

Black Magic Missile Works

Modular, Cost Effective, Flexible, Fully Programmable

Avionics and Hybrid Motor System



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Highlights

- ▶ UFC-3 Avionics have a 10 year Sales History for Sub-Orbital Launches for US and European Universities
- ▶ UFC-3C Upgraded to Orbital Operation Capability
- ▶ User Selects Needed Building Blocks based on Budget and Functional Requirements
- ▶ Networked and Redundant Nodes
- ▶ Customized and Customizable Modules Available
- ▶ Hybrid Motor System with Integrated Avionics Control (Sustainer Precision Orbital Insertion)

UFC-3C Modular Structure

- ▶ Node defined by Base Module and up to 7 additional Functional Modules (not including Power Modules)
- ▶ Up to 9 Nodes Networked together over RS-485 Serial Link
- ▶ Active/Active Redundancy and Active/Passive Failover in under 2 milliseconds
- ▶ Redundant Node Pairs created by stacking one node above the other (top is Primary)
- ▶ Base Module Monitors input Battery Power
- ▶ Standard Module Size: 3.55" x 3.75", 0.625" stacking height (over board thickness; 0.062")
- ▶ Node Input Power: 6-25VDC (22.2VDC nominal), 8 Amps maximum per node
- ▶ Operating Temperature Range; -40°C to +85°C
- ▶ Maximum Acceleration, Bump/Shock; 500g, MIL-STD 810F (40g)

Typical Booster Avionics Configuration

Function	Module
Primary Flight Management System (Canards)	UFC-3C-MEZ FMS Driver Mezzanine (4 Channels)
	UFC-3C-HPF-1 High Performance FMS (NavChip IMU)
Sustainer Release Solenoid Drivers	UFC-3C-DRV Four Channel 4Amp Driver
Telemetry	UFC-3C-TEL-1 900MHz., 1Watt, 115,300 baud
Primary CPU	UFC-3C-CPU w/Garmin 5fps GPS
Secondary Flight Management System (Canards)	UFC-3C-MEZ FMS Driver Mezzanine (4 Channels)
	UFC-3C-HPF-1 High Performance FMS (NavChip IMU)
Secondary CPU	UFC-3C-CPU
Six Redundant Power Modules (Commercial Batteries) - 24VDC @ 4.5Ah	UFC-3C-PWR-1 24VDC @ 750mAh Lithium Power Module
	UFC-3C-PWR-1 24VDC @ 750mAh Lithium Power Module
	UFC-3C-PWR-1 24VDC @ 750mAh Lithium Power Module
	UFC-3C-PWR-1 24VDC @ 750mAh Lithium Power Module
	UFC-3C-PWR-1 24VDC @ 750mAh Lithium Power Module
	UFC-3C-PWR-1 24VDC @ 750mAh Lithium Power Module
	UFC-3C-PWR-1 24VDC @ 750mAh Lithium Power Module

Typical Booster Configuration (cont.)

- ▶ Canard Based Active Stabilization
- ▶ Return to Launch Area During Coast
- ▶ Dual Redundant Active/Active data logging and recovery (Pyro Channels)
- ▶ Dual Redundant Active/Passive Flight Stabilization (Failover)
- ▶ 900MHz Narrow–Band Telemetry
- ▶ 5fps Garmin GPS for Booster Recovery (serial port on Base Module)
- ▶ Able to tolerate loss of two Power Modules
- ▶ 8.9" Stack Height (5.5" if batteries stacked separately)

Typical Sustainer Avionics Configuration

Function	Module
Primary Flight Management System (Hybrid Motor)	UFC-3C-MEZ Driver Mezzanine (1 Channel) UFC-3C-HPF-1 High Performance FMS (NavChip IMU)
Hybrid Motor Ignitors and RCS Thruster Solenoid Drivers	UFC-3C-DRV Two Channel 4Amp Pyro, Four Channel 4Amp Driver
Stage Destruct Ignitors and Fairing Release Solenoid Drivers	UFC-3C-DRV Two Channel 4Amp Pyro, Four Channel 4Amp Driver
High Performance GPS	UFC-3C-GPS High Performance GPS
Telemetry	UFC-3C-TEL-1 900MHz., 1Watt, 9,600 baud
Primary CPU	UFC-3C-CPU Base Module
Secondary Flight Management System (Hybrid Motor)	UFC-3C-MEZ Driver Mezzanine (1 Channel) UFC-3C-HPF-1 High Performance FMS (NavChip IMU)
Secondary CPU	UFC-3C-CPU Base Module
Six Redundant Power Modules (Aerospace Batteries) – 24VDC @ 1.98Ah	UFC-3C-PWR-2 24VDC @ 330mAh Lithium Power Module UFC-3C-PWR-2 24VDC @ 330mAh Lithium Power Module

Typical Sustainer Configuration (cont)

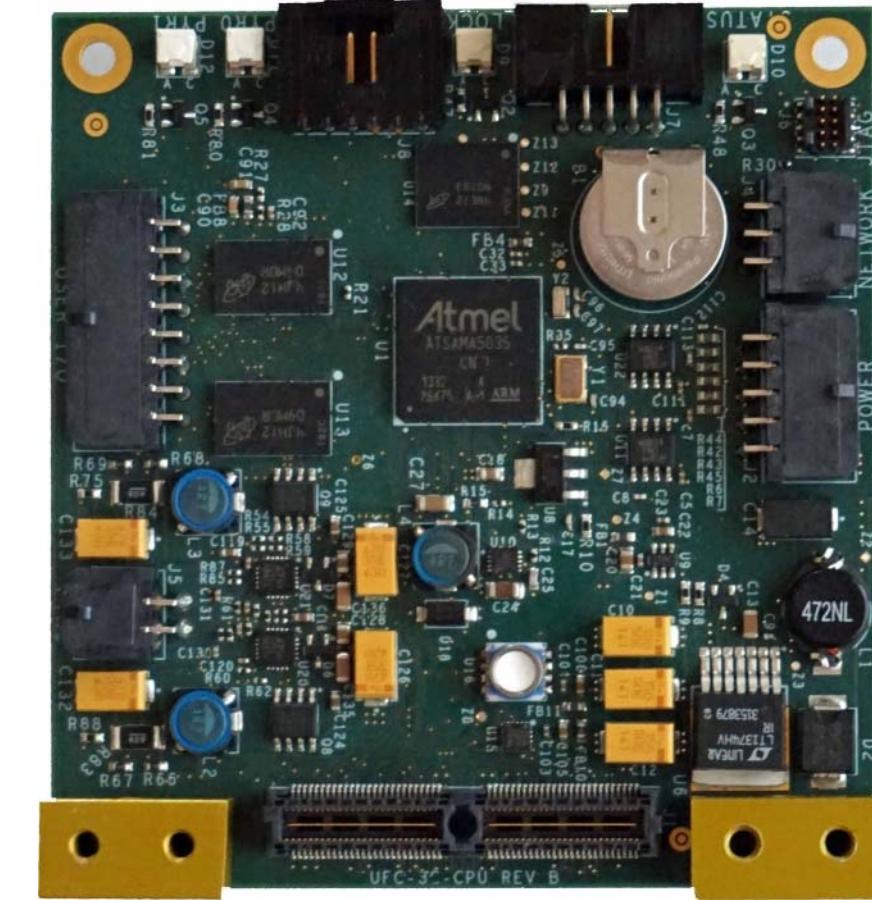
- ▶ Dual Redundant Active/Passive Hybrid Motor Control (Failover)
- ▶ Monitors Launch Pad Nitrous Loading and Pressurization (Pre-Heating)
- ▶ Hybrid Motor Ignitor(s)
- ▶ Stage Destruction Ignitor(s)
- ▶ Cold Gas Reaction Control Flight Path Guidance
- ▶ High Performance 20fps GPS
- ▶ 900MHz Narrow-Band Telemetry (external Power Amplifier)
- ▶ Able to tolerate loss of two Power Modules
- ▶ 10.3" Stack Height (6.9" if batteries stacked separately)
- ▶ Note: this configuration does not support redundant GPS controlled RCS but could at greater cost)

