SOLUTION BROCHURE

Rocket Engine Test Systems

Modern architecture to meet rocket test challenges

Rocket Engine Test Architecture Advantages

- Improves the performance of subsystems by enforcing system independence, avoiding delays due to slower systems.
- Simplifies system maintenance by providing loosely coupled subsystems that can be easily updated to integrate new technologies.
- Enforces a common framework across architecture systems to simplify development and lower maintenance costs.
- Provides flexibility to allow the architecture to grow as the facility grows to support larger numbers of rocket test stands and support systems.

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Rocket Test Overview

There were more orbital attempts made in 2021 than any previous year in history (1). Companies and governments around the world attempted 146 flights, with 135 successful orbits. The first six months of 2022 saw this trend continue with 72 successful flights. And 2021 broke the previous record of 139 attempts set at the height of the space race in in 1967 as the USSR and USA competed heavily to get to space and beyond. The space race of the 2020s includes more than just two countries—with launches now representing USA, UK, Europe, Russia, China, India, Turkey, Iran, Israel, and others. And the race is no longer a government project; many private space companies are competing, bringing large amounts of investor money into the market.

New rocket technologies are enabling this surge in space launches. SpaceX launched 31 Falcon 9 missions in 2021, all of them successfully. Their new approach to rocket design allowed them to launch all these missions using previously used rocket cores—only two new Falcon 9 first stages were introduced to support these launches. As these companies and countries continue to invest in making space launch more reliable, reusable, and affordable the number of launches and the reach of those launches will continue to increase.

The infrastructure to support these launches is increasing as well. There are 35 active spaceports and launch facilities that can support suborbital, orbital, and extra-orbital missions. The list of locations spans the globe, including all the continents and more than 13 countries (2). Additional countries are building new facilities now. And additional sites are used for testing the rockets that launch from those facilities. It’s an exciting time to be part of the space industry.

The FAA regulates rocket launches for any launches on U.S. soil, or outside of the U.S. for any launch by a U.S. citizen or entity (3). Other countries have similar regulations and regulatory bodies. A company cannot launch into space without working through the proper engineering steps. One of those critical steps is to test the rocket vehicle and demonstrate that it has a high likelihood of success.

Testing a rocket starts by testing the various components of the rocket. Engineering teams separately test the materials and components that will make up the structure, the fuels, and the electronics. Those components are then assembled and tested as subsystems, and finally fully assembled into a full stage-level acceptance test.

NI products are used across all aspects of the vehicle. The static and fatigue structural testing platform (4) is ideal for testing the strength of the fuel tank to survive the stress of a flight. NI’s PXI-based modular instruments and automated test software provide a powerful platform for testing the avionics circuitry. NI’s LRU HIL test architecture (5) is ideal for generating a variety of test cases to test avionics controllers. Learn more about these and other solutions at ni.com/space.

This paper focuses on testing the rocket engine, but many of the elements will apply to the final full vehicle test as well.

Rocket engine testing is a vital part of testing all rocket engine types; this testing is required to meet FAA regulations. But testing provides value beyond meeting regulations. A NASA report demonstrated that there was a positive correlation between the amount of time spent testing rocket engines and the reliability of those engines (6). Each engine manufacturer must decide how to balance the investment and cost of additional testing and the expected benefit of that testing.

To test a rocket engine, the engine is mounted into a test stand and fired for a limited amount of time. The test stand must provide a necessary hold-down thrust structure, ground support equipment for propellants, cooling, diversion, and exhaust, as well as a control system to automate the test and maintain safety throughout operations and testing. Engineers must decide if the rocket will be mounted vertically or horizontally—there are advantages for either orientation. It is easier to correlate measurements to a vertically mounted engine because the forces are more like the forces experienced during flight. But a vertically mounted engine presents a problem of routing the exhaust away from the rocket during the test, which is usually done with a flame diverter.

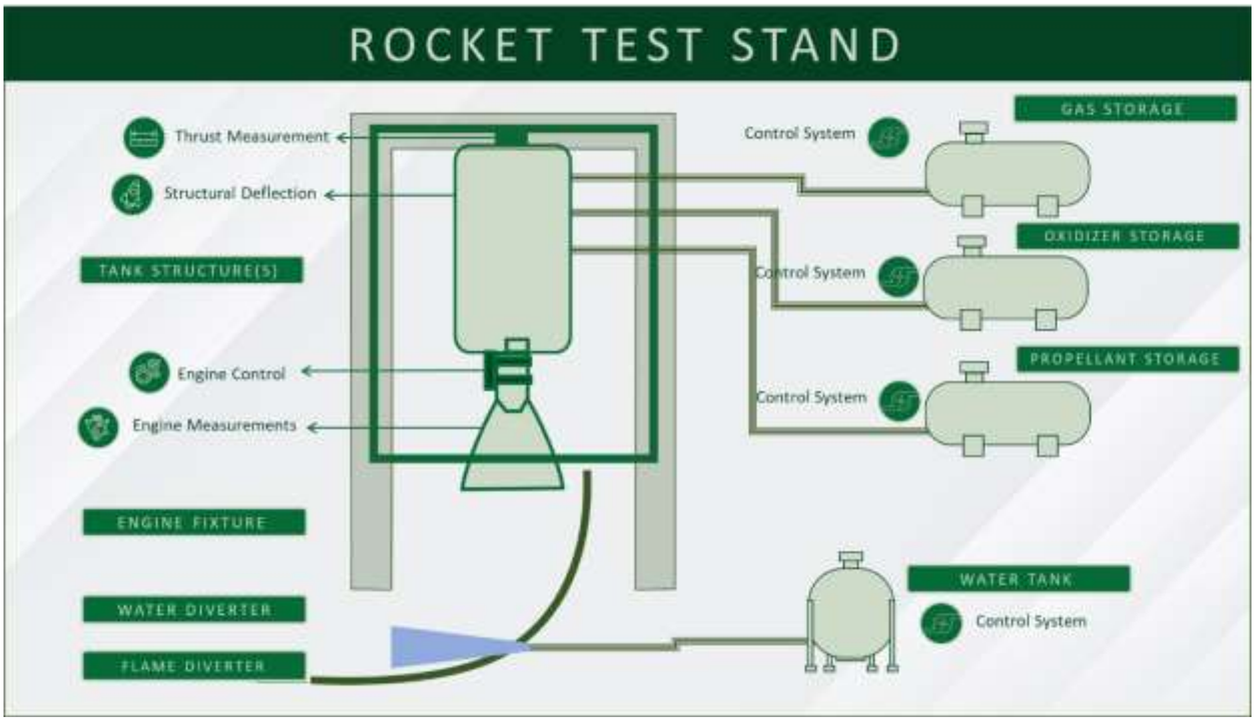


Figure 1. Elements of a Rocket Test Stand

The exhaust poses several challenges to the test facility. In addition to the heat, the exhaust is noisy and dirty. Adding a water deluge to the exhaust can provide a cushion to carry heat away from the engine, and a shield to dampen noise and contaminates from the surrounding community.

There are many variations on a rocket engine test. A standard, sea-level test may be performed on a test stand without a lot of additional equipment, but other tests may require specialized test environments. For example, to test a rocket thruster for attitude control on a satellite in space, the test stand requires a vacuum chamber to replicate the intended operating conditions of the engine. Other tests may require thermal vacuum chamber, or additional mechanical devices to test the engine gimbal.

Test stations also vary based on the stage of the engine development. An early development engine test may include many additional sensors as engineers try to capture more dynamics of the engine performance. A test stand performing qualification or acceptance testing prior to flight duty may test a smaller set of signals that verify proper operation.

An engineering team tasked with designing a rocket test must consider all these potential needs when designing a new test stand. With rocket technology evolving as fast as it is right now, engineers must also plan for tests that might be required in the future. The test design must be powerful enough to meet the known needs, and flexible enough to meet the needs as they evolve over time.

NI engineers have worked closely with engineers designing rocket test systems for more than 30 years. Over this time, architectures have matured with the introduction of new technologies and software techniques. Best practices from related applications—jet engine testing, wind tunnels, and other large test facilities—have influenced the design of systems used to test rocket engines. Some key principles have emerged as core to the success of an architectural design to test rocket engines.

A rocket test facility may support a single test stand, or multiple test stands. Each test stand requires support from various subsystems or pads, which may be dedicated to a stand or may be shared among multiple stands or sites within the test facility. A facility-wide ground control system supervisor brings all the pads and test stands together for coordinated operational management of the facility resources.

