TEST CASE 5: Radar Cross of a Drone Swarm

Toufic ABBOUD (abboud@imacs.polytechnique.fr)
Frédéric DELCORSO (frederic.delcorso@ariane.group)
Gildas KUBICKE (gildas.kubicke@intradef.gouv.fr)

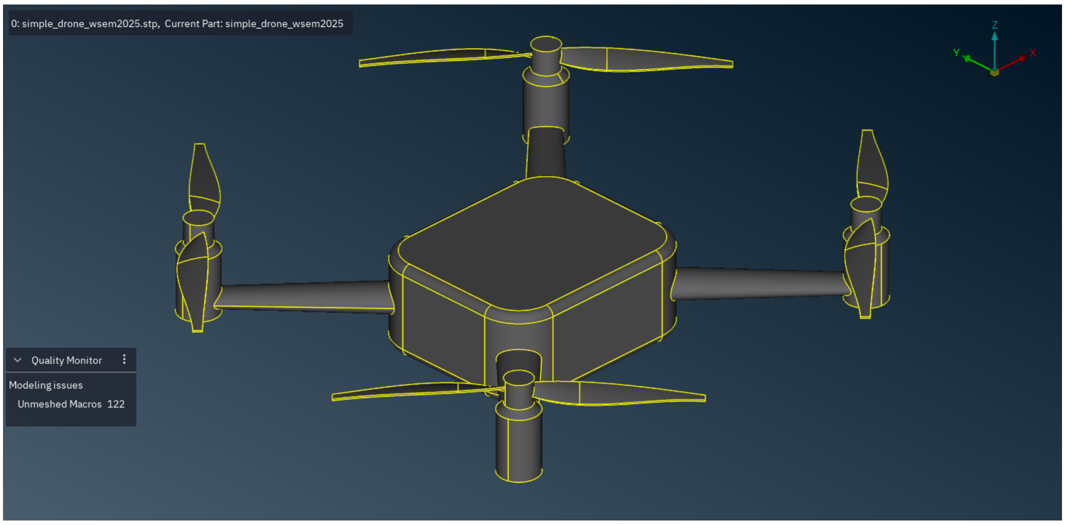
1. Abstract

We are interested in the monostatic Radar Cross Section (RCS) of a drone swarm. The micro-Doppler signature is not considered. The swarm drones are generated from a unit drone through rigid-body transformations (rotations and translations). Three sub-cases are considered: the first involves a frequency sweep for a small swarm in the free space; the second is an angular sweep for a larger swarm above an infinite ground plane; the final sub-case is a variant of the second, obtained by applying a small perturbation of the drone positions.

2. Geometry

We consider a *Perfectly Electric Conductor (PEC) drone* that fits in the bounding box:

COORD_MIN (mm)	-1.97715e+02	-1.87715e+02	-2.70000e+01
COORD_MAX (mm)	1.97715e+02	1.87715e+02	4.65000e+01



Unit drone

CAD is provided in two formats:
unit_drone_wsem2025.stp
unit_drone_wsem2025.iges

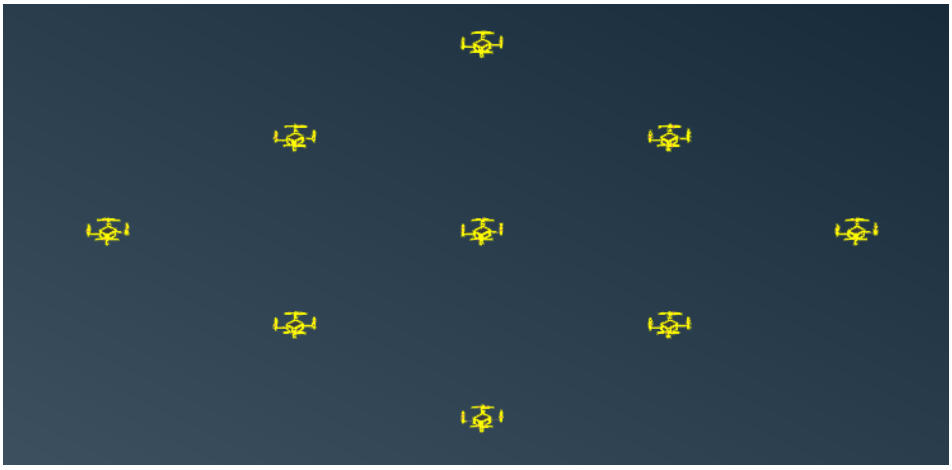
A swarm is generated by applying rigid-body transformations (rotations and translations) to this unit drone. To simplify, we only consider *rotations about the z axis*. The provided data includes the angle ϕ_{rot} (in *degrees*) and the translation vector coordinates $(\delta x, \delta y, \delta z)$ (in *millimeters*), following a 'rotate-*then*-translate' convention. Each swarm configuration is described by a text file in the following format:

