

An Introduction to X-Analysis Integration (XAI)

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Georgia Tech

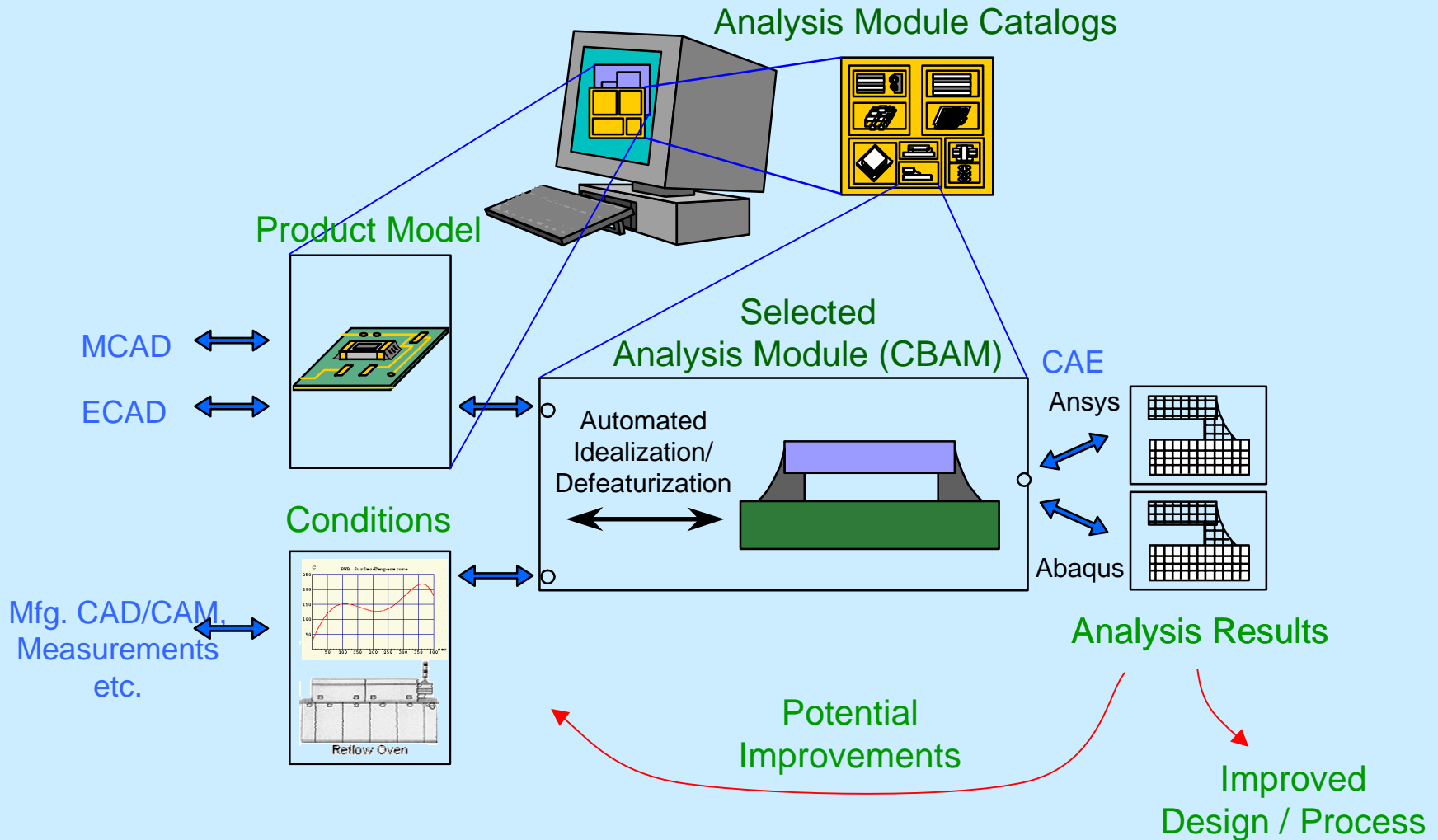
Engineering Information Systems Lab

eislabs.gatech.edu

Outline

- ◆ Analysis Integration Challenges
- ◆ Introduction to Constrained Objects (COBs)
- ◆ Overview of COB-based XAI
- ◆ Example Applications
 - ◆ Electronic Packaging Thermomechanical Analysis
 - ◆ Aerospace Structural Analysis
- ◆ Summary

Analysis Integration Thrust



X-Analysis Integration

(X=Design, Mfg., etc.)

◆ Goal:

Improve product engineering processes by integrating analysis models with other life cycle models

◆ Challenges:

- Heterogeneous Transformations
- Diversity: CAD/CAM/CAX Models, Disciplines, Fidelity, Tools, etc.

◆ One Approach:

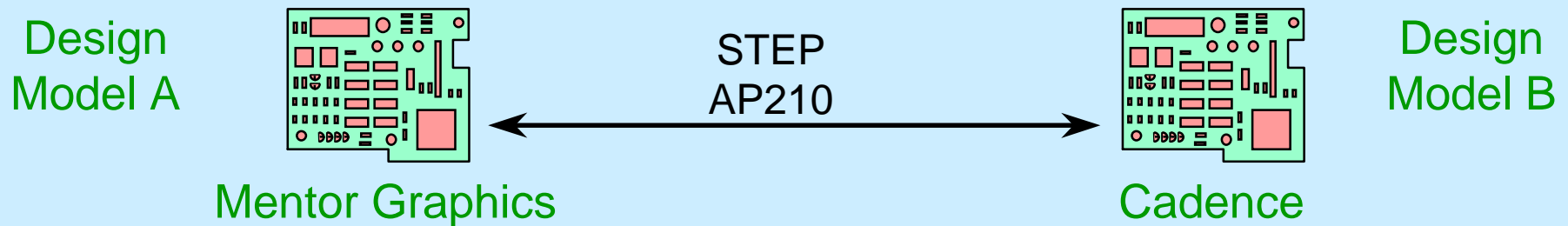
The Multi-Representation Architecture (MRA)

◆ Initial Focus:

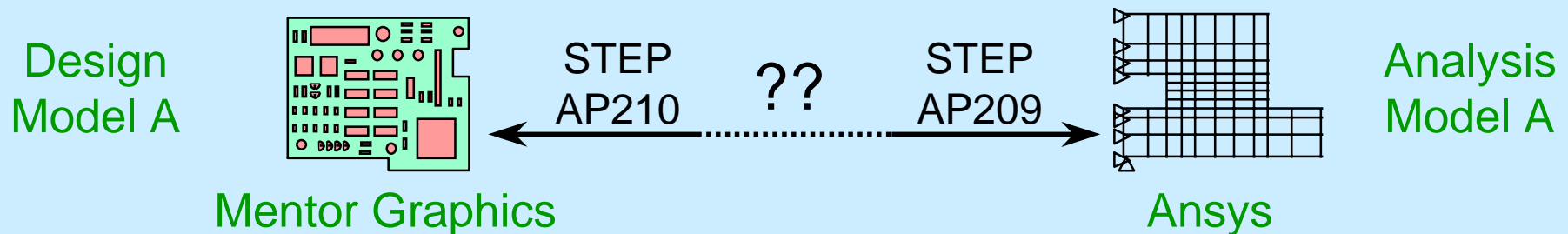
Automation of routine analysis for design

Analysis Integration Challenges: Heterogeneous Transformations

◆ Homogeneous Transformation



◆ Heterogeneous Transformation

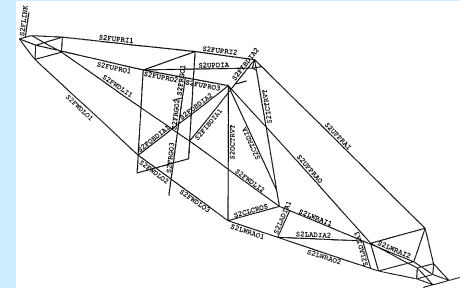


Multifidelity Analysis

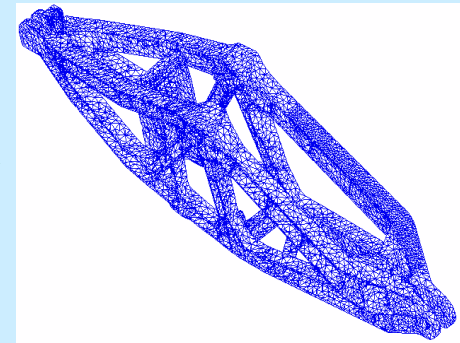
Design Model (MCAD)

Analysis Models (MCAE)

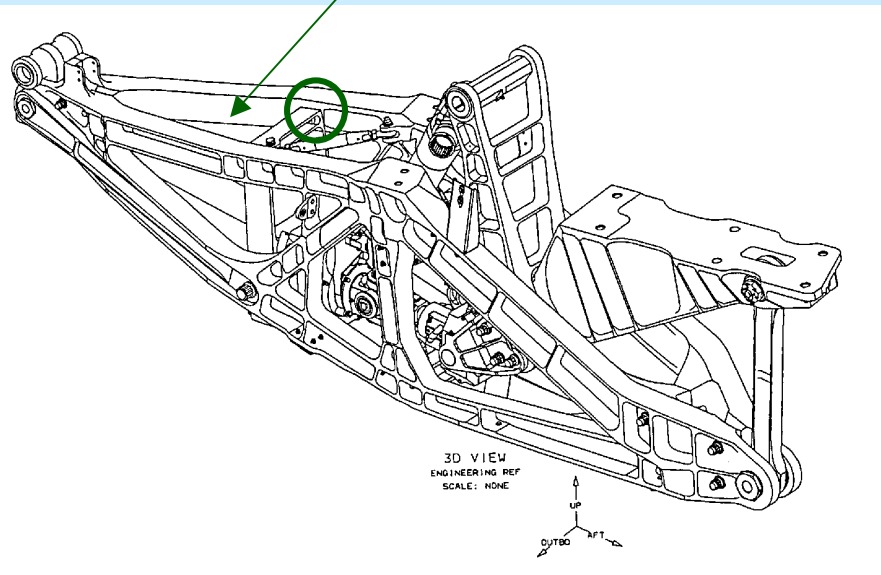
1D Beam/Stick Model



3D Continuum/Brick Model

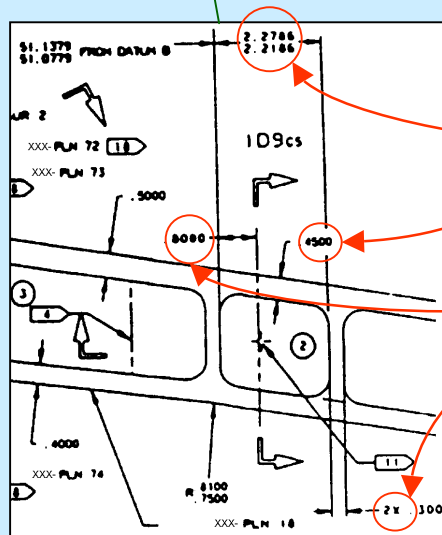
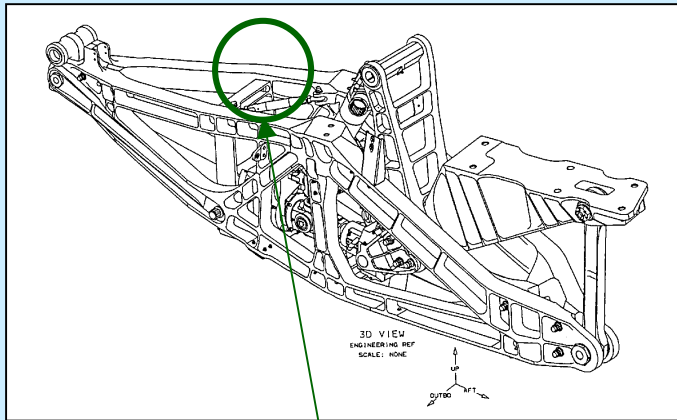


