Rocket Testing: A Case Study in Distributed Control Architecture

NI Connect 2023

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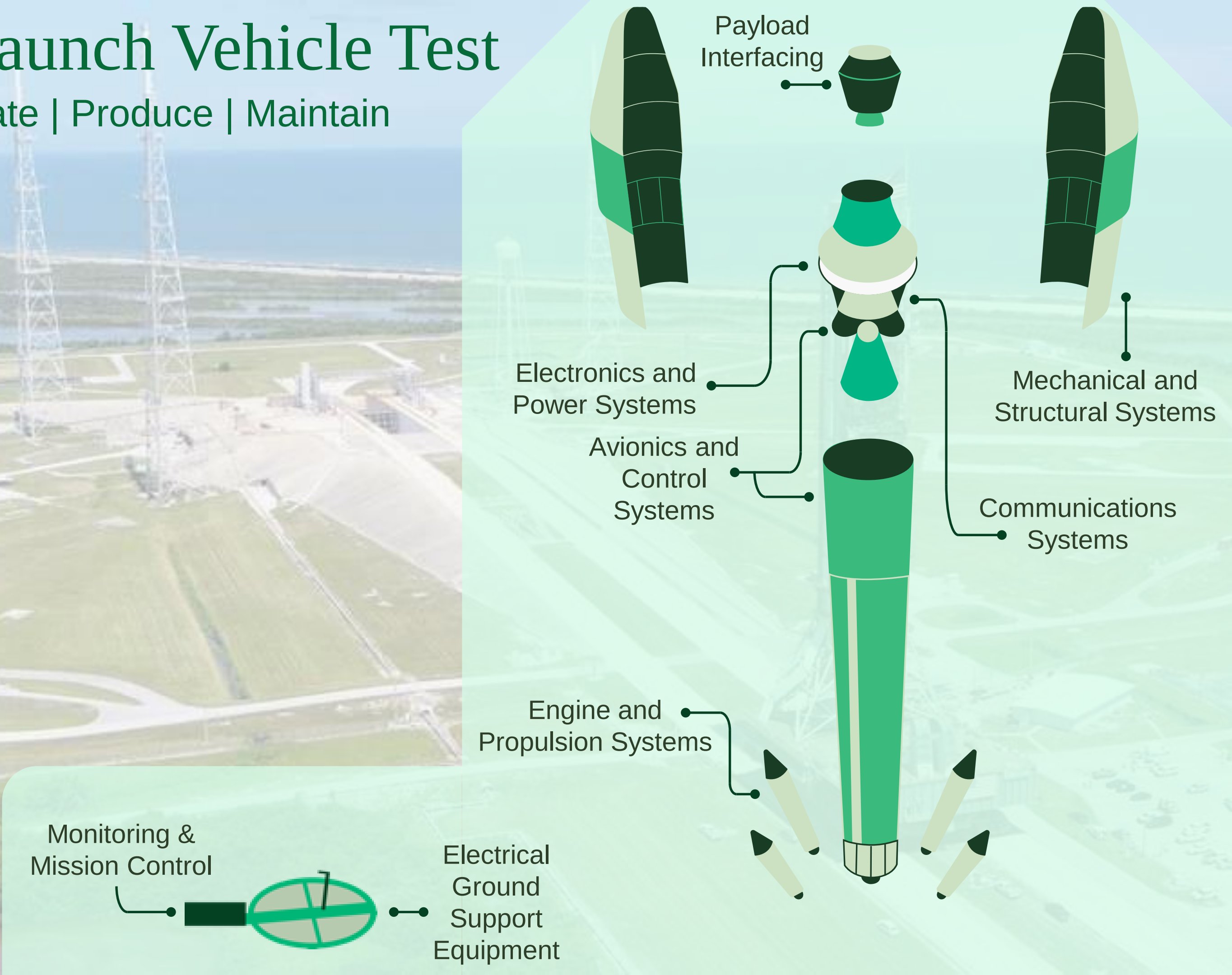
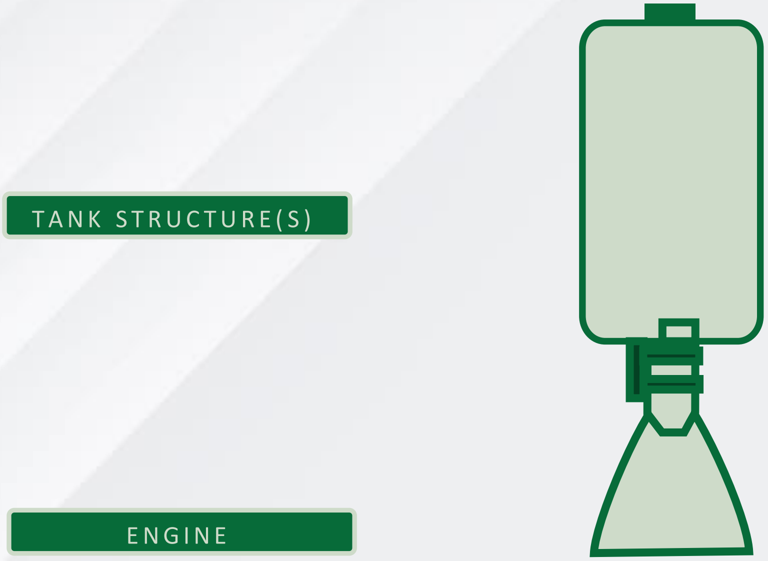
NI and Launch Vehicle Test

Design | Validate | Produce | Maintain

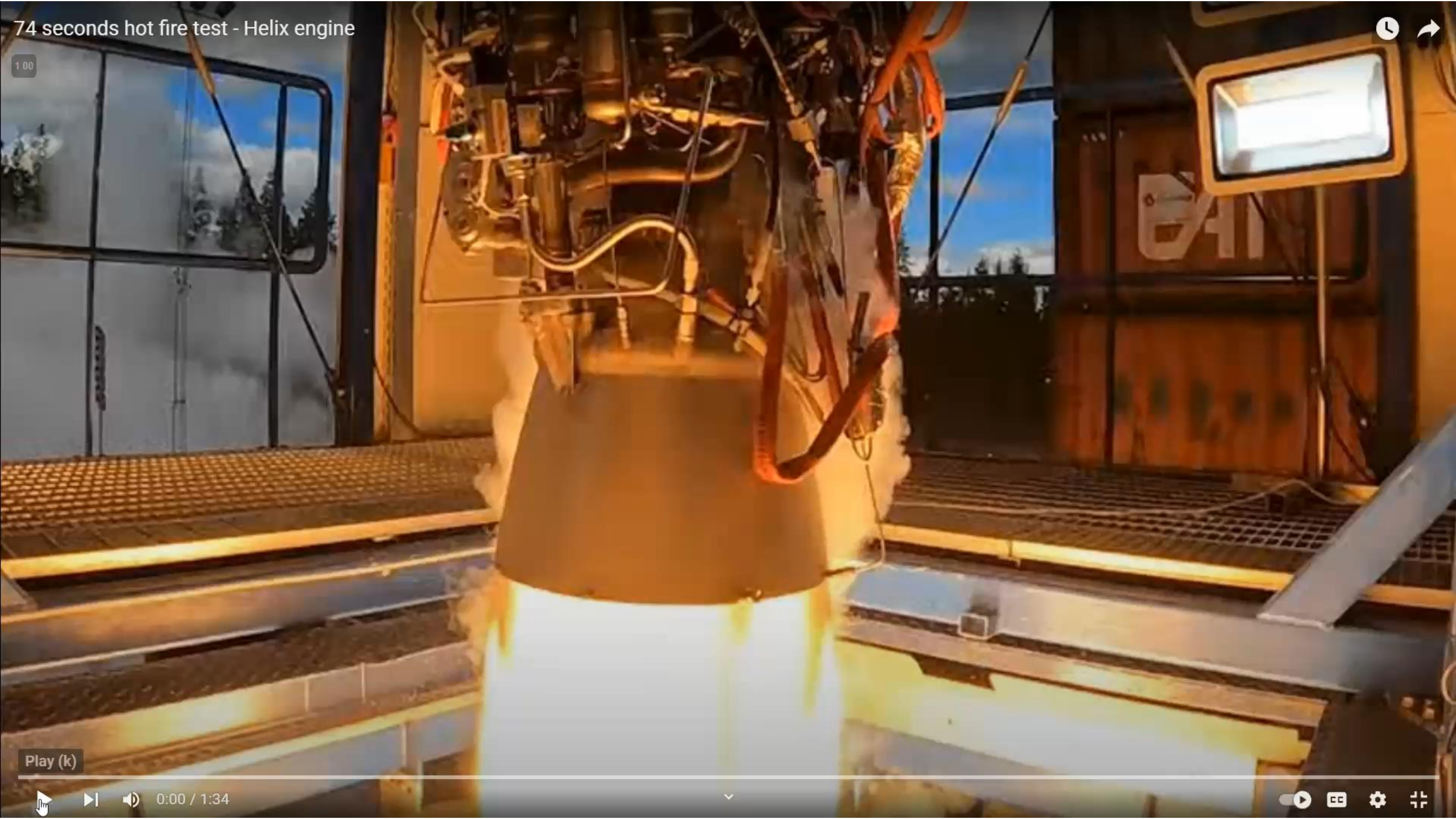


PROPULSION TEST



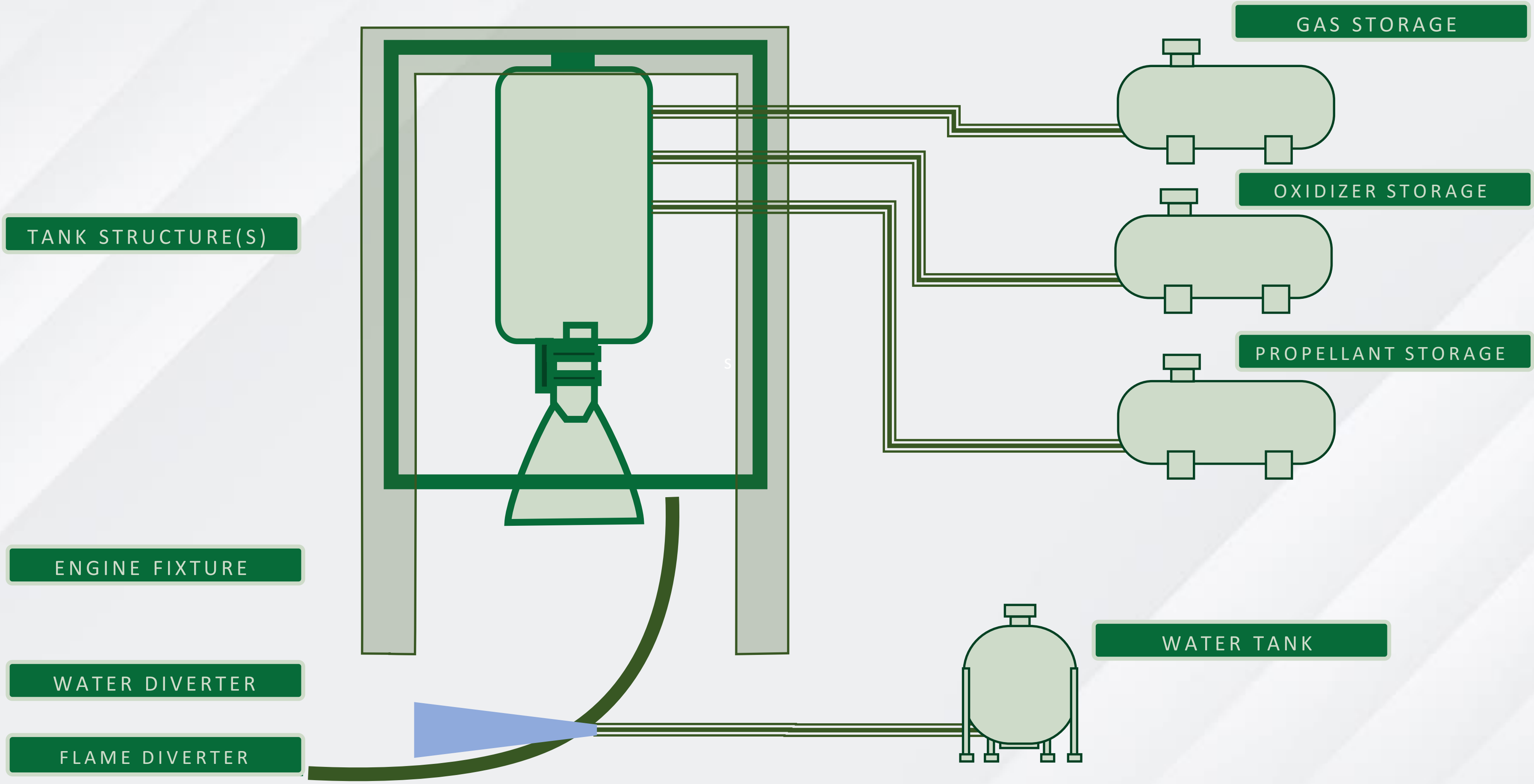
Types of Propulsion Test:

- Engine Test
- Stage Test
- Full Assembly Test

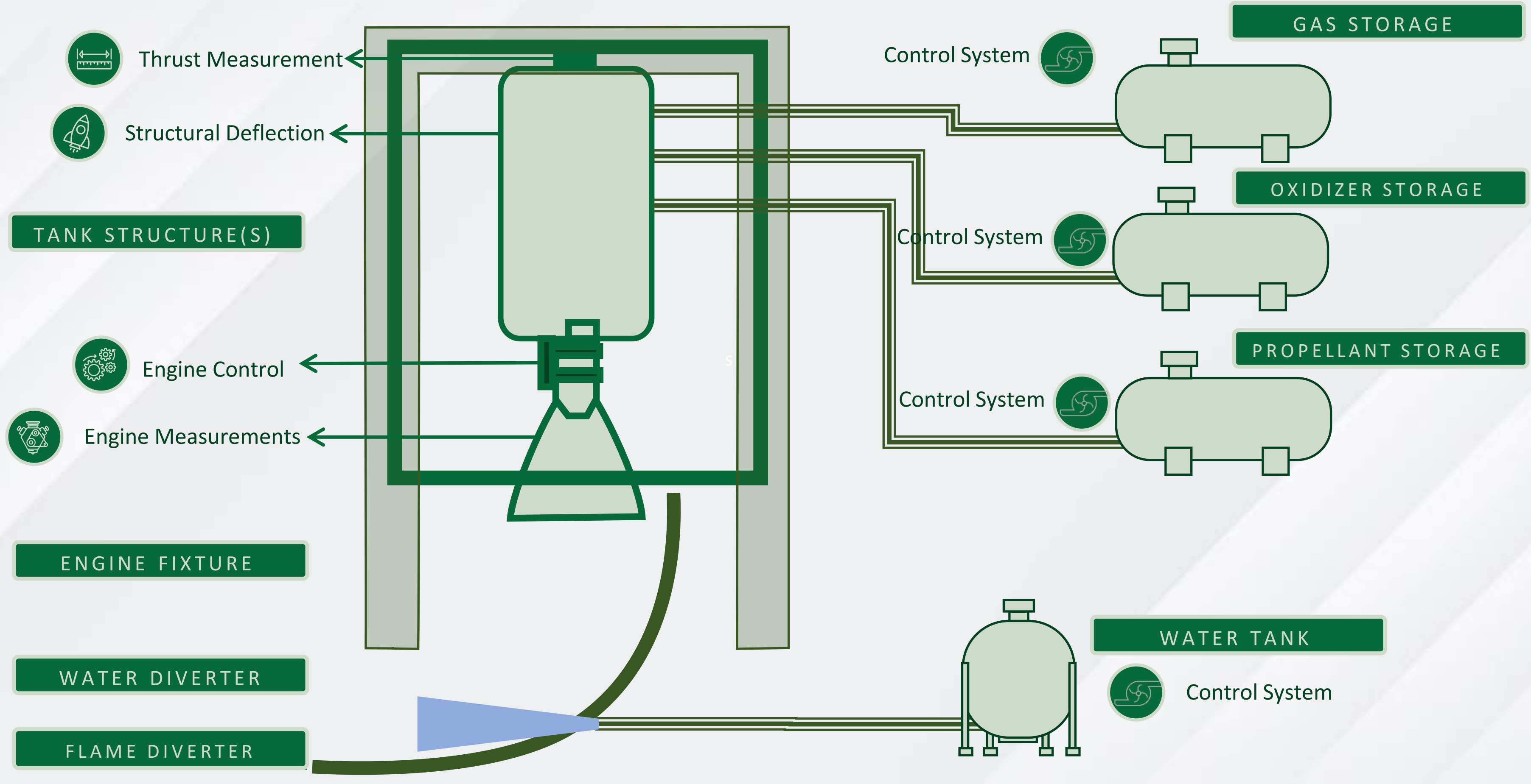

74 seconds hot fire test - Helix engine
1.00
Play (k)
0:00 / 1:34

Source: NASA Images

PROPULSION TEST



PROPULSION TEST



Rocket Test Challenges

Setup

- Cost, time, resources

Environment

- Noise, vibration, elements

System / subsystem failure

- Detection, reaction

Safe, successful execution is critical to success of a program

Managing risks in a rocket test control system

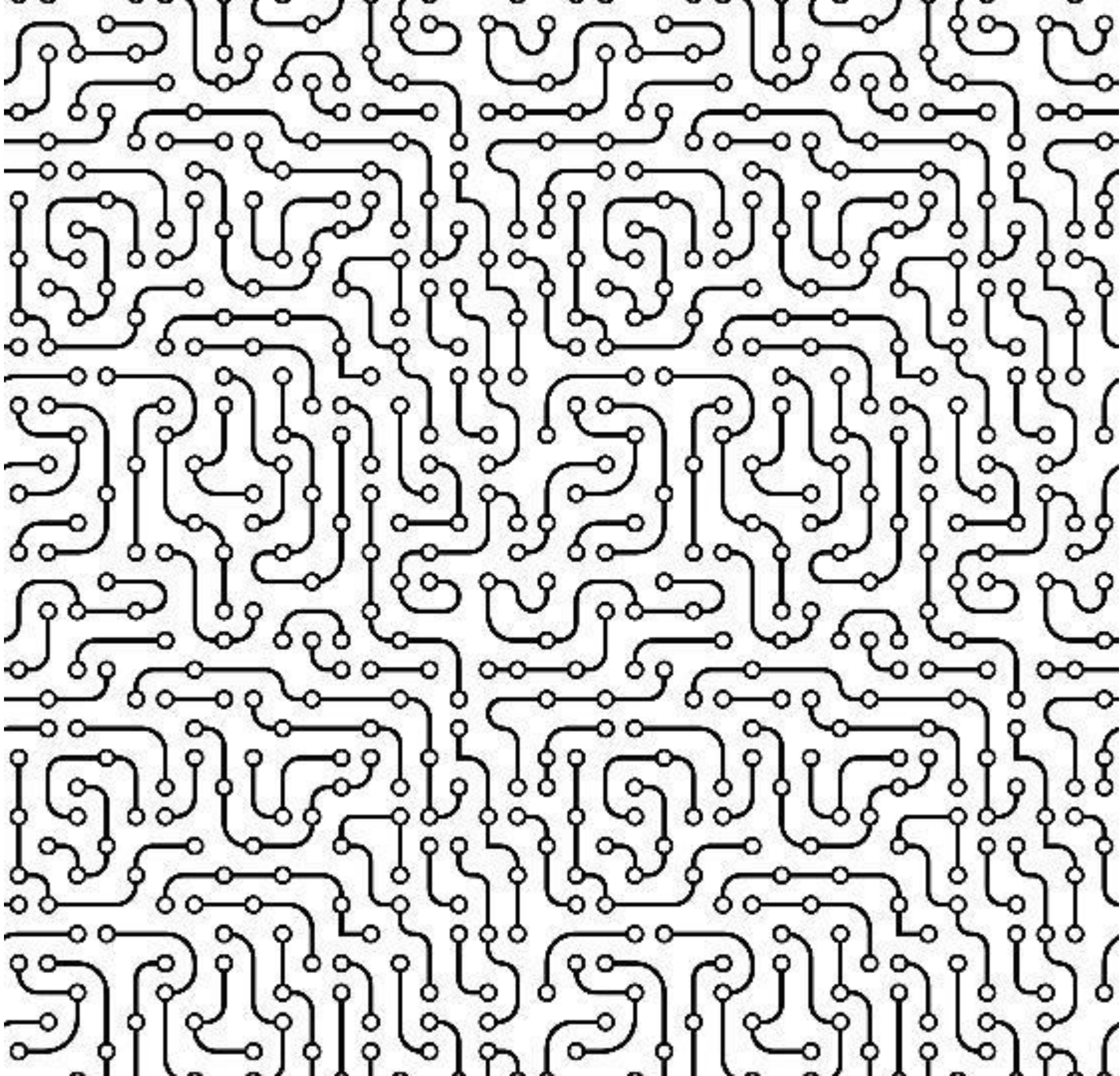
Goal: Architect system components to manage risk.

