Autonomous Flight Termination System (AFTS)

Customer: NASA, DoD, Commercial

Goal: Enable low cost, responsive, reliable access to space

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What is AFTS?

- **Concept of Autonomous Flight Termination System**
  - **Box on the vehicle (AFTU)**
    - Tracking from GPS and INS sensors
    - Rule set built in pre-flight period
    - If a rule is violated the flight is terminated
  - **Radar and Command stations recede into past**
  - **Telemetry down-link drops from safety critical to sit awareness, post-flight, & mishap**
- **Some jobs stay with the humans**
  - **Clear to launch**
    - Good AFTU load
    - Clear range
    - Weather constraints
  - **Mishap announcement and investigation**
    - Air traffic
    - Sea and Ground Debris
  - **Post-flight data review**

Project: Autonomous Flight Termination System (AFTS)

- Definition
  - The Autonomous Flight Termination System (AFTS) is an independent, self-contained subsystem mounted onboard a launch vehicle
  - AFTS flight software has been developed by and is owned by the US Government
  - AFTS autonomously makes flight termination / destruct decisions using configurable software-based rules implemented on redundant flight processors using data from redundant GPS/IMU navigation sensors
- Applications
  - Primary FTS for unmanned Range Safety Operations
  - Primary FTS or Crew advisory system for human space flight
- Advantages
  - Cost reduction due to decreased need for ground-based assets
  - Global coverage (vehicle does not have to be launched from a range)
  - Increased launch responsiveness
  - Boundary limits increase due to 3-5 second gain from not having MFCO
  - Can support multiple vehicles simultaneously (such as flyback boosters)

Traditional FTS

Flight Systems

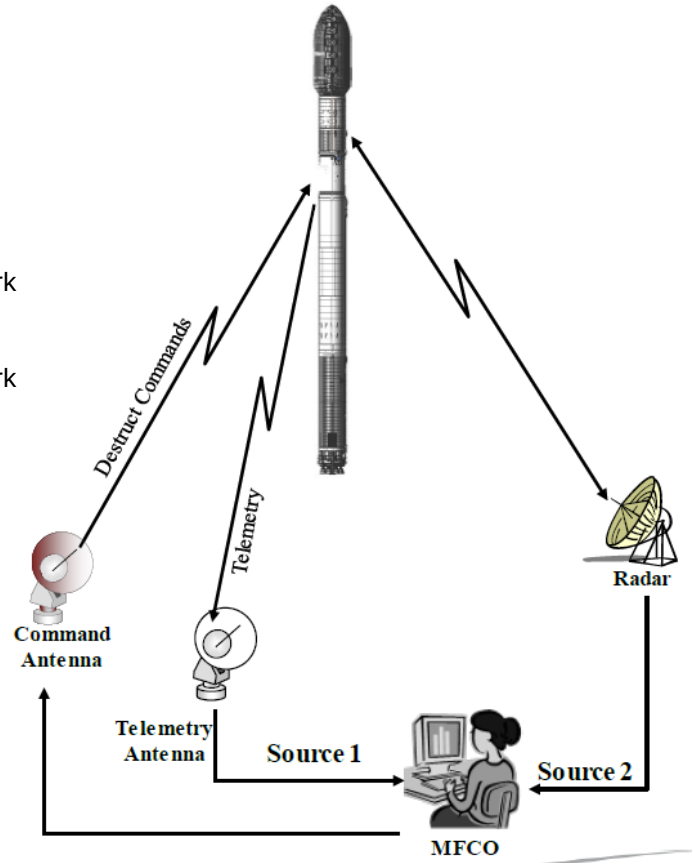
- Flight Termination System
  - Receiver
  - FTS Logic Box
  - Battery
  - UHF Antenna
  - Hybrid Coupler
  - Safe & Arm
  - Ordnance
- Metric Tracking Sources (RCC 324)
  - GPS
  - Telemetry Encoder
  - Telemetry Transmitter
  - S-band Antenna
  - L-band Antenna
  - Couplers
  - Power Distribution Box
  - Vehicle Battery
- Radar Transponder
  - Transponder
  - C-band Antenna
  - Hybrid Coupler
  - Power Distribution Box
  - Vehicle Battery

