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NANO-SATELLITE SYSTEMS LLC

CAL POLY
SAN LUIS OBISPO

CANEUS
MNT

Example of Technology Development *Program*

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Ground rules

- **Power and Volume are King.**
  - **A CubeSat's inability to generate significant power can be offset by using less of it!**
  - **Central, Low Power, High Performance processor running Linux.**
    - **The PC104 architecture typically implements a dedicated MCU per board, requiring more power, and complicating software with more inter-processor communication.**
- **Multi-Function boards. Combine Electrical Power System, with Communication and Data Handling Boards. Blur subsystems.**

Ground rules (Continued)

- **Miniaturized Connectors. Fight for every mm.**
  - **COTS integrated systems have a great number of options**
- **Radiation Mitigation**
  - **Use naturally Rad-Hard parts where it makes sense**
  - **Many Watch-Dog Layers (SW and HW)**
  - **Smart Fuses**
  - **Design the system to Reboot.**
- **Consider the Battery Pack part of the Payload**
  - **Custom battery pack design goes a long way towards optimizing volume**
- **Leverage on R&D from the 10+ years work done at California Polytechnic State University**
  - **Great example of public-private partnership**

Results: Tyvak's Intrepid CubeSat System

- **SystemBoard**
  - 400Mhz Linux Computer, 128MB SDRAM, 512MB NAND, 32MB PCM, MicroSD
  - Electrical Power System (4 Regulated Rails, 8W each)
  - RTC, 3-Axis Gyro, 3-Axis Accel, 3-Axis Magnetometer
  - Umbilical Development (Ethernet, Full signal diagnostics)
  - Basic Bus functionality only utilizes a few % of the systems full capability (lots of room to grow for ADCS algorithms, Image capture, Payload Software, etc)

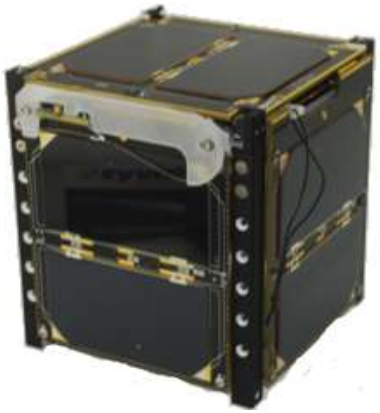
SystemBoard and UHF (in receive mode) peak power draw: <400mW

- **UHF Half-Duplex Comm**
  - 2.4 to 250kbps
  - FSK, GMSK, BPSK, OQPSK
  - Up to 1.5W RF Out
  - 9.6kbps packet reception down to -118 dBm
- **Multi-Functional Side Panels**
  - 3-Axis Magnetometers, 2-Axis Sun Sensors
  - Solar Cells
  - Magnetic Torquers

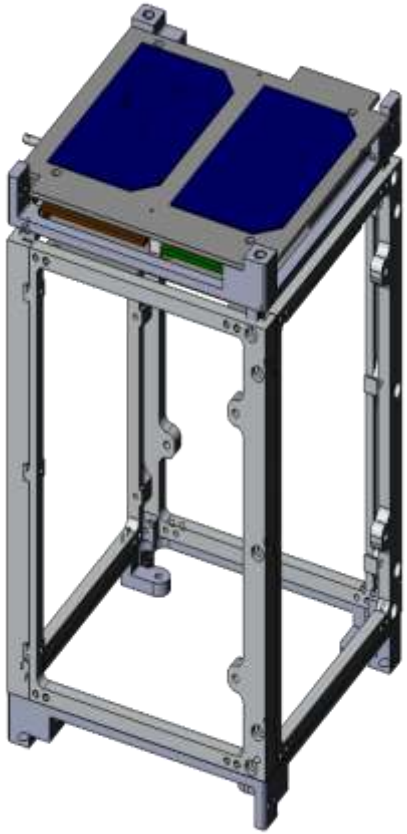
Implications for CubeSat Developers

- **Hardware**
  - Low Power Complete Bus Solution (<400mW)
  - Take advantage of ample spare processing and memory
  - Volume Optimization for 1U translates to dramatically increased payload volume for 2U and 3U systems.
- **Software**
  - Free Development Tools (Linux)
  - Remote Development (Linux + Ethernet!)
  - Take advantage of open source drivers
- **Tight HW and SW integration provides considerable functionality out of the box.**

