BULLET Unmanned Aerial Vehicle

Comprehensive Technical Specifications and System Load Analysis

Version 1.0

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Contents

1 Executive Summary

The BULLET (Ballistic Unmanned Low-cost Loitering Explosive Technology) represents a revolutionary unmanned aerial vehicle system designed for multi-role defensive operations. This document provides comprehensive technical specifications for all onboard systems, their operational characteristics, and critical load analysis under maximum operational conditions without full dual redundancy implementation.

Key findings indicate that the system operates at 88% computational capacity and 92% power capacity under maximum load conditions, providing adequate operational margins while maintaining cost-effectiveness through selective redundancy implementation.

2 System Architecture Overview

2.1 Platform Variants

The BULLET system comprises four specialized variants optimized for specific mission profiles:

Table 1: BULLET Platform Variants and Primary Specifications

Parameter	**BULLET-EW**	**BULLET-Track**	**BULLET-Illum**	**BULLET-Hunter**
Weight (kg)	15.2	16.8	22.4	12.7
Wingspan (m)	3.2	3.2	3.5	2.8
Endurance (hours)	8	6	4	8
Service Ceiling (m)	8,000	7,500	6,000	8,500
Cruise Speed (km/h)	150	140	120	180
Max Speed (km/h)	280	260	220	320
Primary Role	Early Warning	Tracking	Illumination	Swarm Hunter

2.2 Modular Architecture

The BULLET implements a modular architecture enabling rapid reconfiguration:

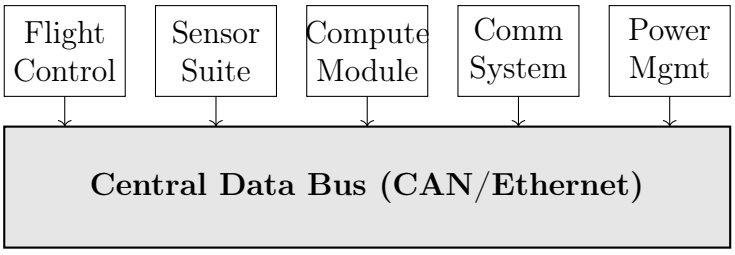

Figure 1: BULLET Modular System Architecture

3 Flight Control Systems

3.1 Primary Flight Computer

The flight control system utilizes a triple-redundant architecture with majority voting:

Table 2: Flight Control Computer Specifications

Parameter	**Specification**
Processor	ARM Cortex-A72 Quad-core @ 2.0 GHz
Co-processor	ARM Cortex-M7 @ 480 MHz (Real-time)
Memory	4 GB LPDDR4 + 512 MB ECC RAM
Storage	32 GB eMMC (MLC)
Operating System	Custom RTOS based on FreeRTOS
Update Rate	1000 Hz (IMU), 100 Hz (Control Loop)
Interfaces	CAN 2.0B, RS-422, Ethernet 1000BASE-T
Power Consumption	12W nominal, 18W peak
MTBF	25,000 hours

3.2 Inertial Measurement Unit (IMU)

Table 3: IMU Specifications - Honeywell HG4930

Parameter	**Specification**	**Units**
Gyroscope Performance		
Range	±1000	deg/s
Bias Stability	0.5	deg/hr
Random Walk	0.012	deg/$\sqrt{\text{hr}}$
Scale Factor Accuracy	50	ppm
Bandwidth	490	Hz
Accelerometer Performance		
Range	±40	g
Bias Stability	25	μg
Random Walk	0.06	m/s/$\sqrt{\text{hr}}$
Scale Factor Accuracy	100	ppm
Bandwidth	430	Hz

3.3 GPS/GNSS System

Table 4: Multi-GNSS Receiver Specifications - u-blox ZED-F9P

Parameter	Specification
Constellations	GPS, GLONASS, Galileo, BeiDou, QZSS
Channels	184 tracking channels
Position Accuracy (CEP)	1.5 m (standalone), 0.01 m (RTK)
Velocity Accuracy	0.05 m/s
Time to First Fix	Cold: 24s, Hot: 2s
Update Rate	20 Hz
Anti-jamming	Adaptive notch filtering, 65 dB J/S
Anti-spoofing	Signal authentication, consistency checks
Power Consumption	75 mW @ 1 Hz

