Alpha Flight Software Development Experience

December 5, 2018

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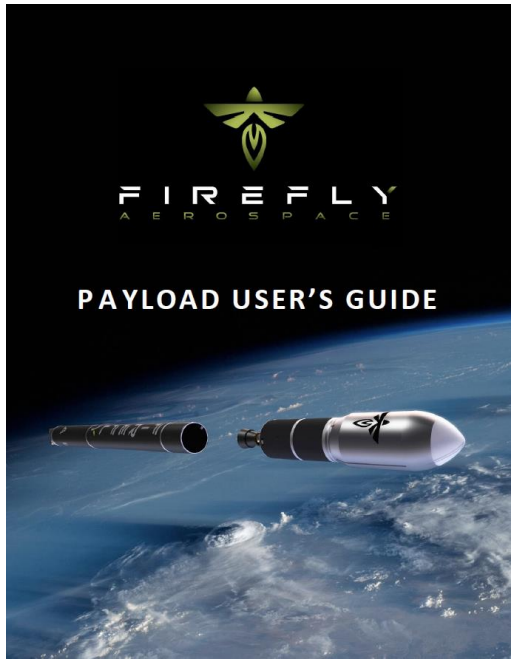
FIREFLY | About

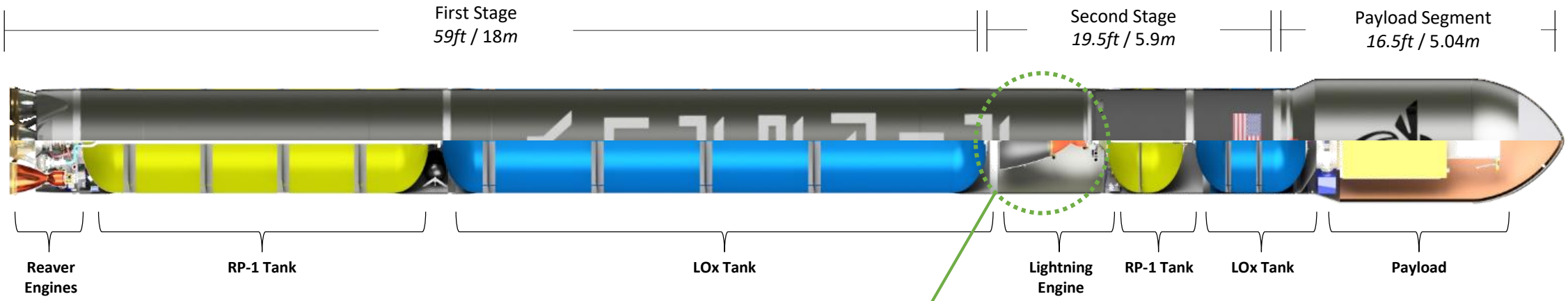
- US-based, with headquarters in Austin TX, business development in Washington, D.C., Dnipro Ukraine & Tokyo, and launch facility at Vandenberg AFB CA
- Led by aerospace industry veteran Dr. Tom Markusic and tech entrepreneur Dr. Max Polyakov
- Advisory Board includes former NASA Chief Operating Officer Robert M. Lightfoot, Jr. and former Secretary of the Air Force Deborah Lee James
- Firefly's employees have significant space industry experience from virtually every space/aerospace company and NASA
- Firefly's first launch vehicle is Alpha, which has been designed to address the needs of the burgeoning small-satellite market

Company Vision

Firefly Aerospace Inc. is committed to providing low-cost, high-frequency access to space for small payloads through the design, manufacture and operation of innovative launch vehicles.



ALPHA | Vehicle



Performance

Payload LEO / 1,000 kg (LEO 28.5°, 200 km)

Payload SSO / 630 kg (SSO, 500 km)

Max Gross Lift-off Weight (GLOW) / 54000 kg

Propulsion: Stage 1

Engine / 4X Reaver 1

Propellant / LOX / RP-1

Propellant Feed / Turbopump

Thrust (vac) / 736.1 kN (165,482 lbf)

Isp (vac) / 295.6 sec

Propulsion: Stage 2

Engine / Firefly Lightning 1

Propellant / LOX / RP-1

Propellant Feed / Turbopump

Thrust (vac) / 70.1 kN (15,759 lbf)

