

Loading Accuracy, Calibration and Measurement Uncertainty on the Hawk LIF FSFT

presented by:

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LIF FSFT Accuracy, Calibration & Uncertainty

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The Primary questions ?

- How do you calibrate a Full Scale Fatigue Test ?
- How do you know you are applying the fatigue test loads that you require ?

Hawk LIF Test goal was 2% of Full scale load application uncertainty over test lifetime with 0.5% repeatability!



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Presentation Content

- Hawk Test - to set the context and scale of the measurement and control accuracy issues
- Measurement Calibration - the methods of calibration and traceability procedures used for measurement of both the control variables and data acquisition system
- Loading Accuracy - sources of loading errors and the implication on system design and component selection
- Conclusion



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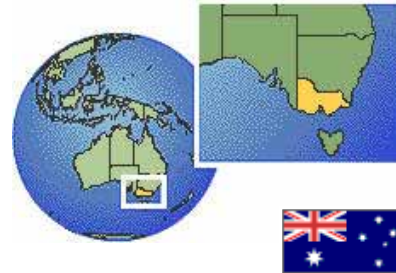


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HAWK Lead In Fighter Full Scale Fatigue Test

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Test Location



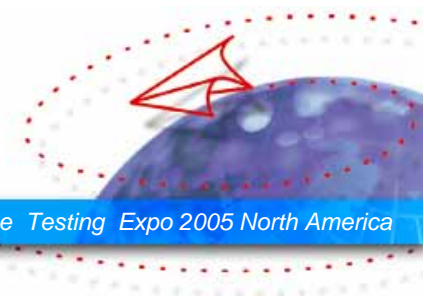
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The Australian Defence Science and Technology Organisation is conducting a Full Scale Fatigue Test under contract to BAE SYSTEMS of the Hawk Mk127 Lead In Fighter airframe at the DSTO Fishermans Bend facility in Melbourne, Australia

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HAWK Lead In Fighter Full Scale Fatigue Test



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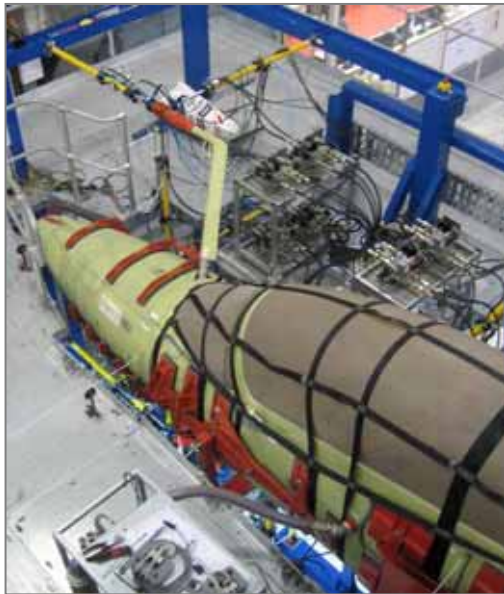


BAE SYSTEMS Hawk Mk127 Lead In Fighter FSFT

HAWK Lead In Fighter Full Scale Fatigue Test

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90 Control Channels



6 pressurised volumes under pressure control



84 hydraulic actuators in load or displacement control



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HAWK Lead In Fighter Full Scale Fatigue Test

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Transducers:

- Control
 - 83 load channels (triple bridge)
 - 1 displacement channel (dual transducers)
 - 6 pneumatic channels (dual transducers)
- Safety unload system
 - 83 pair of pressure transducers
- Monitoring
 - 10 reaction load cells (dual bridge)
 - 16 calibrated load links (dual bridge)
 - 750 strain gauges
 - 28 displacement transducers

With more than 1200 transducers and amplifiers the task of calibration and accuracy checking is significant!



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HAWK LIF FSFT- Measurement Calibration

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Measurement Calibration Topics:

- Measurement Path
- Partitioning of Calibration
- Calibration of Pressures
- Calibration of Loads
- Calibration of Strains

DSTO has a NATA certification in accordance with ISO/IEC 17025 for Mechanical tests on aircraft, marine and land vehicle structures which includes the calibration of transducers used in testing

NATA is Australia's national laboratory accreditation system



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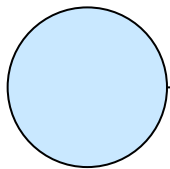
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Measurement Path

Variable being measured

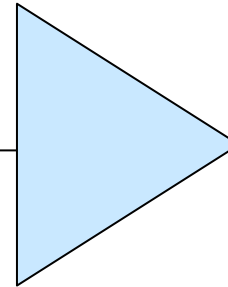


(load,
pressure,
displacement,
strain etc.)

