Crack-Propagation Tests In Thin-Sheet Aluminium Specimens. Correlation With A Mathematical Model

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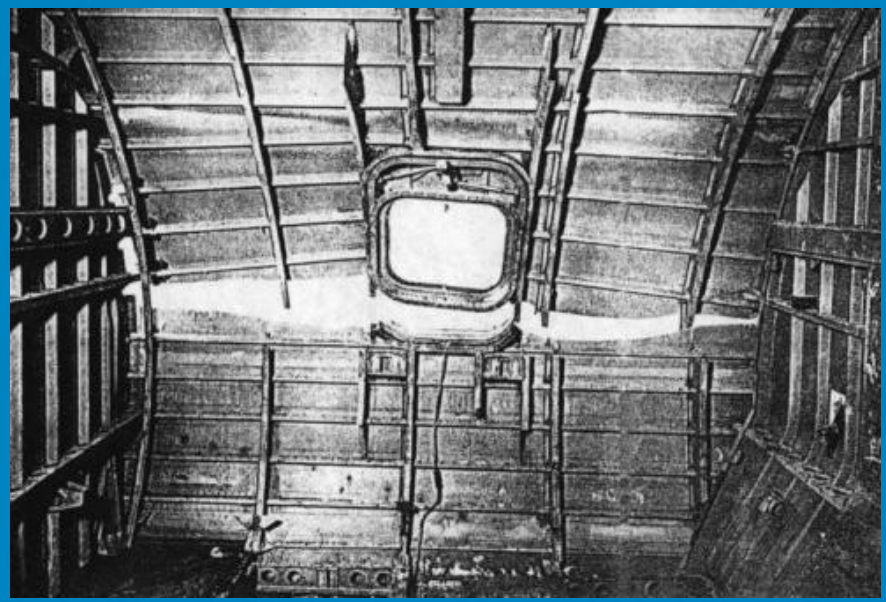
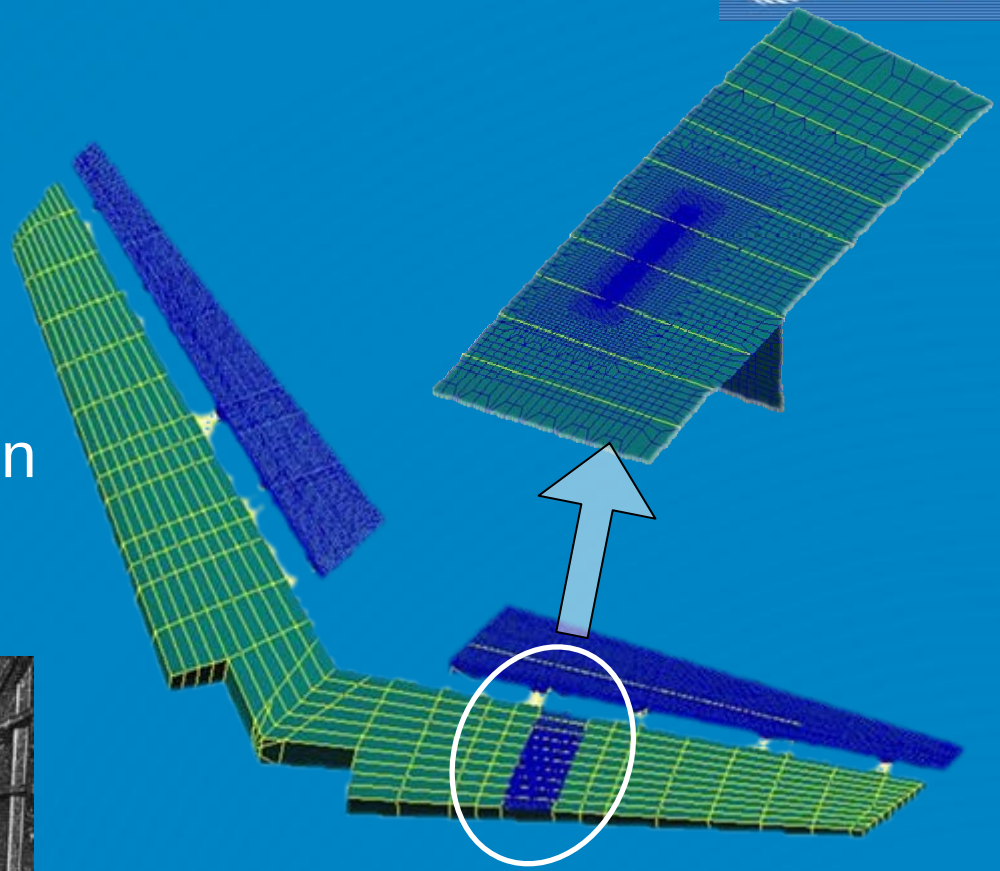
Noordwijk, The Netherlands 9 - 10 February 2009

Contents

Introduction

- Study of crack growth
- Residual strength prediction (quasi-static load)

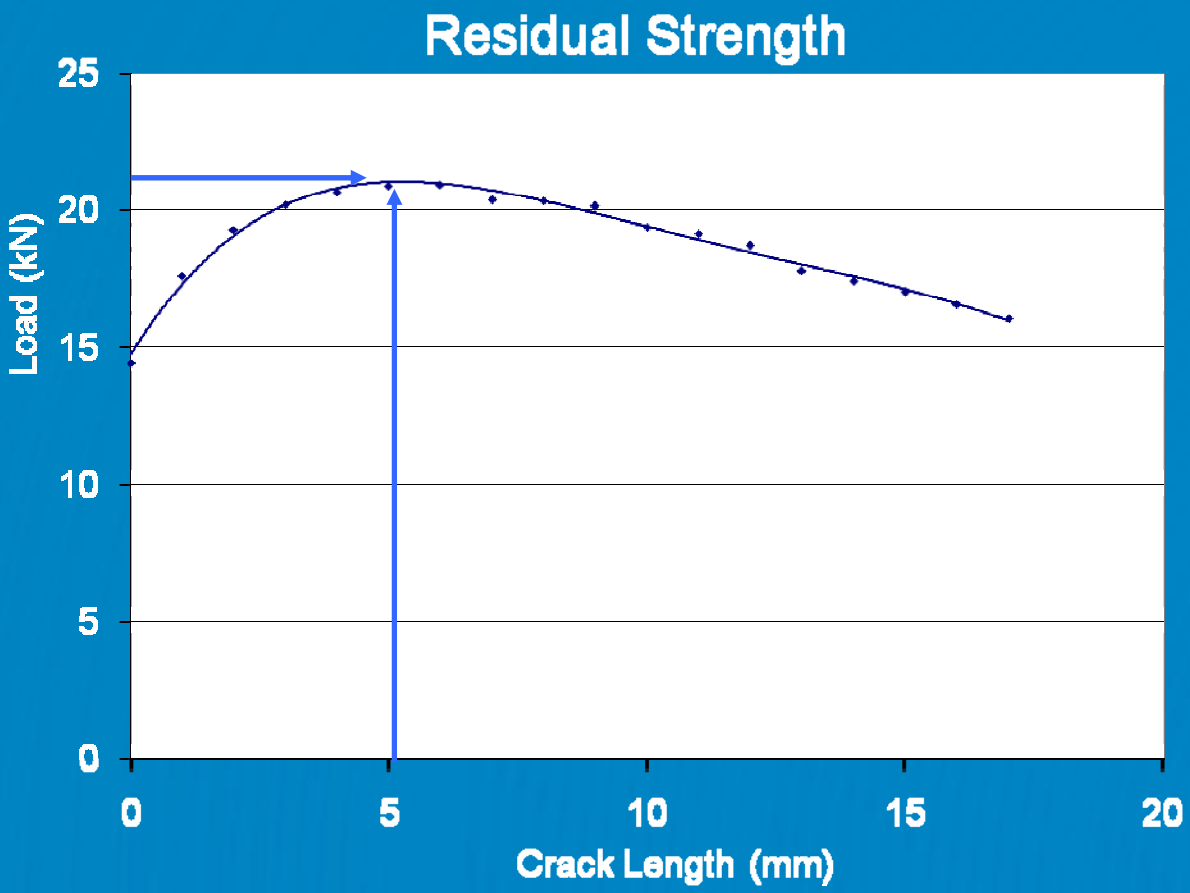


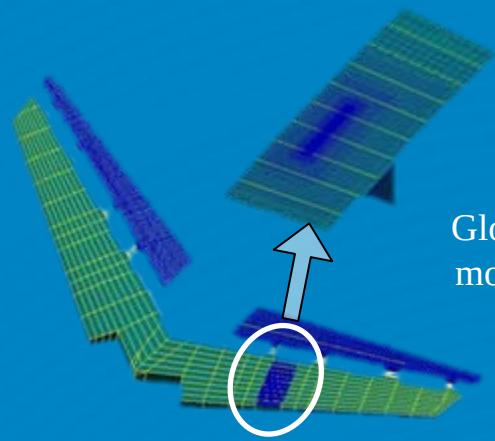


- In skin panels and pressurized fuselages
- Using Finite Element Model Software

Introduction: What is the Residual Strength?

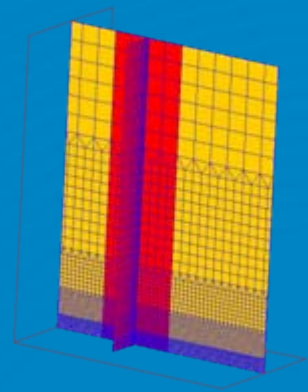
- Maximum load level capability carried by the structure vs. crack length

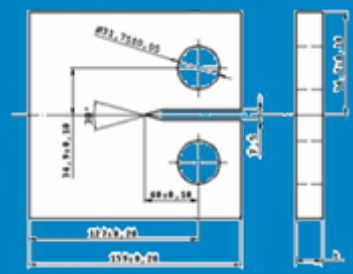




Global model

Stiffened panels

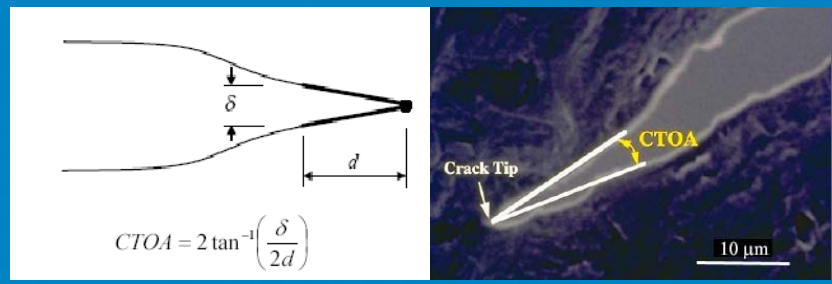




C(T) Specimen

Introduction: What is the CTOA parameter? Crack Tip Opening Angle

- **Definition:**



- **Hypothesis:**

Elastoplastic Fracture Mechanics, presence of significant plasticity in metallic parts, thin walled structures (and thick)

Advantages

–CTOA parameter only is associated to material and thickness. It is independent of the specimen geometry.