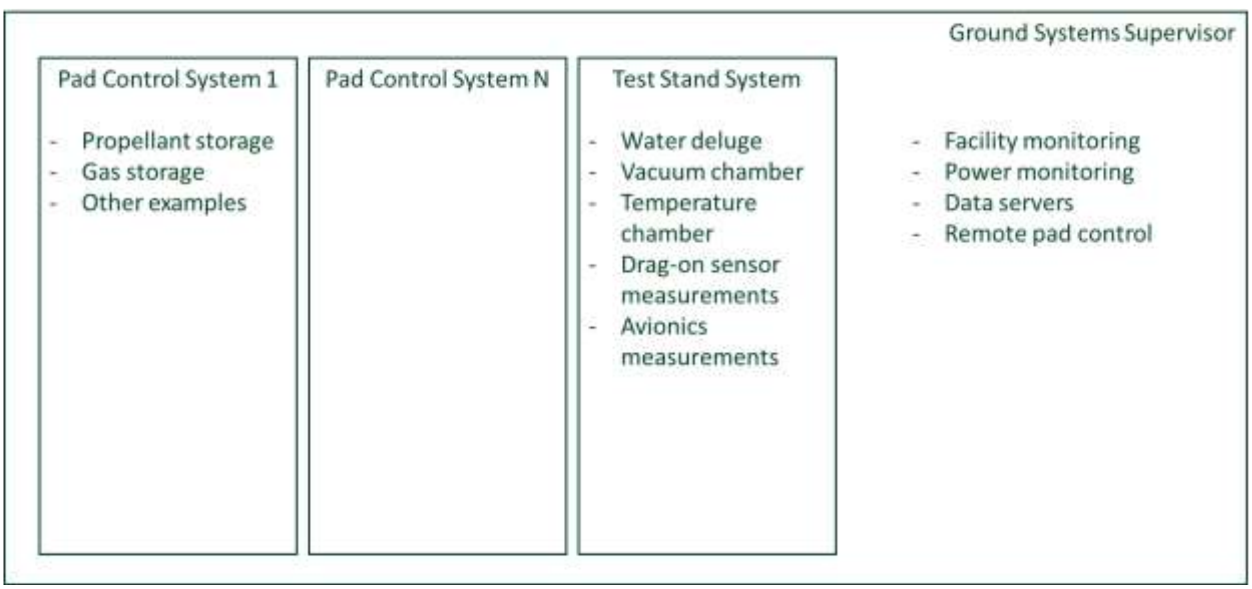


Figure 2. Rocket Test Facility Subsystems

Support pad control systems must provide reliability for control, as well as measurement capabilities to track and improve performance.

Successful implementation of a rocket test site requires careful coordination among these systems. Over the years, a control scheme has developed at major space facilities that provides a design pattern that is flexible to meet the communication among these systems and the variability of the systems between tests. At space companies that manage both test and launch facilities, many of the components of the pattern are shared, to reduce the differences between what is tested and how it is launched.

Rocket Test Architecture

This architecture uses a system design pattern common among all the test stands and pads. The pattern provides the local control needed by each system, while sharing information among systems to ensure synchronization of test operations.

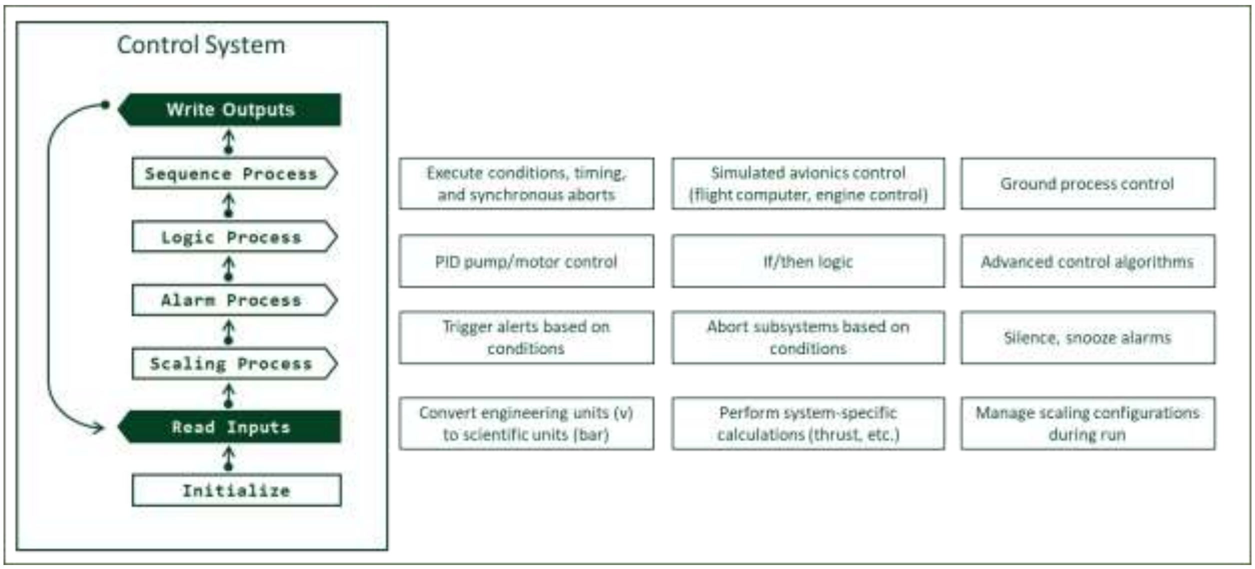


Figure 3. General Control System Design Pattern

In this pattern, control systems read inputs from communication processes described later in this paper.

A scaling process converts these raw units to scientific units appropriate to the subsystem. A scaling process may also combine multiple channels into a single calculated channel—for example, summing all the thrust load cells to provide a single thrust value. A scaling process also applies reconfigurable calibrations, as instrumentation can change between tests or during operations.

An alarm process evaluates the data points' output from the scaling process to identify alarms. Alarms may be classified into multiple categories, such as alerts to abort a test immediately or to notify an operator of a potential issue. An alarm process may manage the successful shutdown of a test sequence, or it may send commands to other systems to manage those actions. Test operators can design for an emergency stop or graceful shutdown using this architecture.

When there are no alarms to prevent test progress, a logic process analyzes the values from the read, scaling, and alarm processes to determine next actions. For example, a logic process may determine that the temperature of a fluid manifold has reached the point when it's time to open a valve to let a fluid flow through the pipeline (i.e., chilling in a Lox manifold), so it will issue a command to another remote subsystem, or it will pass a command to the sequence process to open the valve locally.

A sequence process then executes the actions determined by ordered and timed events with conditions (limits, boundaries, and redlines) developed by test operators and defined by flight requirements (simulated flight control) or launch/facility requirements (simulated launch or nominal test operations). Simple actions may be executed immediately; complex actions may spin off a parallel process to handle the sequential execution. A sequence process uses values from the read, logic, and alarm processes as inputs and updates the parallel sequence process outputs as necessary.

Figure 3 depicts these functions as a series of steps; but in application, this pattern allows for separate parallel modules which are running their own thread yet synchronize with the main operational orchestration thread. This allows the main thread to run at a consistent speed without stopping to wait for an action to complete. A control system loop typically operates between 1 Hz and 400 Hz, depending on the system being controlled.

This general design pattern can be applied to any control system, but in simple systems some elements may be optional or handled in a different system. For example, a simple motor controller may not have an alarm process; instead, the alarm conditions may be handled by another system based on the output of the system controlling the motor. Or, a simple system may not have a sequence process, instead being controlled directly by the logic process for very basic control systems or the sequence process of another control system via iDDS or gRPC, for example.

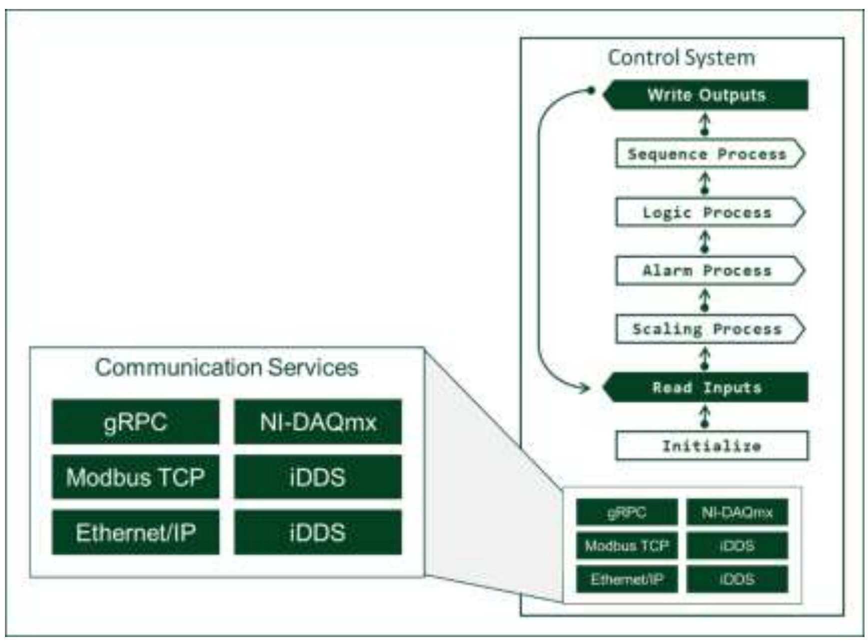


Figure 4. Communication Services

A control system reads and writes remote commands and telemetry through communication services (i.e., commanding a valve to open or starting a sequence on another remote control system controlling a support pad). These services are daemons or microservices that run in the background, instead of executing directly inside the main application. Using a service to communicate, instead of relying on the read inputs function itself, enables the main application to monitor the metrics of the microservice so that any issue does not impact the main application's execution., necessarily. This abstracts the communication away from the main control loop, making it easier to update equipment and configurations over time as new devices with new communication interfaces become available.

