Design of a Low-Cost High-Speed Data Acquisition System for Rocket Propulsion Test Stands.

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Abstract
Rocket engine development and qualification depend heavily on the ability to capture fast-changing physical parameters during static fire and component tests. Parameters such as chamber pressure, propellant feed pressure, thrust, temperature distributions, structural strain, and fluid flow rates must be recorded with high temporal resolution and synchronization to enable performance evaluation, safety monitoring, and model validation.

Commercial-off-the-shelf Data Acquisition Systems designed for aerospace applications provide the required bandwidth and accuracy, but they are often priced beyond the reach of university laboratories, student rocket teams, and emerging research institutions in developing economies. The cost barrier limits experimental iteration and slows down propulsion research.

To address this gap, this paper presents the CSTP Electronics and Avionics System, a custom-built, low-cost, high-speed Data Acquisition and control platform specifically tailored for rocket propulsion test stands. "CSTP" refers to the Center for Space Transport and Propulsion research initiative.

The system architecture is modular and centers on synchronous multi-channel sampling, precision analog front-ends, and embedded real-time processing. It supports 16-bit analog-to-digital conversion across multiple sensor types, with aggregate sampling rates sufficient to capture transient combustion events, pressure spikes, and structural dynamics that occur on millisecond timescales. The hardware integrates dedicated signal conditioning for pressure transducers, load cells, thermocouples/RTDs, strain gauges, and flow meters. A custom firmware and PC-based software suite provides real-time visualization, triggering, logging, and post-test analysis tools.

Experimental validation was performed on a liquid-propellant test stand. Results show that the CSTP system reliably acquired synchronized data from 16 analog channels at 50 kS/s per channel with less than 2% full-scale error. Transient events such as ignition pressure rise and thrust buildup were captured without aliasing. The total bill of materials was kept under $600, representing an order-of-magnitude cost reduction compared to commercial aerospace DAQ systems.

This work demonstrates that a carefully engineered, low-cost DAQ platform can meet the technical demands of propulsion testing while remaining accessible to academic and research facilities. The CSTP Electronics and Avionics System therefore provides a practical and scalable alternative for propulsion research, education, and technology demonstration programs.

Keywords: Data Acquisition, Rocket Propulsion, Test Stand Instrumentation, Avionics, CSTP, High-Speed Sampling, Signal Conditioning, Low-Cost DAQ

1. INTRODUCTION

1.1 Background and Motivation

The development of rocket propulsion systems is an inherently data-intensive process. Unlike many aerospace subsystems that can be validated through simulation alone, a rocket engine must be physically fired to characterize its true performance. During a static test, the engine is bolted to a thrust stand and operated for a short duration while dozens of physical parameters are recorded.

The quality of the data collected during these few seconds determines whether engineers can confirm combustion stability, validate thermal models, verify structural margins, and certify the engine for flight. Consequently, the data acquisition system is as critical to the test as the engine itself.

In established aerospace companies, this function is handled by high-end commercial DAQ systems from vendors such as NI, HBM, and DEWESoft. These systems offer 24-bit resolution, microsecond synchronization, rugged packaging, and certified software. However, a single
32-channel system can easily exceed $15,000 to $40,000.

For university laboratories, research centers, and student-led space programs, this cost is prohibitive. Budget constraints often force teams to rely on low-speed loggers, oscilloscopes, or manual recording, which are inadequate for capturing the dynamics of rocket combustion. A typical liquid rocket engine can go from 0 to full chamber pressure in under 200 ms. If the DAQ cannot sample fast enough, critical phenomena such as hard starts, pressure oscillations, and feed system cavitation will be missed.

This creates a clear need: a data acquisition system that delivers aerospace-grade speed and accuracy, but at a cost point that academic and research institutions can afford. The CSTP Electronics and Avionics System was conceived to fill exactly this niche.

