 1 m short of extreme end of the rope.

Some more features with their photos are described below.
Poles: To make the areal arrangements of the target 10 meter above the ground, this is required to remove the ground clutter while tracking by the Radar. Refer picture in fig.7.
Ladder arrangement with platform: To make any changes in the target, wires, pulley etc. Also to lubricate the entire chain, wire system.

Fig: 7 **Pole with ladder and platform**

Toothed gear chain arrangement:
This is the design for manually shifting of the different surface of the target by rotation of the handle. So as shown in the figure a clamp like structure attached with spring is there to fix the clamp into the hole after 120^0 rotation of the toothed structure so three hole are there to fix the clamp for 3 different surface which are 120^0 apart these all are controlled manually. 2 HP Electric motor was also fixed with the gear to rotate in steps- refer fig 9.

Fig.8 **Toothed wheel with handle for manual rotation**

Electrical Motor:

One 2HP electrical motor (Fig. 9(a), is fitted on the top of the platform which provides the required driving power to move the target both in forward and reverse direction. It is a both forward/reverse geared motor. Another 2 HP motor for rotation of the target on horizontal axis is shown in 9(b)

(a) (b)

Fig: 9 Two HP forward/reverse geared motor

Control panel:

This is the heart of our entire structure which controls the entire operation of the target. Entire operation is achieved by microcontroller programming. This mainly controls:

- ❖ Forward and reverse motion of the target
- ❖ Speed of the target
- ❖ Load capacity of the motor
- ❖ Operating frequency
- ❖ Impact control mechanism

Fig: 10 **Control panel switches**	Fig 11 **Control panel fitted in the pole**

Theory of Operation

As the three faced prism horizontally moves on the wires from left to right and right to left at a fixed speed, it simulates horizontally moving convective cloud. Further, while moving horizontally as it randomly rotates in steps of 120^0 angle on the horizontal axis its different faces, successively would face the radar antennae located at a fixed point at about ≥ 100m from the two poles of ACTR. And because each face of prism has different reflectivity radar would receive random change in reflectivity of the moving target. This would, therefore, simulate the moving convective cloud whose reflectivity is either increasing or decreasing randomly, as noted in the actual DWR data presented in table-1. Refer fig. 12.

