A Highly Scalable, Low Latency, and Deterministic Flight Control System for UAS Estimation and Flight Controls Research

Brian R Taylor

Research Specialist, University of Minnesota
www.uav.aem.umn.edu

Co-Founder and CEO, Bolder Flight Systems
bolderflight.com

University of Minnesota UAS Research Labs

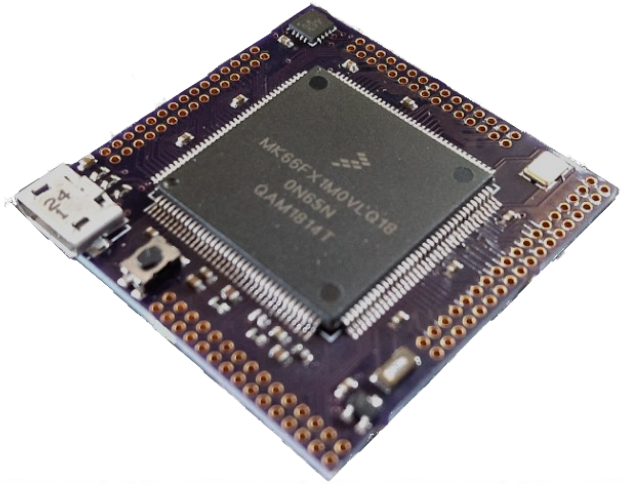
- Focus on flight data to validate research
- Navigation, guidance, and flight control research and education
  - Safety and efficiency
- Flight research and test techniques
  - Test design, uncertainty estimation, system id and parameter estimation
- Applications of UAS
  - Agriculture, invasive species, and surveys

Motivation

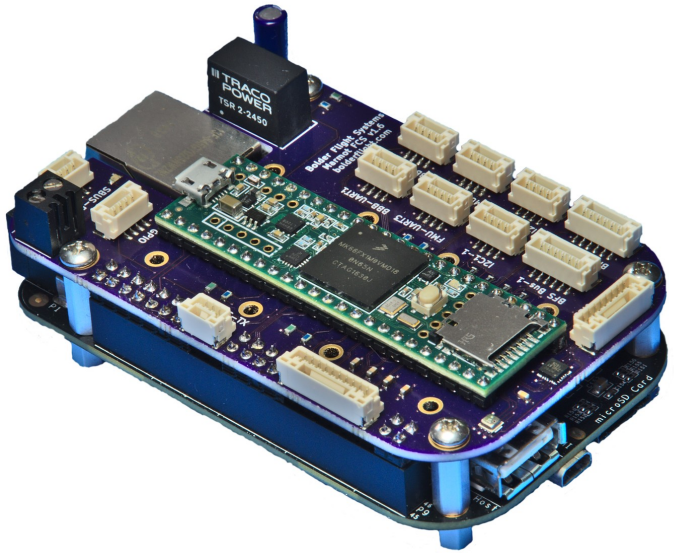
- Scalability
  - Widely varying system requirements
  - UAS size, type, sensors, actuators
- Low latency and determinism
  - Flexible aircraft
- Rapid flight validation
  - Limited resources, fast pace of testing
- License structure
  - Open source for publication
  - Ability to work with businesses and research institutions