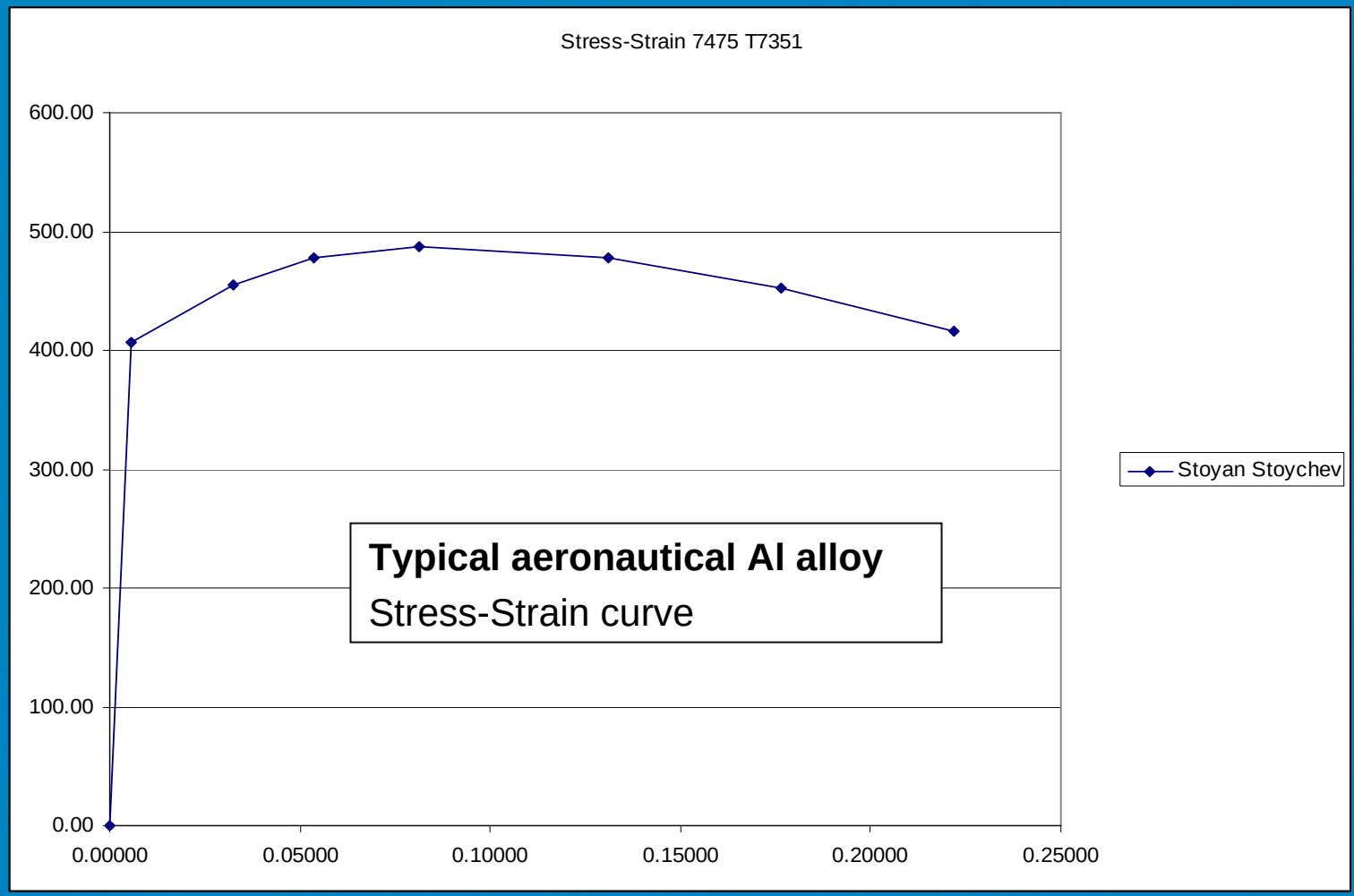
–CTOA concept is more robust than K_I (Stress intensity factor) and J integral.

–Computacional applications are very useful

Disadvantage

–Test coupon campaign is necessary in order to validate the CTOA parameter

Introduction: Elastic-plastic Behavior



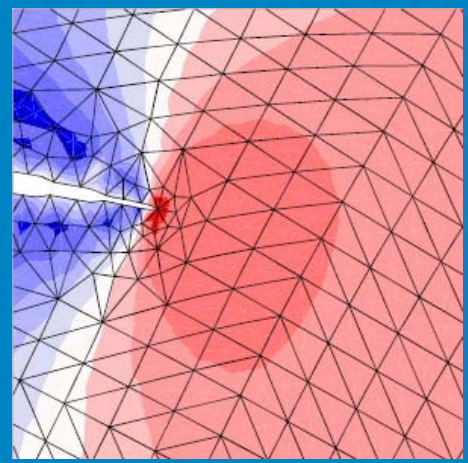
- Reference:

  Stoyan Ivanov Stoychev, *LOAD INTERACTION EFFECTS ON FATIGUE CRACK GROWTH* . Western Michigan University, 2005

Introduction: Previous Works

- M. A. James (Kansas S. U.) “PhD Thesis”
  - → Elastic-plastic crack growth simulation
  - → Fracture Criterion: CTOA
  - → Fracture along predefined path → Nodal Release
  - → Curving crack → Mapping & Remeshing

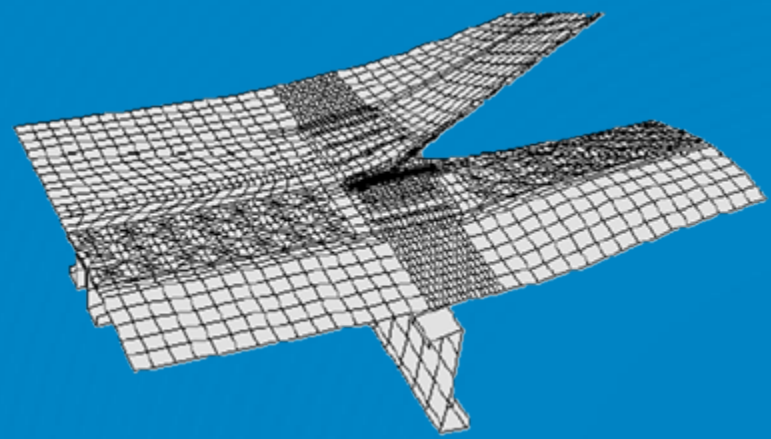
FRANC2D/L code extension
(originally developed at Cornell)



Introduction: Previous Works

- Chen-Wawrzynek-Ingraffea (Cornell U. for NASA Langley) "Crack growth simulation and residual strength prediction in airplane fuselages"
  - → M(T) specimens, multiple cracks, fuselage panels
  - → Elastic-plastic behavior
  - → Fracture criterion: CTOA

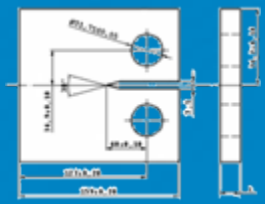
FRANC3D/STAGS code

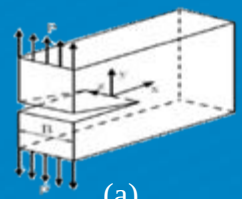


Finite Element Analysis Approach

- **Residual strength prediction 3D Simulation**

  Achieve CTOA parameter, triaxial stress state is considered close to crack tip





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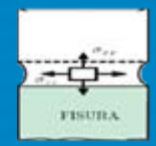
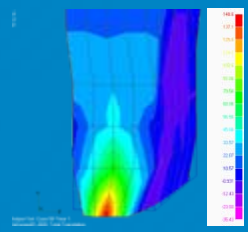


(b)

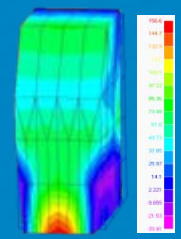
- **Residual strength prediction 2D Simulation**

  Specimen under plane stress condition except close to crack tip, where plane strain condition is considered: introduction of the plain strain core concept

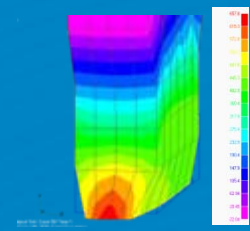
  Correlation between 3D model and 2D model



(c)

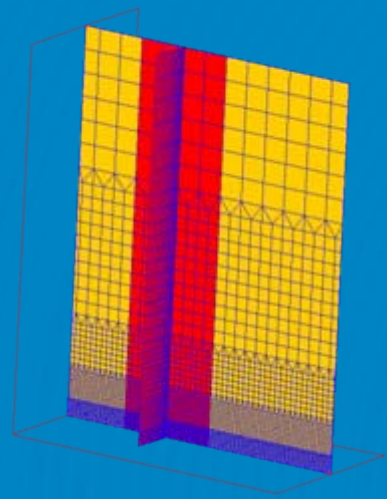


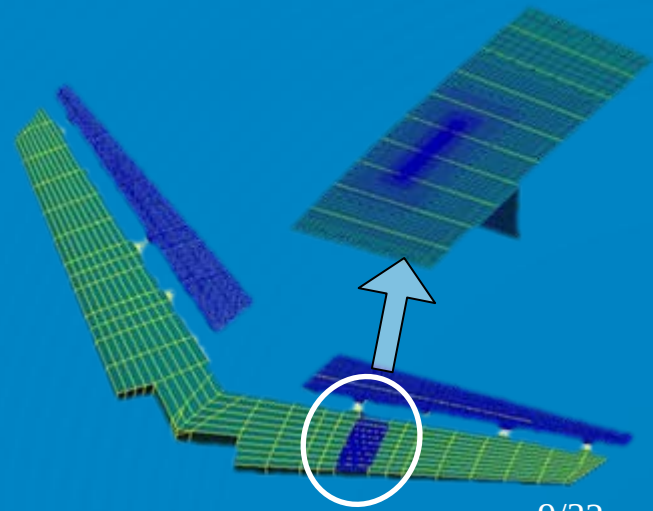
(d)



(e)

CTOAc

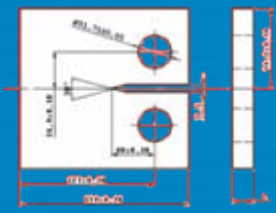




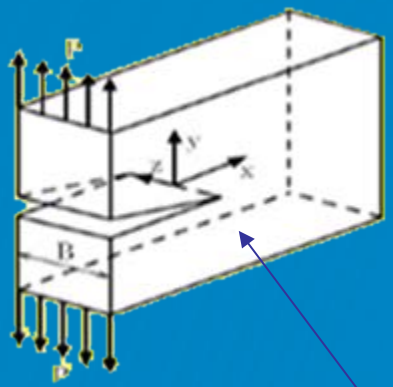
- **2D Simulation for complete stiffened panel or global model**

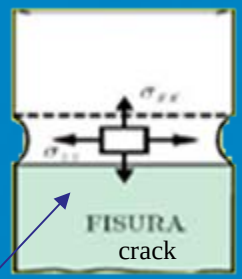
Finite Element Analysis Approach :

