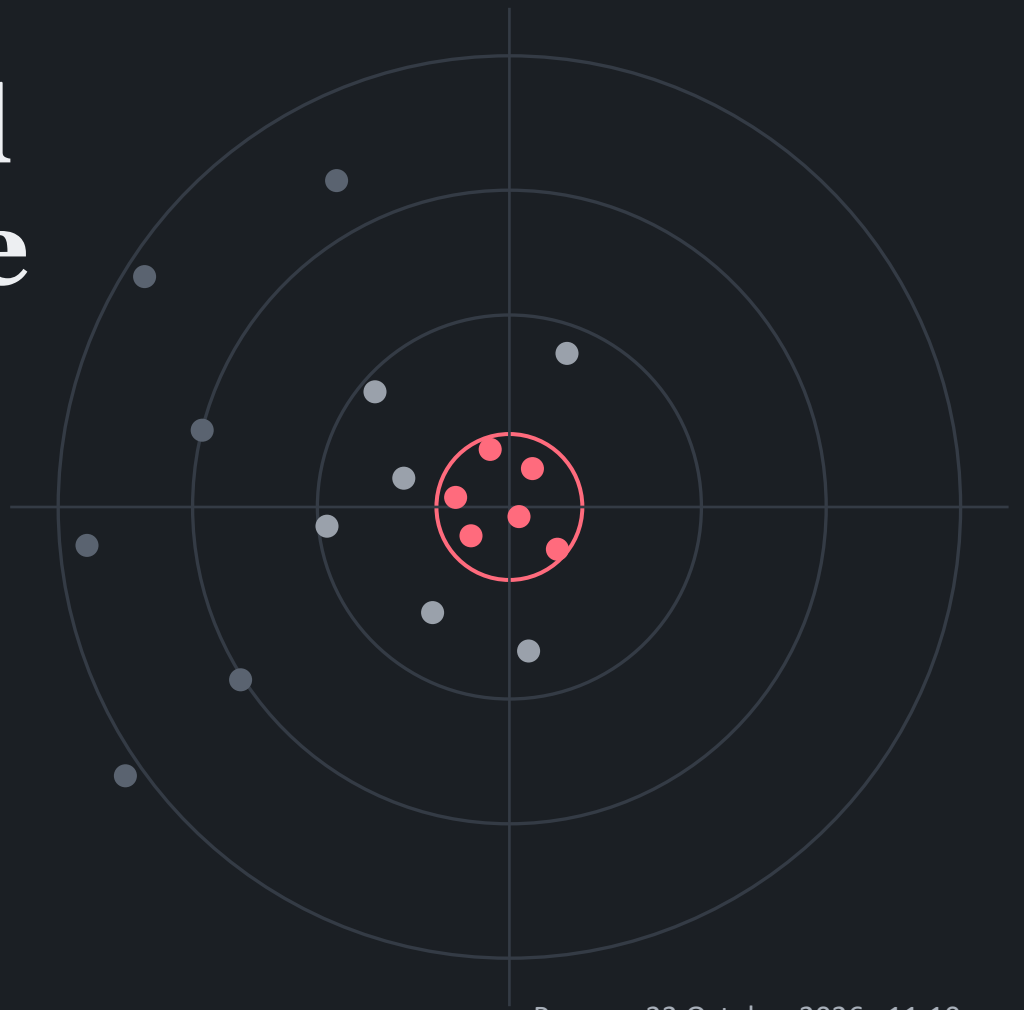
MESAS 2026 · ARTILLERY FIRE SUPPORT AND RECONNAISSANCE

Small Unmanned Aerial Systems in Artillery Fire Support

Modelling the F2T2EA loop and the limits of Precision Mass



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THE SHIFT

From auxiliary tool to embedded component

THEN

Ad hoc reconnaissance, outside formal fire support planning

NOW · UKRAINE 2022–2024

Target acquisition, real-time fire correction and immediate BDA inside the fire mission

WHAT THE LITERATURE CLAIMS

Loop compression

CLAIMED, RARELY QUANTIFIED

Higher first-salvo effect

CLAIMED, RARELY QUANTIFIED

Less ammunition

CLAIMED, RARELY QUANTIFIED

Precision Mass

NO OPERATIONAL DEFINITION

THIS PAPER

Three contributions

I.