Typical Motor Test Configuration

Function	Module
Primary Flight Management System (Hybrid Motor)	UFC-3C-MEZ FMS Driver Mezzanine (1 Channel)
	UFC-3C-HPF High Performance FMS (no IMU)
Telemetry	UFC-3C-WAN 2.4GHz 1Watt, 112MHz Bandwidth (Dual Camera Support)
Data Acquisition (supplemental)	UFC-3C-ADC 8 Channel, 16-bit ADC Module
Primary CPU	UFC-3C-CPU Base Module
Three Redundant Power Modules (Commercial Batteries) – 24VDC @ 2.25Ah	UFC-3C-PWR-1 24VDC @ 750mAh Lithium Power Module
	UFC-3C-PWR-1 24VDC @ 750mAh Lithium Power Module
	UFC-3C-PWR-1 24VDC @ 750mAh Lithium Power Module

Base Module (UFC-3C-CPU)

- ▶ 533MHz. ARM Cortex A5 Core w/MMU and FPU
- ▶ 32KB ICache, 32KB DCache
- ▶ 128KB Internal SRAM
- ▶ 512MB DDR2 RAM
- ▶ 256MB ECC Flash (Data Logging)
- ▶ Temperature Compensated, Factory Calibrated Barometric Altimeter to 100,000'
- ▶ 24g, 3-Axis Accelerometer
- ▶ Dual, Switch-mode Constant Current Pyro Drivers (Recovery/Deployment)
- ▶ Node Input Current Monitoring, Voltage Monitoring for 3 Banks (extendable to 7)
- ▶ On board Serial Port for Garmin 5fps GPS
- ▶ Ground Support Serial Port (Virtual Network Connection)
- ▶ Eight User Defined Digital I/O Ports
- ▶ MTBF; 1,915,000 hours @ 25°C, 98,575 hours @ 85°C

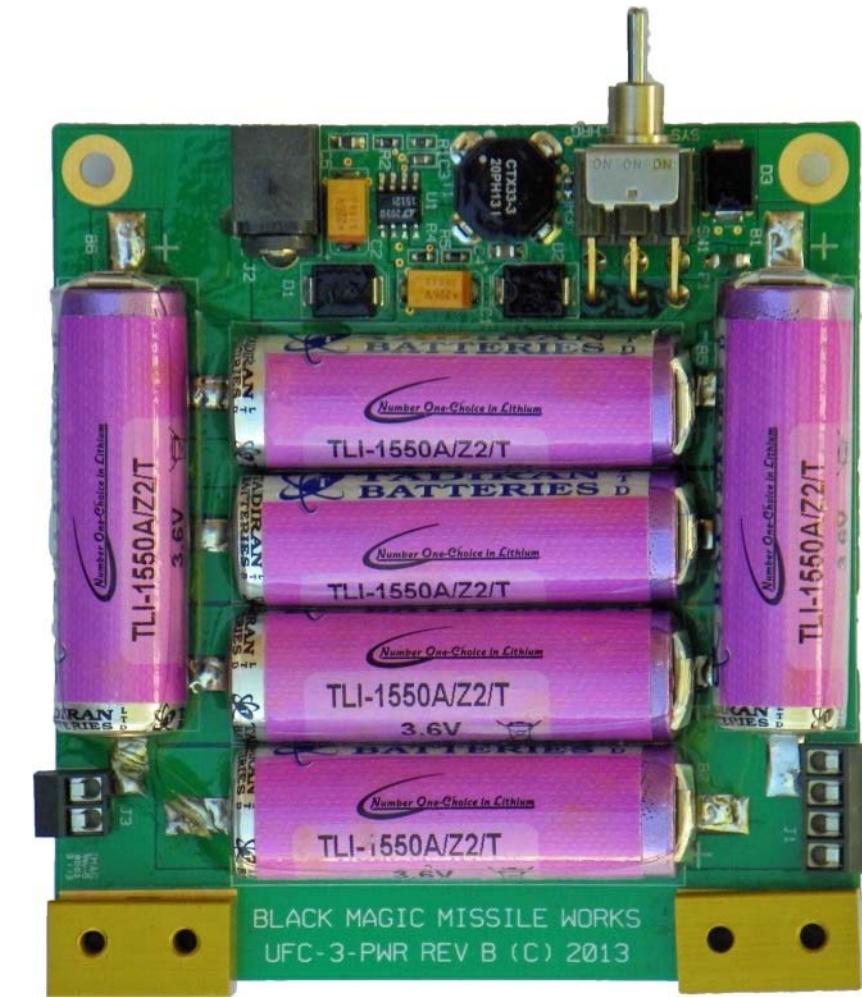


Base Module Applications

- ▶ Redundant Operation Optional
- ▶ Active/Active or Active/Passive
- ▶ Plenty of Excess CPU Clock Cycles and Main Memory for Custom Applications (i.e., GPS controlled RCS)
- ▶ Virtual Terminal Support to Networked Nodes from single Ground Support or Telemetry connection
- ▶ User Defined Names, Scale, Offset for up to 40 ADC Channels
- ▶ User Defined Port Names and State Names for up to 12 Digital I/O Channels
- ▶ Digital I/O Ports used for additional User Defined Functions (i.e., RF Power Management, Active/Passive Failover (Failover Event))
- ▶ Input Ports may be used for sensing switches, break wire, etc.
- ▶ Output Ports may be used with external drivers (FET) for relays, solenoids, etc.
- ▶ Additional 24 Digital I/O Channels assigned to Node Modules
- ▶ Pyro Drivers are 90% efficient (low battery drain) with Continuity Check
- ▶ All Module Parameters stored in on-board EEPROM, plug and play operation (modules are position and system independent)