2D Model Correlation

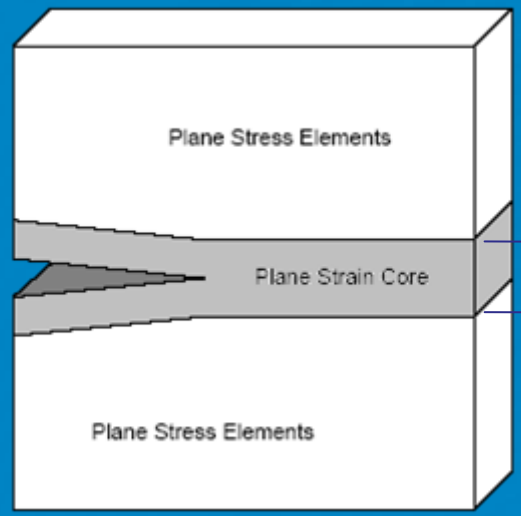


Plane Strain Core

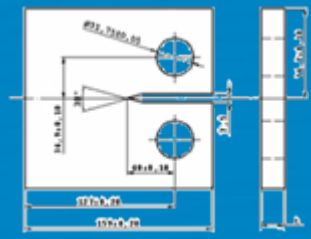




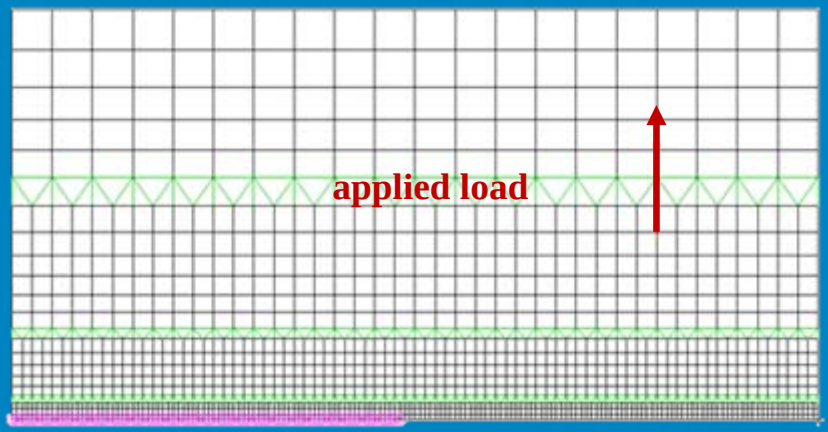
stress triaxiality near crack tip



Finite Element Analysis Approach

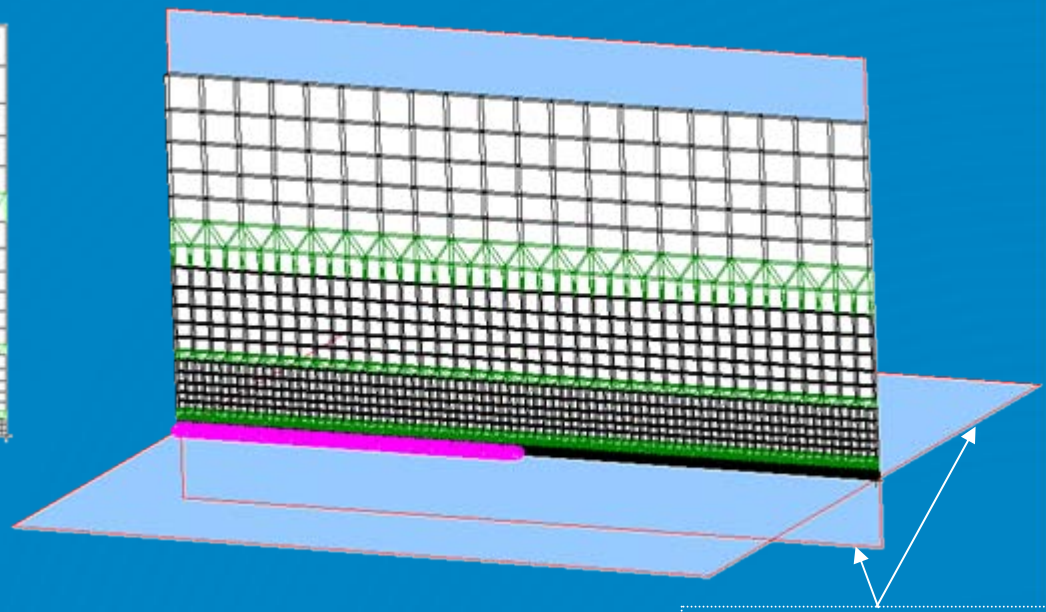


2D Model ½ geometry



crack path horizontal symmetry plane

3D Model ¼ geometry

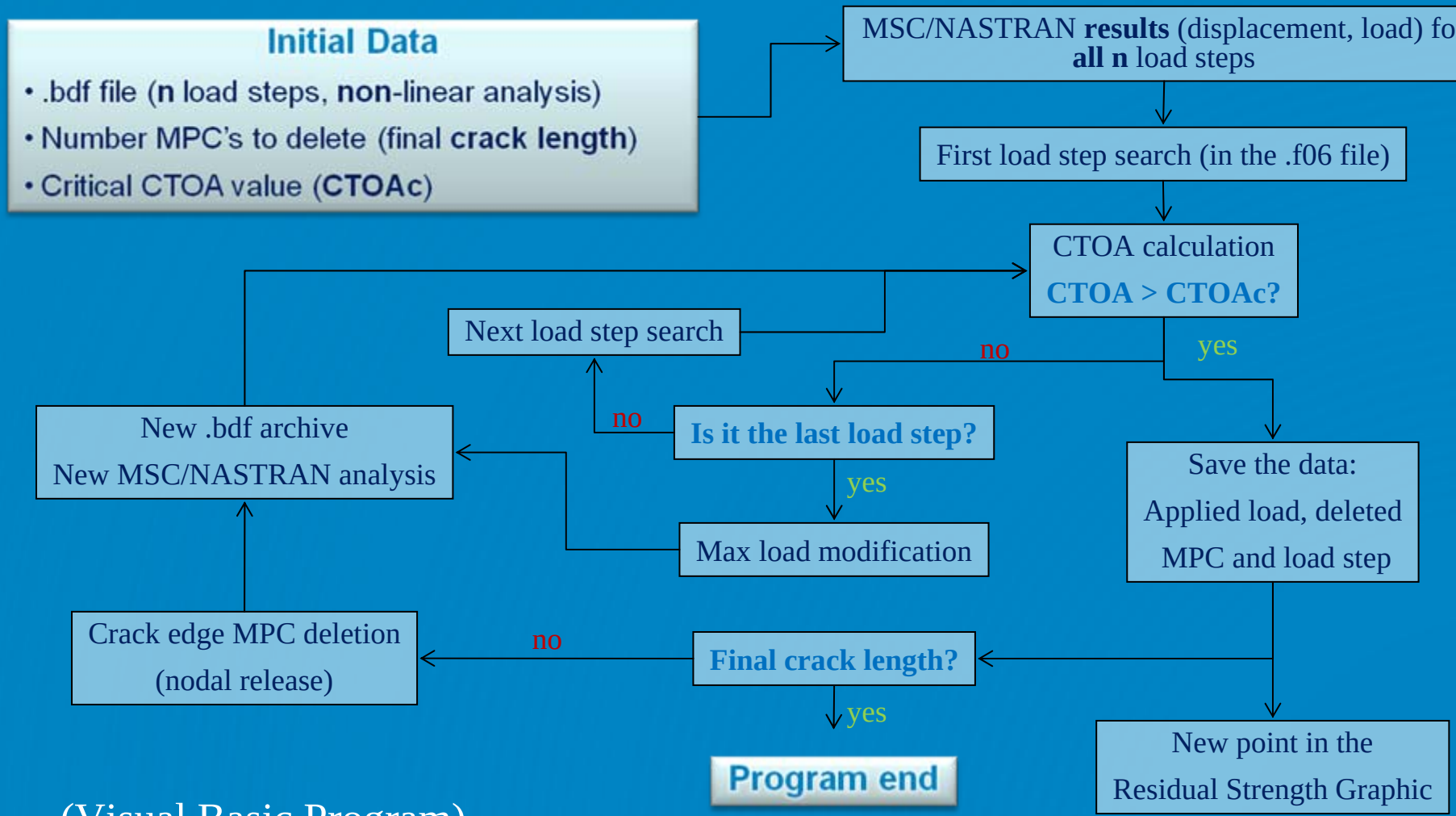


2 Symmetry Planes
- horizontal
- mid-plane

2D mesh extrusion ⟶ 3D mesh (solid elements)

Finite Element Analysis Approach :

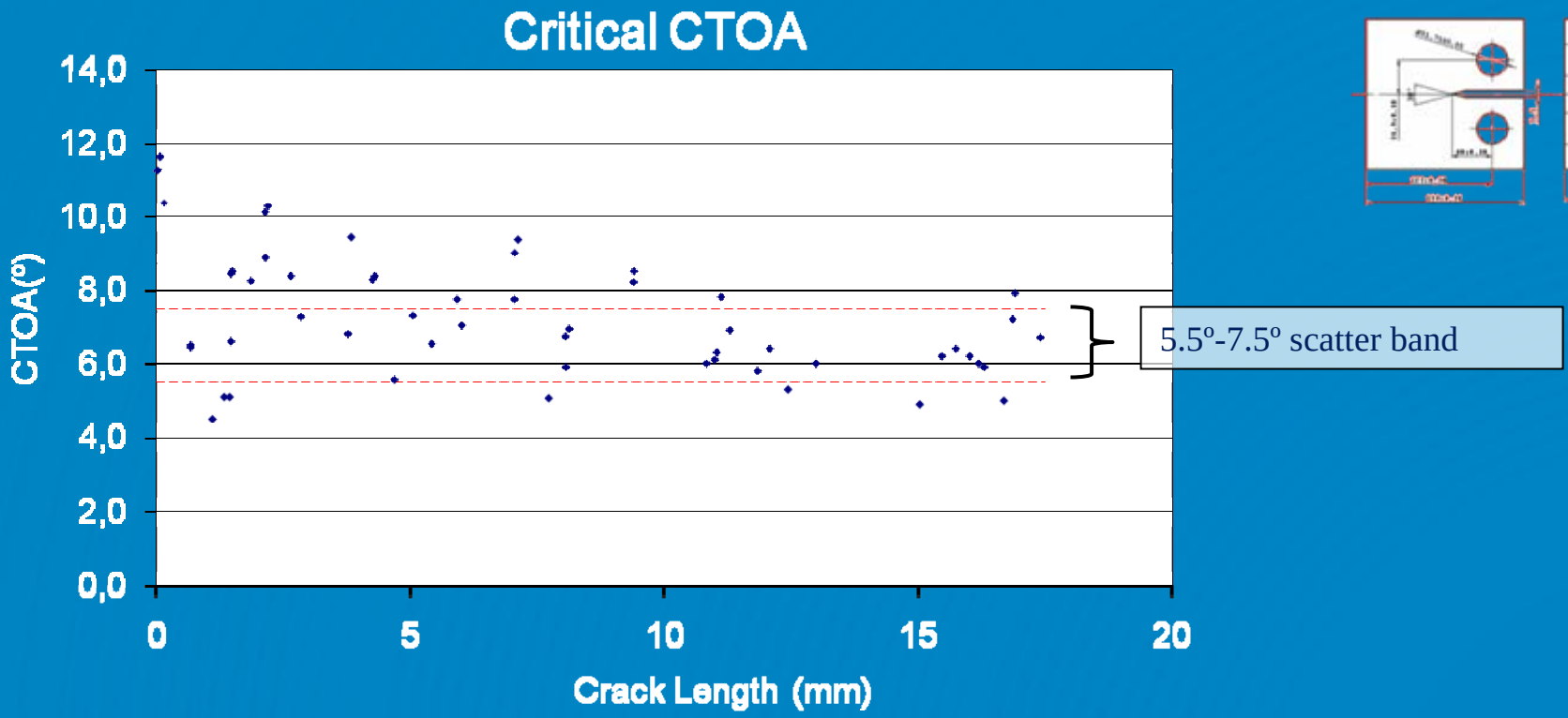
Crack Growth Manager



(Visual Basic Program)