- System-level approach
- Identify acceptable risk profile
- Classify sources of risk
- Use good system design to address risk sources

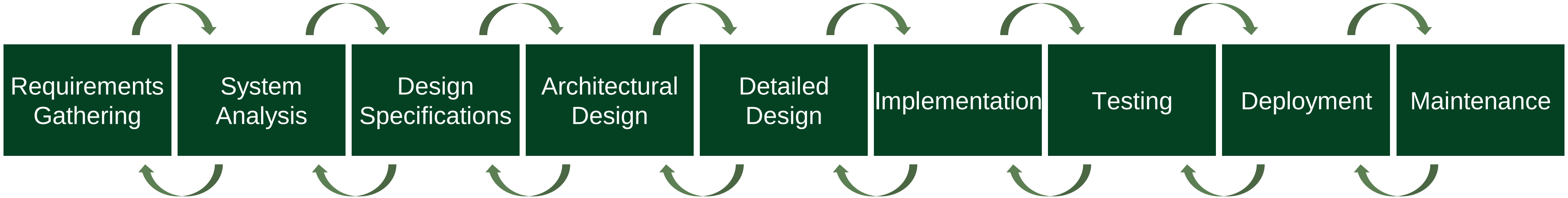
System Design

Reduce risk through:

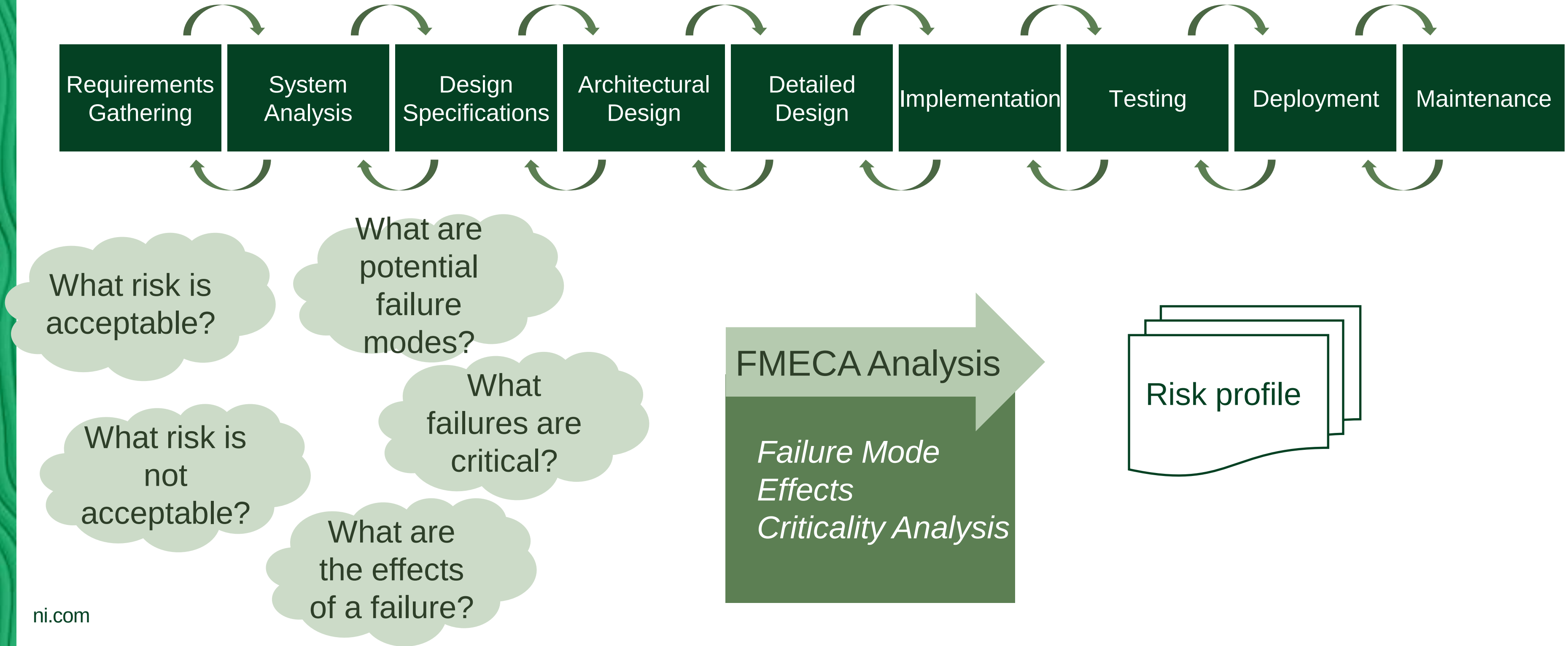
- Identification of risks
- Ensuring security
- Providing redundancy
- Simplified maintenance
- Improved scalability