Isp (vac) / 322.2 sec

Avionics

Mostly COTS Components

Ethernet

Autonomous Flight Termination

Structures

All Carbon Composite Structure

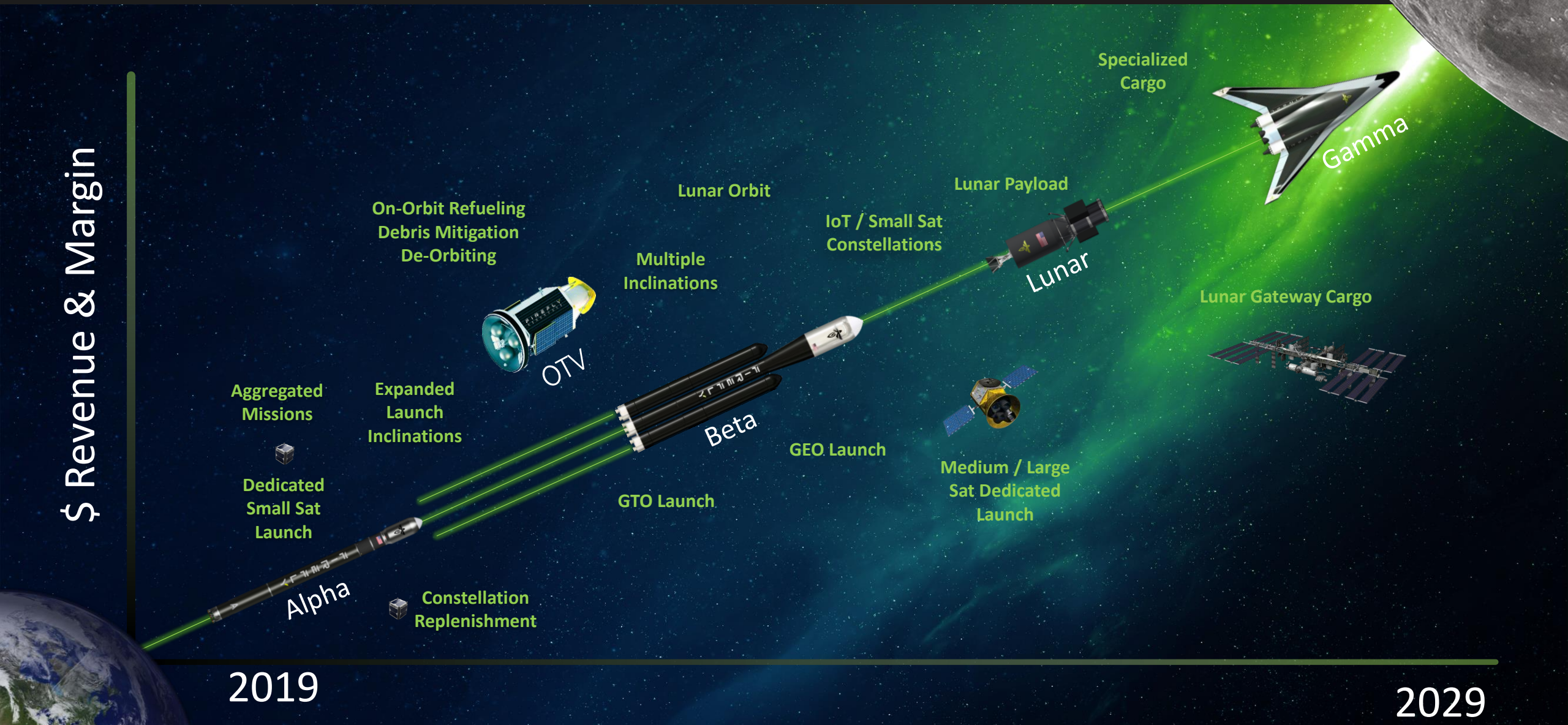
Linerless Tanks with Cryogenic Tolerances

Optimal Strength to Weight Ratio

All design, analysis, and testing done in house

Carbon Overwrapped Pressure Vessels (COPVS)

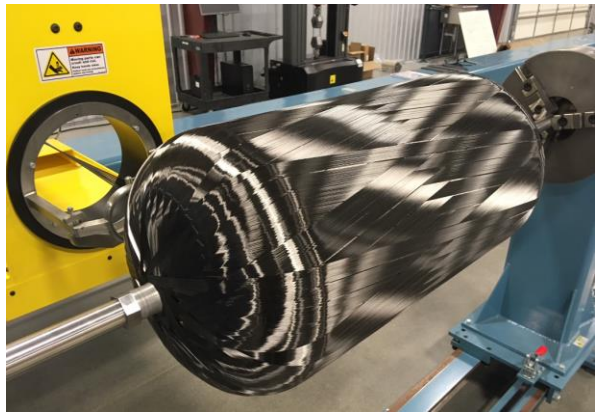
FIREFLY | Evolution and Addressable Markets