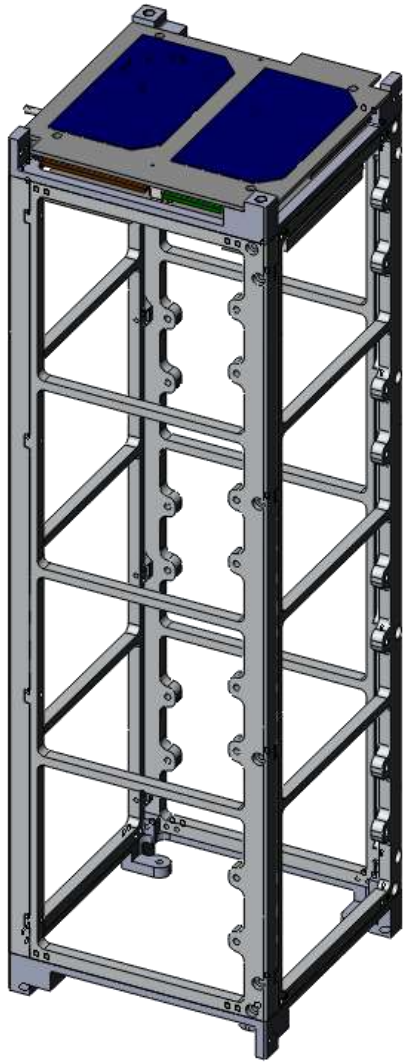
1U Configuration



2U Configuration



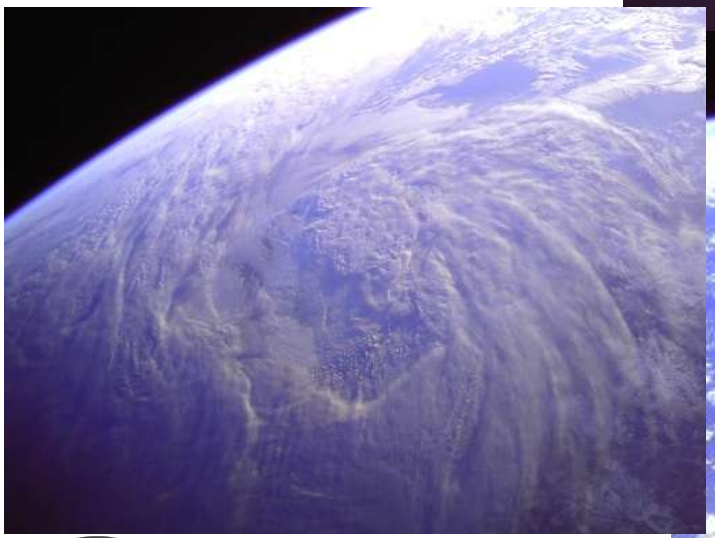
3U Configuration



Missions Enabled by Intrepid: CP8 - IPEX

- **Intelligent Payload Experiment (IPEX) launch on Dec 2013**
- **Autonomous Operations Algorithms**
  - **~10W FPGA for intelligent image processing**
- **All six cameras taken from delivery to testing within a week**
  - **Leverage on standard linux libraries and available intersatellite communication package**

