Project 1
B-21 Threat Detection Range Analysis

Background

The B-21 Raider is an all-aspect, broadband low-observable (LO) bomber designed for long-range penetrating strike inside heavily defended airspace. Before any route is planned, mission planners need one fundamental product: **the range at which each threat radar class first detects the aircraft, as a function of aspect angle and operating band**.

Detection range is not a single number. The B-21 radar cross section (RCS) varies with the aspect the threat sees and with the threat's operating frequency, and the radar range equation turns every dB of RCS into kilometers through the fourth-root law:

$$R_{\max} = \left[\frac{P_t \, G_t \, G_r \, \lambda^2 \, \sigma}{(4\pi)^3 \, S_{\min}} \right]^{1/4}.$$

A broadband LO design suppresses RCS everywhere, but not equally: signature suppression is most effective at high frequency and least effective in the low bands where early warning radars live. The result is that different layers of an Integrated Air Defense System (IADS) see the B-21 at very different ranges, and those differences drive where the ingress corridors are.

Your group is the survivability analysis cell supporting B-21 mission planning. Your product feeds directly into the route-planning work this course returns to in Block 4.

Scenario

A notional adversary IADS sector defends the target area with three radar classes, layered exactly as discussed in L7: an early warning (EW) radar for long-range detection, an acquisition (ACQ) radar for 3D track and handoff, and a target tracking radar (TTR) for fire control. Parameters for each class are given in Table 1.

Table 1: Notional threat radar parameters (consistent with `L7_IADSRadarSurvey.m`).

Class	**Band**	f	P_t	$G_t = G_r$	$S_{\min}$
EW	UHF	0.5 GHz	2 MW	25 dBi	−140 dBW
ACQ	S	3 GHz	1 MW	30 dBi	−130 dBW
TTR	X	10 GHz	100 kW	35 dBi	−140 dBW

All parameters are notional and unclassified, constructed for instruction. Assume free-space propagation, monostatic geometry, and that each radar detects the B-21 whenever the received signal meets or exceeds its $S_{\min}$.

B-21 RCS Model

The provided file `B21_RCS_Table.csv` contains the notional B-21 RCS in dBsm at 5° aspect resolution from 0° (nose) to 180° (tail), in each of the three threat bands. Aspect is symmetric about the nose–tail axis, so the table covers the full 360° azimuth circle. Table 2 summarizes the sector means.

Table 2: Sector-mean B-21 RCS (dBsm), notional. Full 5° table in `B21_RCS_Table.csv`.

Aspect sector	Degrees off nose	UHF	S	X
Nose	0–30	−17.0	−25.0	−31.4
Front quarter	30–60	−17.0	−25.8	−31.3
Beam	60–120	−10.3	−17.9	−24.0
Rear quarter	120–150	−14.1	−22.6	−28.5
Tail	150–180	−13.3	−21.3	−27.6

Two modeling notes:

- **Band matching.** Each radar sees the RCS column for its own band: EW uses the UHF column, ACQ the S column, TTR the X column.
- **Uncertainty.** Treat each table value as the center of a ±3 dB uncertainty interval. How you carry that uncertainty through to detection range, and how you present it, is a group decision you will be asked to defend.

Your Task

This project is a group effort. Groups are assigned in class at L9. Work the analysis as a team; every member must be able to explain every result.

1. **Detection range vs. aspect.** For each threat class, compute $R_{\max}$ as a function of aspect angle using the radar range equation, Table 1, and the in-band RCS from `B21_RCS_Table.csv`. How you bin or smooth aspect is your choice; state it and justify it.
2. **Uncertainty.** Propagate the ±3 dB RCS uncertainty into detection range for each class. Present the resulting range uncertainty in a form a mission planner can use.
3. **Visualization.** Produce at least one visualization that communicates the full detection picture: all three classes, all aspects, with uncertainty. Polar detection-range plots are a natural starting point, not a requirement.
4. **Ingress implications.** Answer, with numbers: Which radar class drives the B-21's detectability, and by how much? Which aspect sectors are most and least exposed? What does the gap between the EW detection range and the TTR detection range mean for the kill chain — detection is not engagement.
5. **Recommendation.** Close with a one-slide recommendation to the mission planning cell: the heading discipline, standoff, or routing implications your analysis supports.

The provided starter script (`L9_Project1Starter.m`) handles CSV ingest, dB conversions, and a single worked $R_{\max}$ so you can verify your pipeline. Everything beyond that point is yours.

Deliverables and Logistics

- **Results presentation** at L10: 10 minutes plus 5 minutes of Q&A. Every group member speaks. Walk your peers through your approach, what you tried, what worked and what did not, and your recommendation.
- **Submission**: slides (PDF) and all analysis code, submitted before the start of L10.
- **Individual Project Quiz 1** (open book, 20 minutes) is taken in class at L10 and covers the project work and Block 1 topics.

Grading

Element	Weight
Analysis correctness (range equation, band matching, units)	30%
Aspect treatment and justification	15%
Uncertainty treatment and presentation	15%
Visualization and communication	20%
Ingress implications and recommendation	10%
Q&A and individual ownership of results	10%

Innovation bonus (up to +5%). Awarded for going beyond the baseline ask in a substantive way: an unexpected visualization that clarifies the trade space, a non-obvious analytical approach reported honestly (including why it did or did not work), a clear connection to a real operational implication, or reusable, documented code other groups could pick up. Executing the baseline cleanly earns full credit; the bonus rewards judgment and creativity on top of it.