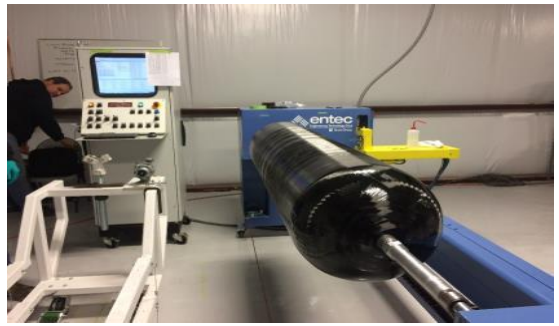
FIREFLY | Engineering and Production Facilities

Cedar Park, Texas (Austin Area)

Briggs, Texas (North of Cedar Park)



Helium COPV Winding



FIREFLY | Briggs, Texas Test Facilities

FIREFLY | Launch Facilities

Vandenberg A.F.B. SLC-2W

FIREFLY | NewSpace Approach

Rapid Design-Build-Test Approach to Firefly's NewSpace Engineering

ALPHA FLIGHT SOFTWARE | NewSpace Approach

- Flight Software Development commenced January 2018
- Flight Computer and RTOS selection were first
- Don’t ‘reinvent the wheel’
- Focus on the FSW application and not BSP/device drivers when COTS solutions are available
- Needed to support avionics hardware and testing almost immediately - Rapid prototyping and development of applications was required
- Make good high-level architectural choices

Software Development Vision

Take the simplest soonest approach with the lowest risk and overhead

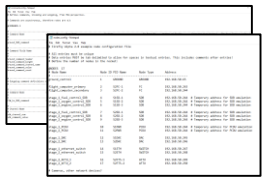
ALPHA FLIGHT SOFTWARE | Initial High-Level Decisions

- The VxWorks Real-Time Operating System (RTOS) was selected to host the Alpha Flight Software
- A COTS flight computer was selected with all necessary hardware interfaces and VxWorks flight-qualified BSP and device drivers
- Move away from a monolithic kernel-resident single application
- Flight Software Applications will operate in protected VxWorks User Space to isolate them from the operating system and each other
- Flight Software Applications will be written in C++
- CPU assignments (core-affinity) will not be used -> trust the VxWorks scheduler
- The flight software will be fully configurable via text-based configuration files
- Only the VxWorks bootloader will reside on the flight computer