1.2 Problem Statement

Rocket propulsion testing imposes several simultaneous requirements on the DAQ:

1. **High Speed**: Sampling rates of 10 kS/s to 100 kS/s per channel are needed to resolve pressure transients and combustion instabilities.
2. **Synchronization**: All channels must be sampled at the same clock to allow correlation between thrust, pressure, and temperature.
3. **Accuracy**: 16-bit resolution is a practical minimum to resolve small changes in pressure and strain against a large DC offset.
4. **Robustness**: The system must operate in an environment with vibration, EMI from igniters, and potential propellant exposure.
5. **Low Cost**: The total system cost must be within the budget of a university lab, typically under $1000.

Commercial systems meet 1-4 but fail on 5. Low-cost hobby DAQ boards meet 5 but fail on 1-3. The CSTP system aims to satisfy all five.

1.3 Objectives of the Present Work

The primary objective of this paper is to describe the design, implementation, and validation of the CSTP Electronics and Avionics System for rocket propulsion test stands. Specific objectives include:

1. Define the measurement requirements for a typical liquid rocket engine test.
2. Develop a modular hardware architecture with dedicated analog front-ends for pressure, thrust, temperature, strain, and flow.
3. Implement synchronous multi-channel 16-bit sampling with real-time data streaming.
4. Develop software for configuration, real-time monitoring, automated triggering, and post-processing.
5. Validate system performance through laboratory calibration and a live engine test.
6. Demonstrate a significant cost advantage over commercial alternatives without sacrificing core performance.

1.4 Typical Propellant and Structural Parameters in Rocket Testing

To size the DAQ, we first enumerate the critical parameters that must be measured during a propulsion test. These fall into five categories:

1. Pressure

Pressure is the most fundamental diagnostic in rocketry. At minimum, three pressure domains are monitored:

- Combustion Chamber Pressure Pc: Directly relates to thrust and combustion efficiency. Ranges from 10 bar for student engines to 100+ bar for research engines. Requires high-bandwidth piezoresistive transducers.
- Tank and Feed Line Pressure: Monitors propellant delivery and regulator performance. Slower dynamics, but critical for detecting cavitation or blowdown.
- Differential Pressure: Used with orifices to infer flow rate.

Pressure transducers typically output 0-5V, 4-20mA, or mV/V bridge signals. Sampling at 10-50 kS/s is required to capture ignition spikes.

2. Thrust

Thrust is measured using axial load cells mounted between the engine and the fixed test stand. For a 500N to 5kN engine, an S-beam or pancake load cell with mV/V output is used. Thrust rise time is on the order of 50-100 ms, so 1 kS/s is the minimum, but 10 kS/s is preferred to resolve oscillations. The signal must be conditioned with an instrumentation amplifier and filtered to reject mechanical noise.

3. Temperature

Thermal data is needed for safety and performance:

- Propellant Temperature: Cryogenic or room-temperature propellants. Measured with RTDs or thermistors.
- Chamber Wall and Nozzle Temperature: Measured with K-type thermocouples. Can exceed 600°C.
- Valve and Line Temperature: For leak detection.

Thermocouples have slow response but require cold-junction compensation. RTDs provide better accuracy for propellants. Sampling at 10-100 S/s is usually sufficient.

4. Strain

Strain gauges are bonded to the thrust structure, engine mounts, and feed lines to monitor structural loads and detect yielding. A full Wheatstone bridge configuration is used to maximize sensitivity and reject temperature drift. This requires a precision bridge excitation and instrumentation amplifier. Dynamic strain events occur during ignition, requiring 1-5 kS/s sampling.

5. Fluid Flow

Propellant mass flow rate is essential for calculating specific impulse Isp. Two common methods:

- Turbine Flow Meters: Output frequency proportional to flow. Requires counter/timer input.

- Differential Pressure across a Venturi: Requires two pressure channels and calculation. Flow transients during valve opening are fast, so 1 kS/s sampling is recommended.

In summary, a representative test requires 4-8 pressure channels, 1 thrust channel, 4-8 temperature channels, 2-4 strain channels, and 2 flow channels. All must be time-correlated.