Reconstruct

Recurring tactical patterns of UAV-enabled artillery, mapped onto F2T2EA from open sources, 2022–2024.

II.

Model

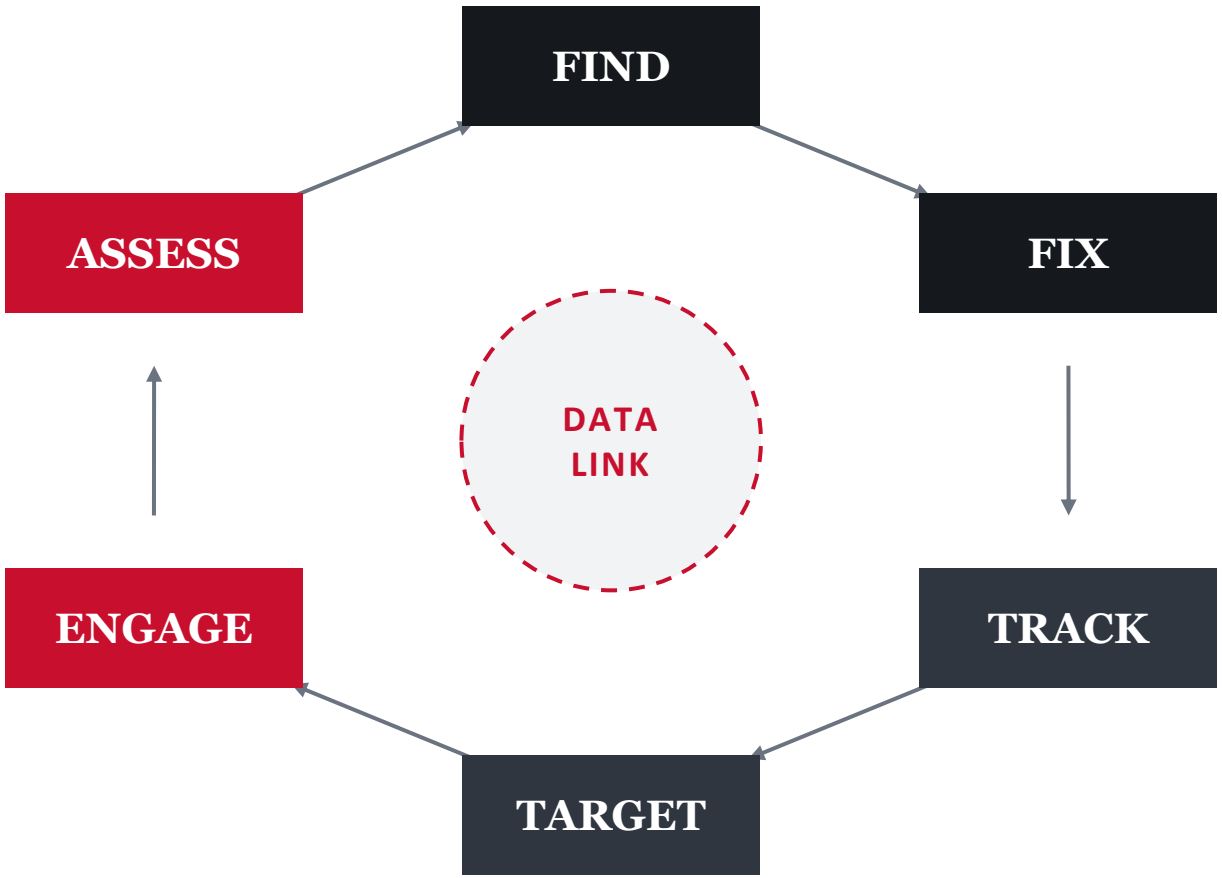
The loop as an explicit timing and effects model, Monte Carlo against a shoot-and-scoot howitzer.

