



Australian Government
Department of Defence
Defence Science and
Technology Organisation

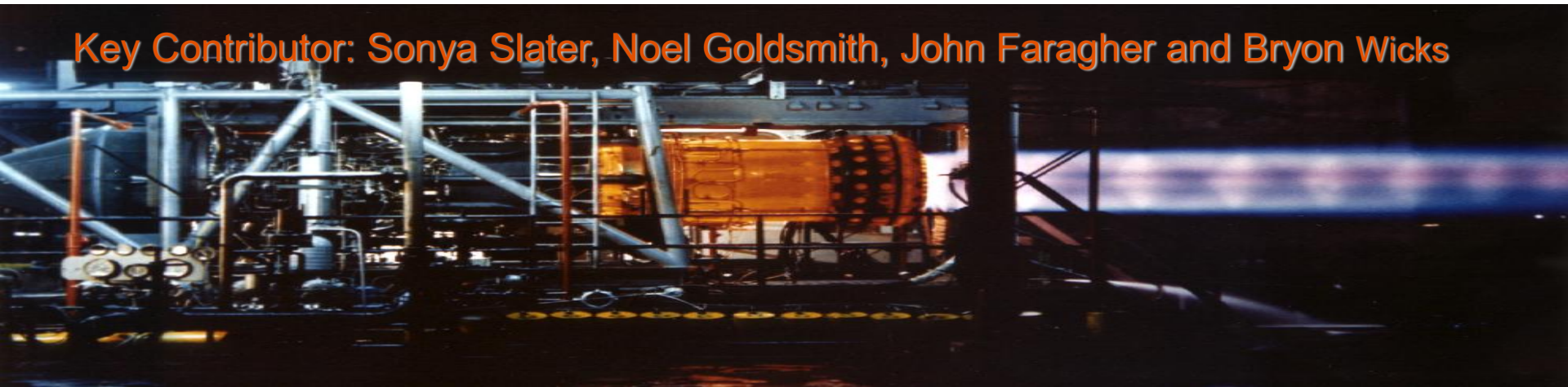
3D Crack Growth Modelling In Gas Turbine Engines

Presented at MSC.Software VPD Conference, 25th and 26th July 2006

Dr Jian Hou

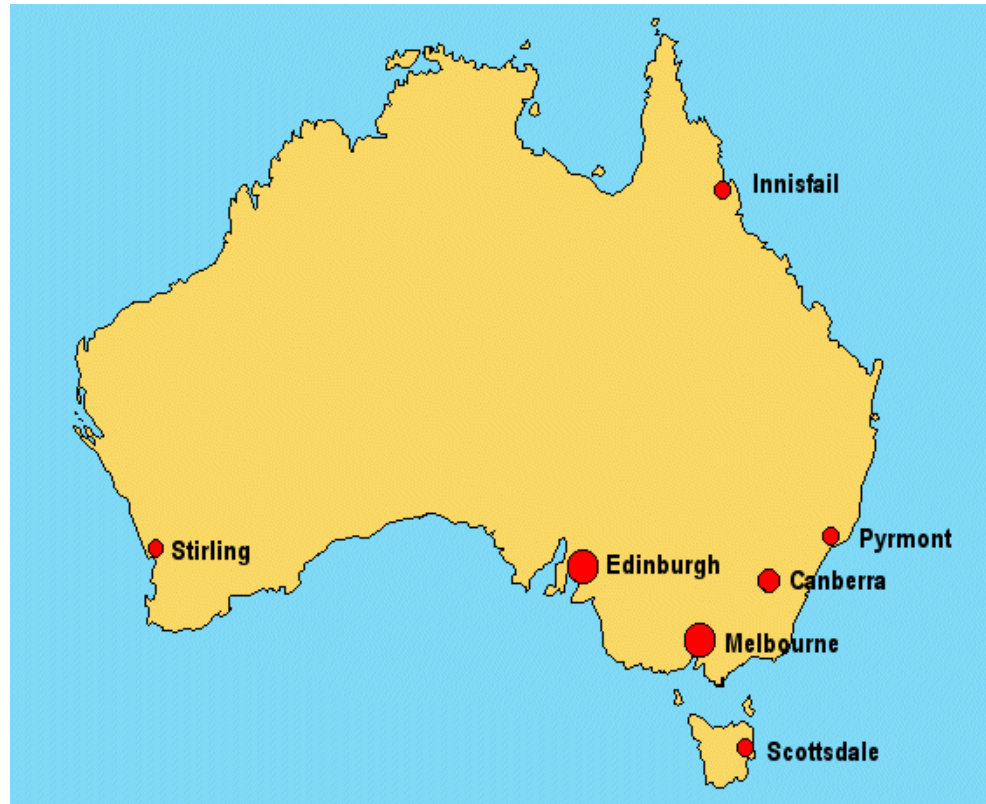
Senior Research Scientist
Air Vehicles Division, DSTO

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DSTO Sites Around Australia



- DSTO is split into 3 laboratories, with 14 divisions in total
- 2200 staff, led by Chief Defence Scientist

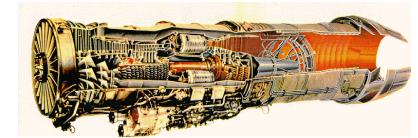
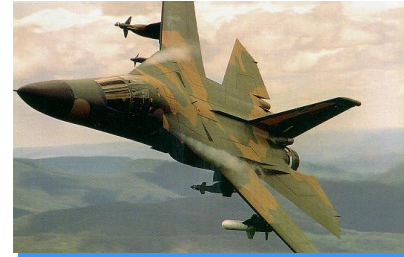


DSTO's Air Vehicles Division

Main mission:

To develop and apply science and technology to the through life support of military aircraft airframes and engines, focus on:

- *life assessment*
- *life extension*

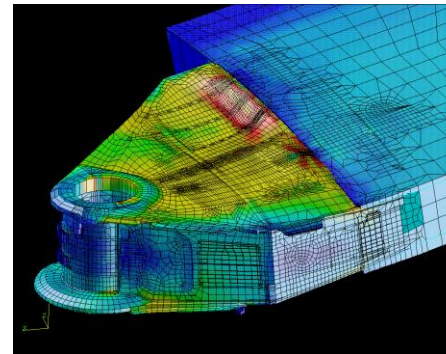


Benefits provided:

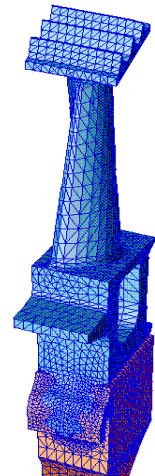
- Reduce the cost of ownership
- Increase readiness and availability
- Improve safety

Resourcing:

- AVD has $\approx$ 250 staff including contractors
- Annual budget $\approx$ \$22M
- Significant use of FEA



Air Frame



Propulsion



Scope of FEA in AVD

- **Requirement:** FEA forms an essential part of the AVD work program, as there is no viable alternative to meet our work objectives
(50 users)
- **FE is used for:** (i) assessing structural integrity of RAAF aircraft components
(ii) developing life extension modifications
(iii) research
- **Covers:** (i) generation of new models
(ii) use/modification of complex existing models
(iii) AVD staff and contractors (*i.e. Aerostructures*)
- **Main codes:** MSC.NASTRAN, MD NASTRAN, PATRAN, MARC, ABAQUS, ANSYS, ZENCRACK, DARWIN
- **H/W:** (i) HP J7000 server, (ii) SGI Origin 2000, (iii) SGI workstations



3D Crack Growth Modelling in Gas Turbine Engines

- Background
- Approaches to Life Management
- Component Stress Analysis
- Methodologies for Crack Growth Analysis
- Inputs for Crack Growth Prediction
- Crack Growth Predictions and Correlation
- Conclusions

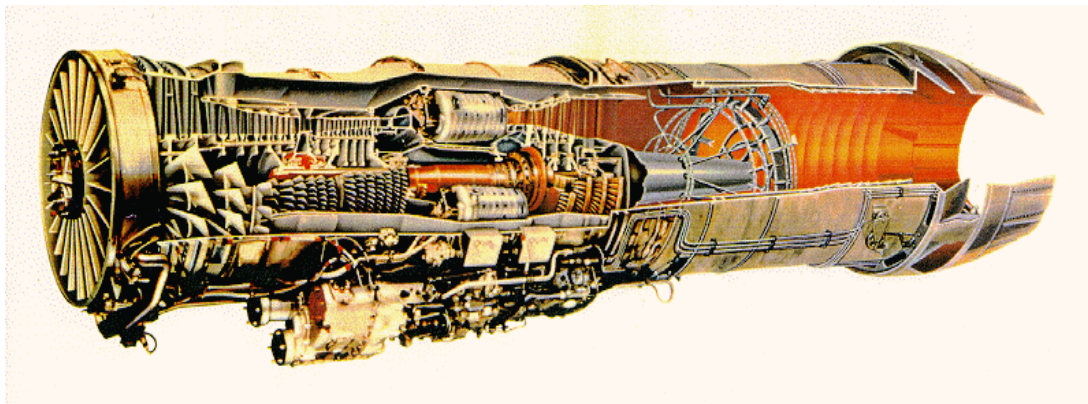


Background



F-111 Aircraft

Most critical components in a gas turbine engine are life-limited by Low Cycle Fatigue (LCF) or creep caused by variations in engine speed or gas temperature or sustained speed or temperature

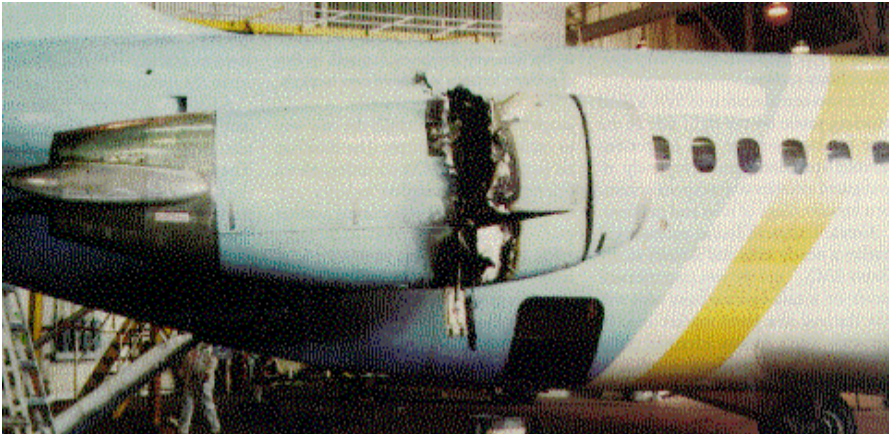


TF-30 turbofan Engine

Background



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JT8D engine uncontained failure on a DC-9 in 1995