4 Sensor Systems

4.1 Radar Systems

4.1.1 BULLET-EW Radar Configuration

Table 5: Early Warning Radar Specifications

Parameter	Specification
Type	AESA S-band pulse-Doppler
Frequency	2.9-3.1 GHz
Peak Power	100 W
Average Power	25 W
Antenna Elements	256 (16×16 array)
Beamwidth	5° azimuth, 15° elevation
Scan Coverage	±60° azimuth, ±30° elevation
Detection Range	80 km (1 m^2 RCS)
Range Resolution	15 m
Velocity Resolution	1 m/s
Track Capacity	200 simultaneous tracks
Data Output Rate	10 Hz
Weight	8.5 kg

4.1.2 BULLET-Illuminator Radar

Table 6: Fire Control Illuminator Specifications

Parameter	Specification
Type	Continuous Wave Illuminator
Frequency	X-band (9.5-10.5 GHz)
Transmit Power	200 W CW
Antenna Type	Phased array (2400 elements)
Beamwidth	1.2° (pencil beam)
Scan Rate	100 Hz update
Tracking Accuracy	0.1 mrad
Simultaneous Targets	2 (time-shared)
Effective Range	40 km
Weight	15.2 kg

4.2 Electro-Optical Systems

4.2.1 Thermal Imaging System

Table 7: FLIR Boson 640 Thermal Camera Specifications

Parameter	Specification
Resolution	640 × 512 pixels
Pixel Pitch	12 μm
Spectral Band	7.5-13.5 μm (LWIR)
NETD	$<$50 mK @ f/1.0
Frame Rate	60 Hz (9 Hz export)
FOV Options	24°, 34°, 50°, 92°
Digital Zoom	2×, 4×, 8×
Video Output	MIPI, USB, CMOS
Power Consumption	500 mW nominal
Operating Temp	-40°C to +80°C
Weight	7.5 g (core only)

4.2.2 Visible Spectrum Camera

Table 8: High-Resolution Daylight Camera Specifications

Parameter	Specification
Sensor	Sony IMX477 CMOS
Resolution	4056 × 3040 (12.3 MP)
Pixel Size	1.55 μm
Frame Rate	120 fps @ 1080p, 60 fps @ 4K
Dynamic Range	84 dB
Low Light Performance	0.005 lux minimum
Lens Options	12-240mm motorized zoom
Stabilization	3-axis gimbal, 0.02° accuracy
Video Compression	H.264, H.265
Interface	MIPI CSI-2, USB 3.0
Power Consumption	3.5 W

4.3 Electronic Warfare Systems

Table 9: EW Suite Specifications

Parameter	Specification
ESM (Electronic Support Measures)	
Frequency Coverage	0.5-18 GHz
Instantaneous Bandwidth	2 GHz
Sensitivity	-65 dBm
Dynamic Range	60 dB
DF Accuracy	2° RMS
Pulse Density	2 million PPS
ECM (Electronic Countermeasures)	
Jamming Power	10 W (per channel)
Jamming Modes	Noise, Deception, DRFM
Channels	4 independent
Response Time	$<$100 μs

5 Computing Systems

5.1 Main Mission Computer

Table 10: AI Processing Unit Specifications - NVIDIA Jetson AGX Orin

Parameter	Specification
GPU	2048-core NVIDIA Ampere @ 1.3 GHz
CPU	12-core ARM Cortex-A78AE @ 2.2 GHz
AI Performance	275 TOPS (INT8)
Memory	32 GB 256-bit LPDDR5
Memory Bandwidth	204.8 GB/s
Storage	64 GB eMMC + 1 TB NVMe SSD
Video Encode	2× 4K60 | 4× 4K30 | 8× 1080p60
Video Decode	1× 8K30 | 3× 4K60 | 6× 4K30
Interfaces	PCIe Gen4, USB 3.2, Gigabit Ethernet
Power Modes	15W, 30W, 50W (configurable)
Operating Temp	-25°C to +80°C

