Project 2
B-21 Standoff Emitter Geolocation

Background

In Block 2 you learned to *listen*: a radar warning receiver (RWR) hears a threat emitter and measures its angle of arrival (L13), and crossing bearings from different points locates the emitter (L14). This project turns that skill into an operational product.

A B-21 on a standoff orbit can hear the radars of an Integrated Air Defense System (IADS) long before it must enter their lethal range. Each RWR bearing is a **line of position**; cross several of them, taken from different points along the aircraft's path, and the lines intersect at a **fix**. The precision of that fix — not merely its existence — is what decides whether the location is good enough to *cue a weapon*.

Your group is the B-21 mission-planning cell. A strike package needs weapon-quality locations for the emitters defending a target area so a standoff weapon can be cued onto them. You must **design a passive collection** — where the B-21 flies and how it gathers bearings — that geolocates those emitters precisely enough to cue the weapon, *while keeping the aircraft outside every threat's engagement range*. Accuracy wants you close and moving; survivability wants you far. That tension is the project.

Scenario

A notional adversary IADS sector defends a target area near the origin of a local North/East grid (all distances in km). Three emitters are present, of the classes introduced in L7: an early-warning (EW) radar, an acquisition (ACQ) radar, and a target-tracking radar (TTR). Prior ELINT has fixed each emitter's position only coarsely (±5 km) — good enough to plan against, not good enough to shoot. These priors are in `IADS_Scenario.csv` and summarized in Table 1.

Table 1: Notional IADS emitters. Positions are coarse ELINT priors (±5 km). Keep-out is the engagement range your aircraft must stay outside.

ID	Class	Band	Prior (N, E) [km]	Keep-out [km]
E1	EW	UHF (0.5 GHz)	(0, 0)	20
E2	ACQ	S (3 GHz)	(10, −8)	45
E3	TTR	X (10 GHz)	(−6, 6)	40

The **keep-out radius** is the lethal engagement range of the surface-to-air system associated with each emitter; the entire B-21 flight path must remain outside all three keep-out circles. (These ranges are notional and consistent with the kind of detectability analysis you did in Project 1.)

RWR and Geolocation Model

The bearing measurement. From any aircraft position the RWR reports the bearing to each emitter, measured from North toward East:

$$\theta = \operatorname{atan2}(\Delta E,\ \Delta N), \qquad \Delta N = N_e - N_r,\ \ \Delta E = E_e - E_r,$$

where subscript e is the emitter and r the receiver (aircraft). Each measurement carries zero-mean Gaussian noise with

$$\sigma_\theta = 0.5^\circ \quad (1\sigma).$$

From bearings to a fix. One bearing is a line; two or more crossing bearings, taken from different points along your path, determine the emitter position (L14). With K bearings the position is found by least squares.

From geometry to accuracy. The fix is not a point but an **error ellipse**. Its size is set by the collection geometry and the bearing noise through the information matrix

$$\mathbf{J} = \frac{1}{\sigma_\theta^2}\sum_{k=1}^{K}\mathbf{H}_k^\top\mathbf{H}_k, \qquad \mathbf{H}_k = \left[-\frac{\Delta E_k}{R_k^2},\ \ \frac{\Delta N_k}{R_k^2}\right], \qquad \mathbf{C} = \mathbf{J}^{-1},$$

where R_k is the range from the k-th aircraft position to the emitter. The 1σ semi-axes of the ellipse are $\sqrt{\operatorname{eig}(\mathbf{C})}$. The lesson from L14 lives in this formula: a **wide crossing ("cut") angle** and a **long baseline** shrink the ellipse; a shallow cut or a long range stretch it along the line of sight.

Location accuracy metric. Summarize each emitter's fix quality by its circular error probable,

$$\text{CEP} \approx 0.59\,(a+b),$$

where a and b are the 1σ semi-axes. You may use a different, clearly-stated metric if you prefer; state and justify your choice.

Cueing Specification

The strike package carries a standoff weapon whose terminal seeker acquires the emitter once it is within an **acquisition basket of radius** $r_{\text{acq}} = 1.0$ **km** of the cued aimpoint. To acquire with high confidence, the cued location error must sit well inside that basket:

$$\boxed{\text{CEP} \ \le\ \tfrac{1}{2}\,r_{\text{acq}} \ =\ 0.5\ \text{km}}$$

Your collection must meet this specification for the lethal emitters (the ACQ and TTR at minimum). The EW radar is a useful additional target if your geometry also pins it.

Collection Tool

RWR collection simulator. The function `rwr_collection_sim.m` stands in for the B-21 RWR collecting along your flight path. Call it with the North and East coordinates of your chosen waypoints:

```
meas = rwr_collection_sim(acN_km, acE_km);
```

It returns a table of noisy bearings (one row per waypoint per emitter: `wp`, `emitter_id`, `az_deg`). Fresh noise is drawn on every call, so you may collect repeatedly to study the spread. The emitters' *true* positions are hidden inside the simulator — the CSV gives only the coarse prior, so you must **estimate** the positions from your bearings.

Starter script. `L19_Project2Starter.m` reads the scenario, flies a two-waypoint sample leg, cross-fixes one emitter, and draws its 1σ ellipse with the resulting CEP. It is a working pipeline for the simplest case; extending it to many cuts, all emitters, and a designed geometry is your job.

Your Task

This project is a group effort. Groups are assigned in class at L19. Work the analysis as a team; every member must be able to explain every result.

1. **Geolocation and uncertainty.** Build the pipeline that turns a set of RWR bearings into an emitter position estimate and its 1σ error ellipse. State your CEP metric. Verify it against the starter's two-point case before scaling up.
2. **Collection design.** Design the B-21 collection: standoff range, leg length and heading (one or more legs), and how many bearing cuts you take. Your entire path must stay outside all three keep-out circles. State your design and justify the geometry in terms of cut angle, baseline, and range.
3. **Execute and geolocate.** Run `rwr_collection_sim.m` along your path, geolocate each emitter, and report the position estimates with their error ellipses and CEP values.
4. **Meet the specification.** Show which emitters meet CEP $\leq$ 0.5 km. For any that do not, state what change would close the gap and quantify the **accuracy-versus-standoff trade**: how much closer (or how much more baseline) would it take, and what does that cost in survivability?
5. **Visualization.** Produce at least one figure that communicates the full picture: emitters, keep-out circles, your flight path, the fixes, and the error ellipses, all to scale.
6. **Recommendation.** Close with a one-slide recommendation to the strike cell: the collection geometry you recommend, which emitters are cueable to weapon quality, and the operational implication of the accuracy versus standoff tension.

Deliverables and Logistics

- **Results presentation** at L20: 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 L20.
- **Individual Project Quiz 2** (open book, 20 minutes) is taken in class at L20 and covers the project work and Block 2 topics (ES/EP/EA, RWR AoA, geolocation geometry, J/S).

Grading

Element	Weight
Geolocation analysis correctness (cross-fix, covariance/ellipse, units)	30%
Collection-geometry design and justification	20%
Meeting the spec and the accuracy–standoff trade	15%
Visualization and communication	20%
Recommendation and operational insight	5%
Q&A and individual ownership of results	10%

Innovation bonus (up to +5%). Awarded for going beyond the baseline ask in a substantive way: a non-obvious collection geometry that beats the straight-leg baseline (a heading change, a two-ship split, or a sequential plan), a clear treatment of how geometry shapes the error ellipse, an honest report of an approach that did or did not work, 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.