Experimental CTOAc & Residual Strength

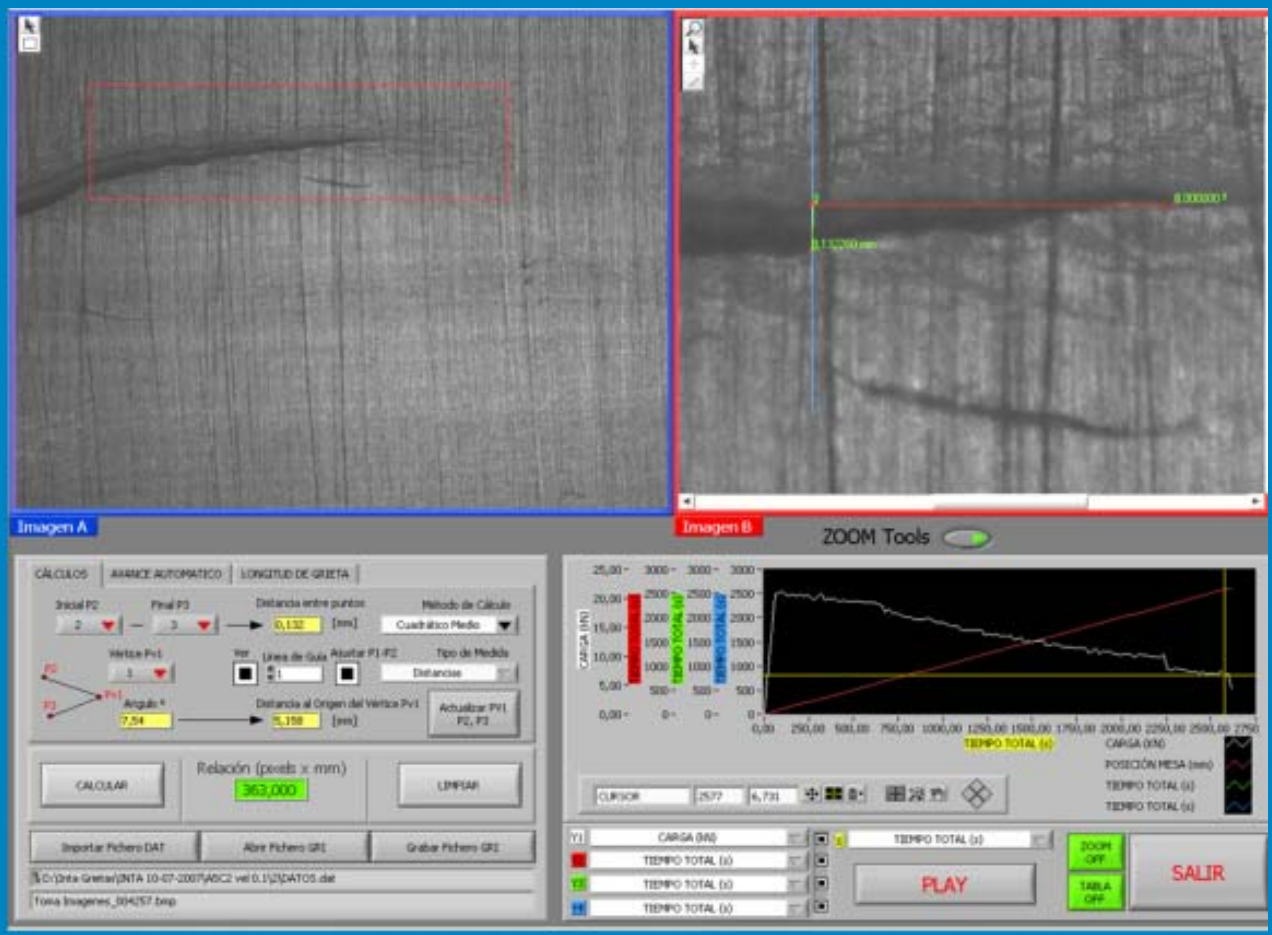
- CTOAc values obtained from the specimen tests AL7475 T7351 4 mm th

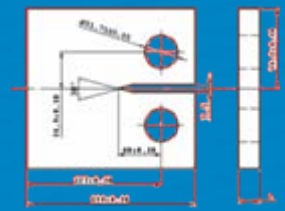


Experimental CTOAc & Residual Strength

CTOAc determination

(INTA SPANISH National Institute for Aeroespace Technology))

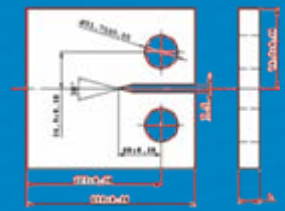




Experimental CTOAc & Residual Strength

CTOAc determination

(INTA SPANISH National Institute for Aeroespace Technology

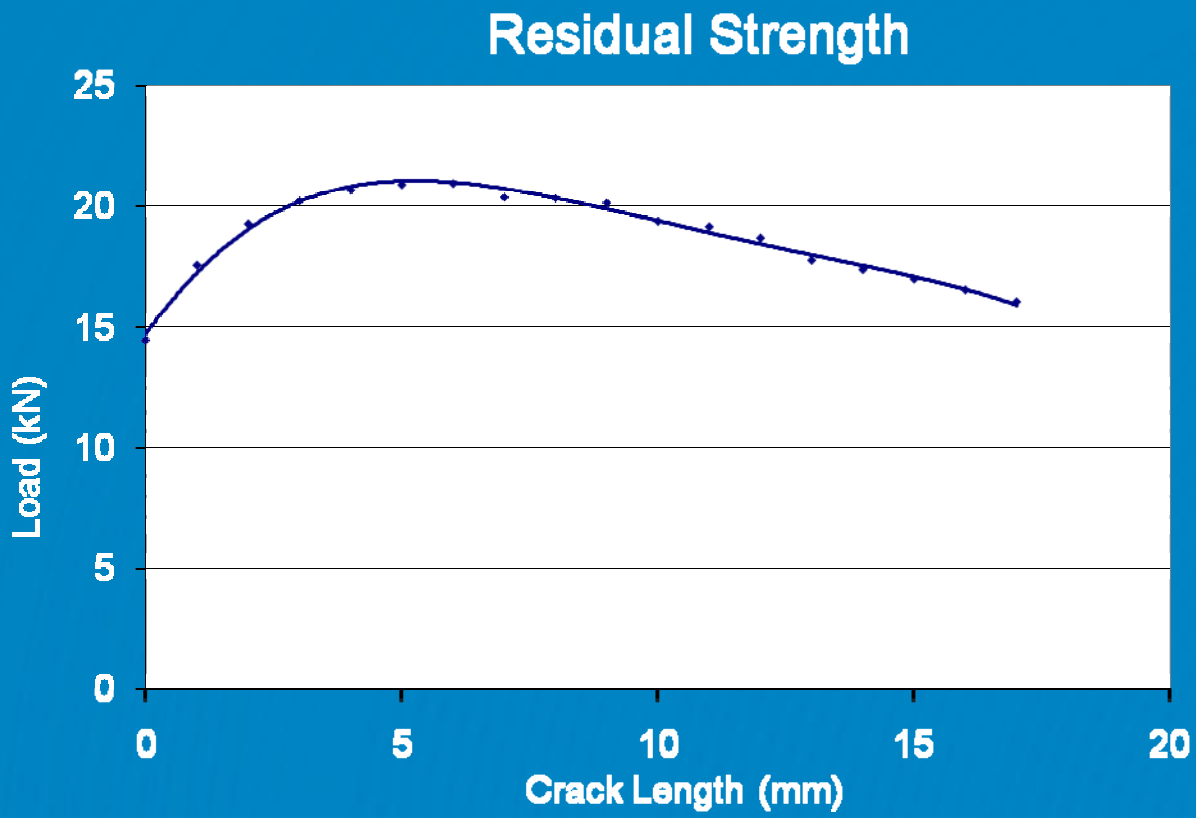


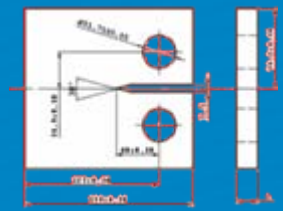
- Optical Instruments
  - High resolution digital camera
  - High precision telecentric lens

→ Aprox. 8μm precision

Experimental CTOAc & Residual Strength

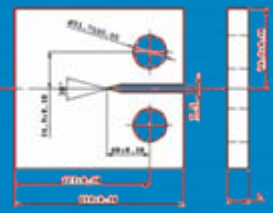
- Residual Strength values obtained from the specimen tests