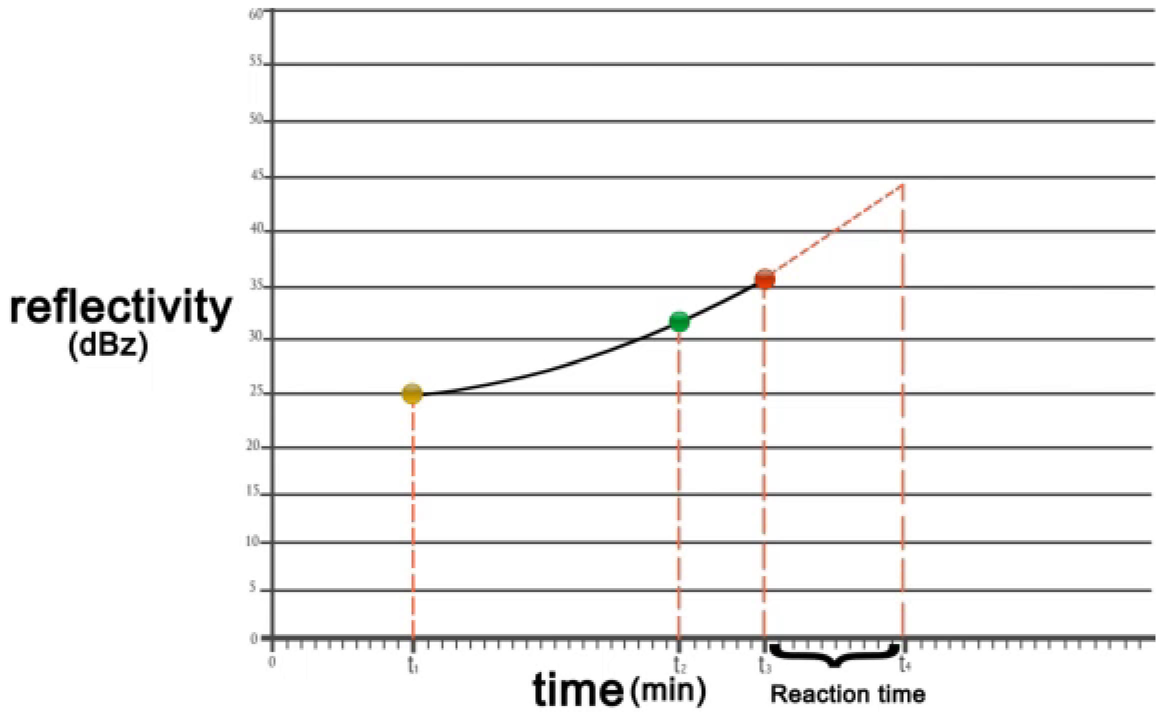


Fig.12 Reflectivity values for time t_1, t_2 and $t_3$are plotted. Best fit quadratic curve is extrapolated to cut 45dBz line at point. Corresponding time t_4 is known and t_4 - t_3 (Available Reaction Time) is computed by software.

For developing a software to ascertain which convective cloud would grow into hailstorm and which would not one needs to obtain three different observations of reflectivity at time t_1, t_2 and t_3 as r_1, r_2 and r_3 and a quadratic best fit curve has to be extrapolated to cut the 45 dBZ line. Corresponding t_4 value would give the time of hail formation. The difference $t_4 - t_3$ would give the Available Reaction Time (ART) for cloud seeding to suppress hail in the convective could.

CONCLUSION

i. ACTR provides repeated data generation, even if there is no cloud.

ii. As reaction time is limited for hail suppression hence each second of Available Reaction Time is precious. ACTR provides instant processing of received data and spontaneous dissemination of processed data to cloud seeding activity without any loss of time.

iii. Beside reaction time ACTR can also be used for predicting the location, speed and direction of motion of the cloud with the same analogy as reaction time.

iv. With known location and speed of moving prism the resulting software outputs of location and speed prediction could be verified, spontaneously.

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Appendix-A

X-Band Radar Hardware

Radar array and hardware : The radar array consists of

i. X-band Transmitter, receiver and processing modules within the single array block.
ii. The signal processor is a single on-board -based chip, which consumes very less power.
iii. The antenna array is made up of "**microstrip (16*64)"** patch array antennas.
iv. The transmitter is a solid state transmitter module, while the separate receiver is "**a super-heterodyne type receiver".**
v. The radar algorithm incorporates "**Digital** Pulse compression**"** Technology, which improves the LPI characteristics, as well as making the radar more accurate.

Display Unit: This is most important part of the radar which the radar output unit.

i. Our radar processing, display units and control functions are integrated on a single, touch sensitive, portable IBM PC, called the Control and Display Unit (CDU).
ii. Some processing elements are also built into the radar.
iii. The processed information is displayed on a high resolution **10.4" LCD** colour display.
iv. The PC operates on a Windows XP-based, menu driven user interface, which makes operating the Radar extremely simple.
v. We can always visualize a high resolution, north oriented; colored radar picture is displayed on PC display.
vi. The radar display can either be in a "Plan position indicators **(PPI)"** display or a "**B-Scope"** display.
vii. A target position can be marked by means of a track ID for further investigation or to keep on tracking the same target for some time.

Radar interface:

i. The interface between the radar and the CDU can be either RS232C or LAN connectivity.
ii. A light weight, rugged, standard 2-wire field cable is used for communicating between the radar and CDU. This allows the operators to be positioned up to **100 m** away from the radar.
iii. The use of wired interface also provides a better security from interception and lower noise, and does not require the radar and CDU to be within Line-of-Sight of each other.

Thermal Imager:

i. A third generation thermal imager has also been configured and integrated with it.
ii. The imager has a single field of view (monocular sighting while operating in the Mid-wavelength Infrared (MWIR) spectrum (3-5 µm wavelengths), this gives the Radar day and night viewing capability.

iii. All Radar data and images are combined and displayed on the common control and display unit (CDU). Thus, the radar can integrate its display with IR sensor output, which improves the overall efficacy of the system.