BLADE-SPACE Governance Simulator

Simulation User Guide

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1. Purpose, Scope, and Assumptions

This guide provides operating procedures for the BLADE-SPACE simulation implementing governance for orbital autonomous platforms operating in Low-Earth Orbit (400- 1200 km, 5-year mission life). Four scenarios cover LEO conjunction response (600 km, closure 14.7 km/s, star-tracker glint event), intercept-threat response (time-to-closest-approach < 60 s), co-orbital rendezvous-proximity operations (uncooperative approach, 200→50 m separation), and Cosmos-1408 debris field retrospective (14 orbits, 28 conjunction alerts). The simulation features a vintage CRT terminal live mode, 11-stage governance pipeline including ERAM escalation authority, Sensitivity Analysis, Fault Tree Analysis, and MITRE ATT&CK for Space (SPARTA) mapping.

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 BLADE-SPACE Governance Simulator simulation. Does not cover mathematical theory (see published paper) or hardware specifications (see project website).

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 orbital dynamics (Keplerian propagation, atmospheric drag, plume interactions) are simplified.
- Cryptographic operations (ECDSA P-256 audit chain) use the WebCrypto API, not hardware TPM/HSM.
- Results are valid for demonstrating architectural behavior, not for operational flight safety assessment.

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

2. Quick Start

Step 1. Open the simulation HTML file in Chrome over HTTPS.

Step 2. Review the interface panels and identify the main controls.

Step 3. Click RUN or START to begin the simulation loop.

Step 4. Observe the governance pipeline processing sensor inputs through all modules.

Step 5. Use export/download buttons to save session data as JSON for verification.

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

3. System Requirements and Security Considerations

Requirement	Specification
Browser	Chrome 90+, Firefox 88+, Safari 15+, Edge 90+

Requirement	Specification
Protocol	HTTPS required (WebCrypto API for ECDSA P-256 audit signing)
Display	Min 1280x720; recommended 1920x1080+
CPU/Memory	Any modern processor. Monte Carlo (50+ runs per scenario): multi-core recommended, ~200MB RAM peak
GPU	WebGL-capable recommended for 3D orbital 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:** ECDSA P-256 signed hash chain via WebCrypto API. Each audit entry signs the previous entry's hash plus the current event payload. VERIFY button recomputes and re-validates the entire chain out-of-process.
- **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 visualizes orbital autonomy scenarios with ASCII art. **Top Panel:** Scenario selector (LEO Conjunction, Intercept Response, Co-orbital RPO, Cosmos-1408 Retrospective) with ASCII art representation of the active orbital geometry. **Center Panel:** Sensor array with real-time readings (Star Tracker, Sun Sensor, Magnetometer, GNSS, IMU, Dosimeter, SEU Monitor, Thermistor) showing values, nominals, and trust scores. 11-stage governance pipeline (SENSORS through EFFECTOR including ERAM). Authority gauge with actuator action status. **CRT Mode:** Vintage terminal display for real-time telemetry. **Tab Bar:** Main View, Sensitivity Analysis, Fault Tree Analysis, MITRE ATT&CK for Space.

4.2 Navigation Tabs

Tab	Function
Main View	Orbital scenario visualization with sensor readings, pipeline status, and authority gauge
Sensitivity Analysis	Parameter sensitivity visualization showing authority response to sensor variations
Fault Tree Analysis	Root cause analysis mapping failure modes to contributing factors and probabilities
MITRE ATT&CK for Space	Attack technique mapping showing which space-specific attacks (SPARTA framework) are detected by the governance pipeline

4.3 Panel Descriptions

Orbital Scenario Panel. ASCII art visualization of the active scenario (LEO conjunction, intercept response, co-orbital RPO, or Cosmos-1408 debris-field retrospective).

Sensor Array. Spaceflight-heritage sensors with real-time readings, nominal values, and trust scores.

11-Stage Pipeline. SENSORS → ADARA → SATA → IFF → HMAA → MAIVA → FLAME → ERAM → CARA → BDA → EFFECTOR

CRT Terminal. Vintage terminal interface showing real-time governance pipeline telemetry.

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 blade-space-simulation.html.

2. The simulation initializes with the O1 LEO Conjunction scenario showing a 600 km LEO platform with star-tracker glint event and GNSS RAIM warning (4 of 7 sensors in alarm or warning state).

3. Observe the sensor array: Star Tracker (alarm), GNSS-Primary (alarm), IMU-Primary (warning), Sun Sensor (warning), GNSS-Backup, IMU-Backup, Magnetometer (nominal) show real-time values.

4. Watch the 11-stage governance pipeline process the sensor data. Note ERAM (Escalation Authority) between FLAME and CARA.

5. Switch scenarios using the scenario selector: O1 LEO Conjunction (avoidance burn), O2 Intercept Response (evasion burn), O3 Co-orbital RPO (magnetorquer hold-off), O4 Cosmos-1408 Retrospective (FLAME deferred).

6. Switch to the Sensitivity Analysis tab to see how authority changes as individual sensor values are varied.

7. Switch to the Fault Tree Analysis tab to see root cause diagrams for each scenario.

8. Switch to the MITRE ATT&CK for Space tab to see which attack techniques (SPARTA framework) map to governance pipeline detections.

9. Enable CRT Terminal mode for a vintage terminal display of real-time pipeline telemetry.

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

Parameters are pre-configured per scenario. See Section 4 for interface controls and the published paper for parameter derivation.

