AERO-ENGINE DYNAMIC TESTING tackling the challenges
Outline

- Introduction to Jet Engine testing
- The challenges of dynamic data acquisition
- Solutions for dynamic data acquisition systems
- Examples
- Conclusion
Jet engines: powered by a turbine engine

Turbine engine main components:

- Compressor
  - Compresses incoming air to high pressure
- Combustion area
  - Burns fuel and produces high-pressure, high-velocity gas
- Turbine
  - Extracts energy from gas flow
Turbine engine

Turbine has 2 parts:

- First stage drives compressor shaft
- Second stage delivers torque to external ‘customer’

Example applications:
- Power generator
- Helicopter rotor
- Armored vehicle
- Or, Turbo-fan
Jet engine = turbine + turbo-fan:

- Fan driven by turbine engine
- Fan moves thrust-delivering ‘bypass air’
- Multiple concentric shafts required
- Turbo-prop: conventional propeller instead of fan
  - Requires gearbox to reduce speed
Jet Engine: theoretically simple concept

Engineering challenges

Jet Engine Design Challenges

- Extremely high reliability requirements
- Extreme temperatures
- Extreme stresses
- Complex mechanical design
- Complex dynamic properties
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Jet Engine Testing challenges

- Instrumentation challenges
  - Measuring rotating parts - telemetry
  - High frequency range – small turbine blade resonances differential strain
  - High temperatures – differential charge transducers

- Measurement system challenges
  - High channel counts
  - High frequency range
  - Endurance - performance testing – long test runs

- Safety challenges
  - Safety monitoring required during prototype engine testing
  - Data integrity requirements – certification and ensurance

- ‘joint venture’ projects – data sharing challenges

Movie courtesy of Rolls Royce
Traditional aero-engine dynamic data acquisition system

- From 30 to 300+ channels
- Frequency bandwidth between 5 and 80 kHz
- Static and Dynamic strains, pressure, accelerometer, microphone, ....
- Short and long test duration
- Real-time scope monitoring
- Dedicated level and order alarming

- Custom made system
- Specialized components
- Long and expensive signal cables
- Expensive maintenance
- Little evolution

Analog cables

Signal conditioning

Recording

Monitoring

Alarming
Challenges for the future

Multi-channel Dynamic Data Acquisition Systems

Quality

Performance

Reduced Costs and Risks

Flexibility
Challenges for the future

- All digital – 16/24 bit
- High quality signal conditioning
- Early digitization
- Full synchronization
- Tight hardware and software integration
- Diagnostics
- Troubleshooting tools
Challenges for the future

Multi-channel Dynamic Data Acquisition Systems

- Uninterrupted raw data storage
- Advanced Real-time alarm checking
- Real-time visualization
- Real-time processing
- Immediate access to measured data
- Fast retrieval of historical data
- Efficient post-processing and report generation

Performance
Challenges for the future

Multi-channel Dynamic Data Acquisition Systems

- Easy Test Preparation
- Easy channel configuration
- Different acquisition bandwidths
- From small transportable to large “super” test
- Flexible online data visualization and processing
- Broad post-processing

Flexibility
Challenges for the future

- COTS components
- Benefit of “standard” IT componentes
- Low training costs
- Reliable single source supplier

Multi-channel Dynamic Data Acquisition Systems

Reduced Costs and Risks
The ideal aero-engine dynamic data acquisition system

Signal Conditioning + ADC + DSP

digital link

Recording

Data Viewing

Processing

Storage
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Networked data acquisition system with centralized data storage

- Network of recording PC’s
- Master-master frontend operation
- Centralized data storage
- Network online analysis on separate visualization PC’s
Data acquisition hardware: the LMS SCADAS III family

SC316
SC317S slave unit

SC310(DC)
SC311S(DC) slave unit

SC305DC
SC306S slave unit
The LMS SCADAS III family
The industry standard dynamic data acquisition system

- Size specific mainframes
- 4 to 500+ channels
- 24-bit ADC w/ 116 dB dynamic range
- 6 Hz - 204.8kHz sampling – 92kHz usable bandwidth
- In-stream digital gain and offset calibration
- Up to 6 MSamples/s per frame sustained throughput to host PC
- 2 MSamples FIFO per Channel
LMS SCADAS III architecture
Focus on Master-only configuration

Master
- Host Interface
- System controller
- Master/slave interface
- SCIII bus
- Tacho processing
- Signal generation
- A/D and signal processing
- A/D and signal processing
- A/D and signal processing
- Input signal conditioning
- Input signal conditioning
- Input signal conditioning
- Tacho conditioning
- Digital to analog conversion

Slave
- Master/slave interface
- SCIII bus
- A/D and signal processing
- A/D and signal processing
- Input signal conditioning
- Input signal conditioning
- Input signal conditioning

Host Interface
next up to 64 m.
20 Aerospace Testing Expo 2005
LMS SCADAS III: a wide range of signal conditioners
Some of which specifically developer for jet engine tests

- Input signal conditioning: Voltage, ICP, (differential) charge, (static and dynamic) strain, microphone, temperature …
- Tacho conditioning – up to 8 tacho signals
- Output conditioning and signal generation
LMS SCADAS III: Jet Engine Testing specific platform extensions and evolutions – a summary

- PQDCA
- PQBA-II
- Multi-master operation
- IRIG-B
- Cabling
New conditioner: PQDCA

