



# Modernization of B-2 Data, Video, and Control Systems Infrastructure

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## **Abstract**

The National Aeronautics and Space Administration (NASA) Glenn Research Center (GRC) Plum Brook Station (PBS) Spacecraft Propulsion Research Facility, commonly referred to as B-2, is NASA's third largest thermal-vacuum facility with propellant systems capability.

B-2 has completed a modernization effort of its facility legacy data, video and control systems infrastructure to accommodate modern integrated testing and Information Technology (IT) Security requirements. Integrated systems tests have been conducted to demonstrate the new data, video and control systems functionality and capability. Discrete analog signal conditioners have been replaced by new programmable, signal processing hardware that is integrated with the data system. This integration supports automated calibration and verification of the analog subsystem. Modern measurement systems analysis (MSA) tools are being developed to help verify system health and measurement integrity. Legacy hard wired digital data systems have been replaced by distributed Fibre Channel (FC) network connected digitizers where high speed sampling rates have increased to 256,000 samples per second. Several analog video cameras have been replaced by digital image and storage systems. Hard-wired analog control systems have been replaced by Programmable Logic Controllers (PLC), fiber optic networks (FON) infrastructure and human machine interface (HMI) operator screens. New modern IT Security procedures and schemes have been employed to control data access and process control flows. Due to the nature of testing possible at B-2, flexibility and configurability of systems has been central to the architecture during modernization.

## **Introduction**

The Space Propulsion Research Facility, commonly referred to as B-2, as shown in Figure 1, is designed to hot fire rocket engines or upper stage launch vehicles with up to 890,000 N (200,000 lbf), after environmental conditioning of the test article in simulated thermal vacuum space environment. As NASA's third largest thermal vacuum facility, and the largest designed to store and transfer large quantities of propellant, it is uniquely suited to support developmental testing associated with large lightweight structures and Cryogenic Fluid Management (CFM) systems, non-traditional propulsion test programs such as Electric and In-Space propulsion, as well as its baseline role for engine developmental and upper stage hot fire tests. B-2 has completed a modernization effort of its facility legacy data, video and control systems infrastructure to accommodate modern integrated testing and IT Security requirements. This paper details the data, video and control systems infrastructure modernization efforts at B-2.