Transducer



Measurement Device



(transducer supply,
amplifier , analogue to
digital converter, &
digital processing)



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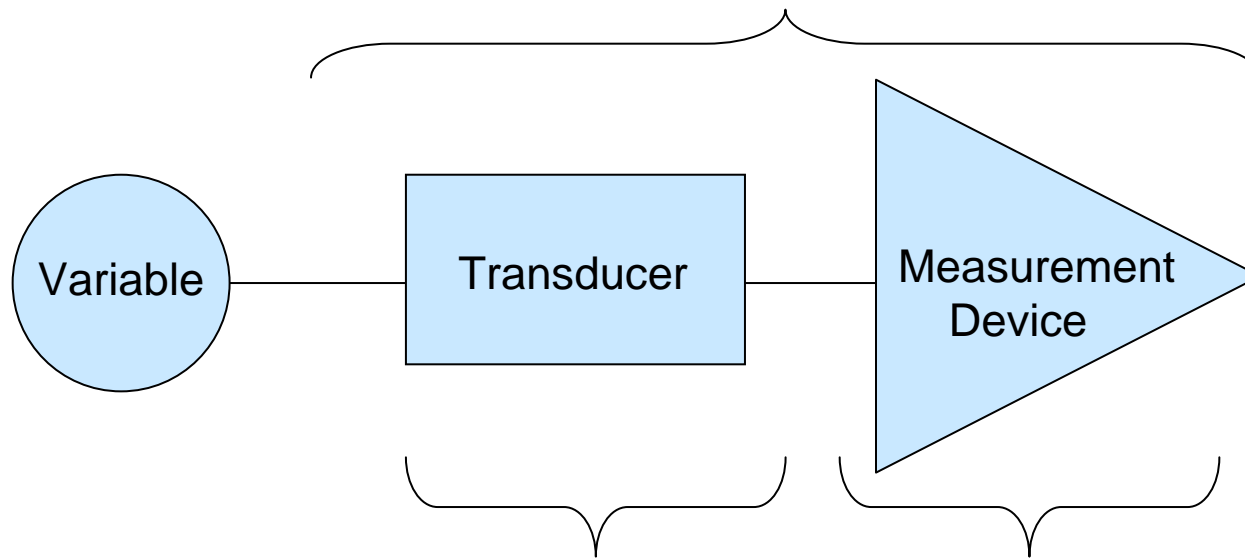
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Partitioning of Calibration

Method 1 – calibrate whole path with reference variable



Method 2 – calibrate each item in path separately & combine

Method 3 – calibrate transducer and check whole path



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Calibration of Pressure Channels

For pressure transducers a traceable Portable Pressure Calibrator was used to:

- Calibrate the transducer
- Check transducer and controller amplifier channel as a combined system in-situ

Druck TM Model DPI 610
Portable Pressure Calibrator



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Calibration of Load Channels

For Load channels the calibration and checking was partitioned

- Calibrate the Transducer (load cell)
- Check gain of the Measurement Device (MTS Aero ST control system)

Load cell calibrations and gain checking carried out annually



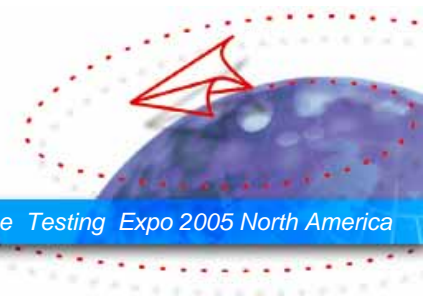
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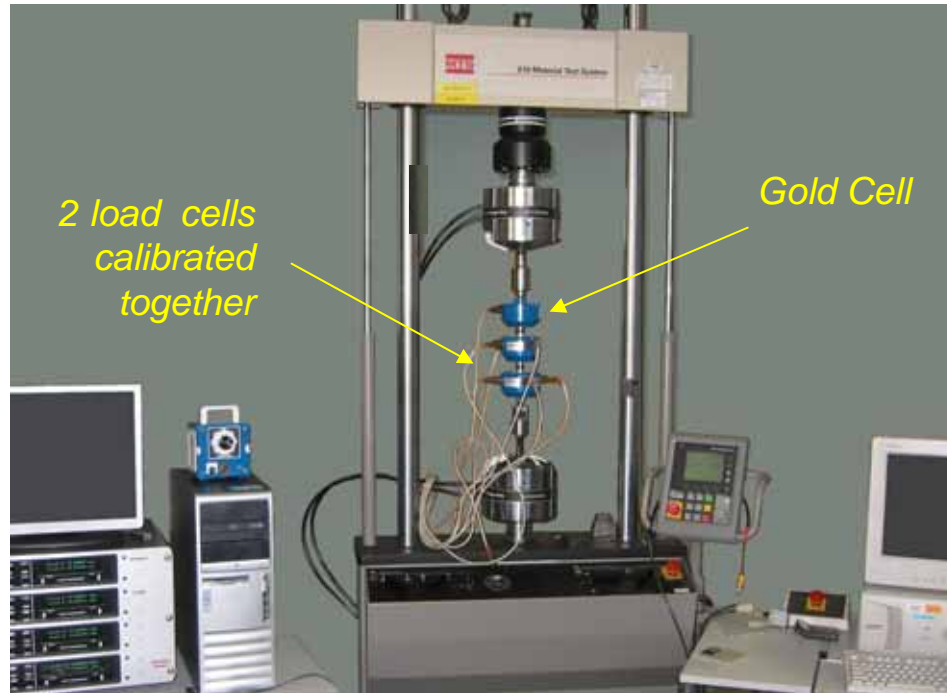
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In-house Calibration of Load Cells