- Programmable Quad Differential Charge Amplifier
- Targeted application: jet engine testing
- Differential charge: high temperature environments
- Input ranges: 12.5pC to 13200pC
- 2-pin shielded LEMO connector
- High dynamic range: SNR > 99dB
- Cable check functionality
- Does support single-ended charge transducers, but does not replace PQCA
New conditioner: PQBA-II

- Programmable Quad Bridge Amplifier
- Basic functionality of PQBA
- Added functionality:
  - shunt calibration
  - higher input range for capacitive accelerometers
  - dynamic strain conditioning using balanced constant current excitation
Dynamic strain measurements

- **Standard ¼ bridge:**
  - Sensitivity depends on cable length
  - No common mode rejection

- **Unbalanced constant current:**
  - Sensitivity independent of cable length
  - No common mode rejection

- **Balanced constant current:**
  - Sensitivity independent of cable length
  - High common mode rejection
Multi master synchronization

- Targeted for high channel count, high throughput speed applications that go beyond 6.5MS/s (or 3.5MS/s in master/slave)
- First delivery: Techspace Aero
- Perfect clock synchronization (like with M/S)
- Plus: perfect data synchronization (like with M/S)
- Implementation: primary master and secondary master(s)
- Connection: serial link, ring topology
- SC316 only
IRIG-B

- GPS based time encoding for industrial applications
- IRIG-B support in SCADAS III:
  - Digital phase-lock-loop derives the system clock from the 1pps. signal → perfect clock synchronization between different front-ends
  - Absolute time annotation of acquired data samples → perfect data synchronization between different front-ends
- Implementation: SCADAS III input module that combines tacho inputs with IRIG-B input
Introducing LMS Test.Lab software …
One single user environment - for any Noise and Vibration job

Rotating Machinery

Acoustics

Structural

Environmental & Durability

Reporting

Data Sharing

Advanced Analysis

LMS Test.Lab®
xpo 2005
Test laboratory concept
Embedded workflow provides sequencing of tasks

Embedded Workflow ...

- Sequence to follow guided through major and minor task workflow
- Consistency in execution delivers quality in results
- Operational within half a day through suggested workflow in the workbooks
- Ease-of-Use for:
  - Occasional User
  - Operator
  - Expert
A complete solution for rotating machinery testing

Measurement Setup
- Throughput Data Recording
- Spectral Analysis
- Order Analysis
- Octave Analysis

Test Execution
- Compare Measurements
- Sign. Data Post-processing
- Throughput Validation
- Throughput Processing
- Operational Deflection Shapes
- Audio Replay & Filtering
- Psycho-acoustic Sound Diagnosis

Test Validation Post-processing

Reporting
- Desktop
- Batch Printing
Flexibility and Expandability using Industry Standard Components

- Signal Conditioning + ADC + DSP
- Optical SCSI
- Supervisor System
- Visualization Systems
- Controllers
- Scalable Storage NAS or SAN
- Post Processing
- Scalable Storage NAS or SAN
- Gibabit LAN
- Reliable
- Distributed Performance
- COTS
- Maintainable
Post-Processing

- General Analysis
  - Data Reduction
  - Time/Frequency/Order/Octave analysis
  - Statistics
  - Specific monitoring of events
  - Visualisation of curves
  - Deformation shapes
  - Using Absolute IRIG-B coding

- Specific analysis
  - Transient Analysis
  - Coherence / Correlation analysis
  - Source Identification
  - Operational Deflection Shape analysis
  - Operational Modal Analysis
  - Time-data Animation

- Automation of analysis
  - Automatic Post-processing in batch
Data organization and retrieval
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Example 1: 200 channel recording and monitoring system

- 200 channel data recording system
  - 40 kHz bandwidth / channel
  - 5 hour continuous recording
  - Real-time visualization of 64 channels simultaneously
  - Peak and RMS alarm level monitoring of all channels
  - Data on tape within ½ hour after test
  - Integrated signal conditioning and ADC close to test bench
  - 150 m digital data transfer to control room
Example 2:
272 channels recording and monitoring system

Layout of IT infrastructure
Example 2: Physical infrastructure location – concrete example

- Control room:
  - 5 x Scadas III
  - 5 x Recording PC’s in existing rack
- Utility room:
  - Master control w/ 2 TFT screens
  - 5 x Visualization PC’s
  - Server + tape library
Example 3:
High-volume data post-processing from aero-engine test cells

- Data input from recorded SIR-1001 tapes
- Capable of performing 5 production data analysis tasks
  - 1/3 octave analysis of steady-state noise for certification
  - 1/3 octave analysis of flight noise
  - Cross-spectral/narrow band engine-ordered analysis
  - Waveform eduction
  - Flight noise de-Dopplerization
- Automation of data transfer, processing, and output reporting
- Completion of process analysis within strict time limits

Results are consolidated in proprietary format

Test data, CADA-X processing results and consolidated data are managed and distributed through Tec.Manager
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- Flexible, Modular Operation
  - Small / Large Channel Count
  - Stand-alone / Integrated
- Performant Data-acquisition
  - Time / Frequency / Order / Octave
  - High Throughput Rate
- Visualization with Added-Value
  - Time data, Frequency Data, Order data
  - Level w.r.t. Warning/Alarm level
- Maintainable
  - Maximal use of Standard Software & Hardware
  - Interchangeable Hardware components
- Safe operation
  - Data Integrity
  - Data Storage / Archiving
- Process-centric
  - Centralized and User-friendly Acquisition Set-up, Control and Monitoring
  - De-centralized visualization
- Cost-effective
Thank you for your attention