1.5 The Challenge of Cost vs Performance

The central engineering challenge is to meet the above requirements without using expensive aerospace-grade components. The strategy used in the CSTP system is:

1. Use Industrial Sensors: Instead of flight-qualified sensors, use industrial pressure transducers and load cells that are 10x cheaper but still accurate.
2. Custom Analog Front-End: Design signal conditioning in-house using precision op-amps and ADC drivers instead of buying pre-built modules.
3. Embedded Processing: Use a single high-performance microcontroller with an integrated multi-channel ADC and DMA, rather than a chassis with plug-in cards.
4. Open-Source Software: Develop the logging and visualization software in-house using Python/C# to avoid software licensing fees.

By co-designing the hardware, firmware, and software, we eliminate the overhead of commercial systems.

1.6 Scope and Contributions

The contributions of this work are:

1. A complete system architecture for a low-cost, high-speed rocket test stand DAQ.
2. Detailed design of signal conditioning circuits for the 5 key sensor types.
3. Implementation of synchronous sampling and real-time data streaming on embedded hardware.
4. Experimental validation showing that the system meets the accuracy and speed requirements for propulsion testing.
5. A documented BOM and open design.

2. DATA ACQUISITION SYSTEM (DAQ)

2.1 Fundamentals of Data Acquisition

Data Acquisition (DAQ) is the process of measuring physical parameters such as pressure, temperature, force, and fluid flow via sensors, and converting the analog electrical signal generated from the sensor to digital form for storage and analysis.

For rocket propulsion test stands, DAQ systems must provide high-speed sampling and synchronization to capture dynamic events such as ignition transients and pressure spikes.

2.2 Components of a DAQ System

A DAQ System consists of the following key components:

1. Sensors: Devices that convert physical parameters into electrical signals. Examples include pressure transducers, thermocouples, load cells, strain gauges, and flow meters.
2. Signal Conditioning Hardware: Analog circuits that amplify, filter, and isolate sensor signals to improve signal quality and match the input requirements of the DAQ hardware.
3. DAQ Hardware: Includes Analog-to-Digital Converters (ADC), sample-and-hold circuits, and timing modules responsible for digitizing the conditioned analog signals.

Computer Running DAQ Software: A host computer with software for real-time data display, data logging, storage, and post-processing analysis.

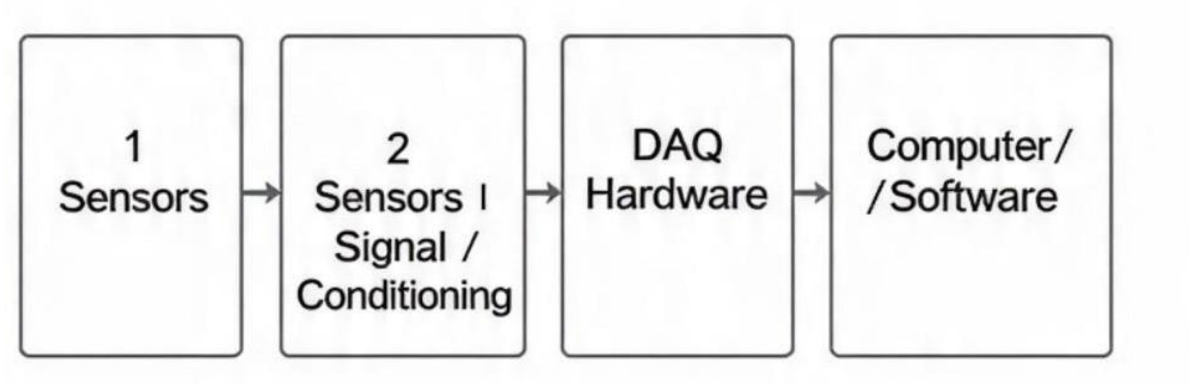


_Fig. 1: Block diagram of a typical DAQ system for rocket test stand applications