A few examples of communication services are listed in Figure 4, but there are many options for communications. The facility design team may establish a custom communication protocol for the facility, or they may select standard protocols that support the equipment used across the facility.

When purchasing new equipment, a key factor will be support for existing communication services at the facility. Controlling the number of communication protocols on the site simplifies the development and maintenance of the software. Using services improves the process when a new communication protocol is allowed.

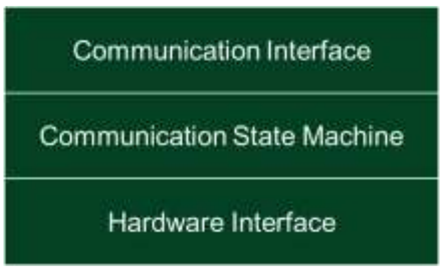


Figure 5. Communication Service Design Pattern

Each communication service will need to be designed to meet the needs of a devices and protocol.

A typical communication service has some common elements.

At the core of a service is a state machine, tracking the current state of the hardware determining the next desired state. For example, a device may need to be initialized before a command can be sent—the state machine tracks the initialization status of the device, requests the initialization, and then requests the command to be sent. The service provides metrics that can be monitored by the other network applications – such as when a step times out or loses communication with a device. These can prompt actions in other systems.

A hardware interface communicates with the hardware using the vendor's API.

A communication interface packages the data for the protocol—which may include specific formatting, meta data, encryption, or compression. Some protocols require handshaking or configuration management, which is passed to the state machine for management.

To provide operator access, each control system may have an operator console or multiple consoles. To avoid confusion in the control system, there is typically only one active control console. This might be a dedicated control console or a console with control arbitration, allowing an operator to request control.

A design feature to consider is reconfigurability in the consoles. Because of changing test needs between tests, or even during a test, test engineers often need access to additional data in these consoles. Since most of the data they might need is available in the communication services, it is possible to create consoles that allow users to subscribe to new data points without changes to the actual software code. This

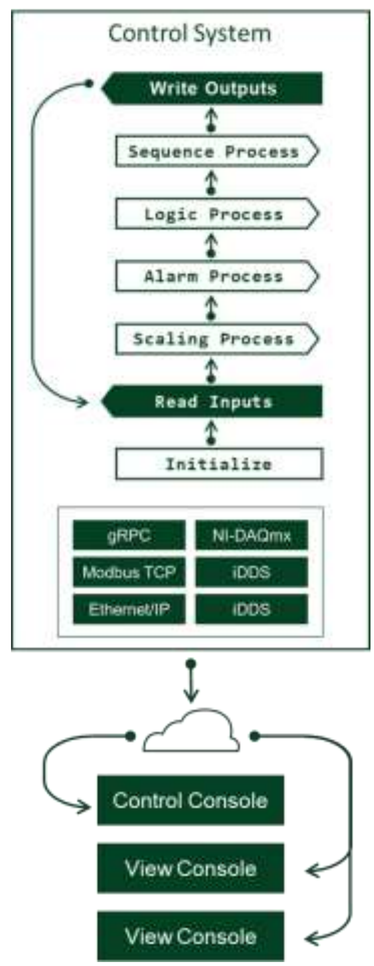


Figure 6. Operator Consoles

provides flexibility to the engineers who need the data and protects the rest of the system from changes made to the software. For example, the console can subscribe to all the data channels in the communication services and let the console user select which signals to view. NI used this design pattern when creating the Static Data Viewer using the G Web Development Software. (7)

Similarly, designers should consider whether to expose command signals to the operator consoles in a configurable way. This allows test engineers to change control capabilities without requiring updates to the software—increasing productivity in the fast-paced rocket test environment. This capability needs to be designed into the communication service that passes the data to the control system during the read inputs step.

A console may be a dedicated device or screen for a specific control system or may be combined with other consoles into an operator station. An operator station provides view and control from a single location across the entire test stand.

Putting this together, a full architecture emerges.

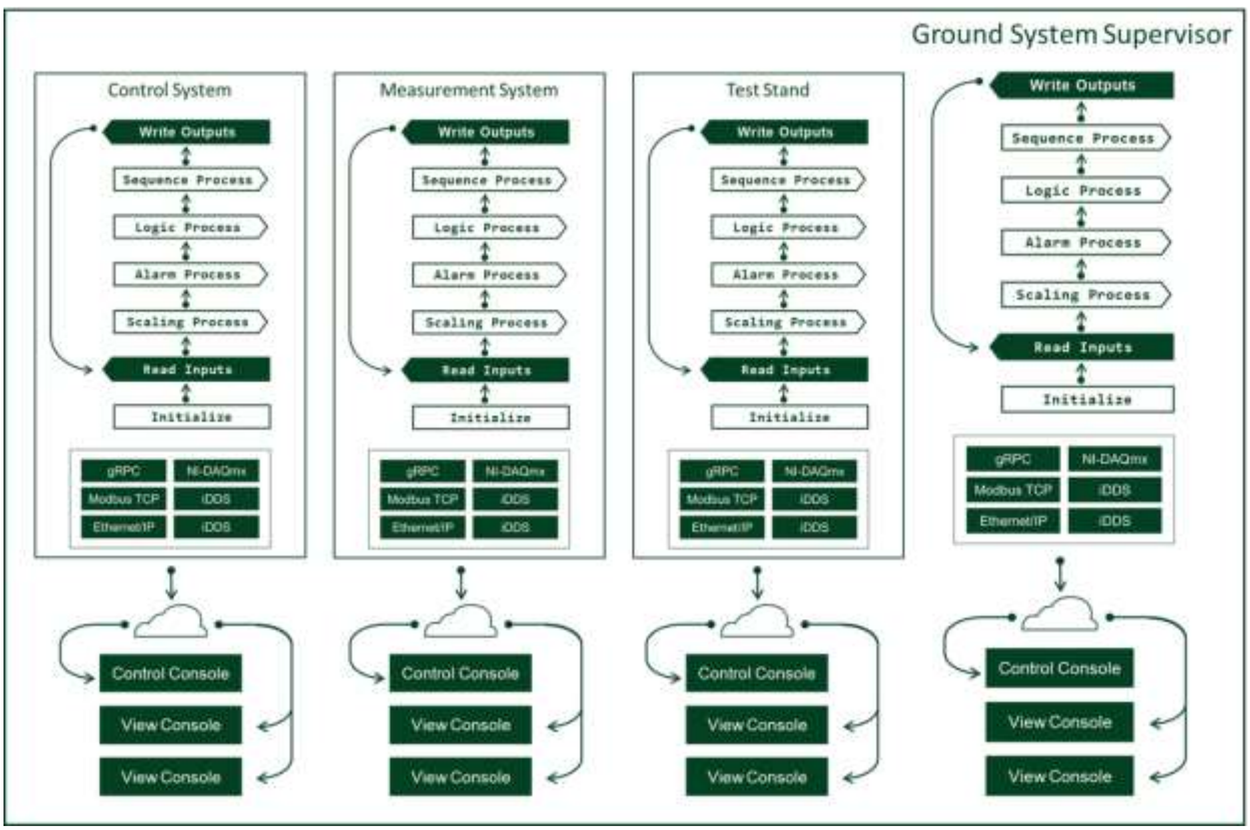


Figure 7. Rocket Test Facility Architecture

This architecture features these benefits:

- Each system runs independent of other systems, avoiding delays from waiting for another system to respond.
- As independent systems, each system can use the most appropriate technology without impacting decisions about technologies on other systems.
- The common design pattern across systems simplifies development and maintenance for both hardware and software teams.
- The architecture can grow as the facility grows, supporting any number of test stands and support systems.
- The architecture supports components from any vendor and can be updated when new technologies become available.

