Boeing Commercial Airplanes
Structures Engineering

Multi-scale Modeling of Airplane Structures

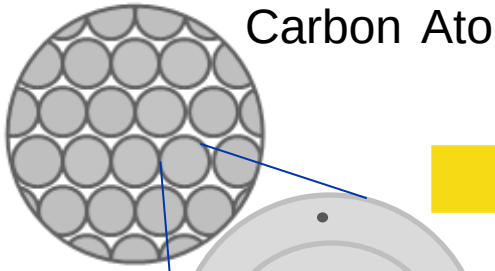
William Grosse

Boeing Commercial Airplanes

Structures Engineering

Vehicle Level Analysis & Optimization

Big Picture…



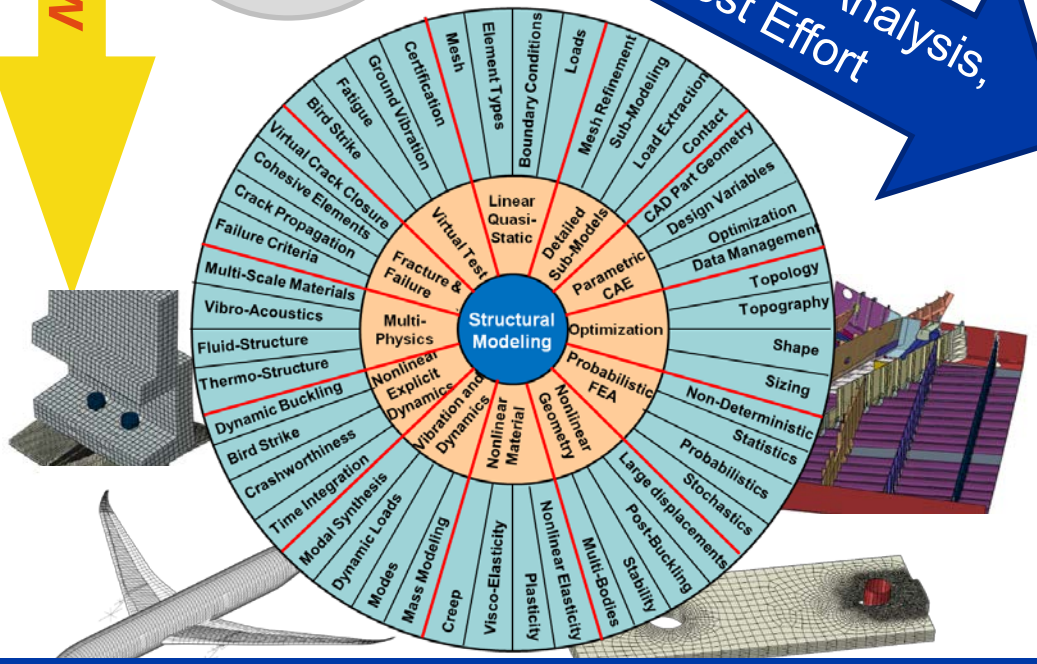
Carbon Atoms

Then

NOW

Huge Design, Analysis, & Test Effort

$$\sigma = \frac{P}{A} + \frac{Mc}{I}$$



Change driven by need to continually improve performance & enabled by technological advances in materials and computational tools