Power Module (UFC-3C-PWR)

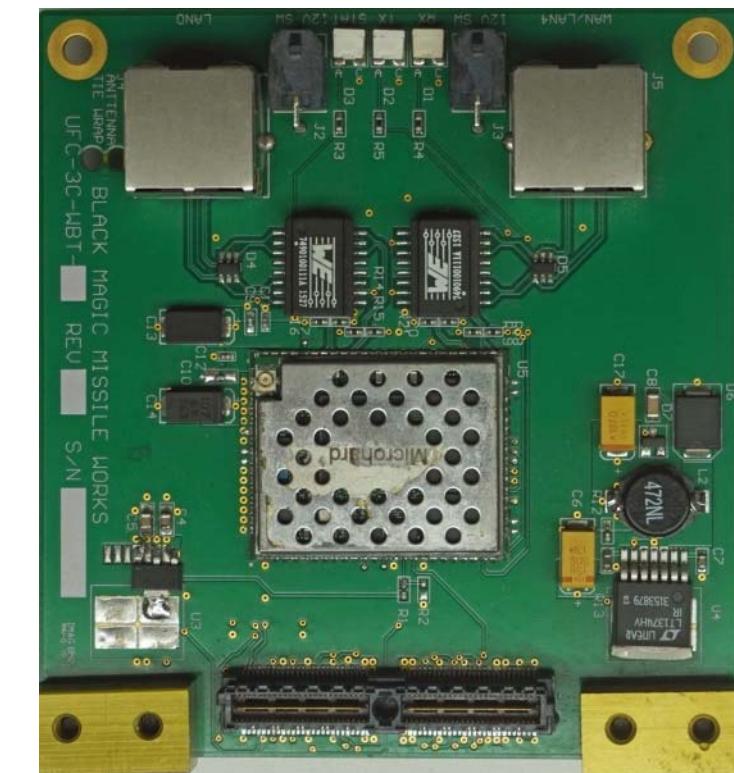
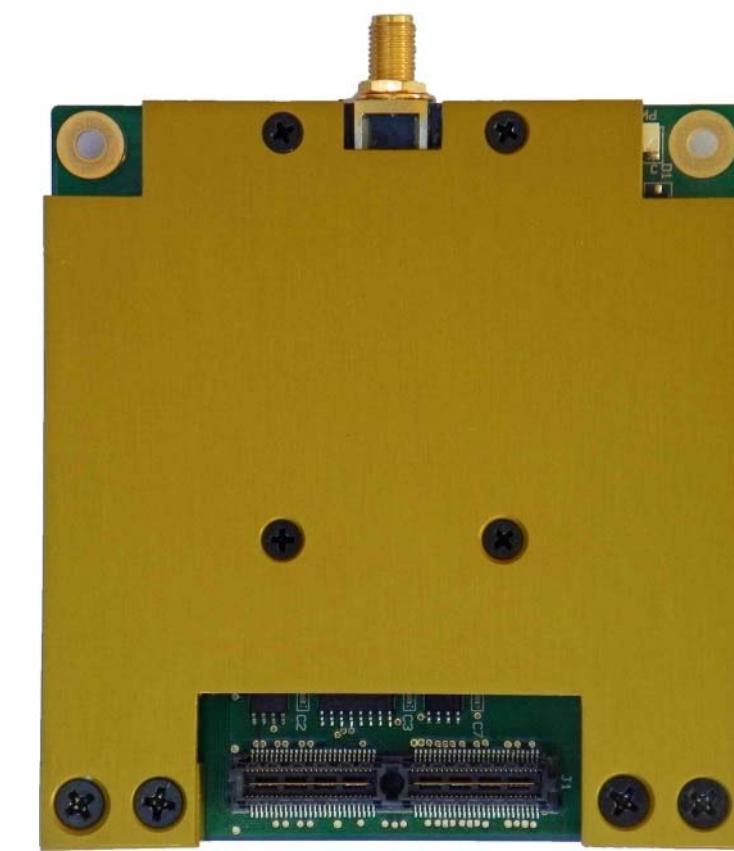
- ▶ 22.2VDC nominal, 24.0VDC maximum
- ▶ Built in Current Sharing Diode
- ▶ Built in Battery Charger (12VDC input)
- ▶ Voltage Sense Port
- ▶ Commercial (-1); 750mAh, -20°C to +60°C
- ▶ Aerospace (-2); 330mAh, -40°C to +85°C
- ▶ MTBF; 5,390,500 hours @ 25°C, 2,609,000 hours @ 85°C



Note: Planned 28VDC version, internally bussed power, changer bus, remote shutdown

Telemetry Modules

- ▶ 900MHz. Narrow-Band or 2.4GHz. Wide-Band
- ▶ 1 Watt Continuous Output
- ▶ Programmable Serial Channel for Command, Control and Data Acquisition
- ▶ Optional High Power Amplifier (external, up to 50Watts)
- ▶ Narrow-Band (UFC-3C-TEL) 9,600 baud/115Kbaud
- ▶ Wide-Band (UFC-3C-WAN) Dual 56Mbps 10/100 Ethernet Ports with Switchable Camera Power
- ▶ MTBF; TBD