Finally, fully assembled, a rocket test facility may look something like this:

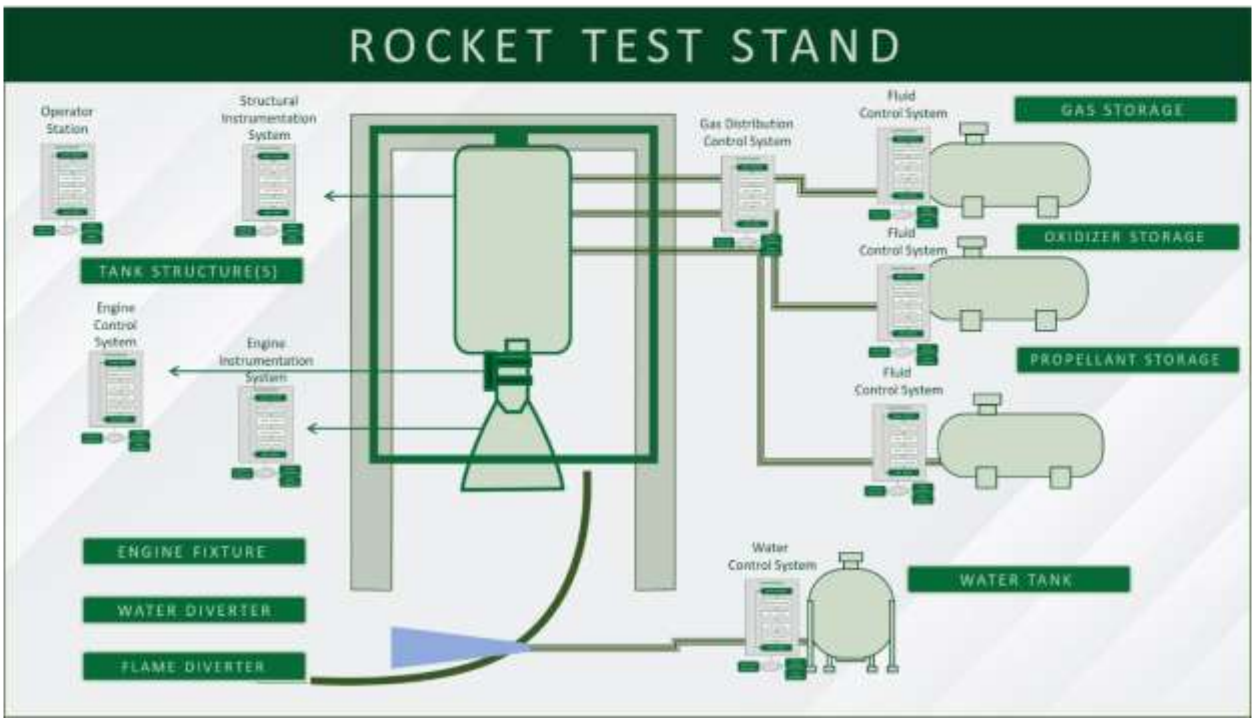


Figure 8. Rocket Test Facility

Considerations

The architecture described in this paper provides a design pattern for the design of a rocket test system. There are many engineering decisions to make to implement this architecture. The goal of this paper is to guide a team through the aspects of the architecture to ensure that the most critical aspects are considered at the start of the design process.

When making decisions about how to implement the architecture, the following topics have proven to be some of the most critical topics to consider as early in the process as possible.

System Latency

Within each subsystem, and across the entire test facility, what is the worst possible delay that can be tolerated to maintain control and safety in the test area?

Latency across the system is the result of several design decisions. Faster loops will increase the communication speed from one component in one system to another component in another system. But engineers must also consider the number of hops between systems—if data must be passed among several systems to reach the final target, the cumulative delays will be more than if data can be passed more directly between control systems. When making design decisions, consider how data is made available to other systems—directly, or by being copied multiple times among the systems.

Timing

Systems spread across the facility will have differing time clocks. What amount of time skew can you tolerate across your measurements?

Most systems tag measurements with the system clock from the local device. When analyzing data across systems, it is helpful to be able to correlate the data across these systems. A common solution is to provide an absolute time across all the systems, using IEEE-1588 or a similar protocol. The time may be provided by the facility supervisor system, or systems may rely on a GPS signal for the timebase.

A related consideration is how to correlate the data between the process computer and the ground system. In a rocket test this is fairly straightforward, but in a launch situation this becomes more complicated because any links between the ground system and the rocket will be lost at launch. Since test systems replicate launch conditions, this should be considered when designing the test stand.

Distribution of Shared Resources

Which subsystems will be shared among test stands, and which subsystems will be dedicated to a specific test stand?

There are two costs to balance when considering shared resources—the costs of duplicating resources and the costs of sharing resources. There is a significant cost to set up a cryogenic tank system. But running cryogenic fluids to two separate test stands also incurs a significant cost and complexity. Sharing resources may also limit the ability to run two activities in parallel if they both require the resource to run.

Managing Race Conditions

How will shared resources be protected from competing instructions from control systems?

Any control system that can be controlled by multiple command systems runs the risk of performing an unintended action because of a lack of discipline in the communication system. For example, a valve may start an operation based on a request from a test stand, but if a second test stand overwrites the set point the result be a catastrophic failure in both stands.

The design team must carefully review the system for potential race conditions to ensure that there is a proper lockout procedure for any command signal in the system.

Race conditions can also affect measurement data if data is overwritten before a storage system retrieves the data. The data being retrieved may not be the intended data.

Redundancy

What systems must have redundant controls in place? What level of redundancy will be in place?

Redundancy can be applied at many places within a system—there can be redundant sensors, wiring, acquisition devices, processors, algorithms, or power supplies. Some space companies require triple redundancy throughout the system for maximum safety. Others identify the highest-risk failure points and focus redundancy efforts on those failure points.

There are several models of redundancy the design team can choose from for each point in the system. In standby redundancy, an identical secondary unit backs up the primary unit. In a cold standby system, the secondary unit is idle, operating only when a watchdog identifies that the primary unit has failed. In a hot standby system, the secondary unit is powered up and actively monitoring the system, but its outputs are not used until a watchdog switches control to it. This can shorten downtime in a failure but does not preserve the reliability of the secondary unit since it is in active operation.

Modular redundancy is similar to the hot standby approach, but both systems run in parallel, and both generate outputs for the system. A voting system, sometimes called an auctioneer or voter, decides which outputs should be used. This provides bumpless transfers in the event of a failure of one of the controllers. This model can be extended beyond two controllers to multiple controllers.

These and other examples are discussed in the NI white paper Redundant System Basic Concepts.

Environmental Requirements

What environments will the measurement equipment be subjected to? What additional infrastructure do we need to protect the measurement and control equipment?

During a propulsion test, equipment on or near the stand will be subject to extreme environmental conditions. These may include sudden shocks, continuous vibration, and high temperatures.

Between tests, equipment will also be subject to environmental extremes. Hot or cold temperatures, humidity, and salt spray are all specific threats to the availability of the equipment for a test.

Engineers must be aware of the environmental conditions of the test stand. With that information, they must select or design equipment that exceeds the potential requirements of the system. This may require that they buy ruggedized equipment, add protection like conformal coating, or protect the equipment in a cabinet or an environmentally controlled outbuilding.

Network Topology

What network technologies will provide the optimum performance for data transfer on the network, including redundancy in case of a component failure?

There are many options available when designing a network topology. A successful facility topology will require detailed conversations between the IT infrastructure team and the test engineering teams. Test teams will need to describe data bandwidth, latency, and technology needs. The IT team will need to understand encryption, layout, and redundancy to plan the network layout.

Among the decisions in designing the network, the design team must decide on a redundancy model—which may include running redundant network cables throughout the facility, using Rapid Spanning Tree Protocol (RSTP), and using multiple distribution switches.

I/O Coverage

What signals do we need to measure or control?

One of the first tasks the engineering team faces is collecting a list of the signals that need to be measured or controlled in the test stand. While documenting signals, they need to list the signal type, location, resolution, data rate, excitation needs, safety needs, and voltage and current levels.

With this information, engineers can collect the signals into measurement banks, and then select the right hardware to provide access to all the signals.

Data Bandwidth

Can the network topology handle the amount of data expected during a test?

The design of the network—including computing devices, switch hardware, and subnetwork architecture—establishes the limit to the amount of data that can be moved across the network. The design team must carefully review the components of the network, looking for any bottlenecks in the system.

A theoretical calculation can provide guidance to a system design, but network applications never achieve full theoretical data rates. Data overhead and latencies impact the total throughput on the network. In designing a network, it is advisable to keep data rates significantly below the theoretical limit.

Safety

What safety systems will be required to be in place?