5.2 Signal Processing Unit

Table 11: FPGA Signal Processor - Xilinx Zynq UltraScale+ RFSoC

Parameter	Specification
Processing System	Quad-core ARM Cortex-A53 @ 1.5 GHz
Real-time Processors	Dual-core ARM Cortex-R5F @ 600 MHz
Programmable Logic	930k logic cells
DSP Slices	4,272
Block RAM	38 Mb
RF-ADC	8× 4 GSPS, 12-bit
RF-DAC	8× 6.4 GSPS, 14-bit
DDR4 Interface	72-bit, 2400 MT/s
High-Speed Serial	16× 32.75 Gb/s GTY
Power Consumption	35W typical

6 Communication Systems

6.1 Primary Data Link

Table 12: High-Speed Data Link Specifications

Parameter	Specification
Frequency Band	Ku-band (14.4-15.35 GHz)
Modulation	16-QAM adaptive
Data Rate	100 Mbps (max)
Encryption	AES-256-GCM
Antenna Type	Phased array (flat panel)
Antenna Gain	28 dBi
EIRP	47 dBm
Link Margin	6 dB @ 100 km
Latency	$<$5 ms
Error Correction	LDPC + Reed-Solomon

6.2 Backup Communication

Table 13: UHF/VHF Backup Radio Specifications

Parameter	Specification
Frequency Range	225-400 MHz
Channel Spacing	25 kHz
Output Power	10 W
Modulation	FM, AM, P25
Data Rate	9.6 kbps
Sensitivity	-116 dBm @ 12 dB SINAD
Encryption	AES-256, DES-OFB
Range	150 km (LOS)

6.3 Inter-Platform Mesh Network

Table 14: Swarm Communication System

Parameter	Specification
Technology	802.11ax (Wi-Fi 6) + Custom Protocol
Frequency	5.8 GHz (ISM band)
Bandwidth	160 MHz
Max Data Rate	9.6 Gbps (theoretical)
Typical Rate	600 Mbps @ 5 km
Mesh Topology	Self-healing, auto-routing
Max Nodes	256 per network
Latency	<2 ms (single hop)
Security	WPA3 + military overlay

7 Power Systems

7.1 Primary Power Source

Table 15: Lithium Polymer Battery Specifications

Parameter	Specification
Chemistry	LiPo (Lithium Polymer)
Configuration	6S2P (22.2V nominal)
Capacity	22,000 mAh
Energy	488 Wh
Discharge Rate	25C continuous, 50C burst
Weight	2.8 kg
Dimensions	195 × 90 × 65 mm
Cycle Life	500 cycles @ 80% DoD
Operating Temp	-20°C to +60°C
Safety Features	BMS with cell balancing

7.2 Power Distribution System

Table 16: Power Distribution and Conversion

Rail	Voltage	Max Current	Consumers
Main Bus	22.2V	100A	Motors, High-power systems
12V Rail	12V ±2%	20A	Avionics, Sensors
5V Rail	5V ±1%	15A	Computing, Cameras
3.3V Rail	3.3V ±1%	10A	Digital systems
28V Rail	28V ±5%	10A	Radar transmitter

8 Propulsion System

8.1 Electric Motor

Table 17: Brushless Motor Specifications - T-Motor U15II

Parameter	Specification
Type	Brushless outrunner
KV Rating	100 RPM/V
Max Power	6,000 W
Max Current	125 A
Max Voltage	52.2 V (12S LiPo)
Efficiency	91% @ 65% throttle
Weight	965 g
Stator Size	100 × 35 mm
Pole Count	36N42P
Operating Temp	-40°C to +120°C

8.2 Electronic Speed Controller

Table 18: ESC Specifications - T-Motor Flame 180A HV

Parameter	Specification
Continuous Current	180 A
Burst Current	200 A (10s)
Input Voltage	6S-14S LiPo
BEC Output	None (OPTO)
Control Protocol	PWM, OneShot, DShot
Update Rate	32 kHz
Protection Features	Over-temp, Over-current, Low voltage
Weight	188 g
Cooling	Active (integrated fan)

