Developments in test facility and data networking for the Altitude Test Stand at the John C. Stennis Space Center

A General Overview

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Developments in test facility and data networking for the Altitude Test Stand at the John C. Stennis Space Center – A General Overview

Space Shuttle Main Engine Test @ A2 Test Stand

RS-68 650 klbf @ B1 Test Stand

Fastrac 60 klbf @ B2 Test Stand

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NASA/SSC’s Mission in Rocket Propulsion Testing Is to Acquire Test Performance Data for Verification, Validation and Qualification of Propulsion Systems Hardware

- Accurate
- Reliable
- Comprehensive
- Timely

Data Acquisition in a Rocket Propulsion Test Environment Is Challenging

- Severe Temporal Transient Dynamic Environments
- Large Thermal Gradients
- Vacuum to 15k psi pressure regimes

SSC Has Developed and Employs DAS, Control Systems and Robust Instrumentation that Effectively Satisfies these Challenges

The Following Presentation Reviews SSC’s Data Acquisition and Controls Architectures
Agenda

- Background – SSC EE Org & Test Facilities
- High/Low Speed Data Acquisition Systems
- Control Systems
- Video Systems
- Network Architecture
Design & Analysis Division

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Design and Analysis Division

• Configuration Management
• Records Retention DB Management

Mechanical and Component Systems

• Cryogenic Propellant Systems
• Storable Propellant Systems & HPIW
• Hydraulics/pneumatics Systems
• Press Gas/Purge Systems (TBA)
• Components
• Materials
• Ancillary Systems
  • TMS, Measurement Uncertainty
  • Standards & Specifications

Electrical Systems & Software

• Data Acquisition
• Instrumentation & Signal Conditioning
• Controls & Simulation
• DACS Lab Management
• Data Systems Management
• Ancillary Systems/Electrical Power

Systems Analysis & Modeling

• Modeling and Analysis development and integration into RPT
• Fluid Mechanics/Thermal Analysis of Propellant Systems
  • Liquid
  • Gas
• CFD
• Structures/Loads Analysis
• Thermal/Heat Transfer Analysis

Organization Goal:

• Develop and maintain propulsion test systems and facilities engineering competencies
  • Unique and focused technical knowledge across respective engineering disciplines applied to rocket propulsion testing, e.g.,
    • Materials selection and associated database management
    • Piping, electrical and data acquisition systems design for cryogenic, high flow, high pressure propellant supply regimes
    • Associated analytic modeling and systems analysis disciplines and techniques
  • Corresponding fluid mechanics, thermal, structures, and electrical engineering disciplines

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SSC Test Facilities

AB-Complex

A-1 Full Scale Engine Devt. & Cert
J-2X

A-2 SSME

B-1/B-2 Full Scale Engine/Stage Devt. & Cert
RS-68/ARES

Components
…Engines
…Stages

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SSC Test Facilities (continued)

E-Complex

**E-1**
Cells 1, 2, 3
High Press., Full Scale Engine Components

**E-2**
Cell 1
High Press. Mid-Scale & Subscale

**J-2X**

**E-2 Cell 2**
Low Press. Mid-Scale & Subscale, Stage

**E-3**
Cell 1
High Press. Small-Scale Subscale

**E-3 Cell 2**

**TGV**

**E-Complex**

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Conceptual View – A3 Test Stand
SSC Test Facilities (continued)

Nominal Vacuum Thrust
294,000 lbs

1st STAGE EJECTOR

2nd STAGE EJECTOR

DIFFUSER

RUN TANKS

SUPER STRUCTURE

ENGINE TEST LOCATION

BLOCK OFF VALVE

TEST LEVEL

TEST CELL

DERRICK CRANE

FOUNDATION

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Typical Test Articles

Integrated Powerhead Demonstrator

LR-89
Test Facility Electrical Systems

- Communications System
- **Control System**
- Facility Fire Alarm System
- Fire & Gas Leak Detect System
- Grounding System
- **High Speed Data Acquisition System**
- Lighting System
- Lightning Protection System
- **Low Speed Data Acquisition System**
- Aural Warning System
- Power Distribution System
- **Uninterruptible Power System**
- **Video System**
- Interconnecting Network
Typical Test Facility
Electrical System Layout