A rocket facility has many dangerous conditions. A mistake in the design, implementation, or operation of the systems may result in a catastrophic accident. The design team must be aware of safety protocols required by Federal and local laws. The design team must also consider how to protect the personnel, equipment, and area associated with the test station in ways that are not covered by laws.

Some of the areas at a rocket facility are hazardous zones because of the gases used to power the rocket engine. Some of these gases cannot be fully contained, creating a zone where any electrical spark can result in a fire or explosion. To prevent this situation, any equipment in the hazardous area must be intrinsically safe—that is, incapable of generating a spark. This can be managed by moving electrical equipment outside of the hazardous zone. An electrically controlled valve can be placed outside the zone, so that the only equipment in the zone is the pipe leading away from the valve.

If a device must be located inside the hazardous zone, the equipment must be certified as intrinsically safe by the equipment vendor. In the U.S. this means Class 1 Div 1 certification. In Europe, this means ATEX certification based on the gas type.

If a device is outside the hazardous zone, but runs a signal into it, the device must have an intrinsic barrier to prevent a spark generated in the device from being passed into the zone. Even low-level devices, like thermocouple measurement instruments, require an intrinsic barrier to prevent power from the device (like an attached power supply) from passing into the zone. An intrinsic barrier can be attached into the signal path between the device and the hazardous zone and provides protection against both voltage and current spikes. Note that intrinsic barriers vary based on the signal type, so a barrier designed for a thermocouple would not be appropriate for a valve controller.

Certifications

What certifications need to be met by the facility, support systems, and test stand?

Different certifications are required for different areas based on populations, the purpose of the facility, local laws, and the purpose of the rocket equipment. For example, a rocket test performed on a U.S. Air Force Base may require AFSPCMAN 91-710 (8) certification prior to any rocket activity.

In addition to certifications required to perform the test, certifications impact the goal of the testing. If the purpose of the testing is to certify the rocket engine for use, the test stand design must meet the demands of that certification. For example, MIL-STD-810 (9) ensures that the device being tested meets the expected conditions of the use of the product. MIL-STD-202 (10) ensures that components under 300 lbs. meet the electrical and environmental requirements of a demanding application. These may be required if the U.S. Department of Defense is an intended customer of the technology being tested.

Implementation Steps

Designing a rocket test facility, with the test stand and support systems, is a large and detail-oriented project. The purpose of this paper is to provide a general design pattern and approach to the design process. It is outside the scope of this paper to outline every step in the process, but the design process will follow these basic steps. If this process is beyond the capabilities of your design team, refer to the following services section for information on how to engage NI and NI's partners in the design process.

Identify Systems

Output: Block diagram of systems and subsystems that will be designed into the facility.

Start by laying out the facility systems. Using the current and future needs of the facility, plan test stand and supporting system locations. Plan for transfer between the systems and connections among them. Decide which support systems will be shared and which will be dedicated to the test stand.

Create System Requirements

Output: Detailed requirements for each system and subsystem to be designed in the facility.

For each of the identified systems, document the requirements. List the expected inputs and outputs, including update rates and communication protocol. Document the expected functionality of the system including required performance. Decide which functional team in the company will be responsible for designing each of the systems.

Identify Facility-Wide Requirements

Output: Detailed requirements of the systems and infrastructure that will tie the facility together.

Using the system requirements, identify the required performance of the facility system to support those systems. Document the update rate necessary to meet the latency requirements of all the systems and components. Work with the IT team to outline the network infrastructure requirements to meet the systems' needs. Calculate the data rates of the worst-case scenarios in the system.

Select Technologies

Output: List of technologies covering the system and facility requirements.

Using the system and facility requirements, identify the specific technologies that will be acquired or developed to meet the documented needs. Meet with vendors to identify off-the-shelf technologies that can be used. Work with engineering teams to identify a custom engineering approach for remaining gaps in the systems. Where possible, test the performance of the systems to ensure they meet the requirements.

Design Communication Services

Output: Document the requirements and implementation of each of the communication services to be used for the systems and facility equipment.

With a good understanding of the technologies available for the systems, document the needs of each of the communication services. Identify the inputs, outputs, and processing of each of the services. Identify the expertise needed to fully implement the services.

Design the System Controllers

Output: Design documents for each of the system controllers in the facility.

Apply the system requirements to the technologies selected for the systems and facility. Document the desired inputs, outputs, and functionality with specific performance criteria. Identify the expertise needed to implement the system controllers.

Implement System Controllers and Communication Services

Output: Code running on each of the system controllers and between systems.

Develop the code running on each of the system controllers and in each communication service. Document any changes from the requirements documents and verify that changes do not have impacts to other systems. Apply proper engineering principles to the development—including unit testing to verify that each component meets the documented requirements.

Connect System Controllers

Output: Values updates among control systems.

Connect the system controllers and communications services. Verify that the systems work properly and within expected performance boundaries. Continue to run unit testing on components, subsystems, and systems as they get connected.

Validate System Performance

Output: Validation of the performance of each system component, system, and interconnected systems.

With the full system in place, perform full validation testing of the systems and the overall system. Review the requirements to verify that all requirements are met. Report any unexpected behaviors to developers and iterate until the desired performance is obtained.

Create Operator Stations and Viewers

Output: Operator screens and stations to control and view the systems.

Operator consoles will be developed along with the systems; apply usability improvements to the consoles and create the final operator consoles.

Rocket Engine Test Technologies

Software and hardware technologies continue to evolve to provide more options to engineers designing engine test systems. This section provides an overview of some of the modern technologies available to engineers today.

Emerging Technologies for Rocket Engine Test

There are several recent advances in available technology that can be used in this rocket test architecture.

gRPC

gRPC is an open source, high-performance framework that can run in any environment. Developed by Google and based on Remote Procedure Call (RPC), gRPC has grown rapidly in popularity in the last 5 years as a way to pass data among parts of a system. Using gRPC, a client application can directly call a method on a server application on a different machine as if it were a local object. This simplifies the creation of a distributed architecture like the rocket test architecture.

NI software and hardware tools work with gRPC. For more information about how to use gRPC with NI platforms, visit https://knowledge.ni.com/KnowledgeArticleDetails?id=kA03q000000oxQGCAY&l=en-US.

iDDS

iDDS is a data abstraction protocol developed for jet turbine engine test by Rolls Royce and MDS Aero. It provides a communication service to collect data from instrument nodes, which becomes available to subscribers on the network. iDDS is built on the Data Distribution Service (DDS) backbone and Open Management Group (OMG) standard. iDDS defines the packaging of instrumentation data on the DDS network, including measurement data like channel metadata, time stamping, configuration, and health monitoring.

Because the communication among devices is standardized within the iDDS model, specific vendor features are abstracted away, making it easier to swap out equipment when new technology becomes available, even if it is from a new vendor.

NI Software for Rocket Engine Test

In this solution architecture, software is used in multiple subsystems. Software powers the system controllers, provides the communication interfaces, and exposes the systems to the operator consoles. NI makes a variety of software tools appropriate for different parts of the rocket test architecture.

Graphical Programming—LabVIEW Development Tools

LabVIEW is a graphical development platform engineers can use to create customized test solutions. It provides thousands of analysis functions, configurable display elements, drivers to interface to instruments and data acquisition equipment, and connectivity to other languages and protocols.

The LabVIEW Professional edition provides tools for engine testing, including the capability to build executable files for distribution to various test stations around the facility. It also includes important development tools including graphical code diff and merge, dynamic code analysis, static code analysis, and unit testing. With this edition, developers can create custom tools for the modular components.

LabVIEW's focus on data and instrumentation makes LabVIEW an ideal tool for developing the data display, data logging, and data processing tools. With LabVIEW's platform-independent code compiler, these can be targeted to Windows, Linux, or MacOS stations.

For custom applications that require real-time reliability and performance, the LabVIEW Real-Time add-on toolkit enables LabVIEW programmers to take graphical code to embedded targets running Linux Real-Time OS. These embedded applications are appropriate for facility control and SPTE/rig control applications.