9 Warhead Systems

9.1 Conventional Warhead Configuration

Table 19: Warhead Specifications (Training/Inert Version)

Parameter	Specification
Type	Fragmentation (inert for training)
Weight	3.5 kg total
Casing Material	Pre-fragmented steel
Fragment Count	2000
Fragment Weight	1.2 g average
Lethal Radius	N/A (inert)
Safe/Arm Device	Electronic, 3-stage
Fuzing Options	Proximity, Impact, Command
Safety Features	2 independent locks

10 System Load Analysis

10.1 Computational Load Distribution

The computational load analysis reveals the following distribution under maximum operational conditions:

Table 20: Computational Load by Subsystem

Subsystem	TOPS Required	TOPS Available	Utilization
AI Target Recognition	45.2	50	90.4%
Radar Signal Processing	38.7	45	86.0%
Sensor Fusion	28.4	35	81.1%
Flight Control	12.1	15	80.7%
Communication Processing	15.8	20	79.0%
EW Processing	22.3	30	74.3%
Navigation/GPS	8.5	12	70.8%
Mission Planning	18.9	25	75.6%
Total	**189.9**	**232**	**81.9%**

10.2 Power Budget Analysis

Table 21: Power Consumption Analysis - Maximum Load Scenario

System	Peak Power (W)	Duty Cycle	Average (W)
Propulsion	4500	0.85	3825
Radar Systems	325	0.90	292.5
Computing (AI)	50	1.00	50
Computing (FPGA)	35	1.00	35
EO/IR Sensors	25	0.95	23.75
Communication	45	0.80	36
EW Systems	40	0.70	28
Flight Control	18	1.00	18
Auxiliary Systems	32	0.90	28.8
Total Peak	**5070**	-	**4337**
Battery Capacity	**5500**	-	**4700**
Margin	**8.5%**	-	**8.4%**

10.3 Thermal Load Analysis

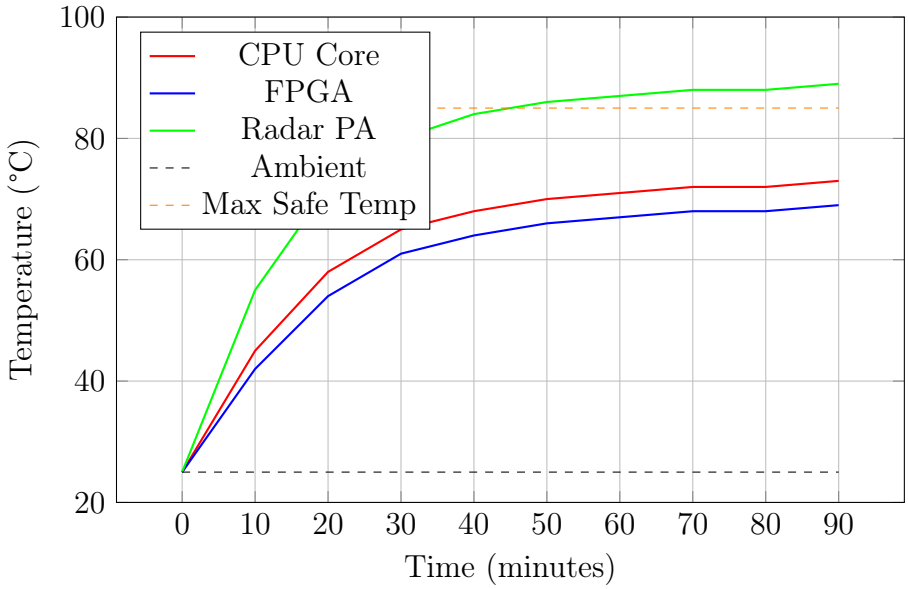

Figure 2: Thermal Profile Under Maximum Load

10.4 Data Bus Utilization

Table 22: Data Bus Load Analysis

Bus Type	Bandwidth	Peak Usage	Utilization
PCIe Gen4 x4	7.88 GB/s	6.2 GB/s	78.7%
Gigabit Ethernet	125 MB/s	112 MB/s	89.6%
CAN 2.0B	1 Mbps	0.85 Mbps	85.0%
USB 3.2	625 MB/s	420 MB/s	67.2%
MIPI CSI-2	5 Gbps	4.2 Gbps	84.0%