Big Picture

Structural Modeling @ Boeing

Challenges & Developments

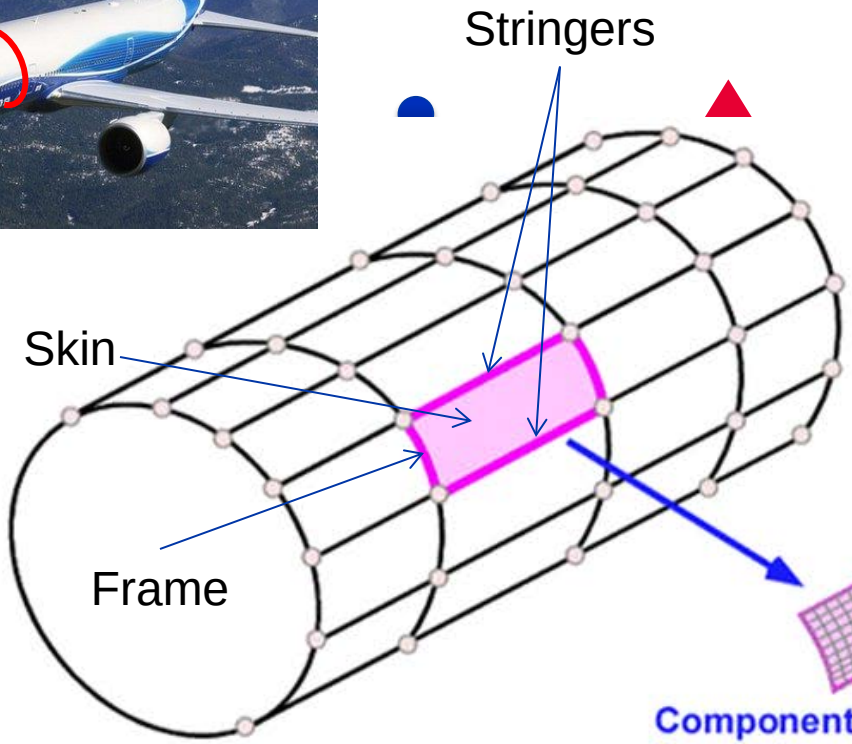
Where You Can Help

Summary

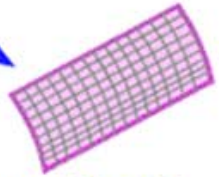
Building Blocks

Complexity of the Product Drives need for Building Block Approach:

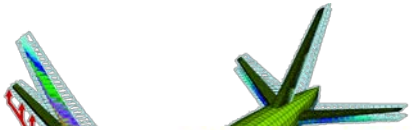
Level of Idealization



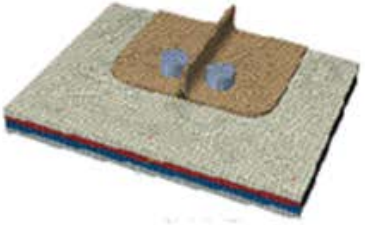
Vehicle Level Model.
Idealized, Coarse Grid.
Shells and beams.



Component Model.
Stand-alone Submodel,
Fine grid mesh assy of parts.
Applied loads come from vehicle level model results. Typically



Structural Detail Model.
Stand-alone Submodel,
Fine grid mesh assy of parts.
Applied loads come from previous submodel results.
Typically includes solids.



We utilize an interdependent hierarchy of models stretching across length scales… all of which require validation.

Simulation Requires Validation

To manufacture and deliver airplanes, Boeing must demonstrate compliance with regulatory requirements.

Airplane structural substantiation by analysis is based on loads and deflections and validated by test.

Excerpts from 14 CFR Subpart C – Structure:

25.301 Loads.

(a) **Strength requirements are specified in terms of limit loads (the maximum loads to be expected in service)** and ultimate loads (limit loads multiplied by prescribed factors of safety). Unless otherwise provided, prescribed loads are limit loads.

(c) If **deflections** under load would significantly change the distribution of external or internal loads, this redistribution must be taken into account.

25.307 Proof of structure.

(a) Compliance with the strength and deformation requirements of this subpart must be shown for each critical loading condition. Structural analysis may be used only if the structure conforms to that for which experience has shown this method to be reliable.

How does Boeing use modeling to meet the above requirements?

Validation

Structural Test	Analysis Purpose	Structural Model

Validation

Full Scale Tests

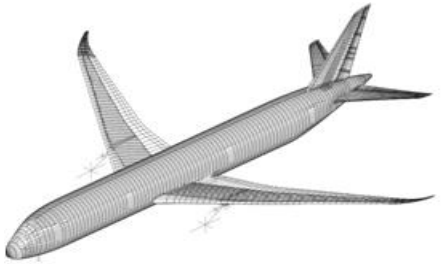
Load Path & Aeroelastic Response Validation

Global Instability

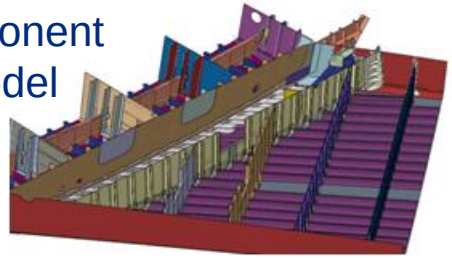
Panel Instability Dam.Tol. Analysis

Method Validation

Vehicle Model

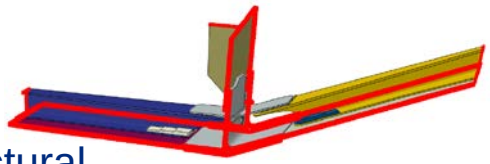


Component Model



Design Value Development

Local Instability Crippling

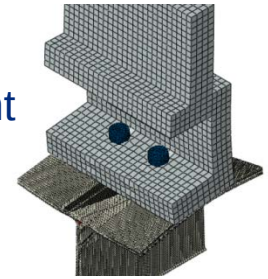


Structural Detail Model

Stiffness Allowables
Ex, Ey, Gxy, vxy, etc.