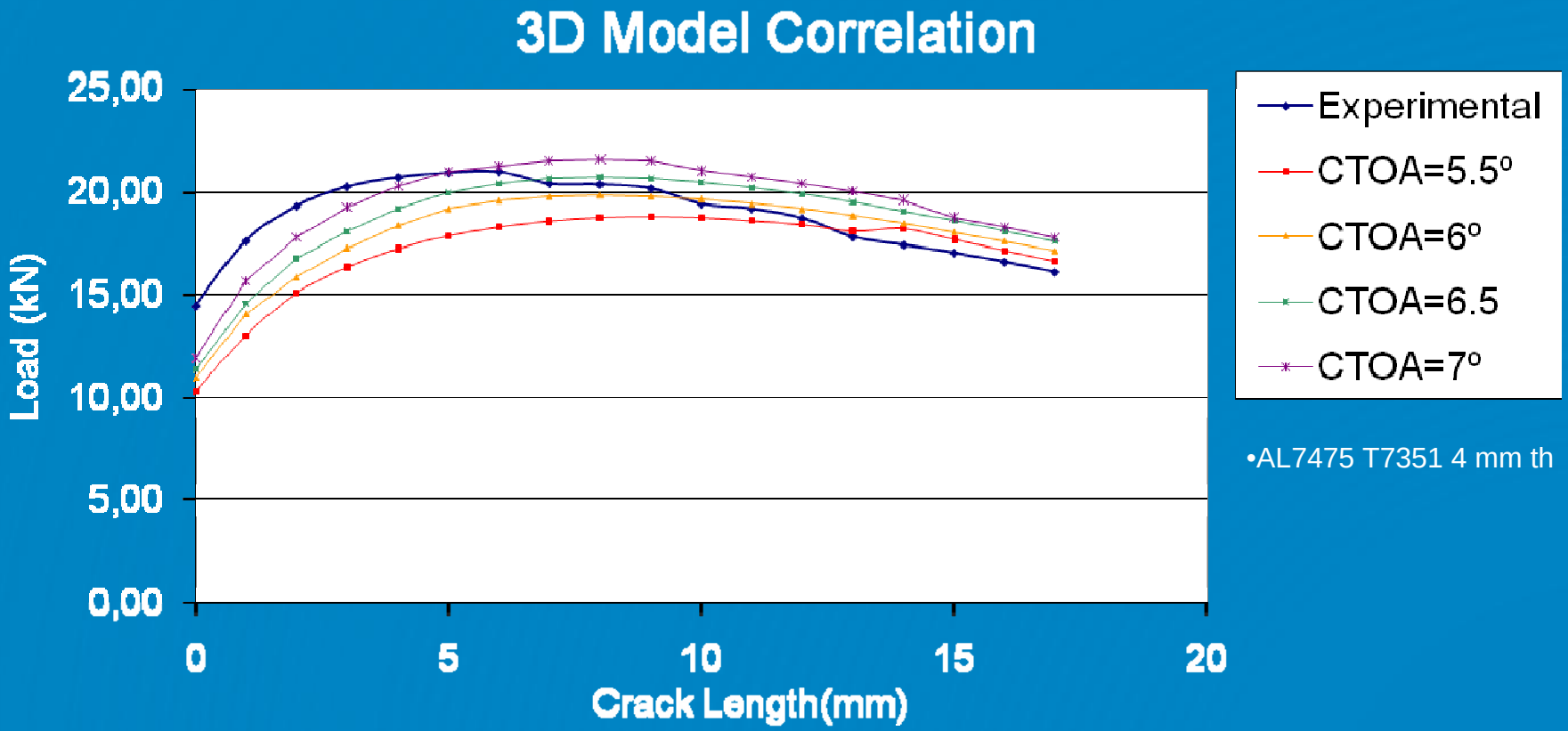




•AL7475 T7351 4 mm th

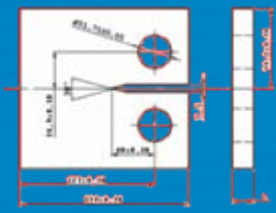
CTOAc Correlation

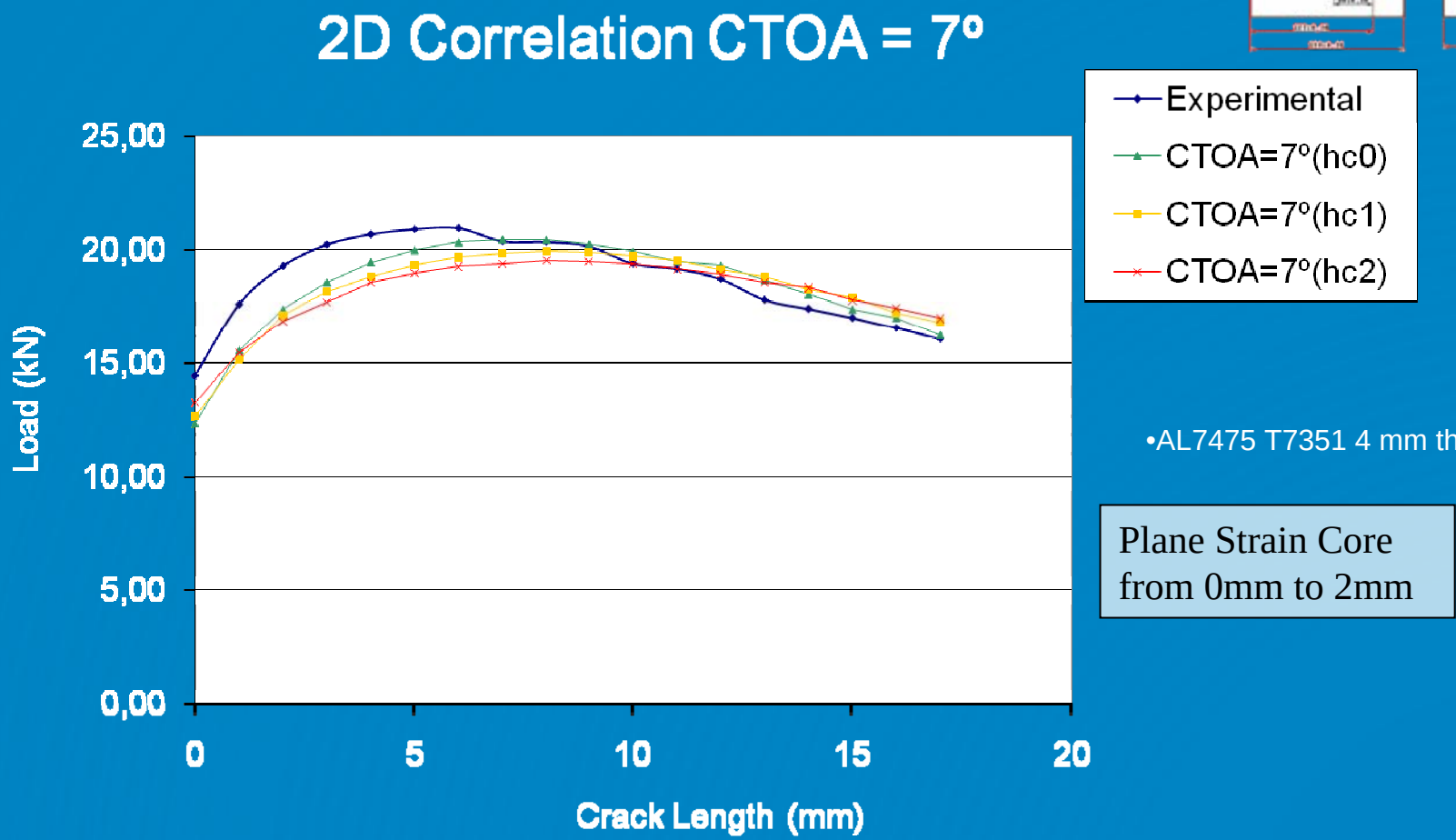




- AL7475 T7351 4 mm th

CTOAc Correlation

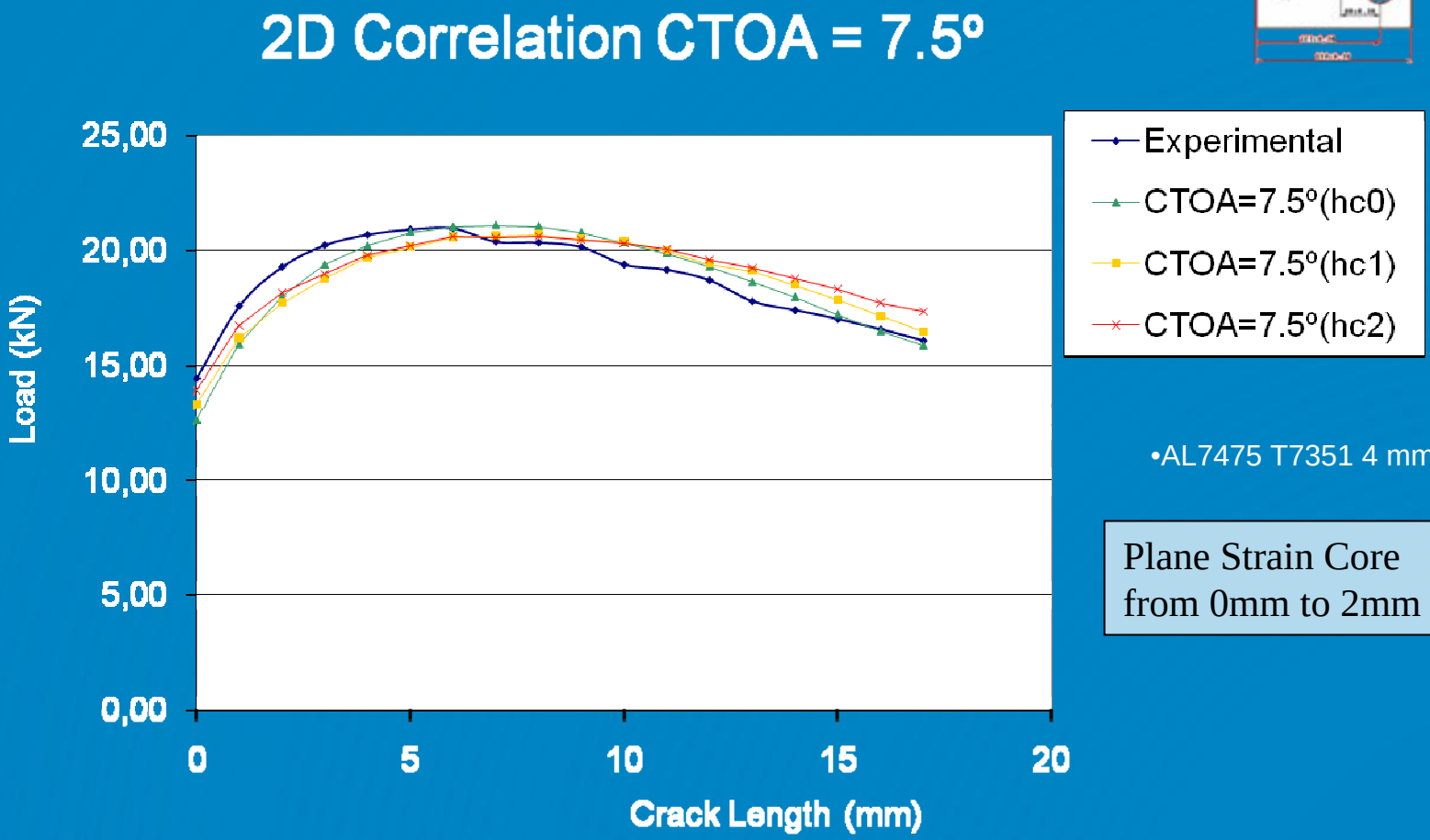




- AL7475 T7351 4 mm th

Plane Strain Core from 0mm to 2mm

CTOAc Correlation

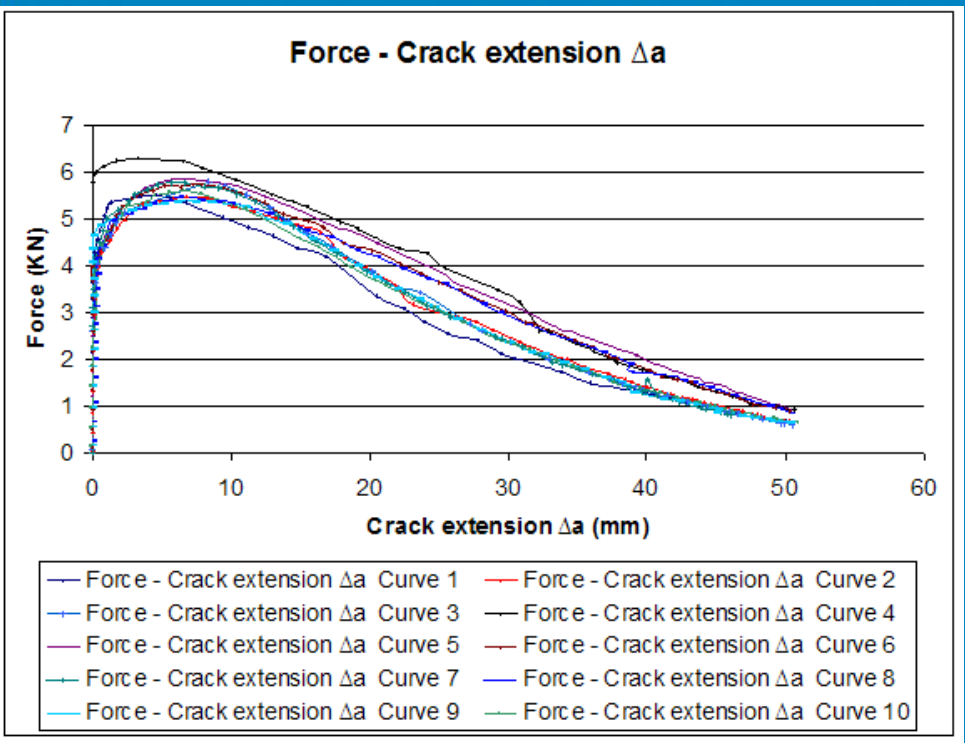


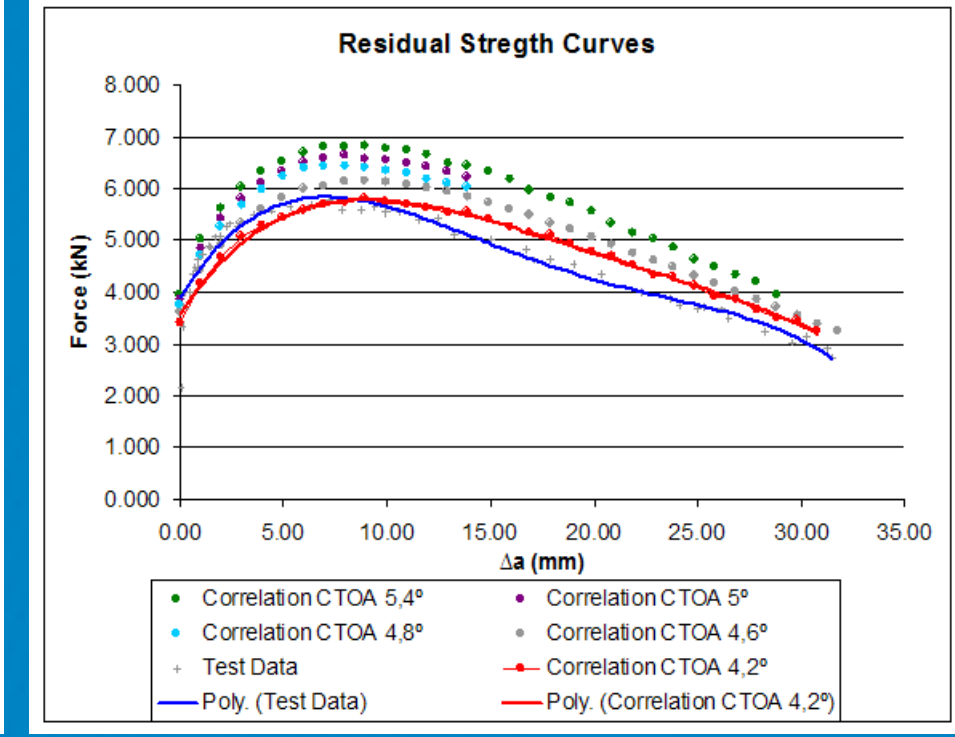
•AL7475 T7351 4 mm th