Engine discs are critical components

If they fail they will cause major damage and possible aircraft loss



JT8D engine uncontained failure on a MD-88 in 1996

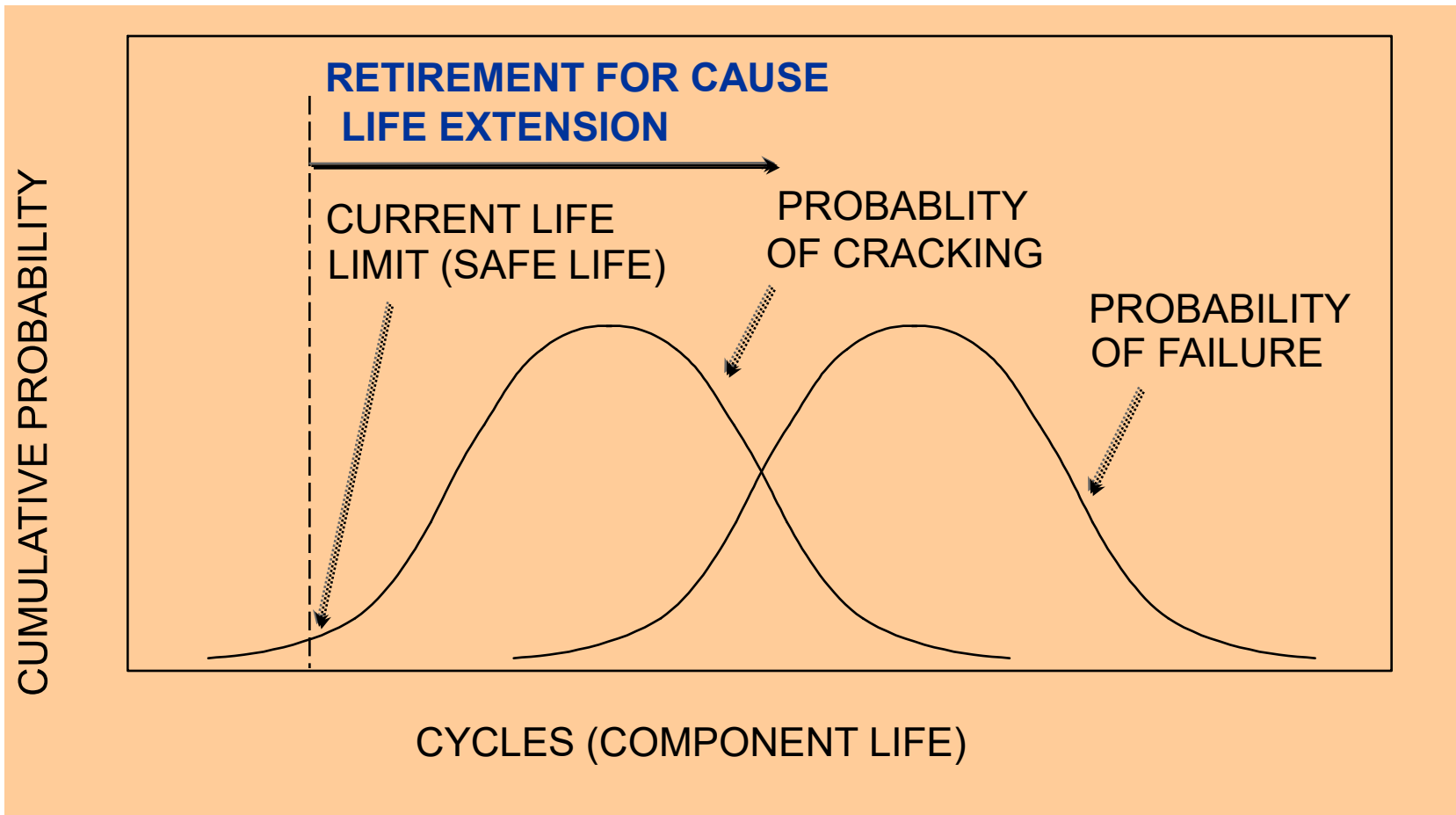


Approaches To Life Management

- **Safe Life**
 - *Analytical method based on a probability of an 0.8mm crack in 1 out of 1000 components with 95% confidence, supported by service experience*
- **Retirement-for-Cause**
 - *Life is determined by the condition of the component, based on interval inspections and service experience*

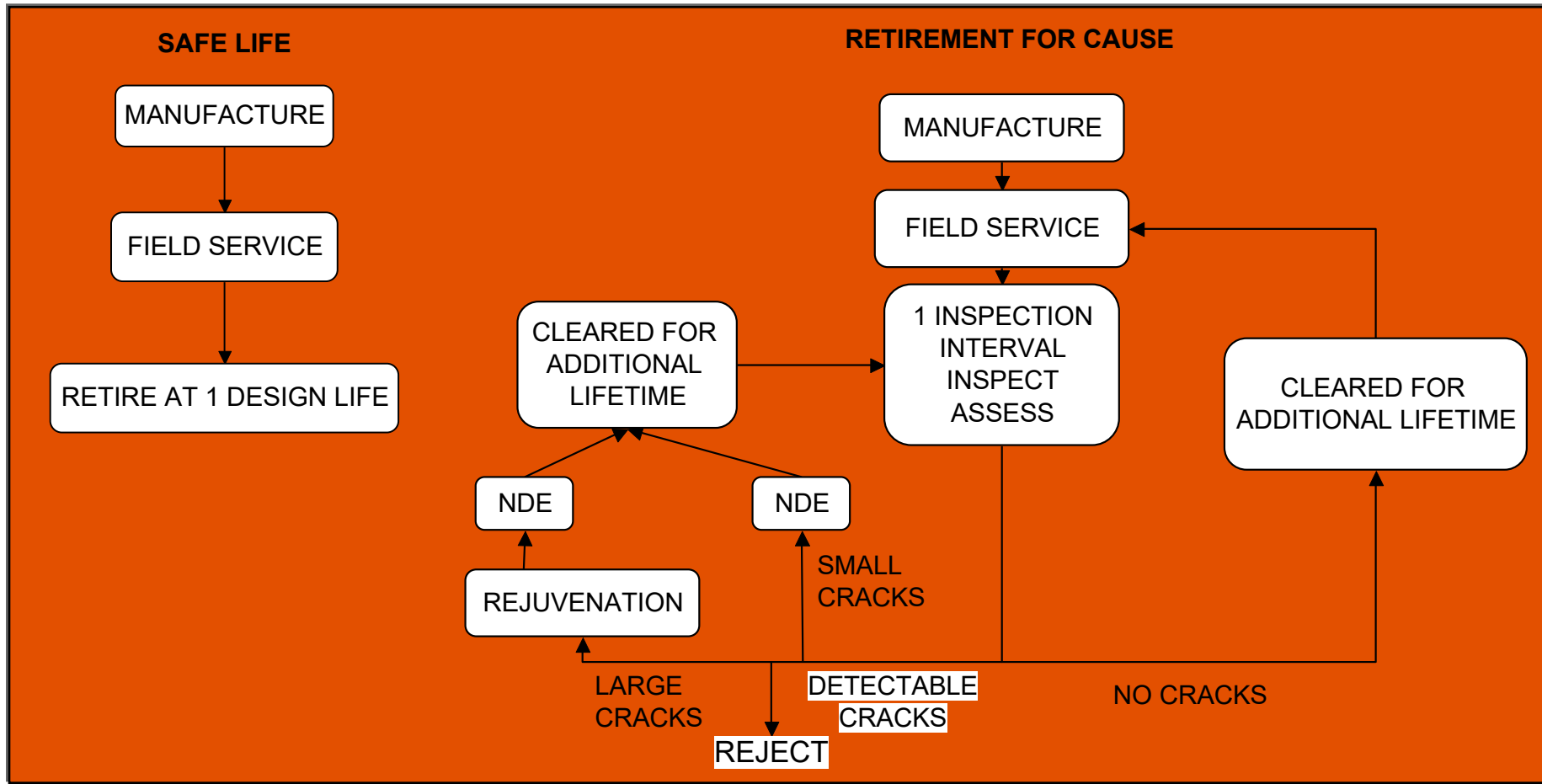


Safe Life And Retirement-for-cause





In Practice





Bolthole Cracking In A Disc

Crack growth is predicted for a crack emanating from a bolt-hole and correlated to fractographic measurement