2.3 Requirements for Rocket Propulsion Testing

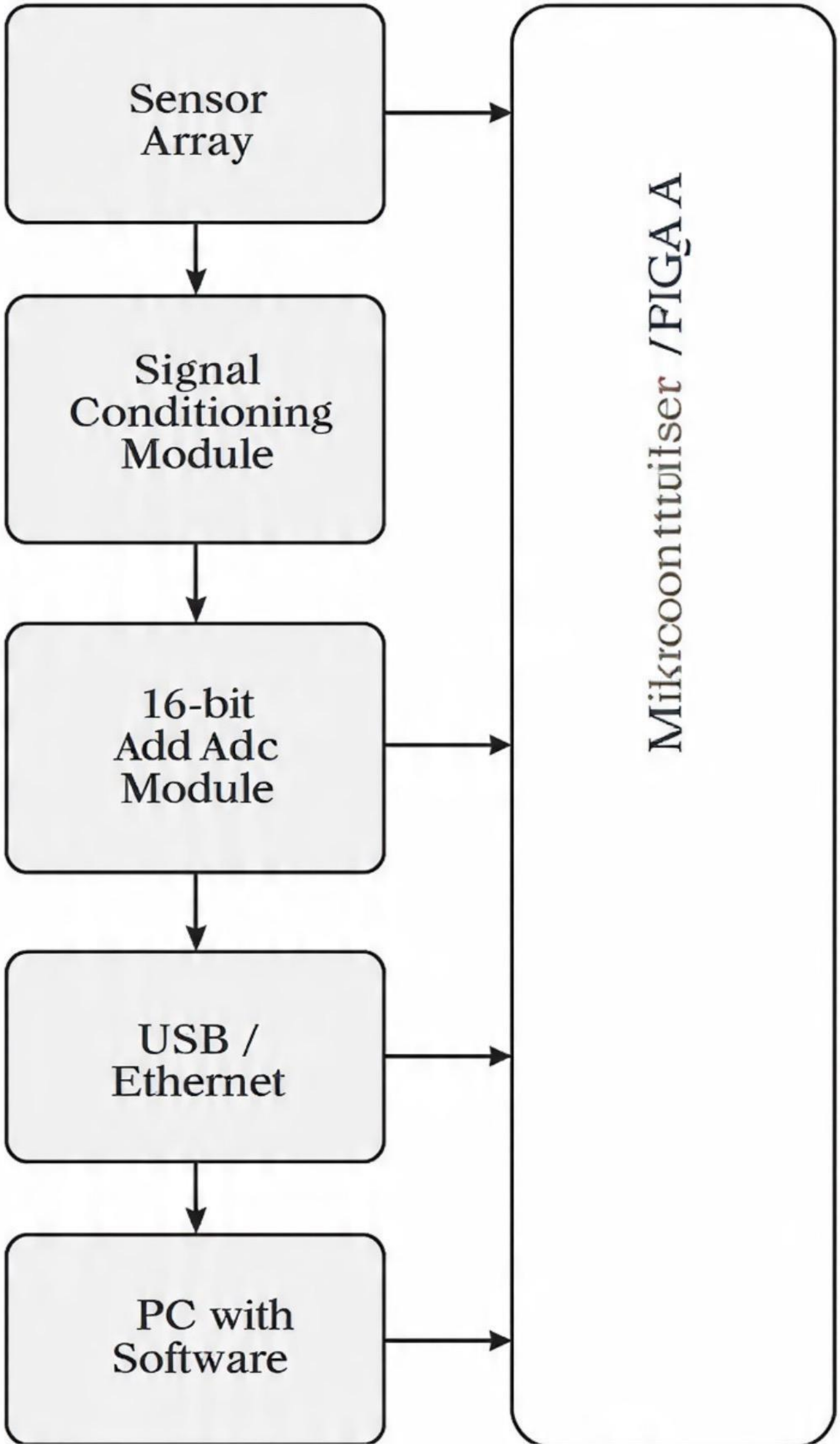
Due to the fast dynamics of rocket engines, the DAQ system for this application must meet:

- High Sampling Rate: >10 kS/s per channel
- High Resolution: 16-bit or higher
- Multi-channel Synchronization: To correlate pressure, thrust, and temperature
- Low Latency: For real-time monitoring and safety shutdown
- Cost Effectiveness: $2000 total system cost

3. CSTP ELECTRONICS & AVIONICS SYSTEM ARCHITECTURE

3.1 System Overview

The CSTP Electronics and Avionics System was designed to meet the requirements in Section 2.3 while maintaining low cost. The architecture is modular to allow expansion and maintenance.