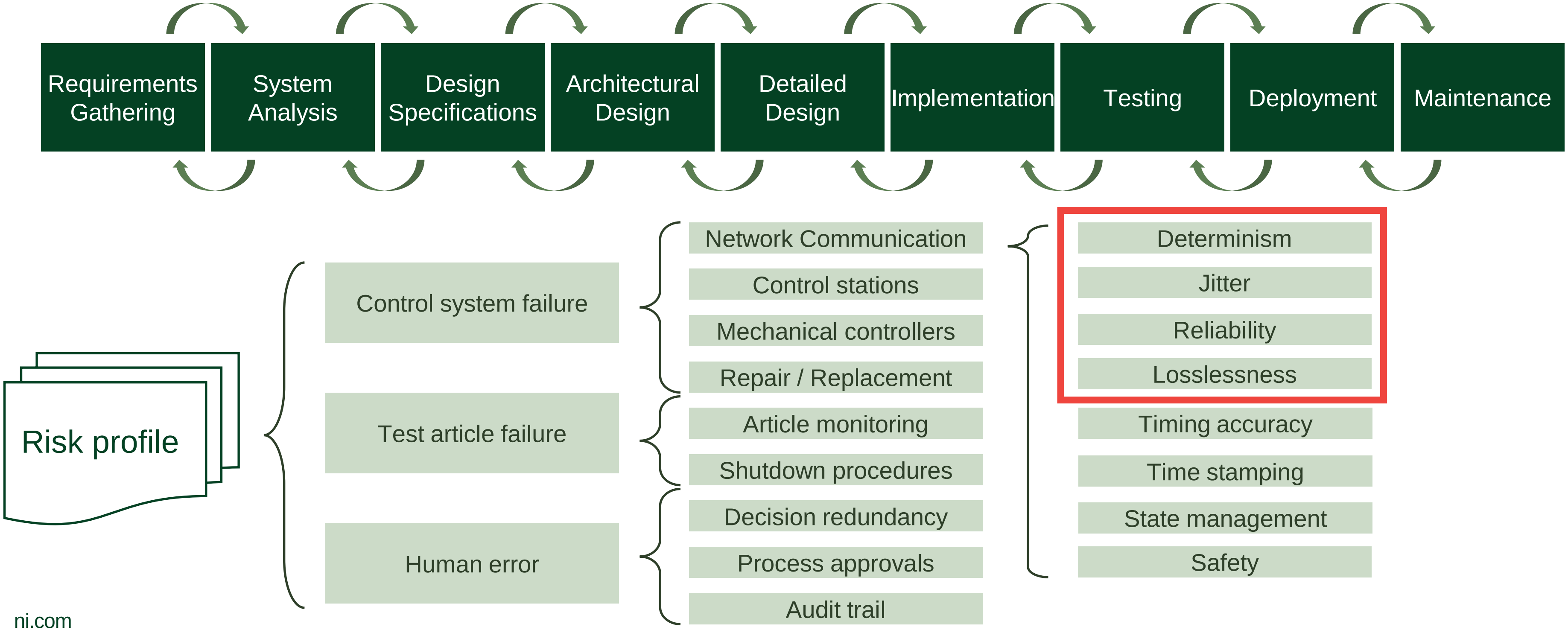
System Design Steps



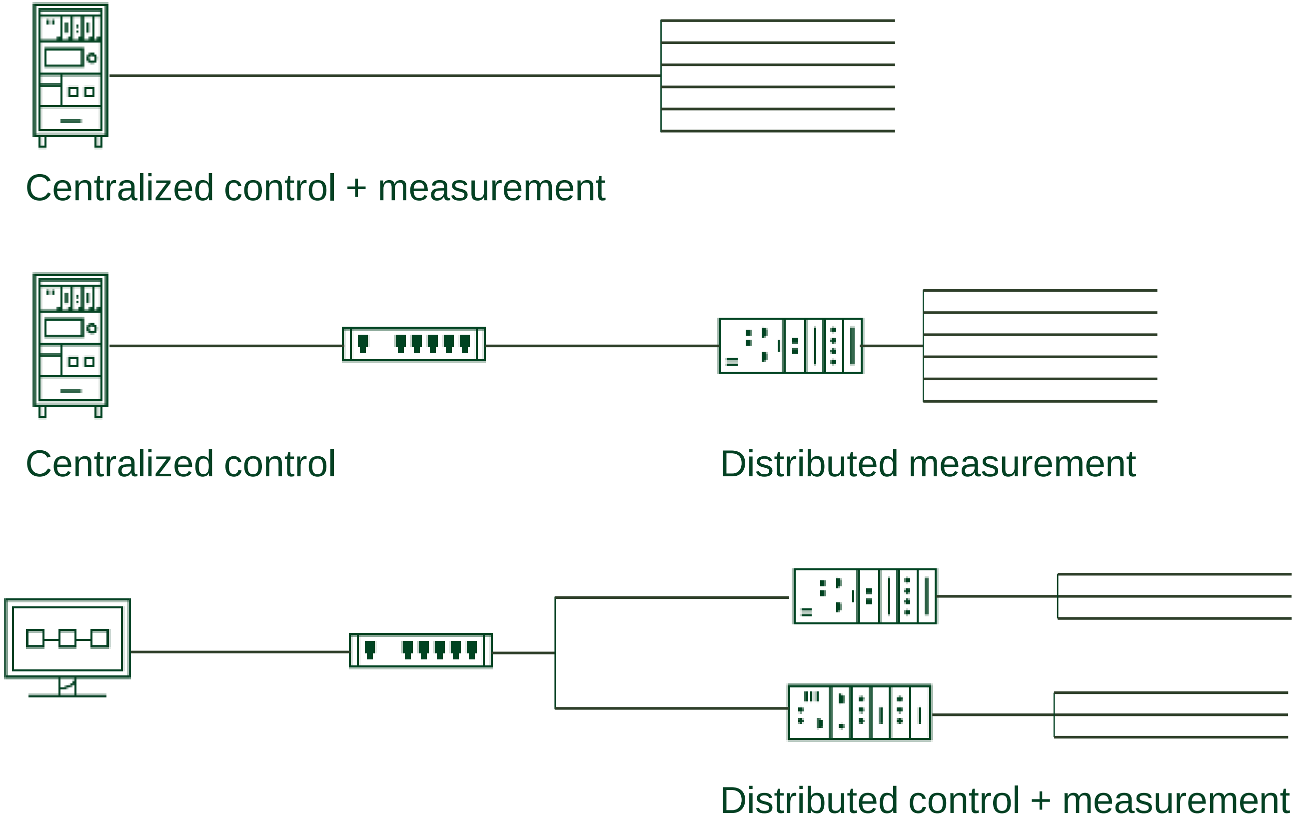
Identifying Risk Profile



Good System Design Choices



System Architecture Options



System Architecture Options

Centralized control + measurement

PXI

Centralized control

Distributed measurement

cDAQ

Distributed control + measurement

cRIO

PXI Options

OS:
- Windows
- Linux
- Linux Real-time

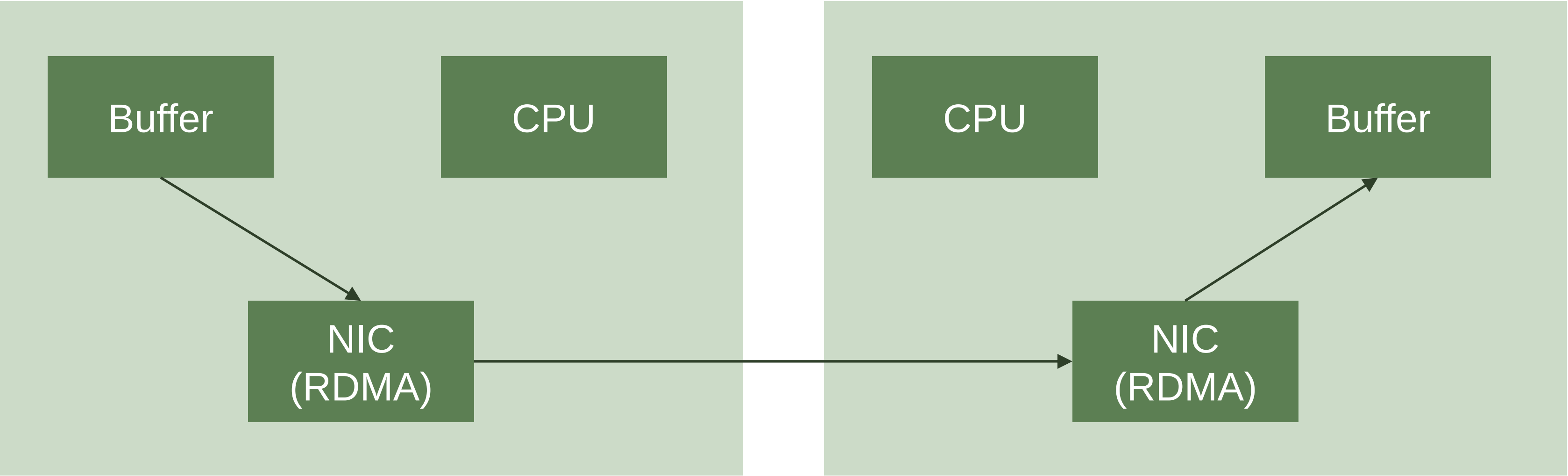
VCXO/OCXO oscillator options for timing

RDMA for communication

RDMA

Data transfer without CPUs to reduce latency and jitter

Available with PXIe-8285 and NI-RDMA driver



CompactRIO Options

Ethernet

Standard ethernet communications – TCP, UDP, etc.

Dual-port ethernet can be used in redundant topologies

TSN

NI cDAQ and cRIO devices support TSN timing

EtherCAT

NI-9145 support EtherCAT

Requires master running RT-OS in the network

Software options to manage risk

Operating System

Windows
Linux
Real-Time

Platform

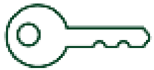
C/C#/C++
Python
Assembly
LabVIEW
Pre-written application

Architecture

Central / distributed
Monolithic / modular
Data brokering

Communication

TCP
UDP
EtherCAT
Shared memory
High/low level



Key to success: Good risk profile definition

- What determinism do I need? → Windows or Real-Time OS
- What level of reliability do I need? → Assembly or LabVIEW
- What happens in loss of network? → Central or distributed architecture
- Can I tolerate lost data points? → TCP or UDP

Communication options

7 Application

6 Presentation

5 Session

4 Transport

3 Network

2 Data Link

1 Physical

OSI Network Model

gRPC Modbus PROFINET HTTP FTP

HTML

SSL/TLS

RPC

TCP UDP RDMA

IP

Ethernet

EtherCAT TSN

CAT5

RS-485/232

Communication options

	Latency	Jitter	Reliability	Comments
TCP	−	−	+	Use existing network Re-transmit on failure
UDP	/	+	−	Use existing network Broadcast Latest value available
RDMA	+	+	/	Requires new network components
EtherCAT	+	+	+	Requires additional master device.
gRPC	/	/	/	Many options for deployment.

DISTRIBUTED CONTROL AND MEASUREMENT SYSTEMS FOR ROCKET TESTING

ALAN SAUCEDO – GROUND SOFTWARE ENGINEER

Rocket Factory Augsburg AG (RFA) is a German New Space start-up located in Augsburg. It was founded in 2018 with the mission to build rockets just like cars. Its multistage rocket, **RFA One**, is currently under development and scheduled to launch in late 2023.

RFA Rocket Factory

FOUNDED
2018

TEAM MEMBERS
220

AVERAGE AGE
29

NATIONALITIES
38

LabVIEW

Alma automotive

roketsan

CERN

3D PRINTED ROCKET ENGINE PARTS

RFA Rocket Factory

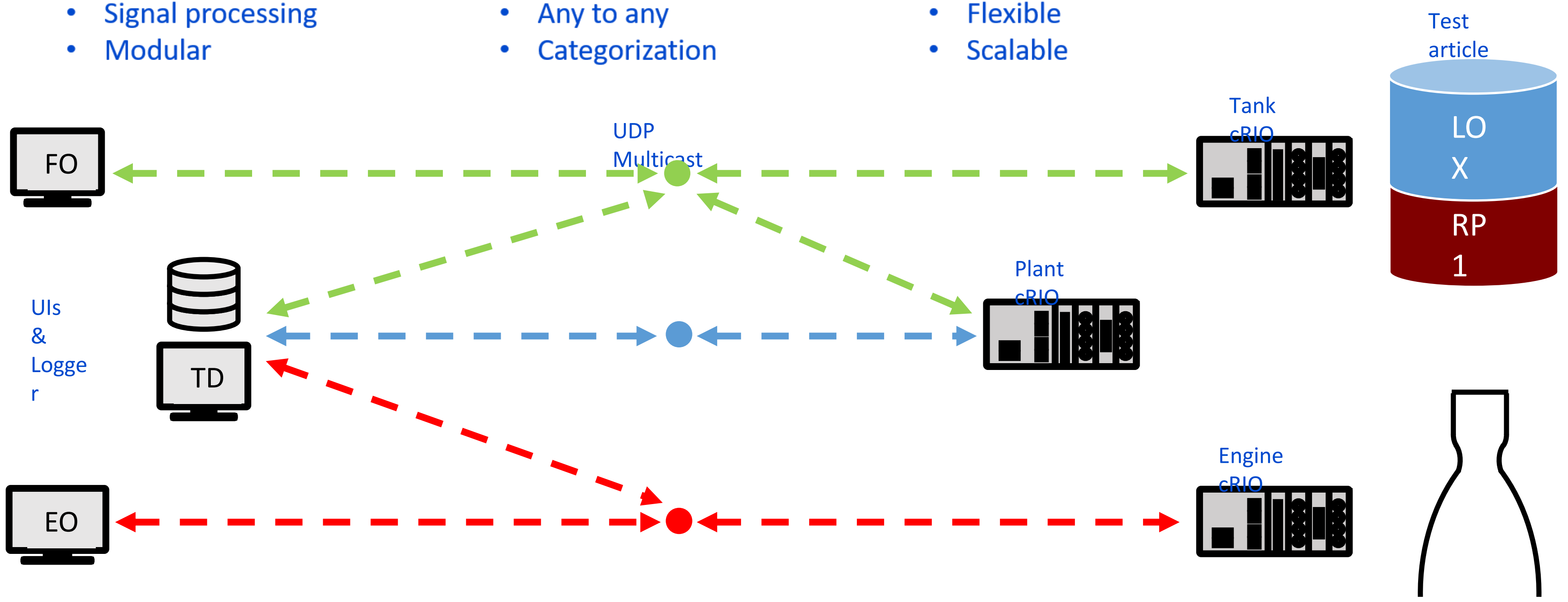
- Flexible design
- Rapid prototyping
- Predictable and controllable timescales and costs

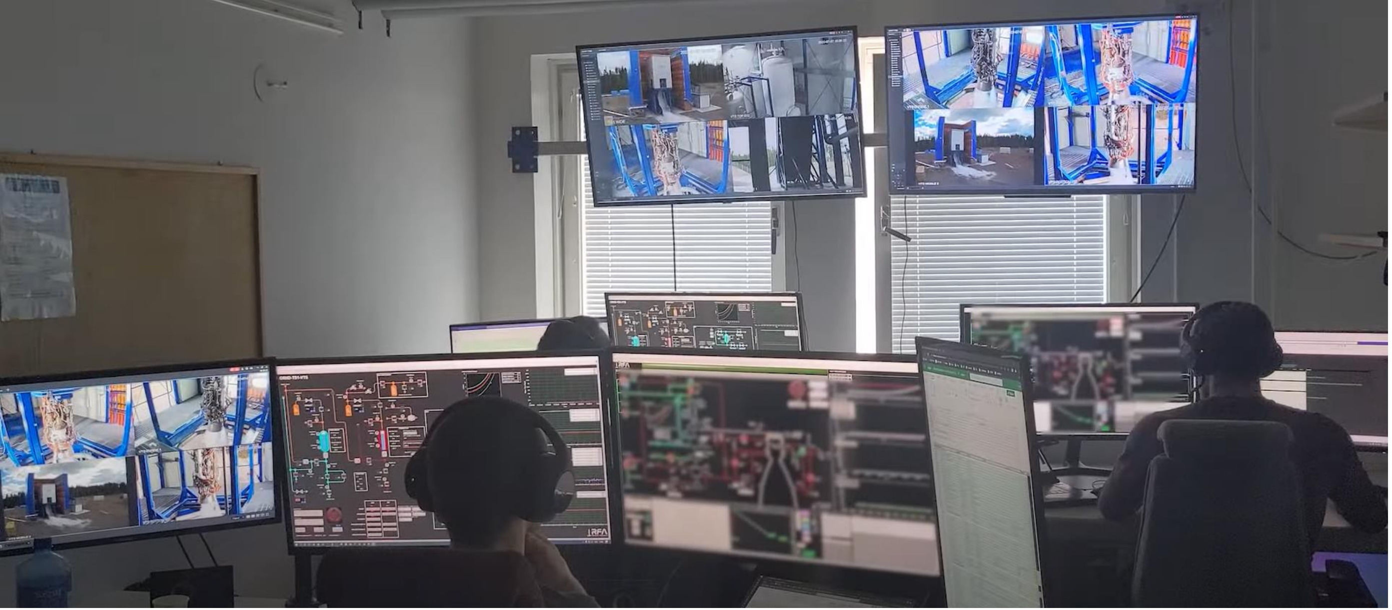
DECISIONS BEHIND BUILDING A RELIABLE DISTRIBUTED CONTROL AND MEASUREMENT SYSTEM

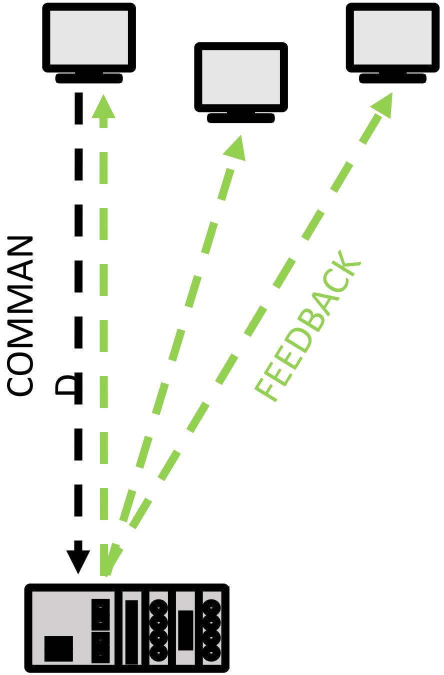
Control & DAQ
- Industrial-grade
- High-speed control
- Signal processing
- Modular