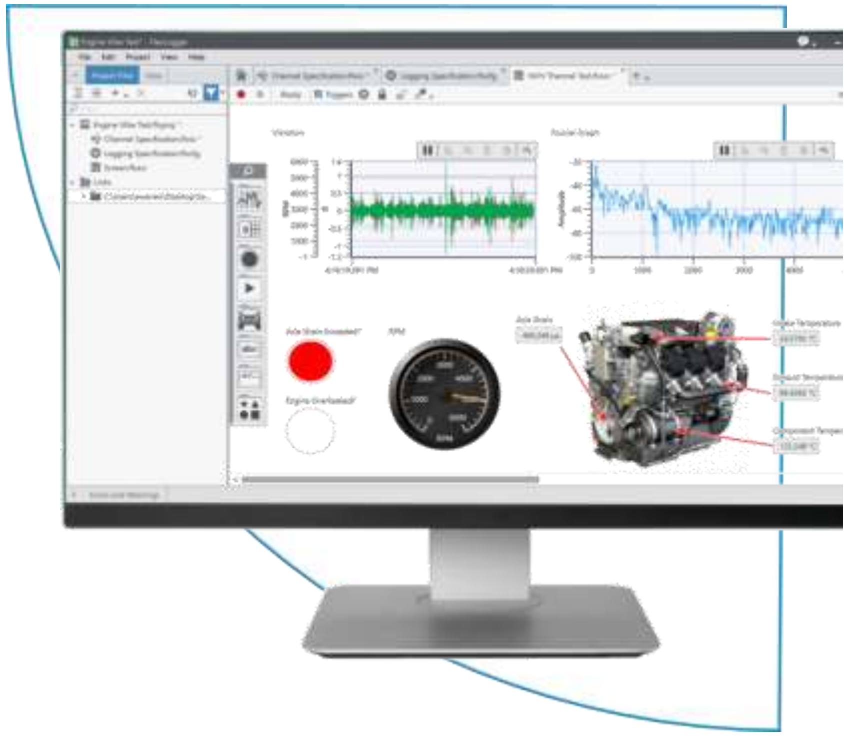
Applications that require high-speed data processing are ideally suited to FPGA targets. The LabVIEW FPGA add-on toolkit supports graphical programming on these targets, with a robust ecosystem to support IP development of avionics monitor tools. LabVIEW FPGA can be used to create interfaces to most avionics buses and share that information to the instrumentation network.

G Web Development Software helps engineers create web-based user interfaces for test and measurement applications without the need for traditional web development skills. Web applications developed with G Web Development Software can connect to existing systems written in LabVIEW, Python, or C#.

More information about LabVIEW Professional, LabVIEW Real-Time, and LabVIEW FPGA is available at ni.com/labview.

Configuration-Based Data Visualization and Logging—FlexLogger

For engineers who want to minimize programming with out-of-the-box software, FlexLogger provides a powerful data display and data logging tool. Engineers configure FlexLogger to collect data from data devices attached to sensors, then have access to analysis, processing, visualization, and logging tools.

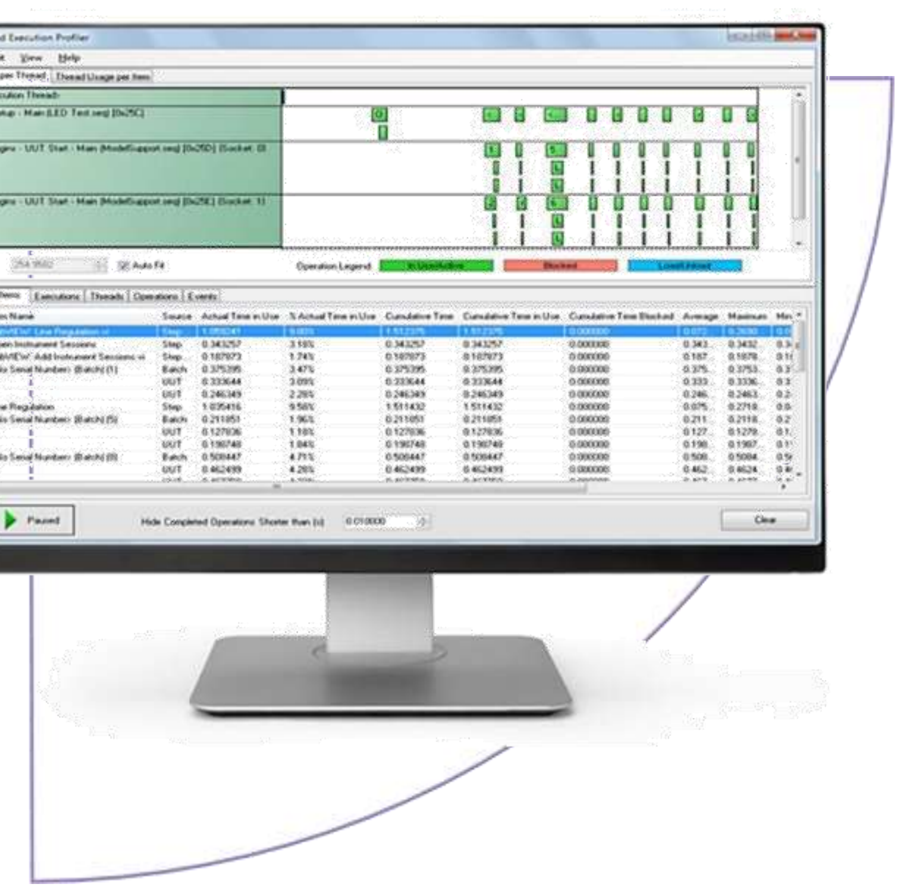


Operators can use sensor-specific configuration workflows to quickly set up, visualize, and log a mix of synchronized measurements from analog sensors, digital signals, and communication buses. FlexLogger can generate voltage, current, or digital signals to drive actuators or control set points. FlexLogger automatically saves metadata documenting test configuration, so engineers can quickly trace test results and make comparisons across multiple tests. Engineers can interactively review test results in the integrated data viewer to visually inspect data and draw conclusions.

FlexLogger supports a variety of hardware platforms, including PXI, CompactDAQ, and FieldDAQ. FlexLogger provides valuable tools in the rocket engine test architecture for data display, data processing, and data logging.

More information about FlexLogger is available at ni.com/flexlogger.

Test Sequencing and Test Management Executive Software—TestStand



TestStand is ready-to-run test management software designed to help engineers quickly develop and execute test routines from test plans. Engineers build TestStand test sequences that integrate code modules written in a variety of programming environments, including LabVIEW, C/C++, .NET, and Python. TestStand also provides extensible plugins for reporting, database logging, and connectivity to other enterprise systems. Engineers can deploy test systems to production with easy-to-use operator interfaces.

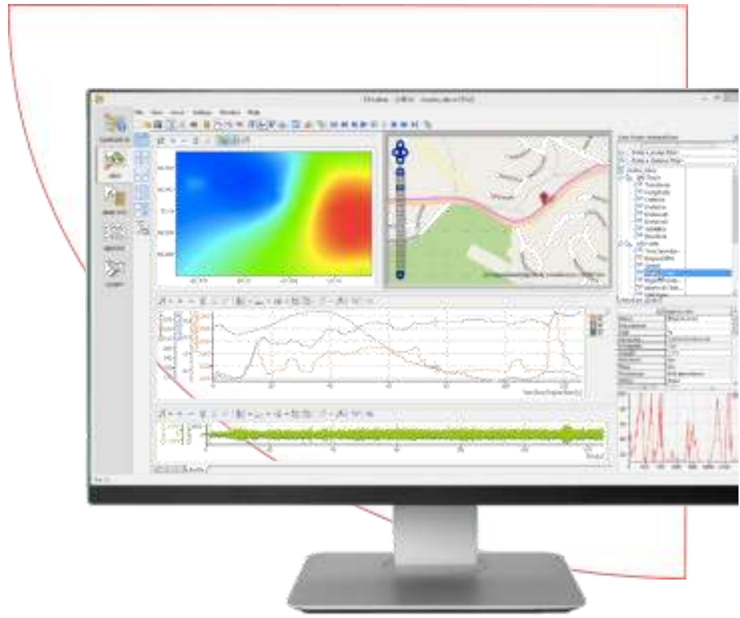
TestStand automates, accelerates, and standardizes the overall test process with native functionality for calling and executing tests written in LabVIEW, Python, C/C++, or .NET. TestStand handles complex tasks, such as parallel testing, sweeping, looping, and synchronization. Engineers can use TestStand to create custom operator interfaces and robust tools for deployment and debugging. TestStand supports unit tracking, automated reports, and storing results to local or network databases.

TestStand is ideally suited in the rocket engine test architecture as the test execution tool.

For more information about TestStand, visit ni.com/teststand.

Data Analysis and Reporting—DIAdem

DIAdem is application software that helps engineers accelerate post-processing of measurement data. It is optimized for the large data sets common in engine test and includes tools to quickly aggregate and search for the needed data. Engineers can view and investigate data with engineering-specific analysis functions. Reports can be built manually or automated through DIAdem's powerful scripting interface.