Ground Systems

- Command Transmitters
  - Power Supplies (Redundant Sources)
  - Antennas (Omnis & Directional)
  - Amplifiers (10 kW Tubes)
- Telemetry Receivers
  - Antennas
  - Decoders
  - Ground Communications Network
- Radars
  - Radar Sites
  - Ground Communications Network
  - Timing Infrastructure
- Mission Flight Control
  - MFCO
  - Telemetry Officer
  - Certified Displays

Operational Considerations

- Telemetry Formats
- Telemetry Tapes
- Launch Constraints
- Range assets are degrading and/or being decommissioned



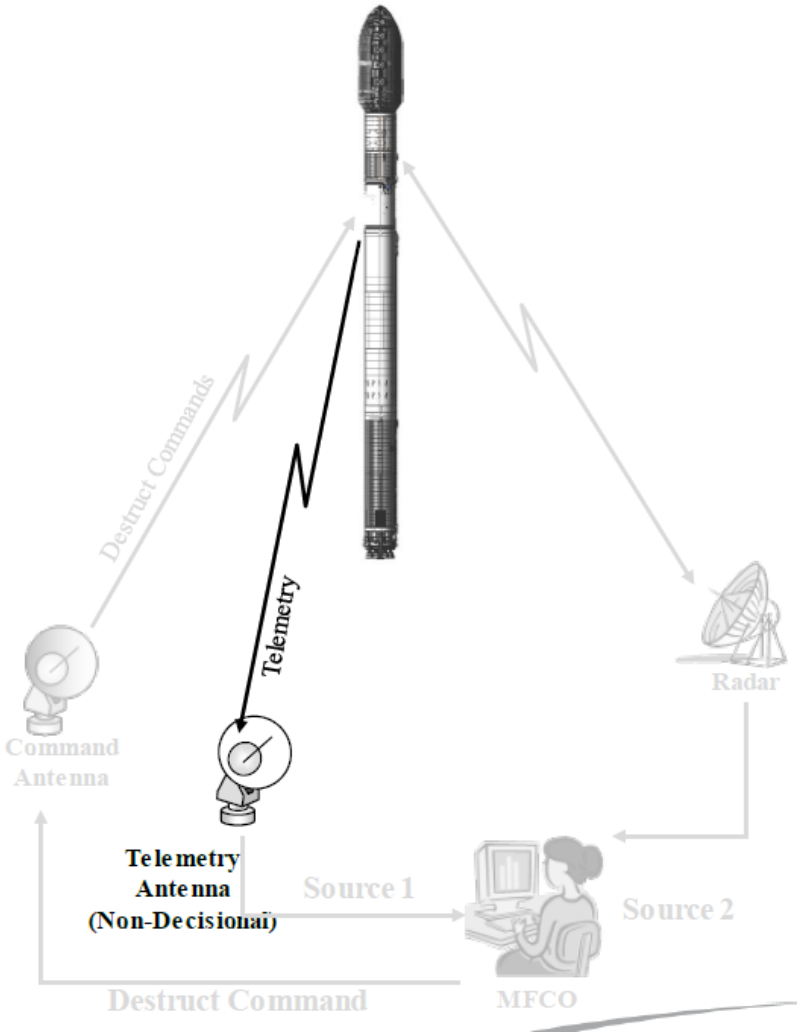
Autonomous FTS

Flight Systems

– Metric Tracking Sources (RCC 324)
  - GPS
  - L-band Antennas
  - Coupler
  - IMU/INS
  - Flight Computer
  - Power Distribution Box
  - Vehicle Battery
– Flight Termination System
  - Autonomous Flight Termination Unit
  - Safe & Arm
  - Thrust termination/Ordnance