Shear Web
Load Cells



Load cells calibrated using Interface™ Gold standard Cells & Tovey Engineering™ Calibration system



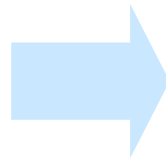
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HAWK LIF FSFT- Measurement Calibration

Load Cell Simulator Amplifier Calibrator



SET	Positive mV/V	Negative mV/V
0.00	0.00000	0.00000
0.04	0.03989	- 0.04009
0.08	0.07990	- 0.08009
0.20	0.19988	- 0.20009
0.40	0.39988	- 0.40008
0.80	0.79994	- 0.80010
1.20	1.19996	- 1.20016
1.60	2.60003	- 1.60022
2.00	2.00005	- 2.00024
2.40	2.39999	- 2.40020
3.20	3.20001	- 3.20020
4.00	3.99974	- 3.99991
4.40	4.39978	- 4.39996

Interface™ Load cell simulator used to calibrate Tovey Engineering™ indicators used for load cell calibration



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Gain Checking of MTS Aero ST control system

Interface
Load Cell
Simulator



Amplifier A/D
converter Path

MTS Aero ST
feedback amplifiers



MTS DUC front end amplifier
Digital Universal Conditioner



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*Controller amplifiers checked for gain stability using Interface load cell simulator
Three point check – Zero and \pm step size in range 40% to 100% Channel Full Scale*

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Calibration of strain gauge channels

The strain gauge manufacturers sensitivity tolerance is accepted and so only the measurement device needs gain verification

HBM K800 Strain Gauge Amplifier Calibration Unit



Accuracy Class 0.03%

Amplifier A/D converter Path

Data Acquisition amplifiers



MTS Aero ST configured with 1200 channels of HBM strain gauge Data Acquisition

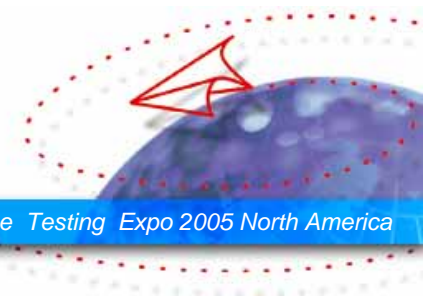


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HBM K800 Strain Gauge Amplifier Calibration Unit

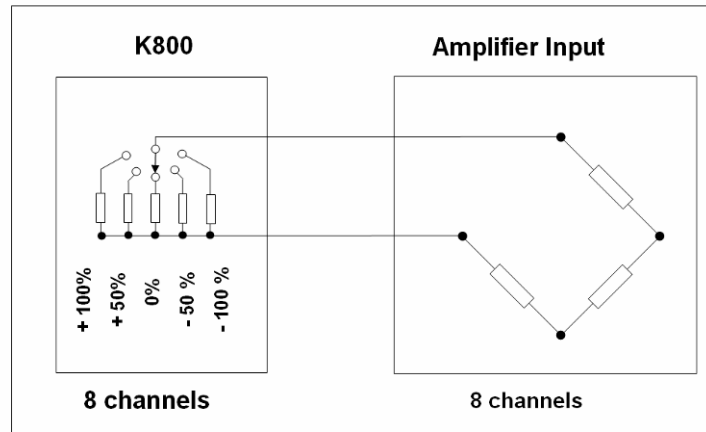


Calibrates 8 amplifier channels at a time under software control



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Range	Sensitivity	Ohms
+ 100%	8 mV/V	361.3821Ω
+ 50%	4 mV/V	355.6452Ω
0%	0 mV/V	350.0000Ω
- 50%	-4 mV/V	344.4444Ω
- 100%	-8 mV/V	338.9764Ω



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Strain Gauges - measurement of lead wire resistance

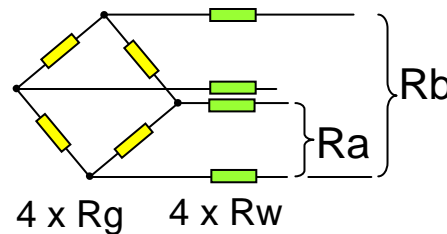
Wiring can cause 1% error!