#	phi	dx	dy	dz
	-3.08	-46.95	6.84	99967.53
	3.67	2.19	-3.72	11988.50
	…	…	…	…

Each row corresponds to one drone in the swarm.

3. Sub-case 5.1: Regular 3x3x1 swarm — Frequency sweep

Swarm configuration: 3x3x1 regular grid in the *free space (no ground plane).*
Positions: Sub-Case51_positions_3_3_1.txt

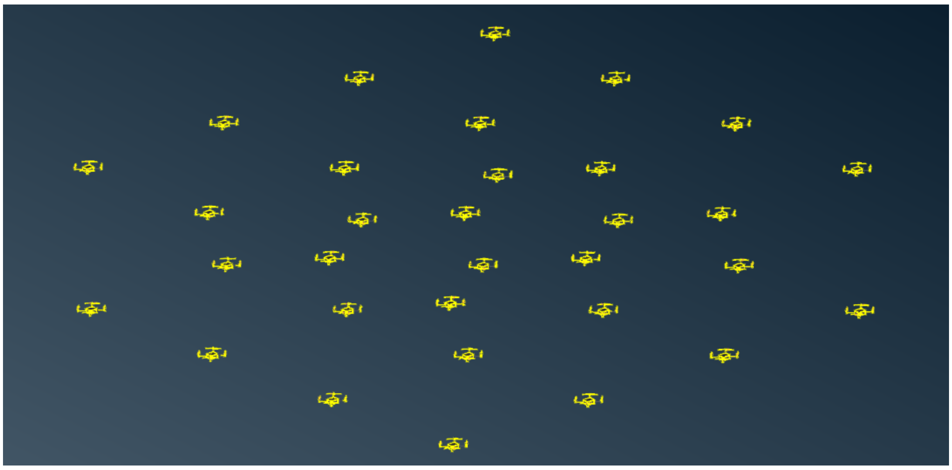


3x3x1 swarm

We ask for the co-polarised and cross-polarised monostatic RCS in both magnitude and phase:
Frequency band: from 8 to 10 GHz with a step of 4 MHz (501 frequencies)
Incident angles: $\theta^{inc} = 90°$, $\phi^{inc} \in \{0°, 30°, 60°, 90°\}$
The elevation angle θ is considered as the angle from z-axis to the horizontal plane (xOy). Thus, $\theta = 90°$ corresponds to a wave vector lying in the horizontal plane.
The azimuth angle ϕ is considered from x-axis to y-axis. Thus, $\phi = 0°$ corresponds to a wave vector collinear but in opposite direction to x-axis. And $\phi = 90°$ corresponds to a wave vector collinear but in opposite direction to y-axis.
The origin of the coordinate system is used as the phase reference.

4. Sub-case 5.2: Regular 4x4x2 swarm — Angular sweep

Swarm configuration: 4x4x2 regular grid above *an infinite PEC ground plane at z=0.*
Positions: Sub-Case52_positions_4_4_2.txt



4x4x2 swarm

We ask for the co-polarised and cross-polarised monostatic RCS (magnitude only):
Frequency: 3 GHz (1 frequency)
Incident angles: $\theta^{inc} = 89°$, ϕ^{inc} from 0° to 90° with a step $\delta\phi^{inc} = 0.025°$.