III.

Define

Precision Mass as cumulative probability over observed corrections, its limit, and the effect of onboard computer vision.

What small drones change in each phase



Find · Fix

Persistence: verify the target just before firing; lower target location error.

Track · Target

Live imagery to the fire direction centre: shorter reporting and recomputation.

Engage · Assess

Continuous adjustment and immediate BDA; FPV can finish a damaged target.

Data link = the binding dependency. Jamming lengthens the correction cycle; it does not move the rounds.

Loop duration sets the number of corrections

$$T_1 = t_{detect} + t_{transmit} + t_{compute} + t_{lay} + t_{tof} \quad (1)$$

Time from detection to first rounds

$$t_c = t_{obs} + t_{rep} + t_{comp} + t_{lay} + t_{tof} \quad (2)$$

Every observed correction adds one cycle

$$k_{max} = 1 + \lfloor (T_d - T_1) / t_c \rfloor \text{ if } T_1 \le T_d, \text{ otherwise } 0 \quad (3)$$

Correction cycles that fit inside the displacement window

A THRESHOLD, NOT A SLOPE

Through the floor function, latency sets the number of chances to correct the fire.

$$T_1 > T_d \rightarrow k_{max} = 0$$

First rounds after the window closes: nothing else matters.

Precision Mass, defined

$$p(e) = 1 - [exp(-R_l^2 / 2(\sigma_d^2 + e^2))]^n \quad (4)$$

Salvo kill probability · σd = 50 m, Rl = 15 m, n = 6 rounds

$$e_k = max(\rho \cdot e_{k-1}, e_{min}) \quad (5)$$

Observation shrinks the aim error · ρ = 0.45, emin = 15 m

$$P_{cum}(k) = 1 - \prod_{j=1..k} [1 - p(e_j)] \quad (6)$$

Probability accumulated over observed corrections

PRECISION MASS

Probability accumulated over successive observed corrections, each fired with a smaller error.

Its currency is correction cycles, not rounds.

Unobserved fire: ρ = 1

Configurations compared

Phase [s]	Classic ground observer, voice	UAV-enabled UAV + operator	Autonomous CV onboard computer vision
Detection / acquisition	120	45	30
Reporting to fire direction	60	15	5
Fire-data computation	90	30	10
Laying and firing	60	30	20
Time of flight	30	30	30
Time to first rounds T1	**360**	**150**	**95**
Correction cycle tc	**195**	**95**	**55**
Initial aim error e0 [m]	150	40	35

Expert estimates: a transparent baseline, not measurements of a specific system.

