

CARA Recovery Protocol Simulation

Simulation User Guide

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Author: Burak Oktenli

Institution: Georgetown University, School of Continuing Studies

Program: M.P.S. Applied Intelligence (STEM)

ORCID: 0009-0001-8573-1667

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1. Purpose, Scope, and Assumptions

This guide provides operating procedures for the CARA (Control Authority Regulation Architecture) simulation. CARA implements the GREP (Graduated Recovery Escalation Protocol) for deterministic authority recovery after lockout events. The simulation demonstrates four recovery phases with hysteresis-protected boundaries, a non-compensatory SALM gate at Phase IV entry, parameter sensitivity heatmaps, and Monte Carlo statistical validation.

Intended Audience: EB2-NIW petition evaluators, defense/aerospace reviewers, academic peers, and technical collaborators seeking independent verification of governance pipeline behavior.

Scope: Operation of the CARA Recovery Protocol Simulation simulation. Does not cover mathematical theory (see published paper) or hardware specifications (see Blueprint.am).

1.1 Assumptions and Constraints

- The user has a modern browser with JavaScript enabled and HTTPS access.
- All parameter values are synthetic research placeholders, not calibrated against physical hardware.
- The simulation models governance logic only. Physical dynamics (aerodynamics, acoustics, electromagnetics) are simplified.
- Cryptographic operations (SHA-256 audit chain) use the WebCrypto API, not hardware TPM/HSM.
- Results are valid for demonstrating architectural behavior, not for operational safety assessment.

IMPORTANT

This simulation is a research prototype. Not for operational planning, safety-critical decisions, or system certification. All parameters are synthetic.

2. Quick Start

Step 1. Open cara-simulation.html in Chrome over HTTPS.

Step 2. Click a scenario preset (e.g., 'EW Active') to trigger a lockout event.

Step 3. Watch the GREP recovery sequence: FAULT -> Phase I -> II -> III -> IV -> NOMINAL.

Step 4. Adjust tau_current slider during recovery to observe phase transitions.

Step 5. Run Monte Carlo for statistical recovery duration analysis.

NOTE

All computation runs client-side. No data leaves your browser. Requires HTTPS (not file://).

3. System Requirements and Security Considerations

Browser	Chrome 90+, Firefox 88+, Safari 15+, Edge 90+
Protocol	HTTPS required (WebCrypto API for SHA-256 audit hashing)

Display	Min 1280x720; recommended 1920x1080+
CPU/Memory	Any modern processor. Monte Carlo (100+ runs): multi-core recommended, ~200MB RAM peak
GPU	WebGL-capable recommended for 3D visualizations (Three.js)
Network	Internet for initial CDN load (~500KB). All computation client-side after load.
Installation	None — zero install, no login, no backend, no database, no cookies

3.1 Security Considerations

- **No data exfiltration:** All computation runs in the browser. No data is sent to any server.
- **CDN dependencies:** React, ReactDOM, and Babel load from cdnjs.cloudflare.com (Cloudflare CDN with SRI hashes where available).
- **Audit integrity:** SHA-256 hash chain via WebCrypto API. Each audit entry links to the previous entry's hash. VERIFY button recomputes the entire chain.
- **No authentication:** The simulation has no login system. All state is ephemeral in browser memory.

4. Interface Layout and Navigation

4.1 Panel Layout

The interface uses a single-column layout with stacked panels. **Top Panel:** Authority timeline chart showing real-time authority level with GREP phase color overlay (red=FAULT, orange=Phase I, yellow=Phase II, light green=Phase III, green=Phase IV). **Middle Panel:** Six parameter sliders (tau_prior, tau_current, salm_score, confirm_score, anomaly_clear, t_locked) with seven scenario preset buttons. **Bottom Panel:** GREP phase state machine diagram with current phase highlighted, hysteresis band visualization, and transition conditions. **Tab Bar:** Dashboard, GREP Phases, Heatmap, Monte Carlo, Assurance Matrix.