flap support assembly inboard beam



Design Geometry - Analysis Geometry Mismatch

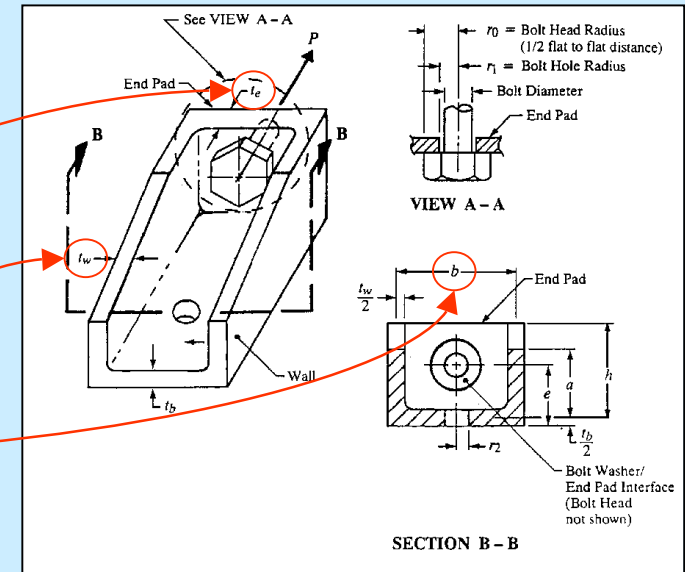
Detailed Design Model



Γ

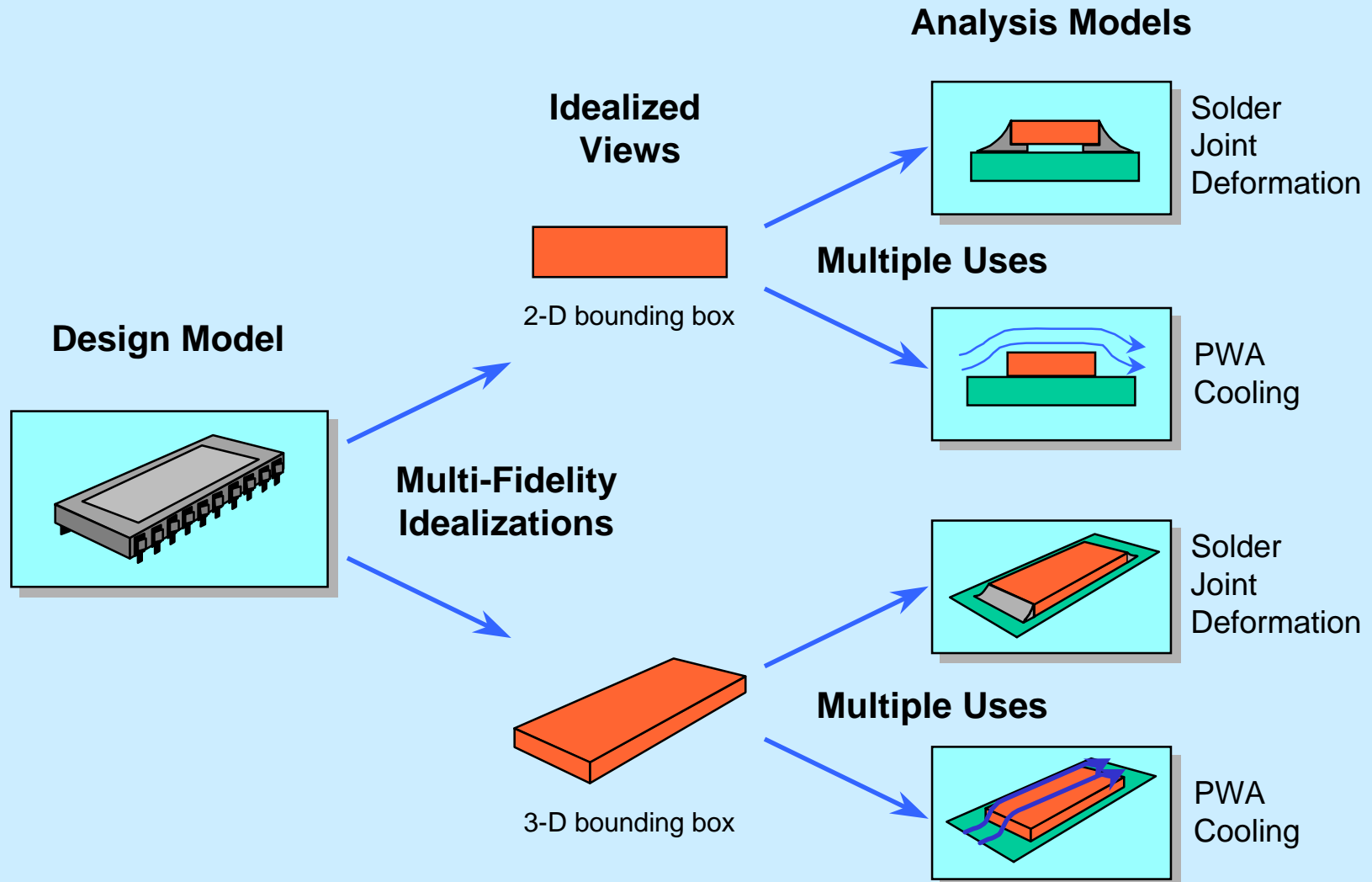
Idealizations

Analysis Model
(with Idealized Features)



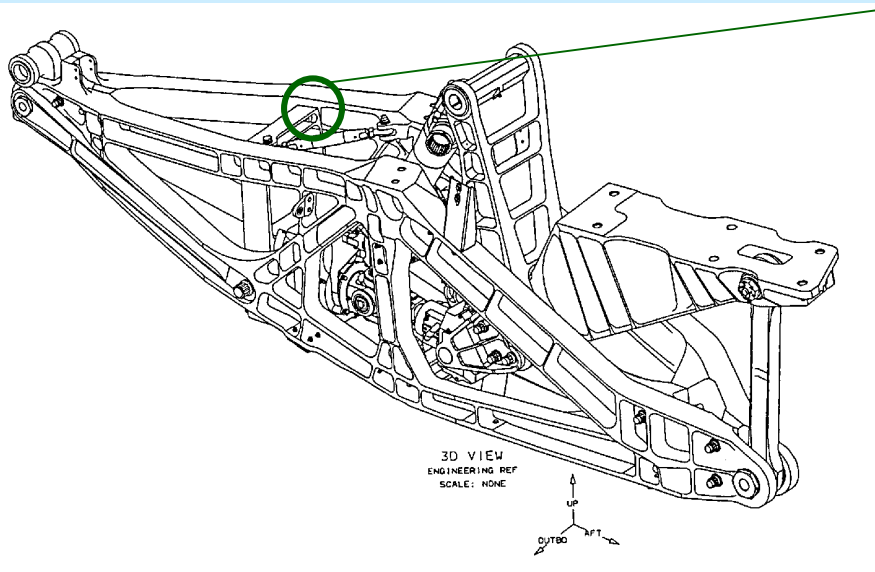
Tension Fitting Analysis

Multi-Fidelity, Multi-Usage Idealizations



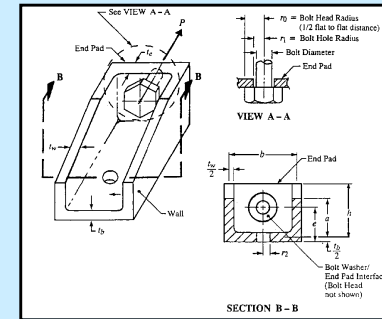
Multilevel Analysis

Design Model (MCAD)

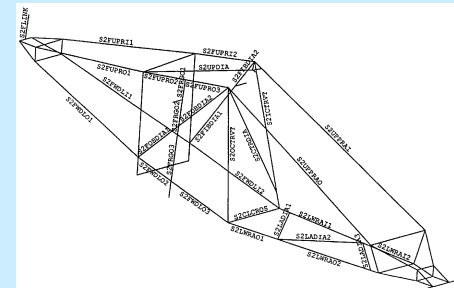


Analysis Models (MCAE)

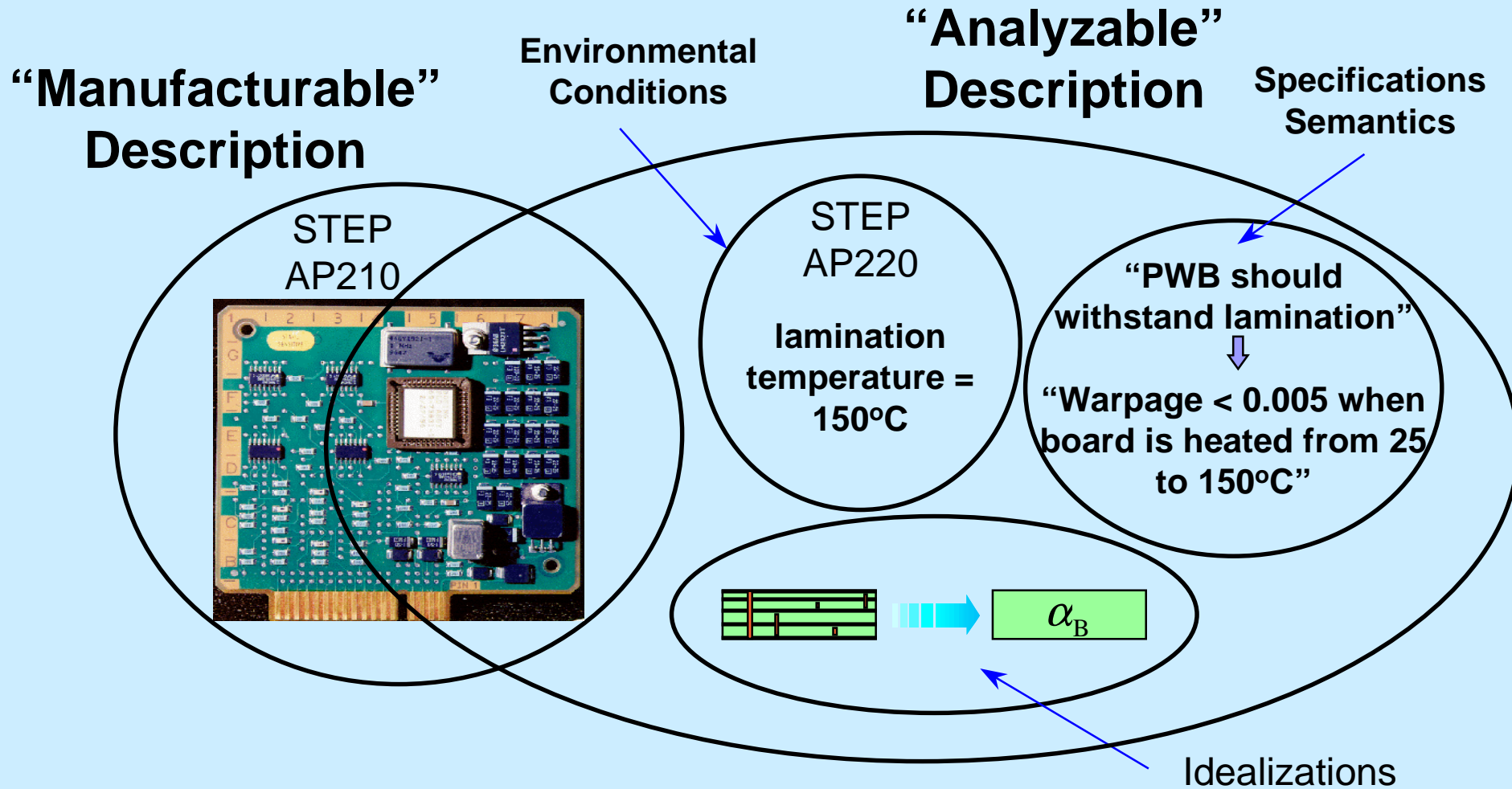
Part Feature Level Model



Assembly Level Model



Analysis Integration Challenges: Information Diversity



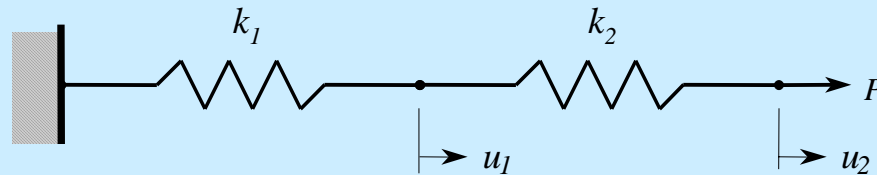
Outline

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- ◆ Introduction to Constrained Objects (COBs) ←
- ◆ Overview of COB-based XAI
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 - ◆ Aerospace Structural Analysis
- ◆ Summary