Plane Strain Core
from 0mm to 2mm

AL 2024 T3 1.6 mm thickness
Numerical Results Comparison vs test results

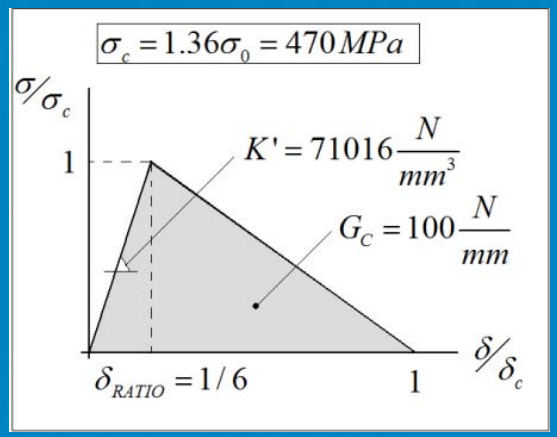
- Residual Strength curves from specimen tests
- Numerical correlation

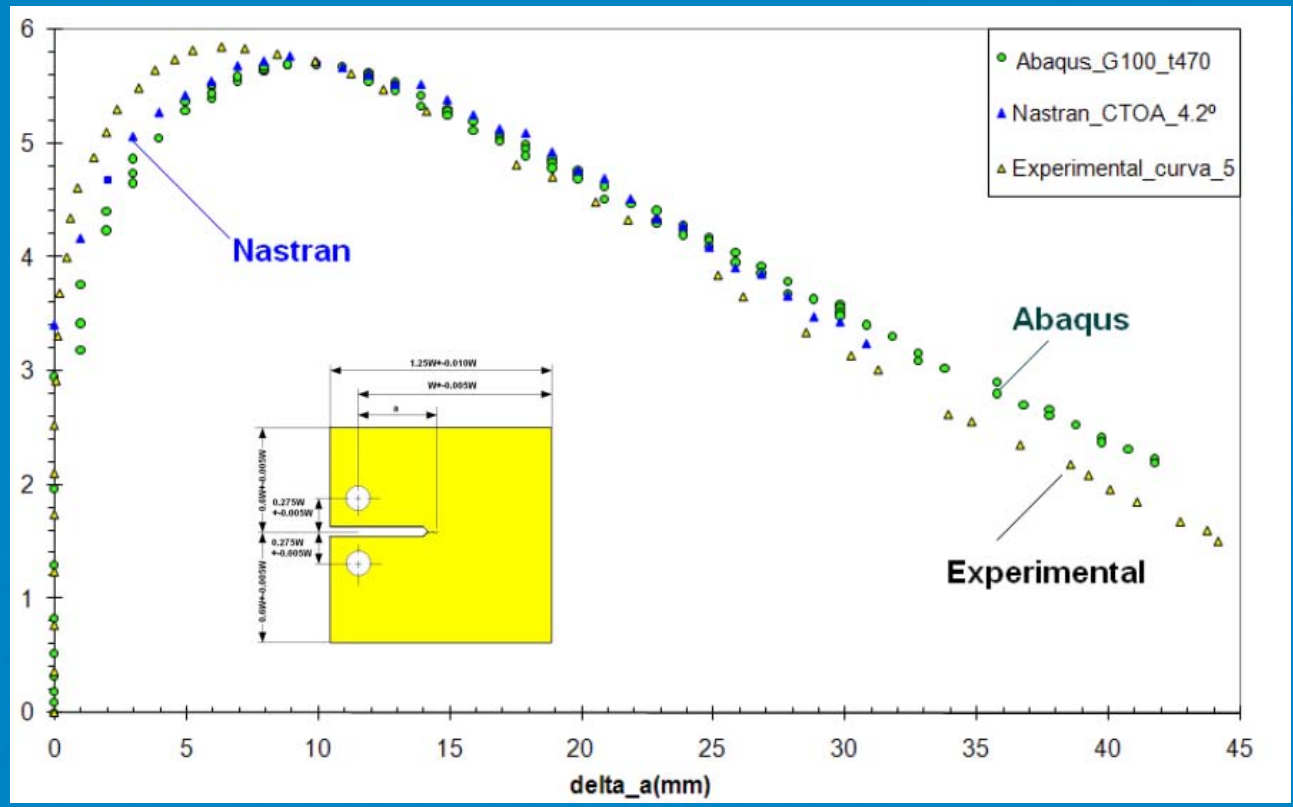




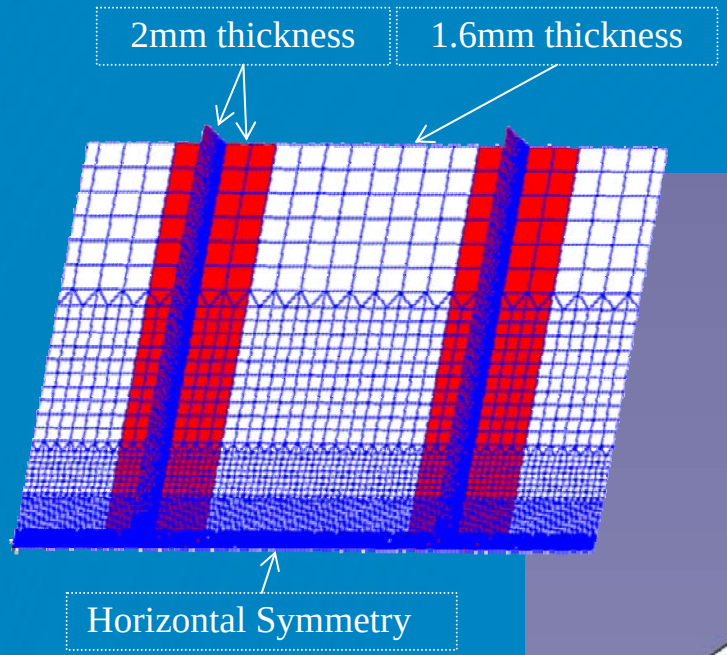
AL 2024 T3 1.6 mm thickness

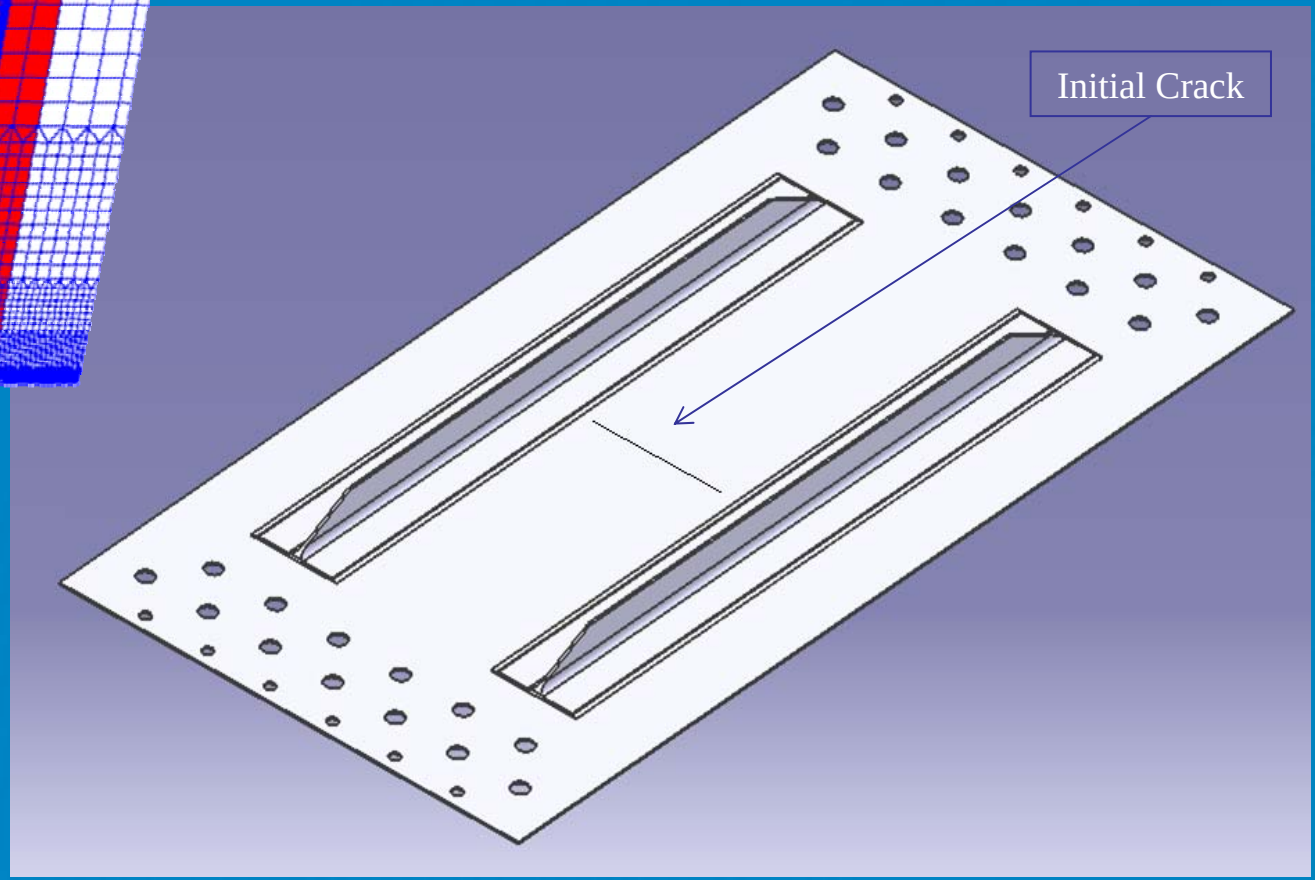
MSC/NASTRAN and ABAQUS Numerical Results Comparison vs test results