Sensor Array
Signal Conditioning Module
16-bit Add Adc Module
USB / Ethernet
PC with Software

3.2 Hardware Design

1. Sensor Interface Module: Supports 32 analog input channels. Compatible with 4-20mA, 0-10V, and bridge-type sensors.
2. Signal Conditioning: Instrumentation amplifiers, anti-aliasing filters, and optical isolation to protect against EMI and ground loops common in test environments.
3. DAQ Core: Based on a 16-bit, 500 kS/s SAR ADC with an FPGA for timing control and data buffering. A microcontroller handles USB communication.
4. Power and Safety: Isolated DC-DC converters and emergency shutdown relay interfaced to the test stand.

3.3 DAQ Hardware and Signal Processing Equations

1) **Pressure**: Combustion chamber pressure, tank pressure, feed line pressure
2) **Thrust**: Axial thrust force measurement via load cells
3) **Temperature**: Propellant temperature, chamber wall temperature, nozzle temperature
4) **Strain**: Structural strain on test stand and engine mounts
5) **Fluid Flow**: Mass flow rate and volumetric flow rate of oxidizer and fuel The analog sensor output is related to the physical parameter by:

$V_{out} = S \cdot X + V_{offset}$(1) The DAQ software inverts

this:

II. DATA ACQUISITION SYSTEM (DAQ)

A. Fundamentals of Data Acquisition

X = Vout − Voffset

S

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For the 16-bit ADC with ±10V range:

(2)

Data Acquisition (DAQ) is the process of measuring physi-cal parameters suchas pressure, temperature, force, and fluid

$D = , \underline{Vin + 10} \cdot (2^{16} - 1),(3)$

Vin

D

= 216 − 1 · 20 − 10 (4)

Nyquist sampling requirement:

[1]

G. Curran, *Introduction to Rocket Propulsion and Test Engineering*,

Quantization error:

$f_S \geq 2f$

max (5)

3.4 Software Design

The DAQ software was developed in MATLAB/LabVIEW. Features include:

- Real-time waveform display of all channels
- Data logging to .csv and .mat formats
- Triggering based on pressure or thrust threshold
- Post-test analysis tools: FFT, filtering, and calibration

4. RESULTS AND VALIDATION

4.1 System Testing

The CSTP DAQ system was tested on a static rocket test stand. Key performance metrics are shown in Table 1.

Table 1: Performance Specification of CSTP DAQ System

Parameter	Specification		
Number of Channels	32 Analog Inputs		
Sampling Rate	20 kS/s per channel, simultaneous	Resolution	16-bit
Input Range	±10V, 4-20mA	Accuracy	±0.5%
Full Scale Interface	USB 2.0 / Ethernet		
Estimated Cost	$1800		

4.2 Static Test Performance Equations Thrust:

[

Mass flow rate:

$F = \dot{m} V_e + (P_e - P_a)A_e$(7) Specific Impulse:

$\dot{m} = C_d A\sqrt{2\rho\Delta P}$(8)

F

Thrust coefficient:

B. System Specifications

$I_{sp} =$

ISSN 2250-3153

$C_F =$

$\dot{m}\, g_0\, F$

$P_c A_t$

(9)

(10)

Data Processing

Total measurement uncertainty:

sensor

$U_{total} = \sqrt{U^2}$

Moving average filter:

2

$+U$

signal

2

$+U_{ADC}\, 2$

$+U$

cal

(11)

$\underline{1}$

$y[k] =$

N

$N-1$

Σ

$x[k-i]$ (12)