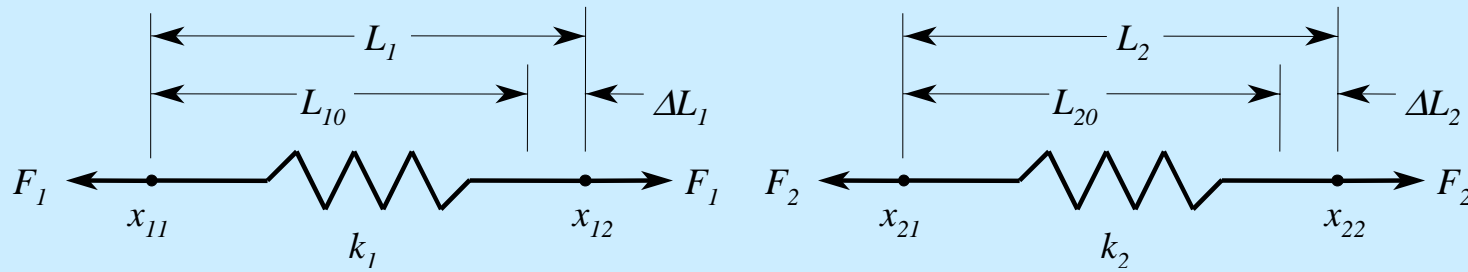
Traditional Mathematical Representation

Two Spring System

System Figure



Free Body Diagrams



Variables and Relations

Kinematic Relations

$$r_{11} : L_1 = x_{12} - x_{11}$$

$$r_{12} : \Delta L_1 = L_1 - L_{10}$$

$$r_{13} : F_1 = k_1 \Delta L_1$$

$$r_{21} : L_2 = x_{22} - x_{21}$$

$$r_{22} : \Delta L_2 = L_2 - L_{20}$$

$$r_{23} : F_2 = k_2 \Delta L_2$$

$$bc_1 : x_{11} = 0$$

$$bc_2 : x_{12} = x_{21}$$

$$bc_3 : F_1 = F_2$$

$$bc_4 : F_2 = P$$

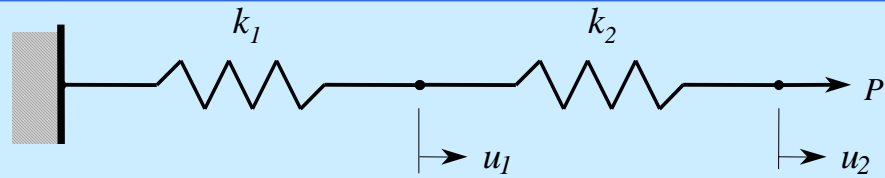
$$bc_5 : u_1 = \Delta L_1$$

$$bc_6 : u_2 = \Delta L_2 + u_1$$

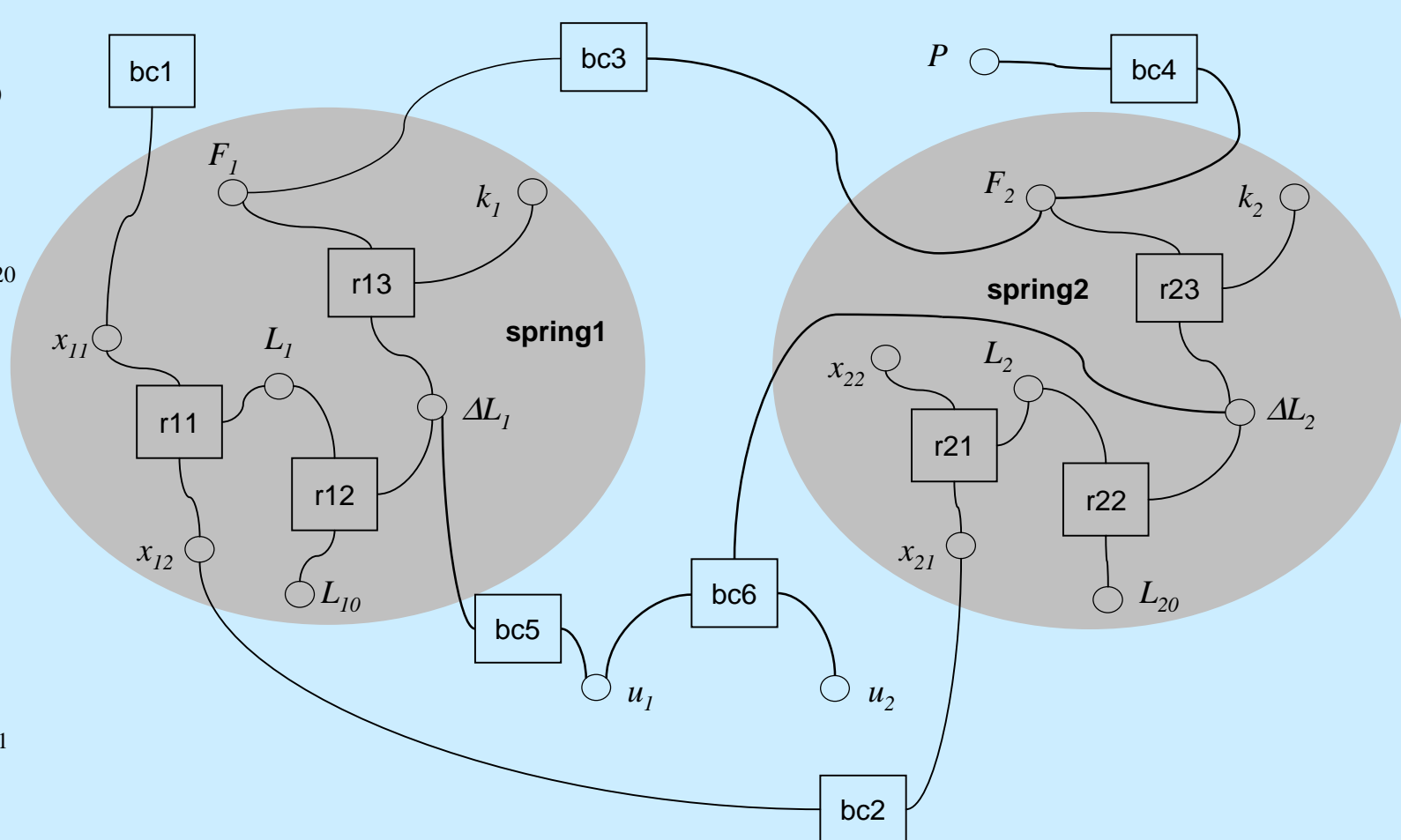
Boundary Conditions

Constraint Graph

Two Spring System

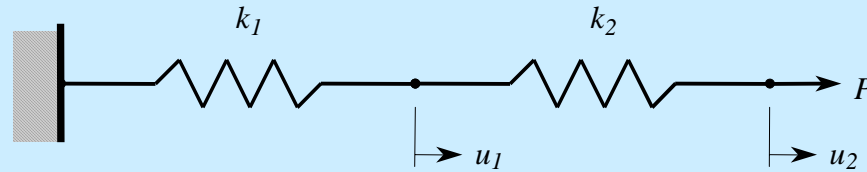


- $r_{11} : L_1 = x_{12} - x_{11}$
- $r_{12} : \Delta L_1 = L_1 - L_{10}$
- $r_{13} : F_1 = k_1 \Delta L_1$
- $r_{21} : L_2 = x_{22} - x_{21}$
- $r_{22} : \Delta L_2 = L_2 - L_{20}$
- $r_{23} : F_2 = k_2 \Delta L_2$
- $bc_1 : x_{11} = 0$
- $bc_2 : x_{12} = x_{21}$
- $bc_3 : F_1 = F_2$
- $bc_4 : F_2 = P$
- $bc_5 : u_1 = \Delta L_1$
- $bc_6 : u_2 = \Delta L_2 + u_1$



COB Constraint Schematic

Two Spring System



*Analysis Primitives
with
Encapsulated Relations*

$$r_{11} : L_1 = x_{12} - x_{11}$$

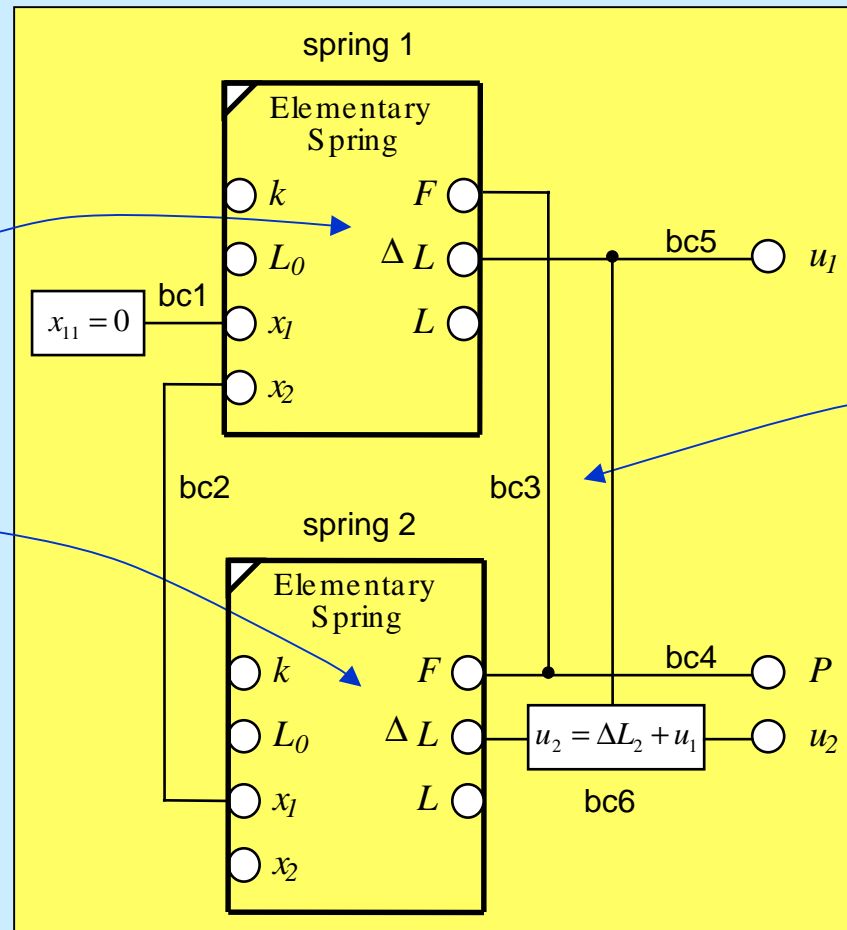
$$r_{12} : \Delta L_1 = L_1 - L_{10}$$

$$r_{13} : F_1 = k_1 \Delta L_1$$

$$r_{21} : L_2 = x_{22} - x_{21}$$

$$r_{22} : \Delta L_2 = L_2 - L_{20}$$

$$r_{23} : F_2 = k_2 \Delta L_2$$



*System-Level Relations
(Boundary Conditions)*

$$bc_1 : x_{11} = 0$$

$$bc_2 : x_{12} = x_{21}$$

$$bc_3 : F_1 = F_2$$

$$bc_4 : F_2 = P$$

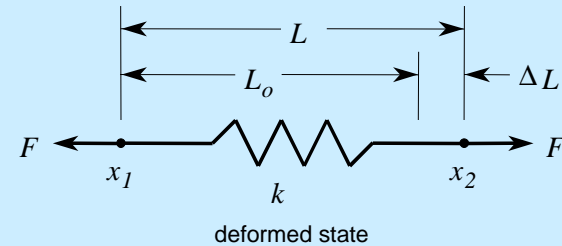
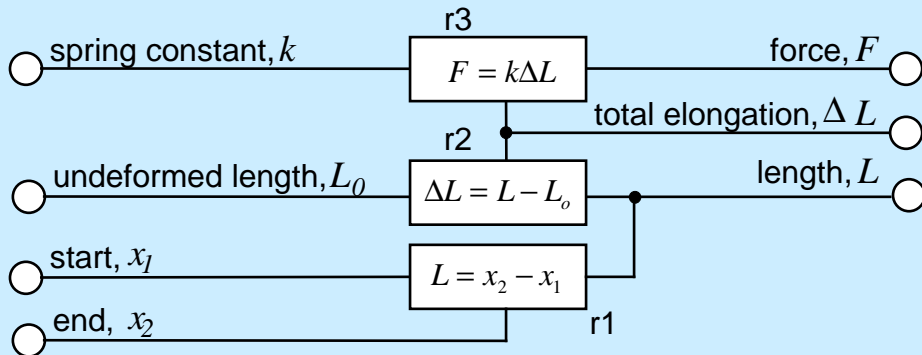
$$bc_5 : u_1 = \Delta L_1$$

$$bc_6 : u_2 = \Delta L_2 + u_1$$

COB Structure: Graphical Forms

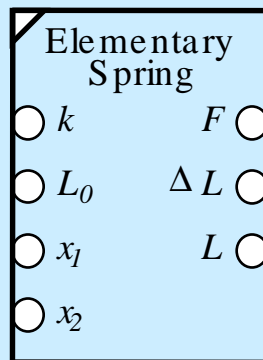
Spring Primitive

Constraint Schematic



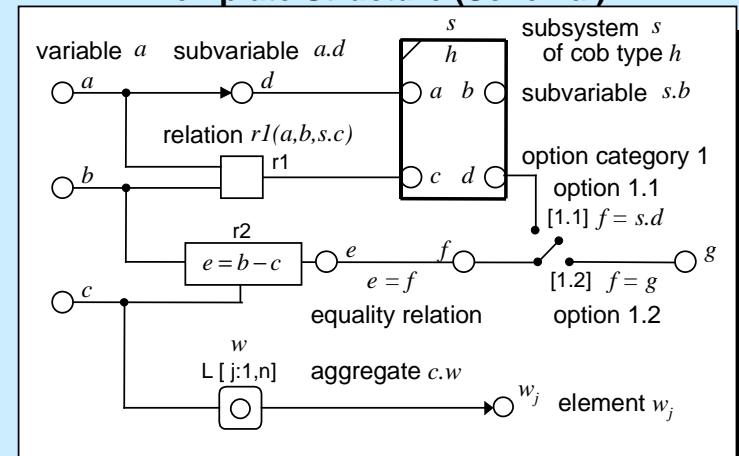
Subsystem View

(for reuse by other COBs)



Basic Constraint Schematic Notation

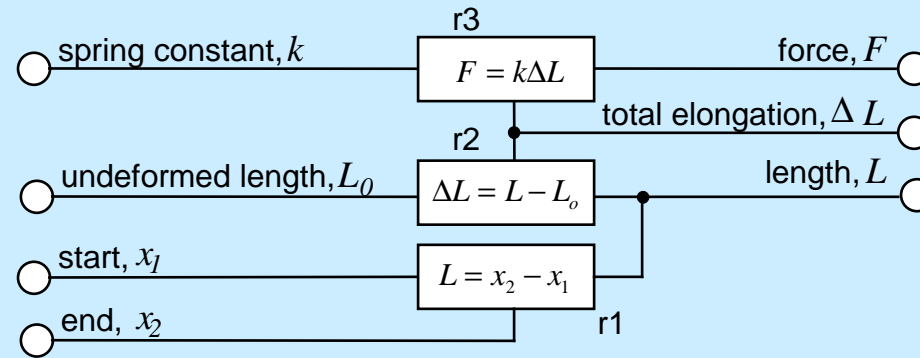
Template Structure (Schema)