5. Sub-case 5.3: Perturbed 4x4x2 swarm — Angular sweep

The same as sub-case 2, but with a small perturbation of the drone positions: we applied a random perturbation of ±5° and ±5cm in each direction
Positions: Sub-Case53_positions_4_4_2.txt

6. Convention and output format

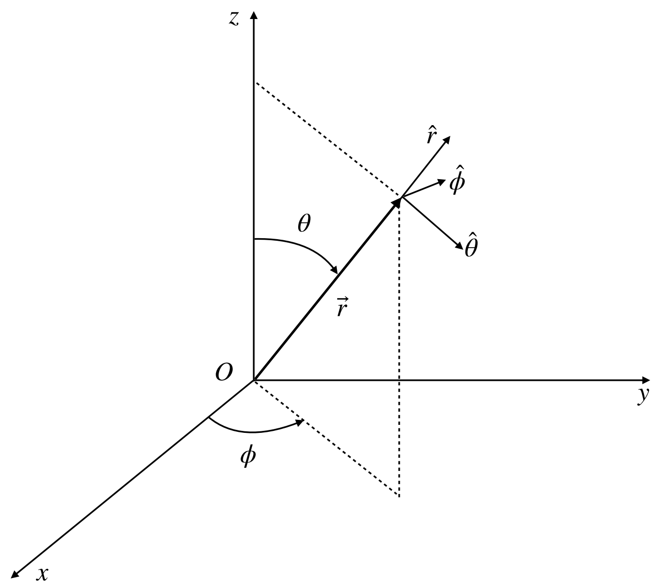


Fig. 1: Spherical coordinates and local basis.

We recall the definition of the monostatic RCS as follow:

$\overrightarrow{E}^{in} = \hat{\phi}$	$\overrightarrow{E}^{in} = \hat{\theta}$
$\sigma_{\phi\phi} = \lim_{r\to\infty} 4\pi r^2 \vert \overrightarrow{E}^{sc} \cdot \hat{\phi} \vert^2, \varphi_{\phi\phi} = \arg \lim_{r\to\infty} r\overrightarrow{E}^{sc} \cdot \hat{\phi}$	$\sigma_{\phi\theta} = \lim_{r\to\infty} 4\pi r^2 \vert \overrightarrow{E}^{sc} \cdot \hat{\phi} \vert^2, \varphi_{\phi\theta} = \arg \lim_{r\to\infty} r\overrightarrow{E}^{sc} \cdot \hat{\phi}$
$\sigma_{\theta\phi} = \lim_{r\to\infty} 4\pi r^2 \vert \overrightarrow{E}^{sc} \cdot \hat{\theta} \vert^2, \varphi_{\theta\phi} = \arg \lim_{r\to\infty} r\overrightarrow{E}^{sc} \cdot \hat{\theta}$	$\sigma_{\theta\theta} = \lim_{r\to\infty} 4\pi r^2 \vert \overrightarrow{E}^{sc} \cdot \hat{\theta} \vert^2, \varphi_{\theta\theta} = \arg \lim_{r\to\infty} r\overrightarrow{E}^{sc} \cdot \hat{\theta}$

The time dependence is assumed to be $e^{-i\omega t}$.

Results for the sub-cases will be provided in three text files: RCS51.txt, RCS52.txt and RCS53.txt. RCS51.txt contains eleven columns

Freq	θ	ϕ	$\sigma_{\phi\phi}$	$\varphi_{\phi\phi}$	$\sigma_{\phi\theta}$	$\varphi_{\phi\theta}$	$\sigma_{\theta\phi}$	$\varphi_{\theta\phi}$	$\sigma_{\theta\theta}$	$\varphi_{\theta\theta}$
(Hz)	(deg.)	(deg.)	(dBm^2)	(deg.)	(dBm^2)	(deg.)	(dBm^2)	(deg.)	(dBm^2)	(deg.)

while RCS52.txt and RCS53.txt each contain seven columns each:

Freq	θ	ϕ	$\sigma_{\phi\phi}$	$\sigma_{\phi\theta}$	$\sigma_{\theta\phi}$	$\sigma_{\theta\theta}$
(Hz)	(deg.)	(deg.)	(dBm^2)	(dBm^2)	(dBm^2)	(dBm^2)