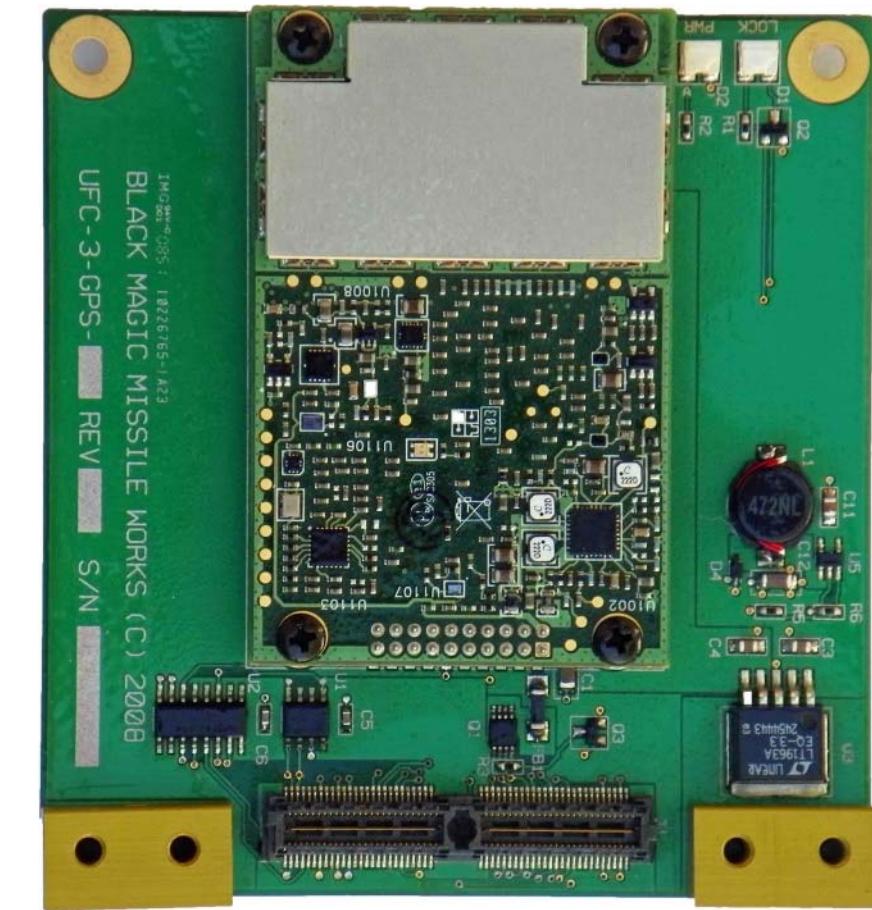


Telemetry Applications (Narrow Band)

- ▶ Bi-Directional Communications, Command Uplink, Data Downlink
- ▶ Downlink Data formatted for Excel (csv) with Processor Number, Time Stamp, Record Type and variable length Data plus System Configuration Header
- ▶ Whole records dropped when bandwidth is exceeded, all transmitted records are complete and uncorrupted
- ▶ User defined Downlink Data from Sensors from 0 to 1,024sps,
- ▶ System Level Messages (i.e., Apogee, Stage, etc.) always transmitted
- ▶ 256-bit AES Encryption
- ▶ FHSS (Frequency Hopping Spread Spectrum)
- ▶ 10 hopping channels, each with over 65,000 unique network addresses available
- ▶ Range a Function of Bandwidth, 40 miles typical for 900MHz @ 9,600baud
- ▶ Range also a function of Antenna(s), Airframe Impact, Orientation
- ▶ Antenna Recommendation; 4 Conformal Antennas at 90° Intervals with Splitter
- ▶ Supports External Power Amplifier, Managed with external Solid State DC Relay (Power) and RF Relay (Antenna Source) using CPU Digital Output Ports (external FET drivers)
- ▶ Support Active Failover using additional RF Relay(s) and Output Ports

High Performance GPS (UFC-3C-GPS)

- ▶ 20fps High Performance GPS (NovAtel OEM615)
- ▶ External Active Antenna
- ▶ GLOSNASS Tracking
- ▶ L1, L2 and L2C Tracking
- ▶ COCOM Removal Option
- ▶ Rated for Orbital Use
- ▶ Position Accuracy; 1.5m Standard, 0.6m WAAS
- ▶ Velocity Accuracy; 0.03m/s
- ▶ Satellite Lock to 20g RMS (MIL-STD-810G, method 514.6, category 24)
- ▶ MTBF; TBD

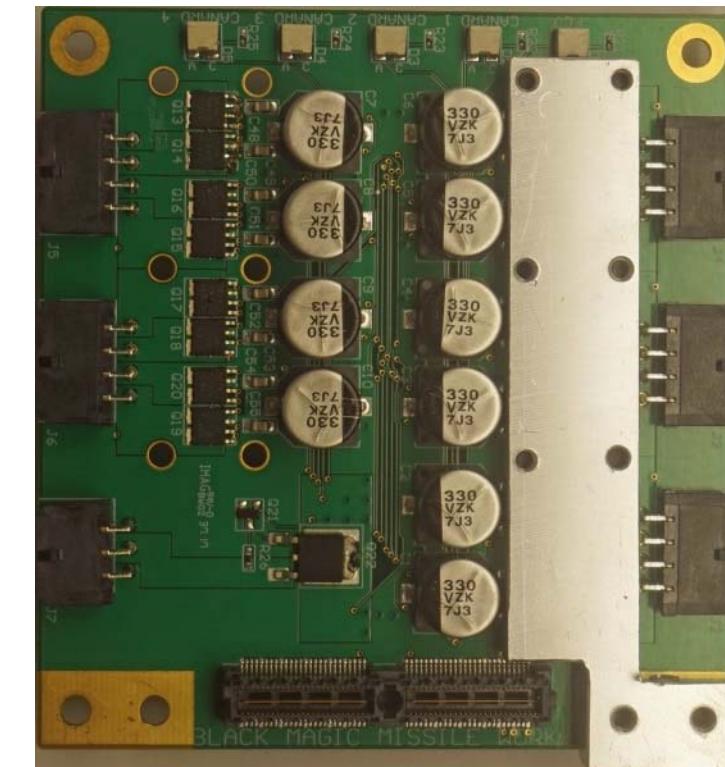
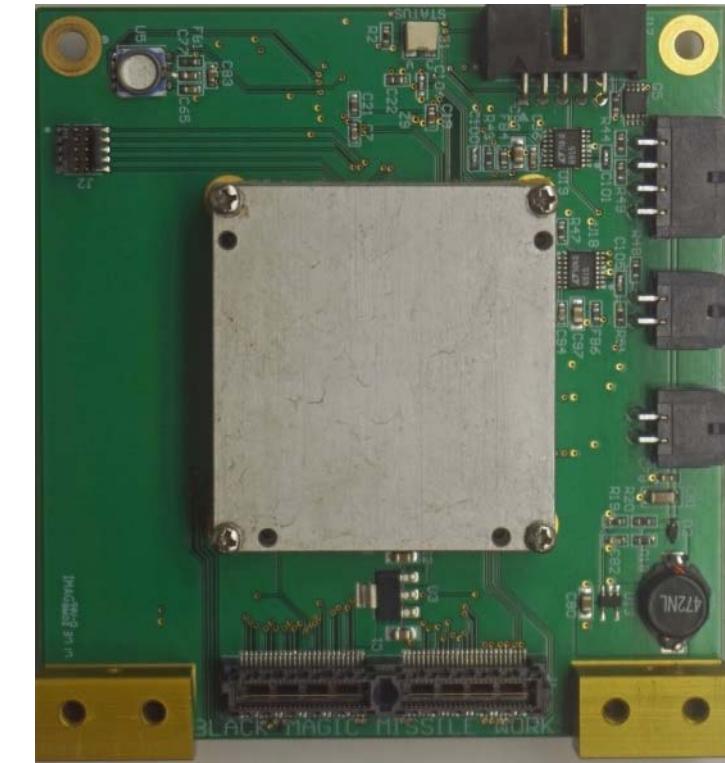