COB Structure: Lexical Form

Spring Primitive

Constraint Schematic



Lexical COB Schema Template

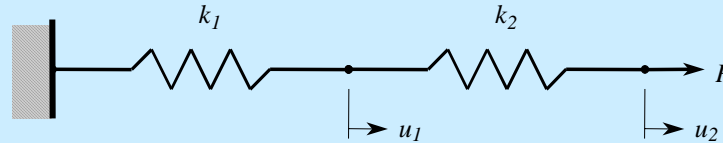
```

COB spring SUBTYPE_OF abb;
  undeformed_length, L<sub>0</sub> : REAL;
  spring_constant, k : REAL;
  start, x<sub>1</sub> : REAL;
  end, x<sub>2</sub> : REAL;
  length, L : REAL;
  total_elongation, &Delta;L : REAL;
  force, F : REAL;
RELATIONS
  r1 : "<length> == <end> - <start>";
  r2 : "<total_elongation> == <length> - <undeformed_length>";
  r3 : "<force> == <spring_constant> * <total_elongation>";
END_COB;

```

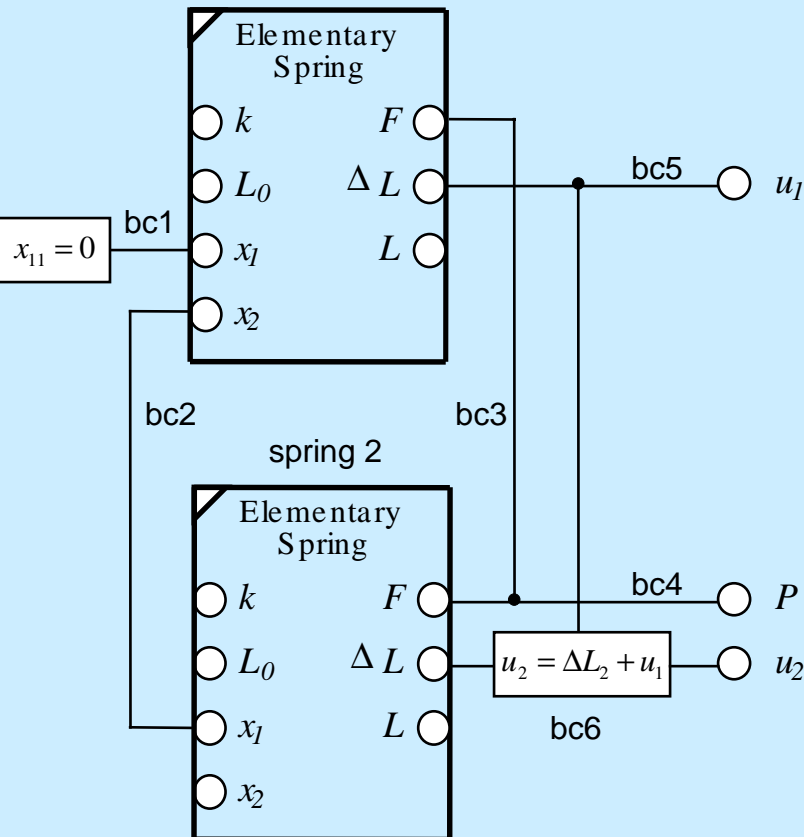

COBs as Building Blocks

Two Spring System



Constraint Schematic

spring 1



Lexical COB Schema Template

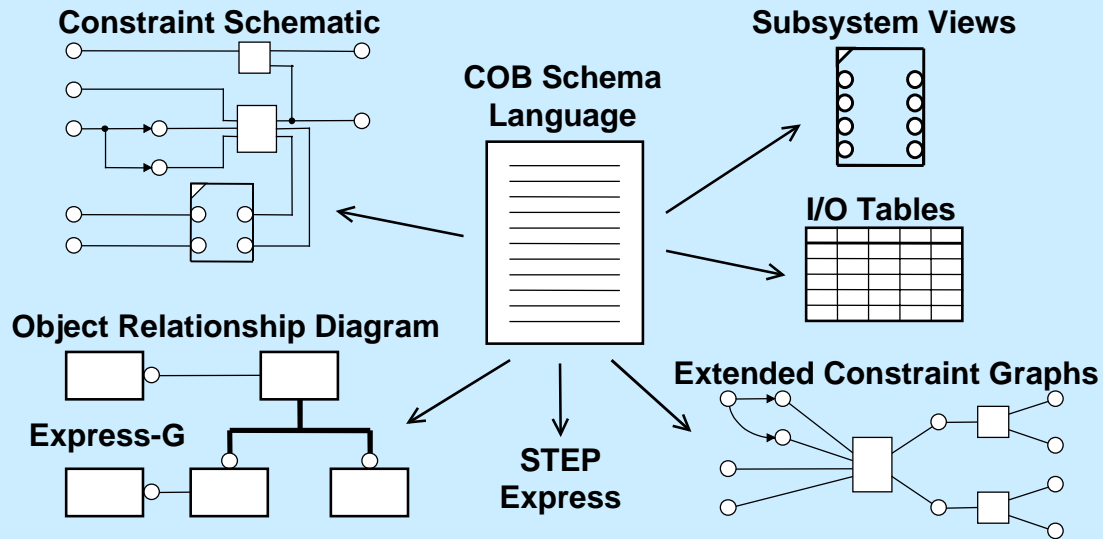
```

COB spring_system SUBTYPE_OF analysis_system;
spring1 : spring;
spring2 : spring;
deformation1, u<sub>1</sub> : REAL;
deformation2, u<sub>2</sub> : REAL;
load, P : REAL;

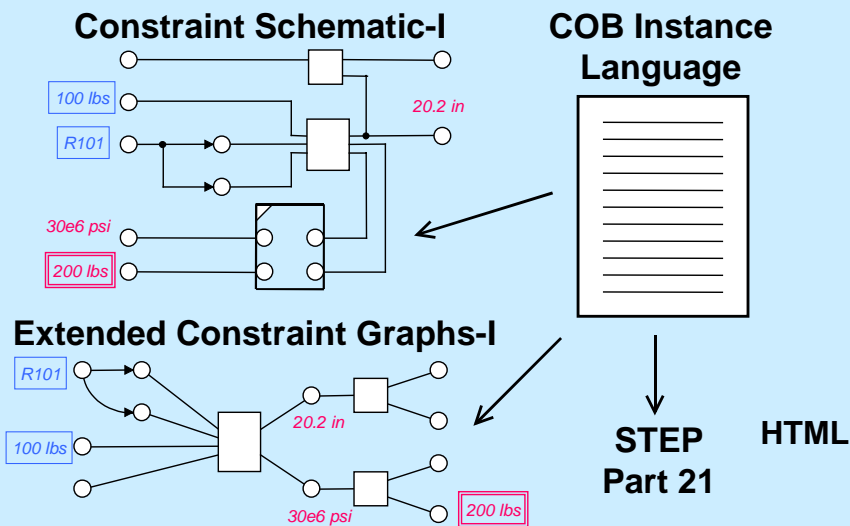
RELATIONS
bc1 : "<spring1.start> == 0.0";
bc2 : "<spring1.end> == <spring2.start>";
bc3 : "<spring1.force> == <spring2.force>";
bc4 : "<spring2.force> == <load>";
bc5 : "<deformation1> == <spring1.total_elongation>";
bc6 : "<deformation2> == <spring2.total_elongation>
      + <deformation1>";

END_COB;
    
```

COB Modeling Views



HTML

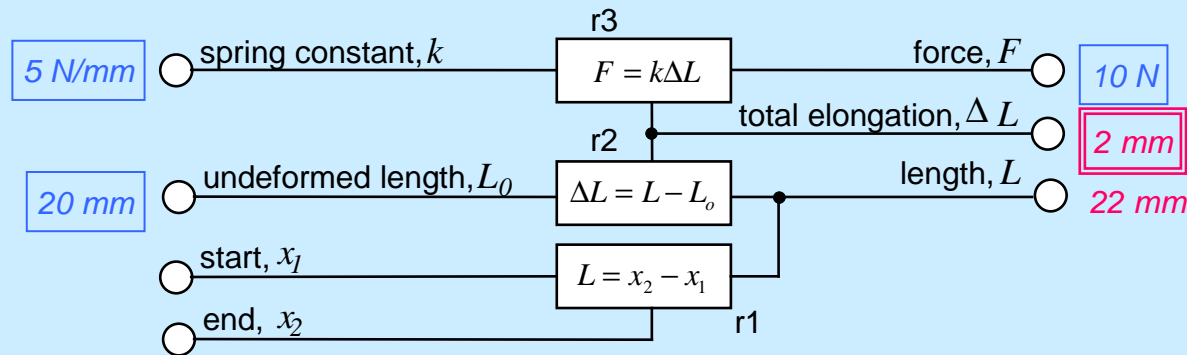


Example COB Instance

Spring Primitive

Constraint Schematic Instance Views

example 1, state 1



Lexical COB Instances

input:

```

INSTANCE_OF spring;
    undeformed_length : 20.0;
    spring_constant : 5.0;
    start : ?;
    end : ?;
    length : ?;
    total_elongation : ?;
    force : 10.0;
END_INSTANCE;
    
```

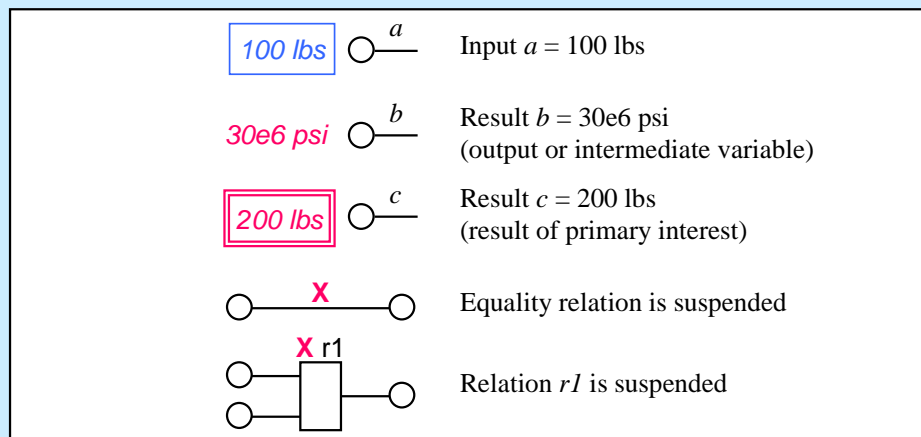
result (reconciled):

```

INSTANCE_OF spring;
    undeformed_length : 20.0;
    spring_constant : 5.0;
    start : ?;
    end : ?;
    length : 22.0;
    total_elongation : 2.0;
    force : 10.0;
END_INSTANCE;
    
```

Basic Constraint Schematic Notation

Instances

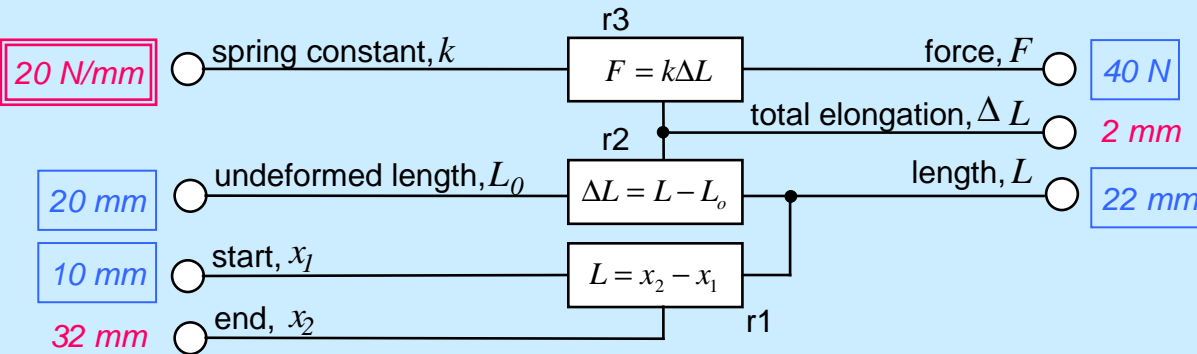


Multidirectional I/O

Spring Primitive

Constraint Schematic Instance View

example 1, state 5



Lexical COB Instance

input:

```

INSTANCE_OF spring;
  undeformed_length : 20.0;
  spring_constant : ?;
  start : 10.0;
  end : ?;
  length : 22.0;
  total_elongation : ?;
  force : 40.0;
END_INSTANCE;
  
```

result:

```

INSTANCE_OF spring;
  undeformed_length : 20.0;
  spring_constant : 20.0;
  start : 10.0;
  end : 32.0;
  length : 22.0;
  total_elongation : 2.0;
  force : 40.0;
END_INSTANCE;
  