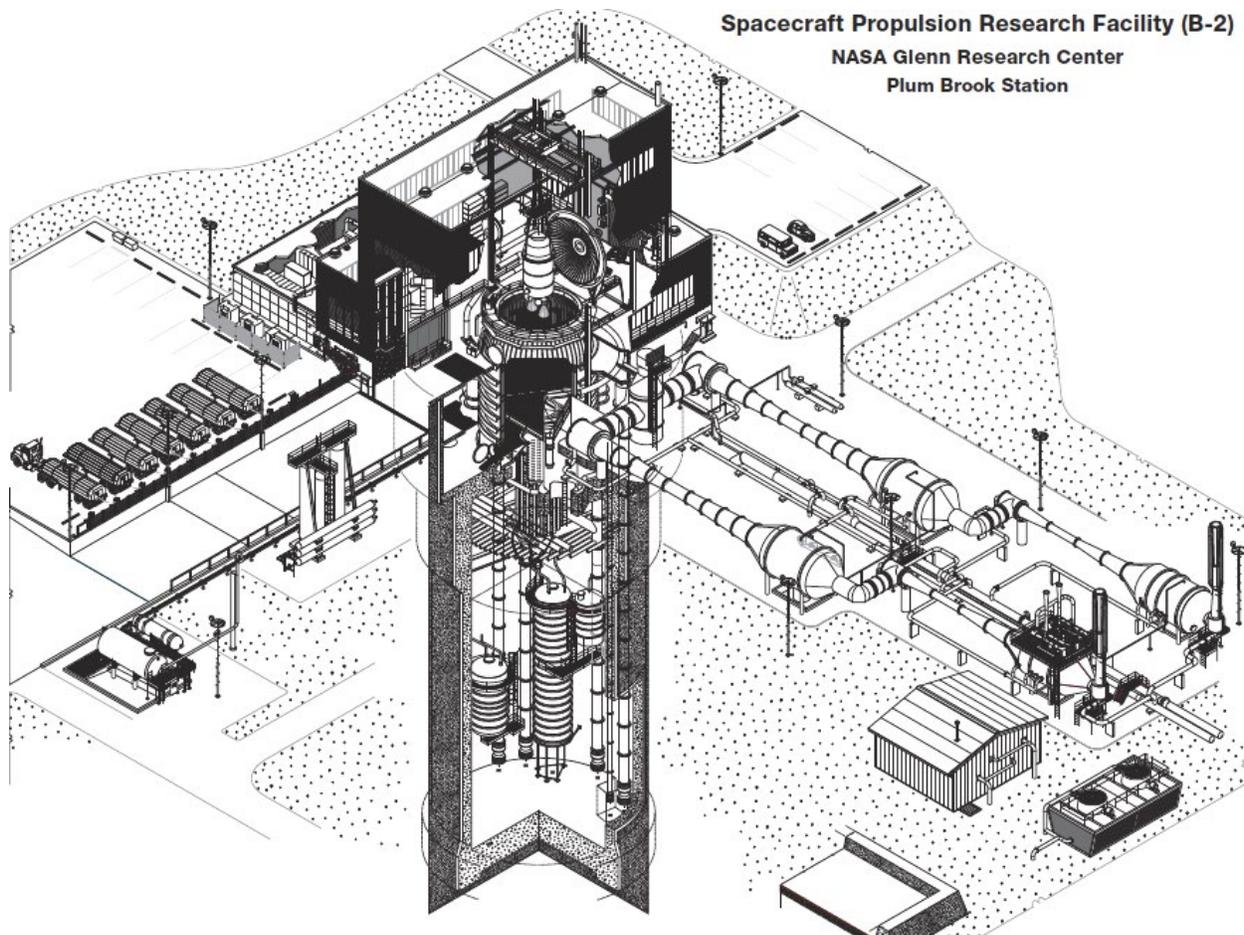


Figure 1.—B-2 Cutaway

## Legacy Systems

The original infrastructure was installed in the 1960s to support upper stage Centaur Vehicle Testing, where the original control room, as shown in Figure 2, is remotely located approximately 2,500 ft from the facility. This infrastructure (Ref. 1) included direct hard-wired cables from field instruments through their analog signal conditioning to the central data system (CDS) located at the control room. Control devices were hardwired via relays from the control room back to facility. Hardwired push buttons and interlock relay logic schemes were employed. The CDS served also as the sequencer and abort system for upper stage vehicle testing. Electrical power for the instruments and control devices was generated at the control room and transmitted to the facility via setup and step down transformers, where this was backed up by a rotating motor-generator set uninterruptible power supply located at the control room. Signal conditioning equipment included thermocouple ovens, balance panels for strain gauge transducers, special bridge conditioners for platinum resistance temperature sensors, and power level circuits for hot wire point sensors. Video was taken by tube cameras and transmitted back via coax to the control room. Data system sampling rates were selectable at either 8 or 25 samples per second and stored on reel-to-reel magnetic tapes. Strip charts were used extensively to record vibration data.

In the 1990s, the facility and control room were modified with a minicomputer based Escort Data System (Refs. 2 and 3), where alpha numeric cathode ray tube (CRT) display capabilities were made available to facility operators to monitor facility and test parameters. This system also improved low speed sampling from 1 to 10 Hz, increased channel counts, and had history file and playback capabilities. For the most part, the facility process systems controls remained the same with push button hardwired



Figure 2.—Original B-Control Room

operator panels and using hard wired relay logic. More modern eight wire analog manual knob signal conditioners for strain gauge transducers were installed along with constant current low temperature silicon diodes as a replacement for cryogenic point sensor and thermocouple temperature measurements. The sequencer and abort system was also replaced with an Allen Bradley SLC 500 programmable logic controller (PLC) implementation which was configured with high speed direct current (DC) input/output (I/O) cards as well as external high speed analog calculation hardware. This PLC implementation improved the abort system reaction response timing to 1 mS and with above red-lined conditions of 20 mS. Previous video cameras were replaced by newer phototube and CCD camera technology were the analog video signals were recorded on VHS recorders. In addition, the motor generator set was replaced by a 50 kVA UPS system.

## Maintenance Issues

With the aging of the facility, many maintenance issues arose within these Legacy systems. Wire cabling buried between the site and control room deteriorated over time due to wire insulation erosion and water infiltration. Lightning strikes would induce voltages that would damage transducers and data system input channels. Floating electrical ground grid potential differences between the facility and control room required isolation amplifiers to be added to the controls and data systems signals. Control, data, and video systems were no longer supported by the original equipment manufacturers. Video systems coax transmission lines deteriorated and did not have the bandwidth to handle higher video frame rates. Flexibility and system re-configurability was limited due to the intensive hardwired infrastructure between specific systems. Preparation of these infrastructure systems and keeping them functional for test

as well as performing manual end to end analog calibrations and verifications between the control room and facility were labor intensive.

## **New Requirements**

New launch vehicle systems and other test article systems that require thermal vacuum conditions become more sophisticated and varied. The improvements in the data, video, and controls infrastructure are required to meet testing needs. Flexibility and scalability of the data video and control is vital to satisfying the varying testing demands.

First of these improvements was to upgrade the control system wiring infrastructure with a new fiber optic based backbone. This fiber optic backbone would replace much of the existing hardwired copper cables where new distributed system PLC technology would be incorporated to activate and monitor field devices, provide man machine interface (MMI) operator screens in lieu of hardwired push button panels, and provide the bandwidth for a host of other controls devices and systems. Data and Video Systems would take advantage of the fiber media. The new media has greater bandwidth and frequency response as compared to copper and reduces and/or eliminates the maintenance issues of water infiltration, lightning, and wire insulation deterioration. The fiber backbone enables the flexibility of adding components to the systems, whether for video, data storage, transmission or other devices required to perform a test.

## **Control System**

The B-2 control system (Ref. 4) has been modernized using a distributed architecture whose primary intelligent modules are PLC and HMI workstations, also referred to as Graphical User Interfaces (GUI), based around a Client/Server System Architecture. The system is designed to offer a robust, redundant architecture with high flexibility and expansion capabilities. One of the key components to the modernization of the B-2 Test Facility was to convert the facility's existing hard-wired control system(s) to a distributed PLC and HMI based Control System Architecture.

The control system also consists of remote input/output (RIO) drops to minimize field wiring to equipment. RIO drops can also be expanded to handle new requirements and processes as needed. An advantage of a PLC-based controls system is the ability to communicate between systems and processes. The B-2 Control system is designed with emphasis on controlling facility operations, automating sequencing and test abort conditions, and control of the major facility sub-systems. Additionally the control system is used to monitor facility ancillary systems, and keep a log of key parameters with the goal to aid in the condition-based maintenance of that hardware.

With a PLC-based control system, capabilities are expanded with the use of HMIs to replace hardwired control panels. Advantages of having an HMI go beyond the ease of adding graphics, they provide the capability to include features such as password protection to limit operations to qualified personnel, key stroke monitoring, pop-ups to force a two-step process to prevent inadvertent operation, animation of objects to show status, history of the data, and the ability to have standardization in the design of the operator screen.

PLCs have been used for decades in industry due to their robustness. To further extend the control system's availability and reliability, the B-2 Control System is designed with redundancy at several levels, including hot standby PLCs, HMI data servers, networking and cabling, and redundant HMI workstations. It is a recent reality that today's PLCs have dual co-processors to minimize the scan time, thereby enabling a hot standby configuration as a viable risk reduction choice for the system architecture. One of the Advantages of the HMI Server/Client Architecture is the ability to expand. The B-2 system consists of eight workstations, with expansion if required. Another benefit is the ability to add functionality and additional data points with minimal cost. This capability also makes the control system seamless in adding functionality to handle multiple test stands or facilities if required.