Strength Allowables
(Delam, Disbond)

Element Model



Material Development

Constituent Properties

Physical testing forms basis of methods & allowables used in analysis models. Large scale tests are then used to validate models.

Putting it All Together

Methods Development

Applicable Method Exists?

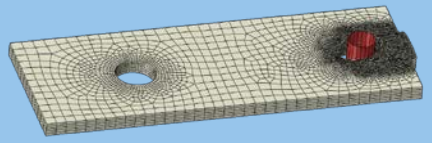
Yes

No

Develop Method

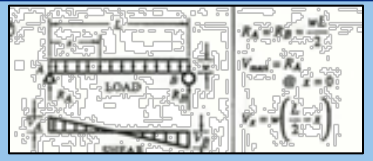
Test Plan Creation

Develop Model/Simulation



Physical Test

Validated Method



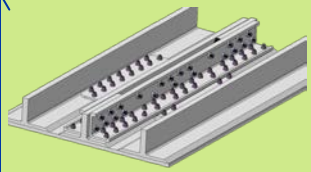
Configuration Analysis

Structural Configuration

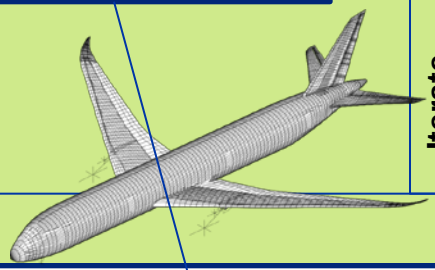
Develop Vehicle & Component Models

Develop Loads

Analyze



Iterate



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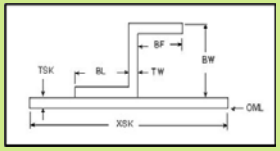


Converged?

Yes

No

Resize

Analysis Validation

Component & Full Scale Testing

Correlate?

Yes

No

Rework & Retest

Validated Analysis Models

Certification

Delivery

Big Picture

Structural Modeling @ Boeing

Challenges & Developments

Where You Can Help

Summary

Challenge

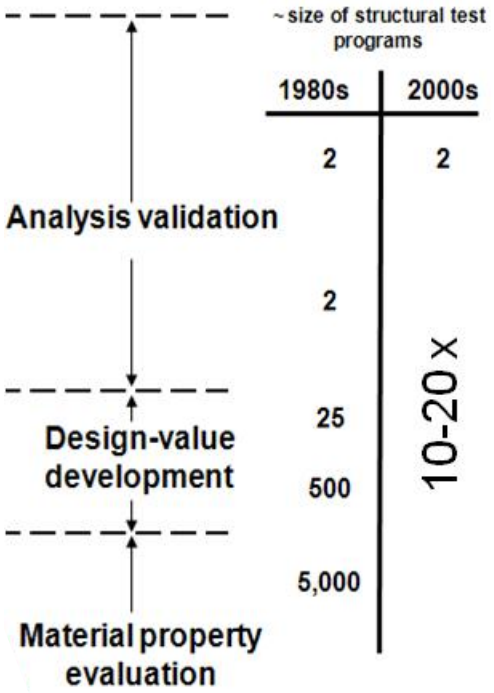
Validation

- Complexity of product has increased
- Use of modeling has grown
- Early development is feasibility focused
- Expertise development has been outpaced

Target:

Reduce risk & cost of new development

Test Program Size



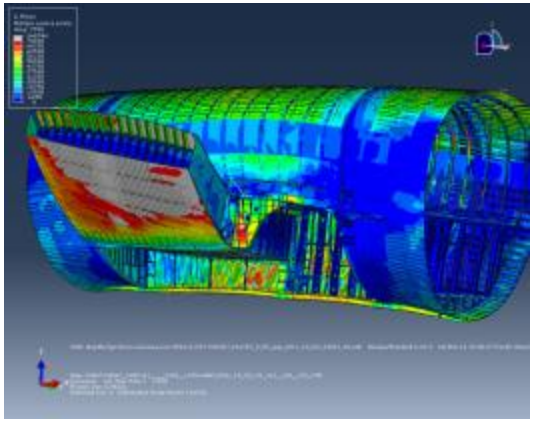
Proposal:

- Capture & transfer knowledge gained from experience
- Provide standards, tools, & oversight to ensure model quality
- Know when to use FEA versus other methods
- Use Uncertainty Analysis to inform trades & design for robustness

Expectations of modeling have grown, need to continue to develop expertise & standards.