```

Spring Examples Implemented in *XaiTools* X-Analysis Integration Toolkit

spring

Name	Symbol	Type	Input	Values
root		spring		
undeformed_length	$L_{₀}$	REAL	Input	20
spring_constant	k	REAL	Input	5
start	$x_{₁}$	REAL	Output	No value
end0	$x_{₂}$	REAL	Output	No value
length	L	REAL	Output	22
total_elongation	ΔL	REAL	Output	2
force	F	REAL	Input	10

Solve

root (spring)

Name	Local	Oneway	Relation	Active
r1	Y		$\langle \text{length} \rangle == \langle \text{end0} \rangle - \langle \text{start} \rangle$	<input checked="" type="checkbox"/>
r2	Y		$\langle \text{total_elongation} \rangle == \langle \text{length} \rangle - \langle \text{undeformed_length} \rangle$	<input checked="" type="checkbox"/>
r3	Y		$\langle \text{force} \rangle == \langle \text{spring_constant} \rangle * \langle \text{total_elongation} \rangle$	<input checked="" type="checkbox"/>

spring_system

Name	Symbol	Type	Input	Values
root		spring_system		
spring1		spring		
undeformed_length	$L_{₀}$	REAL	Input	8
spring_constant	k	REAL	Input	5
start	$x_{₁}$	REAL	Output	0
end0	$x_{₂}$	REAL	Output	10
length	L	REAL	Output	10
total_elongation	ΔL	REAL	Output	2
force	F	REAL	Output	10
spring2		spring		
undeformed_length	$L_{₀}$	REAL	Input	8
spring_constant	k	REAL	Input	20
start	$x_{₁}$	REAL	Output	10
end0	$x_{₂}$	REAL	Output	18.5
length	L	REAL	Output	8.5
total_elongation	ΔL	REAL	Output	0.5
force	F	REAL	Output	10
deformation1	$u_{₁}$	REAL	Output	2
deformation2	$u_{₂}$	REAL	Output	2.5
load	P	REAL	Input	10

Solve

root (spring_system)

Name	Local	Oneway	Relation	Active
r1	Y		$\langle \text{spring1.start} \rangle == 0.0$	<input checked="" type="checkbox"/>
r2	Y		$\langle \text{spring1.end0} \rangle == \langle \text{spring2.start} \rangle$	<input checked="" type="checkbox"/>
r3	Y		$\langle \text{spring1.force} \rangle == \langle \text{spring2.force} \rangle$	<input checked="" type="checkbox"/>
r4	Y		$\langle \text{spring2.force} \rangle == \langle \text{load} \rangle$	<input checked="" type="checkbox"/>
r5	Y		$\langle \text{deformation1} \rangle == \langle \text{spring1.total_elongation} \rangle$	<input checked="" type="checkbox"/>
r6	Y		$\langle \text{deformation2} \rangle == \langle \text{spring2.total_elongation} \rangle + \langle \text{deformation1} \rangle$	<input checked="" type="checkbox"/>

spring

Name	Symbol	Type	Input	Values
root		spring		
undeformed_length	$L_{₀}$	REAL	Input	20
spring_constant	k	REAL	Output	20
start	$x_{₁}$	REAL	Input	10
end0	$x_{₂}$	REAL	Output	32
length	L	REAL	Input	22
total_elongation	ΔL	REAL	Output	2
force	F	REAL	Input	40

Solve

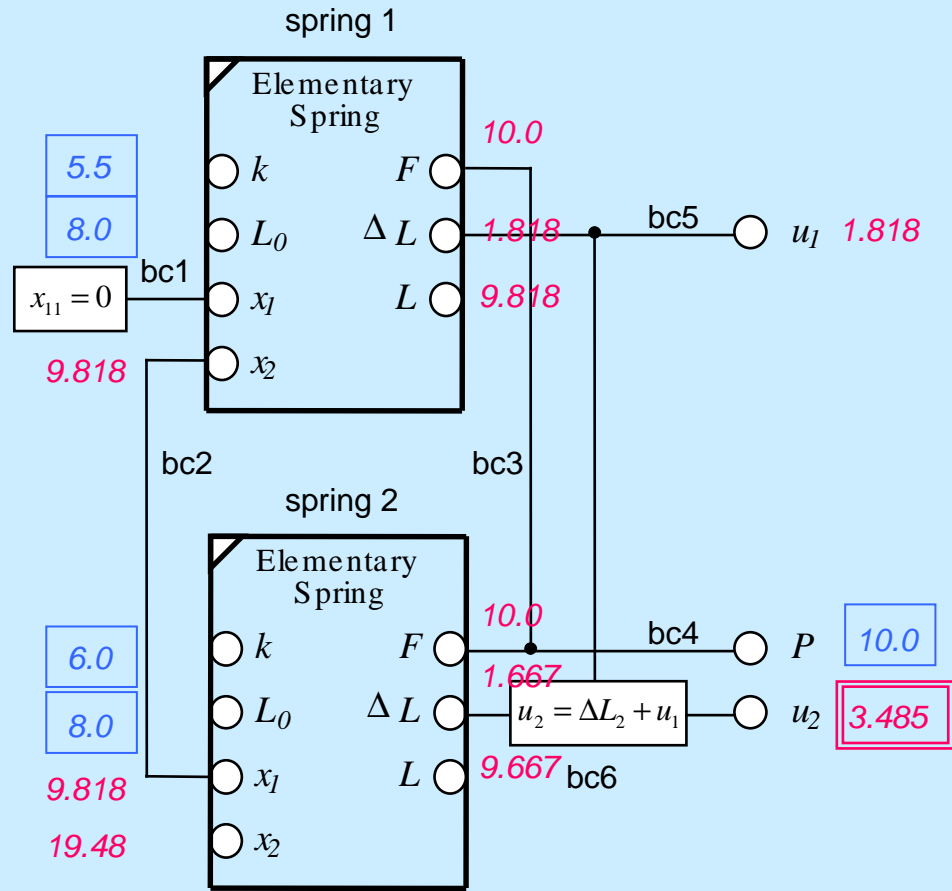
root (spring)

Name	Local	Oneway	Relation	Active
r1	Y		$\langle \text{length} \rangle == \langle \text{end0} \rangle - \langle \text{start} \rangle$	<input checked="" type="checkbox"/>
r2	Y		$\langle \text{total_elongation} \rangle == \langle \text{length} \rangle - \langle \text{undeformed_length} \rangle$	<input checked="" type="checkbox"/>
r3	Y		$\langle \text{force} \rangle == \langle \text{spring_constant} \rangle * \langle \text{total_elongation} \rangle$	<input checked="" type="checkbox"/>

Analysis System Instance

Two Spring System

Constraint Schematic Instance View



Lexical COB Instance

input:

```

INSTANCE_OF spring_system;
    spring1.undeformed_length : 8.0;
    spring1.spring_constant : 5.5;
    spring2.undeformed_length : 8.0;
    spring2.spring_constant : 6.0;
    load : 10.0;
END_INSTANCE;

```

result:

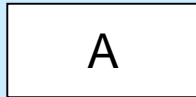
```

INSTANCE_OF spring_system;
    spring1.undeformed_length : 8.0;
    spring1.spring_constant : 5.5;
    spring1.start : 0.0;
    spring1.end0 : 9.81818181818182;
    spring1.force : 10.0;
    spring1.total_elongation : 1.818181818181818;
    spring1.length : 9.81818181818182;
    spring2.undeformed_length : 8.0;
    spring2.spring_constant : 6.0;
    spring2.start : 9.81818181818182;
    spring2.force : 10.0;
    spring2.total_elongation : 1.6666666666666666;
    spring2.length : 9.666666666666667;
    spring2.end0 : 19.48484848484848;
    load : 10.0;
    deformation1 : 1.818181818181818;
    deformation2 : 3.484848484848484;

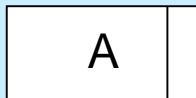
```

END_INSTANCE;

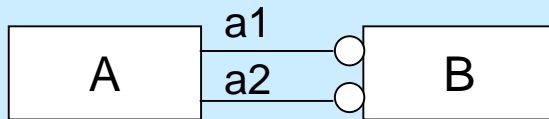
Basic EXPRESS-G notation



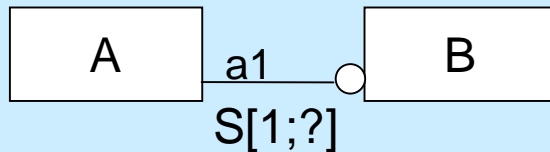
A is an entity (class)
Instance of A are objects



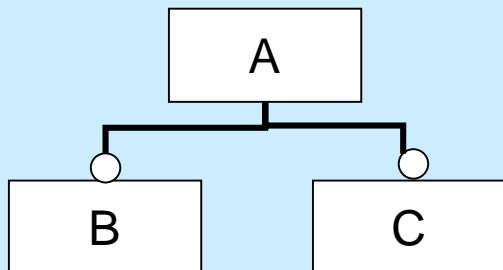
A is a simple type
(BOOLEAN, LOGICAL, BINARY,
NUMBER, INTEGER, REAL, STRING)



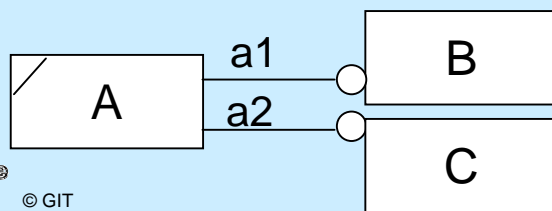
A has two attribute, a1 and a2, that
are both type B



A has an attribute, a1, that is
a Set of 1 or ore entities of type B

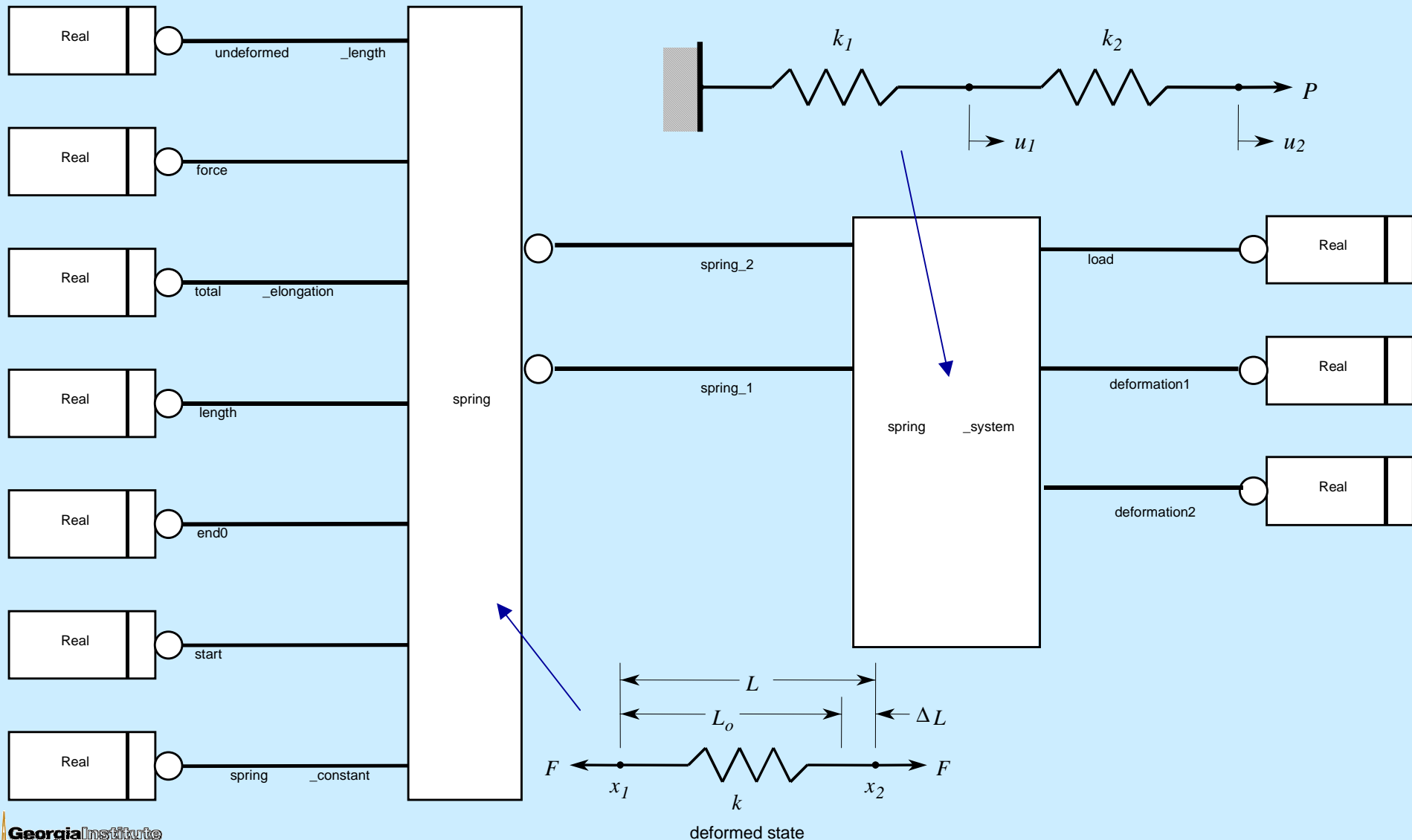


A is a supertype of B and C.
(B and C are subtype of A)



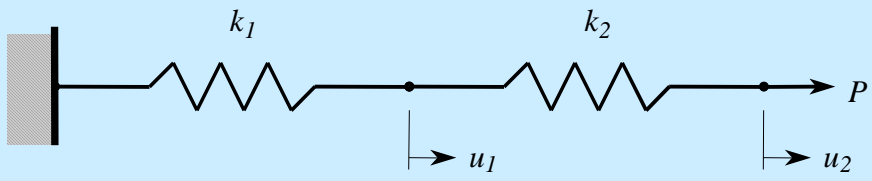
Unofficial extensions:
A has two levels, a1 and a2.
a1 is type B. a2 is type C.

