Integrated Resilient Aircraft Control

Residual Strength Prediction of Damaged Aircraft Structure Using 3D Finite Element Modeling*

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Objectives

➢ How can we enable *safe flight and landing* in damage scenarios like these?

Airbus A300 shortly after takeoff from Baghdad, November, 2003
(image from public domain: www.youtube.com)

Boeing 747-438 en route from London to Melbourne, July, 2008
(image from public domain by Edwin Loobreral/AFP/Getty)

Overall objective of IRAC project: To arrive at set of validated tools that will enable safe flight and landing for aircrafts experiencing adverse conditions. A significant example of such adverse conditions includes discrete- or point-source damage events, such as the two shown here.
-Airbus A300 incurred severe wing damage from surface-to-air missile shortly after take-off from Baghdad. The impact caused significant damage to the aileron and cracked the rear spar.
-Boeing 747 operated by Qantas incurred severe fuselage damage due to an oxygen tank explosion on-board

Objectives

- Develop finite element (FE)-based fracture mechanics analysis methodology to predict growth of point-source damage within airframe structures under realistic conditions and in real-time
- Interface real-time damage assessment with control systems to provide damage-dependent flight envelope to restrict structural loads in presence of severe damage

Our research objectives seek to answer 2 primary questions: 1) How can we most accurately model and predict the growth of point-source damage to airframe structures in real-time?, and 2) How can we then integrate these real-time damage assessment tools with the control system to provide an updated flight envelope limited by the particular damage state?

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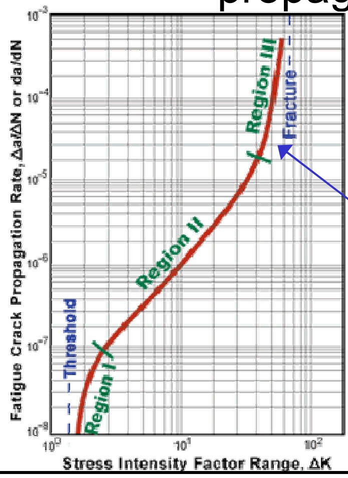
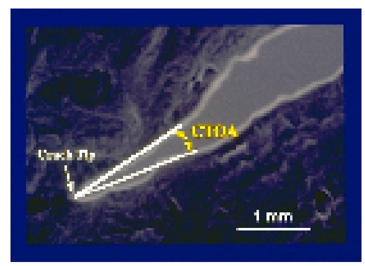
Technical Challenges (1/2)

- Capturing the relevant physics
  - What governs 3D damage propagation?
  - How can we simulate 3D damage propagation using FE-based modeling techniques?
  - What is the validity of currently employed crack propagation criteria?



Predicting nonlinear crack growth behavior (Region III)

