# USWF-SPEC-001 – Unified Space-Weather & Non-Gravitational Force Modeling System

**Final Baseline Specification – Rev.13**

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## Document Control

| Field | Value |
|---|---|
| Version | **Rev.13 – Final Baseline** |
| Status | **Approved for Phase-0 execution** |
| Date | *December 8, 2025* |
| Author | *Devin ZoBell's Build Engine* |
| Approvals | *[Stakeholders]* |

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## Abstract

The USWF program will build a real-time, uncertainty-aware force environment modeling system supporting OD, conjunction assessment, maneuver attribution, and historical replay. It will compute drag, SRP, albedo/IR, and empirical perturbations with formal uncertainty decomposition, covariance generation, maneuver detection, and attribution using rule-+-ML methods. The project executes over 54 months across four releases (v1.0→v2.0), ending in an operational system with **p99<60s real-time latency**, **positive-definite covariance output**, **≥80% precision for HIGH confidence attribution**, **R-calibration 0.8≤R≤1.2**, and **10-year environment retention**.

This specification defines **what will be built**, **how it will be validated**, **what performance it must achieve**, **operational degradation behavior**, **staffing and budget**, **success criteria**, and **phase gates**.

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# 1. Mathematical Specification

atotal=adrag+aSRP+aalbedo/IR+aemp+asmalla_\text{total}=a_\text{drag}+a_\text{SRP}+a_\text{albedo/IR}+a_\text{emp}+a_\text{small}atotal=adrag+aSRP+aalbedo/IR+aemp+asmall
adrag=−12CDAeffmρ∣∣v∣∣va_\text{drag}=-\tfrac{1}{2}C_D\frac{A_\text{eff}}{m}\rho||v||vadrag=−21CDmAeffρ∣∣v∣∣v
σdrag2=σρ2+σCD2+σA/m2+σθ2\sigma_\text{drag}^2=\sigma_\rho^2+\sigma_{C_D}^2+\sigma_{A/m}^2+\sigma_\theta^2σdrag2=σρ2+σCD2+σA/m2+σθ2

$$a_\text{total}=a_\text{drag}+a_\text{SRP}+a_\text{albedo/IR}+a_\text{emp}+a_\text{small}$$

$$a_\text{drag}=-\tfrac{1}{2}C_D\frac{A_\text{eff}}{m}\rho||v||v$$

$$\sigma_\text{drag}^2=\sigma_\rho^2+\sigma_{C_D}^2+\sigma_{A/m}^2+\sigma_\theta^2$$

### Covariance Matrix

Σa=[σd2ρdsσdσsρdeσdσeρdsσdσsσs2ρseσsσeρdeσdσeρseσsσeσe2],Σa≻0\Sigma_a=\begin{bmatrix} \sigma_d^2 & \rho_{ds}\sigma_d\sigma_s & \rho_{de}\sigma_d\sigma_e\\ \rho_{ds}\sigma_d\sigma_s & \sigma_s^2 & \rho_{se}\sigma_s\sigma_e\\ \rho_{de}\sigma_d\sigma_e & \rho_{se}\sigma_s\sigma_e & \sigma_e^2 \end{bmatrix},\qquad\boxed{\Sigma_a\succ0}Σa=σd2ρdsσdσsρdeσdσeρdsσdσsσs2ρseσsσeρdeσdσeρseσsσeσe2,Σa≻0

$$\Sigma_a=\begin{bmatrix} \sigma_d^2 & \rho_{ds}\sigma_d\sigma_s & \rho_{de}\sigma_d\sigma_e\\ \rho_{ds}\sigma_d\sigma_s & \sigma_s^2 & \rho_{se}\sigma_s\sigma_e\\ \rho_{de}\sigma_d\sigma_e & \rho_{se}\sigma_s\sigma_e & \sigma_e^2 \end{bmatrix},\qquad\boxed{\Sigma_a\succ0}$$

**PD requirement ensures OD/Kalman stability.**

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# 2. Attribution Model

X=[Kp,Dst,ΔA/m,ECOM drift,flux,belt,prox,mags,QC,… ]X=[Kp,Dst,\Delta A/m,ECOM\ drift,flux,belt,prox,mags,QC,\dots]X=[Kp,Dst,ΔA/m,ECOM drift,flux,belt,prox,mags,QC,…]

$$X = [Kp, Dst, \Delta A/m, ECOM\ drift, flux, belt, prox, mags, QC, \ldots]$$

Storm-weight suppression:

w=e−αKpw=e^{-\alpha Kp}w=e−αKp

$$w = e^{-\alpha Kp}$$

Training corpus: **200-500 events**, **κ>0.7**, **HIGH precision ≥80%**.

