Australian Government
Department of Defence
Defence Science and Technology Organisation

A Novel Approach for Structural Health Monitoring Using Thermoelastic Stress Analysis

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Full Field Stress/Strain Measurement

A stress and strain analysis is factored into the design of almost every engineering structure we know, from planes to ships to bridges to buildings and so on. Measurement of stress/strain is vital.

Only two practical ways of achieving full-field stress or strain measurement

- Optically – viz., digital image correlation, photoelasticity, ESPI etc.
- Thermographically – thermoelastic stress analysis (TSA)

TSA has some fundamental advantages: practicality, high-stress sensitivity

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Thermoelastic Stress Analysis (TSA)

- Exploits the thermoelastic effect which describes the linear coupling between mechanical deformation and thermal energy:

$$\partial T = -KT_0\partial\sigma$$

temperature change; stress change; Material constant

Aluminium 2024-T351: 3 mK/MPa
Titanium Ti-6Al-4V: 1 mK/MPa

- Observation of thermoelastic effect first reported in 1805.
- Theoretical explanation furnished by Lord Kelvin in 1853
- First commercial stress measurement system arrived in 1982
- System cost and size meant usage was largely confined to the laboratory
- Incredibly, that situation still applies now, some 30 years on.

The net effect is that TSA remains underutilised.

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TSA Systems at DSTO

1982 SPATE 8000 - Ometron

Single-element detector, raster scanning system. Bulky, complex, slow.

1992 FAST - DSTO

Full-field staring array. Processing time reduced from hours to minutes.

2005 MiTE - DSTO

Fast, small, rugged, inexpensive and effective. Game changer. Potential to take TSA out of the lab into widespread industrial use.

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MiTE – Microbolometer ThermoElasticity

Appearance in 2002 of the Indigo Omega, a small microbolometer detector sparked an idea for a radical transformation of the TSA landscape. The vision was to transform TSA from a high cost laboratory based technique to a widely accessible low-cost engineering tool.

Microbolometer v. photonic detectors

Advantages:	low capital cost rugged low power easily miniaturised
Disadvantages:	Low sensitivity (or high Noise Equivalent Temperature Difference, NETD) - between 4-9 times less sensitive than photon detectors

Turns out the perceived disadvantage isn't real

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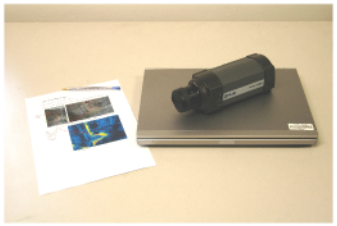
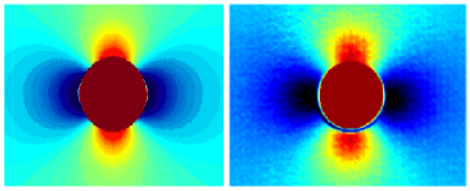
MiTE

By 2005 DSTO had a working prototype. A fraction of the cost and size, but virtually all of the capability.



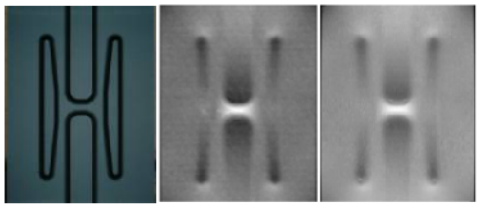
Proof is in the Pudding: Validation Testing

Plate with a Hole



FEA MiTE

F-111 Wing-Skin Coupon



MiTE ($12k) Commercial TSA System ($100k)

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Crack Growth Monitoring

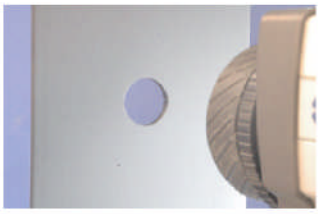
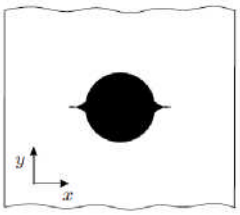
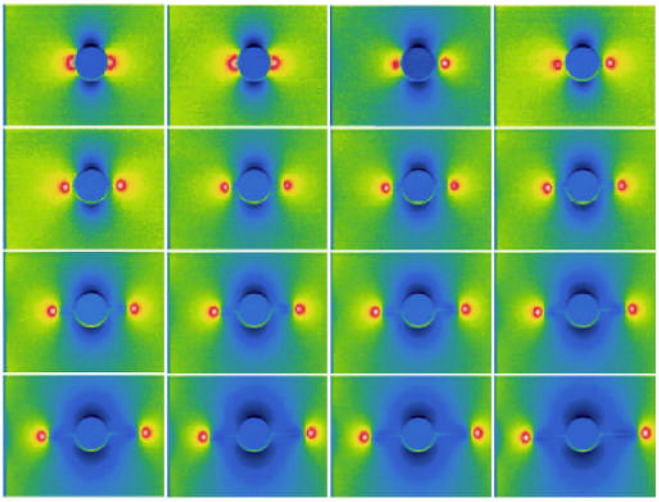