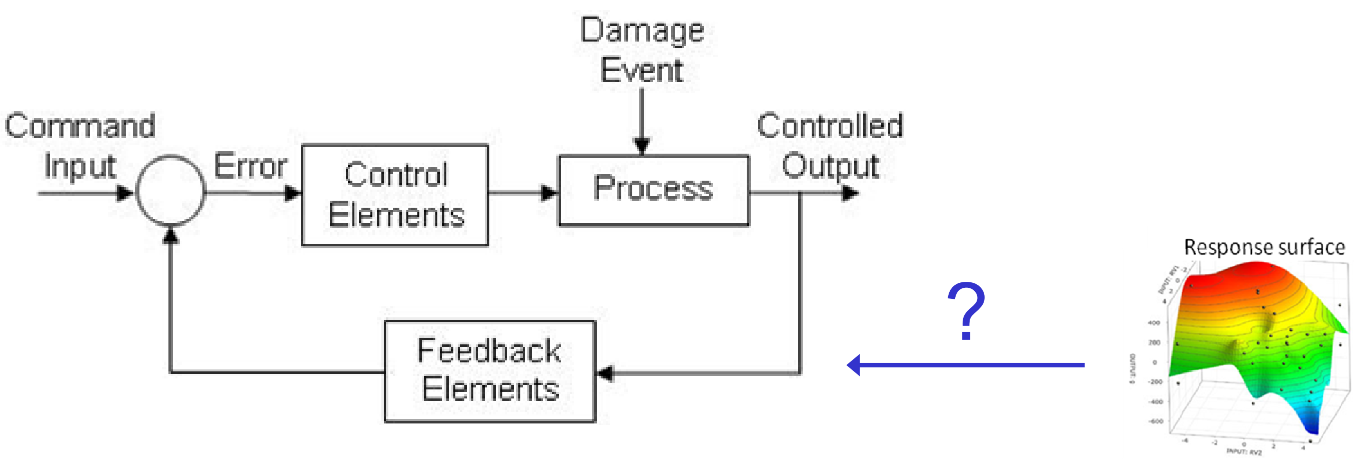


Using CTOA for crack growth criterion

In meeting our research objectives there are two primary technical challenges. One of these challenges is determining how to accurately capture and model the physics that govern 3D crack propagation as well as determining the validity of currently employed crack propagation criteria. Examples of currently employed criteria include various models that predict nonlinear fatigue crack growth rate in the region where a significant amount of damage has accumulated as well as using a critical crack tip opening angle to predict NLFM crack growth.

