Residual Strength Prediction of Damaged Aircraft Structure Using 3D Finite Element Modeling and Response Surface Methodology

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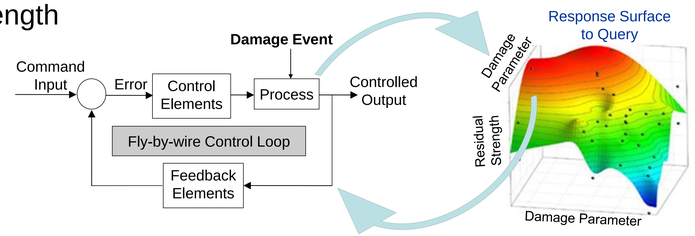
Objectives

➢ Develop finite element (FE)-based fracture mechanics toolset to predict residual strength of damaged airframe structure based on realistic, high fidelity fracture simulations

➢ Combine fracture simulation toolset with response surface methodology to provide damage-dependent structural assessments in real-time

➢ Interface real-time damage assessment tools with control systems to inform flight restrictions based on current residual strength



Technical Challenges

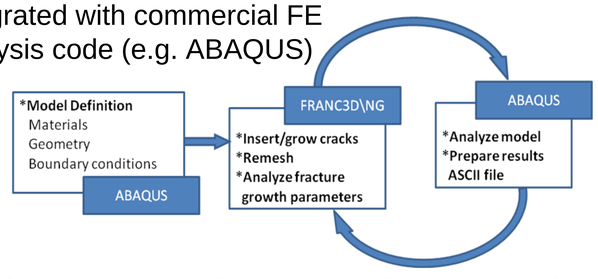
➢ Developing robust numerical tools to explicitly model complex, nonlinear fracture processes using 3D solid/shell FEA with adaptive remeshing

➢ Automating the modeling process so that residual strength predictions used to generate a response surface can be efficiently obtained from fracture simulations

Technical Approach

➢ Employ and augment current software framework:

- Use 3D fracture analysis code (FRANC3D\NG) integrated with commercial FE analysis code (e.g. ABAQUS)



- Develop response surface methodology using existing software framework with linear elastic fracture mechanics (LEFM)
- Simultaneously augment existing software toolset with nonlinear fracture mechanics (NLFM) capabilities to model ductile tearing due to large-scale damage

Response Surface Development Using LEFM

➢ "Design of Experiment"

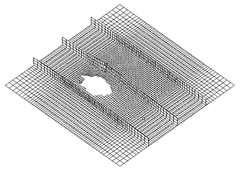
- Inputs are damage parameters (size, shape, location) based on accident reports, images*, and computer simulations

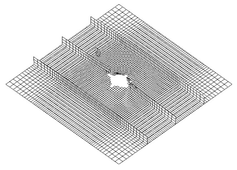
* Images from worldwide web


Bird strike

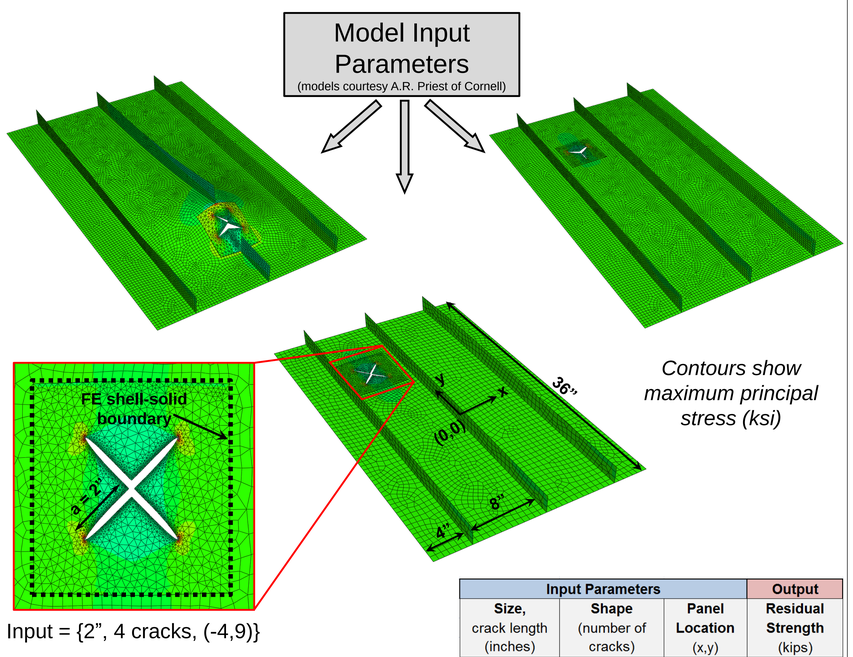

Bird strike


Hail strike




Simulated damage from generic projectile impact
(from Hinrichsen *et. al*, AIAA, 2008)