Other

– Preflight Testing

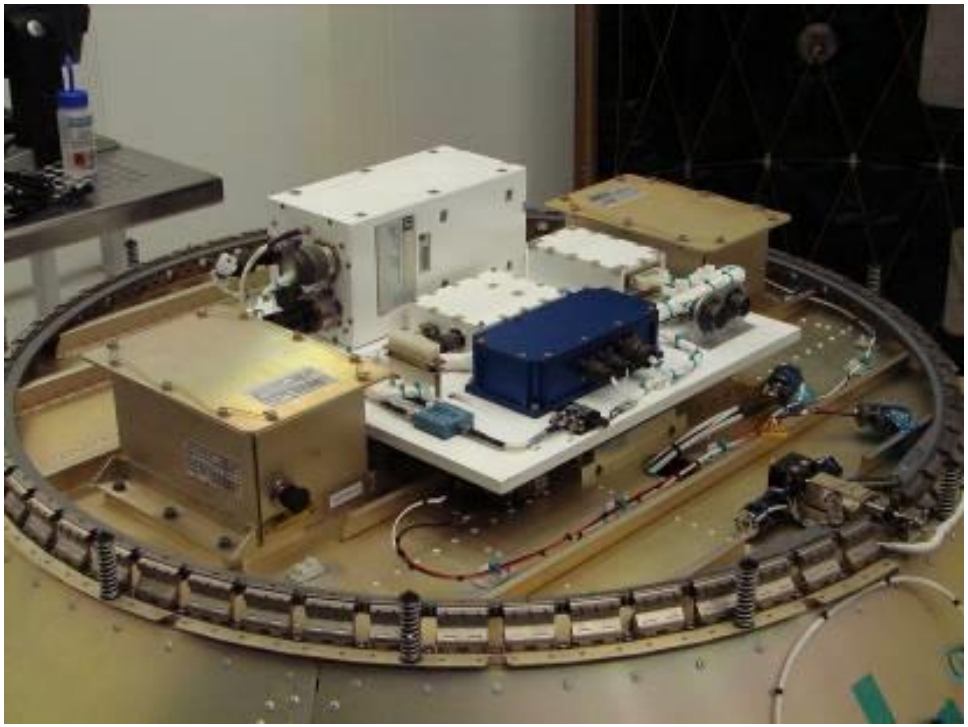


History: NASA and DoD AFTS Development Team

- NASA has maintained a multi-center AFTS engineering development team since 2000, responsible for technology development
- The partnership with the DoD began in 2002 under the joint NASA/USAF Advanced Range Technologies Working Group.
- The Goal of NASA and DoD has always been to develop an AFTS system that is available for use by all Range Users within ITAR that can greatly reduce the cost of access to space.
- AFTS has been supported by several NASA and DoD programs since its inception.
- AFTS recently won the Federal Labs Consortium National Interagency Partnership Award
- The AFTS design package has been transferred to 40 U.S. Companies and U.S. Federal Agencies to date

Project: AFTS
Technical Progress

- **Past Accomplishments**
  - **Technology Development**
    - Prior to 2014, NASA (KSC and GSFC/WFF) has developed and flown several demonstration units consisting of the AFTS custom software using primarily COTS hardware (GPS, INS, Processor)



Project: AFTS Launch Demonstrations

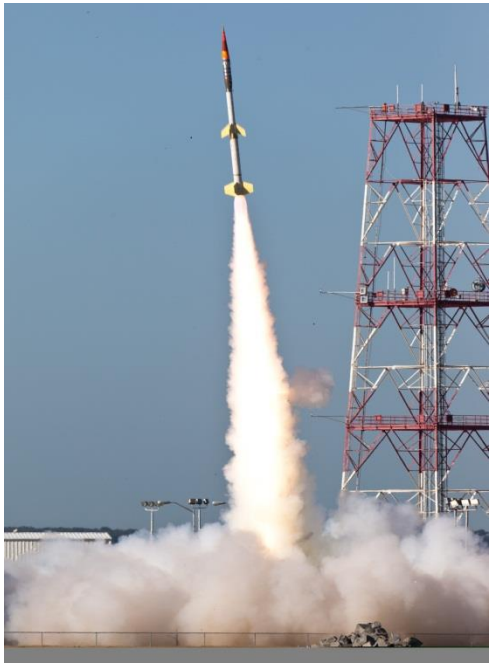
Flight/Launch Demos:

- Sept. 27, 2005, aircraft flight test near Kennedy Space Center
- Apr. 5, 2006, Two-stage Terrier Orion Sounding Rocket at WSMR
- Mar. 21, 2007, SpaceX Falcon 1 at Reagan Test Site, Kwajalein
- Nov. 8, 2007, F-104 aircraft at Kennedy Space Center SLF
- Sept. 21, 2010, Two-stage Terrier Orion Sounding Rocket at WFF
- Nov. 19, 2013, DoD ORS demonstrated ATK AFTS on Minotaur from WFF