Developers:
Cal Poly, NASA JPL, NASA GSFC



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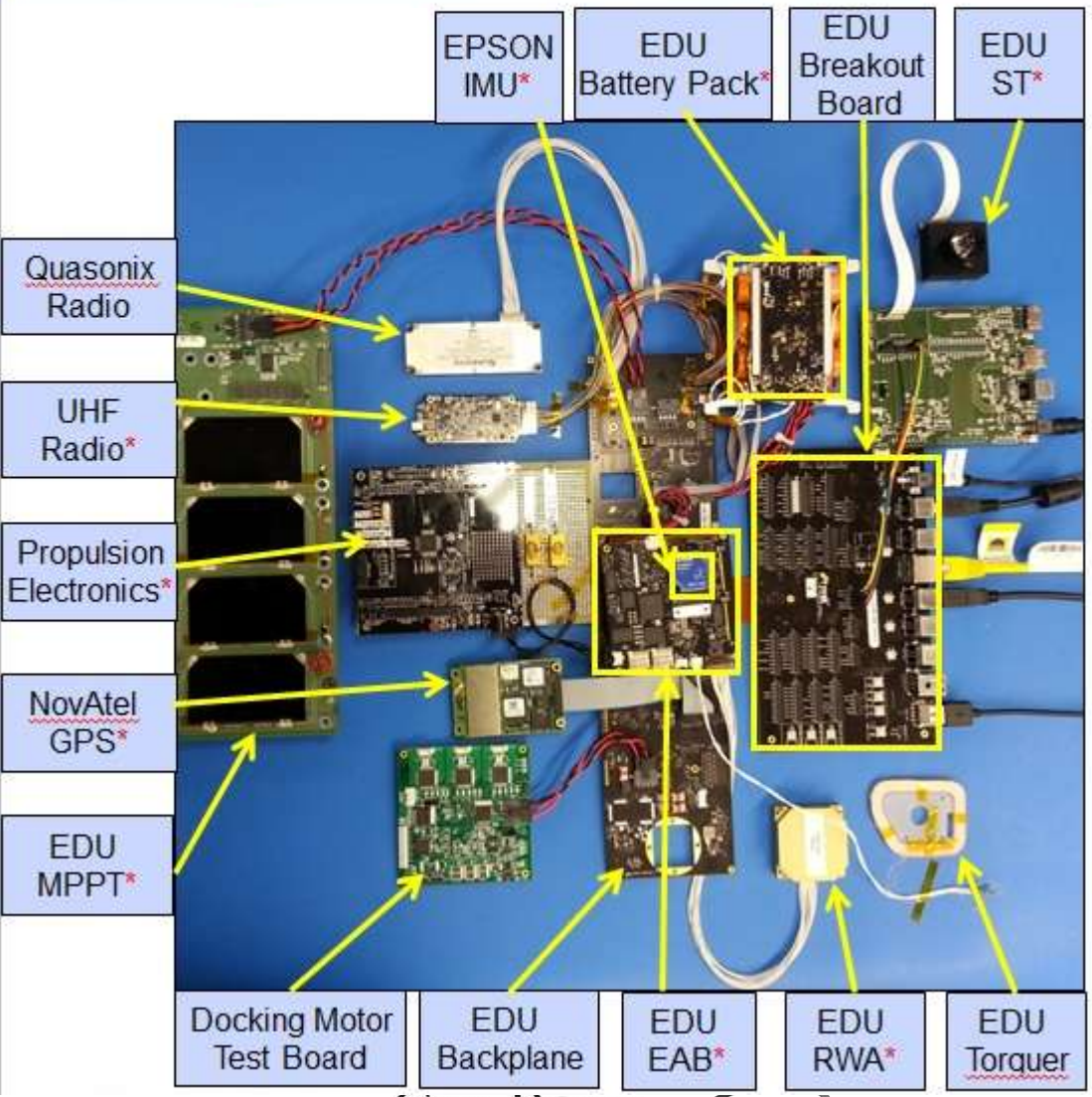
Endeavour Bus

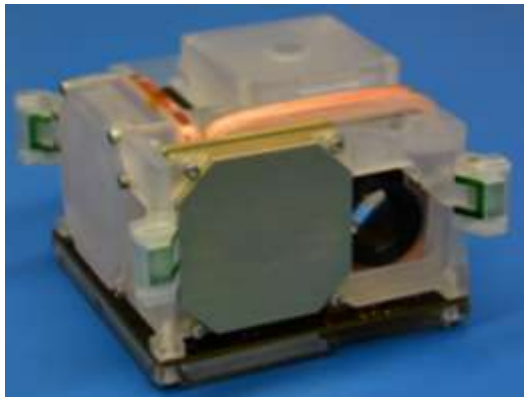
- **Evolution of the Intrepid line to address advanced missions**
  - **Exploits the miniaturization of electronic components and ability to create fully integrated multifunctional products**
- **Scalable upward to support payloads from the 1kg to 100kg class**
  - **Optimized for 3U -> 12U cubesat, but form-factor independent**
- **Ability to customize performance by selecting configuration**
  - **Standard/Core Bus: CD&H, EPS, UHF comm, FSW**
  - **+ Deployable Panels → Extra power availability**
  - **+ Inertial Reference Module → Precision knowledge and pointing**
  - **+ High gain S-Band antenna → Increased communication capability**
  - **+ Propulsion System → Maneuverability**
  - **+ Ground Segment and Operations → Turn Key Solution for any mission**