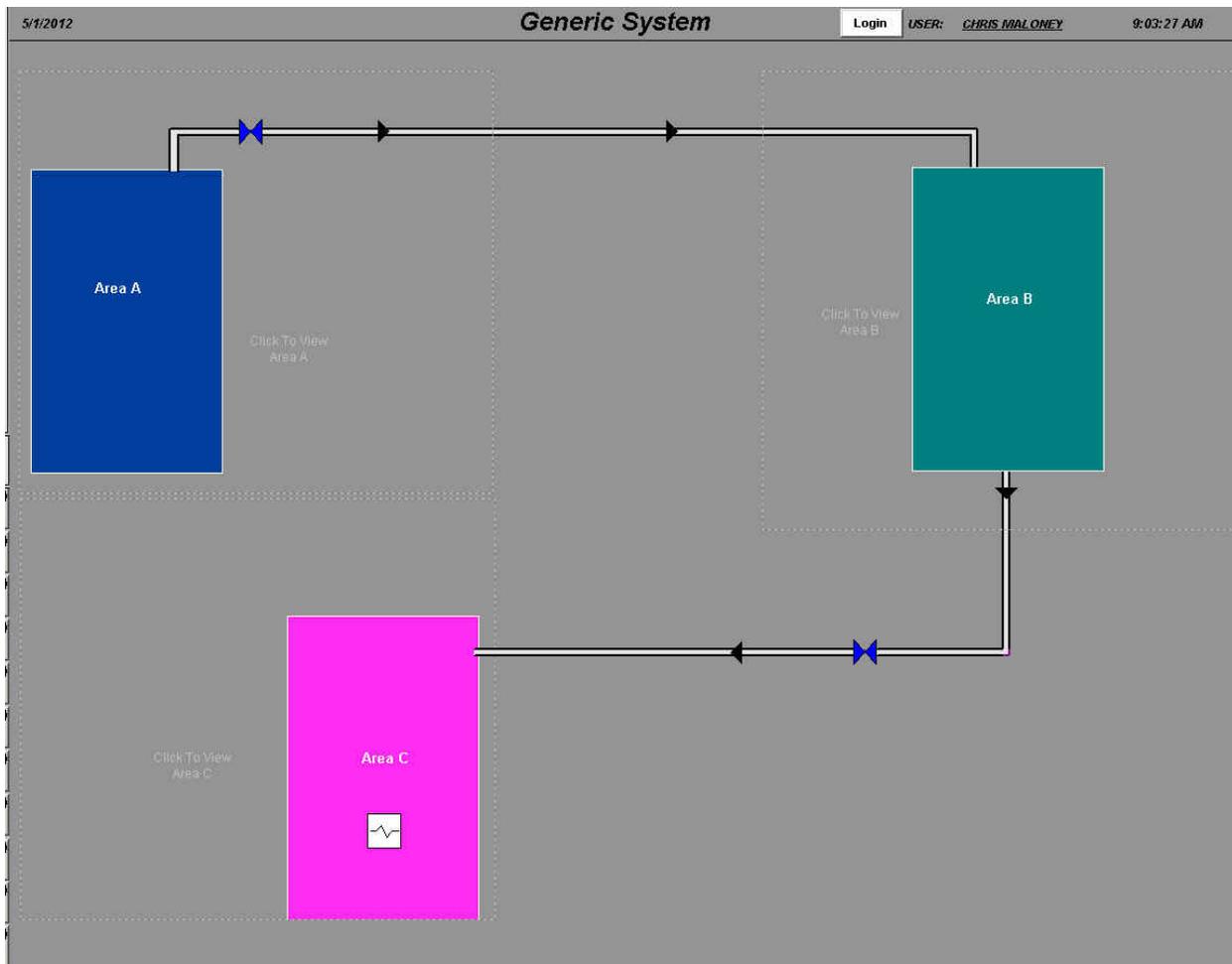


Figure 3.—Generic HMI Control Screen for the B-2 Control System

Human factors were considered in the design of operator screens. This design includes standardized status, alarm, and shortcut buttons; color-coded process systems piping; pop-up control screen standardization; and two-step decision-making operation wherever possible. Figure 3 shows a generic HMI screen for the B-2 control system.

The B-2 Control system is capable of generating alarms based on set points and derived system requirements. Workstations can be configured to display specific alarms for any given system(s) or display all alarms. The system produces event logs with a time/date stamp showing a history of events at any workstation. The event log records the name of the operator and records operator activity. The event log is beneficial in troubleshooting when anomalies exist, processes are out of tolerance, or questions arise concerning operator error. The control system is capable of recording data through its historian data collection server. The system can handle up to 2,500 tags and is expandable up to 250,000 tags with additional investment. An alarm management plan is under development to prioritize alarms, presenting the correct information to the operators early enough to effect changes before events escalate.

A unique feature of the B-2 Control System is the event notification system. This system allows configuration of any alarm condition to dial out a phone message alerting a first responder, which aids in unattended operations. It will also enable audible instructions to personnel, per protection zone, in the event of a hydrogen fire or leak detection event.

Each control room console is prewired with media to aid in the reconfiguration or augmentation required for particular tests. This media includes single and multimode fiber, coaxial cable for video, Cat-

5E, twisted pair and discrete wiring for control and data. This media distribution system allows the control room to be configured as required for test operations, test engineering, QA, and customer needs. Unique test requirements such as high speed video, mission simulators, and test article controls can be accommodated efficiently, minimizing test costs associated with augmenting the control room on a case by case basis.