COMMON TO ALL

240 s
median displacement window

50 m · 15 m
dispersion · lethal radius

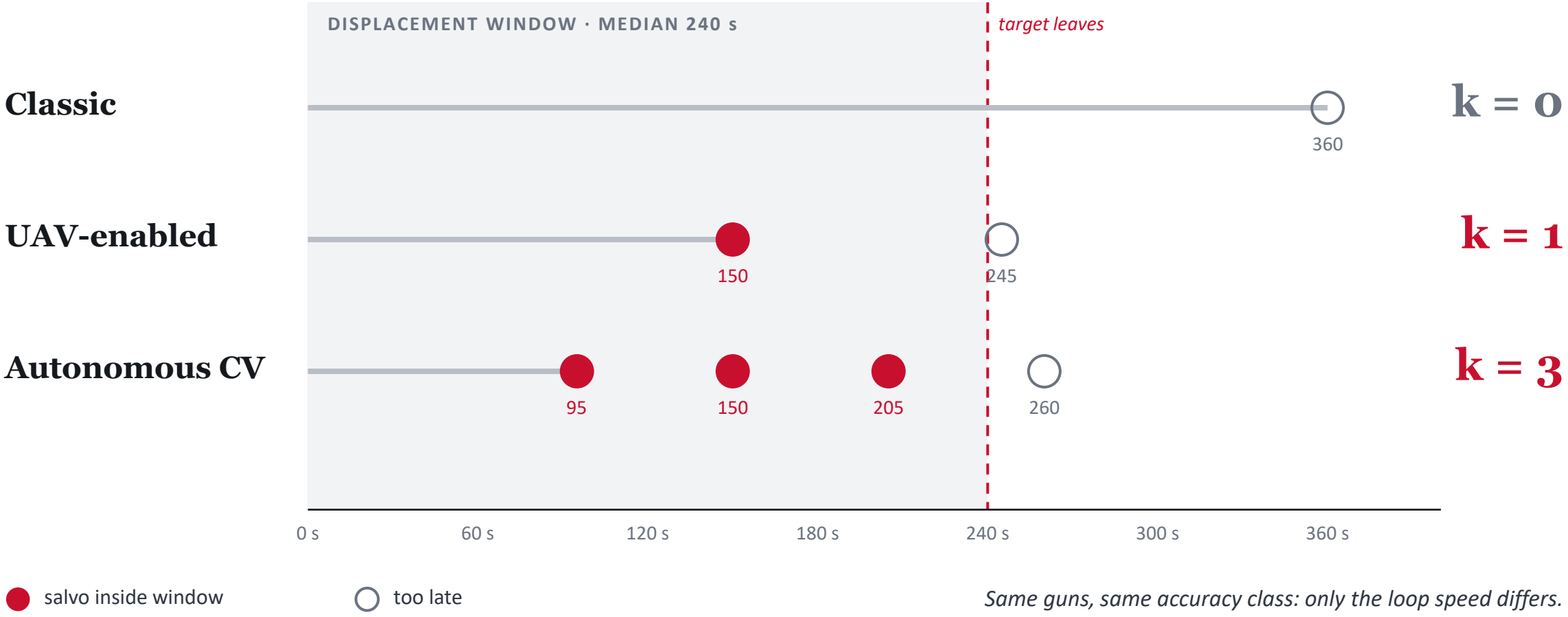
6 rounds
per salvo

ρ 0.45 · 15 m
correction factor · error floor

200 000
replications, lognormal phases (shape 0.30)