Technical Challenges (2/2)

- Control system accessibility in real-time
  - How can we optimize computational resources to develop an accurate response surface?
  - How do we interface response surface with control system to be queried in real-time?



Another technical challenge that we will face in the future is figuring out how we can provide damage assessment results (most likely in the form of a response surface) in such a way that these assessments can be incorporated into the c.s. feedback loop for access in real-time.

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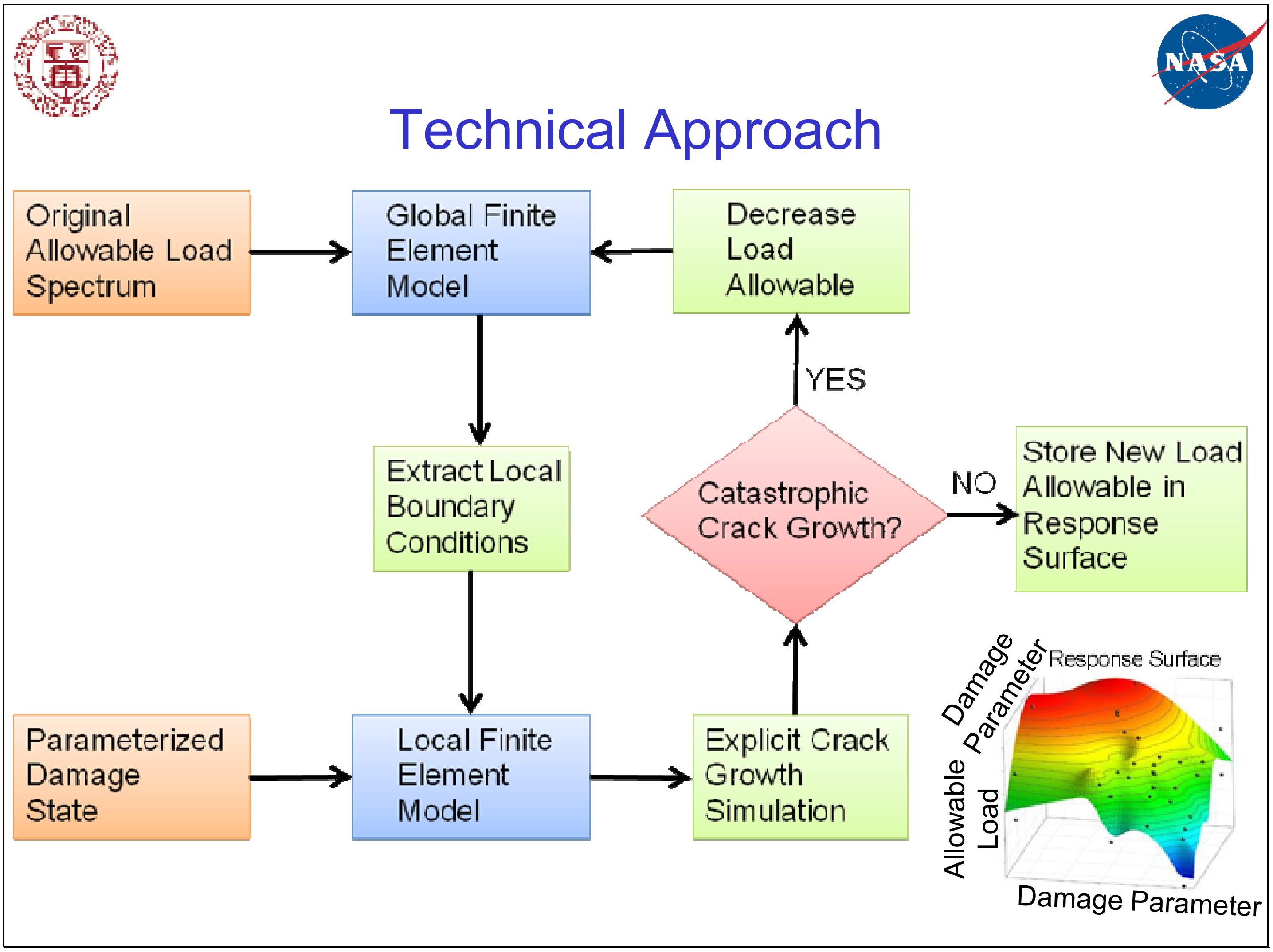