Historical Overview of Systems at SSC

LSDAS Digitizer

Control Consoles Includes PLC Racks

HSDAS

Facility S/C: Programmable Signal Conditioners, Manual Filter Amps, PCB and Dynamics Amps

PLCs

CABLE TERM. ENCL. Disc Vlv

Instruments Analog Vlv

Collector

Facility S/C

Analog Inputs

Test Control Center

Signal Conditioning Bldg

Test Article

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Typical Test Facility
Electrical System Layout

A-3 Test Stand Electrical Systems Software Data Flow & Interactions

Low Speed Data Acquisition System (LSDAS)

High Speed Data Acquisition System (HSDAS)

Low Speed Video System (LSV)

Control System (CS)

High Speed Video System (HSV)

Avionics Interface

Hazardous Gas and Fire Detection and Protection System

Networks

OFF-SITE

J-2X ENGINE

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Test Control Centers –

Currently in Place

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A2 TCC

E2 TCC

Test Conductor’s Station

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E1 SCB
Signal Conditioning Rack

E2 Cell 1
SCB 1 Controls Racks

E2 SCB's
1 & 2

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High Speed Data Acquisition Systems (HSDAS)
The High Speed Data Acquisition System is used to record rocket engine or component data from a variety of dynamic sensors.

- Sampling rates are normally an order of magnitude in sample rates compared to the Low Speed Data Acquisition System.
- High speed data provides the Analyst with information about the dynamic environment/condition of a test article. The data feeds models that characterize the performance of the test article or allows the analyst to help determine the health of the hardware.
- The data is typically analyzed in the frequency domain.
- Challenges to recording good high speed data include the environment (high temperatures, vibration, high flow, cryogenic temperatures, high pressure), proper cabling, appropriate sensor selection, and numerous other considerations.
High Speed Data Acquisition Systems

- **DataMAX II (New to be used for A-3)** - \( \geq 200,000 \) Samples Per Second (Binary & Decimal Sampling)
  - AB Complex (RS-68, J-2X)
  - E Complex
  - Planned for use on A-3

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Typical High Speed Data Acquisition System Instrumentation

Typical Instrumentation not always in the Catalog

- Special Ranges
- Temp Compensation
- Special Materials

Accelerometer
Strain

Dynamic Pressure
Accelerometer
Strain
Proximity
Speed

Typical High Speed DAS Instrumentation

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Typical High Speed Data Acquisition System Instrumentation

- Strain
- Dynamic Pressure
- Speed
- Accelerometer

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Low Speed Data Acquisition Systems
SSC's Low Speed Data Acquisition Systems

- Data acquisition, recording, real time display, data acquisition
  - **Data types:** Low frequency Analog Data, Discrete (event) Data, Pulse Data from flow meters and speed sensors
    - **E-Complex Digitizer** - ~ 200 samples per second or greater
    - **AB-Complex Digitizer** - ~ 200 samples per second or greater
    - **A-3 Test Stand** – ~ 200 samples per second or greater
E-Complex Low Speed Data Acquisition System Architecture

Historical Overview of LSDAS at SSC – E-Complex

TEST FACILITY

- INTER-CONNECT CABLEING RBs & PATCH PANELS
- SENSORS TRANSDUCERS VALVES

SIGNAL CONDITIONING BUILDING

- SIGNAL CONDITIONERS & AMPLIFIERS
- SLAVE HIGH-LEVEL MULTIPLEXOR
- DISCRETE INPUT/OUTPUT MODULE
- IRIG-B TIME SOURCE
- HIGH LEVEL INPUTS

TEST CONTROL CENTER

- MASTER HIGH-LEVEL MULTIPLEXOR
- MULTI-SYSTEM CONTROLLER (LOCAL COLLECTOR)
- DAS SYSTEM CONTROLLER, CAL PC, AND DISPLAY
- REMOTE DAS DISPLAYS

DIGITAL INPUTS FOR CONTROL SIGNALS, LIMIT SWITCHES, ETC

HIGH LEVEL INPUTS

FIBER OPTIC

GPIB

ETHERNET

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AB-Complex Architecture
Low Speed Data Acquisition System

Historical Overview of LSDAS at SSC – AB-Complex

Interconnect Cabling RBs & Patch Panels
Signal Conditioners & Amplifiers
Sensors Transducers
IRIG-B Time Source
Digital Inputs for Control Signals, Limit Switches, ETC.