GPS Applications

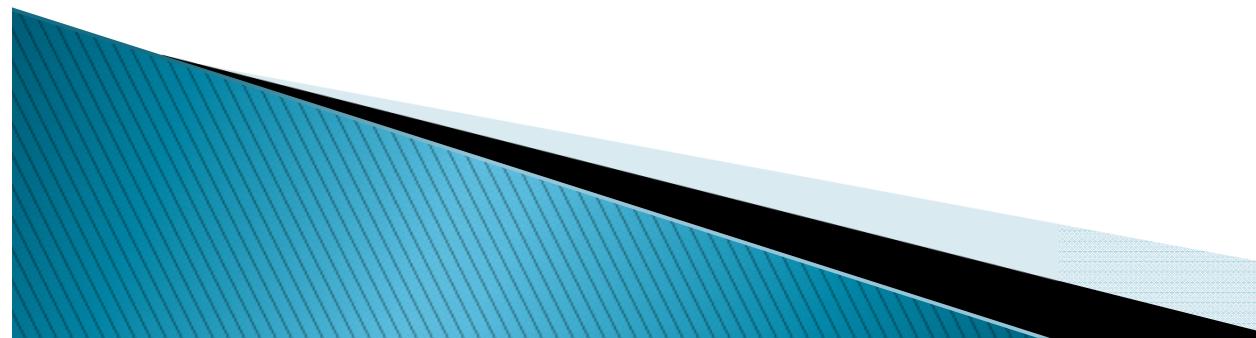
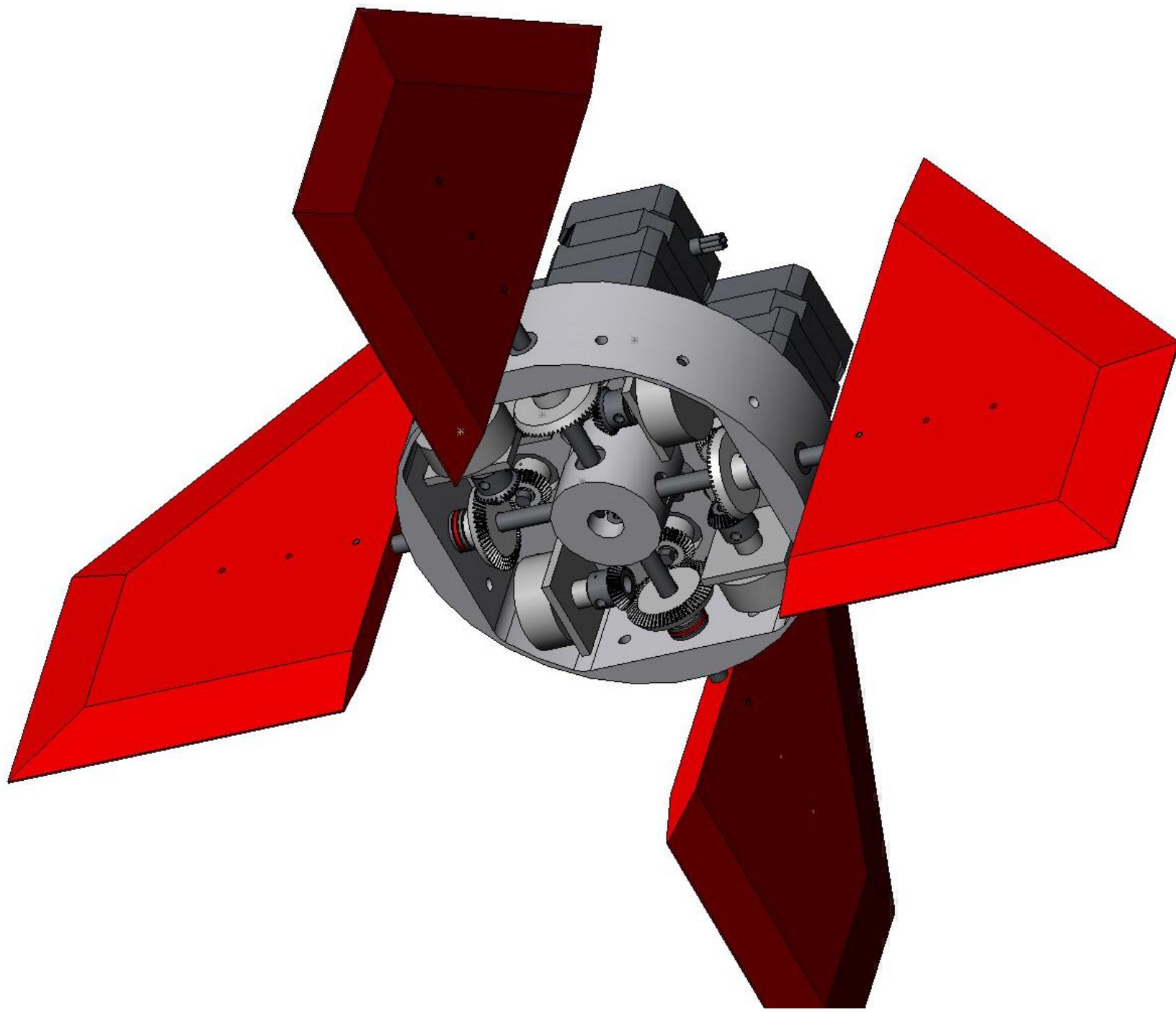
- ▶ High Altitude support with removal of COCOM Limits
- ▶ Fully functional in Orbital Applications
- ▶ Implement GPS RCS control with User Software running on CPU Module
- ▶ Can be dedicated to separate Node for Auto-Destruct on Course Deviation, even Redundant, Cheaper than other 3rd Party Add-ons

Flight Management System

- ▶ High Performance IMU;
 - Thales Aerospace NavChip 6-Degrees of Freedom (-1)
 - Analog Devices Tactical Grade ADIS16488 10-Degrees of Freedom (-2)
- ▶ Cypress Semiconductor PSoC 5 (Programmable System on Chip) with Cortex M-3 64MHz. Processor
 - 64KB SRAM
 - 128KB Program Flash
 - 4 Quadrature Decoders (Canard Position)
 - Embedded Support for Canard Based Active Stabilization and Hybrid Motor Control
 - Open Source and full Development Environment (“C”) and Debugger
- ▶ 128MB ECC Flash (Data Logging) w/DMA
- ▶ 16-bit ADC Channels;
 - Motor Pressure (closed loop motor control)
 - NOS Pressure
 - Load Cell (thrust on test stand or NOS load on launch pad)
 - NOS Temperature with Solid State Relay Drivers for NOS preheater (HPF only)
- ▶ 5 Programmable Stepper Motor Drivers
 - FMS – 1.5Amps per Motor
 - HPF – 4.5Amps per Motor (2 module set)
- ▶ Customizable to Repurpose Stepper Drivers, ADC Channels, etc.
- ▶ MTBF; TBD