F-104

Sounding Rocket at WSMR

SpaceX Launch



Sounding Rocket at WFF

Project: AFTS
Technical Progress, Software

CASS

- NASA wrote the original AFTS Core Autonomous Safety Software (CASS) algorithms and software
- The USAF Air Force (30th Space Wing) rewrote CASS to make it safety critical for operational use
- KSC performed testing, IV&V and AFTS project management
- An AFTS using CASS Operational Release 1.1 (OR 1.1) was flown operationally for the first time on February 19, 2017, and AFTS is now the baseline for at least one launch vehicle provider for all of their operational missions, with many other companies to follow.
- MEI has developed a Flight Analyst Workstation (FAWS) for use with AFTS for mission rule generation and preflight simulation.
- The CASS OR2 software went through IV&V and was recommended for operational use; completed June 2018
- All launch vehicle providers plan to use CASS in their AFTS, even though their AFTS hardware and wrapper software may vary from company to company

WRAPPER

- NASA KSC wrote an original AFTS Wrapper software, which is the interface software between CASS and AFTS hardware
- The NASA Wrapper Software has been released as Class E software to industry within ITAR via NASA KSC's Technology Transfer Office, and interfaces between CASS and the NASA AFTS hardware design
- NASA KSC is performing IV&V on the Wrapper Software, and when complete, will be released as Class B software for operational flight

Project: AFTS
Technical Progress, Hardware

AFTS Hardware Development

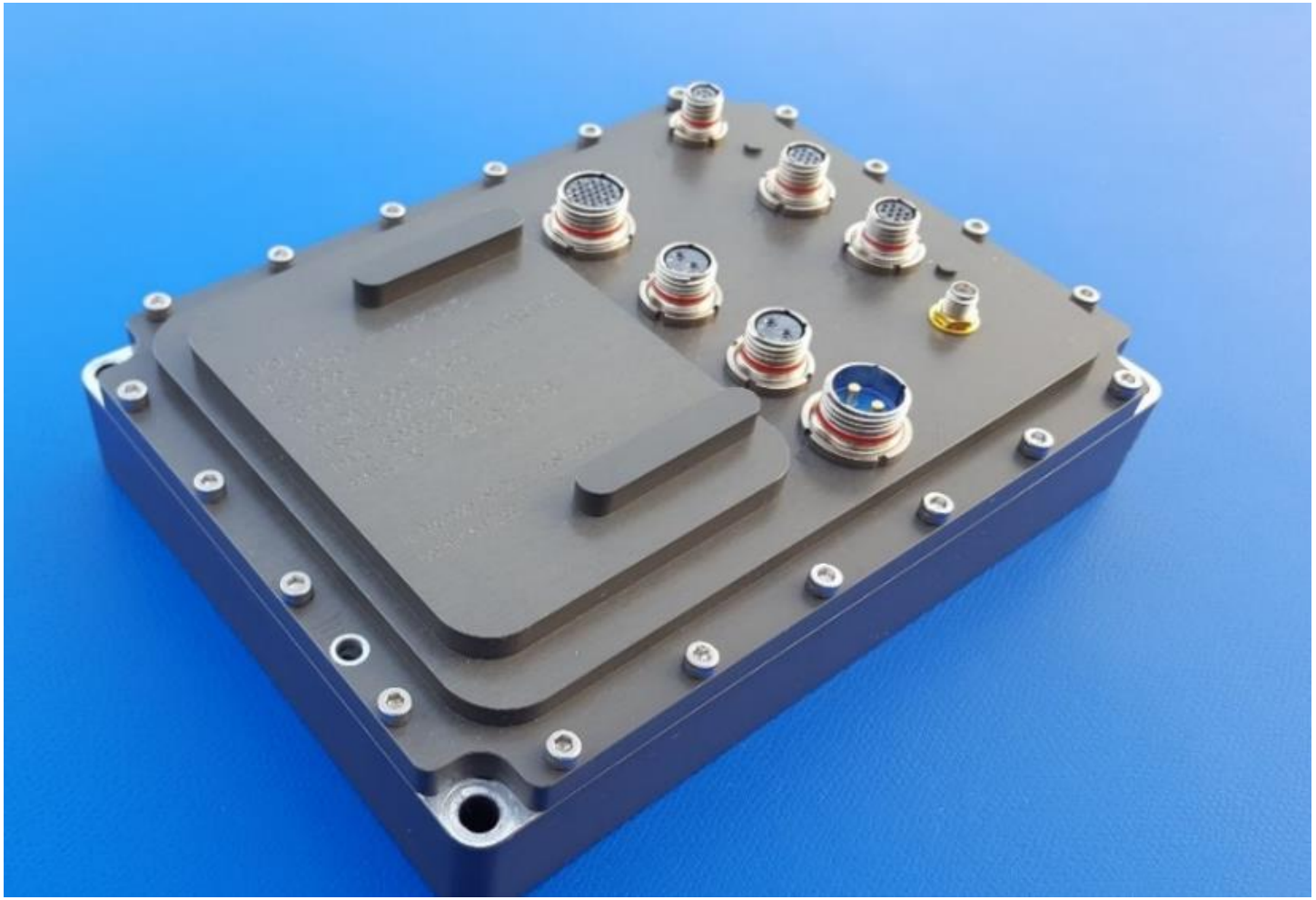
- One launch vehicle provider has developed, certified, and qualified their proprietary AFTS hardware, along with their custom Wrapper software, for operations on the Eastern and Western Ranges
- KSC has designed a generic AFTS hardware architecture that can be used as a reference by future Range Users wanting to implement an AFTS on their launch vehicle – the commercialization office at KSC has released the NASA hardware design via free technology transfer to Range Users within ITAR; KSC qualification and certification scheduled to be complete September 2019

