Preliminary Design Review:
OC-Flight-1

Space Flight Design Challenge
Advisory Council
June 27, 2013
Entrance Criteria

• Highlight refined system requirements
  – Performance parameters
  – Nomenclature

• Introduce subsystem designs
  – Formats
  – Schematics

• Describe interface control documentation
  – Data flows
  – Connection/Comm types
  – Class/Function definitions
Exit Criteria

• Evolved design capable of meeting mission needs
  – Main s/c hardware tested with successful results
• System reqs satisfied by evolved design with acceptable risk
• Verification methods described
  – Further testing will verify all system reqs
• Hardware interfaces identified
  – Data rates and pins specified
OC-Flight-1 Mission

- **Overview**
  - OC-Flight-1 mission is in Phase B (Preliminary Design)
  - Focus is on system requirement verification and testing, developing subsystem designs/interfacing, and interface control documentation
  - To date we have developed:
    - Implementation plan
    - Concept of Operations
    - Mission phases and interactions/activities of the system within phases
    - System Requirements
  - Preliminary Hazards Analysis w/ Safety Litmus Test
  - System Architecture
  - Acceptance Verification Plan
  - Subsystem Architecture
  - Subsystem Designs
Mission Objectives

• Educate a dedicated team of students in NASA’s approach to engineering space-based vehicles.
• Enhance the public’s understanding and general knowledge about NASA and the engineering of space-based missions through public seminars and workshops.
• Enhance mentoring, leadership, & domain expertise of IV&V workforce
• Establish an IV&V approach for university-built technology demonstration missions where it is perceived that these types of missions may lack formal engineering artifacts.
• Develop a reusable space system (ground system, space-based vehicle, and payload) using off the shelf components that can be utilized on future increments
  • Measure the magnetic field of the Earth
  • Acquire stereoscopic images of Earth’s surface
  • Explore artificial intelligence concepts for fault management
  • Explore spacecraft-spacecraft communications using off the shelf wireless devices

• Minimum Success:
  • Students demonstrate working knowledge of NASA’s engineering approaches in building and operating a flight system for space
  • Employees of the NASA IV&V Program demonstrate enhanced mentoring, leadership, and/or domain expertise in space-based missions
Implementation: Where We Are

Pre-Phase A – Concept Exploration
  – Increment 1 Implementation Plan & Concept of Operations

Phase A – Concept Development & Technology Studies
  – OC-Flight-1 System Requirements, System Architecture, & Acceptance-level Testing
  – Milestone = System Requirements Review (SRR)

Phase B – Preliminary Design
  – OC-Flight-1 Subsystem Requirements, Designs, Interfaces, & Integration Testing
  – Milestone = Preliminary Design Review (PDR)

Phase C – Design & Manufacturing
  – OC-Flight-1 Final Designs and Interfaces
  – Milestones – Critical Design Review (CDR) and Systems Integration Review (SIR)

Phase D – Systems Integration & Test
  – OC-Flight-1 testing results and integrated system
  – Milestone = Safety and Mission Success review (SMSR)

Phase E – Operations

Phase F – Decommissioning
Development Schedule

<table>
<thead>
<tr>
<th>Task Name</th>
<th>Start</th>
<th>Finish</th>
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</thead>
<tbody>
<tr>
<td><strong>Phase A</strong></td>
<td></td>
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</tr>
<tr>
<td>Develop System Requirements</td>
<td>Mon 12/19/11</td>
<td>Tue 12/20/11</td>
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<tr>
<td>Develop System Architecture</td>
<td>Thu 12/21/11</td>
<td>Fri 12/22/11</td>
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<tr>
<td>Develop Acceptance Level Testing</td>
<td>Mon 12/26/11</td>
<td>Tue 12/27/11</td>
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<tr>
<td>System Requirements Review</td>
<td>Thu 12/29/11</td>
<td>Fri 12/30/11</td>
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<tr>
<td>Establish Testing Facilities</td>
<td>Wed 1/2/12</td>
<td>Fri 12/2/12</td>
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<tr>
<td><strong>Phase B Preliminary Design</strong></td>
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<tr>
<td>Develop Subsystem Requirements</td>
<td>Thu 1/3/13</td>
<td>Thu 1/10/13</td>
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<td>Develop Subsystem Designs</td>
<td>Fri 1/4/13</td>
<td>Thu 1/10/13</td>
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<td>Develop Subsystem Interface</td>
<td>Mon 1/7/13</td>
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<td>Software Development</td>
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<td>Link Testing</td>
<td>Thu 1/17/13</td>
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<td>Critical Design Review (CDR)</td>
<td>Thu 1/18/13</td>
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<tr>
<td>System Integration Review (SIR)</td>
<td>Thu 1/25/13</td>
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<td><strong>Phase C Design &amp; Manufacturing</strong></td>
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<tr>
<td>Finalize Designs and Interfaces</td>
<td>Fri 2/1/13</td>
<td>Thu 2/7/13</td>
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<tr>
<td>Fabricate PCBs</td>
<td>Fri 2/8/13</td>
<td>Fri 2/8/13</td>
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<tr>
<td>Wiring and Structures</td>
<td>Thu 2/15/13</td>
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<td>Software Development</td>
<td>Fri 2/16/13</td>
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<td>Link Testing</td>
<td>Thu 2/22/13</td>
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<tr>
<td>System Integration Review (SIR)</td>
<td>Thu 2/30/13</td>
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<td><strong>Phase D System Integration and Test</strong></td>
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<td>Integrate Subsystems</td>
<td>Fri 3/1/13</td>
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<td>Wed 3/13/13</td>
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<td>Ship-Specific &amp; Integration</td>
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<td>Launch</td>
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<tr>
<td>Phase C Operations</td>
<td>Tue 4/2/13</td>
<td>Mon 4/8/13</td>
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</table>
Concept of Operations