## Data Acquisition System

The B-2 Data Acquisition System (DAS) (Ref. 4) includes the signal conditioning electronics, data recording, storage, display, and archive systems. Like the control system, the B-2 facility DAS employs a distributed architecture which is designed to meet the unique challenges of a space environmental upper-stage engine testing facility. In addition to addressing the specific requirements of performing large-scale data acquisition for test articles in a thermal-vacuum chamber, the B-2 DAS architecture also meets the hazardous environments NEC code safety requirements for tests which involve the use of propellants (Class 1 Group B Division 2).

As discussed previously, the facility has a dedicated instrumentation Data Room at the test site. This location minimizes the transducer cabling impedance and improves signal to noise ratio, while protecting sensitive equipment from the environments produced by the test facilities. The Data Room allows the front-end electronics of the DAS to operate safely by providing a constant positive air pressure in the room. This allows the signal conditioning and digitizing electronics to function close to the test chamber when propellants are present in the chamber.

Furthermore, the distributed architecture of the DAS is used to mitigate the risk of the potential loss of data in a catastrophic scenario. Once the analog measurements are digitized in the Data Room the resulting data is streamed immediately via fiber optics to data recording units that are located at the B-Control building outside the B-2 facility exclusion zone, approximately one-half mile away from the test facility. This is graphically displayed in Figure 4. Joined together by a 10 Gb fiber-channel switch fabric, the digitizers and the recording units form a fourth generation storage area network for which the distance between the digitizers at the B-2 test site and the recording units at B-Control does not introduce any appreciable time delay. The data is recorded remotely with the same latency it would have if the recording units were located in Data Room with the digitizers.

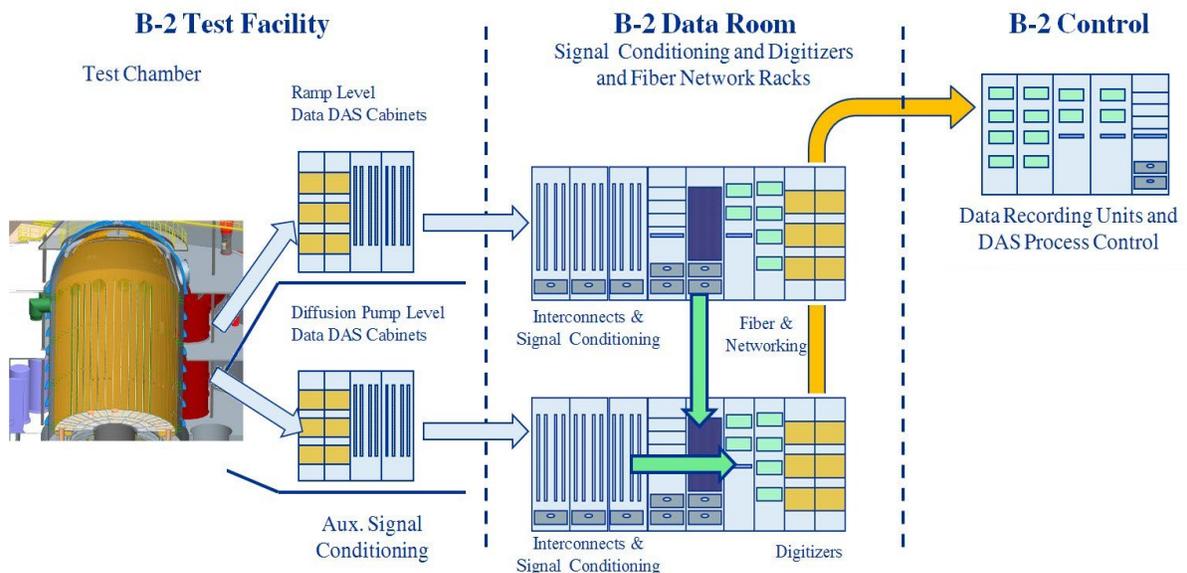


Figure 4.—Signal Flow from Test Chamber to Storage/Display

The B-2 DAS is based entirely on commercial off the shelf (COTS) hardware, and open hardware/software standards. The acquisition stations which house the A/D converters, digital signal processor (DSP) board, FC interfaces, and embedded processors are connected to a storage area network (SAN) over fibre channel. The architecture is designed to guarantee deterministic data acquisition and recording at designed bandwidth per channel. There are currently 576 channels of A/D's arranged in 32- or 96-channel subsystems, including low speed, high speed and discrete channels. Data is synchronized through a clock generator which is phase-locked to an externally supplied IRIG-B signal for accurate time stamping.

The data lab in the B-Control building houses the control, monitor, and archive workstations. The control workstation runs the application to configure the hardware, define the test parameters, and control access to the test data. There are three monitor workstations that run the visualization software for near real-time data display, as well as the limit-check monitoring software. The archive server backs up acquired data to mass storage and to magnetic tape library. The server has the capability to locate and serve archived data to other workstation clients (test customers) for analysis, reduction or transmission. An on-line post processing workstation is available to define and automatically execute analyses on any number of channels once acquisition is complete.

Data displays and control interfaces are extended to the control room shown in Figure 5.

The B-2 DAS includes programmable analog signal conditioners to condition response transducers used in a wide variety of measurements including both high-speed ( $SR > 5$  kHz) and low-speed ( $SR < 4$  kHz) sample rates used for a diverse range of measurements. Hardware self-tests and calibrations are traceable to National Institute of Standards and Technology (NIST). Programming of the conditioning system via Ethernet is controlled through the DAS control computer using the Test Definition Editor. For configuration management purposes, all parameters associated with the measurement are contained in this test definition file.