Primary Multiplexer
Primary Events
Primary DAS PC
Primary Events PC
Primary Event Logger
Primary Display PC

Secondary Multiplexer
Secondary Events
Secondary DAS PC
Secondary Events PC
Secondary Data Logger
Secondary Display PC
AB-Complex Architecture
Low Speed Data Acquisition System

The AB-Complex LSDAS consists of four test stand systems:

- A1, A2, B1, B2 (B1/B2 one structure with two distinct sides)
  - Systems contain >= 500 analog input channels and >= 700 digital input channels
  - Each system contains a primary and secondary system for redundancy. Data from the secondary system is only processed if a problem occurs on the primary system.
AB-Complex Architecture
Low Speed Data Acquisition System

Historical Overview of LSDAS at SSC – AB-Complex

- Fully populated analog box
  - >= 200 analog input channels
- Fully populated discrete box
  - >= 400 digital input channels
AB-Complex Architecture
Low Speed Data Acquisition System

Historical Overview of LSDAS at SSC – AB-Complex

- Model 8300
  - Programmable
    - Gain, filter, excitation
  - Automated calibration
    - Voltage Insertion
    - Shunt
    - Rcal
  - Various Mode Cards
    - Strain Gauge
    - Full Bridge, Half Bridge
    - RTD
    - Thermocouple
  - Measurements
    - Strain Gauges
    - Pressure Transducers
    - RTD’s
    - Thermocouples

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Proposed A-3 Low Speed Data Acquisition System Architecture

A-3 Test Stand Proposed LSDAS

SIGNAL CONDITIONING BUILDING(s)

TEST CONTROL CENTER

TO SDC

A-3 LAN SERVER

FIBRE-CHANNEL

DATA PROCESSING TRANSMISSION PC

SSC LAN

DAS REAL-TIME TRANSMISSION SERVER

REMOTE DISPLAYS

DISplays

DISPLAYS

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Software:

- **Existing functionality**
  - All of the E-Complex Low Speed DAS software is developed in LabVIEW
    - LSDAS Operational and Control Software
    - Display Screens
    - Calibration Software
    - Measurement System Analysis (MSA’s)
    - “Near” real-time data transmissions

- **Proposed for A-3**
  - Currently considering option of having vendor provided software or Pratt-Whitney Rocketdyne developed Stennis Data Acquisition (SDAS) software for the following functions:
    - LSDAS Operational and Control Software
    - “Near” real-time data transmissions
    - Display Screens
    - Calibration Software
  - The Measurement System Analysis (MSA’s) function is planned to be developed in-house by NASA Engineering & Sciences Directorate (E&SD).
Software

- **Data Acquisition and Real-time Display**
  - Provides for the control of the data acquisition process and the distribution of data for real-time display
  - Combines both the analog and discrete data

- **Measurement System Analysis**
  - Software originally and methodology developed by Rocketdyne
  - Purpose is to quantify a system precision for the LSDAS by evaluating the drift over time of the data system.
  - It consists of a two point calibration performed every hour during an eight hour time span. This is to simulate the maximum time between a pre-test calibration and a test.
Calibration Software

- Provides computer controlled setups and calibration of the Signal Conditioners.