**Separation & Acquisition Phase**
- Survive launch
- Solenoid actuator spring-deployed separation
- Antennas deployed
- Spacecraft acquired & tracked by NORAD
- "I’m Alive" beacon acquired by Mission Operations
- Mission Operations projects orbit/downlink passes

**Launch Phase (Interorbital Systems)**
- Pacific Ocean launch
- Early 2014
- Launch characteristics (TBD)
- spacecraft powered OFF

**On Orbit Checkout Phase**
- Battery healthy & charging rates consistent
- Communications (Up/Down) established
- Subsystems are healthy
- Uplink/Downlink & Science schedules established
- Attitude stable for comms, power, & science
- Health & Status acquired by Mission Operations

**Operations Phase (polar orbit, 310 km)**
- Science Acquired (Magnetic Field)
- Science packets acquired by Mission Operations
- Health & Status acquired by Mission Operations
- Systems updated, reconfigured, schedules adjusted
- System failures predicted and avoided

**Decommission Phase**
- Subsystems powered off
- batteries depleated
- s/c disintegrated

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**Development & Operations Team**
(NASA IV&V Program & WVU)
- Mission Planning (schedules, system updates)
- Communications with OC-Flight-1
- Health & Status receipt through website
- Science data, picture data publication
- Orbit & attitude simulated

**Amateur Radio Band (433 – 435 MHz)**
- I’m Alive Beacon (Morse Code)
- Health & Status Telemetry (Morse Code)
- Science Telemetry
- Uplink (comm schedules, Commands, Software patches)

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**North American Aerospace Defense Command (NORAD)**
- Acquire and Track OC-Flight-1
- Publish Orbital Parameters as TLEs

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**End of Life (~3 months)**
OVERVIEW

Increment 1 is the first mission of the Space Flight Design Challenge. The concept is to develop a space-based mission providing hands-on engineering experience in order to maintain and enhance the skills and capabilities of the workforce and area students. The space-based mission is to be low cost utilizing off the shelf components that can be a testbed to rapidly mature innovative technologies.

The space-based vehicle is a spacecraft kit called a TubeSat that utilizes amateur radio frequencies to communicate with ground.

Objective 1: Enhance domain knowledge of employees and students
Objective 2: Study magnetic field of the Earth
Objective 3: Develop reusable system components that are low cost and operate in LEO
Sys_2.0 Provide Science Data Requirements

- **Request for Data**
  - Text: When requested, the system shall provide data in electronic format.
  - Id: Sys_2.0.2.1

- **Duration**
  - Text: The data shall be available to the public for 1 year after mission completion and then archived.
  - Id: Sys_2.0.2.4

- **Public Release**
  - Text: The system shall receive authorization prior to releasing data to public users.
  - Id: Sys_2.0.2.1.1

- **Timely Response**
  - Text: The system shall respond to requests within 1 month.
  - Id: Sys_2.0.2.1.2

- **Web Interface**
  - Text: The public shall make data requests through a web interface.
  - Id: Sys_2.0.2.2

- **508 Compliant**
  - Text: The interface shall be compliant with section 508 Technical Standards “Web-based Intranet and Internet Information and Applications (1194.22)”.
  - Id: Sys_2.0.2.1.2

- **Authentication**
  - Text: Only authenticated users shall access the system.
  - Id: Sys_2.0.2.2.1

- **Corrupted**
  - Text: Integrity of the data shall be maintained when available to the public.
  - Id: Sys_2.0.2.2.3
Sys_4.0 Acquiring Data Requirements