Disc geometry and crack growth direction



Fractographic Assessment

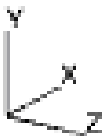
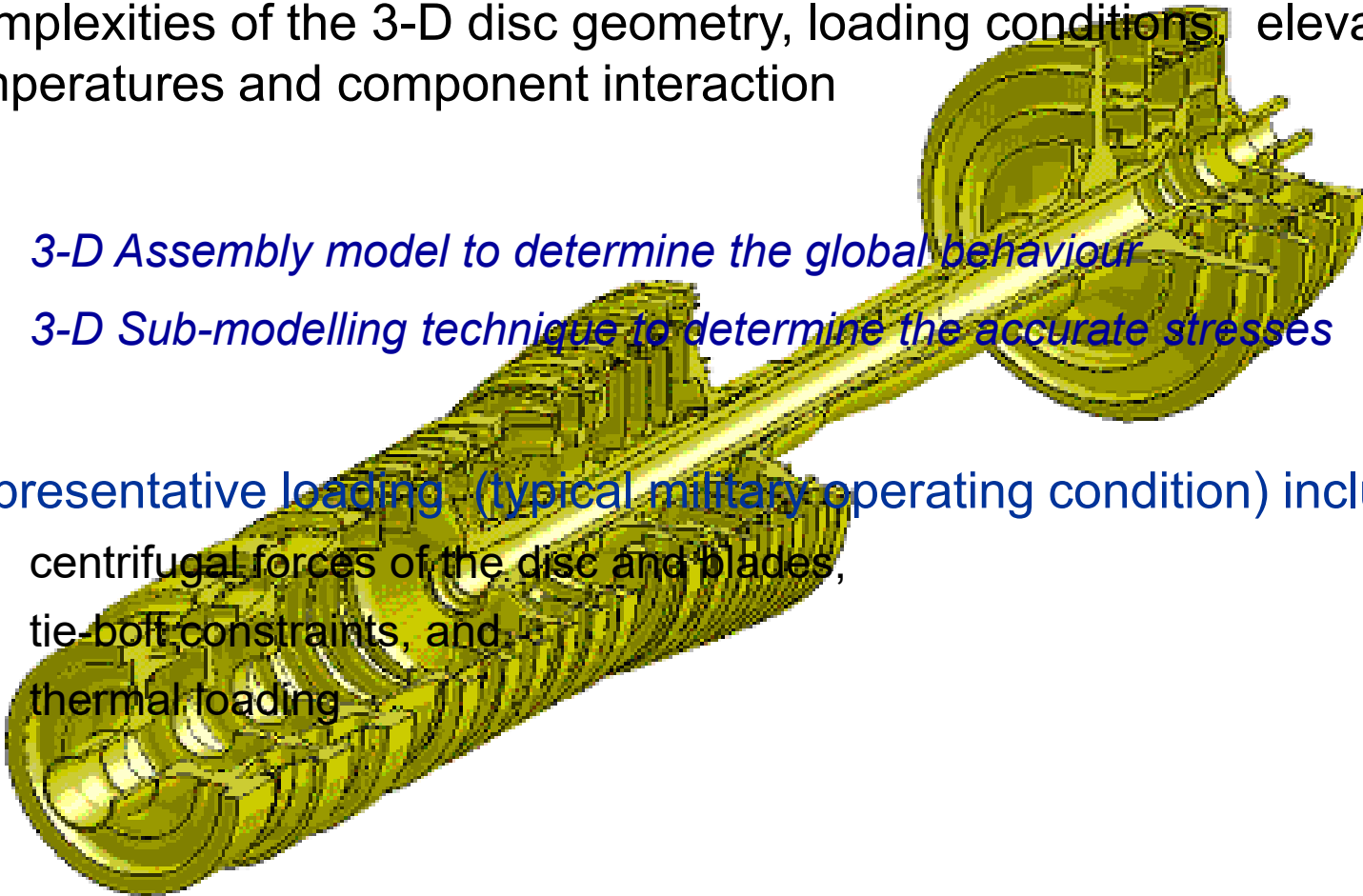


- Examined using optical and scanning electron microscopy
- Cracking was identified as fatigue, originating at the bore of the bolt-hole
- Crack growth curve produced using high-powered optical microscopy based on prominent markings which represent a start/stop cycle