Photo of experimental set-up



Schematic of hole with starter notch and crack



TSA scans with increasing number of cyclic loads

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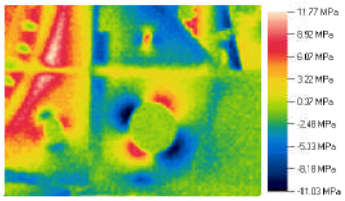
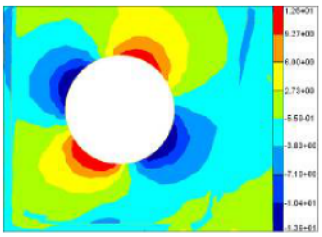
At the Coal Face
Full-Scale Testing: F/A-18 Centre Barrel

MiTE goes where commercial systems fear to tread – i.e. structural integration

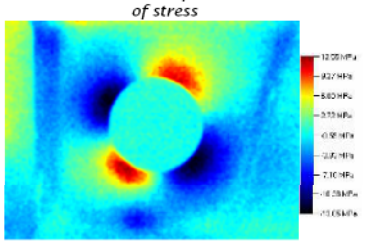
Area of interest. (Y488 Lower Hydraulic Hole)



MiTE is structurally integrated. In going for the ride, motion problems are eliminated.



Finite element prediction of stress



Thermoelastic measurement (MiTE) of stress (close up)

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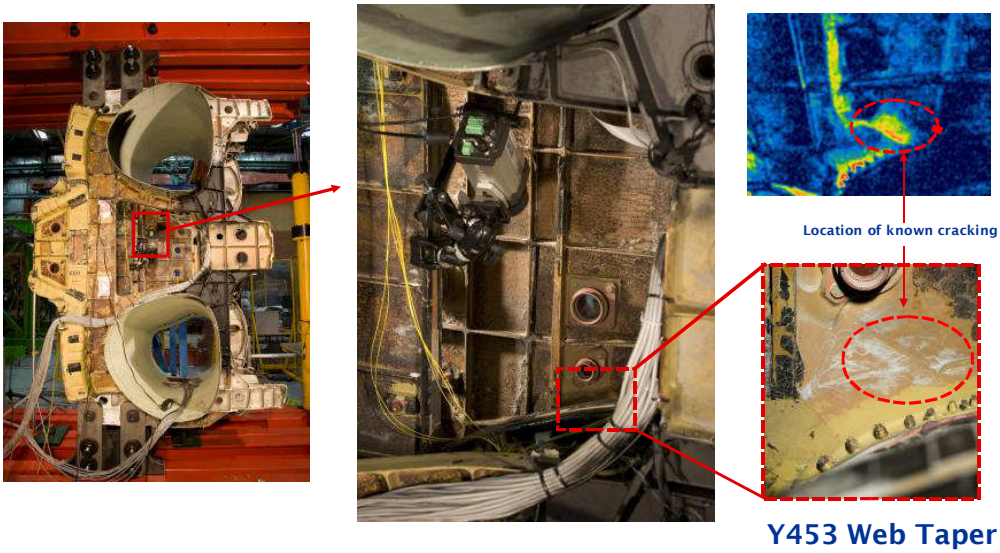
Inspection of Hard to Access Hot Spots



Y453 Web Taper

It's a small step from here to Structural Health Monitoring
i.e. ubiquitous sensing with a network of miniaturised wireless devices