COB Object Model View (EXPRESS-G) Spring Schema



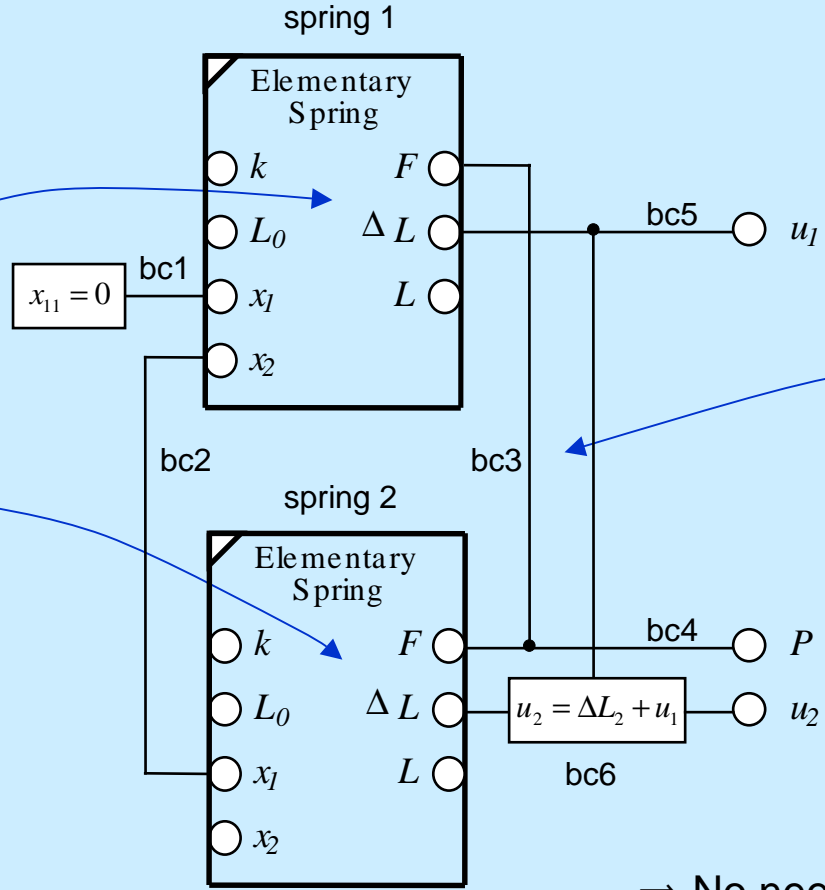
Declarative Knowledge / Derivable Behavior

Two Spring System



$r_{11} : L_1 = x_{12} - x_{11}$
 $r_{12} : \Delta L_1 = L_1 - L_{10}$
 $r_{13} : F_1 = k_1 \Delta L_1$

$r_{21} : L_2 = x_{22} - x_{21}$
 $r_{22} : \Delta L_2 = L_2 - L_{20}$
 $r_{23} : F_2 = k_2 \Delta L_2$



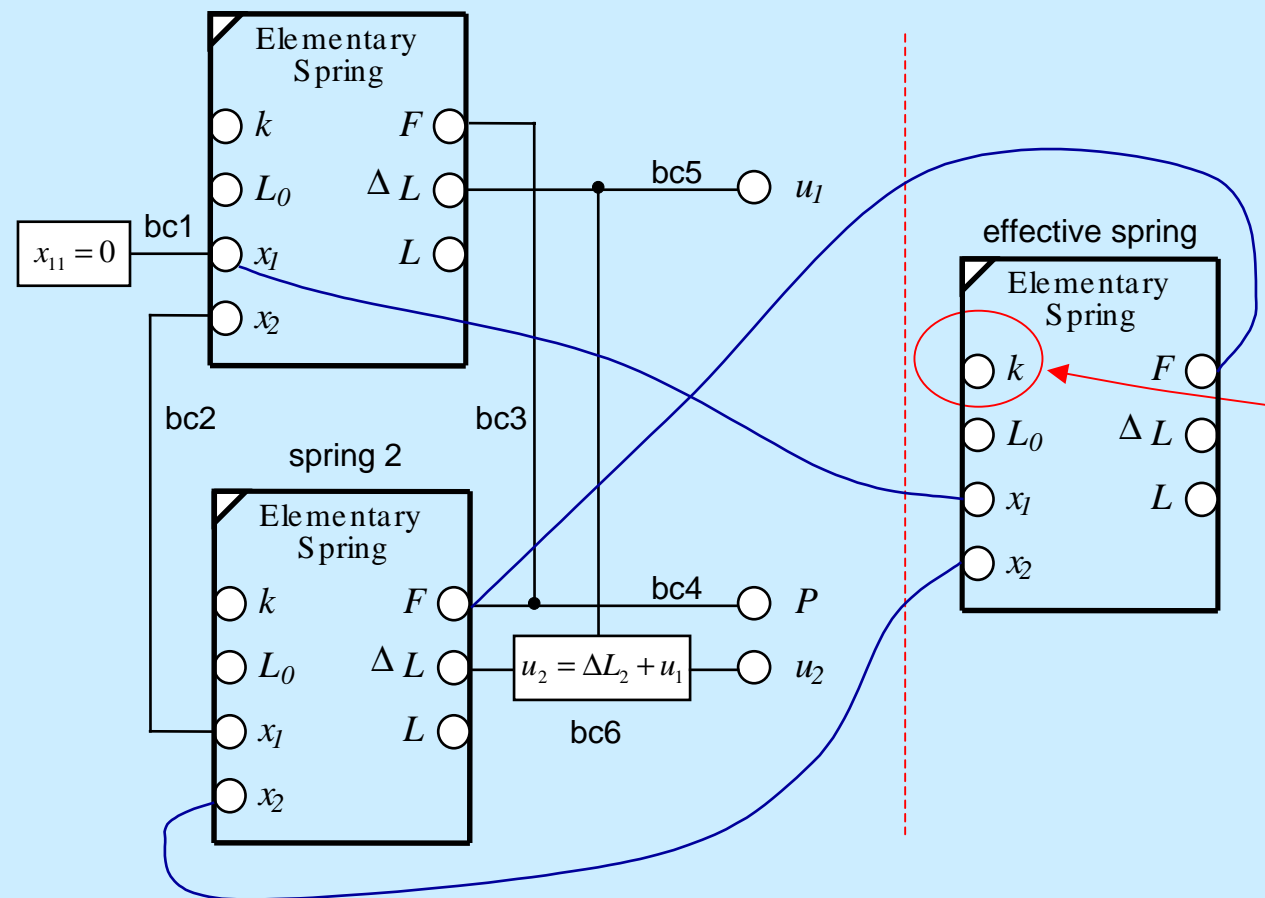
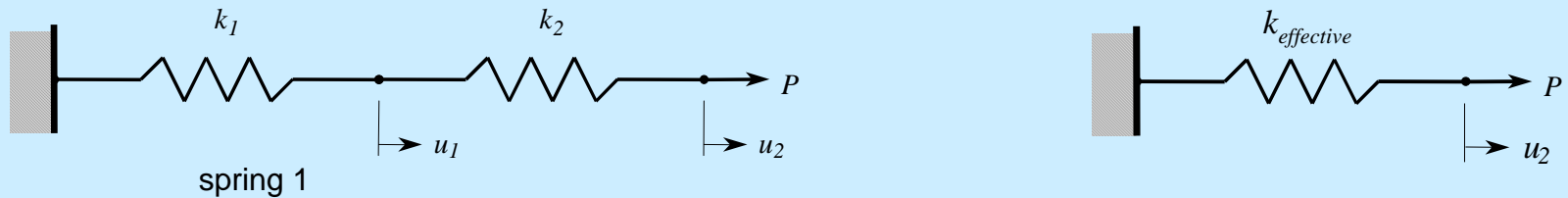
$bc_1 : x_{11} = 0$
 $bc_2 : x_{12} = x_{21}$
 $bc_3 : F_1 = F_2$
 $bc_4 : F_2 = P$
 $bc_5 : u_1 = \Delta L_1$
 $bc_6 : u_2 = \Delta L_2 + u_1$

Derivable Behavior

$dr_1 : u_1 = \frac{P}{k_1}$
 $dr_2 : u_2 = P \frac{k_1 + k_2}{k_1 k_2}$

⇒ No need to include explicitly (redundant)

Achieving Effective System Properties via Semantically Rich COBs



Derivable System Level Properties

$$dr_1: k_{effective} = \frac{1}{\frac{1}{k_1} + \frac{1}{k_2}}$$

$$dr_2: \Delta L_{effective} = \Delta L_1 + \Delta L_2$$

etc.

- ⇒ No need to derive
- ⇒ Minimal extra work
- ⇒ Semantically richer

Constrained Object Language (COBs)

◆ Capabilities & features

- Various forms: computable lexical form, graphical form, etc.
- Sub/supertypes, basic aggregates, multifidelity objects
- Multidirectionality (I/O change)
- Wrapping external programs as black box relations

◆ Analysis module/template applications:


- Product model idealizations
- Explicit associativity relations with design models & other analyses
- Black box reuse of existing tools (e.g., FEA tools, in-house functions)
- Reusable, adaptable analysis building blocks
- Synthesis (sizing) and verification (analysis)

Constrained Object Language (cont.)

◆ Summary

- Declarative knowledge representation combining objects & constraints
- COBs = (STEP EXPRESS subset) + (constraint concepts & views)
- Advantages over traditional representations:
 - » Greater solution control
 - » Richer semantics (e.g., equations wrapped in engineering context)
 - » Capture of reusable knowledge

Outline

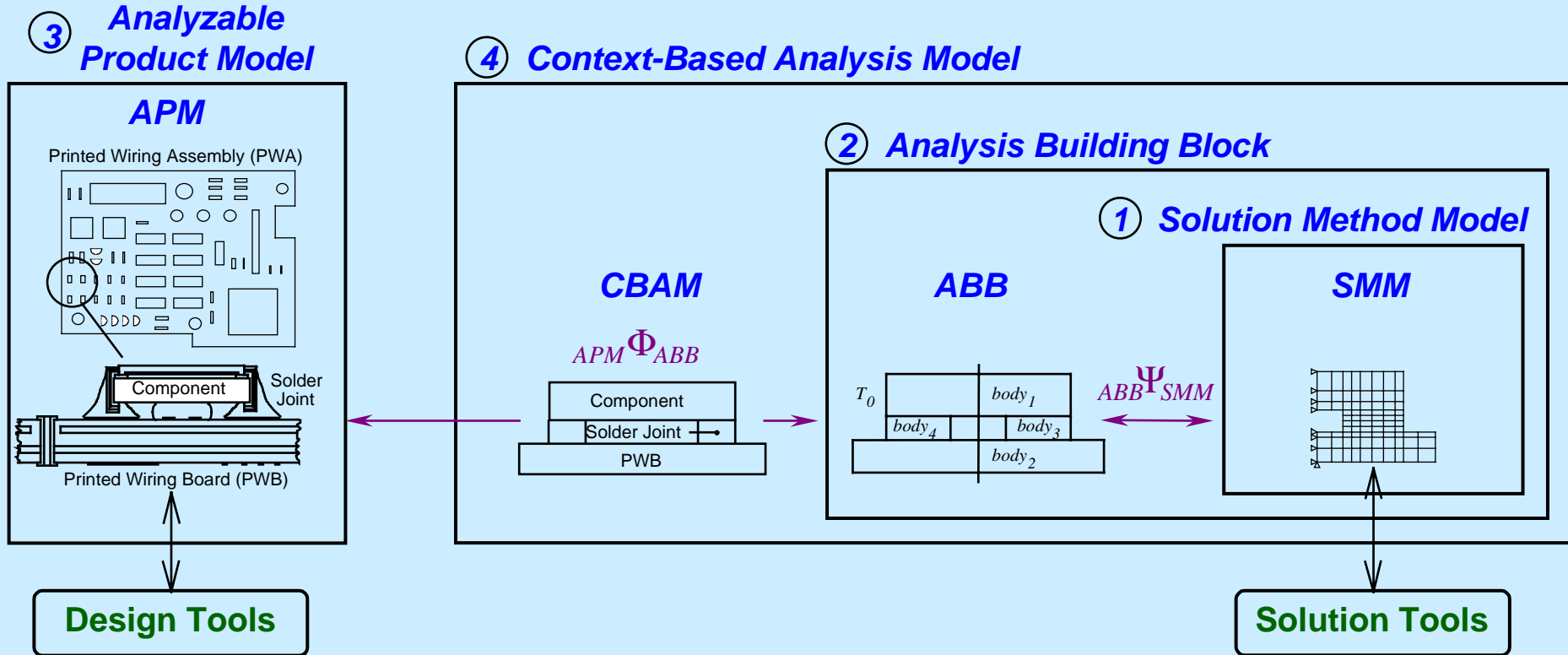
- ◆ Analysis Integration Challenges
- ◆ Introduction to Constrained Objects (COBs)
- ◆ Overview of COB-based XAI 
- ◆ Example Applications
 - ◆ Electronic Packaging Thermomechanical Analysis
 - ◆ Aerospace Structural Analysis
- ◆ Summary