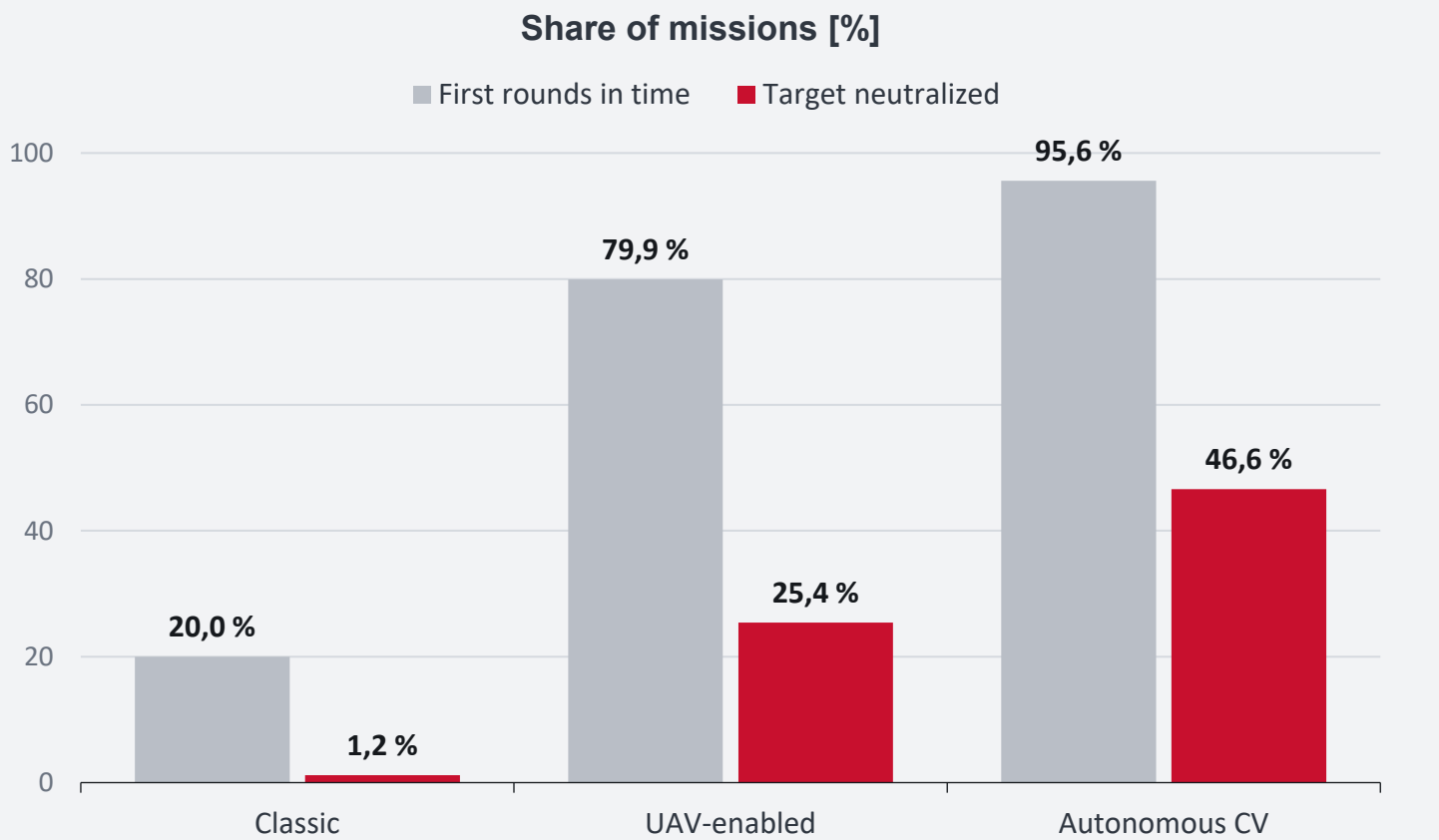
EQUATION (3) AT MEDIAN VALUES

Who fires inside the window?



Same guns, same accuracy class: only the loop speed differs.

Arriving in time is most of the battle



	Classic	UAV	Auto CV
Cycles in window kmax	0	1	3
Mean salvos fired	1.05	1.61	2.42
Unobserved fire: in time	*20 %*		
Unobserved: neutralized	*0.7 %*		

Classic loop: rounds arrive in time in 1 mission of 5.

Autonomous CV: almost 2.5 salvos per mission, because there is time to fire them.