Virtual Test

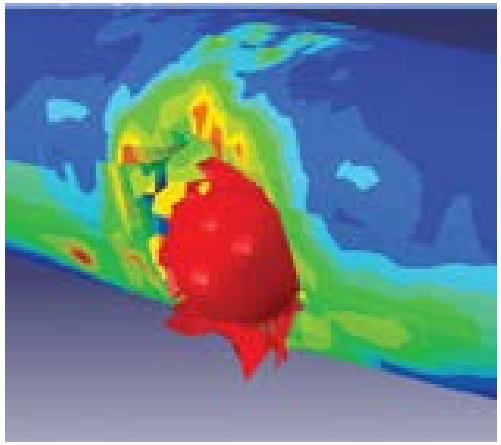
Nonlinear analysis with high fidelity geometry to simulate physical test



Benefits:

- Reduce risk prior to physical test
- Develop confidence in tools & procedures
- Reduction may be possible via validated techniques

Simulated Bird Strike



Example: Bird-strike Criteria

- FAR 25.571 requires resistance to impact of 4 pound bird
- Impact testing is expensive
- Use of real birds pose environmental concerns
- FEA may help reduce number of development strikes

Success builds confidence and enables expanded use of modeling.

Challenge

Integration

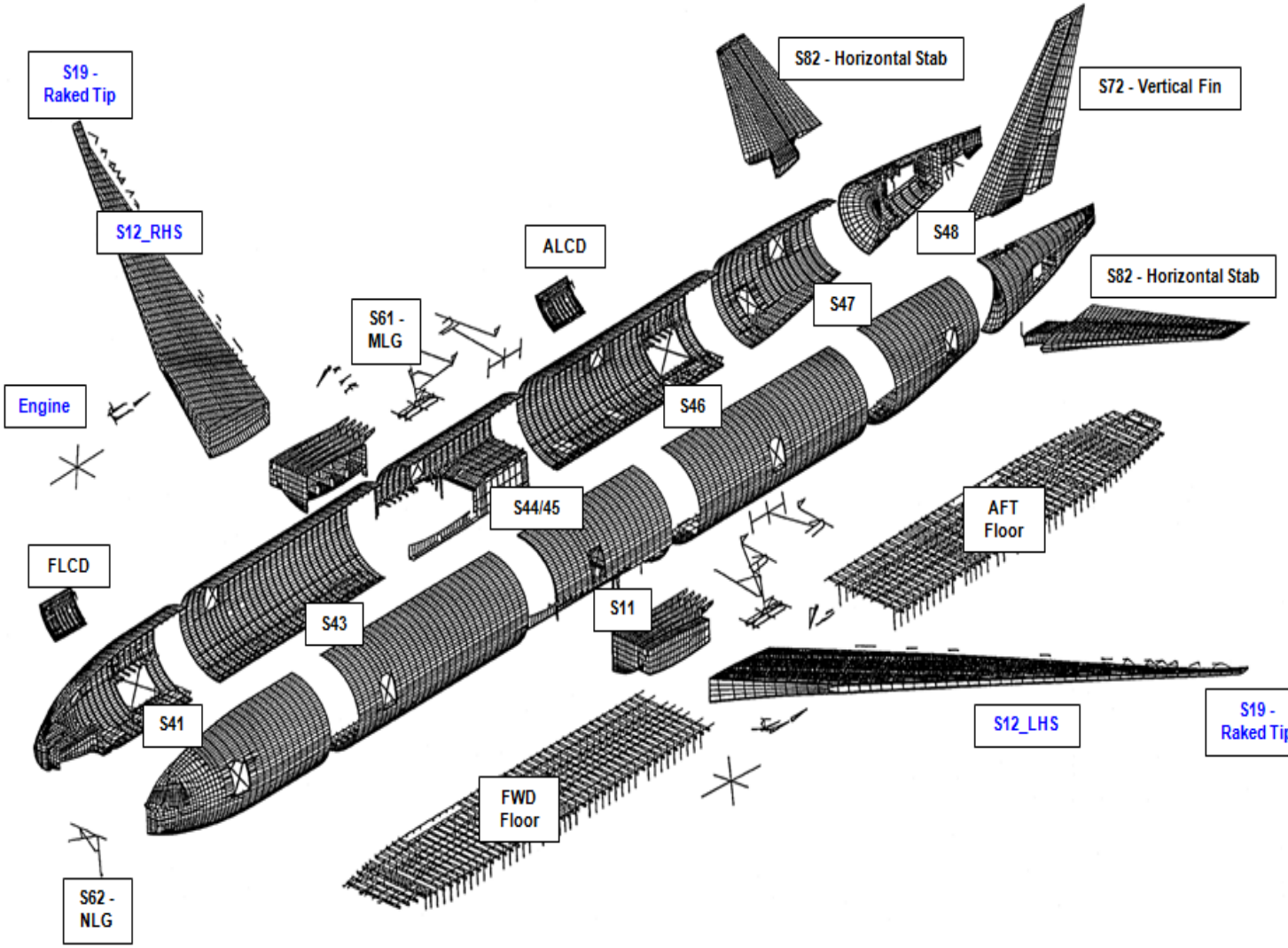
- Different abstractions of the same physical object
- Man
- Larg