ALPHA FLIGHT SOFTWARE | Overview

Ground Server

Configuration files



01101100
01101111
01110110
01100101 VxWorks Operating System

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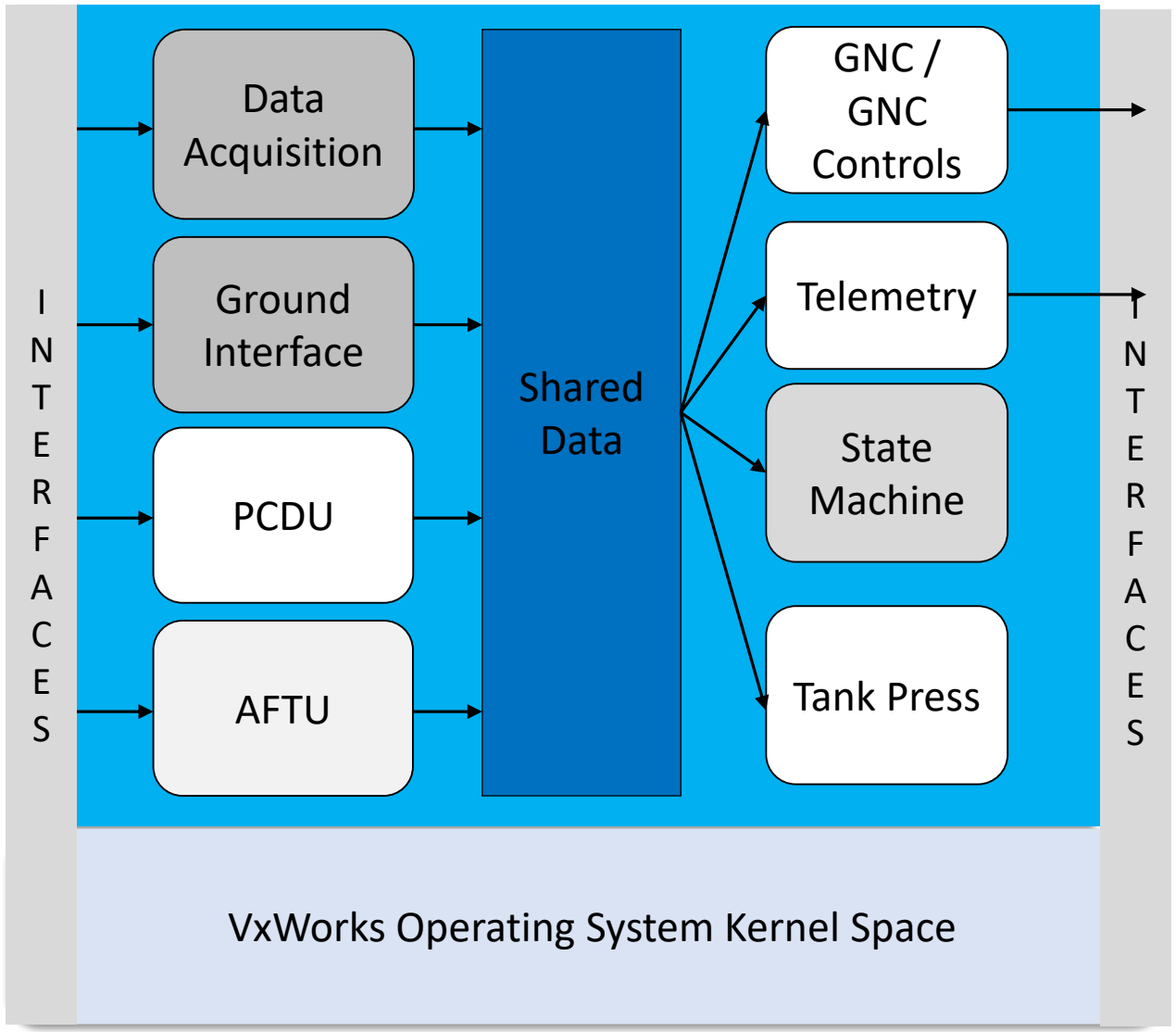
Rocket Hardware