AFTS Flight Hardware Qualification

AFTS Hardware Qualification

- DARPA has funded NASA KSC to build 12 AFTS flight test units (6 for flight testing (2 units to be flown on 3 different launches), 3 for single use qual testing and 3 for development testing)
- A NASA New Technology Report (NTR) has been released for the new Hardware design
- Part of this phase will be to IV&V the AFTS Wrapper (Interface Software) – NTR submitted for the Wrapper software
- Following the Engineering Flight Test on Rocket Lab's Electron launch vehicle in May, NASA has commercialized the AFTS hardware design for industry use via free technology transfer within ITAR. Wrapper Class E tech transfer followed with Class B planned for September 2019.

AFTS Engineering Flight Hardware



AFTS Overview

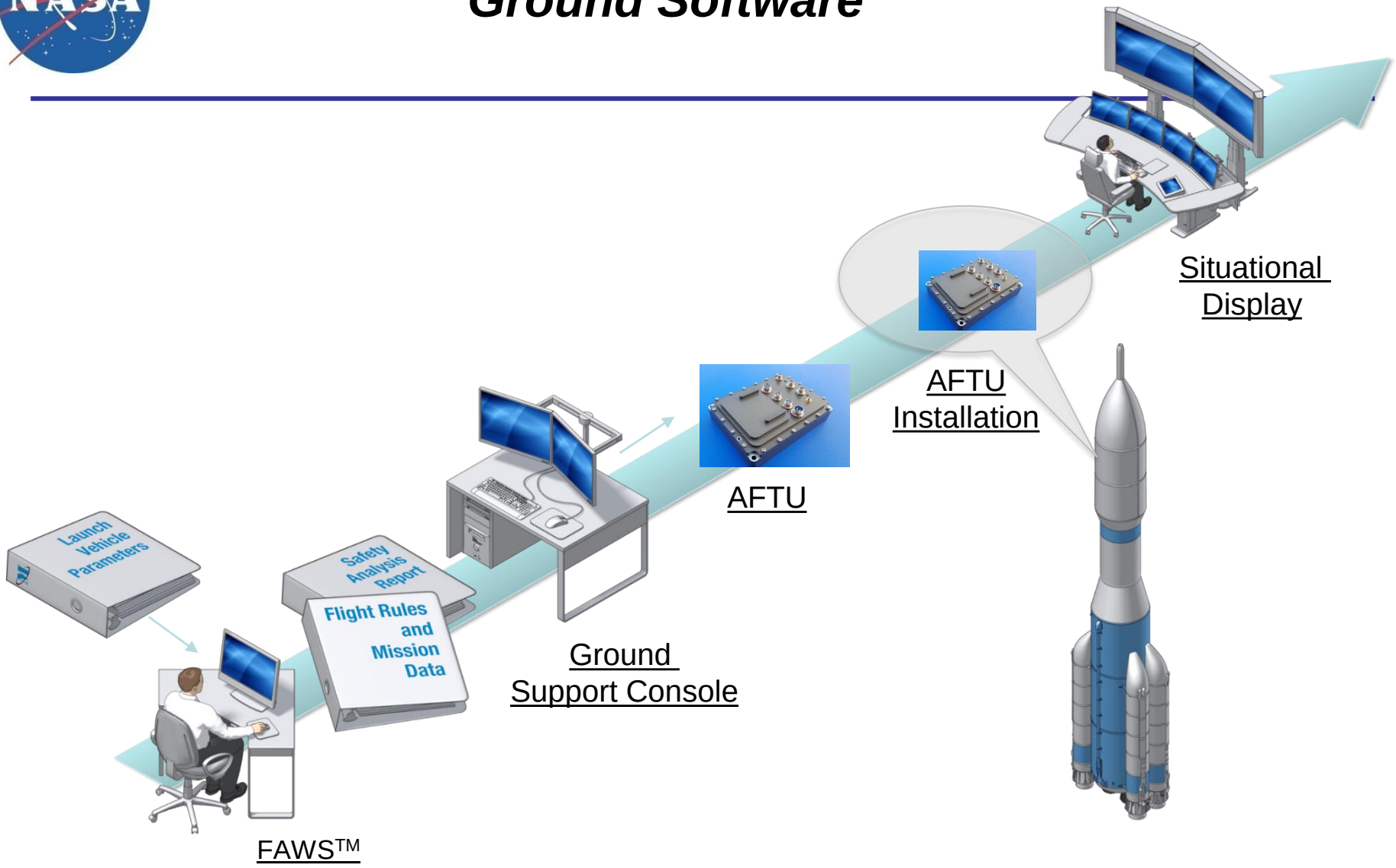
AFTU Overview

- < 1.3kg
- Nominally <7 watts at 28 V DC
- Estimate 5cm X 14cm X 19cm
- Outputs discrete signals or up to 5.5 amps at 28 V DC
- Term or TermNOT (for normally closed valves) configurable
- Using Mil-spec parts (simplified piece parts plan) in critical circuits
- Qualifying to AF/NASA/FAA range requirements.
- Up to 5 sensor combinations may be connected to one AFTU
    - GPS, INS, GPS/INS hybrid or IMU.
- Single or cross strapped configurations.

Key Requirements

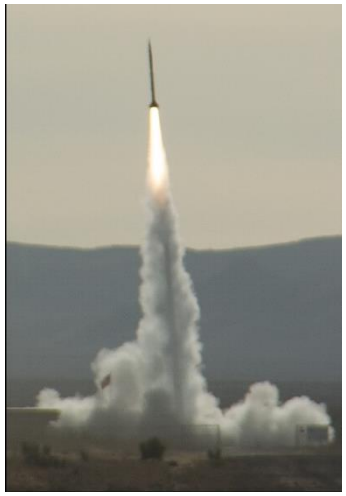
- No single point failure (failsafe exception for single AFTU)
- Ensure no inadvertent termination
- 0.999 Reliable at 95% Confidence.
- RCC 319-14
- RCC 324-11
- 91-712
- CASS Requirement Spec

Ground Software



KSC AFTS Flight Tests

Rocket Lab Electron Launch



UP Aerospace Spaceloft Launch

- DARPA initiated a partnership with NASA on a low cost, flight demo to flight test KSC's AFTS Reference Design Hardware