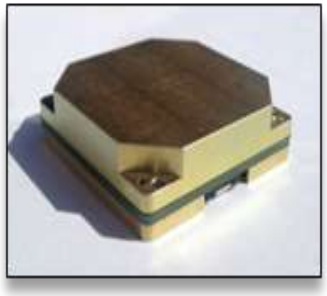
Integrated Flat-Satellite



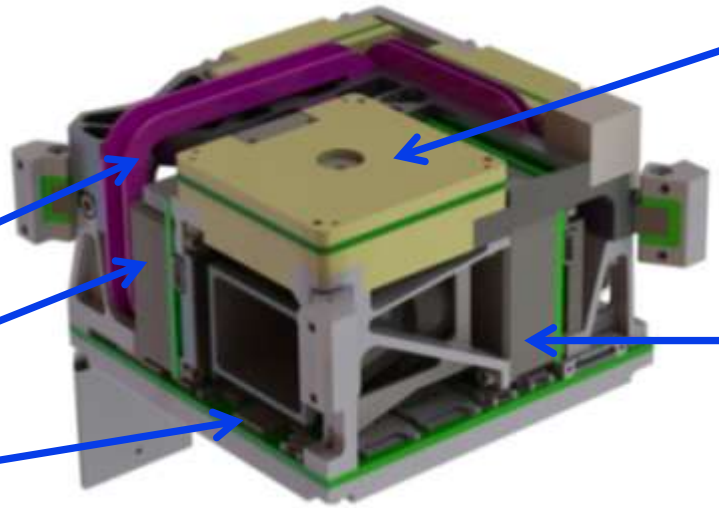
- **EDU Avionics**
  - **FlatSat bring up complete with 75% of subsystems functionally verified**
  - **Complex low-level bus protocols functionally verified with flight data rates and full connectivity**
  - **Performed environmental risk-reduction test for all new components**

Endeavor Vehicle: C&DH and ADCS ½U Solution





3x Tyvak Reaction Wheels
- 1 mN-m torque



3-Axis Magnetorquers

COTS 3-Axis IMU

2x Tyvak Star Tracker

Endeavor Avionics Board (EAB)

- **Endeavor C&DH and ADCS System**
  - **400Mhz Linux Computer w/ Radiation Tolerant Memory**
  - **Less than 0.15 deg attitude control accuracy**
  - **Greater than 3 deg/s slew rate**
  - **Less than 25 arc-sec (3 sigma) continuous attitude knowledge**

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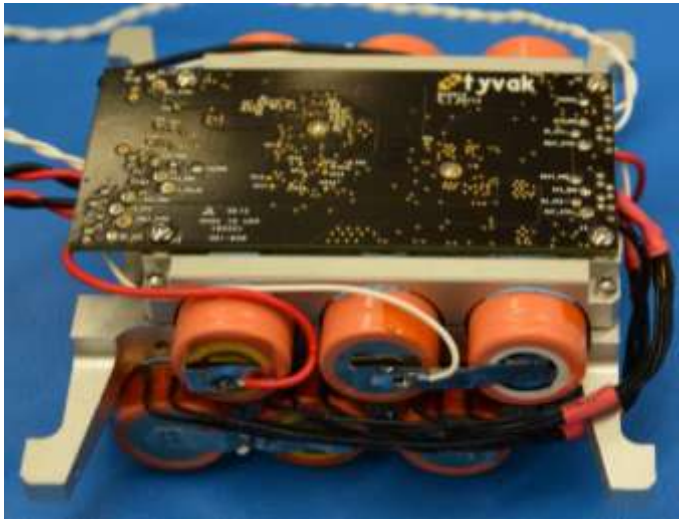
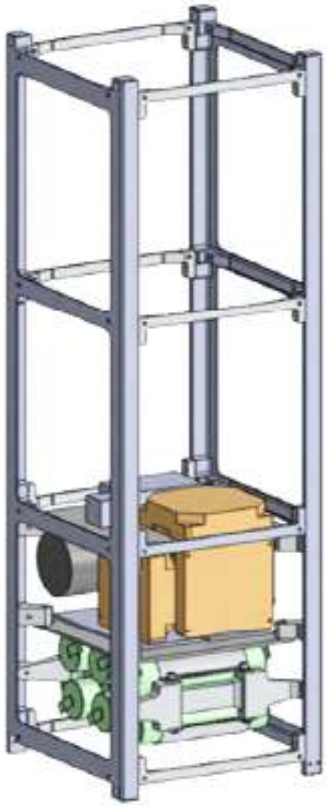
Spacecraft EPS – Battery Module and Solar Panels