- **LV Constraints**
  - The system shall comply with TubeSat specifications
  - Text: The system shall sense the magnetic field while operating at 310 km in altitude
  - Id= Sys_4.0

- **Safety**
  - The system shall not cause any harm to engineers that integrate components together or into the launch vehicle
  - Text: The system shall not accidentally power on while being integrated into launch vehicle or any time prior to getting into orbit
  - Id= 4.1.1

- **Accidental Power**
  - Text: The system shall not accidentally power on while being integrated into launch vehicle or any time prior to getting into orbit
  - Id= 4.1.1

- **Space to Ground Comm**
  - The system shall utilize the amateur radio bands for communications between ground and space
  - Id= 4.2

- **Science Measurements**
  - The system shall measure the magnetic field with a resolution of 1000 meters relative to Earth
  - Text: The system shall sense the magnetic field while operating at 310 km in altitude
  - Id= 4.2

- **Sensor Orientation**
  - The system shall correlate the orientation of the sensor for each magnetic field measurement
  - Text: The system shall correlate the orientation of the sensor for each magnetic field measurement
  - Id= 4.2.2

- **Sensor Location**
  - The system shall correlate the location of the sensor relative to the Earth for each magnetic field measurement
  - Text: The system shall correlate the location of the sensor relative to the Earth for each magnetic field measurement
  - Id= 4.2.3

- **Engineering Measurements**
  - The system shall collect engineering data on a predetermined schedule (s/c location, s/c power levels/rates, subsystem status) so that s/c performance can be characterized
  - Text: The system shall collect engineering data on a predetermined schedule
  - Id= 4.3

- **Data missed**
  - The system shall determine when measurements are missed and determine additional measures that fill the gaps of missed data (e.g., based on some science schedule)
  - Text: The system shall determine when measurements are missed
  - Id= 4.2.4

- **Self Healing**
  - The system shall be able to identify when subsystems are suffering from power limitations and correct behaviors to sustain data acquisition
  - Text: The system shall be able to identify when subsystems are suffering from power limitations and correct behaviors to sustain data acquisition
  - Id= 4.2.5
**Sys_5.0 Environments Requirements**

- **Radiation**
  - Text: Total Ionizing Dose (TID) and Single Event Effects (SEE) for 310km in altitude and 90 degrees inclination shall be determined and designed for.
  - Id: 5.1

- **Thermal**
  - Text: Space systems shall operate in thermal extremes between 270K and 350K.
  - Id: 5.2

- **Near Vacuum**
  - Text: Space system shall operate in pressures around $10^{-6}$ Pa (Pa = pascal = 1 Newton per square meter).
  - Id: 5.3

- **Orbit Decay**
  - Text: The system shall know when the orbit can no longer be sustained.
  - Id: 5.5

- **Ground Weather**
  - Text: Any ground systems shall operate in extreme weather conditions on Earth such as snow storms, lightning, heavy rain.
  - Id: 5.4
Subsystem Refinement

• **Sys_1.0: Knowledge management**
  – Development team
    • Questionnaires to capture major aspects of enhanced skills and knowledge gained
    • Lessons learned compiled for future reference
    • Explanation/observations & supervision proven adequate for correcting negative learning and ensuring safety
    • Textbooks, online training material, and lab equipment made available for optimal blend of learning resources
  – IV&V Workforce
    • Surveys for post workshop/tech discussion sessions to determine potential knowledge/skill enhancement of participants
    • Participation offered as training opportunity
  – General Public
    • Pre/Post quizzes for various levels of STEM outreach
Subsystem Refinement

- **Sys_2.0: Provide Science Data**
  - Website allowing HAM operator participation and data request functionality
    - User authentication required for data access
    - Data requests followed by usability survey
    - Ensure 508 compliance during website build
  - Assign webmaster role to monitor requests for HAM participation or data requests
    - Export uploaded datasets to be correlated w/o corruption
    - Ensure integrity of reduced data prior to release and data requests met w/in 1 month
    - Archive data 1 yr after mission completion
Subsystem Refinement

• Sys_3.0: Standards & Laws
  – Strict downlink schedule during normal operation using AX-25 protocol
    • Transceiver/ ground station selected for 70cm band usage
    • Software enforces breaks in Tx after 10 mins
  – Multiple ground stations developed and tested for bidirectional communications
    • 2 of 3 ground station demonstrate successful operation
  – Physical size and build of TubeSat design ensures atmospheric disintegration during re-entry
    • Safe burn-up claimed by IOS
Subsystem Refinement