FE Stress Analysis

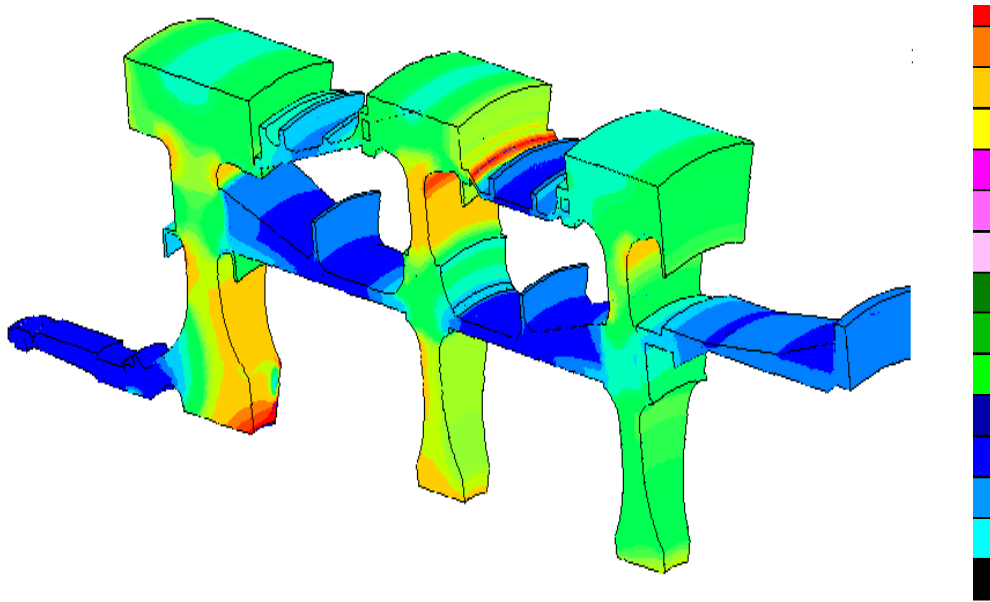
- Inherent modelling difficulties include:
- Complexities of the 3-D disc geometry, loading conditions, elevated temperatures and component interaction
 - *3-D Assembly model to determine the global behaviour*
 - *3-D Sub-modelling technique to determine the accurate stresses*
- Representative loading (typical military operating condition) includes:
 - centrifugal forces of the disc and blades,
 - tie-bolt constraints, and
 - thermal loading



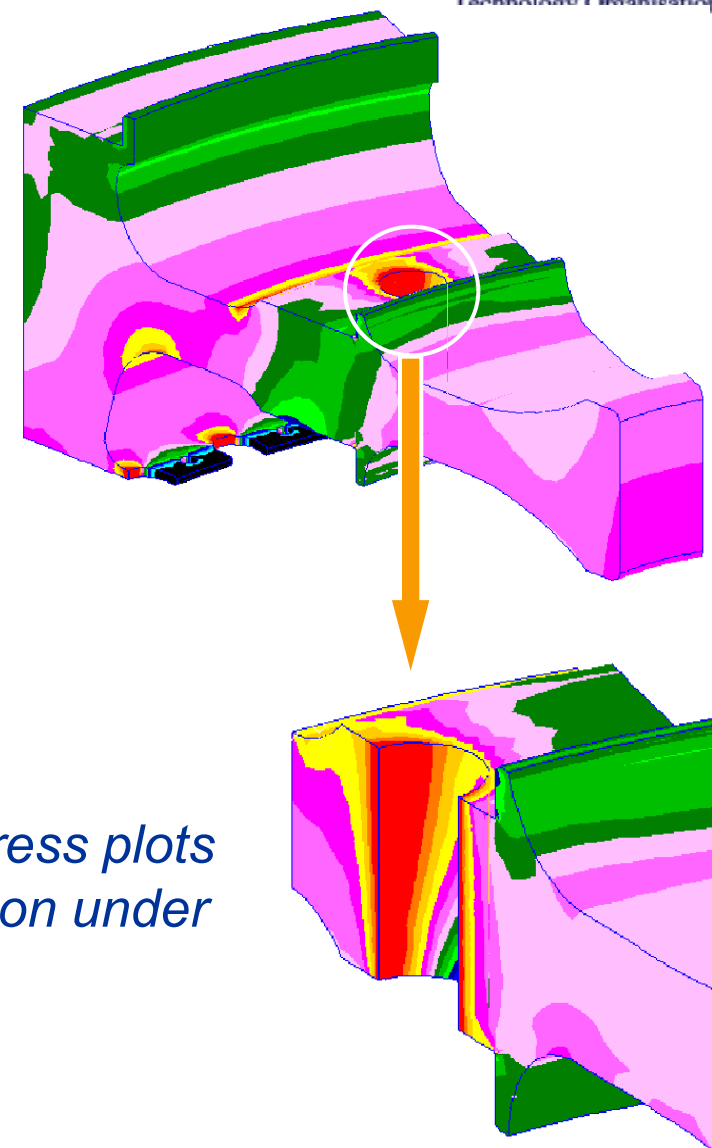
FE Stress Analysis



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- *Maximum principal stress plots for the assembly - global behaviour*
- *Disc sub-modelling: Maximum principal stress plots - Peak stress of 435 MPa at bolt hole region under military power setting condition*



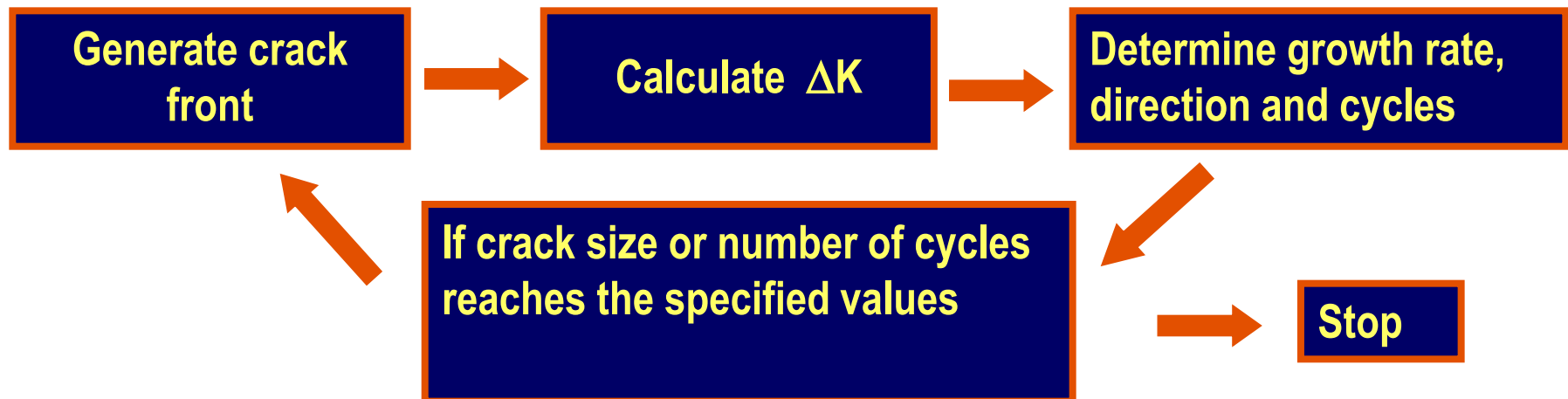
Methodology Of Crack Growth Analysis

Methodologies examined:

- Numerical method: ZENCRACK package - FE based
- Analytical method: AFGROW

Methodology Of Crack Growth Analysis

- Numerical Method - ZENCRACK
- Automatic generation of cracked mesh from 3-D FE model Stress intensity factor calculated by J-integral method
- A virtual crack extension technique is used to determine:
 - ***crack growth magnitude - maximum strain energy release rate***
 - ***growth direction - direction of maximum strain energy release rate***





Numerical Method - ZENCRACK

- The energy release rate G is related to the stress intensity factor K :

$$G = \frac{[1 - (\alpha v)^2] K^2}{E}$$

- The direction of the crack front is governed by the direction of the maximum strain energy release rate

$$G = \frac{dU}{da}$$

- The mode I crack growth rate, in the form of the Paris equation, can be expressed by the strain energy release rate:

$$da/dn = C' (G_{\max}^{1/2} - G_{\min}^{1/2})^m$$

Analytical Method - AFGROW

- Analytical stress intensity factor solutions for simple geometries
- Stress gradients can be accounted for by applying a correction to the geometric function (beta correction) based on actual stress distribution to standard stress distribution
- Various crack growth models can be utilised: Walker, Forman, NASGRO Equation, Harter -T
- Various Retardation models can be used, eg. Willenburger, Closure and Wheeler



Crack Growth Prediction Inputs

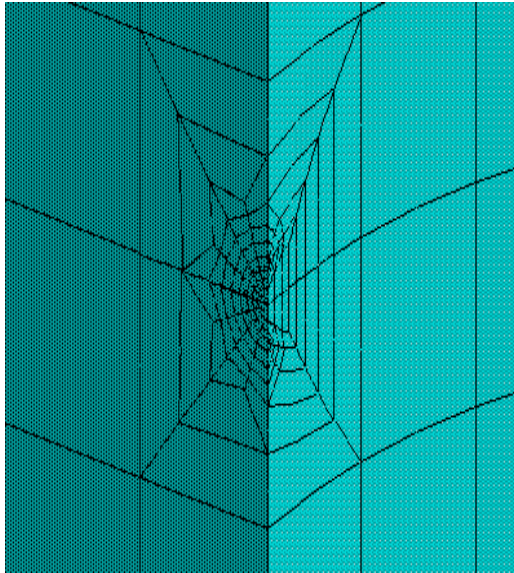
- Crack growth data obtained for various stress ratios and interpolated to the operating temperature.
- A representative spectrum was obtained and used in crack growth analysis.

In AFGROW

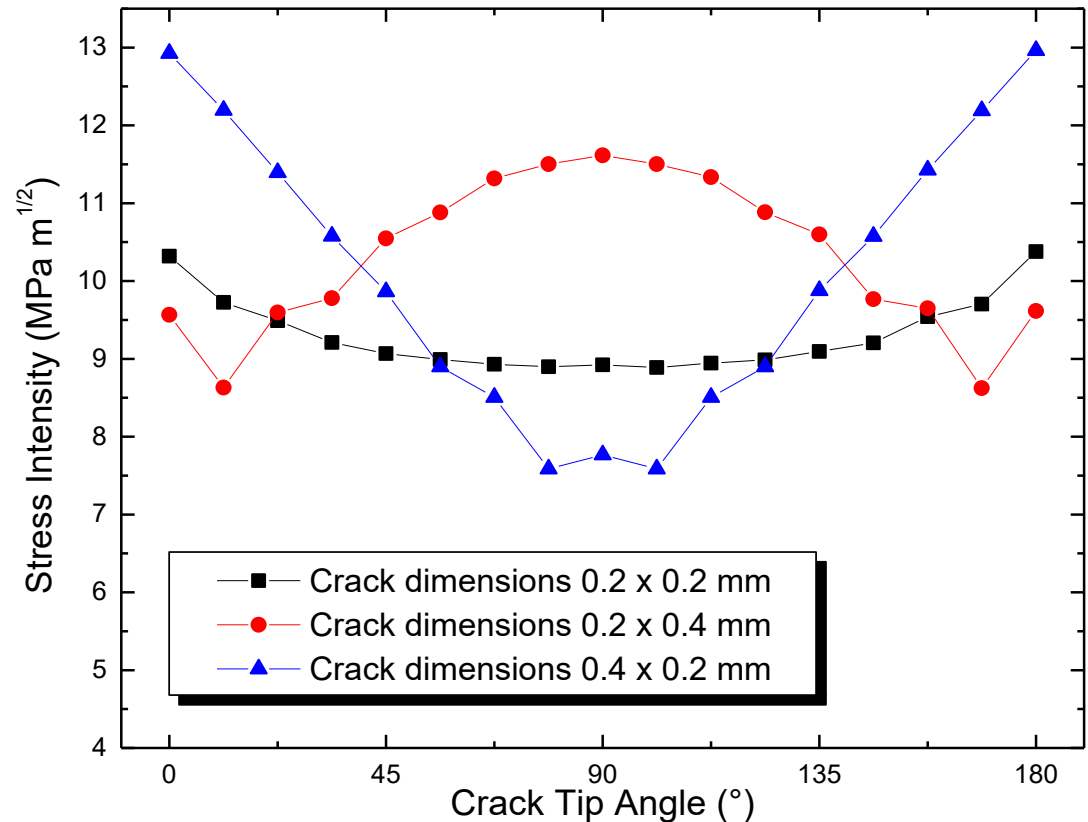
- ♦ Crack growth rates with various stress ratios
 - Walker equation on a point by point basis
- ♦ Disc geometry was idealised to a bolt-hole specimen
- ♦ Beta correction from FE Stress distribution