Ethernet Switch

Flight Computer

Rocket Software



Flight Software Configuration files are ASCII-based and configuration-controlled

```
# Firefly Alpha sample node configuration file

@NODES 12
# Node Name                    Node ID   PID Name          Node Type          Address
# ------------------------------------------------------------------------------------------
ground_control                 1         GROUND            GROUND             10.10.10.2
stage_1_ethernet_switch        2         S1ETH             SWITCH             10.10.10.3
stage_2_ethernet_switch        3         S2ETH             SWITCH             10.10.10.4
flight_computer_primary        4         S2FC-1            FC                 10.10.10.5
flight_computer_secondary      5         S2FC-2            FC                 10.10.10.6
stage_1_engine_control_SDB     6         S1SD-3            SDB                10.10.10.10
stage_1_PCDU                   7         S1PWR             PCDU               10.10.10.30
stage_2_PCDU                   8         S2PWR             PCDU               10.10.10.31
stage_1_DAC                    9         S1DAC             DAC                10.10.10.40
stage_2_DAC                    10        S2DAC             DAC                10.10.10.41
stage_2_AFTU_1                 11        S2FTS-1           AFTU               10.10.10.100
stage_2_AFTU_2                 12        S2FTS-2           AFTU               10.10.10.101
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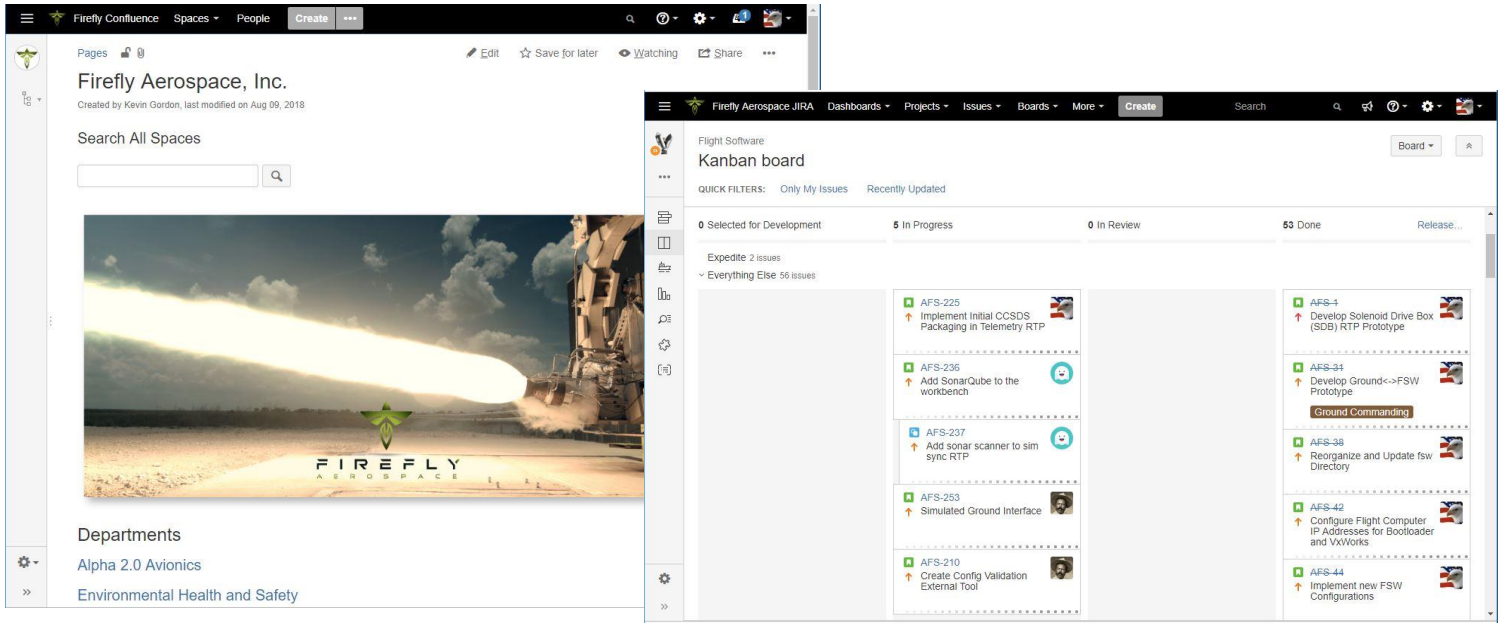
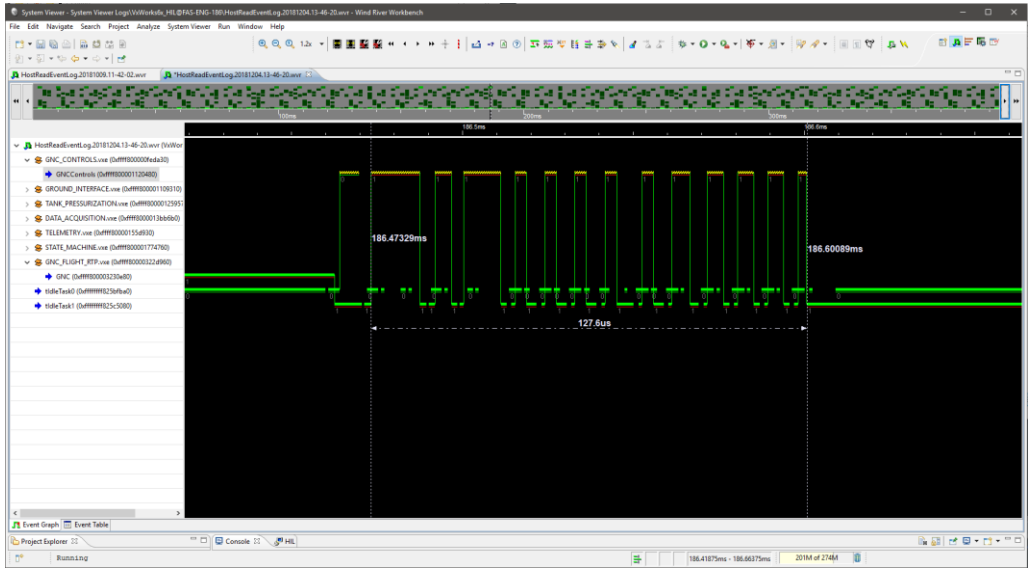
ALPHA FLIGHT SOFTWARE | Processes and Environments