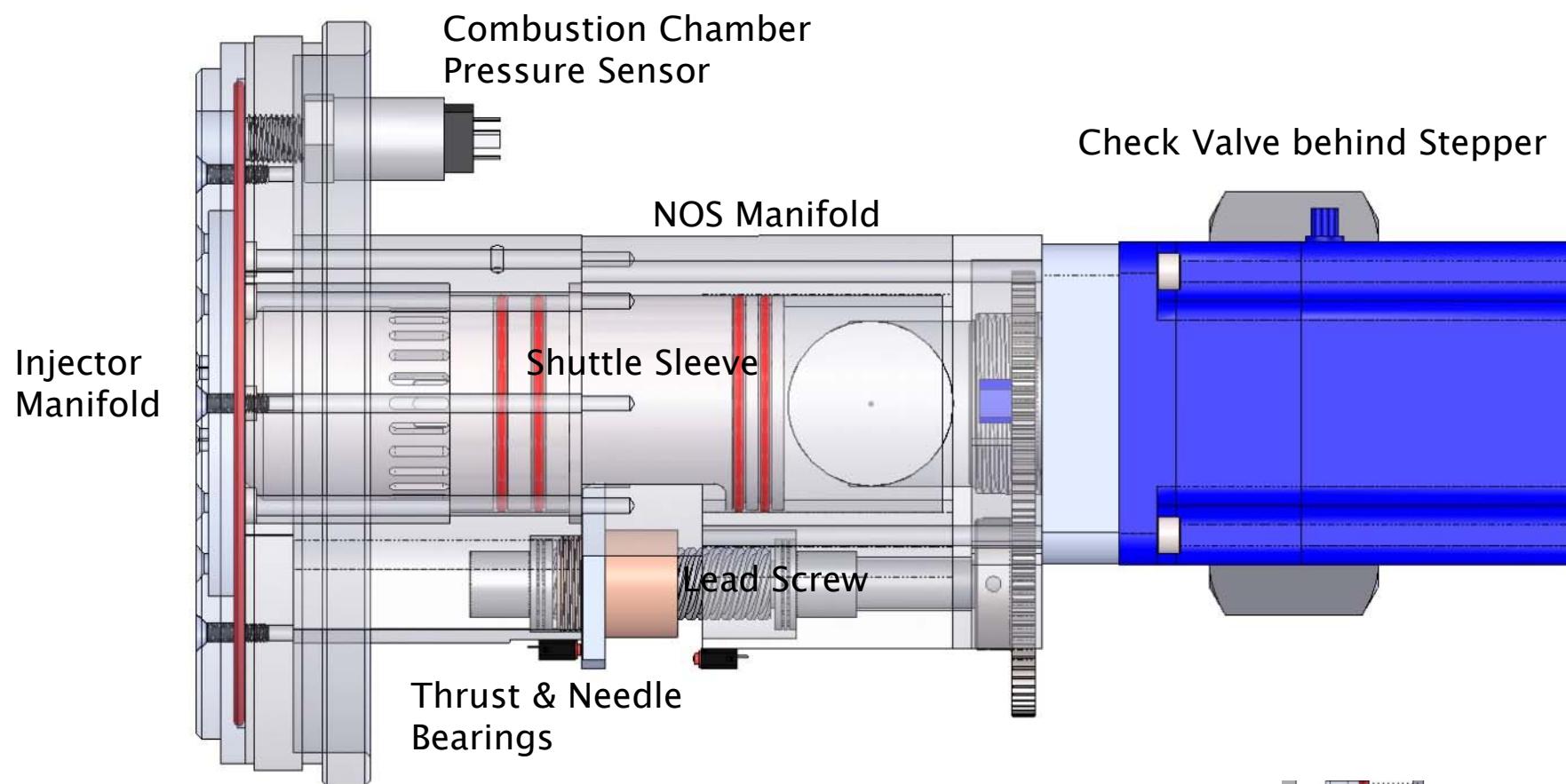
Canard Configuration



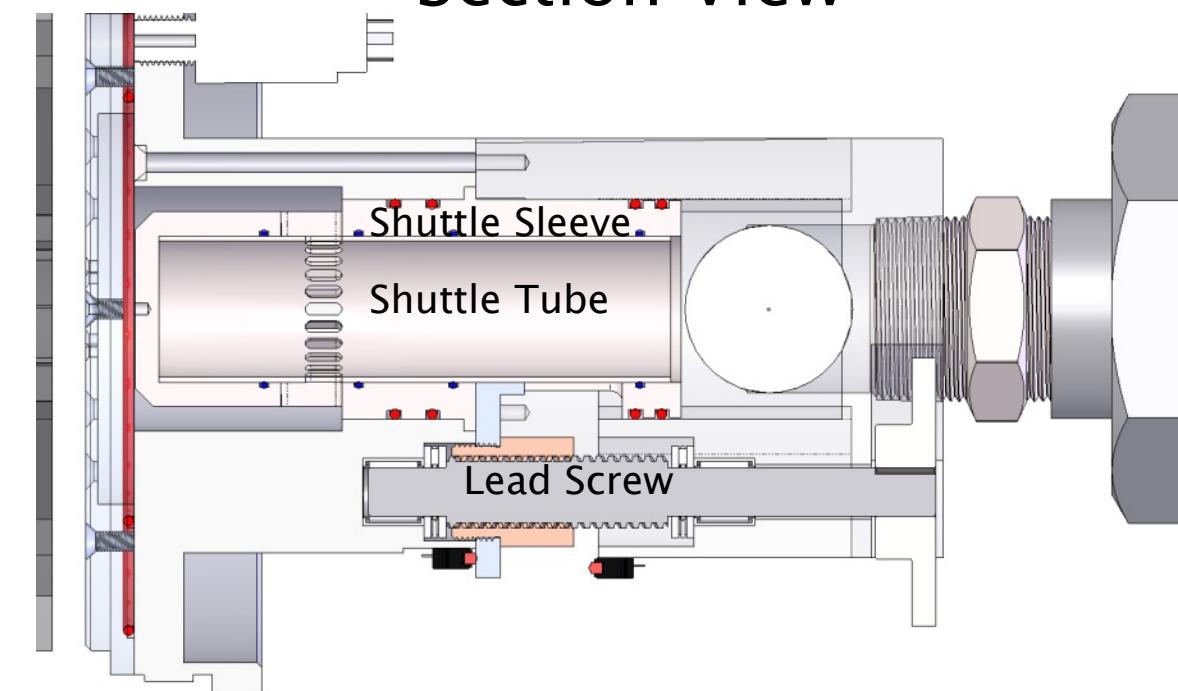
Canard Based Active Stabilization

- ▶ Supports Four Independent Stepper Motors w/Quadrature Position Decoders
- ▶ Stepper Motor Assignment (Pitch+/-, Yaw +/-)
- ▶ Programmable Stepper Current
- ▶ Maximum Airfoil Deflection Angle
- ▶ Reverse Encoder Direction
- ▶ Reverse Roll Direction
- ▶ Pulse Rate (256, 512, 1,024 steps per sec.)
- ▶ Step Rate (pulses per revolution)
- ▶ Stepper Overshoot Allowance
- ▶ Drive Ratio
- ▶ Loop Gain
- ▶ Encoder Rate (Encoder pulses per revolution)
- ▶ Pitch/Yaw Damping Factor
- ▶ Roll Damping Factor
- ▶ Telemetry and Flash Log Data Rates for IMU and Steppers

Hybrid NOS Flow Control Valve



Section View

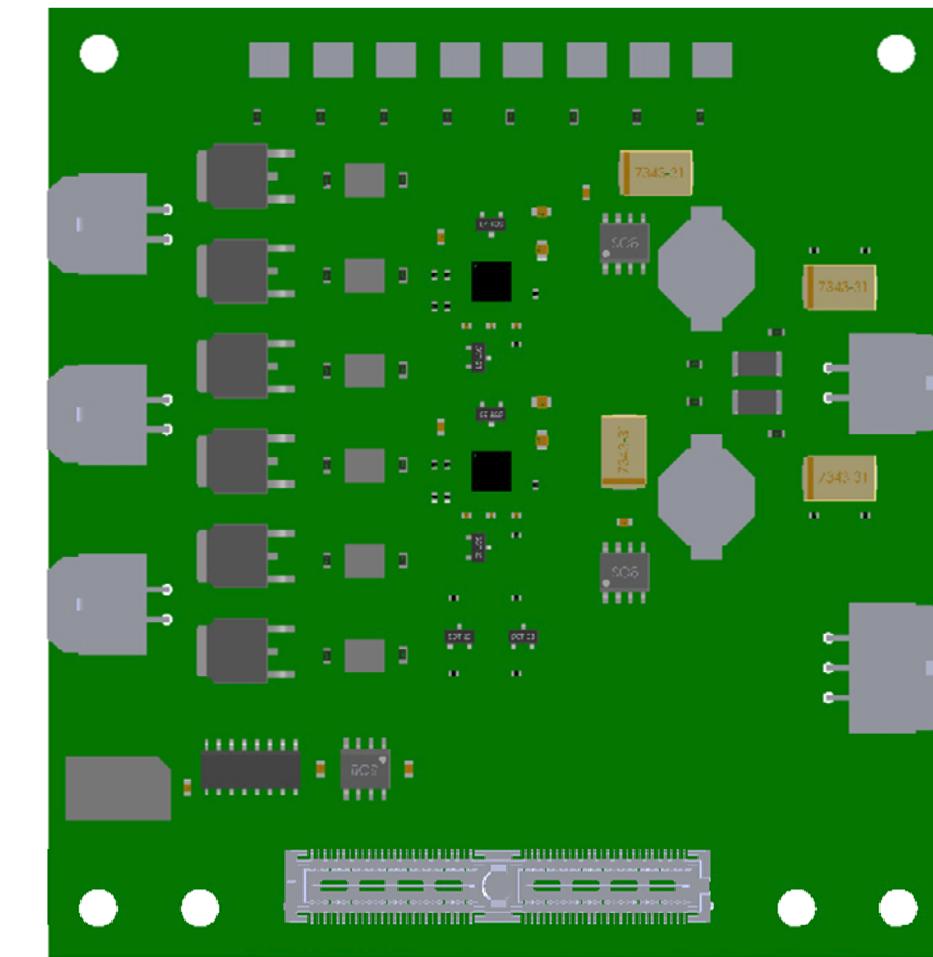