R_g = gauge Resistance

R_w = wire Resistance

R_a & R_b are measurements used to calculate R_w and R_g to correct strain gauge sensitivity for supply loss

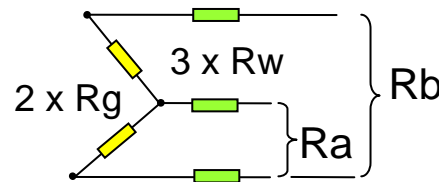
Full Bridge



$$R_a = 0.75 R_g + 2 R_w$$

$$R_b = R_g + 2 R_w$$

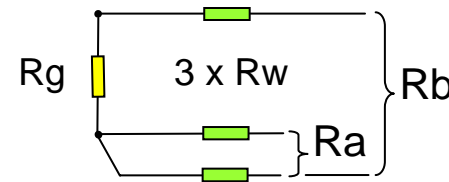
Half Bridge



$$R_a = R_g + 2 R_w$$

$$R_b = 2 R_g + 2 R_w$$

Quarter Bridge



$$R_a = 2 R_w$$

$$R_b = R_g + 2 R_w$$



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HAWK LIF FSFT- Loading Accuracy

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Sources of load application errors

Measurement errors:

- Sizing of load cells
- Amplifier settings

Control errors:

- Sizing of actuators
- Minimising friction
- Sizing of servo valves
- Minimising backlash
- Control configuration and tuning
- Valve balance

Implications on system design and component selection



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Control Errors - sizing of load cells and selecting amplifier ranges

- Load cells ranges come in course ranges (steps up to a factor of 2.5) - typical Fatigue Rated capacities are 1.25, 2.5, 5, 12.5, 25, 50, 125, 225 kN
- Choose full scale fatigue load to be in range of 40% to 110% of fatigue rated load cell capacity
- Set control channel full scale to be between 110% to 120% of full scale fatigue load
- Zero offsets need to be made as the average of many readings

In the worst case you may have control channel full scale only 33.3% of load cell capacity.



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Control Errors – due to mechanical design

- Actuator sizing - actuators need to be sized so that full scale fatigue load is in range 50% to 75%, preferably 66%, to provide optimum response and reduce the influence of actuator friction
- Non linearities - Actuator friction and linkage backlash need to be minimised. Non-linearities can result in limit cycling which impacts on settling time and repeatability



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Control Errors – controller capability and configuration

- Valve Balance - regularly valve balance or use wash out integrator to reduce static errors due to valve balance
- Tuning - Use as high a Proportional gain as possible as high open loop gains: reduce static errors, improve linearity and improve response (in some cases additional Forward Loop Filter terms can enable higher open loop gains)



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Control Errors – Other factors

- Feed forward – Local channel feed forward and multi-channel feed forward improve response and dynamic tracking but do not improve static accuracy
- Redundancy – duplicate feedback (A-B compare) provide insurance against transducer or amplifier failure (a fault causing a drop in amplifier gain or transducer sensitivity can result in a higher than expected load being applied, even though the displayed and recorded load appears correct)



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Conclusion

- All control channels and data acquisition measurement channels need calibration regularly throughout a long term full scale fatigue test
- The measurement uncertainty varies between channels and depends on the range of transducer and analogue to digital converter in use
- Design choice of load cells, actuators, load linkages and control system impact on the overall loading accuracy
- Measurement uncertainty of most individual items needs to be more than 10 times more than final requirement
- Configuration and tuning of control system has an impact on loading accuracy and repeatability



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Conclusion – Traceable items needed by LIF FSFT for load , pressure and strain measurement



Gold standard load cells



Pressure Calibrator

Load Cell Simulator



Strain Gauge simulator



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Questions?



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**Abstract: Loading Accuracy, Calibration and Measurement
Uncertainty on the Hawk LIF FSFT**

DSTO / MTS Systems Corporation

Speaker & Author: Graeme Burnett - Engineering Manager HAWK LIF FSFT, contracted to Defence Science and Technology (DSTO) Australia.

Author: Daniel Van Horn - Software Engineer, MTS Systems Corporation.

Australia's Defence Science and Technology Organisation (DSTO) is conducting a FSFT of the BAE SYSTEMS Hawk Mk127 Lead In Fighter airframe at the DSTO Fisherman's Bend facility in Melbourne, Australia, for BAE SYSTEMS UK and the RAAF. The test is configured with 96 channels of hydraulic and pneumatic control, 1200 channels of integrated data acquisition, and a fully autonomous 96 channel controlled unload safety system. This presentation reviews the methodology developed to ensure that the MTS control and data acquisition system and instrumentation employed to drive the test are calibrated accurately and comply with all applicable standards regarding calibration and measurement uncertainty.