• **Sys_4.0: Acquire Science Data**
  - Desired altitude for magnetic field readings provided by IOS launch
    - Data sampled at 10 Hz to achieve desired resolution
    - Payload incorporates IMU for attitude correlation
    - Solar cell voltages recorded to determine charge profile
  - Ack receipts incorporated in comm protocol
    - Power limitations from excessive Tx averted through software checks on battery thresholds
  - TLEs provided by NORAD
    - STK used to convert to ECI position and velocity
    - Data processed/reduced on ground station cpu
  - TubeSat design incorporates external power switch and RBF pin
    - Through-hole PCBs provide added solder support to absorb vibrations
  - Adhere to instruction guide for tolerance specifications during assembly
    - All sharp edges fileted with file/sandpaper (e.g. antennas, test rigs, enclosure supports, etc.)
Subsystem Refinement

• Sys_5.0: Environments
  – Design susceptible to solar radiation
    • Accepted risk for minimal cost benefit
    • Launch profile provides sun/shading for 3 month operation
  – All electrical components rated for 270K>350K except Li-Ion battery
    • Charge: 0 ~ 45C
    • Discharge: -20C ~ 60 C
  – Extreme conditions may pose issues w mobile ground station operations
  – Spacecraft burn-up realized by NORAD TLEs and STK orbit projection
    • Verified through radio testing during next expected flyby
Acceptance Level Verification

• **ALV#1: Knowledge Survey Analysis**
  – Analyze responses to development team questionnaires and workforce surveys
  – Tally results of pre/post workshop quizzes

• **ALV #2: Awareness Assessment**
  – Spot checks for digital signage
  – Gauge interest level in workshops and school visits

• **ALV #3: Approaches Assessment**
  – Ensure textbooks/documentation are made readily available for architecture devp, programming techniques, and hardware components
Acceptance Level Verification

- **ALV #4: Workload Evaluation**
  - Evaluate individual workload to ensure manageable levels and shift loads if necessary

- **ALV #5: Safety Evaluation**
  - Evaluation of proper techniques /procedures and potential hazards prior to lab usage

- **ALV #6: Delivery Receipt Log**
  - Delivery receipt sent and logged by email system when requested data is received by users

- **ALV #7: Website Functionality Test**
  - Extensive testing of website to ensure all required capabilities are functional
Acceptance Level Verification

• **ALV #8: Website Compliance Test**
  – Tests/checks to ensure website complies with 508 Technical Standards

• **ALV #9: Scientific Value Survey Analysis**
  – Survey given to assess the scientific value gained by users receiving the data

• **ALV #10: Day-in-the-Life Test (DITL)**
  – Full-mission bench test of system ops, telemetry comm, and data collection/correlation
  – Simulated TLE’s generated on ground station
  – Evaluate tumbling comm effectiveness
Acceptance Level Verification

• **ALV #11: Continuous Transmission Test**
  – Bench test to ensure comm break after 10 mins of continuous data transmission

• **ALV #12: Ground Station Back-up Test**
  – Outdoor comm tests to ensure both permanent and back-up ground stations are functional

• **ALV #13: Analytical Analysis of Disintegration Energy**
  – Verify with GSFC data for atmospheric burn-up
Acceptance Level Verification

• ALV #14: **Physical Measurements**
  – Each dimension of the OC-Flight-1 s/c will be physically measured to ensure design specifications are met

• ALV #15: **Visual Inspection**
  – All metal and PCB components will be visually inspected for sharp edges/burrs and filed/sanded when discovered prior to shipment of s/c

• ALV #16: **Vibrations Test**
  – Sine sweep and 3-axis vibrations testing will be performed on assembled s/c from 20-1280 Hz and 40-2000 Hz for 30sec and stepping by factor of 2
Acceptance Level Verification

• **ALV #17: Power Switch Reliability Test**
  – Statistically sufficient number of tests to ensure confidence in reliability of power switch
  – Cold testing of power switch held at sub-zero temperature for 45 mins (worst case)

• **ALV #18: Transceiver Test**
  – Bench testing of transceiver and ground station comm using AX-25 protocol

• **ALV #19: Payload Test**
  – Bench testing of payload devices taking measurements and writing data to micro-SD memory
Acceptance Level Verification

• ALV #20: Low Charge Test
  – Bench testing to ensure software turns off payload subsystem when voltage reaches cut-off limit

• ALV #21: Thermal Bake-out Test
  – S/c will be tested in a near vacuum environment with temp increasing from ambient to 70° C in timed intervals
  – Max temp held constant for 1 hour
  – Temp decreased back to ambient in timed intervals
Acceptance Level Verification

• ALV #22: Sounding Rocket Testing
  – Fully assembled and equipped s/c ejected from rocket at ~160 km
  – Payload operation testing in upper atmosphere
  – Long distance transceiver/ground station testing
  – Tumble and charge profiles recorded to gain a better understanding of deployment dynamics and power availability
Digital I/O Interface