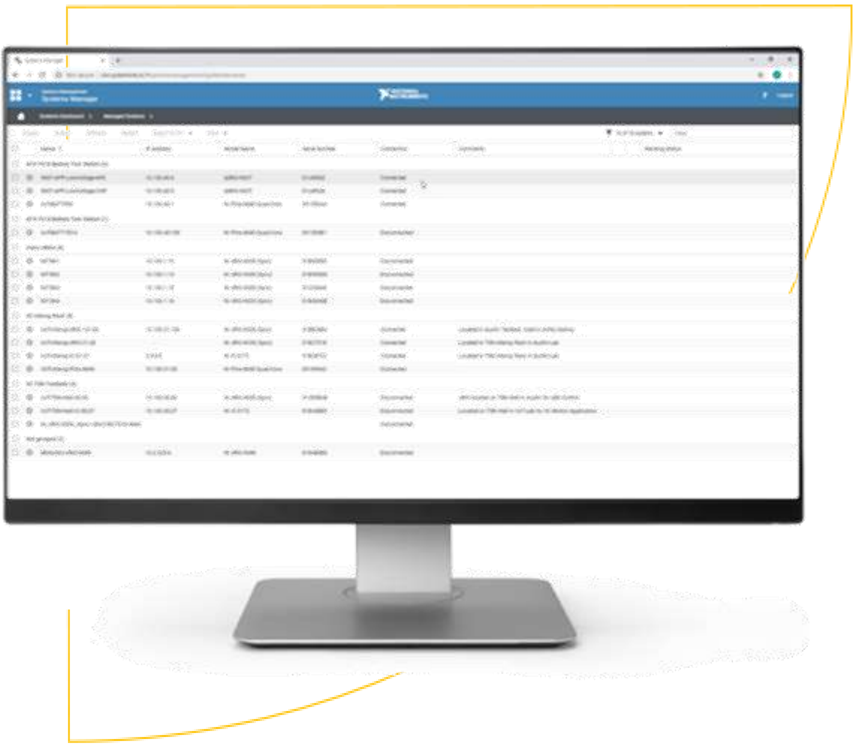


Using DIAdem, engineers can build integrated report dashboards that include data visualizations, graphs, graphics, and even video files from the test. Test engineers, design engineers, and data analysts can use these dashboards to gain valuable insights into the engine, the facility, and the test process.

DIAdem is a powerful tool to provide reporting for the rocket engine test solution.

For more information on DIAdem, visit ni.com/diadem.

Data and Systems Management—SystemLink Software



SystemLink is an intelligent Systems and Data Management environment that connects the test facility to the rest of the organization. Designed for engineering use cases, SystemLink software combines focused applications and data services that accelerate time-to-knowledge and time-to-market by leveraging comprehensive real-time information. From engineering teams to enterprises, SystemLink software helps organizations achieve peak performance.

SystemLink centrally manages test equipment and assets across the engine test facility, including software, systems, and fixtures. SystemLink collects calibration status, system and application software versions, and equipment health. Using this information, test engineers can plan to minimize downtime for maintenance. Test engineers can also deploy software updates for system software, drivers, and applications.

SystemLink also centrally collects valuable data about the test facility and the testing in the facility. From this data, test engineers can monitor test trends, facility efficiency, and engine data. Using this data, engineers can predict equipment failures and schedule repairs to reduce cost and minimize downtime. Managers can use this data to adjust engine test schedules and most efficiently use these valuable resources.

SystemLink provides an important set of tools for facility monitoring and asset monitoring in the rocket engine test architecture.

For more information on SystemLink, visit ni.com/systemlink.

NI Hardware Components and I/O for Rocket Test

Hardware provides critical interfaces from rocket test systems to physical systems. Hardware must be carefully selected to match the acquisition requirements, processing speed, signal accuracy, and environmental specifications demanded by the engine test application.

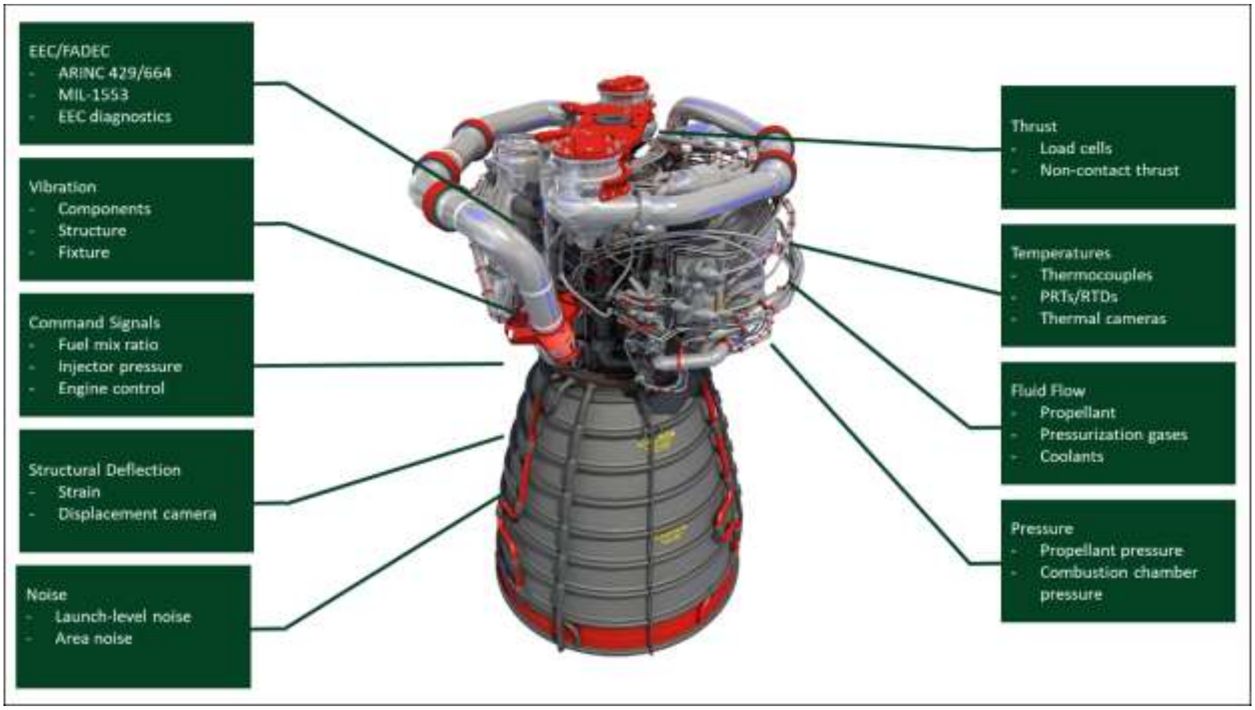


Figure 9. Rocket Engine Signals

Figure 9 lists some of the signals that need to be tested during a rocket engine test. Most signals require some amount of excitation or conditioning, which must be factored into any device selection.

Rocket test stands present a unique test environment, with extreme environmental conditions. High vibration, sudden shock, extreme heat or cold, humidity, and even salt spray limit the devices that can survive the typical rocket test environment.

NI provides a range of hardware platforms to ensure that you can match the measurement and environmental performance needs of the test stand. Some products may be delivered with conformal coating to further enhance the survivability of the devices in outdoor environments.

Rugged	Distributed I/O	Distributed Control	High Performance
Short-cable measurements Temperature, pressure	**Larger number of channels** Temperature, voltage, flow, strain, vibration, acoustic	**Permanent channels** Safety interlocks, environmental parameters, facility control signals, PLCs	**Bus signals** Current measurements, avionics buses
High vibration Electrical noise	Medium vibration Electrical noise	Low vibration	No vibration
Rugged connectors Rugged Ethernet Power over Ethernet No moving parts Extended temperature	No moving parts Extended temperature	Rugged hard drive Real-time performance	Computer-grade instruments
FieldDAQ	CompactDAQ	CompactRIO	PXI

Figure 10. NI Hardware Options for Rocket Engine Test

Rugged I/O: FieldDAQ

FieldDAQ delivers NI measurement capabilities in a rugged form factor appropriate for on-stand measurements, even when those devices are not protected from the environment. FieldDAQ devices have an ingress protection rating up to IP67, which means they are dust-resistant and water-resistant. They maintain excellent accuracy across a wide range of extreme environments, including temperatures from -40 °C to 85 °C, 10 g vibration, and 100 g shock.

Test engineers can distribute FieldDAQ systems across Ethernet networks to get closer to sensors and signals. FieldDAQ also distributes timing signals with Time Sensitive Networking (TSN) to provide accurate synchronization within 1 µs over long distances using standard Ethernet cables. FieldDAQ also supports 1588 timing. Sharing data transfer and synchronization over a single cable cuts cabling costs and complexity.

FieldDAQ devices are available to support a variety of sensors, including voltage, strain, IEPE/vibration, and thermocouples.

For more information about FieldDAQ devices, visit ni.com/fielddaq.