KEY OBSERVATION

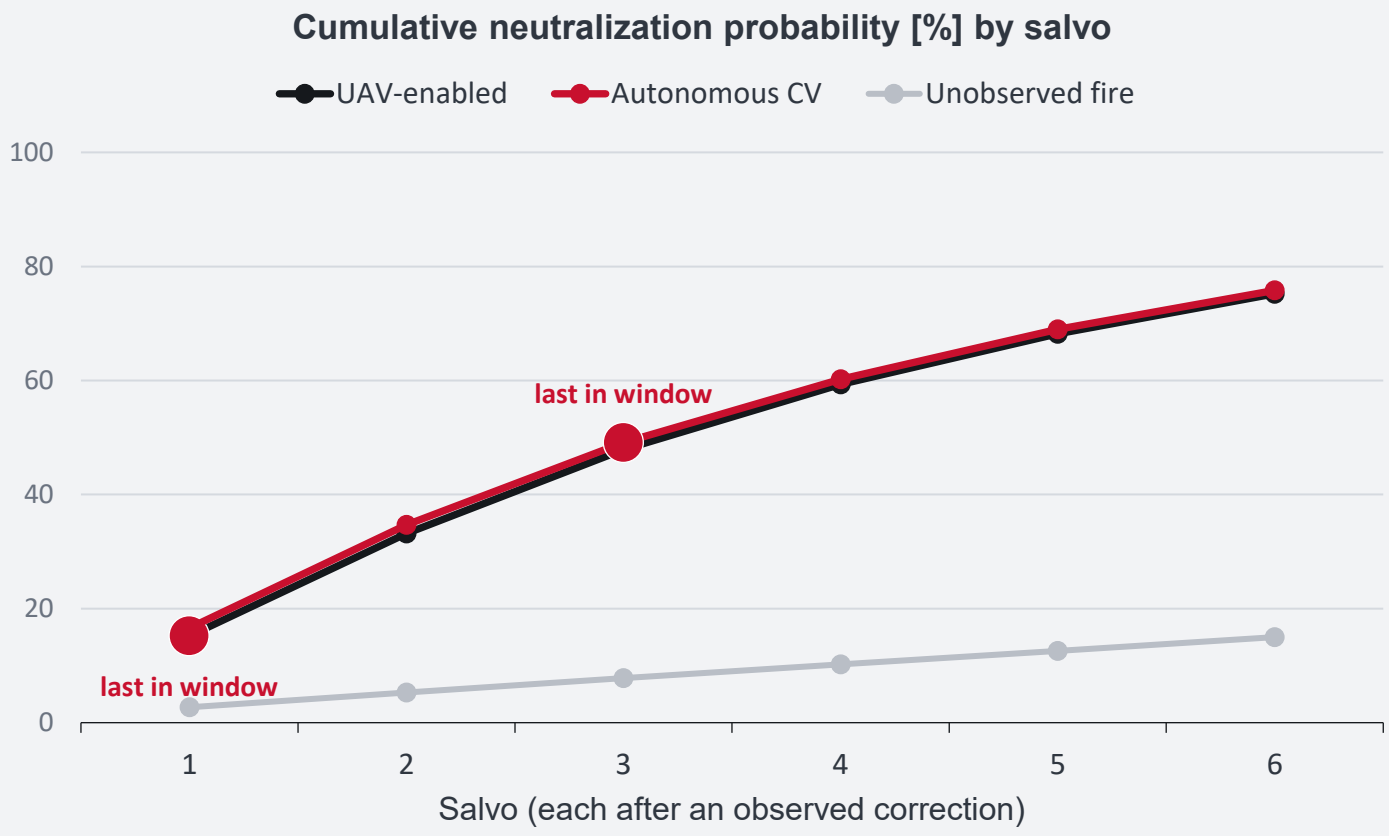
Failure is temporal before it is ballistic.



Even perfect accuracy would not save the classic loop in four missions out of five: the rounds arrive after the target has left.

EQUATION (6)