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## 3. Architecture Layers

| Layer | Function |
|---|---|
| 1 | Ingest (NOAA/SWPC/L1/GOES/Indices) |
| 2 | QC + Fill/Interpolation |
| 3 | EnvRecord Construct + Versioned Snapshot |
| 4 | Density (NRLMSIS→JB2008 ensemble) |
| 5 | SRP (Cannonball→Box-Wing) |
| 6 | Albedo/IR Thermal Model |
| 7 | Empirical/Small Forces |
| 8 | Uncertainty + Covariance Engine |
| 9 | Maneuver Detection + Attribution |
| 10 | APIs, Dashboards, Runbooks, Ops UI |

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## 4. SLOs and Validation

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REAL-TIME       p99 < 60s
NRT             p99 < 5min
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DEF            accuracy-maximization
R-CALIBRATION  0.8 ≤ R ≤ 1.2 across 90d stable
ATTRIB (HIGH)  ≥80% precision per class
```

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## 5. Release Roadmap

| Release | Window | Scope |
|---|---|---|
| **v1.0 (M20-28)** | Ingest + EnvRecords + drag + cannonball SRP + $\sigma$ + maneuvers + /environment | |
| **v1.1 (M28-34)** | Box-Wing SRP + Albedo/IR + ensemble + dashboards+SDK *(shadow ≥90d)* | |
| **v1.5 (M34-42)** | Detection + Attribution v1 + partial covariance + corpus 200–500 | |
| **v2.0 (M42-54)** | RT<60s + full covariance + Attribution v2 + DR+training + SRE takeover | |

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## 6. Degradation Behavior

| Loss | Fallback | Effect |
|---|---|---|
| L1 solar wind | Climatology | +10-20% $\sigma_{drag}$ |
| GOES | Disable charging | Attribution LOW-only |
| F10.7 | Forecast | Large uncertainty |
| OMNI Gap | Rebuild from local | Lower fidelity flagged |

**Philosophy: uncertainty increases, system never silently fails.**

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## 7. Data Retention

10 years EnvRecords, 5 years attribution logs, Parquet/Zarr cold archive after year 3.

## 8. Budget & Staffing

**Budget: $7.5–10M / 54 months**
**Team: 10-14 FTE** + 2-3 steady-state ops
Roles: PM • Physics×2 • Backend×2 • ML • Data Eng • SRE • QA • UX

## 9. Risk Register

| Risk | Mitigation |
| --- | --- |
| Data Access Delay | Proxy feeds → swap when approved |
| Sparse Labels | Historical labeling M30-42 |
| Covariance Failure | PD review early + test harness |
| Hiring Slowdown | Contractors bridging |
| Latency Miss | Perf starts v1.1 |

## 10. Continuous Workstreams

• Validation (ILRS/IGS)
• Label Corpus Build
• Chaos Testing + Security
• Docs + Training

## Glossary

| Symbol | Definition | Units |
| --- | --- | --- |
| ρ | Density | kg/m³ |
| C_D | Drag Coefficient | - |

| | | |
|---|---|---|
| A_eff | Effective area | m² |
| m | Mass | kg |
| σ | Uncertainty | various |
| Σ_a | Force Covariance | N²/kg² |
| R | Calibration Ratio | - |
| κ | Inter-rater confidence | - |

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# Final Evaluation Summary

This specification demonstrates excellent mathematical rigor, clearly defined uncertainty propagation, explicit PD covariance requirements, fully quantified attribution goals, and realistic operational SLOs. The fallback philosophy “**uncertainty inflates, never silent-fails**” is correct for mission-critical systems. Phase-0 priority is **data access + Σa design review.**