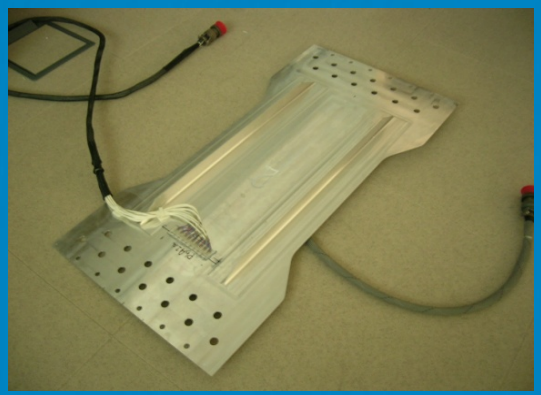




Multisite Damage Analysis on Stiffened Panels

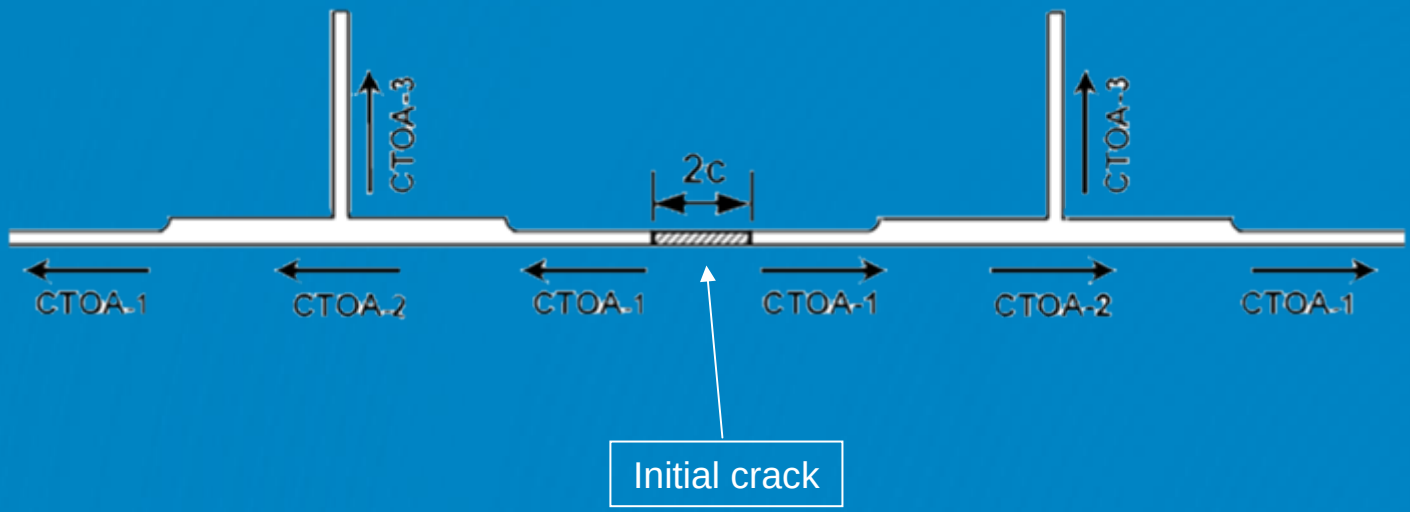


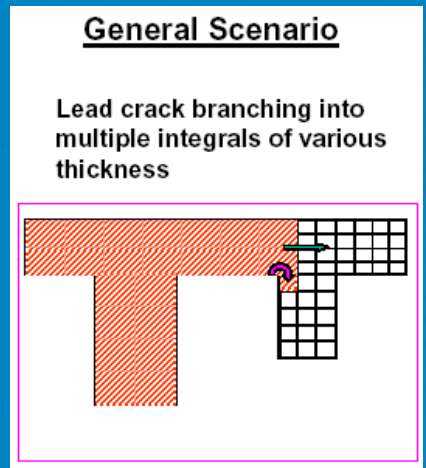




Multisite Damage Analysis on Stiffened Panels

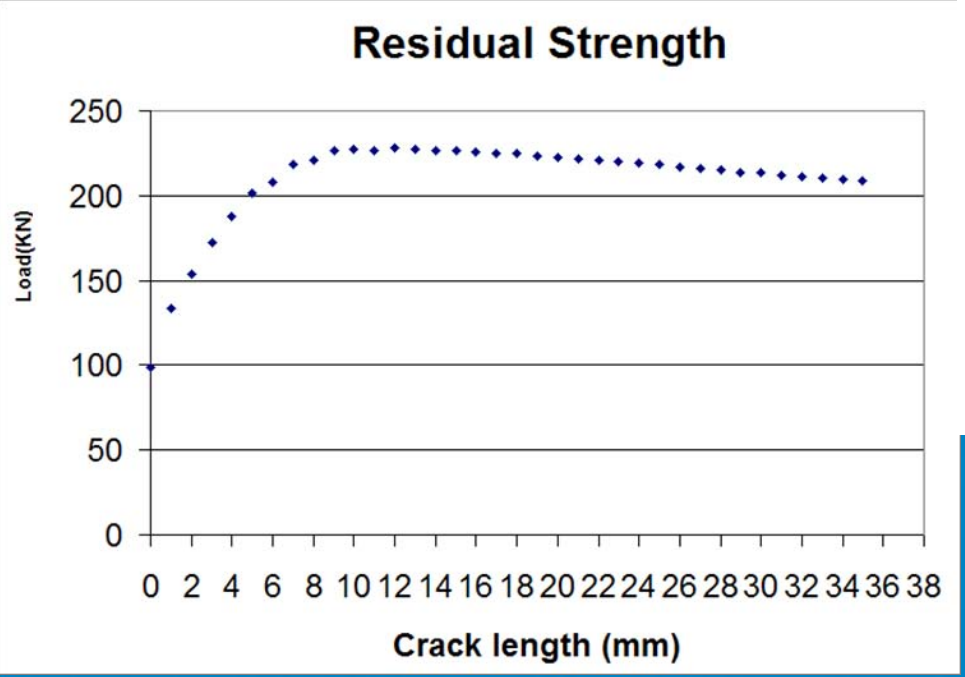
CTOAc is thickness dependant ⟶ use different CTOAc for each zone