SIFs for a surface crack under typical military operating conditions



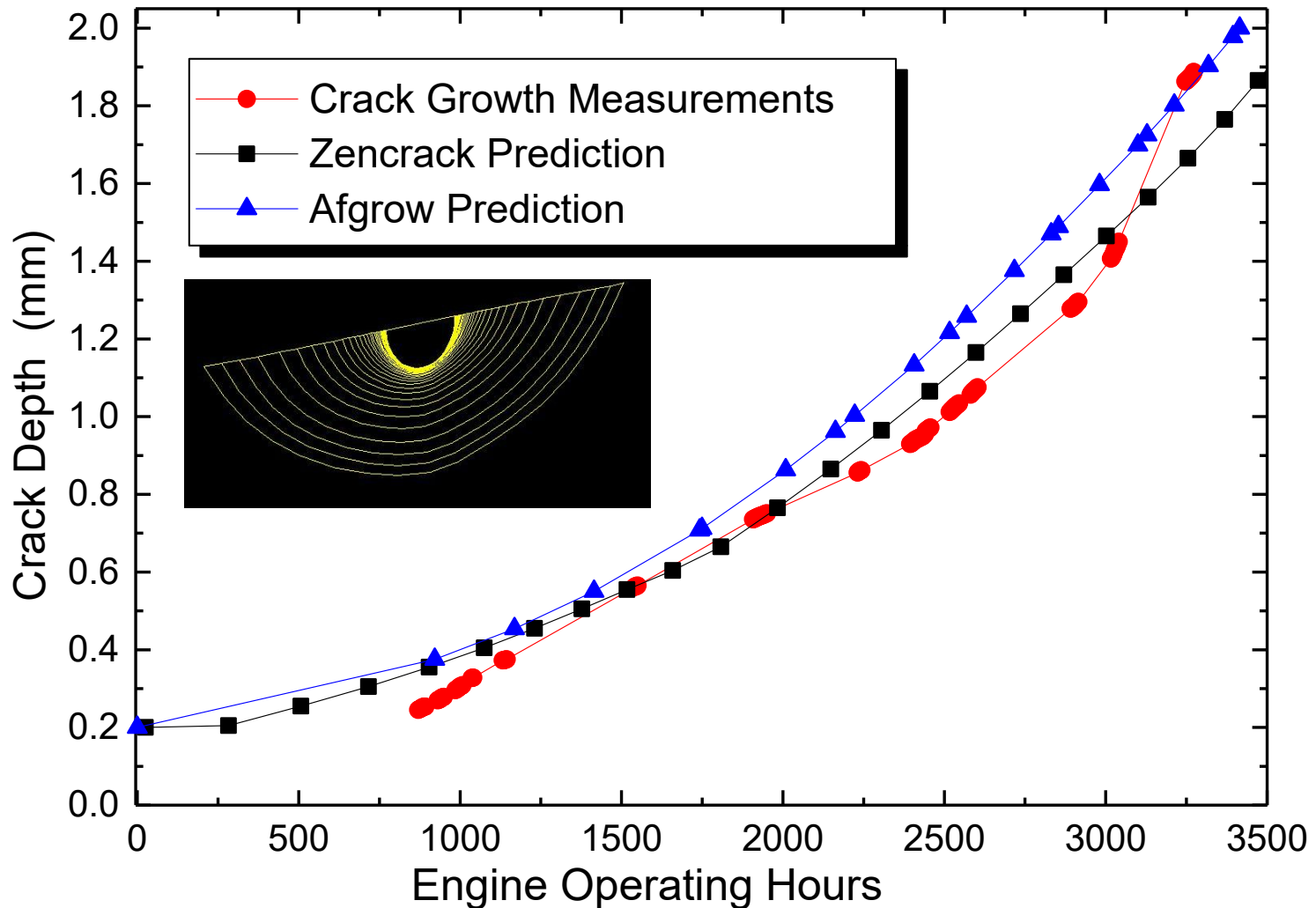
*FE model with an
inserted crack*



*Stress intensity factors for 3 different crack
configurations (depth by half length).*



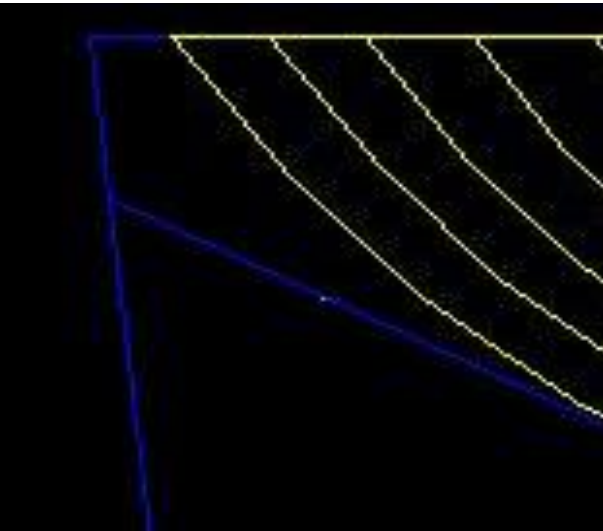
Predicted Crack Growth Rates Compared with Fractographic Measurement