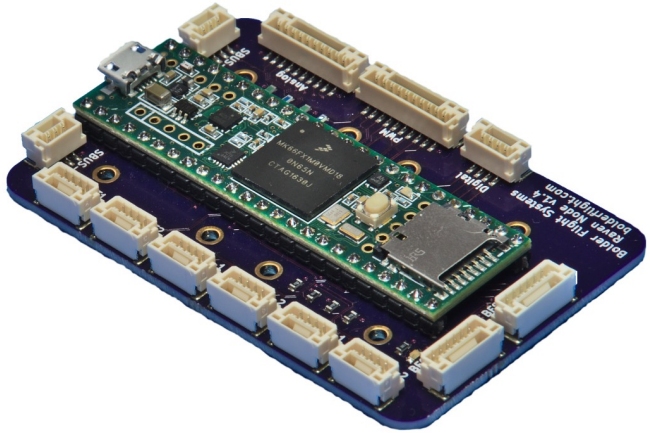
Bolder Flight Systems

- UAS Labs spinoff
- Platform to rapidly research, develop, and commercialize aeronautics technologies
- Develop, manufacture, and commercialize:
  - Hobbyist and educational breakout boards
  - Flight control systems
  - Research aircraft
  - Proprietary derivatives
- Engineering, flight test, and analysis services
- Designed and manufactured in Oregon



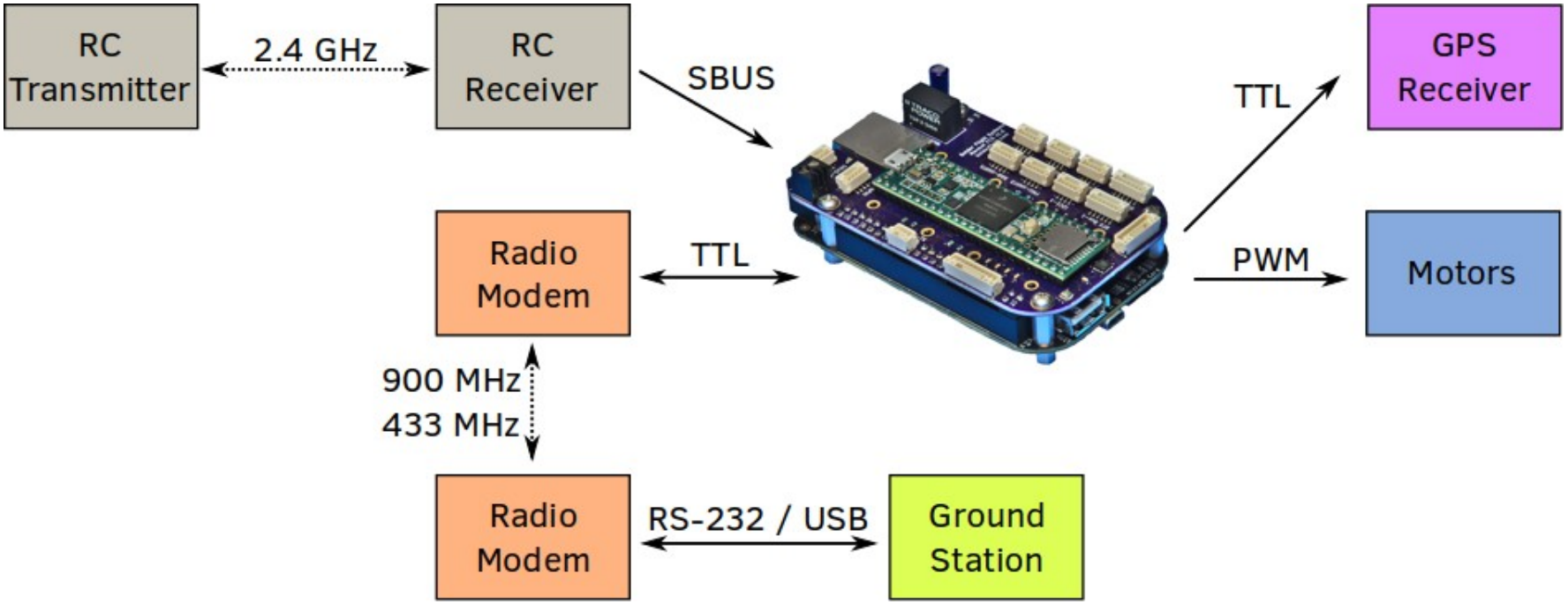
System Overview





- Flight management unit
  - Systems, sensor, and actuator management
  - Hard real time
  - Integrated voltage regulation and sensors
  - SBUS, PWM, I2C, SPI, UART
  - Baseline sensor processing, estimation, and control laws
- SOC
  - Research / application interface
- Node
  - Sensor and actuator expansion