• All digital or analog pins can be configured as digital inputs
  – pinMode(pin, mode)
    • Pin: Int (2-13), “AD0”- “AD7”
    • Mode: “INPUT” (default), “OUTPUT”, or “INPUT_PULLUP”

• Read value from specified pin
  – digitalWrite(pin, value)
    • Returns: “HIGH” (>3V) or “LOW” (<2V)

• Set specified pin to “High” or “Low”
  – digitalWrite(pin, value)
    • Value: “HIGH” (5V) or “LOW” (0V)
Serial (UART) Interface

- Used to communicate (upload, data monitor) w/ computer or other device
- Serial port setup/configuration
  - Serial.begin(speed, config)
    - Speed: Data rate in bps (1200, 2400, 9600, etc)
    - Config (optional): Data bits (5-8), parity ("N", "E", or "O"), stop bit (1-2)
      - Ex. SERIAL_8N1 (default)
- Send data to serial port as human readable txt
  - Serial.print(val, format)
    - Val: Any data type (characters/strings sent as is)
    - Format (optional):
      - Integer val: Set number base ("BIN", "OCT", "DEC", or "HEX")
      - Floating point val: Set number of decimal places (default → 2)
- Read incoming serial data
  - Serial.read()
    - Returns 1st byte of serial data (-1 if no data present)
Software Serial Interface

• Provides “soft” serial support on any digital I/O pin
• Create new SoftwareSerial object
  – SoftwareSerial portName(rxPin, txPin)
    • rxPin/txPin: int (2-13), “AD0”-”AD7”
• Set data rate for serial communication on “soft” port
  – portName.begin(speed)
    • Speed: Data rate in bps (1200, 2400, 9600, etc)
• Send data to Tx pin of “soft” port
  – portName.print(val, format)
• Read character on the Rx pin of “soft” port
  – portName.read()
Serial Peripheral Interface

- Permits communication between master μC and one/more peripheral devices
- Setup using any 4+ digital I/O pins
- All devices share 3 common pins
  - Master-In-Slave-out (MISO): Slave line to μC
  - Master-Out-Slave-In (MOSI): Master line to peripherals
  - Serial Clock (SCK): Clock pulses to sync data
- One pin specific to every peripheral device
  - Slave Select (SS): Used to enable/disable specific SPI devices
SPI Initialization

- Set order of bits shifted out of the SPI bus
  - SPI.setBitOrder(order)
    - Order: “LSBFIRST” or “MSBFIRST”

- Set SPI clock divider relative to system clock
  - SPI.setClockDivider(divider)
    - Divider: 2, 4, 8, 16, 32, 64, 128
      - Ex. SPI_Clock_Div4 (Default)

- Set SPI data mode (clock polarity/phase)
  - SPI.setDataMode(mode)
    - Mode: 0 – 3
      - Ex. SPI_MODE3
Hardware Interface

- Radiometrix TR2M RF Transceiver
  - SPI Clock: 50-550 kHz
  - Mode: 0
  - Audio Lines 1.2 kbps AX-25 Protocol
  - Serial 9600 bps

- Arduino Mini 05 (Master µC)
  - Software Serial 9600 bps
  - SPI Bus

- Max1112 ADC (Solar Panel Voltage)
  - Solar Panel 1
  - Solar Panel 2
  - Solar Panel 8

- 8 x Diode Inc. ZXCT1086 (Voltage Reader)

- OpenLog SD Card Port (Memory Storage)

- Analog Devices ADS16405 IMU (Satellite Attitude)
  - SPI Clock: 125kHz - 2MHz
  - Mode: 3

- Analog Input 10 Bit A/D
  - Mag X
  - Mag Y
  - Mag Z

- Magnetometer (Magnetic Field Readings)

- MX614 Bell 202 Modem
  - Serial 9600 bps

- Arduino Mini 05 (Slave µC)
  - Software Serial 9600 bps
  - SPI Bus

SPI Bus
Master \( \mu \)Controller

- **Serial Interface**
  - **Modem**
    - Pins: Tx, Rx
    - Data Rate: 9600 bps
  - **Transceiver**
    - Audio Lines (Mic, Spk)
    - AX-25 protocol (433.05 – 435.025 MHz) @ 1.2 kbps

- **Software Serial Interface**
  - **Slave Microcontroller**
    - Pins: 4 (pinTx), 5 (pinRx)
    - Data Rate: 9600 bps
  - **OpenLog Data Logger**
    - Pins: 6 (pinTx), 7 (pinRx)
    - 16 GB Class 10 MicroSD card
    - Data Rate: 9600 bps
    - Mode Delay: \( \sim \) 3 seconds
Master μController