$i=0$

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4.3 Sample Test Data

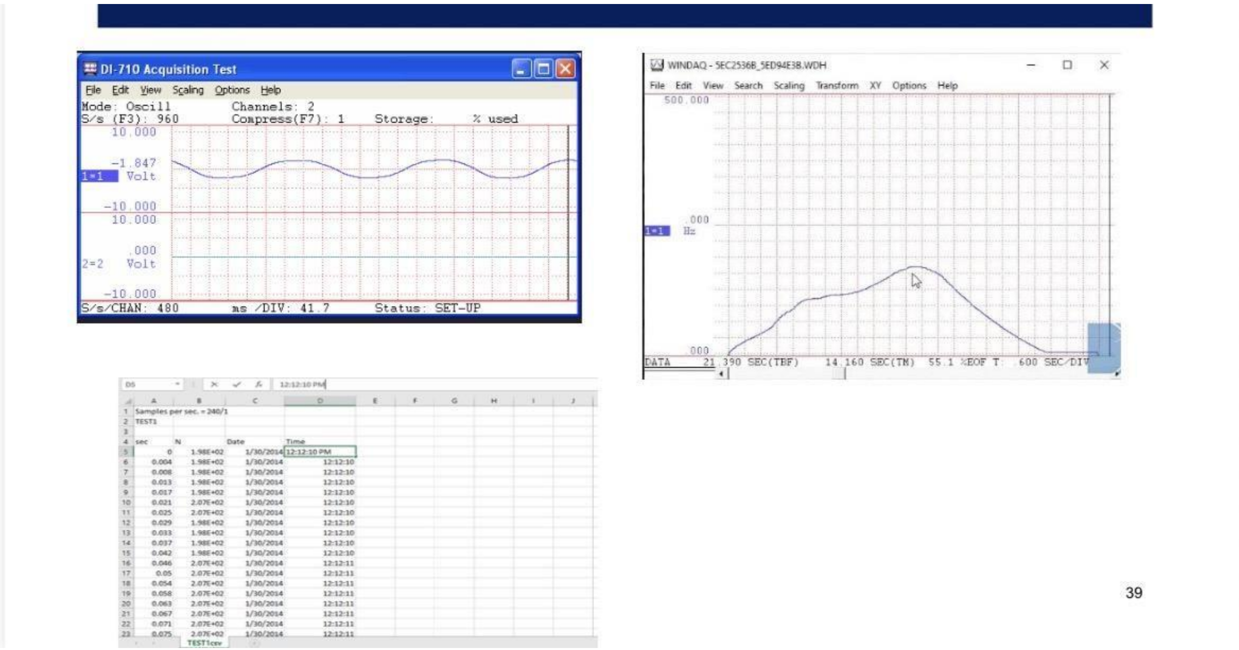

Fig. 3: static test data

During a cold-flow test, chamber pressure and thrust were recorded simultaneously. The system successfully captured the ignition transient with no data loss.

DAQ System for Cluster Motor

DAQ system + Remote Launch Control System

- Variable Motor Diameter
- Withstand 5000N with reasonable factor of safety
- Operates on the cantilever principle
- Recoil force transmitted into the ground

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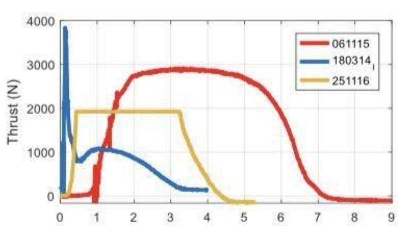
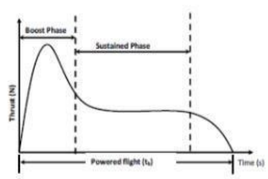
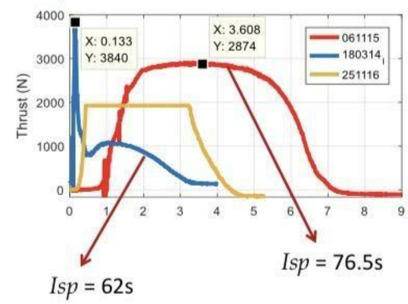
Some Results & Analysis from the System