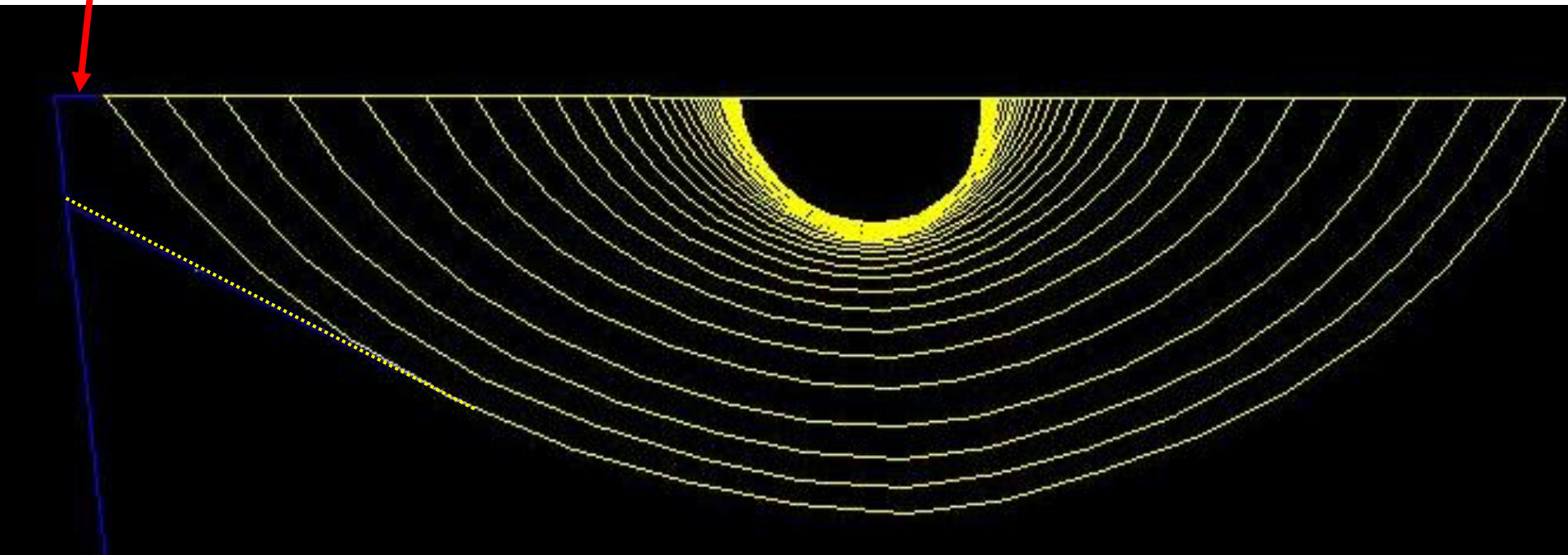
Crack Transitioning and Mapping



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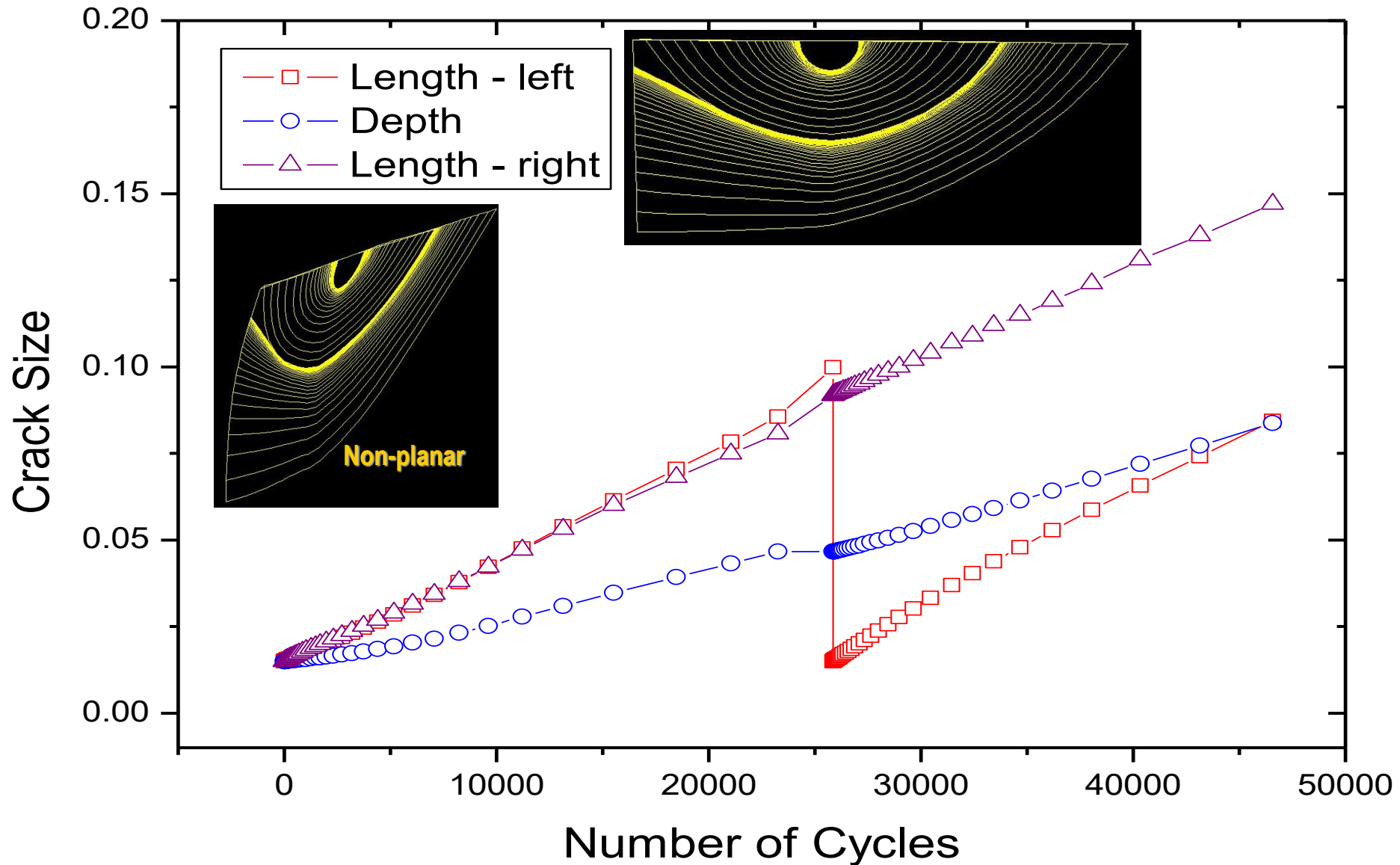


- A new corner crack front is defined by slightly modifying the final crack front of the surface crack.
- The new crack front can be mapped on to the modified surface crack using a spline.





Results for Crack Transitioning





Conclusions

- Fatigue crack growth in gas turbine engines can be predicted using both numerical and analytical methods with good correlation between them.
- The ***predicted*** crack growth rates are in good agreement with ***fractographic*** observations.
- Crack growth can be successfully predicted for practical applications in the life management of engine components.
- Applicable to other industries.