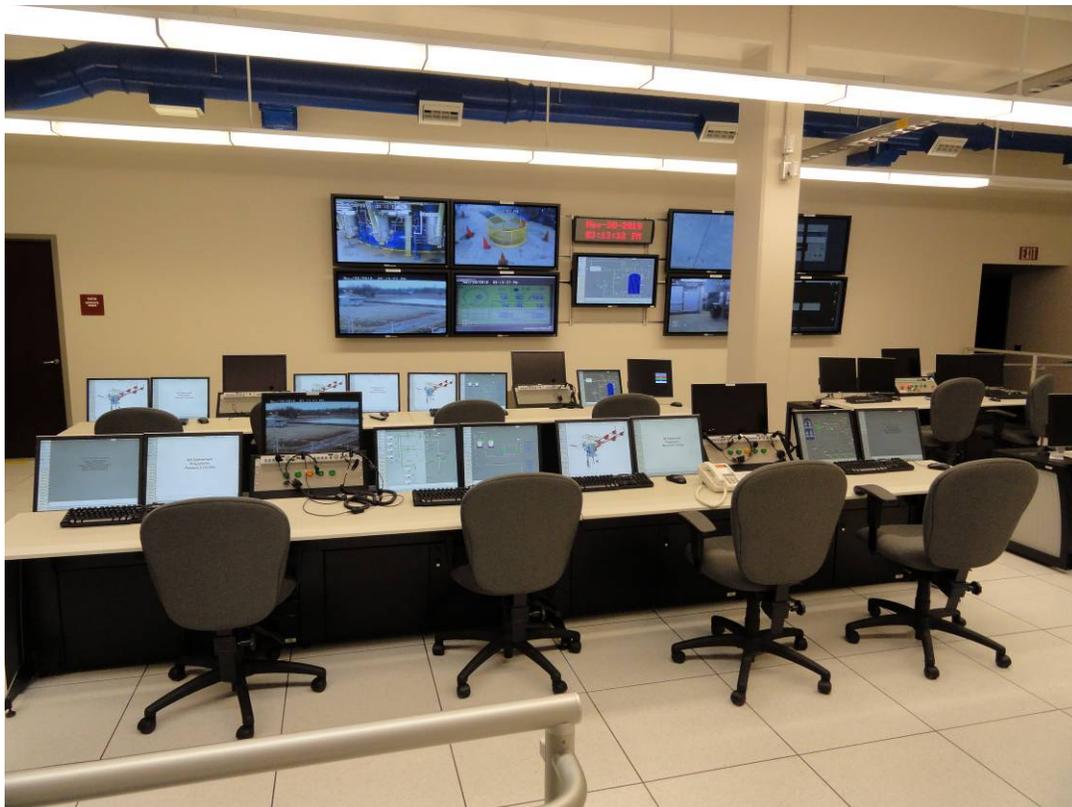


Figure 5.—B-2 Control Room

All of the signal conditioners have a 4-pole programmable low-pass Flat/Pulse filters (300 Hz to 30 kHz, as well as Bypass mode), for either time or frequency domain. The amplified output voltage of the signal conditioners can be buffered and made available as needed to other systems, such as the controls system and/or the red-line abort system as required. Conditioner types include 1-2 or 4 arm voltage bridge, frequency to DC converters, charge and IEPE accelerometers, constant current, and voltage amplifier/filters.

The functional role of the signal conditioning system in the B-2 DAS is to accurately prepare the analog portion of the signal chain for processing by the commercial off the shelf (COTS) digitizing and data processing system. Transducer interface cabling would be the other key component to complete the B-2 measurement system. There are many DAS requirements that relate strictly to the capabilities of a digital acquisition system, however, good system design places limitations on the location of hardware, cable lengths, transmission media, and data transport. Keeping the digitizers close to the signal conditioner outputs minimizes the cabling between the two systems, and reduces the risk of any unwanted transmission line effects between the signal conditioning system's outputs and the digitizer system's inputs. While the benefit of this design choice is clearly recognized at the boundary between the two systems, the choice puts additional requirements on the digitizing system to be selected; specifically, the ability to keep all of the individual digitizer sample clocks synchronized and the ability to transport the resulting data effectively. The B-2 DAS is a complete COTS turn-key data acquisition system solution with numerous state-of-the-art features, including the ability to provide complete control of the signal conditioning system, in effect treating the signal conditioning system as a native part of the DAS. Multiple digitizer bricks can be operated independently or in concert to form more complex systems with larger channel counts. The digitizer bricks are joined together on a 10 Gbps Fiber-Channel Switched Fabric along with remote redundant array of independent disks (RAID) storage units and Control PCs to form the distributed architecture. This architecture provides an unprecedented level of modularity and scalability that maximizes the versatility of the over-all system without compromising the system's high-speed capabilities (Ref. 5).

## **Measurement Systems Analysis**

A degree of uncertainty and variation exists in every measurement. It is an unavoidable part of the measurement process. While systematic errors can be eliminated by calibration, random errors can only be minimized through understanding the reason for the errors, minimizing their effects, and quantifying the residual errors for the test customer. The methodology for estimating the uncertainties in measurements and in the experimental results calculated from them must be structured to combine statistical and engineering concepts. Various methods of standardizing the uncertainty in the single channel measurement are accepted. As system channel counts grow large and signal chain diversity increases (accelerometers, strains, voltages, pressures, temps, discrete values, speed etc), it becomes challenging to ascertain the quantified level of measurement variability that exists in the data acquisition system. We refer to this process of characterizing the measurement variability of each channel in a system as Measurement Systems Analysis (MSA) (Ref. 5).

A measurement system analysis is a vital component for many data systems quality improvement initiatives. Accurate measurement should be consistent over the time (stability), have a measure of the amount of bias in the system (accuracy) and a measure of the bias values though the expected range of measurements (linearity). Precision measurement consists of repeatability and reproducibility of measurements under similar conditions with different operators operating the same system. Major challenge for any test facility is to provide customer with reliable data with accuracy. Given the large channel count, high-speed digitizing rates and diverse instrument types being supported by this Low Speed Data Acquisition System (LSDAS), avoiding the potential difficulty in performing MSA activities for the whole system has been addressed at the earliest stages of the system design. The methodology for estimating the uncertainties in measurements and in the experimental results calculated from them must be structured to combine statistical and engineering concepts.