Distributed Measurements: CompactDAQ

For measurements distributed around the facility, especially on the test stand and other fixtures, CompactDAQ provides a rugged, modular platform. Engineers select CompactDAQ chassis based on communication interfaces (USB, Ethernet, or wireless) and the number of module slots (4 or 8). CompactDAQ delivers rugged performance at a cost reasonable for large numbers of channels. CompactDAQ can be used in environments with temperatures ranging from -40 °C to 70 °C, 5 g vibration, and 50 g shock.

Test engineers select from more than 70 C Series data I/O modules to create a customized measurement node. Modules available from NI and other providers support signals including voltage, current, temperature, vibration, digital, relays, frequencies, flows, avionics and automotive buses, and GPS.

CompactDAQ chassis support Time Sensitive Networking (TSN) to synchronize measurements across the entire engine test network within 1 µs. CompactDAQ also support IEEE 1588 timing to conform to standard timing networks.

For more information about CompactDAQ chassis and C-Series modules, visit ni.com/compactdaq.

Distributed Processing and Control: CompactRIO

CompactRIO adds distributed control and processing for control systems in engine test stands. CompactRIO systems provide a local processor running embedded NI Linux RT OS and a user-programmable Field-Programmable Gate Array (FPGA). CompactRIO systems are rugged enough to survive engine test environments, with temperature ranging from 0 °C to 55 °C, 5 g vibration, and 50 g shock.

Test engineers select from the same C Series modules for CompactRIO as they do for CompactDAQ, reducing maintenance costs across applications. Modules available from NI and other providers support signals including voltage, current, temperature, vibration, digital, relays, frequencies, flows, avionics and automotive buses, and GPS.

Engineers can program the CompactRIO device using LabVIEW Real-Time software, or with other industry standard Linux tools. Using these tools, programmers add signal processing or local control and distribute this around the facility, including next to the engine. They also program the on-board FPGA using LabVIEW FPGA software or other FPGA toolchains. Additionally, engineers add complex algorithms to the CompactRIO node with FPGA, operating at hardware speeds and reliability.

CompactRIO is NI's platform for iDDS. NI engineers have developed embedded software to run on the CompactRIO processor, collecting data using C Series devices and publishing that data to the iDDS network.

For more information on CompactRIO systems, visit ni.com/compactrio.

Image Courtesy of Virgin Orbit

Industrial Computing: NI PXI/PXI Express

PXI is a PC-based industrialized system that combines PCI Express electrical bus features, a modular chassis, and I/O synchronization technology with user-defined or application-specific test software. PXI is an open industry standard governed by the PXI Systems Alliance, a group of more than 70 global test companies. NI was one of the pioneer companies in the formation of PXI and is recognized as a leader in PXI test and measurement devices.

Instrumentation available in PXI/PXI Express form factor includes:

- Analog and digital I/O
- Digital multimeter
- Oscilloscope/digitizer
- Waveform generator
- Switch and timing/synchronization
- Source Measure Unit (SMU)
- Programmable DC power supply
- Electronic load
- Instrument control and synchronization
- FPGA processing boards

Engineers select from a variety of available chassis and controllers, then add instrumentation and measurement modules to create measurement systems. These systems can be customized to match the specific needs of the test facility.

PXI controllers run standard operating systems, including Windows and Linux. For embedded control applications and real-time performance, NI Linux Real-Time OS is available on PXI controllers. Engineers can program these systems using LabVIEW Real-Time software.

PXI chassis are available with redundant, hot-swappable power supplies, making them reliable for rocket testing and easily maintainable for fast repair between tests.

Programmable FPGA boards available for PXI can be programmed using LabVIEW FPGA software and provide powerful signal processing capabilities to engine test engineers. These boards can also be used to interface to avionics buses and run models of avionics components to complete the test environment for the engine under test.

For more information on PXI systems, visit ni.com/pxi.

Avionics

Using the PXI or CompactRIO/CompactDAQ platforms, engineers can select from a variety of avionics interfaces to read or write from the rocket system flight data.

The most common avionics buses are ARINC-429 and MIL-STD-1553. These cards are available directly from NI for PXI, or from NI partners for CompactRIO and CompactDAQ.

There are many other avionics buses used in rocket systems, from simple serial communications to advanced high-speed buses. Using NI's programmable FPGA modules, engineers can install industry standard communication protocols, or create custom protocols. These modules make it possible to read or write from the rocket engine during the test process. Using these cards, NI provides support for:

- Fibre Channel
- Serial RapidIO
- ARINC-664p7/AFDX
- 1394b FireWire
- Ethernet I/P
- ARINC-708
- ARINC-717
- ARINC-818
- SpaceWire
- DVI

Power Supplies

NI provides a variety of power supplies for applications across the rocket facility.

The RMX Programmable Power Supplies provide DC power in rack-mount form factors, with up to 1500 kW of power and flexible voltage and current limits ranging up to 650 VDC or 150 A. Higher power is available by combining devices in series or in parallel. These supplies provide a local user interface or remote operability as well as support for multiple redundancy operation modes.

PXI chassis are powered by removable power supplies. Some chassis feature dual supplies, with hot-swappable capabilities to provide maximum reliability and to streamline system maintenance.

NI also offers a family of DIN rail-mountable power supplies for distributed systems like CompactDAQ and CompactRIO. These supplies are tested for performance and matched to the needs of these modular systems.

Services and Support

NI provides several services and support options to help ensure your short-term and longer-term success with our products. We've partnered with many aerospace and defense companies to provide extended, long lifecycle support that can span decades. Select from NI's services and support options to design a system management approach that meets your budget, risk, and resource needs.

TRAINING

Choose from online, classroom, and on-site training options for NI products

SUPPORT

Access online technical support, phone support, or dedicated support resources

REPAIR

Select standard 3-year or optional 5+-year repair options

CALIBRATION

Send products to NI or certified centers for repair, or arrange on-site calibration services

SPARING

Minimize downtime with locally spared repair pools set up to meet your needs

LONG LIFE SUPPORT

Get product update notifications and arrange long-life support (20 years or more) for your system

NI applications engineers are available to provide expert consulting in test stand architectures and control system designs.

NI offers a full suite of service and support offerings to meet your individual project needs. For more information about any of NI's services, visit ni.com/services.

Image Courtesy of Rocket Factory Augsburg

NI’s Partner Ecosystem for Rocket Engine Test

We work closely with our uniquely qualified partners so that our customers see the greatest return on investment from their rocket engine test systems. ACS is a high value partner that has the scope of internal knowledge and capabilities that enable them to undertake large, complex projects effortlessly, deliver small projects cost effectively and do both with the highest level of value

ACS

ACS designs, integrates, and builds technically complex equipment, controls, and facilities for commercial aircraft OEMs, tier suppliers and defense contractors in the aerospace market. ACS is well-versed in the testing of systems, sub-systems and components used in aerospace development, research, production, and Maintenance, Repair and Operations (MRO) applications. ACS has experience building the complex systems that are required for rocket propulsion test.

From turnkey complex test facilities, fuel delivery systems, test cell subsystems, and facility controls and safety systems to custom equipment and real-time control and data acquisition solutions, ACS’ expertise and project management experience have been vital to the success of hundreds of test cell projects across the country and around the world.

Capabilities include:

Figure 11. Rocket Test Facility

CUSTOM EQUIPMENT FOR:

- Thrust stands
- Turbomachinery
- Cryogenics
- Thermal management
- Hydraulics testing

MECHANICAL AND ELECTRICAL UPGRADES

CONTROLS AND SAFETY UPGRADES

SOFTWARE SOLUTIONS

FRONT END PLANNING—SCOPE, SCHEDULE, COST DELIVERABLES

TURNKEY R&D FACILITY UPGRADES AND NEW CONSTRUCTION

Export Controlled Technology and Regulations

ACS fully complies with all U.S. export control regulations, including the International Traffic in Arms Regulations (ITAR).

For Additional Information

More Rocket Engine Test Resources

- ni.com/space application solutions
- Fielding wiring best practices
- Signal-Based vs. Time-Based Synchronization
- Time-Based Synchronization in NI-Sync
- Signal-Based Synchronization in NI-Sync
- Overview of NI PXI Timing & Synchronization
- Signal-based sample clock synchronization
- Example of product-specific details on IEEE-1588
- Distributed synchronization topology details/considerations

Customer Success Stories

- NASA Data Acquisition System Software for Rocket Propulsion Testing
- Using LabVIEW, CompactRIO, and a Compact Vision System to Upgrade a Hot-Fire Rocket Test Facility

Products

- C Series Modules for Signal Measurement and Control
- CompactDAQ
- CompactRIO
- DIAdem
- FieldDAQ
- FlexLogger
- LabVIEW Development Environment
- LabVIEW FPGA Module
- LabVIEW Real-Time Module
- PXI
- SystemLink
- TestStand
- Web Development Module

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