7. Scenario Reference

ID	Name	Description	Expected Behavior
O1	LEO Conjunction	Star-tracker glint + GNSS RAIM warning at 600 km, closure 14.7 km/s	AVOIDANCE BURN action, α = 0.9143
O2	Intercept Response	Time-to-closest-approach < 60 s scenario	EVASION BURN action, α = 0.9518
O3	Co-orbital RPO	Uncooperative approach, 200→50 m separation	MAGNETORQUER HOLD-OFF, α = 0.9234
O4	Cosmos-1408 Retrospective	14 orbits, 28 conjunction alerts in fragmentation field	FLAME DEFERRED, 0 automated burns

8. Metrics, Formulas, and Verification

8.1 Key Metrics

Orbital Authority α

Operational authority for the orbital autonomous platform. Governs actuator commands (thruster firings, magnetorquer drives, reaction wheel commands, pyrotechnic isolations).

Sensor Trust Array

Spaceflight-heritage sensors with weighted trust: Star Tracker (BCT NST, w=0.92), GNSS (NovAtel OEM7600-RG ×2, w=0.88), IMU primary (Sensonor STIM-300, w=0.85), IMU backup (Honeywell HG1700, w=0.82), Sun Sensor (Adcole MAI-SS ×2, w=0.70), Magnetometer (ZARM AMR-1 ×2, w=0.60). Dosimeter and SEU monitor feed ADARA / ERAM (not SATA frame).

11-Stage Pipeline

Complete governance pipeline with ERAM escalation authority: SENSORS → ADARA → SATA → IFF → HMAA → MAIVA → FLAME → ERAM → CARA → BDA → EFFECTOR.

SIL 3 Compliance

IEC 61508 Safety Integrity Level 3 monitoring on thruster firing line. PFH (Probability of Failure on demand per Hour) tracked for safety functions.

Spaceflight Standards Mapping

Compliance posture against ECSS-E-ST-50-12C (SpaceWire), ASTM E595 (outgassing TML<1.0%, CVCM<0.1%), IEEE 1588 PTP, CCSDS SDLS authentication, AE9/AP9 trapped-radiation envelope.

MITRE ATT&CK for Space Coverage

Space-system attack technique detection coverage based on SPARTA framework (Bailey et al. 2024): percentage of mapped techniques (TA0108 Reconnaissance, TA0110 Initial Access, TA0114 Impact) detectable by the governance pipeline.

8.2 Verification Checklist

Perform the following checks to verify correct simulation behavior:

Action	Expected Result
Start simulation (RUN/START)	Interface loads. Governance pipeline begins processing.
Observe default state (O1)	Authority α converges near 0.9143. All pipeline stages PASS.
Inject a fault or coordinated spoof	Authority reduces proportionally. Affected stage shows FAIL or DEFERRED.
Monitor recovery	If CARA active, observe GREP recovery phases.
Export session data (JSON)	File downloads with parameters, history, and ECDSA-signed audit trail.
Reload and verify reproducibility	Same PRNG seed + params = identical outputs.

9. Data Export and Reproducibility

Click export/download to save session JSON with parameters, history, and ECDSA-signed 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

Property	Value
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	ECDSA P-256 via WebCrypto (SubtleCrypto API); out-of-process Python verifier in deposit

10. Limitations and Threat Considerations

Limitation	Description
Simulation-Only Evidence	Browser-based computation. No physical sensor data or on-orbit measurements.
Uncalibrated Parameters	All values are synthetic research parameters, not empirically derived from flight heritage data.
No Real-Time Guarantees	JavaScript engine provides no timing guarantees for safety-critical operations.
Simulated Cryptography	ECDSA P-256 uses WebCrypto. TPM/HSM and tamper-mesh operations are modeled, not hardware-backed.
Single-Session State	All state held in memory. Closing the tab discards all data.

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

Problem	Likely Cause	Solution
Black screen after loading	React render error or CSP violation	Open F12 Console for error details. Try Chrome Incognito mode.
Simulation runs slowly	CPU-intensive Monte Carlo or 3D rendering	Close other browser tabs. Reduce sample count.
Controls not responding	Browser tab lost focus	Click inside the simulation window. Ensure tab is active.
Export button not working	Pop-up/download blocked	Allow downloads from the simulation domain in browser settings.
Loading screen never completes	CDN scripts blocked by firewall/extension	Disable ad blockers. Allow cdnjs.cloudflare.com.

12. Glossary and References

12.1 Glossary

Term	Definition
BLADE-SPACE	Beam-Layer Authority for Directed Engagements Space-Edge Node
SATA	Sensor Authority Trust Allocation - Dempster-Shafer trust fusion (Patent 64/002,453)
HMAA	Hierarchical Multi-Authority Adjudication - authority computation (Patent 63/999,105)
FLAME	Fault-Limited Authority Modulation Engine - cascade prevention (Patent 64/005,607)
CARA	Compositional Autonomy Recovery Architecture - GREP recovery protocol (Patent 64/000,170)
ADARA	Adversarial Detection and Risk Assessment - anomaly correlation stage
MAIVA	Multi-Agent Intelligent Voting Architecture - weighted advisory consensus
ERAM	Escalation and Response Authority Manager - logically independent 3-level escalation
IFF	Identification, Friend or Foe - command source authentication (CCSDS SDLS)
BDA	Battle Damage Assessment - orbital state assessment, conjunction reporting
AOCS	Attitude and Orbit Control System - conventional spacecraft control that BLADE-SPACE augments
GREP	Graduated Recovery Execution Protocol
Authority Level	Computed governance authority α (0.0-1.0) governing operational actions
PRNG	Pseudo-Random Number Generator - Mulberry32 seeded for reproducibility
Governance Pipeline	Sequential processing chain: SATA → HMAA → MAIVA → FLAME → CARA

Term	Definition
TID / SEU	Total Ionizing Dose / Single Event Upset - radiation environment effects
TCA / CDM	Time of Closest Approach / Conjunction Data Message

12.2 References

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12.3 Contact

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

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