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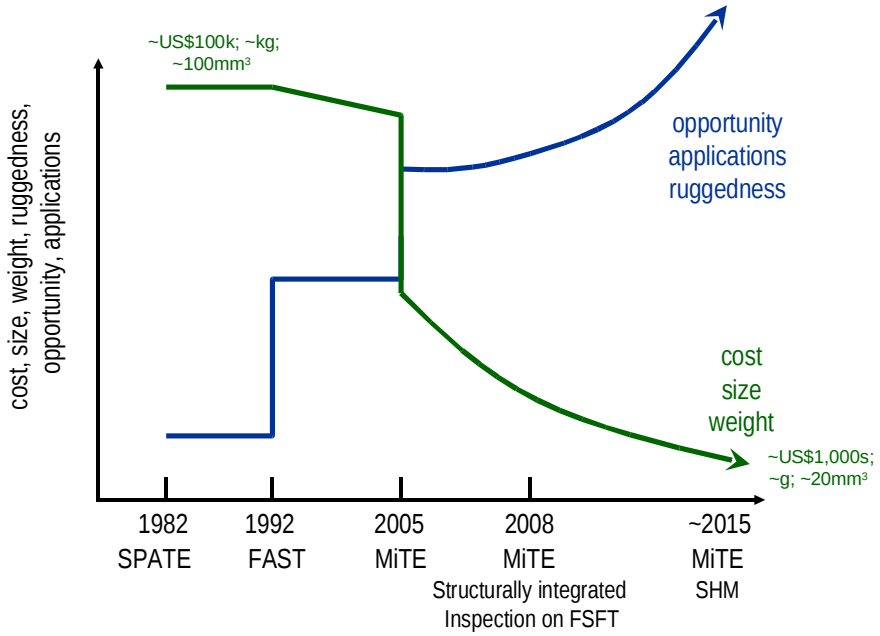
TSA Systems – Evolution of Capability



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The Technology is Here

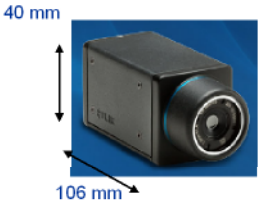
As Cost and Size decrease the Opportunities Increase

MiTE 2005

NETD: 120 mK
Array: 160x120

MiTE 2012

NETD: 50 mK
Array: 336x256



MiTE 2013

NETD: 120 mK
Array: 640x512

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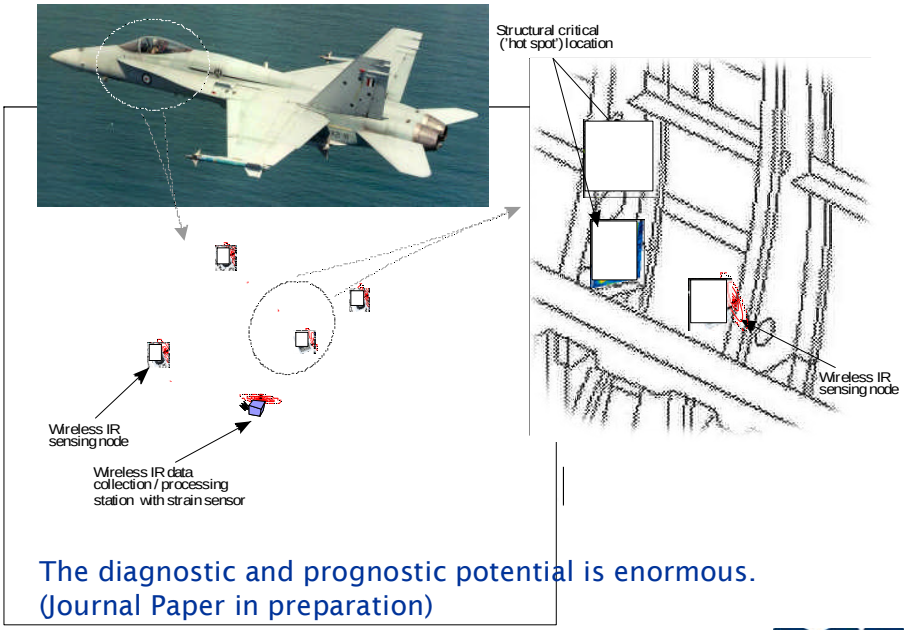
Future Opportunities in SHM



The diagnostic and prognostic potential is enormous.
(Journal Paper in preparation)

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Conclusion

- MiTE improves the practicality of TSA
  - More attractive to industry
  - Broader scope of application
- Further developments underway at DSTO
  - Reduced size
  - Improved performance
  - Networked arrays – wired and wireless
- A potentially powerful SHM technology

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