Precision Mass is bounded by the window



REALIZABLE INSIDE THE WINDOW

15 % *of 75 %*

UAV-enabled · stops after salvo 1

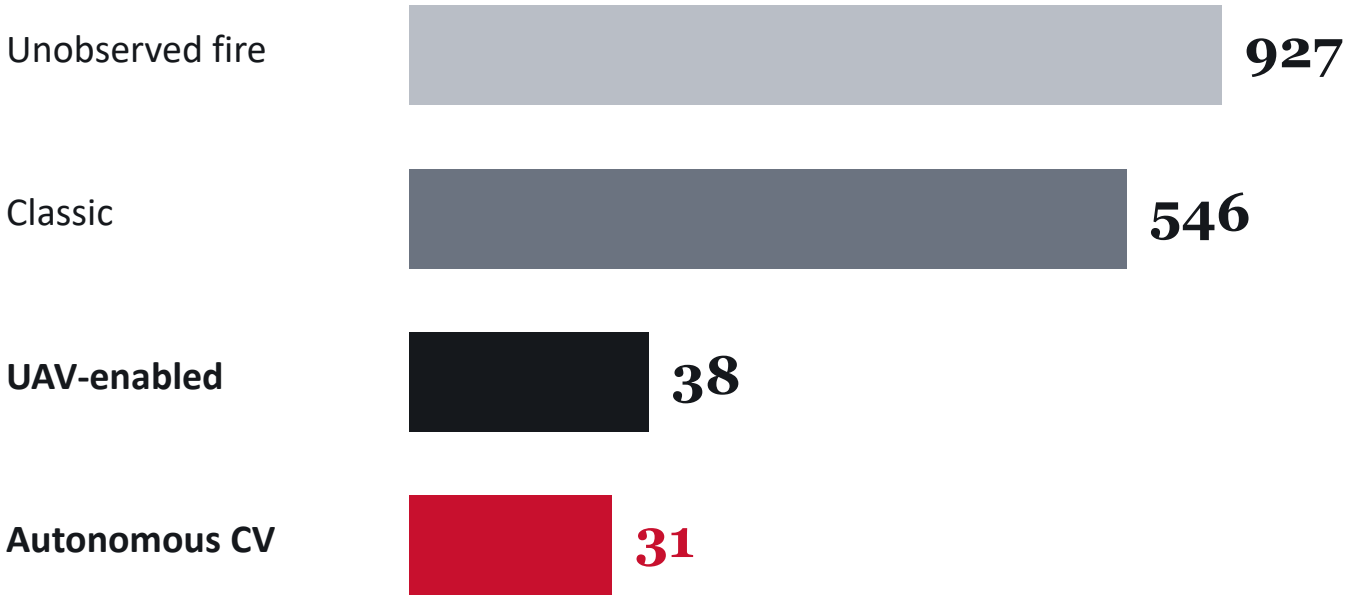
49 % *of 76 %*

Autonomous CV · reaches salvo 3

Unobserved fire: 15 % after six salvos. Accumulation comes from correction, not volume.

From 546 rounds to 38 per neutralization

ROUNDS PER NEUTRALIZATION · LOG SCALE



50 % neutralization needs ~154 rounds unobserved vs. 24 observed: 6.4× fewer.

COST-EXCHANGE RATIO

target value / cost of one neutralization

Unobserved	1.4
Classic	2.4
UAV-enabled	34.6
Autonomous CV	42.3

EUR 3,000 per round · EUR 2,500 per UAV, 15 % attrition · target EUR 4 M

One mechanism: a shorter correction cycle

CORRECTION CYCLE	FIRST ROUNDS	CORRECTIONS IN WINDOW	NEUTRALIZATION
95 s → **55 s**	150 s → **95 s**	1 → **3**	25 % → **47 %**

UAV-enabled → Autonomous CV. Sensors and guns unchanged; only reporting and computation get shorter.

Purely temporal

Accuracy is almost the same: 40 m vs 35 m initial aim error. Hold the cycle at operator speed and the gain disappears.

Only for fleeting targets

Against a static target all configurations converge on the same asymptote. Autonomy answers time pressure.

DISCUSSION

Precision Mass is an accumulation in time

Mass fires	concentration in space
Swarming	simultaneity from many vectors
Precision Mass	accumulation in time, through correction

Same effect with ~6× fewer rounds than unobserved fire: economy of force.

FOR CAPABILITY DEVELOPMENT

1 Specify against fleeting targets

Static and fleeting targets have different binding constraints.

2 Latency is a design parameter

Decision and computation time sit next to range and accuracy.

3 Protect the data link

Jamming lengthens tc: EW hits Precision Mass where Eq. (3) is most sensitive.

What the model leaves out

Limitation	Likely effect on the results
Open sources under-report failed engagements	Qualitative picture is optimistic
Timing and accuracy values are expert estimates	Read relative comparisons, not absolute values
Salvos independent; isolated point target; no terrain or hardening	Cumulative probability likely overstated
Crew does not react to incoming fire	Slower loops would be penalized even more
Autonomy modelled as latency only	Add a false-positive / wrong-correction rate

Loop speed, not accuracy, sets the ceiling

1. The classic loop fails mainly because it is too slow: 20 % in time, ~1 % neutralized.
2. Precision Mass is bounded by how many correction cycles fit inside the displacement window.
3. Drones cut ammunition per neutralization from 546 rounds to 38; autonomy helps by shortening the cycle.

Thank you. Questions?

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