Components of the MRA Analysis Integration Technique

- ◆ Conceptual architecture: MRA
- ◆ Methodology
- ◆ General purpose MRA toolkit: *XaiTools*
 - Toolkit architecture
 - Users guide
 - Tutorials (work-in-process)
- ◆ Product/company-specific applications
 - PWA/Bs (ProAM)
 - Aerospace structural analysis (Boeing PSI)
 - Chip packaging/mounting (Shinko)

See <http://eislabs.gatech.edu/> for references

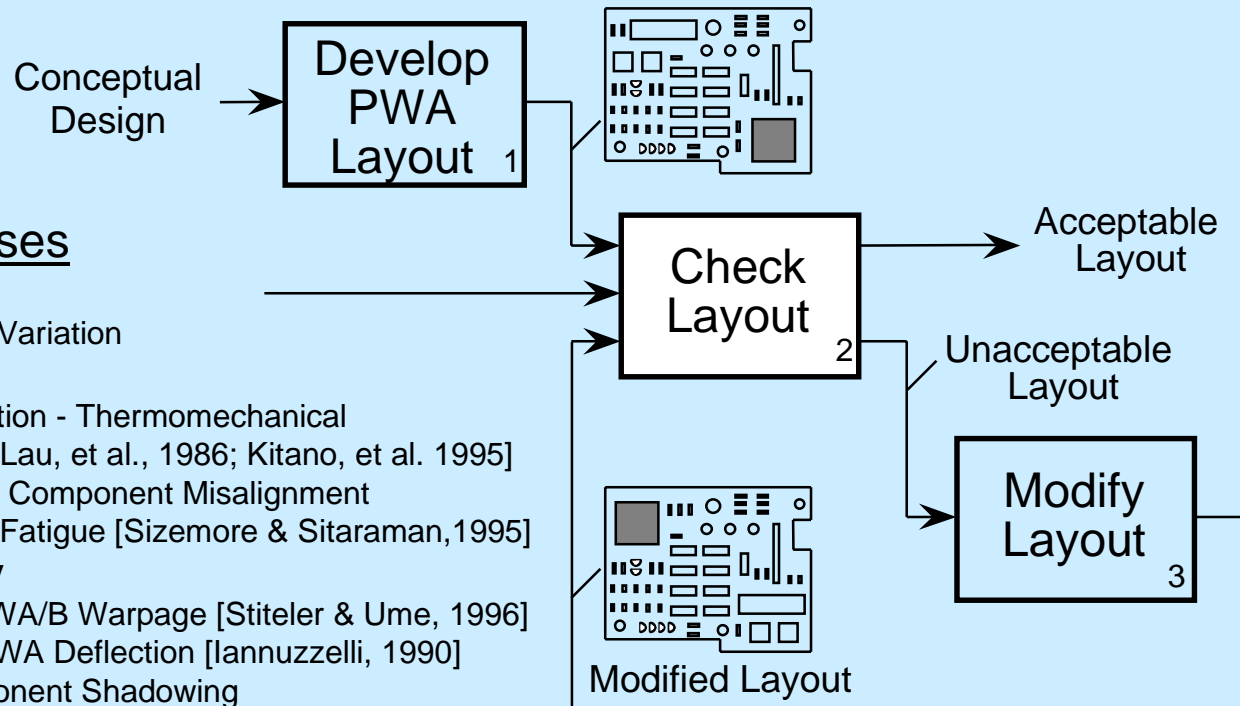
Multi-Representation Architecture for Design-Analysis Integration



- ◆ Composed of four representations (information models)
- ◆ Provides flexible, modular mapping between design & analysis models
- ◆ Creates automated, product-specific analysis modules (CBAMs)
- ◆ Represents design-analysis associativity explicitly

Routine Analysis: Opportunity for Automation

Typical PWA Design Process



Routine Analyses

Performance

EMI - Trace Spacing Variation

Reliability

Solder Joint Deformation - Thermomechanical

[Engelmaier, 1989; Lau, et al., 1986; Kitano, et al. 1995]

Solder Joint Fatigue - Component Misalignment

Plated Through-Hole Fatigue [Sizemore & Sitaraman, 1995]

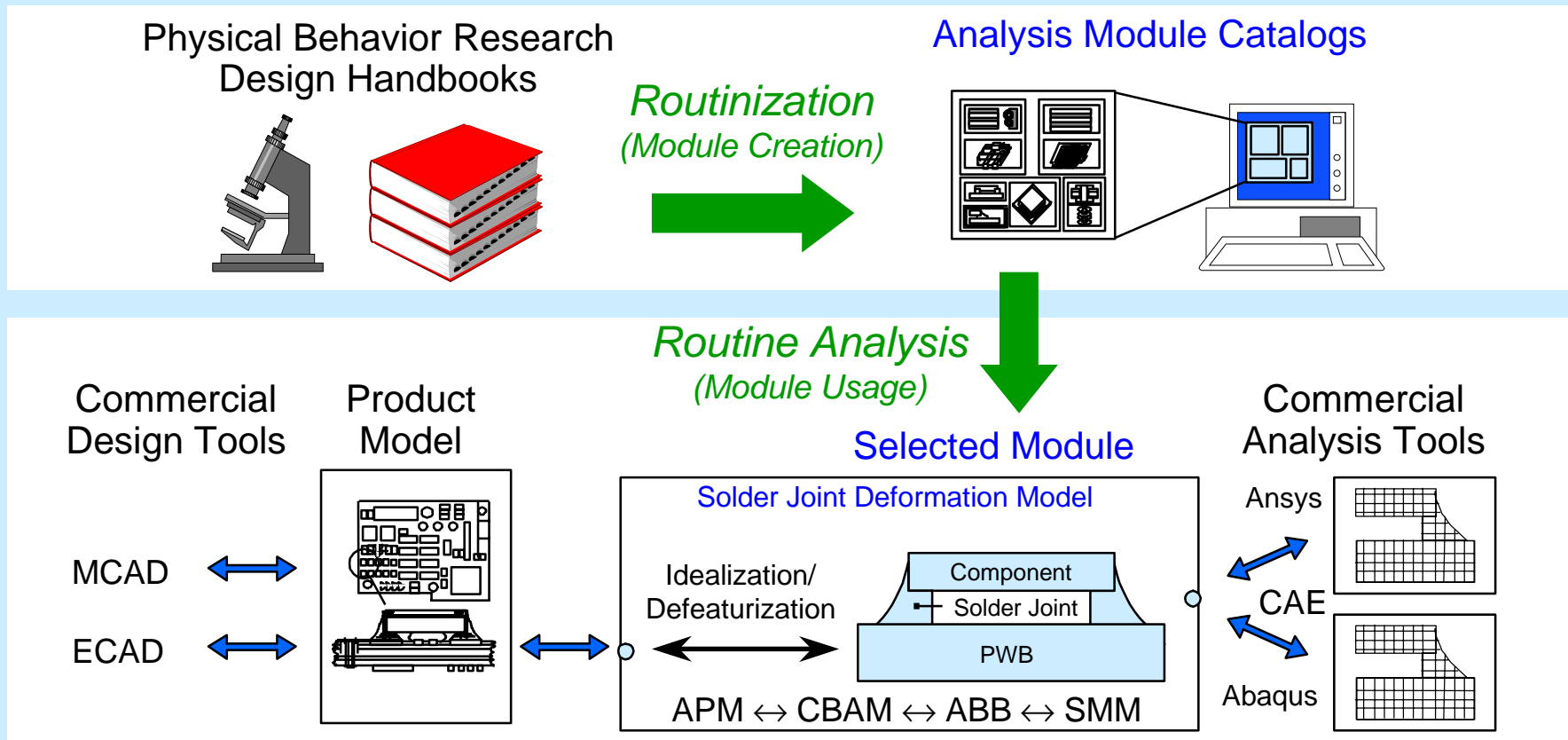
Manufacturability

Reflow Soldering - PWA/B Warpage [Stiteler & Ume, 1996]

Bed-of-Nails Test - PWA Deflection [Iannuzzelli, 1990]

Solder Wave - Component Shadowing

Design-Analysis Integration Methodology

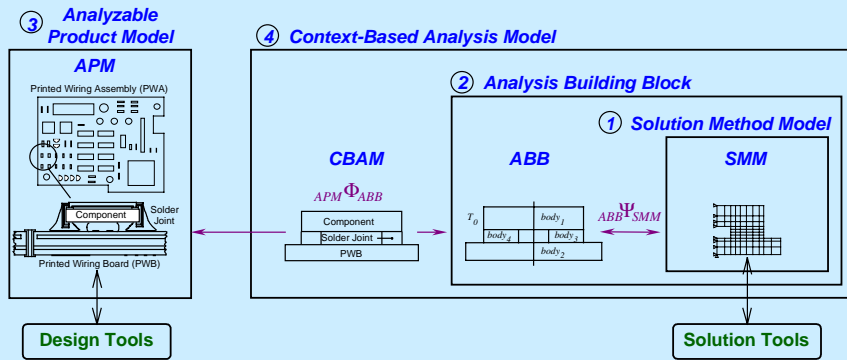


- ◆ Provides technique to bridge CAD-CAE gap
- ◆ Uses AI & info. technology: objects, constraints, STEP

XaiTools

Prototype X-Analysis Integration Toolkit Second Generation - Java-based

Multi-Representation Architecture (MRA)

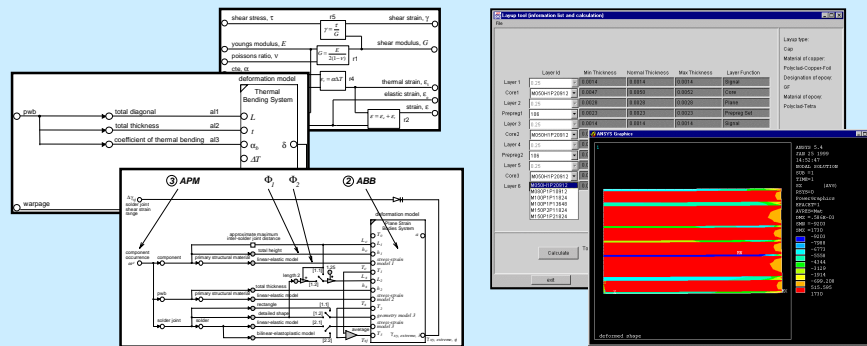


- ◆ Product-independent MRA toolkit
- ◆ Lexical constrained objects (COBs)
 - Data-driven creation
 - User-adaptable
- ◆ Mathematica constraint solver
 - More capabilities
- ◆ SMM-type wrappings:
 - FEA tools: Ansys, Abaqus*
 - Symbolic Eqn. Solver: Mathematica
- ◆ Extended APM technique for design links:
 - CATIA MCAD modeler
- ◆ Updates/Extensions in progress*:
 - PWB/A: GenCAM; STEP AP210-based APM link w/ Mentor Graphics BoardStation
 - Generalized MCAD modeler links
 - Advanced parametric FEA transformation
 - Object-Oriented Optimization
 - CORBA-based tool interchanges
 - XML views of analysis results etc.

Analysis Modules & Building Blocks

Constraint Schematics

Implementations



XaiTools Tool Architecture

Company/Product-Independent View

Capabilities as of 12/98

Plus ECAD AP210 link
and items from first gen. prototypes:
full SMMs, complex meshing, etc.