Each component of the LSDAS provides high degree of network controllability and network status monitoring. The signal conditioning system design consists of signal conditioners, Test Subsystem software, digital multimeter and digital function generator for signal injection. The digital multimeter and function generator are fully network controlled and fully integrated into the signal conditioning system, to provide seamless NIST traceable calibrations for all of the analog signal components of the subsystem (Ref. 5). Graphical User Interface software for signal conditioning allows an operator to conduct fully automated factory acceptance test (FAT) NIST traceable (Z540) calibration and a GO-NO-GO daily (or more frequent) integrity Test. FAT run before and after the test provides assurance to the test conductor and the customer about the integrity of the signal conditioning system. These tests allow an operator to validate the system reliability and repeatability. For the LSDAS, the NIST traceable calibration capabilities of the signal conditioning subsystem are available to be utilized by the DAS. This allows the Calibration Calculator (MSA Calibration Software) to utilize the Signal Conditioning test subsystem to extend the system's ability to calibrate the analog to digital converters (A/D) and perform complete NIST traceable calibrations of the entire system (Ref. 5). MSA Calibration Software provides flexibility to calibrate the DAS threat multiple levels including transducer end to end (XDR), (Channel Signal Conditioning) CSC and Digital Signal Processing (DSP).

The uncertainty determined and reported for a particular measurement should be the most realistic estimate possible. A Comprehensive approach has been used in estimating measurement uncertainty for B-2 Measurement Systems Analysis. Central goal of the MSA is the task of quantifying the normality of the data acquiring and providing a high level report which clearly shows the quality of the data from each channel across the entire system. Random and Systematic errors are considered in various calculations performed to obtain confidence level for Thermocouple, Heat Flux Sensor and RTD temperature measurements performed at the B-2 Spacecraft Propulsion Facility. Using a consistent criterion, MSA software calculates the average, mode, standard deviation, skewness and kurtosis for each channel. The Standard Deviation is the measure of the spread of data points from the mean. Skewness is a measure of symmetry, or more precisely, the lack of symmetry, where a distribution, or data set, is symmetric if it looks the same to the left and right of the center point. Kurtosis is a measure of whether the data points are peaked or flat relative to a normal distribution. That is, data sets with high kurtosis tend to have distinct peaks near the mean, decline rather rapidly, and have heavy tails (Ref. 6). Data sets with low kurtosis tend to have a flat top near the mean rather than a sharp peak. The standard normal distribution of a data set has a kurtosis of zero. MSA software algorithm provides detailed graphs for individual channels across the entire system to validate the uncertainty in the acquired data. Figure 6 shows the MSA report for an individual Low Speed Channel. The top 2 charts in Figure 6 show the Histogram of the data acquired on an individual Low Speed Channel indicating the 99 percent confidence limit for data uncertainty to be within 30  $\mu\text{V}$ . Data normality tests for each channel can be performed developing similar plots. Figure 7 shows the Power Density Spectrum of an individual channel providing further information to ensure normality of acquired data and signal strength at higher or lower frequencies.

Figure 8 shows the MSA report charts for the 40 Low Speed Channels. The five charts in Figure 8 shows various statistical calculations performed on the acquired data across the 40 channels to obtain a fair understanding of system reliability and channel uncertainties. The skewness, standard deviation, kurtosis, average and mode of the data sets indicate a mainly normally distributed data set for most channels, with one notable exception of channel 3. The B-2 DAS MSA performed using the MSA software compares each of the values to a pass/fail threshold limit to assure normality of the channel and calculate uncertainty limits. The combined capabilities of the features and characteristics of this LSDAS, in combination with the automated MSA processes, the NIST traceable calibrations, and the measurement system uncertainty analysis for the LSDAS, provides the test facility with a highly efficient method of conducting Data Validation and Verification exercises (Ref. 7).