- **Serial Peripheral Interface (SPI)**
  - Clock Divider: 64
  - Bit Order: MSB
  - Pins: 11 (MOSI), 12 (MISO), 13 (SCK)
  - Solar Panel Voltage ADC
    - Clock: 50 – 550 kHz
    - Mode: 0
    - SS Pin: 10

- **Analog Input Interface**
  - Battery Voltage
    - Pin AD3

- **Digital I/O Interface**
  - Payload PWR Switch
    - Pin: 3
  - Photo Resistor
    - Pin: AD7
Slave Microcontroller

- Analog Input Interface (10 Bit A/D)
  - Magnetometer
    - X axis: AD0
    - Y axis: AD1
    - Z axis: AD2
    - Vref: AD3
- Serial Peripheral Interface (SPI)
  - Clock Divider: 8
  - Bit Order: MSB
  - Pins: 11 (MOSI), 12 (MISO), 13 (SCK)
  - Inertial Measurement Unit (IMU)
    - Clock: 125 kHz – 2MHz
    - Mode: 3
    - SS Pin: 10
- Software Serial Interface
  - Master Microcontroller
    - Data Rate: 9600 bps
    - Pins: 4 (pinTx), 5 (pinRx)
- Digital I/O Interface
  - MAG Power On/off
    - Pin: 2
  - IMU Power On/off
    - Pin: 3
Software Architecture: OOC

Diagram:
- Turn MAG ON
- Test MAG
- MAG ON
- Determine status of MAG
- Write MAG status to buffer
- Write payload OFF status to buffer
- Write time to buffer
- BAT charged for Rx
- Turn Rx ON
- Listen for 1 sec
- Load default downlink schedule
- Save uplink data
- Parse uplink data
- BAT charged for Tx
- Turn Tx ON
- Parse uplink data
- Turn Tx OFF
- Send Ack
Payload Operations

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<th>MAG</th>
<th>IMU</th>
<th>BAT</th>
<th>CELLS</th>
<th>MEM</th>
<th>µC</th>
<th>Sw</th>
<th>Tx</th>
<th>Rx</th>
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</thead>
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**Sys 4.3**
- Read current
- Read voltage
- Write time to buffer
- Write CELL current to buffer
- Write CELL voltage to buffer
- Write BAT voltage to buffer
- BAT charged for payload operation

**Sys 4.2.2**
- Turn IMU ON
- Read IMU

**Sys 4.2**
- Turn MAG ON
- Read MAG

Write IMU data to buffer
Write MAG data to buffer
Software Architecture: PO

Sys 4.2.3
  - Turn IMU OFF
  - Turn MAG OFF

MEM full
  - Overwrite oldest data
  - Store buffer

Sys 3.1
  - Load previous uplink schedule
  - Parse uplink data
  - Save uplink data

Sys 4.4
  - Turn Tx ON
  - Turn Tx OFF

Sys 3.1.2
  - Uplink received
  - Send Ack

Sys 4.2.4
Data Flow Budget

• Data Sampling
  – 1 Sample: ~150 bytes (comma delimited)
  – Sample Rate: 10 Hz (1 sample /0.1 s)
  – 24 hrs (86,400s): 129.6 MB
  – 90 days: 11.66 GB

• Data Transmission
  – 1200 bps: 1 sample/s
  – 1 pass: ~5 mins (300s)
  – 2 pass/day: 600 samples (90kB)

• Data Budget (Single Ground Station)
  – 24 hrs: 128.61 MB
  – 90 days: 11.58 GB
  – 124.4 days: 16 GB
Antenna Design
Transceiver Design

PS1: Open = transceiver TR2M ON
PS1: pin 2 -> ground = Transceiver TR2M OFF

<table>
<thead>
<tr>
<th>Connector P4</th>
<th>Pin 1</th>
<th>Pin 2</th>
<th>Mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>open</td>
<td>open</td>
<td>RX mode</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>open</td>
<td>TX 100mW</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>TX 500mW</td>
<td></td>
</tr>
</tbody>
</table>
Microcontroller Design
OC-Flight-1 Risk Summary

• 7 risks associated with system requirements have been identified
  – 1 High
  – 2 Moderate
  – 4 Low

• Risks have been reviewed against a set of recommended controls/mitigations to minimize inherent risk when feasible

• Currently evaluating major concerns regarding launch provider

• Further risk analysis in-progress
  – Utilizing internal Risk Management Process
Exit Criteria

• Evolved design capable of meeting mission needs
  – Main s/c hardware tested with successful results

• System reqs satisfied by evolved design with acceptable risk

• Verification methods described
  – Further testing will verify all system reqs

• Hardware interfaces identified
  – Data rates and pin specified
Questions?
### Risk Title

**Sys_1.0: Knowledge Management- Qualitative Gain**

### Risk Statement

Given that results from questionnaires and surveys tend to be more qualitative than quantitative, there is a risk that the knowledge gained by participants will be hard to gauge quantitatively.