Signal Conditioning Setup

- Select gain, filter
- Setup and adjustment of individual signal conditioners and amplifiers

Calibration

- Automatic calibrations on any number of selected signal conditioners
- Calibrate all active measurements pre-test
- Calibration Types
  - Shunt Calibration
  - Voltage Substitution
  - Excitation Power Supply Calibration
  - External Calibration
Typical Low Speed Data Acquisition
System Instrumentation

- Standard Instrumentation - Not always in the Catalog
  - Special Ranges (Cryogenics, Hundreds of Degrees F)
  - Special temperature compensation circuits
  - Special Materials
  - Extremely High Pressures
  - Vacuum pressure transducers - Specific to the A-3 Test Stand

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Typical Low Speed Data Acquisition
System Instrumentation

Pressure
- Transmitter
- Delta P

Temperature
- Thermocouples
- RTD’s

Flow
- Pressure Transmitter
- Venturi Flowmeter
- Turbine Flowmeter

Strain
- Strain Gauges

Speed
- Speed Probe
Control Systems
Control Systems

- The Control System manages the test complex and rocket engine or component systems during day-to-day operations and testing while maintaining a safe environment allowing for orderly test shutdown and making facility systems safe in emergency situations.

- Programmable Logic Controllers (PLCs) form the backbone of the SSC Control Systems – New term Programmable Automation Controllers (PAC).
- PLCs primary functions are to sequence rocket engine or component tests and maintain daily operations.
- Hard-wired controls are provided as a backup to the PLCs.
Control Systems Functions

Day to Day Operations

- Unloading cryogenics/propellants (Oxygen, Hydrogen, Nitrogen, Methane, etc.)
- Propellant transfers from storage to run tanks
- Pumping up bottle pressures (Nitrogen, hydrogen, helium etc.)
- Gas leak and fire detection.
- Engine drying
- Facility Readiness Test (FRTs)
- Redline cut checks (Redlines are measurements that are monitored by the PLC for the purpose of initiating an immediate shut down when out of tolerance.)
Control Systems Functions

Test Day Operations

- Propellant Transfers
- Engine chill down and prep
- Blue-line monitoring (Permissives to start test.)
- Test stand valve sequencing and control during hot fire test
- Redline monitoring during hot fire test
- Performs a controlled shutdown of the engine
  - Critical valves are also wired to a backup PLC or timed relays
- For the A-3 Test Stand, proper control of the Chemical Steam Generator (CSG) system is also required.
A-3 Test Stand Control System

Seven PLC functions:
- Facility Control
- CSG Control
- CSG Control Backup
- Blue-Line and Redline Monitoring & Test Sequence Control
- Fire and Hazardous Gas Detection
- Dock – Propellant Transfer
- Calibration Control

Generic Ladder Logic is envisioned
- System is configured entirely through Excel or Database
- Excel tables and/or Database can be configured in advance and downloaded on test day.
- Excel tables and/or Database can be archived for historical reference

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Historical Overview of Controls System at SSC – E1

- **LSDAS Digitizer**
- **Control Consoles**: Includes PLC Racks
- **HSDAS**

**Facility S/C**: Programmable Signal Conditioners, Manual Filter Amps, PCB and Dynamics Amps

**CABLE TERMINAL ENCLOSURE**: Includes PLCs

**FEED THROUGH CABLE COMPRESSION BOX**
- **DRAG-ONS (RB, TEB)**
- **CABLE BOX**
- **STE/TA Instruments**
- **STE Valves**

**Analog Inputs**

**Collector**

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Typical E1 SLC Programmable Logic Controller (PLC) Installation

Historical Overview of Controls System at SSC – E1

E1 PLC Cabinet

- Dedicated STE PLC for Cell 2
  - DO
  - AI
  - AO
  - DI
- Shared Display PLC~
  - AI
  - DI

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Proposed A-3 Control System Architecture

Emergency Shut-Down (Test Conductor’s Console)

Watch-Dog Timers

PLCs

Immediate Bus A

Timer B

Timer C

Timer D

*HOLD

To Engine Controller

* If deemed necessary
For specific valves

To Control Valves

Fail-Safe Solenoid

S

VDC

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• Migration to faster PLCs in a Distributed Architecture outside the E1 Test Facility

• A-Complex Redline System
• A-Complex Fire & Gas Leak Detect System
• B-Complex Redline System
• B-Complex Fire & Gas Leak Detect System in design
• E3 Redline System

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Test Control Center with Graphical User Interface (GUI) Screens

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Hard Wired Controls

Controls GUI

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InTouch by Wonderware GUI

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Video System
The A-3 Video System is envisioned to be a digital media video recording system. To this date at SSC, video recording system has been based upon a system that records to video tapes.