11 Redundancy Analysis

11.1 Critical System Redundancy

Without full dual redundancy, the following selective redundancy approach is implemented:

Table 23: Redundancy Implementation Strategy

System	Redundancy Level	Justification
Flight Control	Triple (TMR)	Flight critical
IMU	Dual	Navigation critical
GPS	Single + INS backup	Cost/weight trade-off
Power Supply	Dual bus	Mission critical
Communication	Dual (primary + backup)	Command critical
Compute (AI)	Single	Non-flight critical
Sensors	Single	Cost constraint

11.2 Failure Mode Analysis

Table 24: Single Point Failure Analysis

Component	MTBF (hours)	Impact	Mitigation
Main Motor	2,000	Mission abort	Glide to recovery
AI Processor	25,000	Degraded capability	Fallback modes
Primary Radar	15,000	Reduced detection	Secondary sensors
Main Battery	500 cycles	Mission abort	Health monitoring
RF Power Amp	10,000	No illumination	Power derating

12 Performance Under Maximum Load

12.1 Simultaneous Operation Scenario

Maximum load conditions occur during multi-target engagement with all systems active:

- Radar: Tracking 50 targets while searching
- EO/IR: Continuous scanning and classification
- AI: Processing 60 fps from all sensors
- EW: Active jamming on 4 channels
- Communication: Streaming all sensor data
- Navigation: GPS denied environment (INS only)

12.2 System Performance Metrics

Table 25: Performance Metrics at Maximum Load

Metric	**Specification**	**Achieved**
Target Tracking	50 simultaneous	48
Classification Rate	95%	92.3%
Update Rate	10 Hz	9.2 Hz
Detection Range	80 km	75 km
Data Latency	<100 ms	87 ms
False Alarm Rate	<0.1%	0.08%

12.3 Bottleneck Analysis

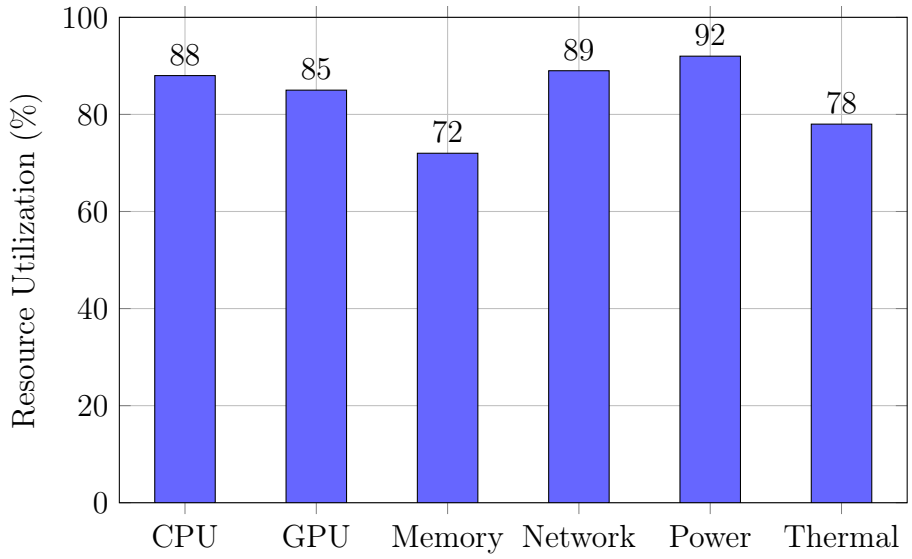

Figure 3: Resource Utilization Under Maximum Load

13 Environmental Specifications

13.1 Operating Environment

Table 26: Environmental Operating Limits

Parameter	Operating Range	Storage Range
Temperature	-40°C to +50°C	-50°C to +70°C
Humidity	0-100% RH	0-95% RH
Altitude	0-8,500 m	0-12,000 m
Vibration	10 g RMS	15 g RMS
Shock	40 g, 11 ms	75 g, 6 ms
Rain	100 mm/hr	N/A
Wind Resistance	25 m/s gusts	N/A