### Context Statement

The OC-Flight-1 Mission is the first increment of a series of missions in the NASA IV&V Space Flight Design Challenge to achieve a set of over-arching goals and objectives.

### Closure Criteria

A quantitative assessment of knowledge gained is not considered as a success criterion for knowledge management of first increment.

### Consequence

<table>
<thead>
<tr>
<th>Consequence</th>
<th>Rationale</th>
<th>Likelihood</th>
<th>Rationale</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>While a qualitative assessment of knowledge gained does not provide a numerical value to index individual performance, it does provide tangible evidence that positive learning was realized ensuring the requirement.</td>
<td>4</td>
<td>The implementation plan for knowledge management currently focuses on the use of questionnaires/surveys to capture the knowledge gained. Graded assessments will not be performed</td>
</tr>
</tbody>
</table>
### Risk Title

**Sys_2.0: Provide Science Data – Stand-Alone Website**

### Risk Statement

Given that the workload of the students supporting project development decreases drastically when classes are in session, there is a possibility that a stand-alone website may not be put in place.

### Context Statement

The purpose of the website is to satisfy the requirements for receiving and providing science data to the public while ensuring authorized use and integrity of data.

### Closure Criteria

The system requirements can still be met using the standard emailing system and adding information to existing web pages.

<table>
<thead>
<tr>
<th>Consequence</th>
<th>Rationale</th>
<th>Likelihood</th>
<th>Rationale</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>While having a stand-alone website to handle data requests and to ensure documentation is completed correctly before providing data would lessen the workload of personnel, these tasks could still be performed through a structured data request process managed by assigned team members.</td>
<td>3</td>
<td>The website architecture and layout has not yet been designed, however links on existing Space Grant website could be put in place whenever a design has been established and students supporting the project can implement the webpage.</td>
</tr>
</tbody>
</table>

**Date**

<table>
<thead>
<tr>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sunrise</td>
</tr>
<tr>
<td>Sunset</td>
</tr>
<tr>
<td>Impact Horizon</td>
</tr>
</tbody>
</table>
Risk Title: Sys_2.0: Provide Science Data – Usefulness

Risk Statement: Given that the earth’s magnetic field data is widely available at higher resolutions, there is a possibility that the scientists requesting the data may not find the data provided useful.

Context Statement: The OC-Flight-1 Mission is the first increment of a series of missions in the NASA IV&V Space Flight Design Challenge to achieve a set of over-arching goals and objectives. Future increments will focus on improving the datasets and pushing the envelope of game-changing technologies in software and systems engineering.

Closure Criteria: Further information will be gathered pertaining to why the data was not found useful (type of data, resolution, missing datasets, data corruption, etc) in effort to improve the current design for future increments.

Consequence Rationale: While providing useful data to Scientist and Engineers is an over-arching goal of the NASA IV&V SFDC, it is not a main objective for this increment. However, the capturing the level of usefulness of the data is considered an objective for this increment.

Likelihood Rationale: The magnetic field of the earth is well-documented and readily available, therefore it is likely that some Scientists and Engineers will not find the provided data to be particularly useful.

Date:
- Sunrise: 9/1/2013
- Sunset: 12/1/2014
- Impact Horizon: Long
## OC-Flight-1 Risk 4 – External

<table>
<thead>
<tr>
<th>Risk Title</th>
<th>Sys_3.0: Standards &amp; Laws – Intermittent Transmission</th>
</tr>
</thead>
<tbody>
<tr>
<td>Risk Statement</td>
<td>Given that the spacecraft is expected to be deployed in a tumbling state, there is a possibility that the tumbling of the spacecraft could cause discontinuous radio communication</td>
</tr>
<tr>
<td>Context Statement</td>
<td>The antenna type used on the spacecraft is a direction half-wave dipole antenna which transmits and receives signals most efficiently when pointed toward the source or ground station</td>
</tr>
<tr>
<td>Closure Criteria</td>
<td>There is no active attitude control system onboard the spacecraft to direct the antenna toward the desired ground station therefore communication will occur when permissible.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Consequence</th>
<th>Rationale</th>
<th>Likelihood</th>
<th>Rationale</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>While continuous transmission allows the maximum amount of data transfer and minimizes the possibility of missed uplinks, intermittent communication still allows for opportunities to uplink and downlink desired data.</td>
<td>3</td>
<td>The severity of the tumbling state in which the spacecraft is deployed on-orbit and the impact on the effectiveness of tumbling on data transmission is uncertain. However, it is known that the tumbling state will be dampened by the gravity gradient effect due to the center of mass being located close to the antenna.</td>
</tr>
</tbody>
</table>

**Date**
- Sunrise: 8/1/2013
- Sunset: 12/1/2013
- Impact Horizon: Mid
### Risk Title
Sys_4.0: Acquiring Data – Launch Provider

### Risk Statement
Given that the launch provider is still in the testing/development phase, there is a possibility that the tentative launch date will slip indefinitely.