Our research approach is shown here. We begin with a global finite element model of, say, a wing, subject to an original allowable load spectrum. From the global model we can extract a local model, such as a stiffened wing panel to which we impose a parameterized state of damage. [see next slide]

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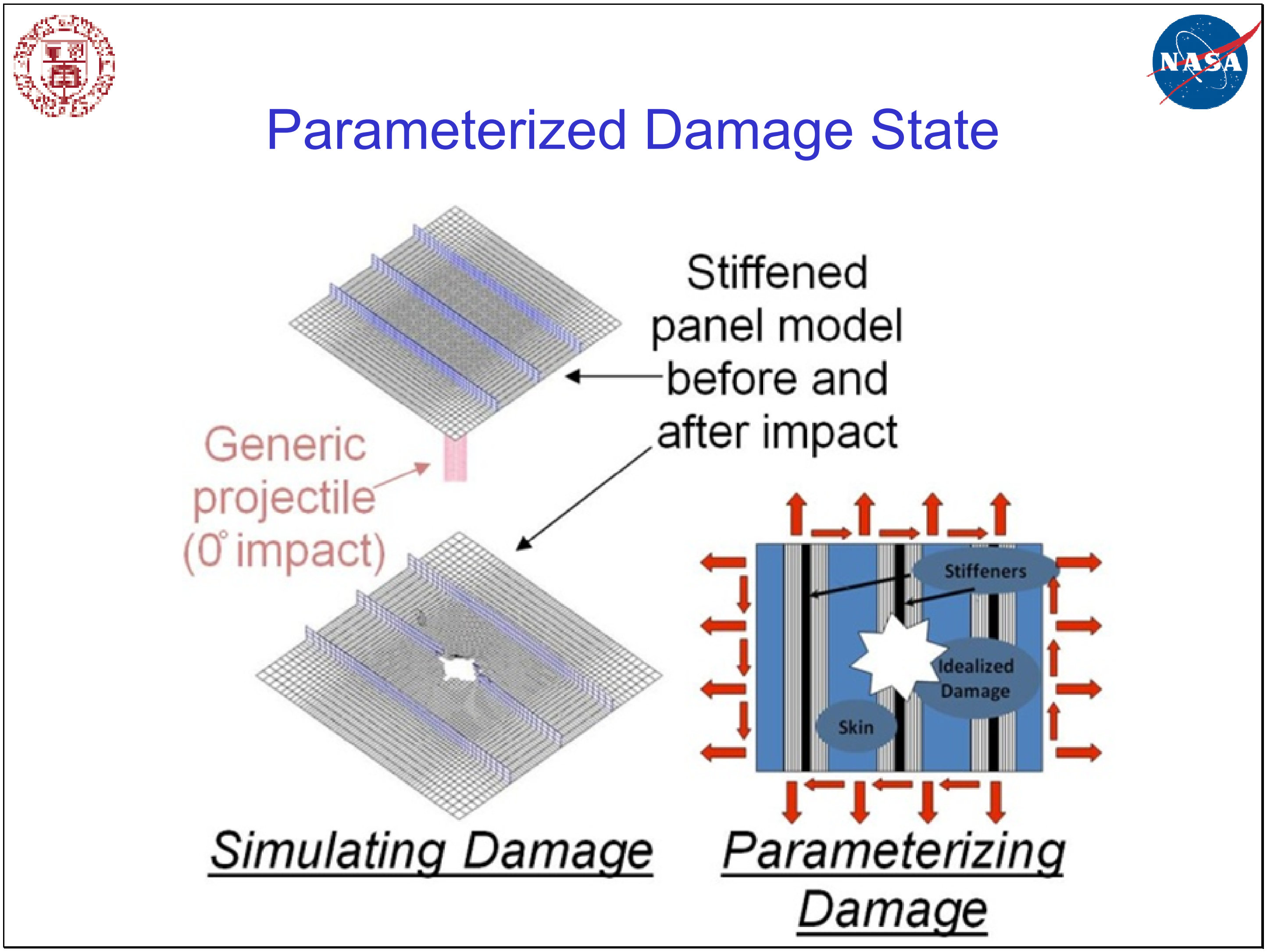