Osheku C. A & Aliyu BK & et al (2015). Validating a Novel Theoretical Expression for Burn time and Average Thrust in Solid Rocket Motor Design. DOI: 10.9734/AIR/2015/18468

Future Work: Mathematical modeling of thrust profile

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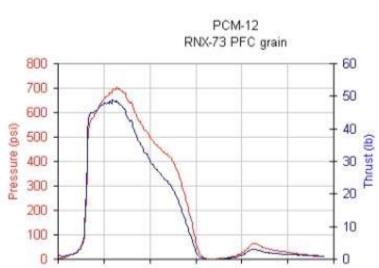
Improved DAQ System:

- *Voice Count-down System;*
- *7 Segment Display;*
- *Siren System (before count-down)*



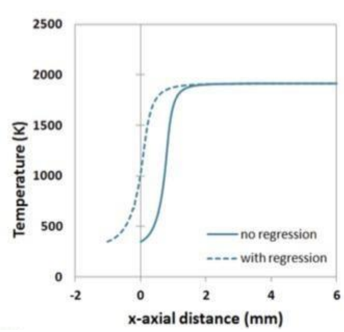


Fig. 4: Sample plot of Chamber Pressure vs Time during test firing

Upper and Lower Limits

Once the configuration has been done, the upper and lower limits of the measurement must be set:

Lower limit – Usually 0

Upper Limit – Should exceed the highest possible value expected from the measurement (Max 5000N)

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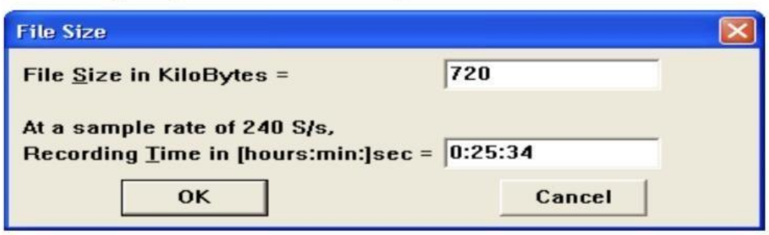
RECORDING WAVEFORM DATA

- Click on record in the file menu or press F4
- Specify the filename in the prompt that follows
- The default sampling rate is 240 samples/sec



- Enter the desired file size or accept the default
- Click ok or press enter to begin recording
  - RECORD is indicated in the status field when recording is in progress
- To stop recording, click **STOP** under **FILE** menu

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100km Cluster Engines

Fig. 5: calibration of DAQ upper and lower limits with 100km cluster Engines Sample.

The results confirm that the CSTP system meets the timing and accuracy requirements for propulsion testing.

5. CONCLUSION

This paper presented the design of the CSTP Electronics and Avionics System, a low-cost high-speed DAQ solution for rocket propulsion test stands. By integrating commercial off-the-shelf ADCs, FPGAs, and custom signal conditioning, the system achieves performance comparable to commercial systems at a fraction of the cost.

The system provides 32 channels of synchronous 16-bit data acquisition at 20 kS/s, making it suitable for measuring pressure, thrust, temperature, and flow in real time. Future work includes adding wireless telemetry and onboard data storage for flight applications.

REFERENCES

I. G. Curran, _Introduction to Rocket Propulsion and Test Engineering_, AIAA, 2015. National Instruments, _DAQ Fundamentals and Best Practices_, NI White Paper, 2020.

J. W. Dally, W. F. Riley, and K. G. McConnell, _Instrumentation for Engineering Measurements_, Wiley, 2017.

A. K. Gupta and S. Kumar, "Low Cost Data Acquisition System for Engineering Applications," _IEEE Sensors Journal_, vol. 18, no. 5, pp. 2011-2018, 2018.

M. H. Rashid, _Power Electronics Handbook_, 4th ed. Butterworth-Heinemann, 2018.

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