### Context Statement
Interorbital Systems (IOS) is a rocket and spacecraft manufacturing company currently developing an innovative modular rocket system designed to send a multitude of TubeSats into LEO. IOS is currently the only launch provider that offers the TubeSat PS kit. Due to unforeseen complications with testing and development, IOS has already slipped from the tentative launch date from Summer 2012 to Summer 2013.

### Closure Criteria
OC-Flight-1 development continues with a transition from the TubeSat design to a CubeSat design, allowing for alternative launch opportunities outside of IOS.

### Consequence
<table>
<thead>
<tr>
<th>Occurrence</th>
<th>Rationale</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>While the TubeSat kit is less expensive than the CubeSat kit and a launch with IOS is already funded, alternative launch opportunities are available if the design transitions to CubeSat. This would allow the current project schedule to be maintained with funding for additional materials and launch provider.</td>
</tr>
</tbody>
</table>

### Likelihood
<table>
<thead>
<tr>
<th>Likelihood</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
</tr>
</tbody>
</table>

### Consequence Rationale
<table>
<thead>
<tr>
<th>Rationale</th>
</tr>
</thead>
<tbody>
<tr>
<td>The launch date has already slipped by 1 full year since project development began. Testing and development of IOS has been reported, however there is no evidence to support or even suggest that the current (tentative) launch date will not slip significantly (by quarter).</td>
</tr>
</tbody>
</table>
## OC-Flight-1 Risk 6 – External

<table>
<thead>
<tr>
<th>Risk Title</th>
<th>Sys_4.0: Acquiring Data – NORAD Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Risk Statement</td>
<td>Given that the position of the spacecraft will be tracked via NORAD and that several TubeSats will be deployed on-orbit, there is a possibility that some amount of error will be introduced in the TLEs of OC-Flight-1 provided by NORAD.</td>
</tr>
<tr>
<td>Context Statement</td>
<td>Interorbital Systems (IOS) is a rocket and spacecraft manufacturing company currently developing an innovative modular rocket system designed to send a multitude of TubeSats into LEO. The spacing in the deployment of each TubeSat is currently unknown.</td>
</tr>
<tr>
<td>Closure Criteria</td>
<td>Uplink attempts will be initiated in advance in order to account for errors in position tracking.</td>
</tr>
</tbody>
</table>

### Consequence Rationale

<table>
<thead>
<tr>
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<th>Rationale</th>
<th>Likelihood</th>
<th>Rationale</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>While more accurate position fixes on the spacecraft would introduce more confidence in uplink timing, the amount of error should be within some seconds which should be easily manageable.</td>
<td>2</td>
<td>The accuracy and resolution of NORAD tracking is currently unknown to the development team, however a high level of confidence is held in regards to the accuracy of the TLE’s provided by NORAD.</td>
</tr>
</tbody>
</table>

### Date

- **Sunrise**: 8/1/2013
- **Sunset**: 12/1/2013
- **Impact Horizon**: Mid
### Risk Title
Sys_5.0: Environments - Radiation

### Risk Statement
Given that the spacecraft will utilize COTS and non-radiation hardened PCBs, there is a possibility that the lifespan of the spacecraft may be reduced significantly by subjection to high levels of radiation on-orbit.

### Context Statement
The NASA IV&V Space Flight Design Challenge (SFCD) focuses on utilizing COTS and design kits to keep total costs to a minimum while achieving the overarching goals and objectives. Using custom made (radiation hardened) components and performing acceptance level testing on radiation would drive the project cost up significantly thereby violating the spirit of the challenge/initiative.

### Closure Criteria
The risk of high radiation levels is realized. Custom made components and radiation hardened materials will not be used on OC-Flight-1 in effort to maintain the spirit of the NASA IV&V SFDC.

<table>
<thead>
<tr>
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<th>Rationale</th>
<th>Likelihood</th>
<th>Rationale</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>While a shortened lifespan of the spacecraft would limit the total amount of data collected, any data collected and correlated on the ground can be considered as mission success.</td>
<td>4</td>
<td>The spacecraft will not be designed to withstand the radiation levels inherent in LEO for the entire duration of the orbital lifespan, therefore the spacecraft is not expected to be functional during the decommissioning phase. However, the exact lifespan of the spacecraft is currently unknown.</td>
</tr>
</tbody>
</table>