# ECE 495 – Electromagnetic Warfare and Survivability

## Block 3: IR EW and Signature Management

## Lesson 25: RCS Physics

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## Where We Left Off

The IR arc is complete: signature components (L22), the sensors that exploit them (L23), and the countermeasure duel (L24).

Now the **RF twin**. Back in Block 1 the radar range equation carried a mysterious $\sigma$ — we priced it, but never opened it.

Today we open it. *What makes a radar echo big or small, and why does the same aircraft shout at one angle and whisper at another?*

## Lesson Objectives

By the end of this lesson, you will be able to:

- Define **RCS** as an effective echo area and place targets on the **dBsm** ladder
- Decompose $\sigma$ into **geometric cross section**, **reflectivity**, and **directivity**
- Rank canonical shapes and explain why **directivity** dominates
- Read an **aspect pattern** and defend the median as the honest single number

# RCS: the Radar-Side $J$

$\sigma$ is the target's **effective echo area** — the size of the fictitious perfect reflector that would return the same power:

- It is **not** physical size: a shaped 50,000-lb bomber can echo less than a bird
- Logarithmic currency: **dBsm** (0 = 1 m$^2$): insects $-40$, fighters $+7$, ships $+30$
- Like L22's $J$, it depends on **aspect**, **frequency**, and **polarization** — it is a function, not a number

**RCS measures cooperation with the radar, not size.**

# The Rule: Three Knobs on the Echo

$$\sigma = \underbrace{A_{\text{geo}}}_{\text{projected area}} \times \underbrace{\Gamma}_{\text{reflectivity}} \times \underbrace{D}_{\text{directivity}}$$

- $A_{\text{geo}}$ — the **intercepted** power: how much of the wave the body catches
- $\Gamma$ — the fraction **re-radiated**: materials live here (L27's RAM attacks this knob)
- $D$ — how much of the echo goes **back at the radar**: shaping lives here
- $A_{\text{geo}}$ and $\Gamma$ buy factors; $D$ buys **orders of magnitude** — L26 is built on that fact

# The Canonical Shapes

Same physical size, wildly different echoes — directivity at work:

| Shape | Peak $\sigma$ | Behavior with aspect | Verdict |
|---|---|---|---|
| Sphere | $\pi r^2$ | constant | the calibrator |
| Flat plate | $4\pi A^2/\lambda^2$ | huge spike, then collapse | loud but narrow |
| Corner | plate-class | huge over *wide* angles | the disaster |
| Ogive / cone | tiny nose-on | grows off-axis | the LO nose |

- A 1 $m^2$ plate at X-band echoes $\sim$14,000 $m^2$ broadside, gone within degrees

# The Corner Trap

Two flat plates are survivable. Two flat plates **at a right angle** are not:

- A dihedral **retroreflects**: double-bounce geometry sends energy straight back over a *wide* range of angles
- Add a third face and the trihedral returns fire from almost anywhere — which is why they make good **calibration targets**
- Aircraft grow corners by accident: tail-fuselage junctions, open bays, pylons, and **inlets** (a cavity is a corner with a grudge)
- First commandment of shaping: *thou shalt not present a right angle*

# RCS Is a Pattern, Not a Number

Plot $\sigma$ around the compass and the three knobs draw the picture:

- Narrow **specular spikes**, tens of dB tall, where a facet faces the radar
- A deep, noisy **floor** everywhere else — edges and traveling waves whisper
- The **max** lies in the spikes; the **median** describes the floor a search radar sees
- Quoting one number for an aircraft means choosing which story to tell — specs and stats live in that gap

# The Radar Gets a Vote: Frequency

$\sigma$ carries the radar's fingerprints, not just the target's:

- **Optical regime** ($L \gg \lambda$): shape rules — everything today assumed this
- **Resonance regime** ($L \sim \lambda$): the whole body rings; shaping tricks lose their grip
- **Rayleigh regime** ($L \ll \lambda$): only gross size matters
- This is why **VHF early-warning** radars are the counter-LO play from B1 — they drag a shaped target toward resonance
- Polarization matters too: edges and wires favor one polarization over the other

# Where This Is Headed: What a dB of RCS Buys

Why fight for every dB? Because Block 1's fourth-power law now pays *us*:

- $R_{\max} \propto \sigma^{1/4}$: cut the **median RCS** 10 dB and detection range falls to $\sim$56%
- Cut 30 dB and the radar keeps $\sim$18% of its reach — rings on the IADS map collapse
- The IR side scaled as $\sqrt{J}$; the RF side is even more forgiving of bold cuts
- L26 asks *where* the dBs hide on an airframe; L27 buys more with materials

**Stealth does not make you invisible — it shrinks the rings.**

# Quick Exercise / Type-along: Big Echo or Small?

For each, say whether $\sigma$ is **large or small** and name the **knob** responsible. Call it out.

1. A calibration sphere, viewed from any angle
2. A barn door, exactly broadside to an X-band radar
3. The same barn door, tilted $10^\circ$ away
4. A B-21 planform, nose-on, at fighter-radar frequencies
5. That same planform to a VHF early-warning radar

# Today's Interactive Demo: Reading an Aspect Pattern

Today's interactive demo. Today you get **data**, not a model:

- Load `L25_RCSPattern.csv` — a notional faceted target, 360° of $\sigma$ vs aspect
- Plot it on a **polar** axis and find the four specular spikes
- Compute **max, mean, median** over the nose sector and the full pattern
- Watch a 2° spike drag the mean — *which number belongs in the spec?*

*Companion script:* `L25_RCSAspectPattern.m`

*In L26: where the echoes hide on a real airframe — and how design fights each one.*

# Wrap-Up

Key ideas:

- RCS is **effective echo area** in dBsm — cooperation with the radar, not physical size
- One rule: $\sigma = A_{\text{geo}} \times \Gamma \times D$ — and **directivity** owns the orders of magnitude
- Plates spike, **corners** betray, spheres calibrate, ogives whisper nose-on
- $\sigma$ is a **pattern** over aspect and frequency; the **median** is the honest planning number
- $R_{\max} \propto \sigma^{1/4}$ turns dB of signature into miles of sanctuary

Next lesson:

- **L26: the Aircraft RF Signature** — contributors, faceting vs curvature, broadband LO
- Pre-flight quiz for L26 due before class