As a side note, damage can be parameterized according to size, shape, and location of damage. Results from computer simulations such as the one shown here will be used to characterize the damage used in our models. The work shown is courtesy of researchers at NASA Langley and shows the resulting damage caused by generic projectiles impacting a stiffened wing panel at various impact angles.

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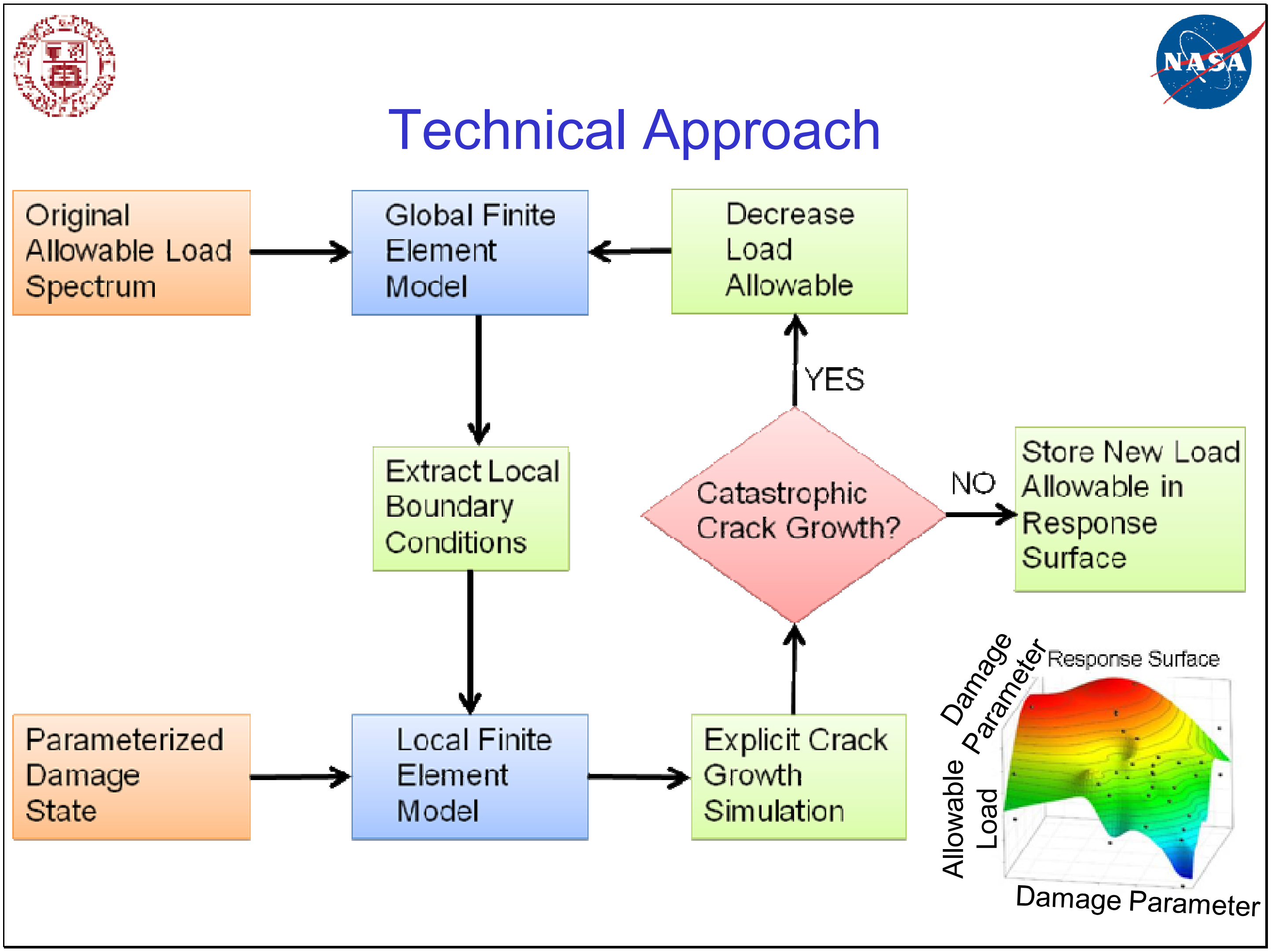
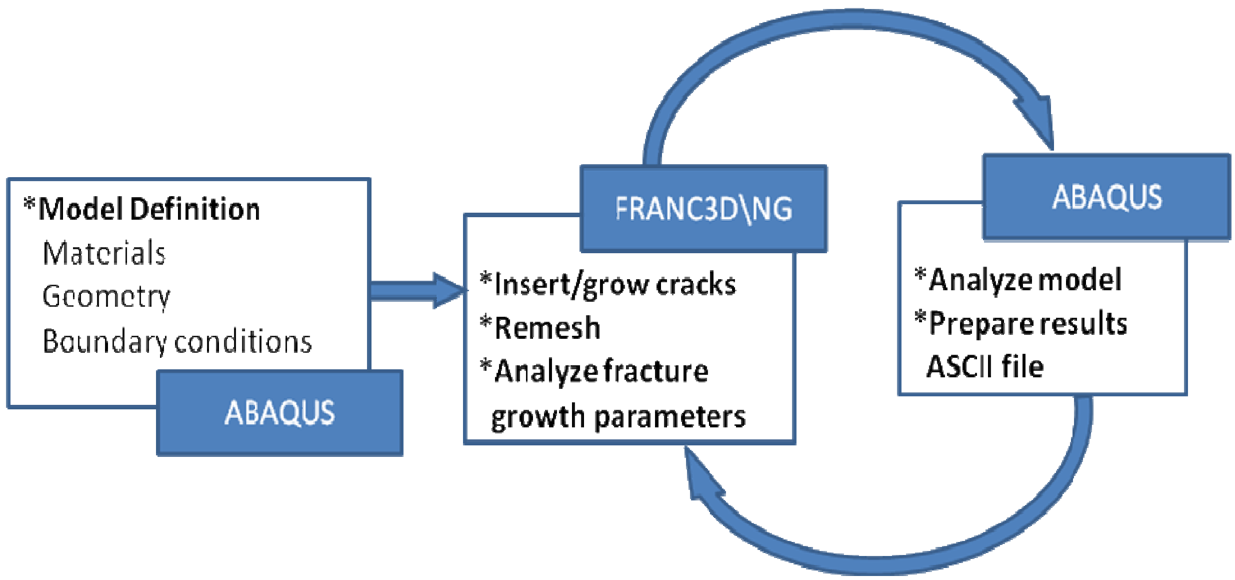