**A-3 TEST STAND VIDEO REQUIREMENTS:**
- Must record digital data to either hard drive or DVD.
- Low Speed frame rate of ~30 frames per second (fps). High Speed frame rate of ~200 fps or greater.
- Recording time of >= steam generation time plus margin, minimum for both Low and High-Speed Video Systems.
- Recording must be remote from the camera.
- Cameras and/or enclosures must operate at expected vacuum pressures.
- Must digitally stream real time Low Speed test video off-site.
- Must support Infrared (IR) video.
A-3 Test Facility Network Architecture
A-3 Network Architecture

Description

• The A-3 Network System is designed to provide overall network connectivity between all of the sub-networks required for the A-3 Electrical Systems.

  • A-3 TEST STAND NETWORK REQUIREMENTS:
    • Test data network must be physically isolated from facility data network.
    • Transmission of “near” real-time data and video must use outgoing only physical connections.
    • Provide method of transmitting post-test data outside of Test Facility network.
    • Provide a means of digitally transmitting “deterministic” LSDAS data to the Control System.
A-3 Network Architecture
Block Diagram

**Acronyms**
- CS: Control System
- LSDAS: Low Speed Data Acquisition System
- HSDAS: High Speed Data Acquisition System
- Tx: Transmit
- Rx: Receive
- SSC: Stennis Space Center
- SDC: Stennis Data Center
- TCC: Test Control Center

**Stennis Space Center**

**A-3 Test Facility LAN**

- CS LAN ESK-A3-2001-FAC
- LSDAS LAN ESK-A3-4071-FAC
- Video LAN ESK-A3-7071-FAC ESK-A3-7571-FAC
- HSDAS LAN ESK-A3-5071-FAC
- Video LAN ESK-A3-7571-FAC
- Video LAN ESK-A3-4071-FAC
- LSDAS LAN ESK-A3-5071-FAC
- A-3 LAN Server
- DAS Transmission Server
- To SSC LAN
- Tx

**TCC**

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A-3 Network Architecture
Block Diagram

Typical Control System Type Inputs

- INTERCONNECT CABLEING RECEPCTACLE BOXES (RBs) & TEBs
- SENSORS & TRANSDUCERS
- DIGITIZER / MULTIPLEXER(S)
- RECORDER / CONTROL WORKSTATION (SCB)
- LDSAS DATA TO CS

Networked Control System Connection

- To Controls System
- To LSDAS
- To HSDAS* (if necessary)

ControlLogix Chassis

- Processor Slot
- Ethernet for GUI
- Reflective Memory
- I/O

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A-3 Network Architecture

Block Diagram

• **Advantages of network connectivity:**
  - **Reduced Input modules to the controller:**
    - Reduce costs of acquiring unnecessary analog input modules
    - Reduce costs of wiring channels to the CS
    - Reduce effort of programming required for analog inputs
    - Reduce schedule by not requiring additional wiring, programming, and activation time.
    - Reduce space required to house CS channels
    - Reduced potential failure points with less hardware
    - Potentially increased scan speed with fewer modules to query
    - Data consistent between LSDAS and Controls Systems

• **Disadvantages of network connectivity:**
  - Lack of comparison of measurements between systems (Controls vs. DAS)
  - Reduced independence of Controls operations.
  - Controls blindness if DAS fails.
Summary

NASA/SSC’s Mission in Rocket Propulsion Testing Is to Acquire Test Performance Data for Verification, Validation and Qualification of Propulsion Systems Hardware

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- Reliable
- Comprehensive
- Timely

Data Acquisition in a Rocket Propulsion Test Environment Is Challenging

- Severe Temporal Transient Dynamic Environments
- Large Thermal Gradients
- Vacuum to high pressure regimes

A-3 Test Stand Development is equally challenging with respect to accommodating vacuum environment, operation of a CSG system, and a large quantity of data system and control channels to determine proper engine performance as well as Test Stand operation.

SSC is currently in the process of providing modernized DAS, Control Systems, Video, and network systems for the A-3 Test Stand to overcome these challenges.