- **Battery Module Features**
  - Greater than 80 watt power output capability
  - Greater than 40 watt power input (charge) capability
  - Fail-safe battery heater controller
  - Mission end-of-life solar power disconnect
  - Dual deployment switch power output inhibit
  - Solar power short protection/isolation
- **Solar Panels**
  - Supports 3 to 5 cell strings
  - Maximum Peak Power Tracking on Panels
  - Deployable Configurations Available.



Payloads Accommodation

- **3U Volume & Mass: Approx. 9.3 x 9.3 x 20 cm; Approx. 3 kg**
  - **Expandable to a 6U, 12U or any other form factor to accomodate bigger payloads**
- **Power & Voltage: 80 W (peak), 5-20 W (Orbit Average); Unregulated 9–12.6 V**
- **Data Interfaces: Dedicated I2C bus, SPI bus, RS422/485, and USB 2.0**
- **Discrete Logic: Discrete I/O (On/Off), Hardware Interrupts**
- **Multi-Payload interface board**
  - **Customized per Mission Requirements**
  - **Enables Significant Electrical Harness and EMI Reduction**
  - **Allows Flexible Payload Mounting and Configurations**



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Thank you

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(dhan'yavāda)

Endeavour Cubesat Buses Summary

Payload Accommodations

Parameter	Value
3U Volume & Mass	Approx. 9.3 x 9.3 x 20 cm; 2.8 kg
Power & Voltage	80 W (peak), 5 - 20 W (OAP); Unregulated 9 – 12.6 V
Data Interfaces	Dedicated I2C bus, dedicated SPI bus, RS422/485, and USB 2.0
Discrete Logic	Discrete I/O (On/Off), Hardware Interrupts

Tyvak's *Endeavour* family of CubeSat buses represents the most advanced CubeSat technologies available in an integrated high performance nano-satellite specifically designed to enable scientifically and operationally relevant missions for Earth orbit and Interplanetary destinations

Electrical Power System (EPS)

Key Features
• Standard 56 W-hr Battery Capacity @11.1V
• Maximum Peak Power Tracking
• Supports Wide Variety of Body and Deployable Solar Array Configurations, as well as Tracking Array
• GEO and Interplanetary Version Under Development
• Deployable Solar Arrays Restrained During Launch with Burn-Wire Release Mechanism

Command & Data Handling (C&DH)

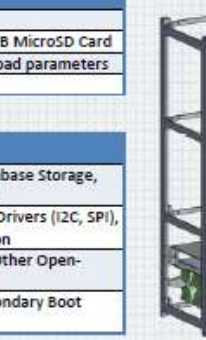
Parameter	Value
Processor	Atmel AT91SAM9G20, 400 MHz
Memory	128 MB RAM, 512 MB NAND Flash, 32 MB PCM, 32 GB MicroSD Card
Electrical GSE	Umbilical unit provides access to all key bus and payload parameters
Radiation Tolerance	Compatible with specified orbit. TID, SEL Tolerant