Atlassian's Confluence, Jira, and Bitbucket are utilized for an integrated Agile-based process framework

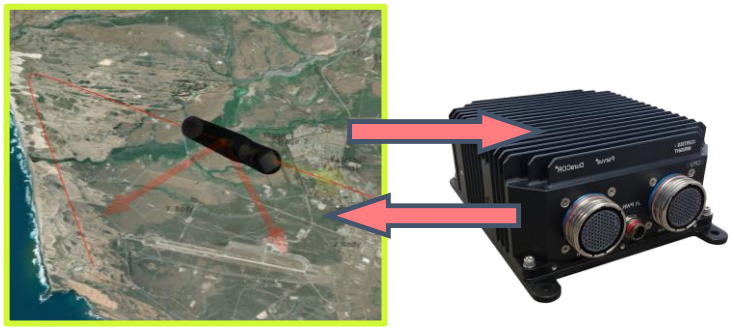


Wind River Workbench Integrated Development Environment is used to develop, test, and analyze flight software directly on the target flight computer

ALPHA FLIGHT SOFTWARE | Validation

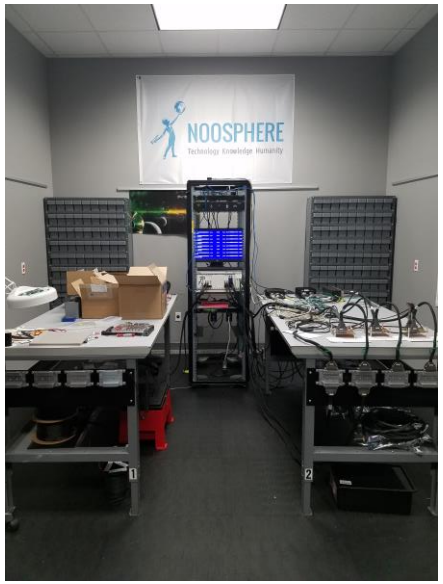
GNC Processor-in-the-loop

- All future changes to GN&C code will be assured to be stable on flight computer through internal testing process prior to Hardware-in-the-loop testing



Hardware-in-the-loop Testing

- All Flight Software additions / modifications are tested in a HITL environment, which may including scenario testing

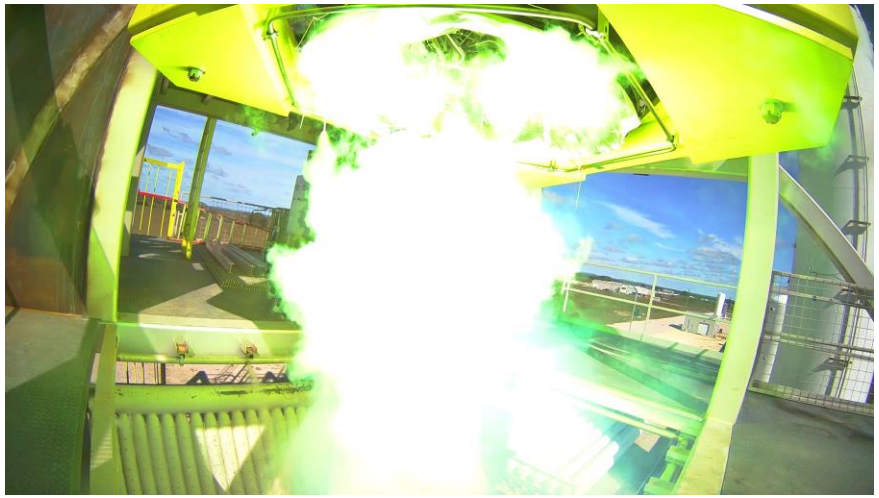


Stage Testing

- HITL-tested Flight Software is continually available for integrated stage testing at Firefly's Briggs Test Facility

ALPHA FLIGHT SOFTWARE | Progress

- VxWorks Real-Time Operating System and Bootloader built for flight computer mid-January 2018
- GNC Application integration and initial Processor-In-The-Loop validation April 2018, ~9 weeks ahead of schedule
- Application Prototypes completed May 2018, 6 weeks ahead of schedule
- Flight Software/Ground Software Hardware-In-The-Loop validation commencing July 2018
- Flight Software used for Stage 2 Integration Testing and engine tests commencing November 2018



ALPHA FLIGHT SOFTWARE | Takeaways and Path Forward

- Firefly has made good choices to use qualified COTS hardware and proven RTOS software
- The flight software high-level design choices have proven to be sound
- Continuous testing of updates in HITL lab
- Support integrated/qualification testing of stages at Briggs
- Launch Q4 2019 Vandenberg AFB