Communications
- Standard protocol
- Low latency
- Any to any
- Categorization

Software
- Deterministic
- Configurable
- Flexible
- Scalable







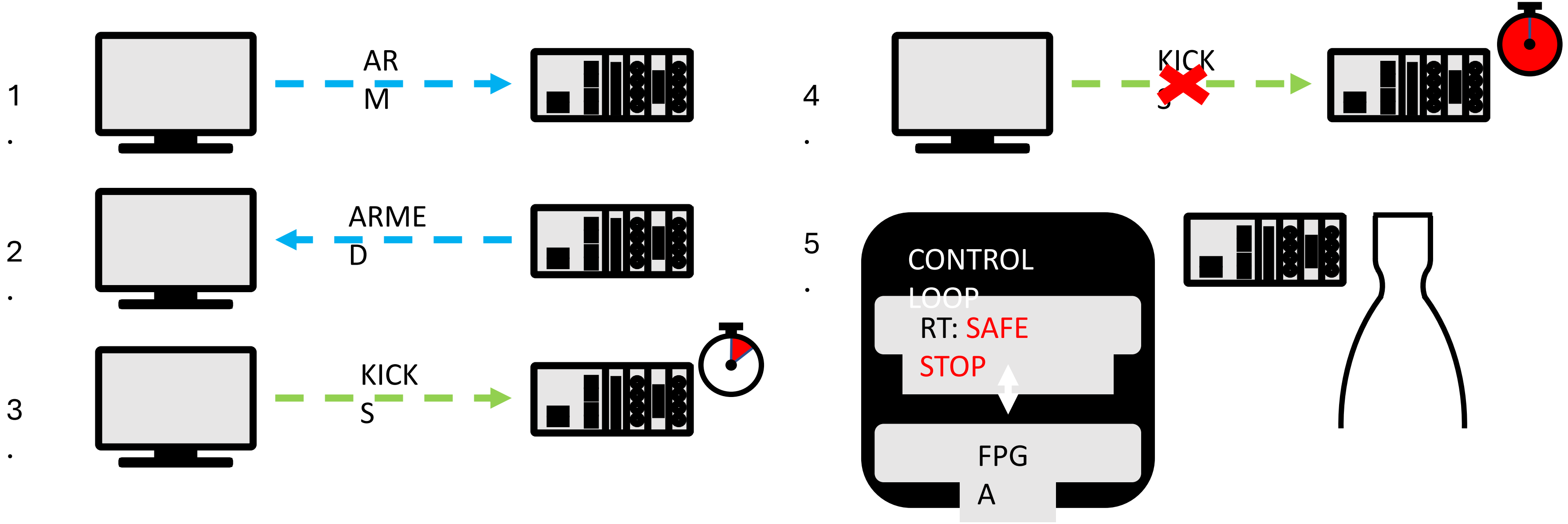
USER INTERFACES

- Real-time sensor data
- Control manipulation reflection
- Command acknowledgement
- Actuator feedback
- Configuration of sequence execution
- Health status from control system
- Launch and listen
- **Watchdog timer on demand**

WATCHDOG TIMER

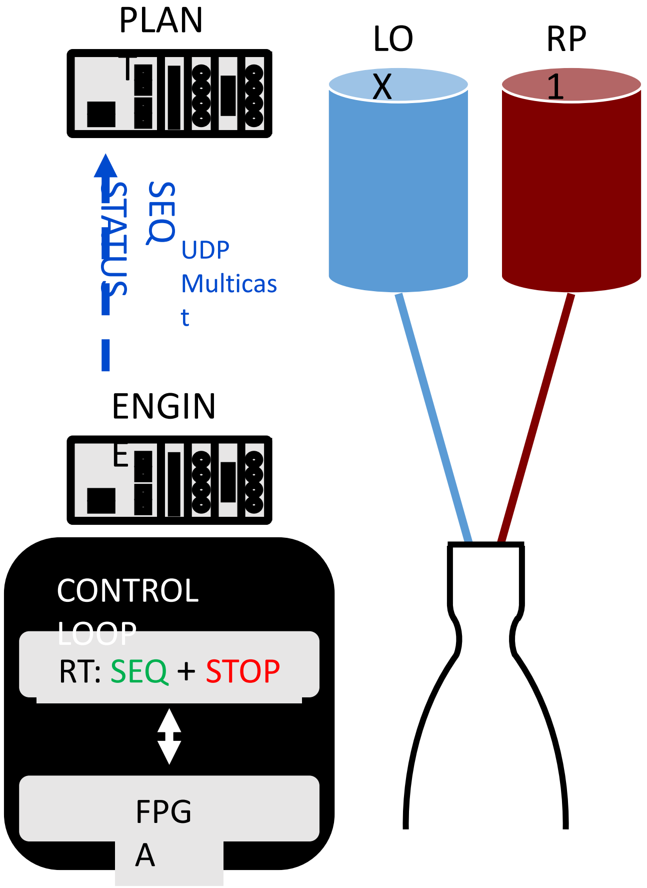
- Self-reliant software-based timer used to detect a malfunction in the network connection or responsiveness of the monitoring and control interface which triggers a safe shutdown sequence of the plant and test article.

HOW DOES IT WORK?



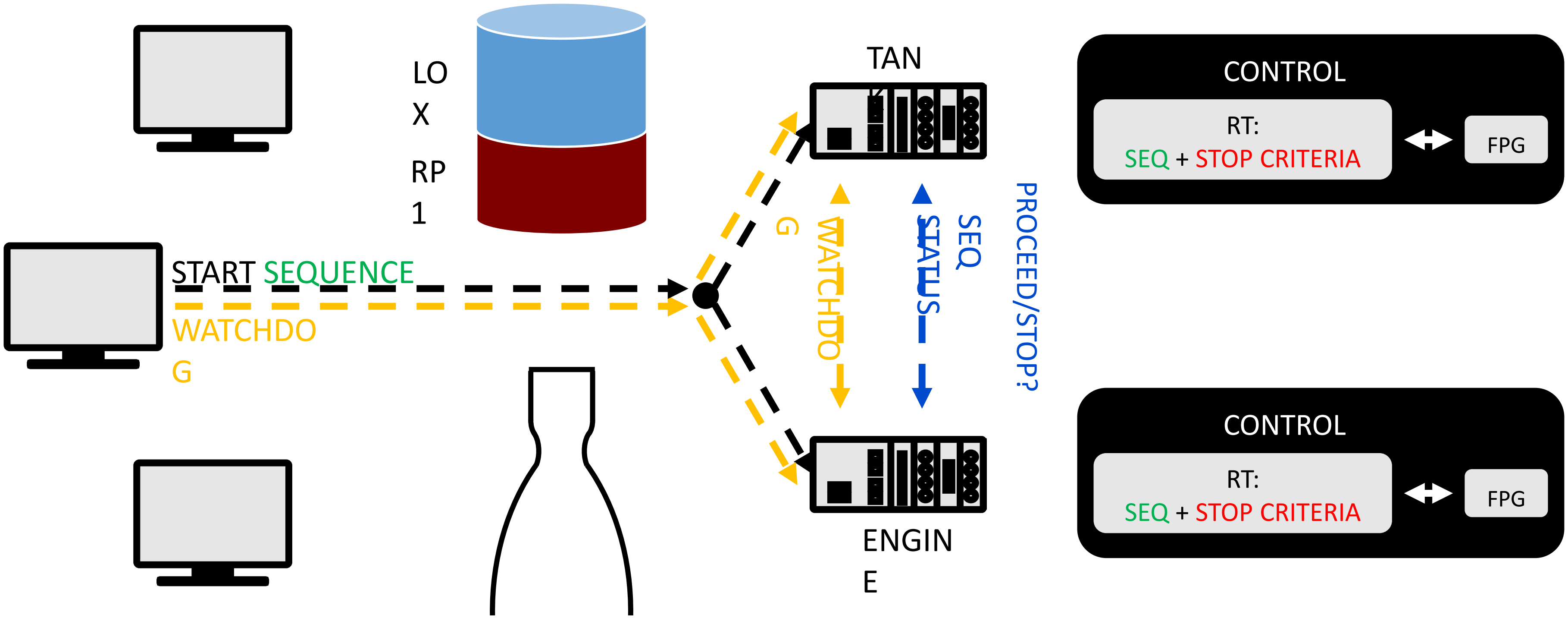
ENGINE TEST

- Sequence + abort criteria executed in real-time
- Cross-platform communication for event triggering based on sequence status
- Measurement timestamping at source