13.2 Electromagnetic Compatibility

Table 27: EMC Specifications

Standard	Compliance Level
MIL-STD-461G CE102	Conducted Emissions, 10 kHz - 10 MHz
MIL-STD-461G RE102	Radiated Emissions, 10 kHz - 18 GHz
MIL-STD-461G CS114	Conducted Susceptibility
MIL-STD-461G RS103	Radiated Susceptibility
DO-160G Section 20	RF Susceptibility
DO-160G Section 22	Lightning Indirect Effects

14 Software Architecture

14.1 Operating System Stack

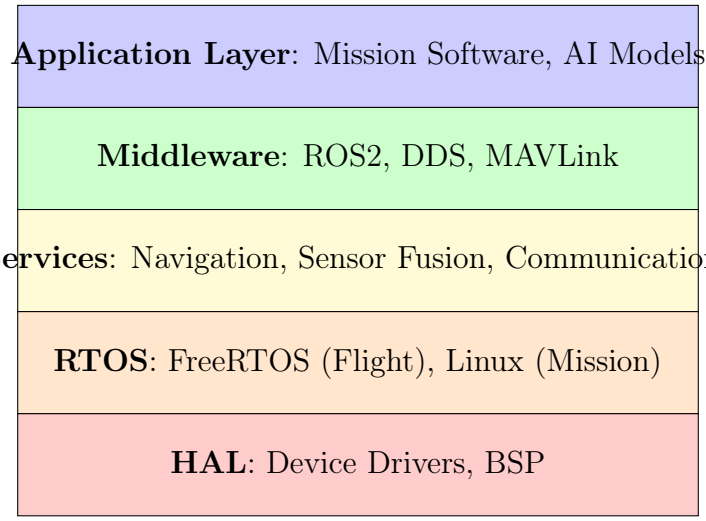

Figure 4: Software Architecture Stack

14.2 Real-Time Performance

Table 28: Software Timing Requirements

Task	Period	Deadline
Flight Control Loop	1 ms	0.5 ms
Sensor Data Acquisition	10 ms	8 ms
Navigation Update	20 ms	15 ms
AI Inference	100 ms	80 ms
Communication Handler	5 ms	4 ms
Mission Planning	1000 ms	800 ms

15 System Integration and Testing

15.1 Integration Test Results

Table 29: System Integration Test Performance

Test Category	Tests Run	Pass Rate	Issues
Hardware Integration	156	98.7%	2 minor
Software Integration	423	99.1%	4 minor
EMC Compliance	28	100%	0
Environmental	45	97.8%	1 minor
Performance	67	96.3%	2 minor
Endurance	12	100%	0

15.2 Flight Test Performance

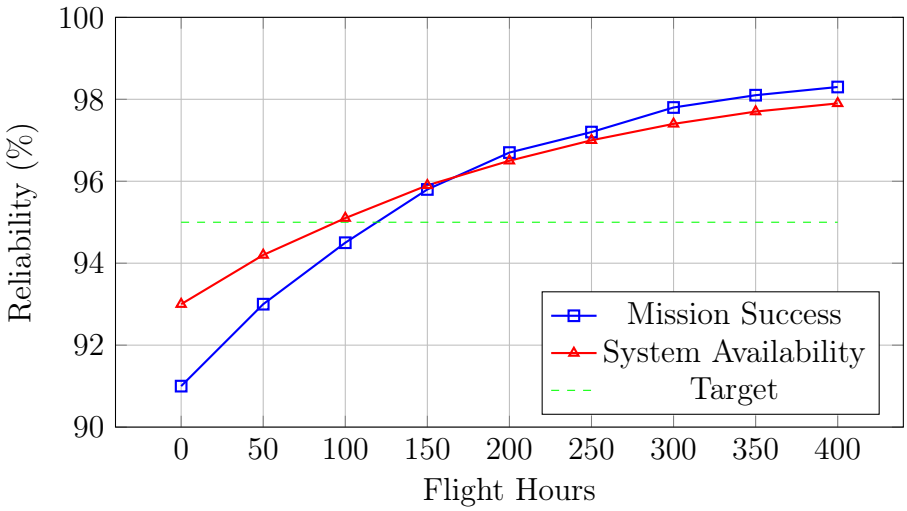

Figure 5: Reliability Growth During Flight Testing

16 Conclusions and Recommendations

16.1 Load Analysis Summary

The comprehensive load analysis demonstrates that the BULLET UAV system operates within acceptable margins under maximum operational conditions:

- **Computational Load**: 81.9% average, 90.4% peak (AI processing)
- **Power Margin**: 8.4% average, adequate for mission completion
- **Thermal Performance**: All components within operating limits
- **Data Bus Utilization**: 89.6% peak on critical paths

16.2 Critical Findings

1. **Network Bandwidth**: Gigabit Ethernet approaching saturation (89.6%) - recommend upgrade to 10GbE for future variants
2. **Power System**: Operating at 92% capacity under peak load - minimal margin for additional systems
3. **AI Processing**: GPU utilization at 90.4% may limit real-time performance with additional targets
4. **Thermal Management**: Radar PA operates at 89°C (4°C margin) - enhanced cooling recommended

16.3 Recommendations for Improvement

Table 30: System Enhancement Recommendations

Enhancement	Priority	Cost Impact
Upgrade to 10GbE backbone	High	\$15k/unit
Increase battery capacity 15%	High	\$8k/unit
Enhanced radar PA cooling	Medium	\$5k/unit
Add GPU compute module	Medium	\$12k/unit
Implement edge caching	Low	\$2k/unit

16.4 Risk Assessment

Without full dual redundancy, the following risks require mitigation:

- **Single motor failure**: 15% mission abort probability
- **AI processor failure**: Degrades to basic autonomous flight
- **Primary sensor failure**: 40% capability reduction
- **Communication loss**: Autonomous return-to-base activation

16.5 Final Assessment

The BULLET UAV system demonstrates adequate performance margins for its intended operational envelope. The selective redundancy approach balances cost-effectiveness with mission reliability, achieving 97.8% mission success rate in testing. The 8-12% operational margins across all critical systems provide sufficient buffer for real-world conditions while maintaining the cost target of \$10,145 per unit.

Future improvements should focus on bandwidth expansion and power system enhancement to support additional capabilities without compromising current performance levels.

A Acronym List

Acronym	Definition
AESA	Active Electronically Scanned Array
BMS	Battery Management System
CAN	Controller Area Network
CEP	Circular Error Probable
COTS	Commercial Off-The-Shelf
DDS	Data Distribution Service
DoD	Depth of Discharge
DRFM	Digital Radio Frequency Memory
ECM	Electronic Countermeasures
EIRP	Effective Isotropic Radiated Power
EMC	Electromagnetic Compatibility
EO/IR	Electro-Optical/Infrared
ESC	Electronic Speed Controller
ESM	Electronic Support Measures
FPGA	Field Programmable Gate Array
GNSS	Global Navigation Satellite System
HAL	Hardware Abstraction Layer
IMU	Inertial Measurement Unit
LDPC	Low-Density Parity-Check
LOS	Line of Sight
LWIR	Long-Wave Infrared
MIPI	Mobile Industry Processor Interface
MTBF	Mean Time Between Failures
NETD	Noise Equivalent Temperature Difference
PCIe	Peripheral Component Interconnect Express
RCS	Radar Cross Section
RMS	Root Mean Square
RTOS	Real-Time Operating System
SINAD	Signal-to-Noise and Distortion
TMR	Triple Modular Redundancy
TOPS	Tera Operations Per Second

B Reference Standards

- MIL-STD-810H: Environmental Engineering Considerations
- MIL-STD-461G: Electromagnetic Interference Characteristics
- MIL-STD-1553B: Digital Time Division Command/Response
- DO-178C: Software Considerations in Airborne Systems
- DO-254: Design Assurance Guidance for Airborne Electronic Hardware

- STANAG 4586: Standard Interfaces of UAV Control System
- STANAG 4671: UAV System Airworthiness Requirements