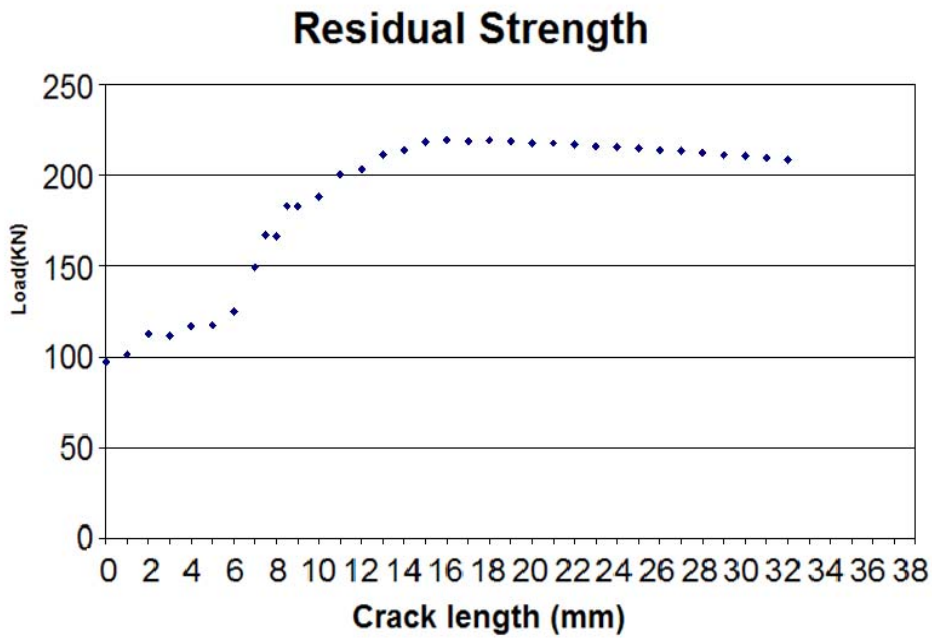




Multisite Damage Analysis on Stiffened Panels

Residual Strength curve obtained from a centered damage model

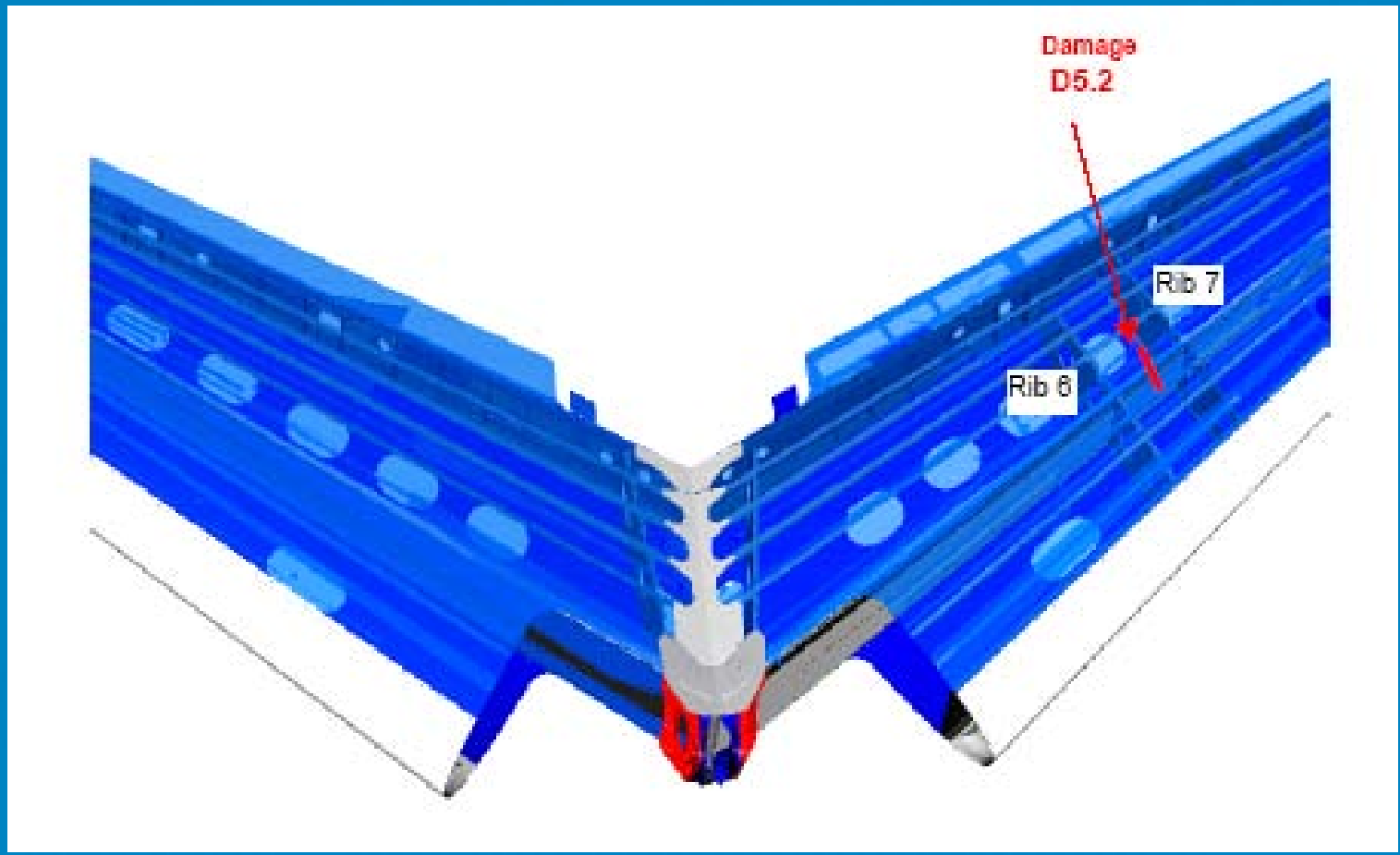




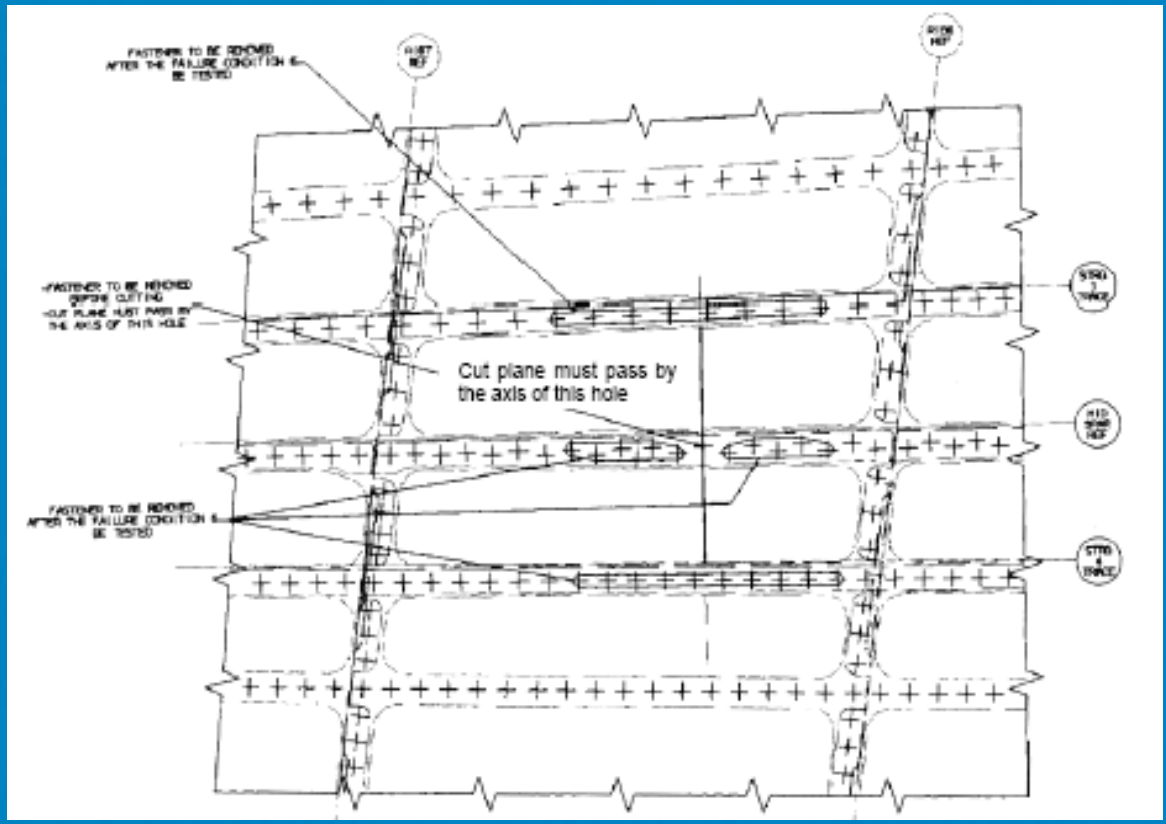
Residual Strength curve obtained from a multisite damage model

Crack growth analysis on skin panels

Residual strength analysis on a typical regional jet Horizontal Stabilizer FEM model



Crack growth analysis on skin panels

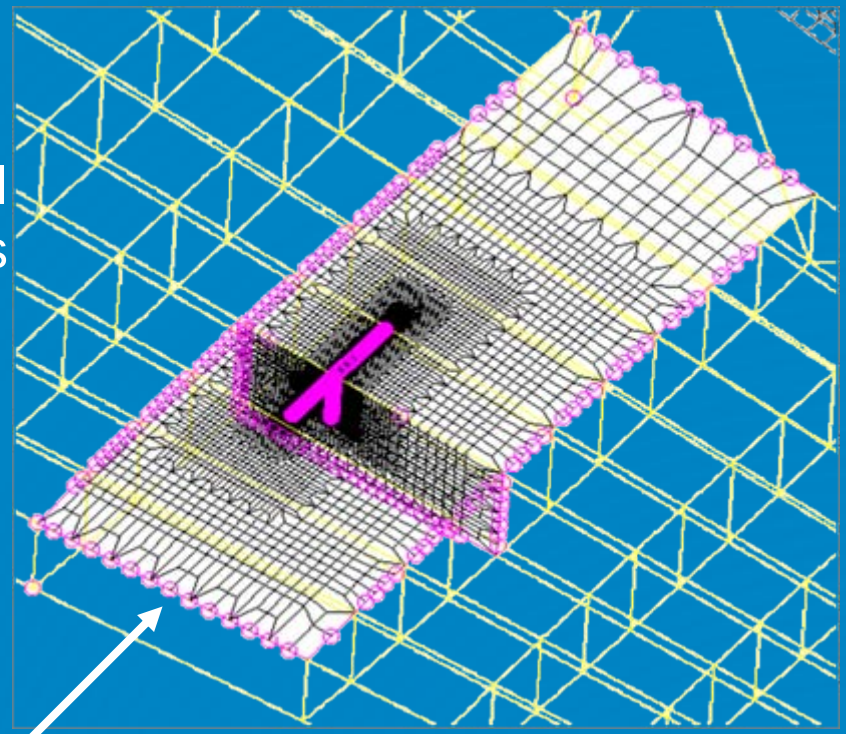


The Damage is performed by cutting the Mid Spar Upper Cap, Web and upper skin between Ribs 6 and 7

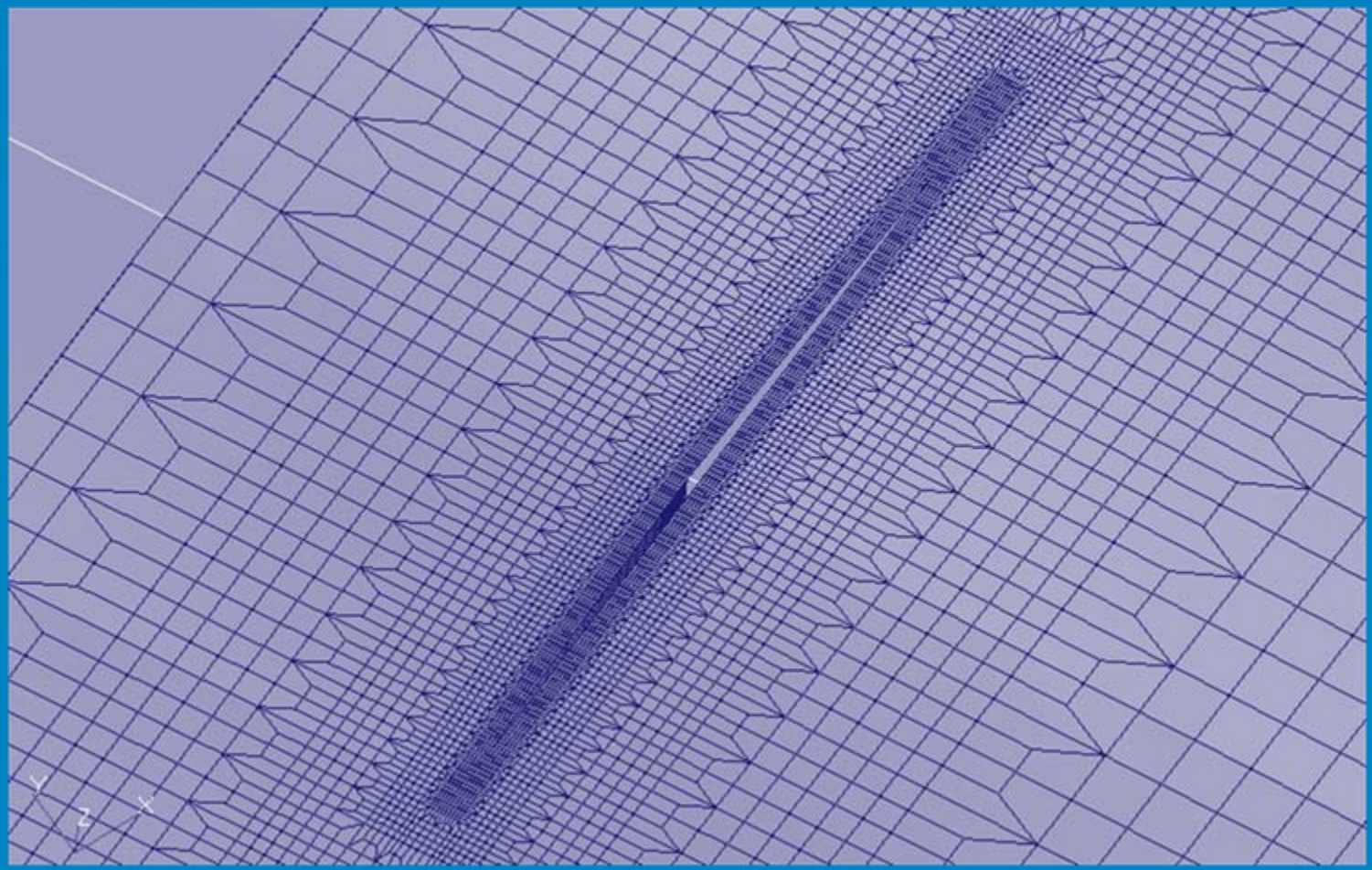
The cut on the skin shall be performed between Stringer 3 and 4 without cutting the stringers

Crack growth analysis on skin panels

Finite Element Model modifications



Crack growth analysis on skin panels



Concluding Remarks

- The residual strength of integrally-stiffened panels has been predicted using critical CTOA and plane strain core height concepts.
- The data has been calibrated with laboratory coupon test results
- MSC/NASTRAN analysis of 1.6 and 2 mm thickness C(T) specimen predicted residual strength to within 3% of the experimental data
- The Finite Element Model Software and the CTOA criterion are useful in the future design of integrally-stiffened thin and thick structures

THANK YOU FOR YOUR ATTENTION

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