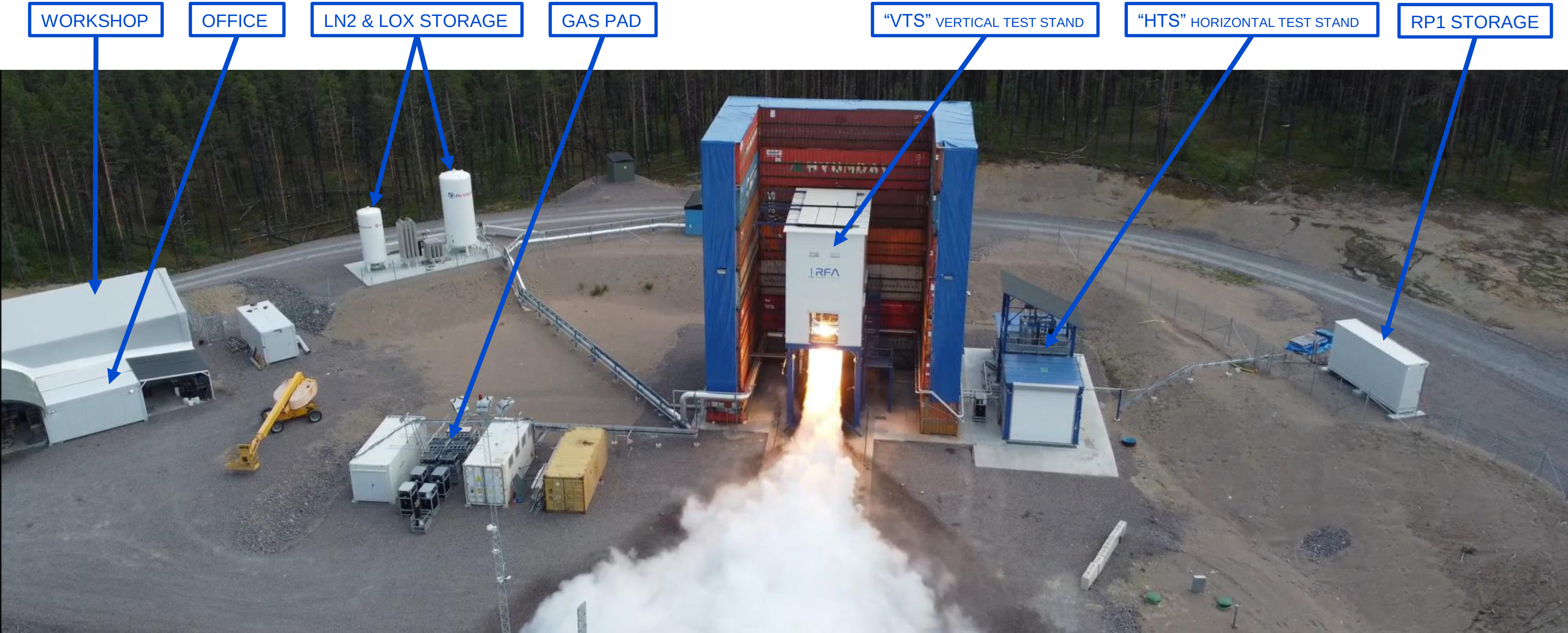

RFA

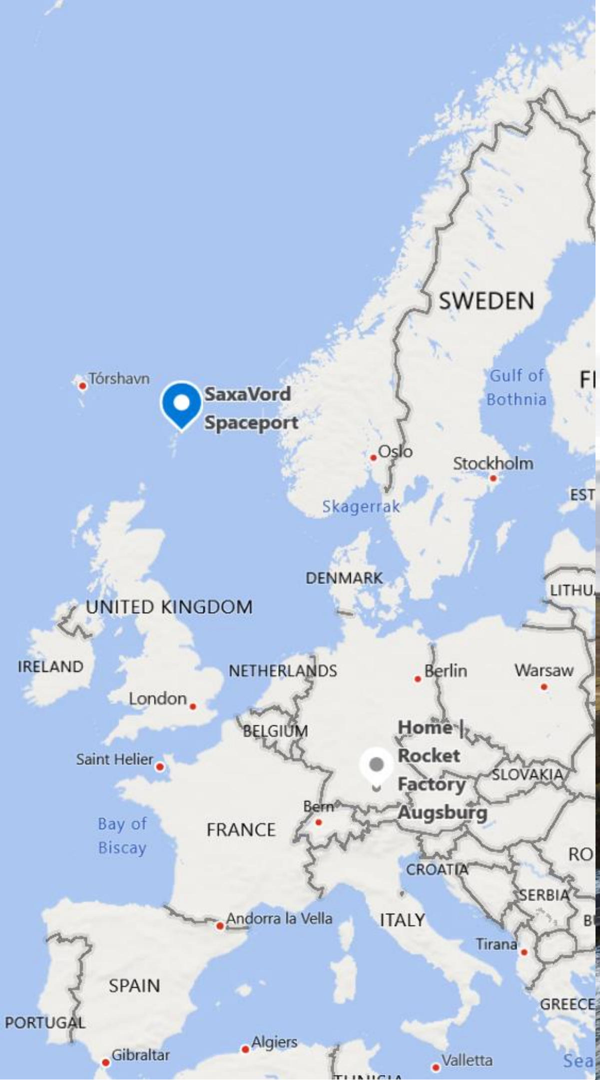
SECOND STAGE TEST



TEST SITE IN KIRUNA, SWEDEN (2022)

- ~ 520 sensors
- ~ 170 actuators
- 9 cRIOs



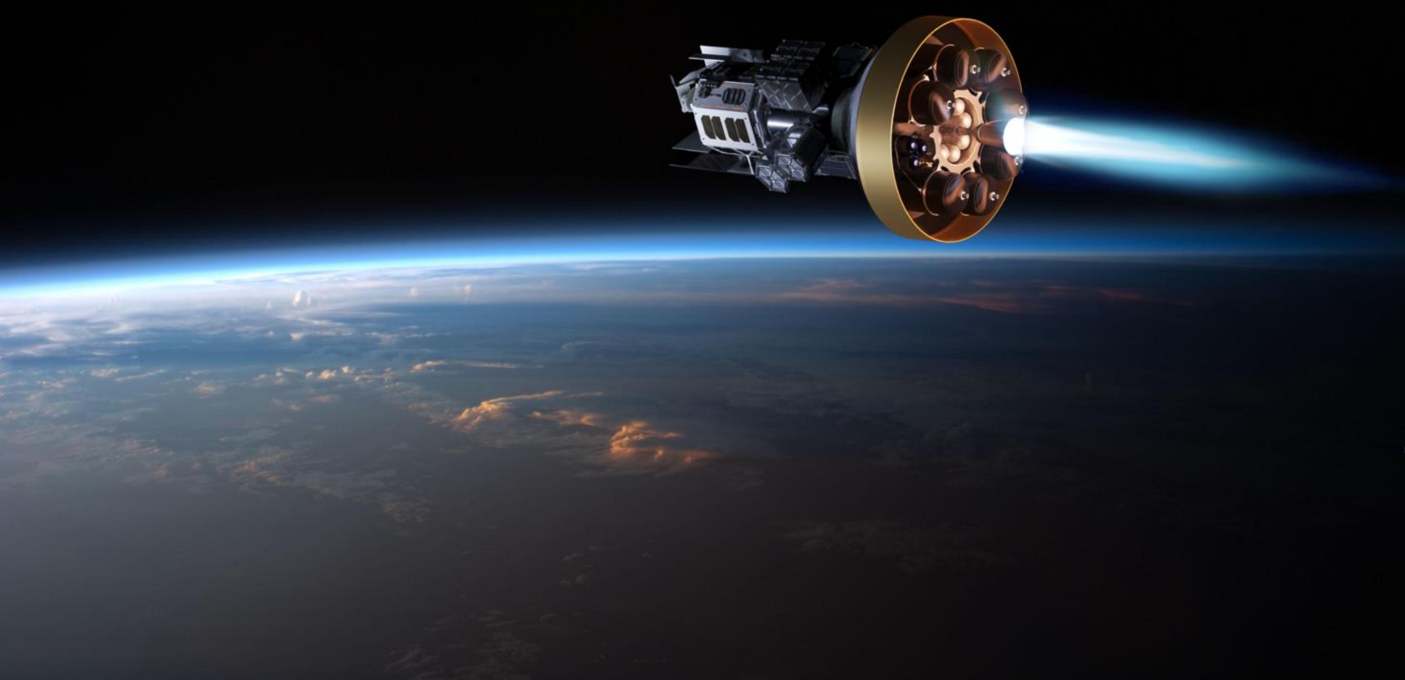


SAXAVORD UK SPACEPORT

RFA Rocket Factory


RFA
Rocket Factory
SAXAVORD
UK SPACE PORT
STREAMLINE

Thank you for joining our mission



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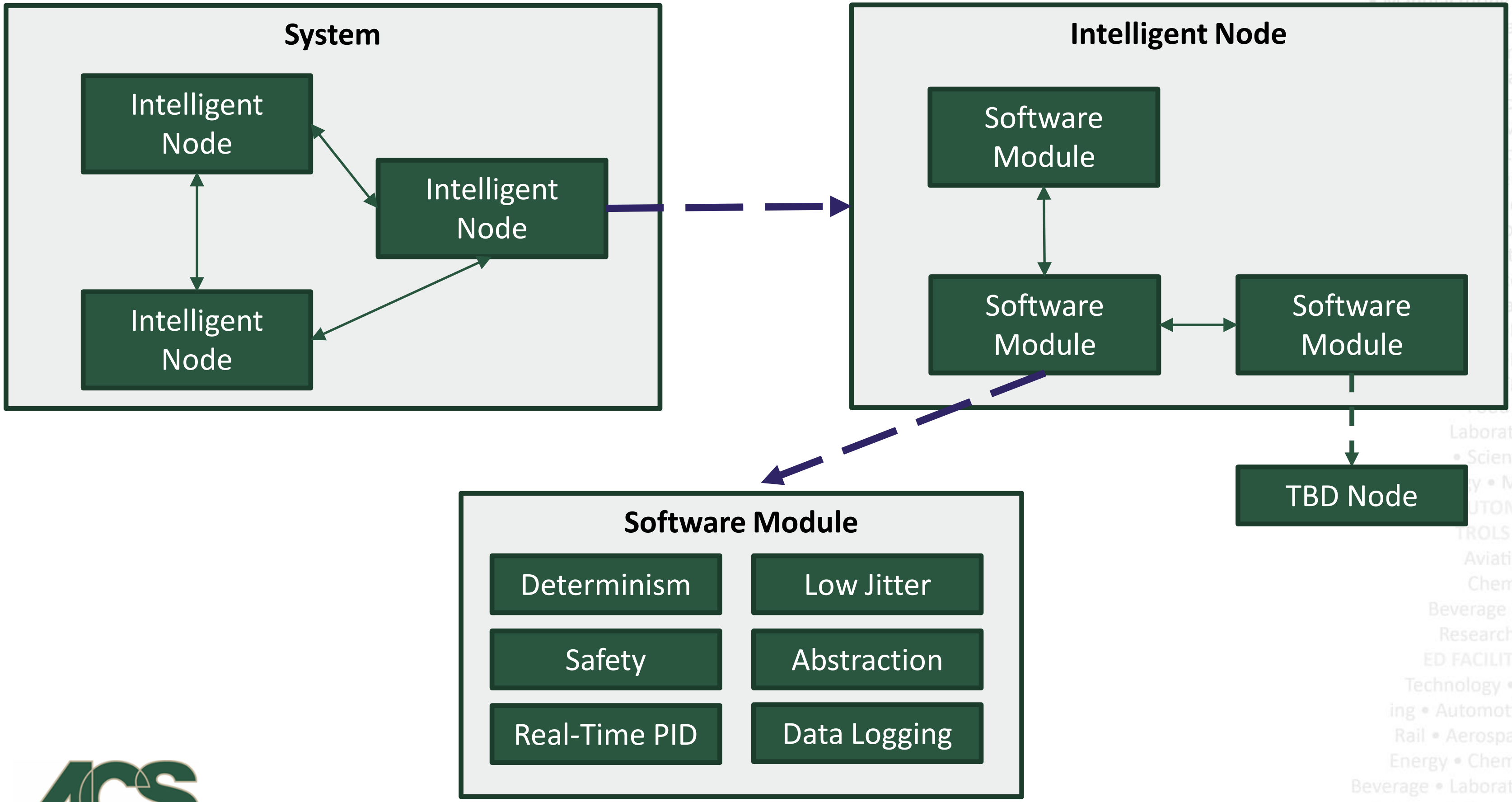
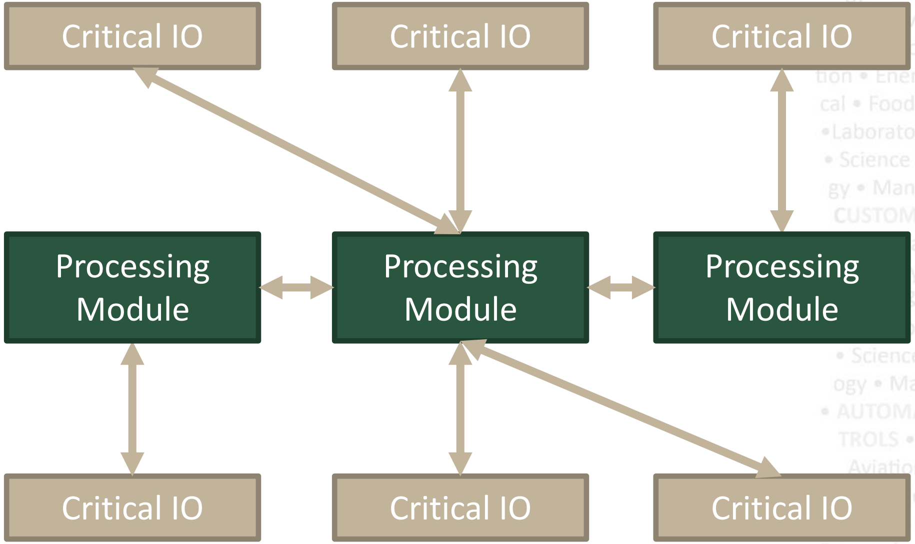
DELIVERING SOLUTIONS **BUILDING TRUST**