Missile strike



Input = {2", 4 cracks, (-4,9)}

Contours show maximum principal stress (ksi)

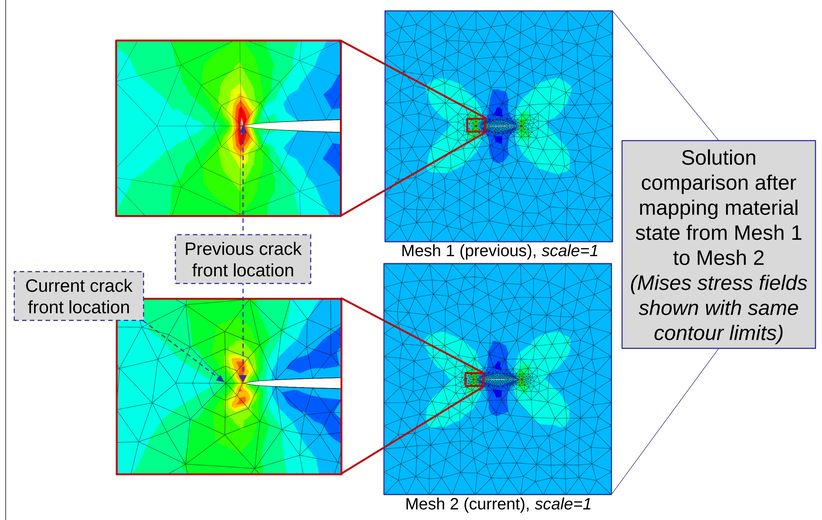
- Outputs are residual strength predictions based on critical stress intensity factor (SIF) combinations obtained at any crack front location

Input Parameters			Output
Size, crack length (inches)	Shape (number of cracks)	Panel Location (x,y)	Residual Strength (kips)
2	4	(-4,9)	43.3
1.5	3	(-4,9)	38.4
1.5	5	(-4,9)	36.9
1.5	5	(0,-11)*	32.2
2	4	(0,-11)*	31.1
1.5	3	(0,-11)*	28.6
.	.	.	.
.	.	.	.
.	.	.	.

* Stiffener severed by damage

Toolset Enhancement for NLFM Capability

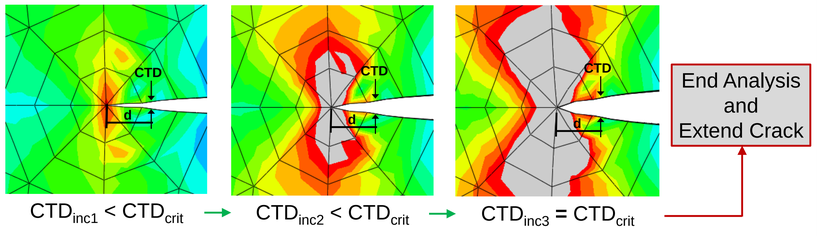
➢ Material state mapping employed between 3D FE meshes during incremental crack growth and adaptive remeshing



Images show face of 3D mesh model

➢ Nonlinear fracture parameter incorporated into analysis

- Crack tip displacements (CTD) are evaluated during nonlinear FE analysis and are compared to user-specified critical value
- CTD values are computed through-the-thickness at user-specified distance, d, behind crack front(s)
- CTD values describe three displacement modes



$CTD_{inc1} < CTD_{crit}$ → $CTD_{inc2} < CTD_{crit}$ → $CTD_{inc3} = CTD_{crit}$

Future Work

➢ Construct an initial response surface upon completing "design of experiment" using LEFM results

➢ Validate the enhanced fracture toolset capabilities

➢ Apply the toolset and framework to predict residual strength of more complex geometry and damage configurations using NLFM

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