From an explicit crack growth simulation, we can determine whether or not the parameterized damage state will result in structural failure. If yes, we must decrease the allowable load and repeat the modeling process until we determine the load at which the structure will not fail given the particular damage state. This new load allowable is then stored on a response surface such as the generic one shown here.

Analysis

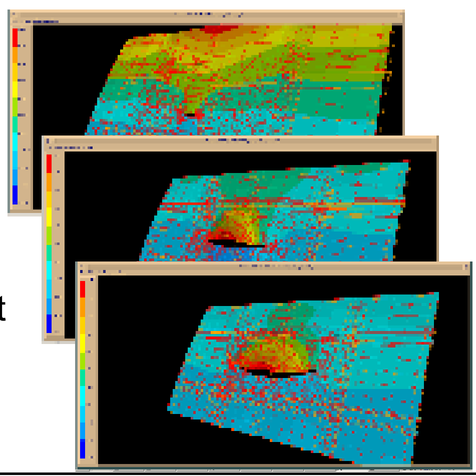
- 3D fracture analysis code (FRANC3D/NG) integrated with commercial FE analysis code (ABAQUS)



Illustrated here is the computational analysis process. We build and define our finite element models using commercial codes like ABAQUS, which we then read into our in-house 3D fracture analysis code, FRANC3DNG, to insert and grow cracks and analyze the fracture growth parameters.

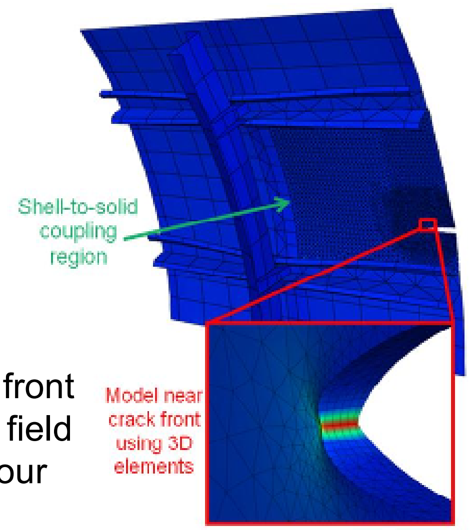
Proof-of-Concept: Crack Growth Simulations

- Simulation of curvilinear crack growth from point-source damage in stiffened fuselage panel subject to internal pressurized loading



Out-of-plane displacement contour

- Shell-solid coupled sub-model of fuselage panel using highly refined mesh of solid elements near crack front

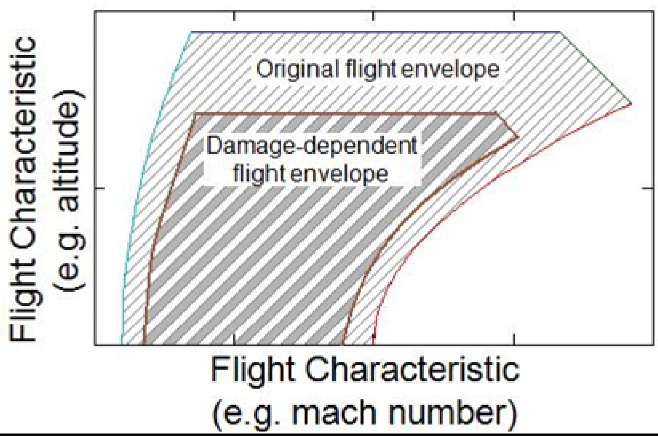


Crack front stress field contour

So far, we have been able to simulate curvilinear crack growth from point-source damage in a pressurized fuselage panel. We have also created shell-solid coupled submodels by replacing the region surrounding the crack front with solid elements in order to capture through-thickness effects while maintaining computational efficiency over the entire model.