Functional Block Diagram



Functional Block Diagram

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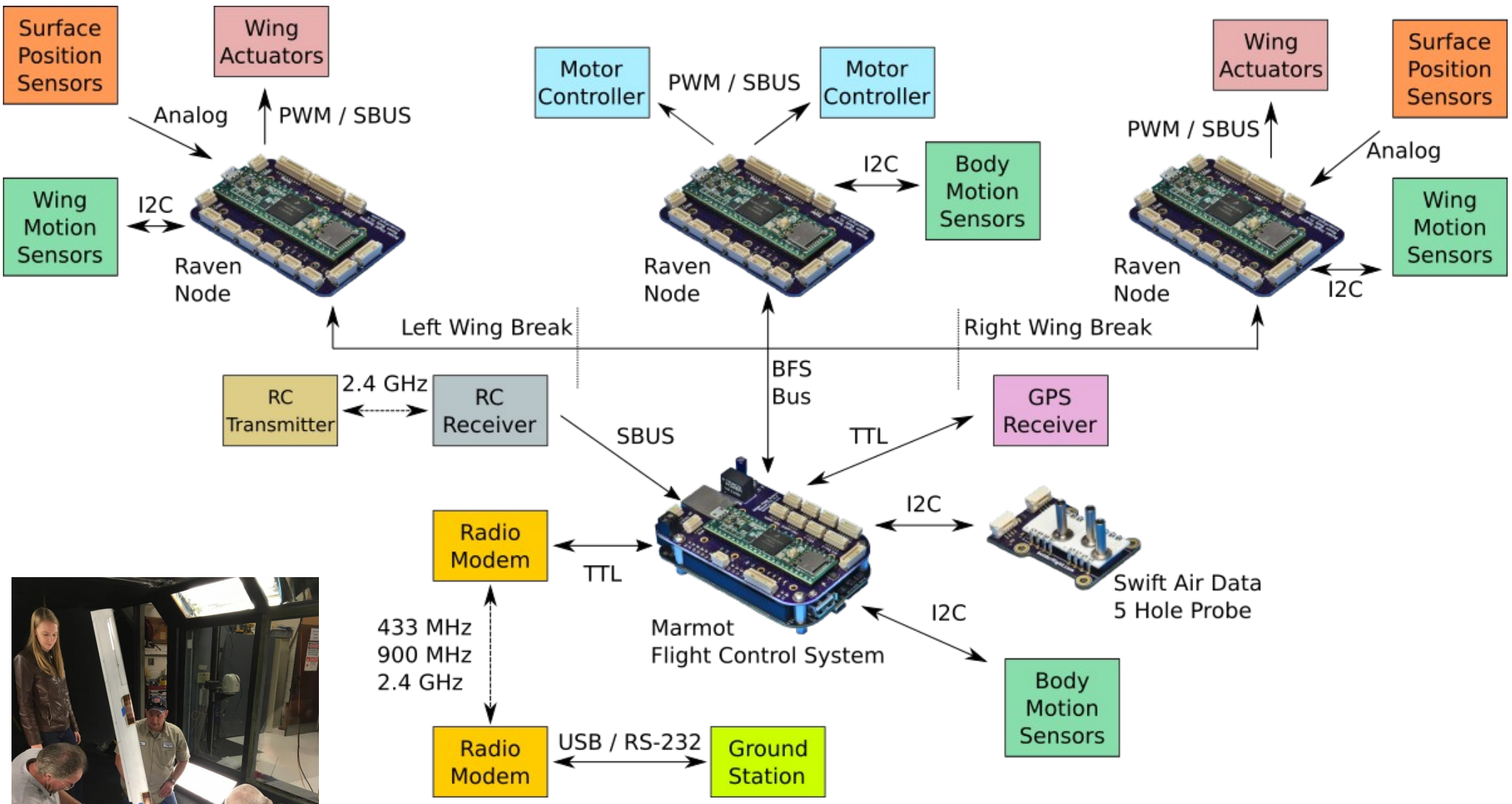
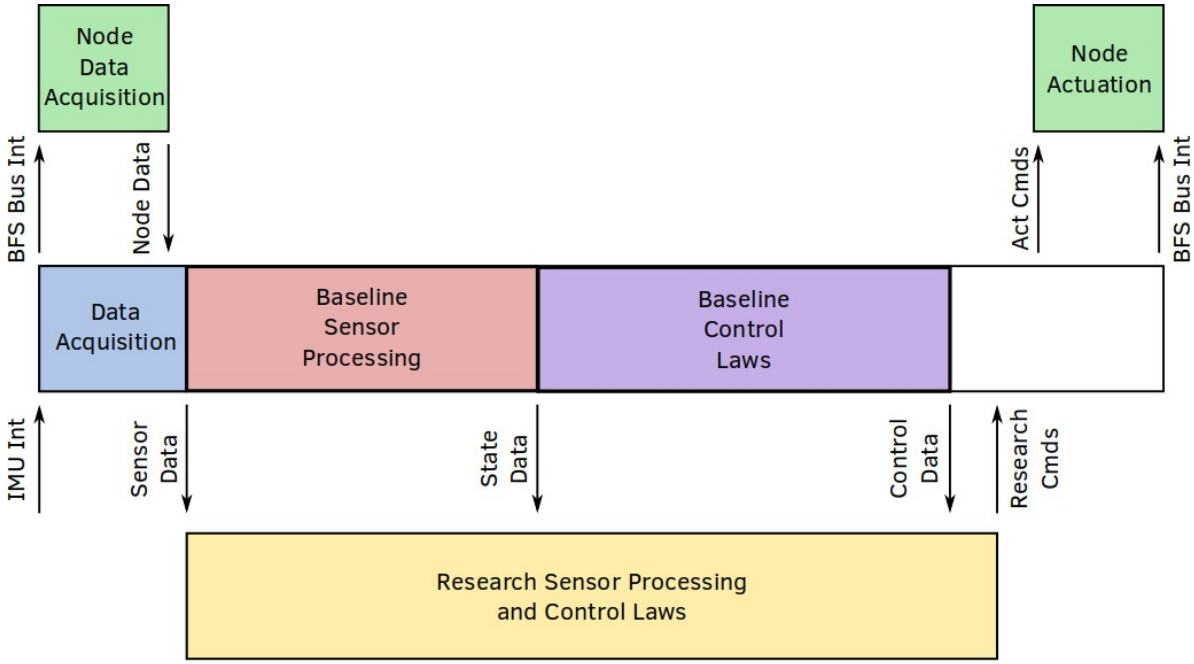