How d

- Autc
- Link
- Star
  - Da

Greate

- Red
- **Glol**



eometry
tion

Right level of integration allows engineers to focus on engineering

Global Optimization

Large Scale = Entire Wing, Entire Fuselage, … Entire Plane

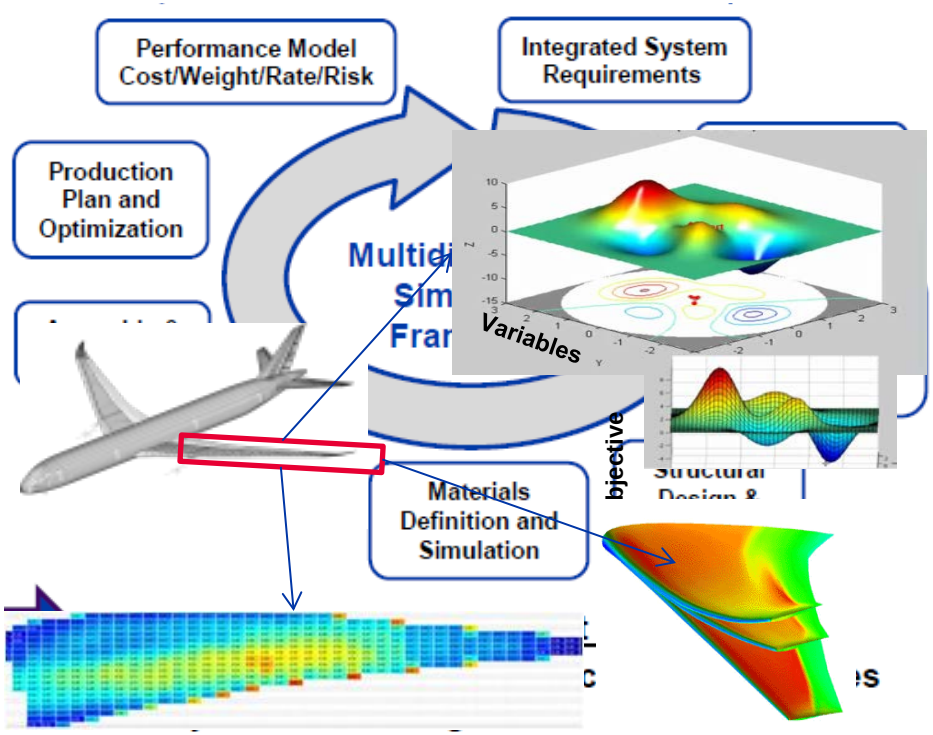
Large # of responses & design variables

Objectives:

- Weight
- Cost
- Rate

Multi-disciplinary

- Loads, Dynamics, & Flutter
- Design
- Performance
- Stability & Controls
- Manufacturing



- Robust design architecture provides rapid trade capability and risk assessment.
- Include manufacturing, and certification criteria to optimize design for weight, cost, and rate.

Not meant to give us "the answer" but are useful to increase our understanding and enable exploration of design space.

Big Picture

Structural Modeling @ Boeing

Challenges & Developments

Where You Can Help

Summary

Where you can Help

Virtual Test

- Easy and reliable methods for simulating failure mechanics

Optimization

- Robust algorithms for efficiently solving large problems
- Visualization to navigate & interrogate large data sets

Uncertainty Analysis

- Standard use in academia will help set expectations of people currently in industry and about to enter

Overview

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Summary

Summary

Multi-Scale Structural Modeling is an Essential Tool for Boeing

- Can't test everything, so we need to model.
- Standardization, best practices & judicious use are essential.
- Validation tests are critical, but simulation can help reduce risk & #.
- Better integration enables engineers to focus on engineering.
- Optimization is key to design space exploration & expansion.