Future Work

- Further develop methodology for simulation of point-source damage propagation
- Incorporate results of damage propagation predictions within a response surface
- Provide results that are amenable to integration within the control system



Future work on the project includes further development of the methodology and framework for simulating point-source damage propagation, incorporating the results from these simulations within a response surface, and providing results that are amenable to integration within the c.s. We envision that the damage assessment tools will ultimately be accessed to generate an updated damage-dependent flight envelope like the generic one shown here. (Currently, primary focus is placed on generic, narrow-body transport with discrete-source damage at several locations in wing.)

Concluding Remarks

- The current approach is being incorporated within the Level 2 Airframe and Structural Dynamics element of IRAC
- Must understand the effect of point-source damage on the ability to control an aircraft
- Extreme flight conditions may cause propagation of point-source damage

The approach presented here is being incorporated within the Airframe and Structural Dynamics element in Level 2 of the IRAC project. In order to meet the overall IRAC objective of enabling safe flight and landing for aircraft in the presence of adverse conditions, we really must be able to understand and model how point-source damage affects the ability to control an aircraft.

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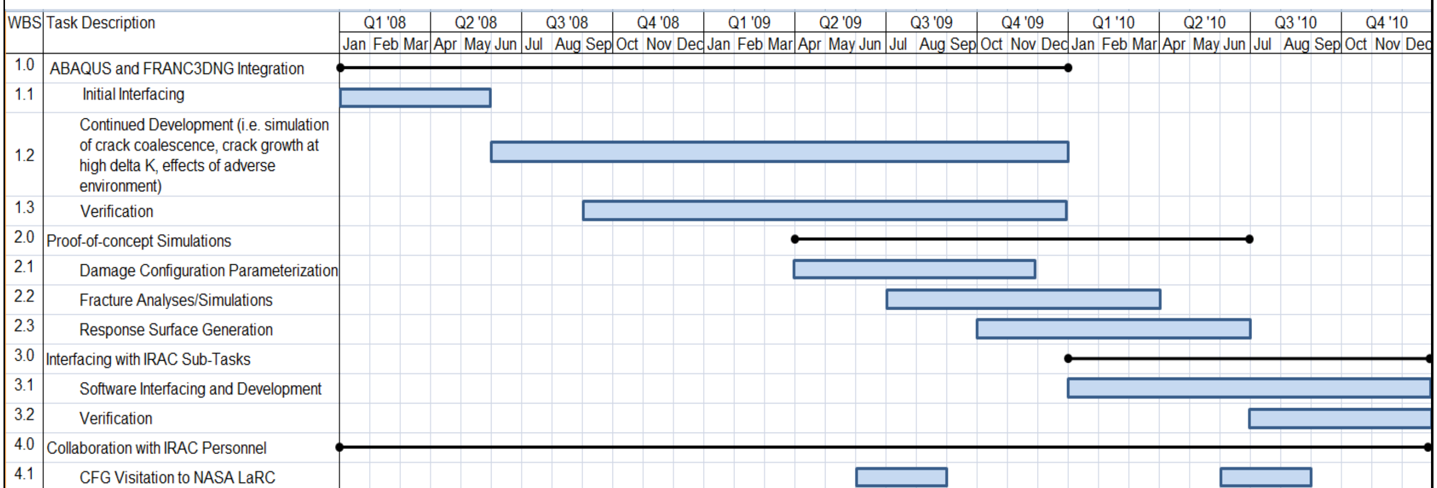
Additional Slide: Project Timeline