4.2 Navigation Tabs

Dashboard	Main view with authority timeline, current GREP phase, and recovery progress
GREP Phases	Detailed phase transition diagram with hysteresis bands and gate conditions
Assurance Matrix	Gap analysis between current simulation capabilities and operational requirements
Monte Carlo	Statistical analysis across 100 automated recovery trials
Heatmap	Parameter sensitivity visualization for recovery threshold interactions

4.3 Panel Descriptions

- Authority Timeline.** Real-time chart showing authority level over time with color-coded GREP phase overlay
- GREP Phase Display.** Current phase (FAULT, Phase I-IV, NOMINAL) with transition conditions
- Parameter Sliders.** Six sliders: tau_prior, tau_current, salm_score, confirm_score, anomaly_clear, t_locked
- Scenario Presets.** Buttons: Nominal, EW Active, SALM Corrupt, Extreme t=300, Adversarial, Cleared, Fault

TIP

Hover over interface elements for tooltips. Most gauges include ARIA labels for screen reader accessibility.

5. Operating Procedures

5.1 Startup

1. Navigate to the simulation URL or click Launch Simulation from burakoktenli.com.
2. Wait for loading (2-5 seconds). CDN scripts load from cdnjs.cloudflare.com.
3. Verify interface loads completely. All panels should be visible.

5.2 Standard Operation

1. Open the simulation via Launch Simulation or navigate to cara-simulation.html.
2. The dashboard shows the authority timeline in NOMINAL state.
3. Click a scenario preset (e.g., 'EW Active') to trigger an authority lockout event. Observe the transition to FAULT state.
4. Watch the GREP recovery sequence: FAULT (red) -> Phase I (orange) -> Phase II (yellow) -> Phase III (light green) -> Phase IV (green, requires SALM \geq 0.60) -> NOMINAL.
5. Adjust the tau_current slider during recovery to simulate improving sensor conditions. Observe phase advancement when thresholds are crossed.
6. Note the hysteresis bands: authority must cross the band fully to transition. Try oscillating tau_current near a boundary to verify anti-chatter behavior.
7. Switch to the Heatmap tab to see how recovery time varies across parameter combinations (tau_locked vs. salm_score).
8. Run Monte Carlo (100 trials) to generate statistical distribution of recovery durations. Review mean, standard deviation, and worst-case recovery time.
9. Click JSON export to download the full recovery trace for independent verification.

5.3 Shutdown

1. Export session data. 2. Close browser tab (all state discarded).

IMPORTANT

State is not persisted. Export before closing to preserve results.

6. Parameter Reference

tau_prior	Slider	0.00 - 1.00	0.50	Trust score before lockout event
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tau_current	Slider	0.00 - 1.00	0.30	Current sensor trust score during recovery
salm_score	Slider	0.00 - 1.00	0.70	SALM audit chain integrity score
confirm_score	Slider	0.00 - 1.00	0.50	External confirmation score
anomaly_clear	Slider	0.00 - 1.00	0.80	Anomaly clearance indicator
t_locked	Slider	0 - 600	120	Time in lockout state (seconds)

NOTE

All defaults are synthetic. Replace with empirically derived values before operational use.

7. Scenario Reference

NOM	Nominal Recovery	Standard lockout with clean recovery	Full GREP sequence in ~60s
EW	EW Active	Electronic warfare jamming active	Extended Phase I due to low tau
SALM	SALM Corrupt	Audit chain integrity compromised	Phase IV gate blocks (SALM < 0.60)
EXT	Extreme t=300	Very long lockout duration	Tests t_locked decay behavior
ADV	Adversarial	Persistent adversarial interference	Oscillation at phase boundaries
CLR	Cleared	All conditions favorable	Rapid recovery through all phases

8. Metrics, Formulas, and Verification

8.1 Key Metrics

GREP Phase

Current recovery phase: FAULT (authority locked at 0), Phase I (initial recovery, $A < 0.20$), Phase II (progressive, $0.20 \leq A < 0.45$), Phase III (approaching nominal, $0.45 \leq A < 0.70$), Phase IV (requires SALM ≥ 0.60 , non-compensatory gate), NOMINAL ($A \geq 0.70$, full recovery).

Hysteresis Band

0.03 symmetric band at each phase boundary. Authority must exceed boundary + 0.03 to advance, or drop below boundary - 0.03 to retreat. Prevents chatter.