Hybrid Motor Control

- ▶ Flow Control Valve (Shuttle Valve) for NOS or NOFBX
 - High Flow Rate
 - Fast Open/Close
 - High Pressure
 - Machine Shop Fabrication
- ▶ Closed Loop (Combustion Chamber Pressure) or Open Loop (Absolute Valve Position) Control with Programmable Sequence
- ▶ Launch Pad NOS Heater Control for maximum NOS Pressure
- ▶ Launch Pad NOS Fill Status with external Load Cell
- ▶ Programmable Stepper Current
- ▶ Reverse Stepper
- ▶ Home Limit Switch Enable
- ▶ Minimum Open Position
- ▶ Maximum Open Position
- ▶ Heater Set Points (°C)
- ▶ Telemetry and Flash Log Data Rates for Sensors and Stepper
- ▶ Sensor Scale Factors and Offsets
 - Combustion Chamber Pressure
 - NOS Tank Pressure
 - NOS Tank Temperature
 - Load Cell

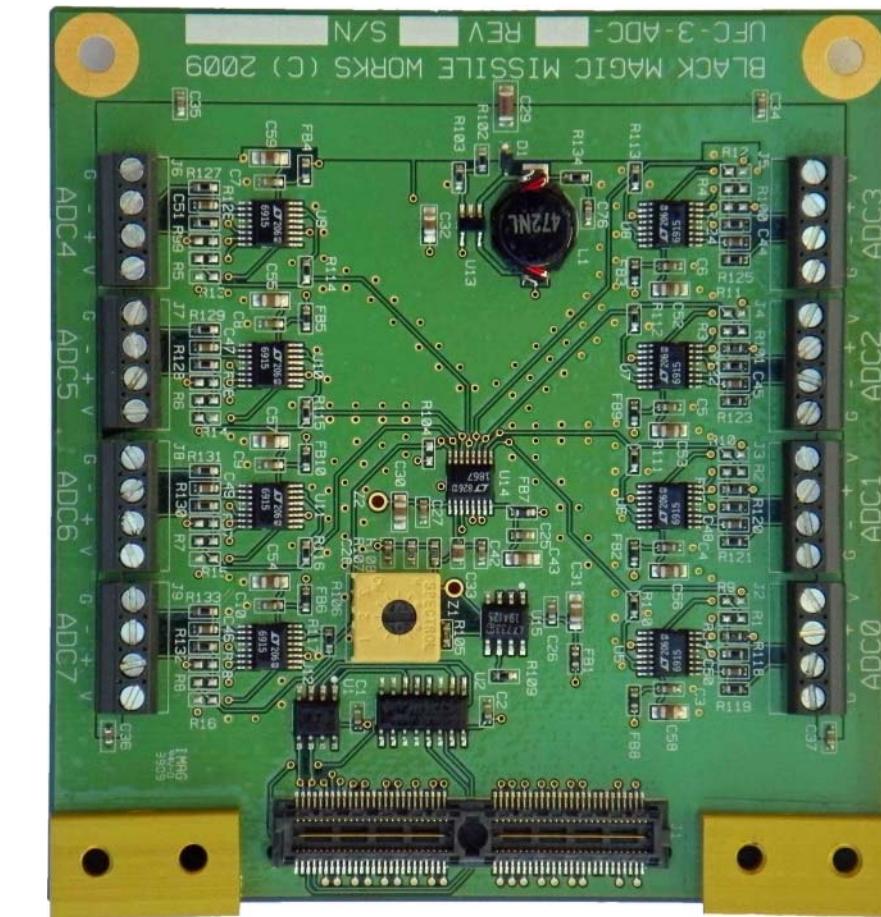
Driver Module (UFC-3C-DRV)