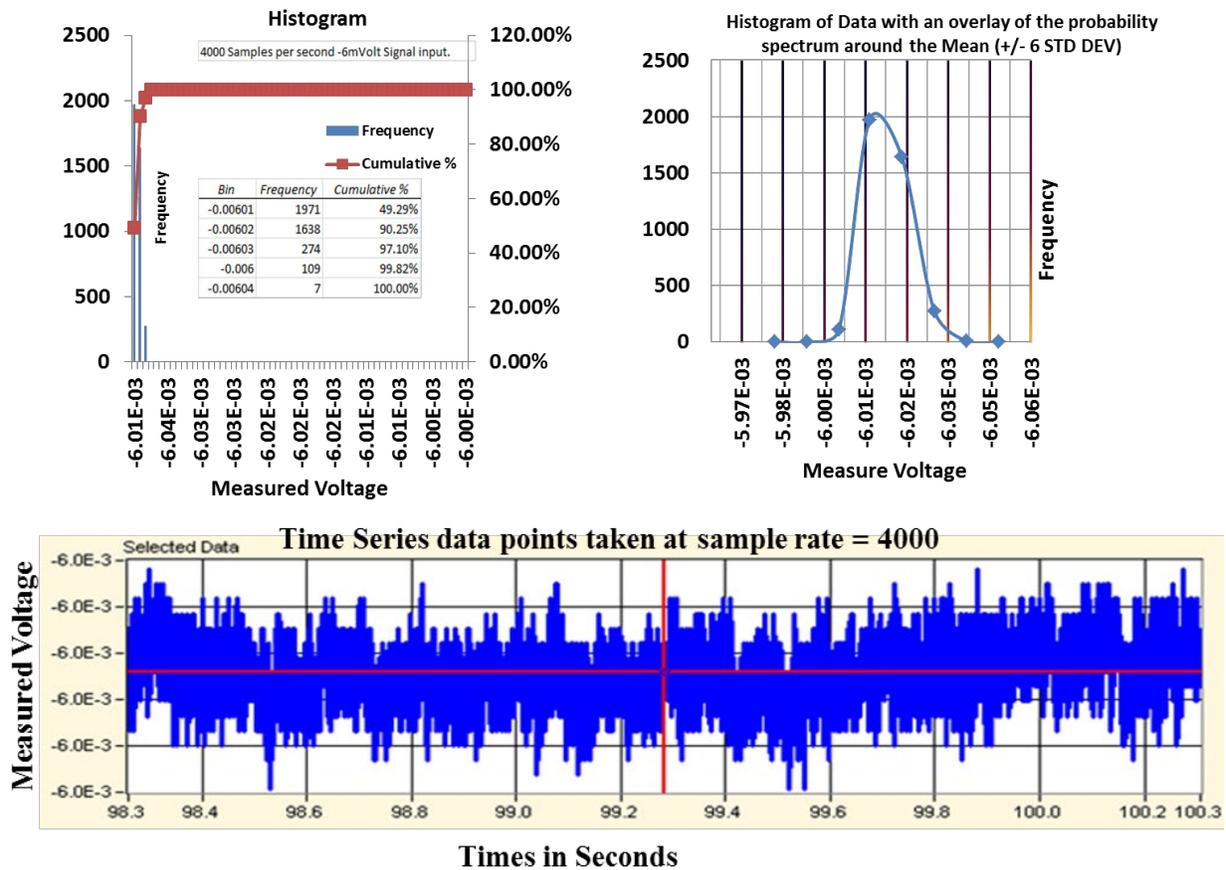


Figure 6.—MSA Report for an individual Low Speed Channel

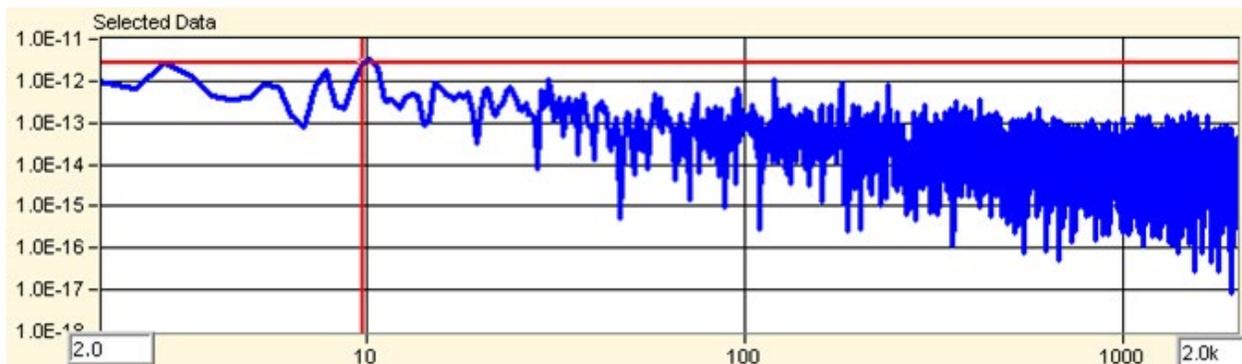


Figure 7.—Power Density Spectrum for an individual Low Speed Channel

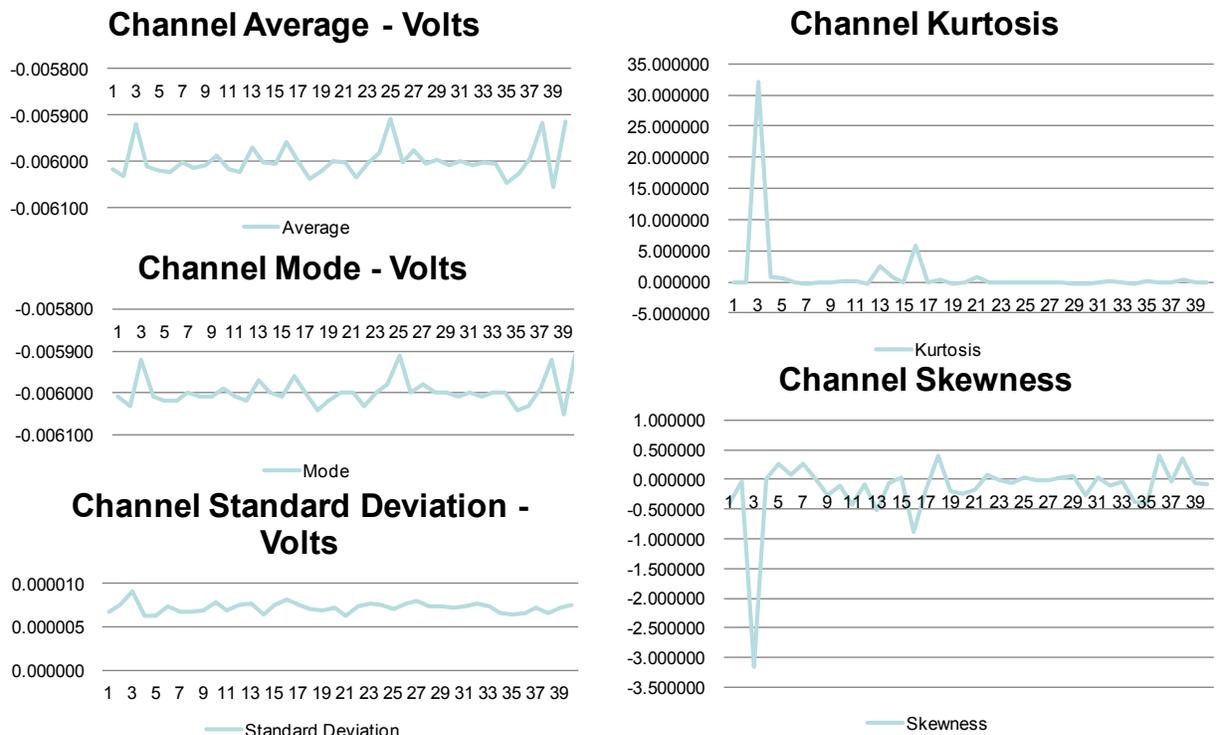


Figure 8.—MSA Report for 40 Low Speed Channels

## Video Systems

The B-2 video system is an integral part of the facility modernization. This new video system enables Managers, Engineers and Technicians to have easy visual access to points of interest during test operations. It also provides a vast amount of information and opportunity to visually inspect the facility, its surroundings and control room area with respect to security. The B-2 video system consists of 32 digital image cameras. Various high quality cameras with extensive features including high zoom lens, preset and pan/tilt capabilities are used in this surveillance system. Cameras installed in the vacuum chamber are capable of sustaining thermal vacuum environment and provides high quality picture. A matrix switching system capable of supporting 256 camera inputs and 32 monitors is supported by digital hard disk recorders (DDR) and a video multiplexer designed to be used within surveillance system. Video signal is time stamped using the Society of Motion Picture and Television Engineers (SMPTE) time code prior to being recorded on DDR. DDR provides recording live video stream capability up to 30 frames per second. DDR feature allows replay without interrupting the recording and download of recorded files of to external recording devices with ease.

The B-2 video surveillance system is supported by fiber switches for fiber to coax conversion of the video signal transmitted over long distance. Video signal amplifiers accommodate amplification supporting the matrix switching system setup for multiple video input cameras, controlling DDR, PC and joystick controllers, and output monitors supporting various distant terminals throughout the facility. Encoders designed to transmit video signal over to web interface allows B-2 video system streaming for internal network. Remote control of camera pan-tilt-zoom and recording is accomplished by DDR, joystick controller and remotely connected network PC. Options are being investigated for providing remote access to advertise facility capabilities from remote locations ensuring proper security.

## **Summary**

Modernization of the B-2 Data, Control and Video Systems along with use of Measurement Systems Analysis techniques has revitalized the facility for its use as a flexible and configurable multi-use space simulation vacuum chamber ready to meet new customer test article development requirements using currently available technology. The combined capabilities of these features and characteristics of the data and control systems in combination with the automated MSA process utilizing the NIST traceable calibration tools and MSA software , provide the facility with highly efficient methods of conducting data Validation and Verification exercises, identifying problems, quantifying errors, and performing facility controls checkouts. This modernization eliminates legacy maintenance issues and increases the reliability of overall facility systems performance.

## Appendix A.—Acronym List

NASA	National Aeronautics and Space Administration
A/D	Analog to Digital
CCD	Charged Coupled Device
CDS	Central Data System
CFM	Cryogenic Fluid Management
COTS	Commercially Off The Shelf
CRT	Cathode Ray Tube
CSC	Channel Signal Conditioning
DAS	Data Acquisition System