- The ride share demonstrated the AFTS system (with validated CASS SW).
- This demonstrated a path forward that doesn't require traditional 30th or 45th Range support for vehicle tracking and command destruct.
- The FAWS was exercised.
- The DARPA funded, NASA AFTS payload launched on Rocket Lab's Electron Launch Vehicle from New Zealand in 5/2017.
- DARPA has selected three additional RL flights to fly two of their AFTS units on each as shadow/certification flights.
  - Three certification flights have been completed
- NASA AFRC purchased 6 units; two units were flown on the UP Aerospace SL-12 launch, two were flown on a bonus RL launch, the two from SL-12 were recovered and will be re-flown on UP Aerospace SL-14, and the last two were sent to NASA WFF for testing in their AFTS lab
- Several launch vehicles have baselined NASA AFTS units into their vehicles for operational use

Summary

- AFTS is an enabling technology for KSC's Spaceport – very attractive to new launch vehicle providers (much less expensive than traditional, ground-based, FTS systems)
- AFTS provides responsive access to space at a reduced cost
- CASS OR1 and OR2 have been released for operational use
- The FAWS is available for use for mission rule generation and preflight simulation
- NASA's AFTS has undergone hardware development and flight certification, and is completing ground test qualification for operational use – planned completion July 2019
- Commercialize the AFTS hardware and wrapper software via free technology transfer to broaden use of AFTS by all interested range users within ITAR
  - Make AFTS History and Documentation available to Range Users
- Support launches of NASA AFTS Flight hardware on:
  - Rocket Lab, UPA and other launch vehicles in the future

THANK YOU!