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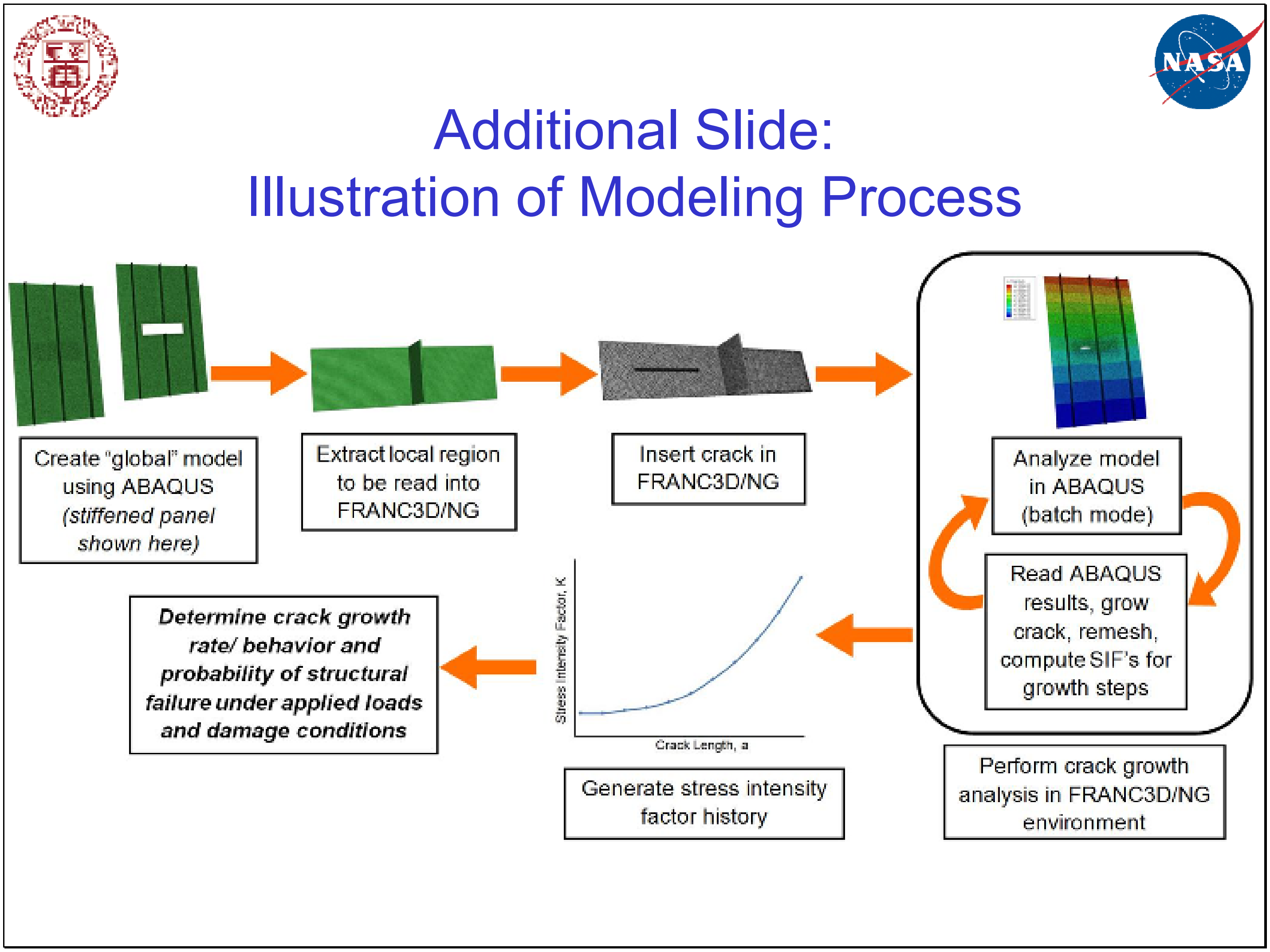

An example of the solution process is shown here. Again, we create some type of larger, global model, from which we extract a local region (shown here, an integrally stiffened wing panel). This local region is read into the F3D/NG environment where we insert damage and perform fracture growth simulations. From these simulations, we can determine how the damage will behave and affect the airframe structure.