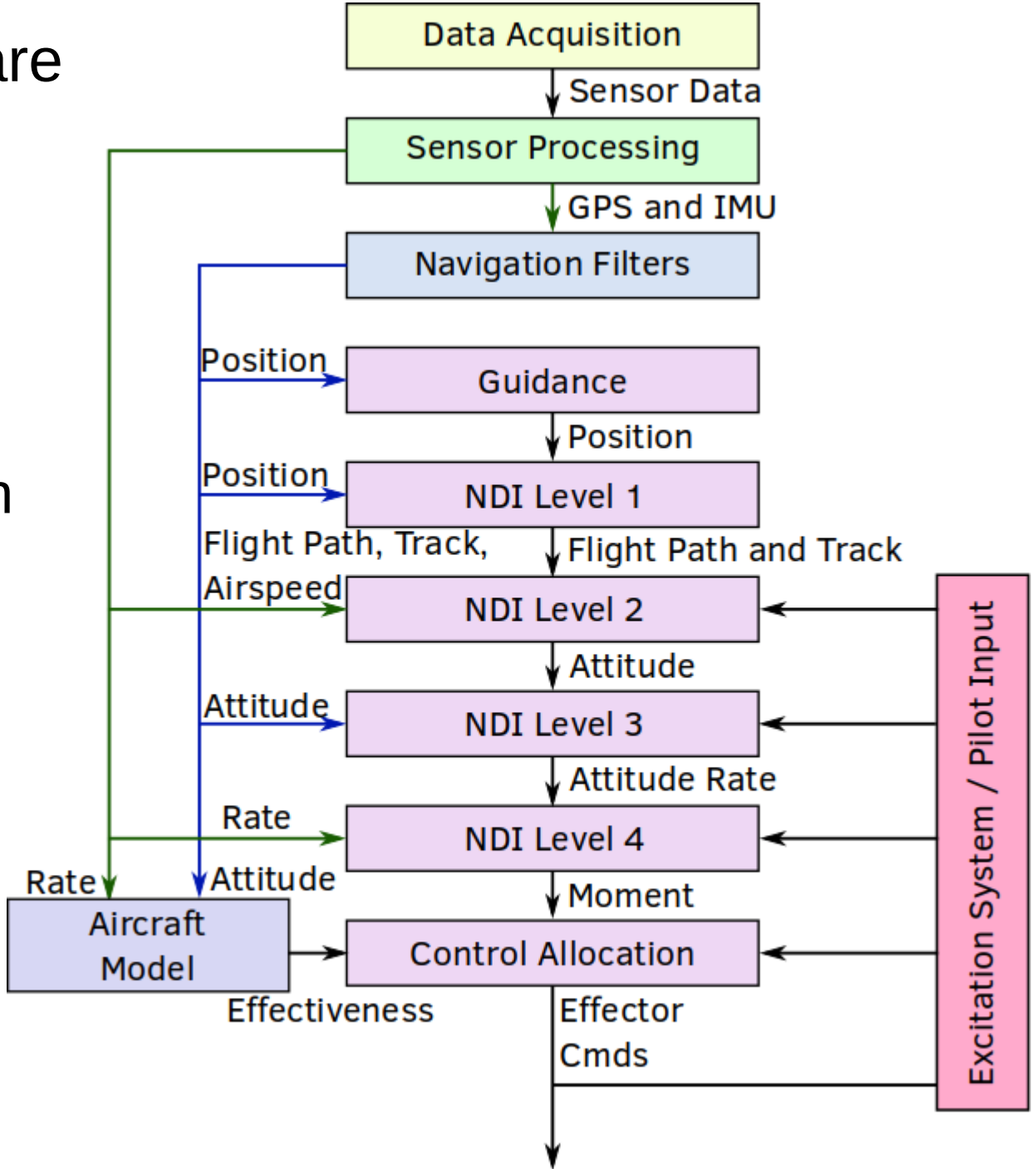
Hardware

- FMU / Node
  - 240 MHz Cortex M4, single precision hardware floating point
  - Hardware crypto unit
- SOC
  - 1 GHz Cortex A8
  - High bandwidth connection to FMU (3 Mb/s)
- BFS Bus
  - High bandwidth connection from FMU to Nodes (2 Mb/s)
  - Digital lines to sync data acquisition and actuation