SALM Gate (G4)

Non-compensatory terminal gate: Phase IV entry requires SALM integrity score ≥ 0.60 regardless of other parameters. This cannot be bypassed.

Recovery Duration

Total time from FAULT entry to NOMINAL restoration. Measured in simulation ticks and wall-clock seconds.

Monte Carlo Distribution

Statistical distribution of recovery durations across 100 trials with varied initial conditions.

8.2 Verification Checklist

Perform the following checks to verify correct simulation behavior:

Click 'EW Active' preset	Authority drops to FAULT state.
Increase tau_current above Phase I threshold	Phase I -> Phase II transition occurs.
Set salm_score below 0.60	Phase IV gate blocks. Cannot reach NOMINAL.
Set salm_score above 0.60	Phase IV gate opens. NOMINAL reachable.
Oscillate tau_current near boundary	Hysteresis prevents chatter. No rapid switching.
Run Monte Carlo (100 trials)	Recovery duration distribution displayed.

9. Data Export and Reproducibility

Click export/download to save session JSON with parameters, history, and audit trail.

Verification: 1) Export JSON. 2) Note PRNG seed. 3) Reload with same seed/params. 4) Verify bit-exact match.

9.1 Reproducibility Guarantee

PRNG	Mulberry32 (32-bit seeded)
Math.random()	Zero calls in computation paths
Cross-Browser	Verified: Chrome, Firefox, Safari, Edge
Cross-Platform	Verified: Windows, macOS, Linux
Audit Chain	SHA-256 via WebCrypto (SubtleCrypto API)

10. Limitations and Threat Considerations

Simulation-Only Evidence	Browser-based computation. No physical recovery data.
Symmetric Hysteresis	0.03 band is fixed. Production may require adaptive or asymmetric bands.
No Hardware Watchdog	Recovery timing uses JavaScript setTimeout, not hardware watchdog timers.
Single-Channel Recovery	Models one authority channel. Multi-channel recovery (per-actuator) not modeled.
Instantaneous Transitions	Phase transitions are discrete. Real systems may require continuous ramp.

10.1 Threat Considerations

- **CDN compromise:** React/Babel load from cdnjs.cloudflare.com. A CDN compromise could inject malicious code. Mitigation: Subresource Integrity (SRI) hashes on script tags where available.
- **Browser extensions:** Malicious extensions could modify simulation DOM/state. Mitigation: test in Incognito mode for clean results.
- **Local modification:** Users can modify simulation code via DevTools. Exported data should be verified against the published source on burakoktenli.com.

11. Troubleshooting

Recovery stuck in Phase I	tau_current too low	Increase tau_current slider above Phase I threshold.
Phase IV blocked	SALM score below 0.60	SALM gate is non-compensatory. Increase salm_score above 0.60.
Heatmap not rendering	No Monte Carlo data	Run Monte Carlo before switching to heatmap tab.
Phase oscillation	Parameters near boundary	This is expected; hysteresis should prevent it. If oscillating, check band width.
Scenario preset not triggering lockout	Authority above lockout threshold	Try 'Adversarial' or 'Sensor Collapse' presets for guaranteed lockout.

12. Glossary and References

12.1 Glossary

CARA	Control Authority Regulation Architecture — deterministic recovery protocol
GREP	Graduated Recovery Escalation Protocol — four-phase recovery sequence
Phase I-IV	Recovery phases with increasing authority: I (<0.20), II (0.20-0.45), III (0.45-0.70), IV (SALM gate)
SALM Gate (G4)	Non-compensatory terminal gate: Phase IV requires SALM >= 0.60
Hysteresis Band	0.03 symmetric buffer at each phase boundary preventing chatter
t_locked	Duration in lockout state (seconds), used for recovery decay computation
tau_prior	Trust score at the moment of lockout event
tau_current	Current sensor trust score during recovery

12.2 References

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12.3 Contact

Burak Oktenli — Georgetown University, School of Continuing Studies

Website: burakoktenli.com | ORCID: **0009-0001-8573-1667**

For questions about this simulation or the governance architecture research program, use the contact form at burakoktenli.com.

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