Vehicle Software

Parameter	Value
Tyvak S/W Libraries	Watchdog Monitoring, Telemetry Collection and Database Storage, Sensor Drivers, Scheduling, Network Communication
Open-Source S/W Components	Embedded Linux OS, Network Socket IPC, Peripheral Drivers (I2C, SPI), File Management, SQLite Database, Data Compression
Development Tools Compatibility	Eclipse, GDB, KDB, Oprofile and Perf, Buildroot, and Other Open-source Development Tools
On-Orbit S/W Upload	Image-based Updates with Integrity Verification, Secondary Boot Memory Slot, and Roll-back Recovery

UHF Communications

Parameter	Value
Data Rate	4.8 to 200 Kbps. Configurable in software
Frequency	400 – 470, 800 – 930 MHz
Modulation	FSK, GMSK, BPSK, OQPSK
Encryption	SSL / TLS
Power	Transmit: Up to 1.5 W. DC in: 3.75 W
Sensitivity	-115 dBm (for 9.6 kbps FSK)



Standard / Core Bus

Part Number: NE-8110

Key Features
• Includes C&DH, Linux Software Libraries, EPS with Multi-Functional Body Panels, UHF Radio
• Scalable Power Systems for Standard LEO and GEO Configurations
• Supports a Wide Variety of Third Party Radios
• Modular and Extensible Structure and Thermal Interfaces
• Payload Volume Highly Configurable to Support Unique Payload Needs
• Bus Resources Utilizes Approximately ½ U Volume and 1 W

Add Star Trackers, IMU, and Control System Processor

Multi-Payload Interface Board

Key Features
• Customized per Mission Requirements
• Enables Significant Electrical Harness and EMI Reduction
• Allows Flexible Payload Mounting and Configurations

Precision Knowledge Bus

Part Number: NE-8120

Parameter	Value
Attitude Knowledge	<25 arc-sec (3 Sigma). At all time, in all axes.
Coarse Knowledge	Sun sensors, magnetometers
Precision Knowledge	Star trackers, IMU
Bus Resources	Approx. ¾ U volume; Approx. 1.5 W

Add Reaction Wheels and Support Frame

Precision Pointing Bus

Part Number: NE-8130

Parameter	Value
Attitude Control	0.15 deg. (Staring performance better)
Slew Rate	> 3 degrees / sec
Precision Control	Reaction wheels with magnetorquer based desaturation
Bus Resources	Approx. <1 U volume; Approx. 2 W

High Performance Reaction Wheel

Parameter	Value
Dimensions	44 x 44 x 13 mm
Mass	80 g
Nominal Power	Approx. 150 mW
Momentum Storage	10 mNms @ 12,000 rpm

Other Subsystems and Options

6U Structure Frame

Utilizes common mounting with 3U Frame

3U HP Structure Frame

Provides additional volume for external body panels and payloads

Attitude Determination and Control Subsystem (ADCS)

Parameter	Value
Control System Processor	Cortex-A8 processor with FPU; 800MHz DSP coprocessor; 1 GHz; 2,000 DMIPS
Control Modes	High accuracy staring, inertial, LVLH, Earth fixed targeting, low power (coarse control), Sun-safe, de-tumble, and others.
Orbit Knowledge	On-board orbit propagators (multiple fidelities), GPS
Emphersis Models	Magnetic field, Sun, Moon, etc.
Std. Components	Sun sensors, magnetometers, star trackers, IMU, optical cube, reaction wheels, magnetorquers

High Gain S-Band Antenna

Parameter	Value
Stowed Volume	Approx. ½ - ¾ U [depending on reflector dia.]
Reflector Dia.	0.5 – 0. 85m
Antenna Gain	Approx. 18 dBi @ 2.4 GHz (0.5m dia.)

Miniature Star Tracker

Parameter	Value
Dimensions	38 x 38 x 38 mm
Mass	35 grams
Nominal Power	100 mW (Imager); <350 mW (Processor) [@ 1Hz update]
Accuracy	< 25 arc-sec (Pitch & Yaw); < 110 arc-sec (Roll) [3 Sigma]
Processor	Cortex-A8 Processor; [1Ghz, 2,000 DMIPS]
Update Rate	<1 sec (Full Lost in Space)

Performance values for production units may be different.

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Endeavour CubeSat Buses

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