Software Approach

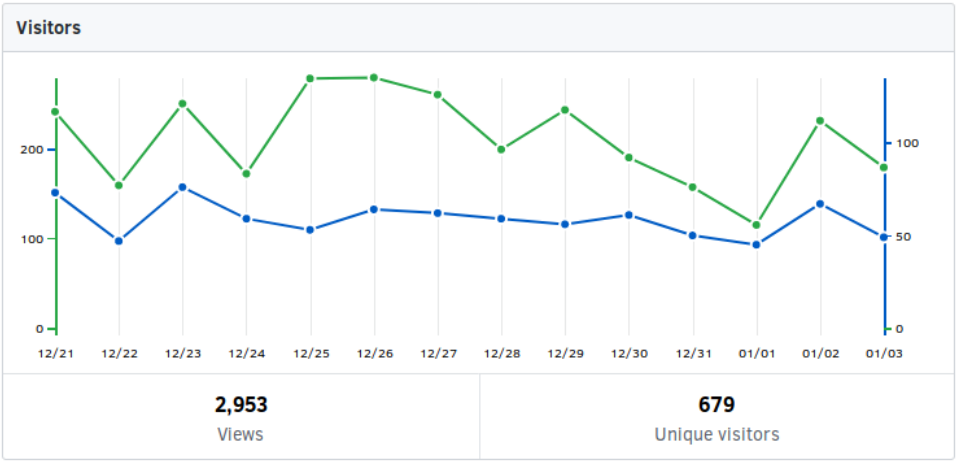
- Cascaded flight software architecture
  - Logical grouping
  - Flexible reference command source
  - Modular configuration



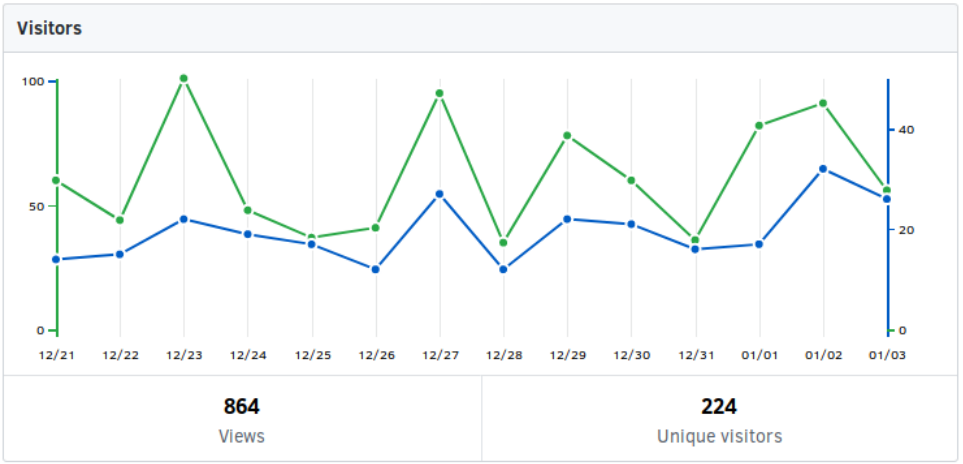
Software Environment

- Development
  - C 11 / C++ 17
  - General use sensor drivers, communication, and estimation algorithms
    - Widely used for other projects and platforms
  - Common utility classes
    - Eigen matrix math library
    - Timing, hardware drivers
- Protocol Buffers
  - Flexible research / application interface
    - Broad language support
  - Easy to add new object and message definitions
- Cmake build tools

MPU-9250 Sensor Driver



SBUS Receiver and Actuator Driver



Configuration Overlay

- Configurable software
  - Objects
  - Hash tables
  - Functions, managers, and factories

```
{ "Type": "PID2", "Reference": "/Control/refV_ms",
  "Feedback": "/Sensor-Processing/vIAS_ms", "Output": "cmdMotor_nd",
  "Sample-Time": 0.02,
  "Gains": {"Proportional": 0.200, "Integral": 0.075},
  "Limits": {"Upper": 1, "Lower": 0}
}
```

```
"SOS": { "Type": "MultiSine", "Duration": 20.0,
  "Frequency": [0.9425, 1.5708, 2.5133, 4.0841, 6.5973, 10.6814, 17.2788],
  "Phase": [0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0],
  "Amplitude": [1.0, -0.6, 0.375, -0.2308, 0.1429, -0.0882, 0.0545]},
```