- ▶ Two Switch–Mode Constant Current 4 Amp. Pyro Channels
- ▶ Four 4 Amp. Switch Channels
- ▶ Continuity Status
- ▶ LED Status Indicators
- ▶ Selectable Stack Power or External Battery Power
- ▶ Uses are Motor Ignition, Self-Destruct, Solenoid Valves for RCS, Payload/Upper Stage Release, etc.
- ▶ MTBF; TBD



ADC Module (UFC-3C-ADC)

- ▶ 8 Channel, 16-bit ADC,
Differential/Single-Ended Input
 - ▶ 1,024sps maximum
 - ▶ On-Board 8Volt Excitation Power
Supply
 - ▶ Termination Option for Type K
Thermocouples (-180°C to +1,200°C)
 - ▶ Programmable Gain from 1 to 4,096
(powers of 2)
 - ▶ Direct Accuracy; 0.1%
 - ▶ PGA Accuracy; 0.25%
 - ▶ Readings may be used for any Action
Function, Pre-Flight Check
 - ▶ MTBF; 11,948,000 hours @ 25°C,
298,000 hours @ 85°C



Terminal I/O

- ▶ Power-up Plug and Play Configuration and Self-Test
- ▶ Ground Support or Telemetry Uplink Command Terminal, Virtual Connection to any Node (Node ID part of prompt)
- ▶ Configure any Module
- ▶ Calibrate Altimeter, Accelerometer, IMU
- ▶ Report Module Status
- ▶ Load Script
- ▶ Simulate Launch
- ▶ Prepare for Launch
- ▶ Read Stored Flight Data
- ▶ Download Firmware Update
- ▶ Set Time/Date
- ▶ Port Connect (i.e., GPS or Telemetry manual programming, FMS direct access)

Control Scripts

- ▶ Simple text based Scripts control Pre-Flight Checks/Calibration and Flight State Machine
- ▶ Script order only relevant for Pre-flight sequencing, can be intermixed with State Machine statements which can be in any order
- ▶ Simulation Mode allows pre-flight Script and Hardware Validation, Scripts only Stop on Syntax Error, not Flight Check Faults (Acceleration and Velocity Commands replace Altimeter Inputs). Same script file used for Simulation and Launch (started with different commands)
- ▶ Pre-Flight Checks support Check of Any Sensor for User Defined Limits
- ▶ Pre-Flight Calibration of all essential Sensors (IMU, Altimeter, Accelerometer)
- ▶ Also used to specify Barometric Altimeter or GPS based Altitude/Speed Decisions

Flight State Machine

- ▶ Uses Simple to understand Event/Action Statements
- ▶ User defined Sensor Names and Units allow Hardware Independent Scripts with meaningful names for Clearer Scripts
- ▶ Multiple Events specify implicate “AND”
- ▶ Multiple commands using same Action specify implicate “OR”
- ▶ Time Delays (millisecond resolution) on any Action
- ▶ 26 Soft Flags can be Set/Reset Actions to Merge previous Events with new ones

Pre-Flight Preparation

- ▶ Calibrate Altimeter
- ▶ Calibrate Accelerometer
- ▶ Calibrate Inertial Sensor (IMU drift compensation)
- ▶ Use GPS (instead of Altimeter for Speed/Altitude)

Pre-Flight Checks

- ▶ Analog Inputs (i.e., individual Battery Bank voltage checks)
- ▶ Digital Inputs (i.e., Fairing Closed, Chute Stored, etc.)
- ▶ Pyro and Driver Continuity
- ▶ Altimeter Self-Test
- ▶ Altitude
- ▶ IMU Self-Test
- ▶ Accelerometer Self-Test
- ▶ Temperature
- ▶ GPS Lock
- ▶ FMS Check (i.e., Canard Encoder Test, NOS Tank Pressure/Temperature)

Events

- ▶ Ready – to Launch, Preflight Successfully Completed, Scripts started
- ▶ Launch – detected
- ▶ Stage – Staging detected (by occurrence)
- ▶ Ascent – through Ascending Altitude
- ▶ Apogee – peak Altitude
- ▶ Descent – through Descending Altitude
- ▶ Landed – end of Descent
- ▶ Remote – User defined Command via Telemetry or Network
- ▶ Analog Inputs – Any of 40 ADC channels for User Value (<=, =, >=)
- ▶ Digital Inputs – Input or Output State by Port Name and State or by unique State Name Only
- ▶ Roll (rate), Pitch, Yaw
- ▶ Temperature (Base Module)
- ▶ Vertical Speed (fps)
- ▶ Horizontal Speed (knots)
- ▶ Flag Set or Clear (26 individual)
- ▶ FMS Data

Actions

- ▶ Set Analog Recording/Telemetry Rate (per channel)
- ▶ Set Digital Recording/Telemetry Rate
- ▶ Set Altimeter Recording/Telemetry Rate
- ▶ Set Accelerometer Recording/Telemetry Rate
- ▶ Set IMU Recording/Telemetry Rate
- ▶ Set GPS Recording/Telemetry Rate
- ▶ Set Temperature Recording/Telemetry Rate
- ▶ Set FMS Recording/Telemetry Rate
- ▶ Set/Clear Digital Output (including those built into modules such as Power Enable, Driver Channel, etc.)
- ▶ Change Telemetry Configuration (narrow-band only)
- ▶ Activate Pyro Channel
- ▶ End (Shutdown and stop all recording)
- ▶ Set/Clear Flag (A-Z)
- ▶ FMS Command (User Defined 3 letter code)
- ▶ Network Command (User Defined 3 letter code, by node number or all)
- ▶ DDL Power Enable/Disable
- ▶ Simulate Acceleration (simulation mode only)
- ▶ Simulate Velocity (simulation mode only)