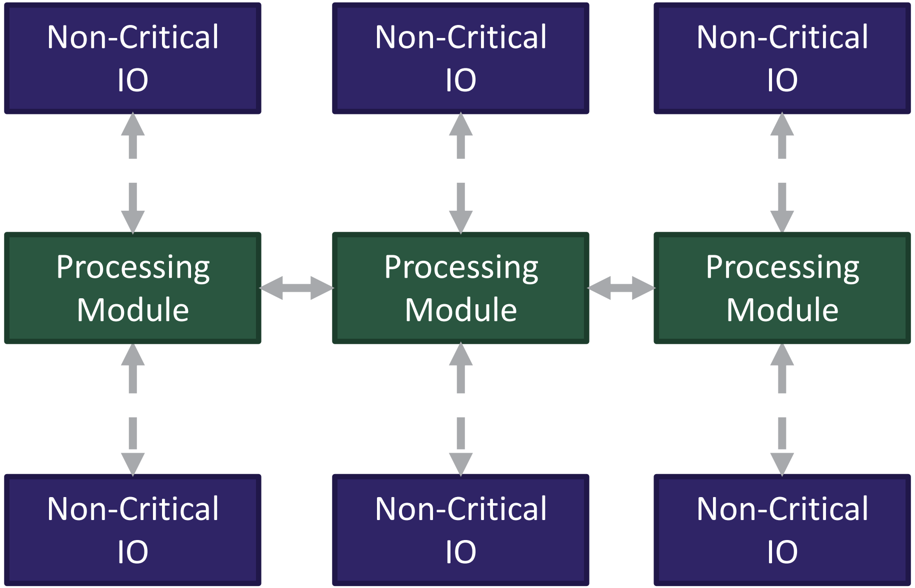
Integrated Facility, Equipment, and Controls Solutions


System
Intelligent Node
Intelligent Node
Intelligent Node
Intelligent Node
Software Module
Software Module
Software Module
TBD Node
Software Module
Determinism
Low Jitter
Safety
Abstraction
Real-Time PID
Data Logging

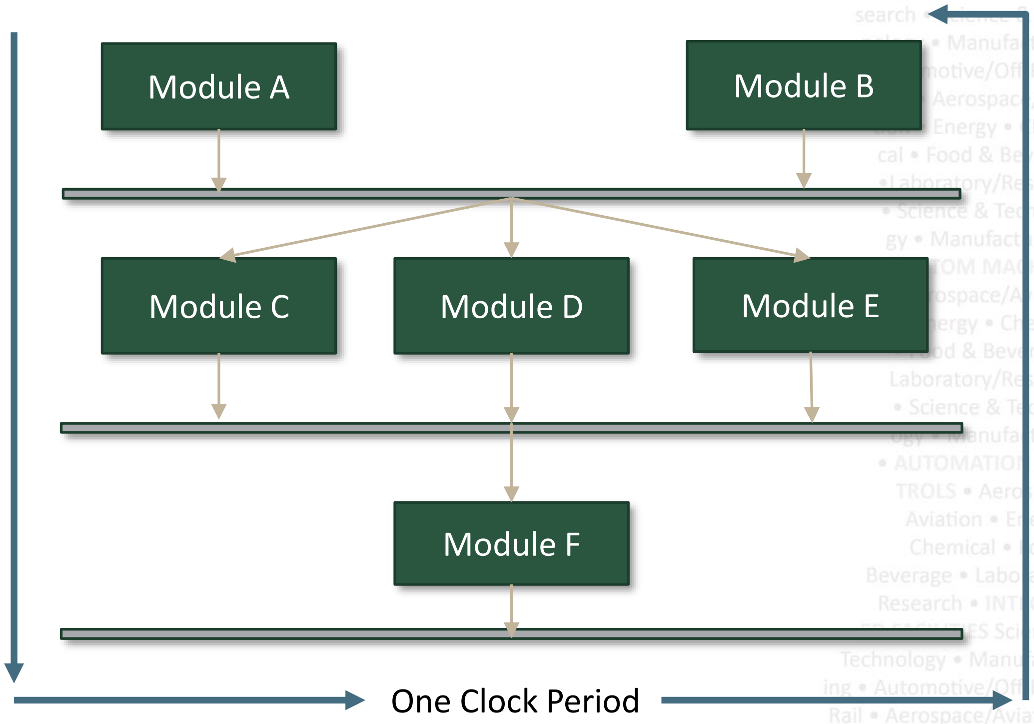
- Deterministic communication
  - Internal real-time FIFOs
  - TSN
  - FPGA
  - DDS
  - Reflective memory
  - EtherCAT
  - CAN



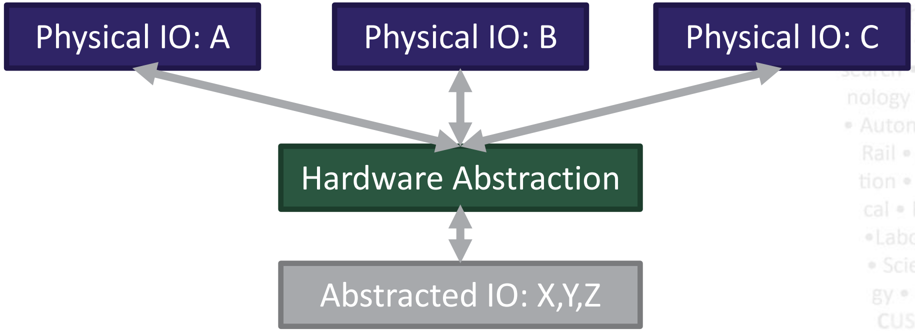
- Asynchronous communication
  - TCP/IP
  - Modbus
  - Serial
  - Queued messaging

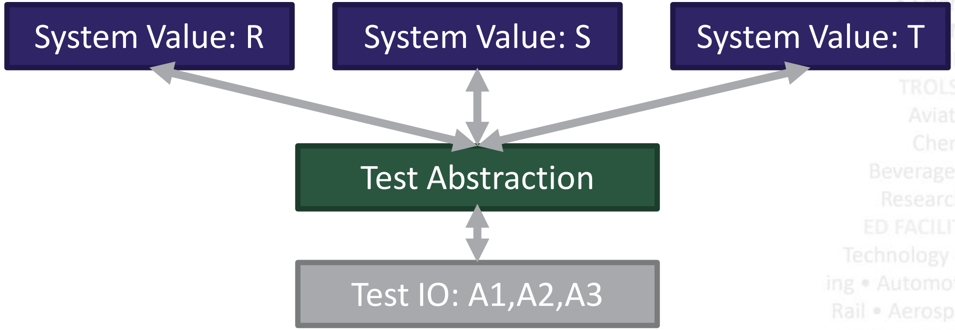


- Processing jitter
  - Range of processing time within a processing loop
  - Minimize the time variance
  - OS dependent component
  - Architecture and coding component



- Abstraction
  - Remove reliance on specific hardware channels
  - Minimize reliance on specific system channels





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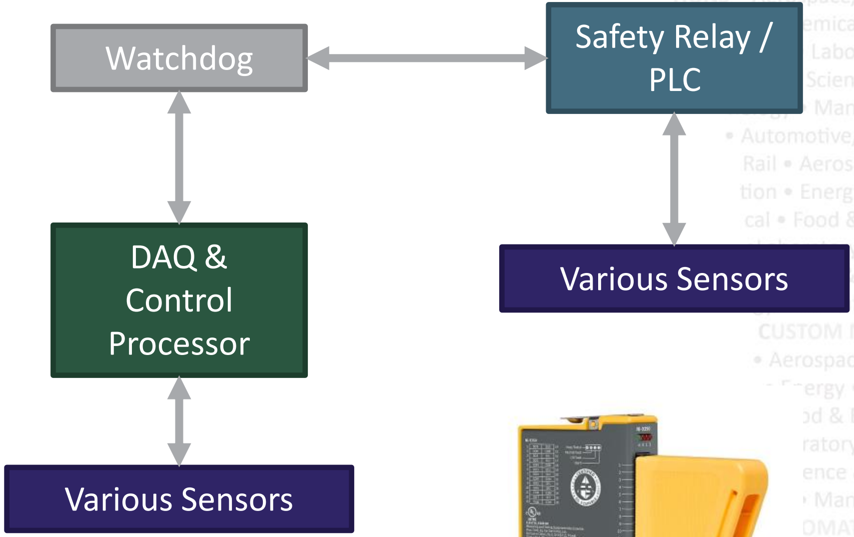
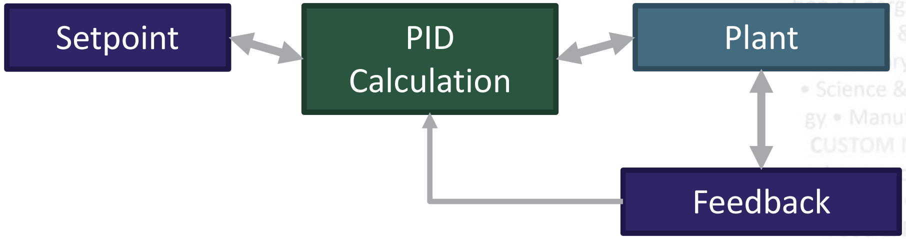
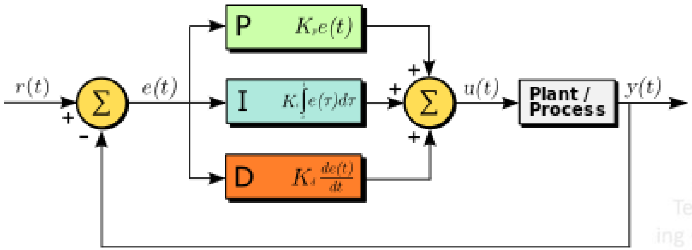
- Safety and limits
  - Monitoring safety critical events in hardware - safety rated
  - Monitor health of main control system – watchdogs
  - Monitor general system limits – software
  - Redundancy



- Real-Time Control
  - Closed-loop PID (proportional, integral, derivative)
  - Deterministic calculation within a clock cycle
  - Digital loops with adjustable output, feedback and setpoint selection
  - Custom algorithm support





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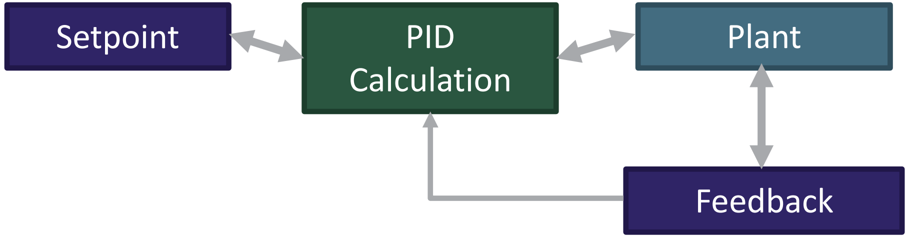
- Test Profiles
    - Parallel threads
    - Sequential options



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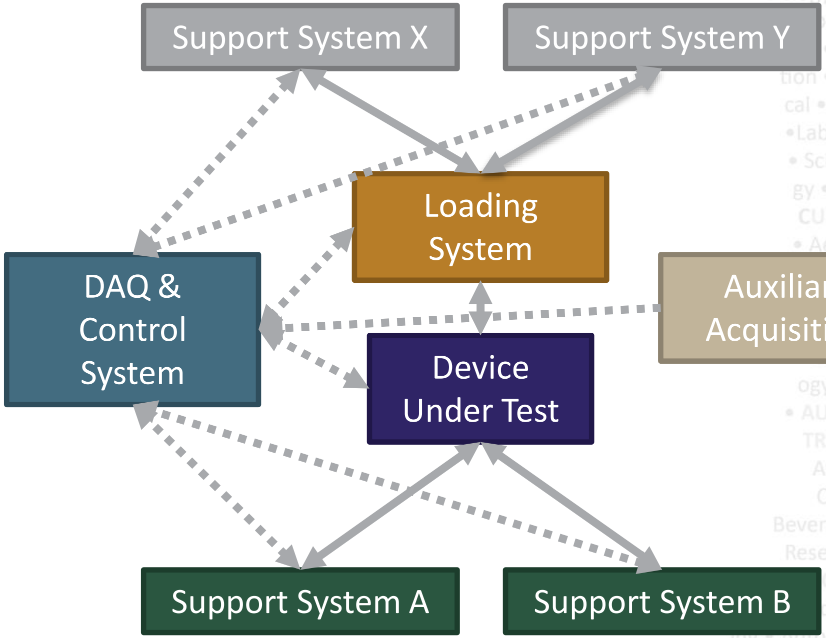
- Flexibility
  - Accommodate wide variety and quantity of subsystems
  - Versatility to handle various types of devices under test
  - Small, medium and high channel count support
  - Support for customization and expansion
  - Additional acquisition devices such as oscilloscopes, power meters, etc.