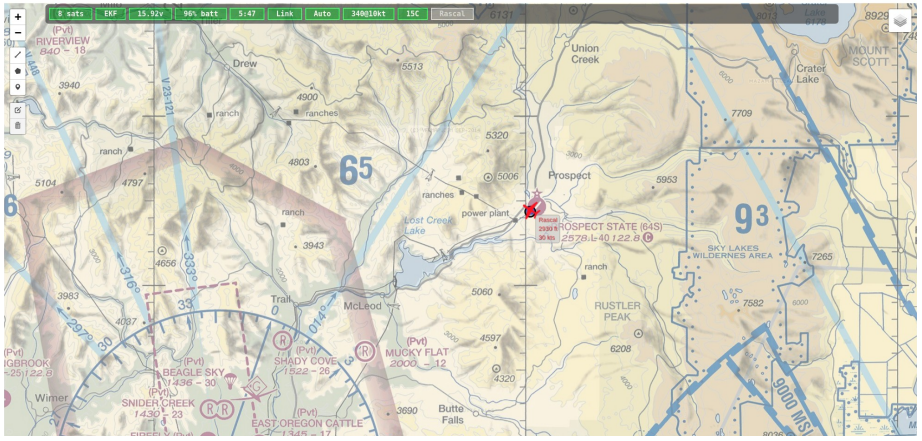
```
"Test-Points": [
  { "Test-ID": "0", "Sensor-Processing": "Baseline", "Control": "PilotAttitude23", "Excitation": "1-Cos_q10"},
  { "Test-ID": "1", "Sensor-Processing": "Baseline", "Control": "PilotAttitude23", "Excitation": "SOS_H5"},
  { "Test-ID": "2", "Sensor-Processing": "Baseline", "Control": "PilotAttitude17", "Excitation": "1-Cos_q10"},
  { "Test-ID": "3", "Sensor-Processing": "Baseline", "Control": "PilotAttitude17", "Excitation": "SOS_H5"},
```

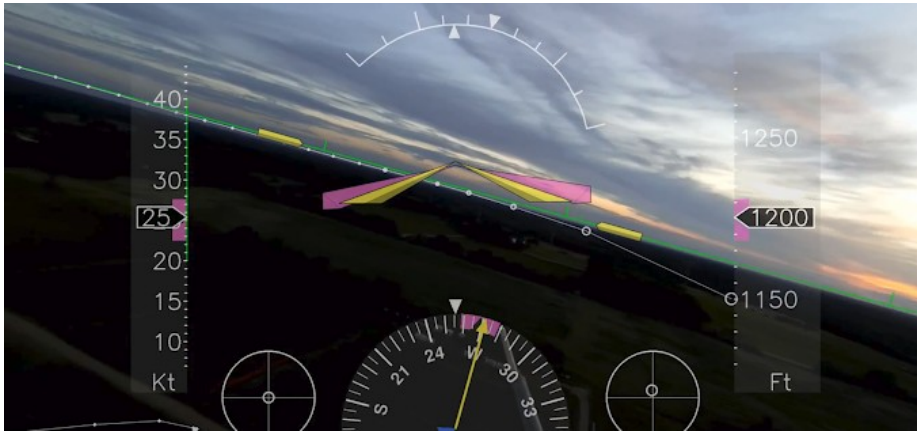
Case Study

- System id and handling qualities research
- Ultra Stick 120 fixed wing UAS and a quad rotor UAS
- Similar excitations and maneuvers
- Very different vehicle, sensor, and actuator configuration
- Able to limit the configuration differences to the sensor, actuator, and inner loop control laws
- Reuses outer loop, excitation system, and test point definitions
- Initial flights on Ultra Stick 120 completed, currently flight validating quad rotor inner loop control laws

Future Work

- Updating APIs and research / application interface
  - Much easier integration of new sensors and software
- Graphic configurator
- Ground station
- MATLAB and Simulink integration
- Autonomous Flight Development
  - Model updating, control law tuning, flight envelope clearance





Questions

- Contact: brian.taylor@bolderflight.com