DC	Direct Current
DDR	Digital Disk Recorder
DSP	Digital Signal Processing
FAT	Factory Acceptance Test
FC	Fiber Channel
FON	Fiber Optic Network
Gb	gigabit
GRC	Glenn Research Center
GUI	Graphical User Interface
HMI	Human Machine Interface
Hz	Hertz
I/O	Input / Output
IEPE	Integrated Electronics Piezo Electric
IRIG-B	Inter-Range Instrumentation Group
IT	Information Technology
kHz	kilohertz
kVA	kilovoltampere
LSDAS	Low Speed Data Acquisition System
MMI	Man Machine Interface
MSA	Measurement System
NEC	National Electric Code
NIST	National Institute of Standards and Technology
PBS	Plum Brook Station
PC	Personal computer
PLC	Programmable Logic Control
QA	Quality Assurance
RAID	Redundant Array of Independent Disks
RIO	Remote Input Output
RTD	Resistance Temperature Detector
SAN	Storage Area Network
SMPTE	Society of Motion Picture and Television Engineers
SR	Sampling Rate
UPS	Universal Power Supply
VHS	Video Home System
XDR	Transducer

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## Biographies

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Mr. Butala is a civil servant working at Plum Brook Station, NASA located at Sandusky, Ohio. He is currently serving as the Data System Engineer at the Space Propulsion Research Facility (B-2). He has about 2 years of experience as a Data System Engineer. He is currently serving in the United States Army Reserves as a Paralegal Specialist. He has served in the U.S. Armed forces for 7 years, including 4 years active duty service. He holds a Master's of Science in Information Resource Management from Central Michigan University. He earned his Bachelor's degree in Electronics and Communications Engineering degree from Government Engineering College Modasa, India, in 2004.

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14. ABSTRACT The National Aeronautics and Space Administration (NASA) Glenn Research Center (GRC) Plum Brook Station (PBS) Spacecraft Propulsion Research Facility, commonly referred to as B-2, is NASA's third largest thermal-vacuum facility with propellant systems capability. B-2 has completed a modernization effort of its facility legacy data, video and control systems infrastructure to accommodate modern integrated testing and Information Technology (IT) Security requirements. Integrated systems tests have been conducted to demonstrate the new data, video and control systems functionality and capability. Discrete analog signal conditioners have been replaced by new programmable, signal processing hardware that is integrated with the data system. This integration supports automated calibration and verification of the analog subsystem. Modern measurement systems analysis (MSA) tools are being developed to help verify system health and measurement integrity. Legacy hard wired digital data systems have been replaced by distributed Fibre Channel (FC) network connected digitizers where high speed sampling rates have increased to 256,000 samples per second. Several analog video cameras have been replaced by digital image and storage systems. Hard-wired analog control systems have been replaced by Programmable Logic Controllers (PLC), fiber optic networks (FON) infrastructure and human machine interface (HMI) operator screens. New modern IT Security procedures and schemes have been employed to control data access and process control flows. Due to the nature of testing possible at B-2, flexibility and configurability of systems has been central to the architecture during modernization.					
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