Application Examples

Aerospace – R&D/V&V Landing Gear Control System Upgrade

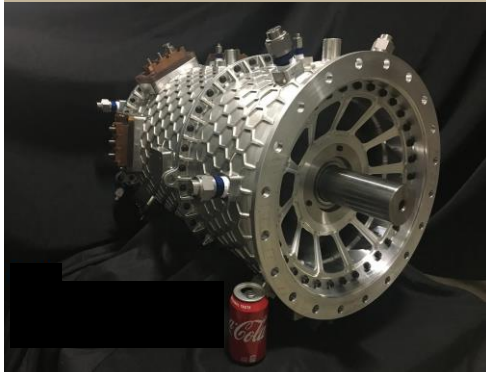
Transportation – R&D eAxle Test System

Aerospace – R&D Thermal Management

Transportation – R&D High-Speed eMotor Test System

Aerospace – ATP EOL Fuel Pump Test System

Aerospace – R&D 2MW eMotor



Aerospace – R&D/V&V Flight Control SiL/HiL Control System

Aerospace – R&D eActuator Test System

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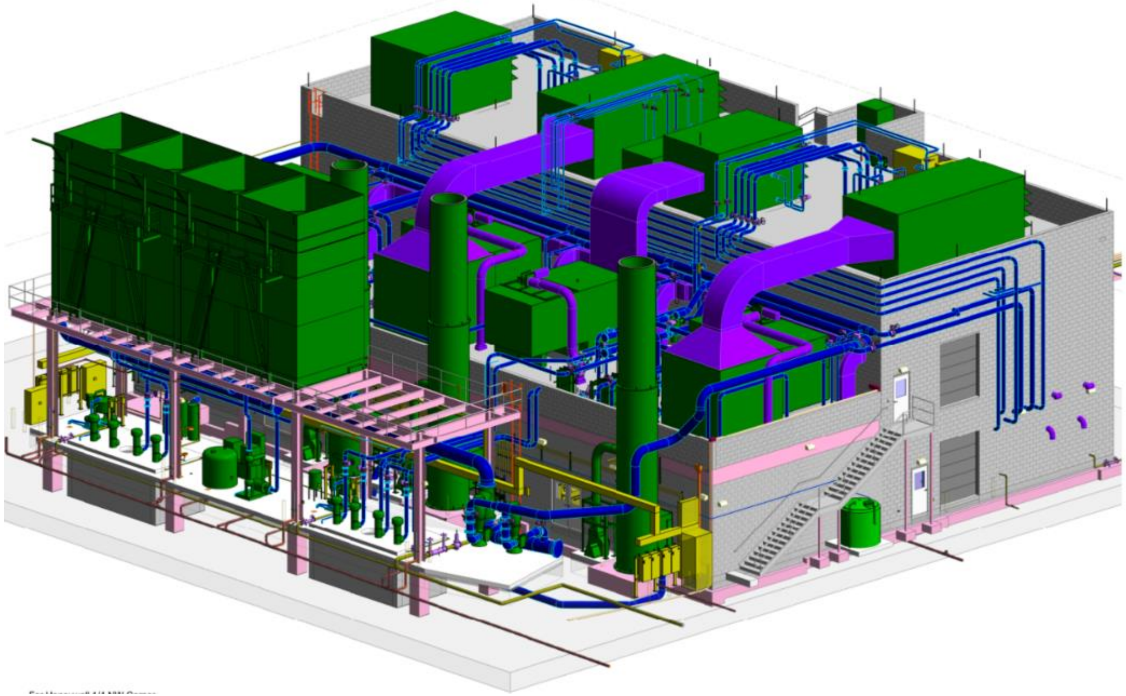
Key Benefits

- Standardization
  - Standardize at a framework and architecture level not application level. Users are capable of creating custom GUIs, custom modules, but all using a framework and industry standards.
- Quicker ROI
  - Utilize existing framework modules and DAQ engines to quickly build test systems, leaving more time to focus on value-added tasks such as test article test profiles, custom GUIs, and machine control logic.
- Lower Costs
  - Not only build test systems faster, but the one-time purchase cost and optional yearly subscription fees for site-wide usage is a relatively low total cost.
- Reduced Support and Maintenance
  - A familiar and consistent framework provides for simplified training and understanding, and support services are available from internal resources, ACS, or any integrator familiar with the framework or LabVIEW. Original source code for each project stored in our secure GitHub repository.
- Licensed Open Source
  - Customers are free to use and modify the framework source as they see fit across their facility and can decide to upgrade on their schedule.
- Continuous Improvement
  - The framework itself continues to improve through contributions by ACS, integrators and the LabVIEW community with all updates available to subscribed customers. Customizations considered proprietary or customer specific are not shared with the community.
- Reduced Obsolescence
  - The modularity of the source code reduces the impact of obsolescence as hardware is abstracted from all but a single software module.

- Design and build a new turboshaft test facility for turboshaft engine testing

We Provided:

- Turnkey, single source design and construction
- Phased approach for complete design build.
- Mechanical systems
- Control system
- Safety system
- Tempered engine air make-up
- Custom ACS controls solutions
- Commissioning and acceptance testing



Turboshaft Engine Test Facility (Exterior)

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Aerospace Test Campus

- Upgraded existing test facilities with supporting infrastructure and site improvements
- Designed and built an entire new cell for rocket engine testing

We Provided:

- Turnkey, single source design and construction
- Phased approach for site wide renovation and expansion
- Custom ACS controls solutions
- Commissioning and acceptance testing

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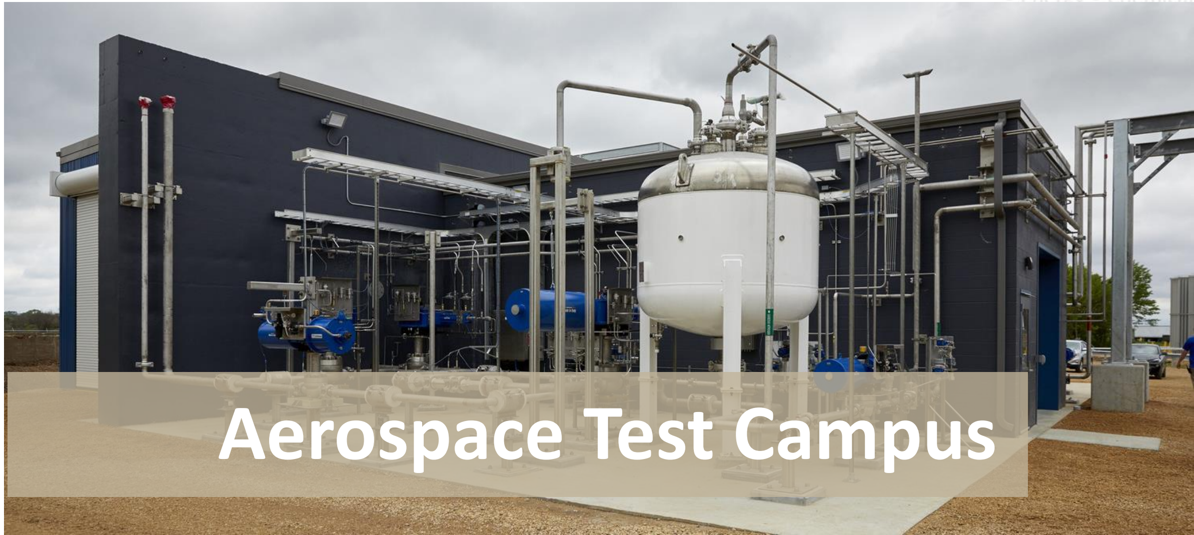

- R&D test firing of Sierra Nevada Corporation (SNC) patented *VORTEX*® engine
- Test in horizontal & vertical positions
- Multiple fuels
- Remote control room connected via CCTV and PLC communications

We Provided:

- Turkey design build of new test cell
- Systems integration

Rocket Engine Test Cell

Credit: Sierra Nevada Corporation

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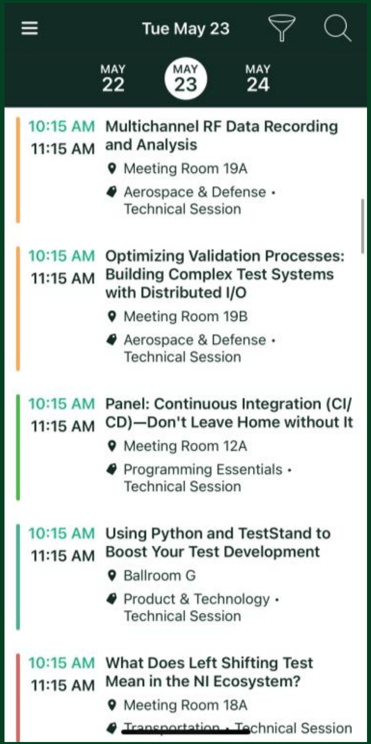

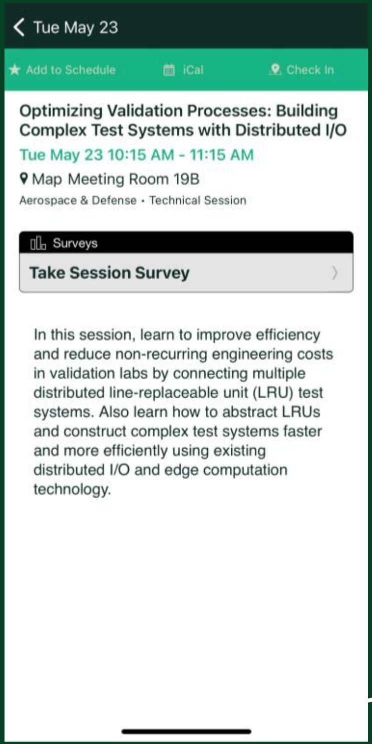

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