Design Tools

MCAD Tool

CATIA

Material Properties Manager

MATDB-like files

Standard Parts Manager

FASTDB-like files

Tagging Technique &
Interpretive
CATGEO
Interface

COB Instances

objects, x.coi, x.step

Tool Forms
(parameterized tool
models/partial SMMs)

Template Libraries: CBAMs, ABBs, APMs

Instances: Usage/adaptation of templates

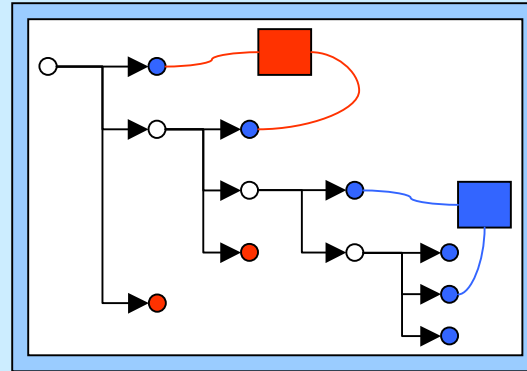
COB Schemas

objects, x.cos, x.exp

Examples:

aerospace, electronics,
tutorials

COB Server XaiTools



Analysis Codes

FEA: Ansys

General Math: Mathematica

Constraint Solver

Mathematica

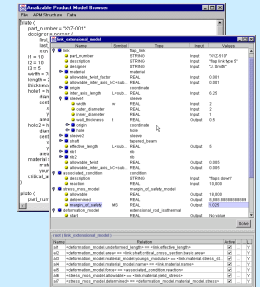
CORBA Wrapper

Analysis Mgt. Tools

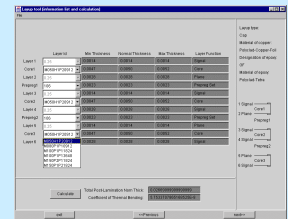
COB Analysis Tools

Navigator: XaiTools

Editor (text): WordPad

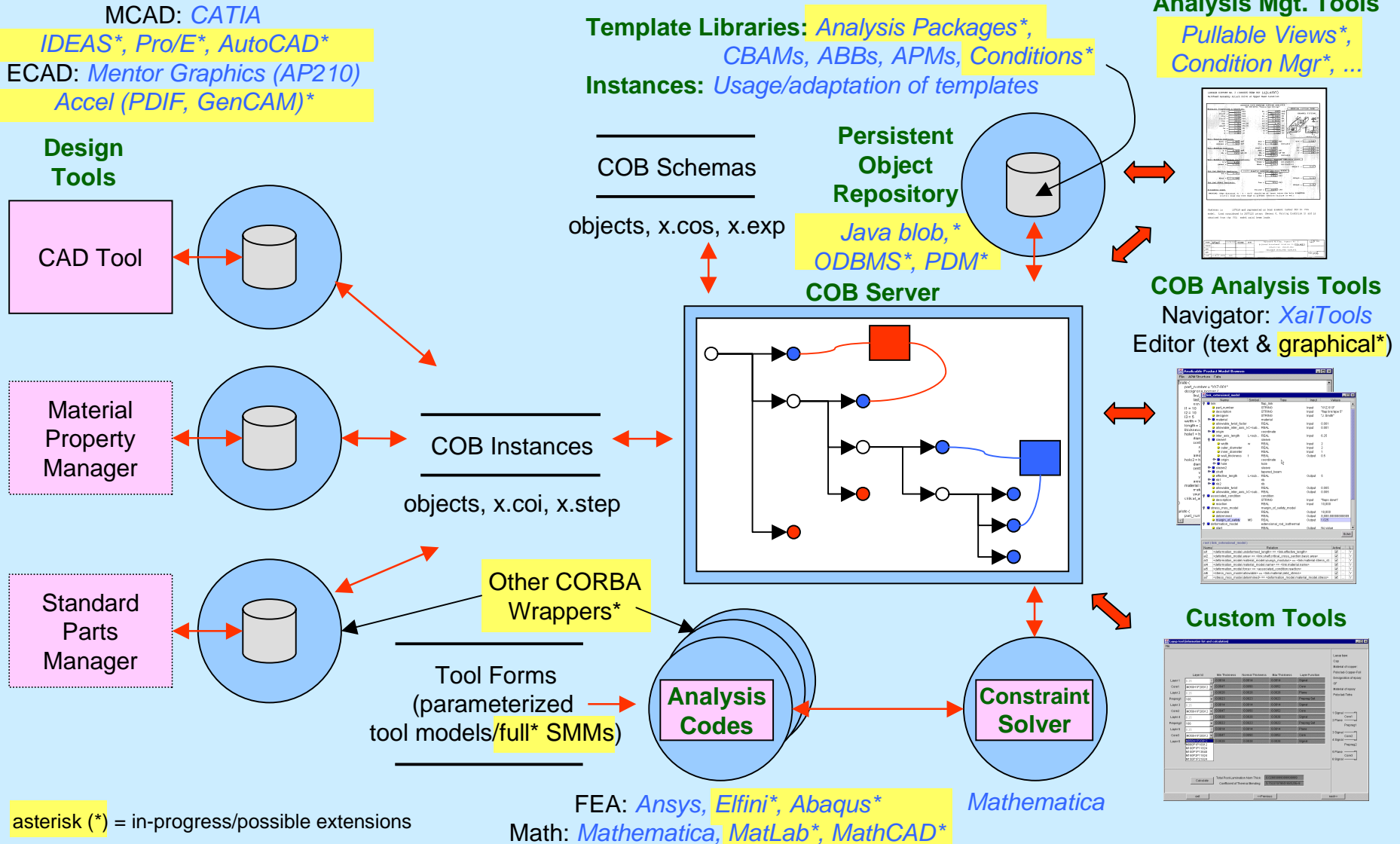


Custom Tools



XaiTools Tool Architecture

Company/Product-Independent View
In-Progress & Potential Extensions as of 6/99

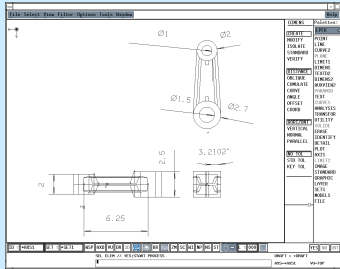
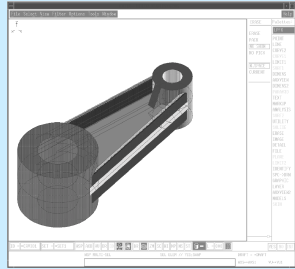


asterisk (*) = in-progress/possible extensions

Flexible High Diversity Design-Analysis Integration

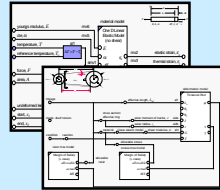
Tutorial Examples: Flap Link (Mechanical/Structural Analysis)

MCAD Tools
CATIA



Materials DB

MATDB-like



Modular, Reusable
Template Libraries

Analyzable
Product Model

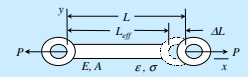
XaiTools

Analysis Modules (CBAMs)
of Diverse Mode & Fidelity

XaiTools

Analysis Tools

General Math
Mathematica



FEA *Ansys*

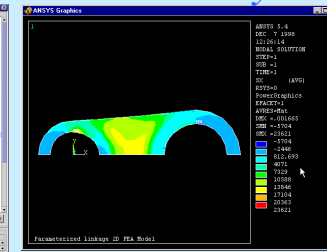
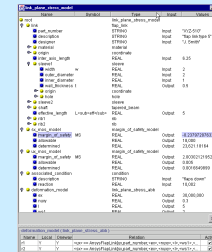
Extension

1D,
2D,
3D*



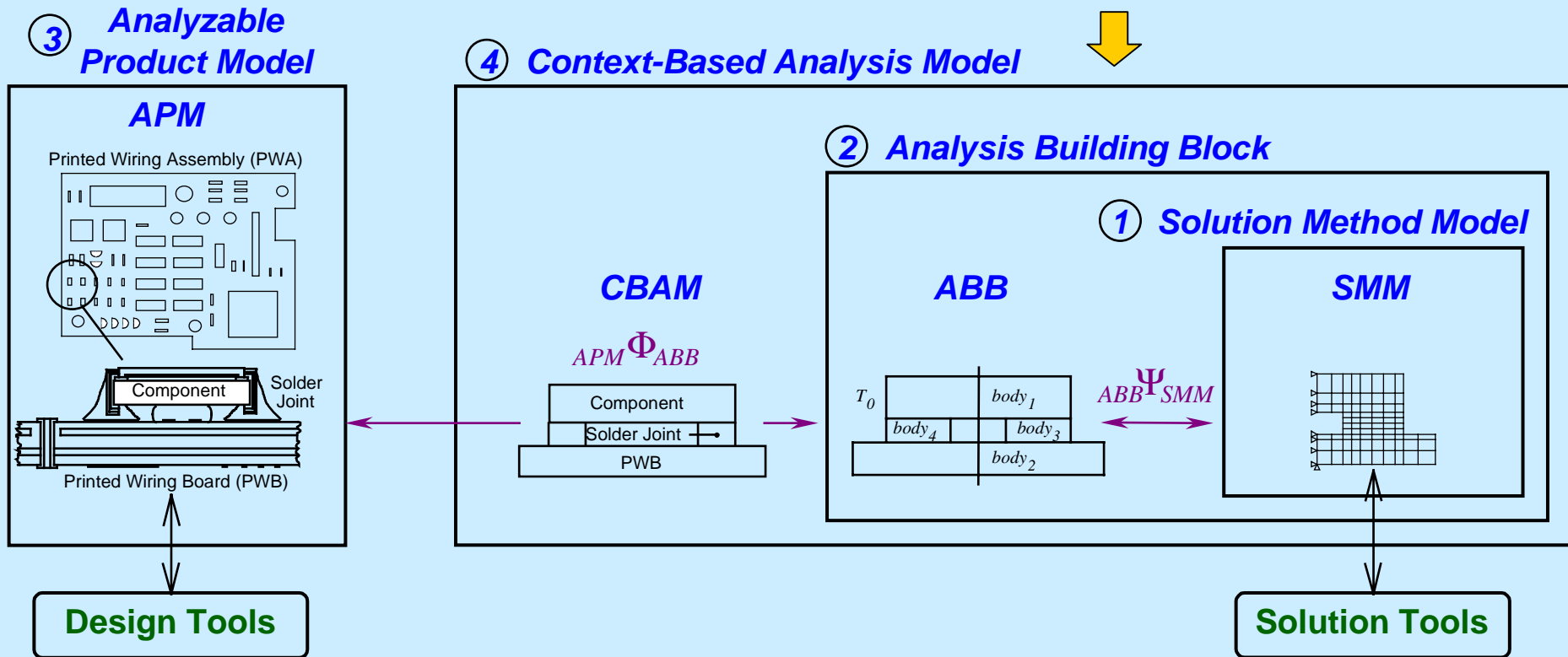
Torsion

1D



* = Item not available in working prototype yet (all others have working examples)

Multi-Representation Architecture for Design-Analysis Integration



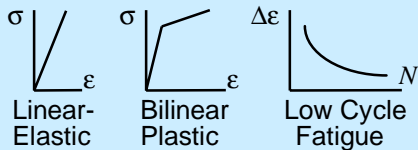
Analysis Building Blocks (ABBs)

Object representation of product-independent analytical engineering concepts

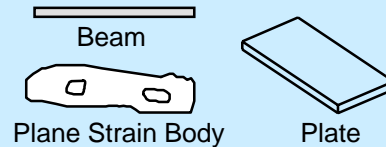
Analysis Primitives

- Primitive building blocks

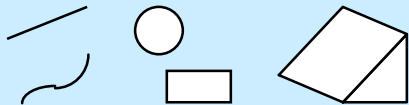
Material Models



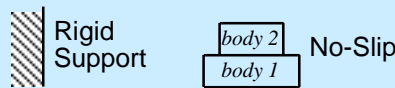
Continua



Geometry



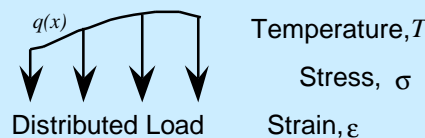
Interconnections



Discrete Elements



Analysis Variables

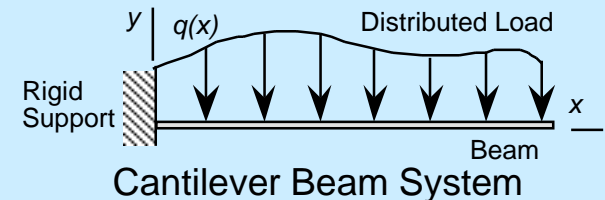


Analysis Systems

- Containers of ABB "assemblies"

Specialized

- Predefined templates



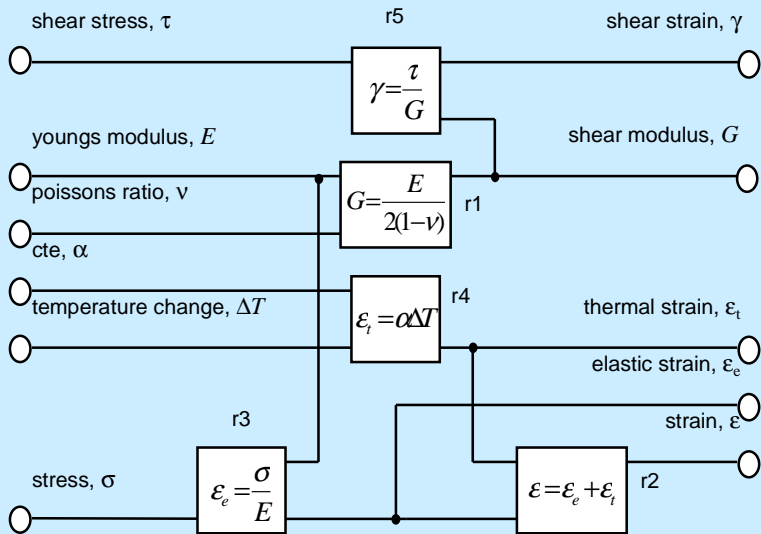
General

- User-defined systems

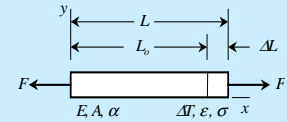
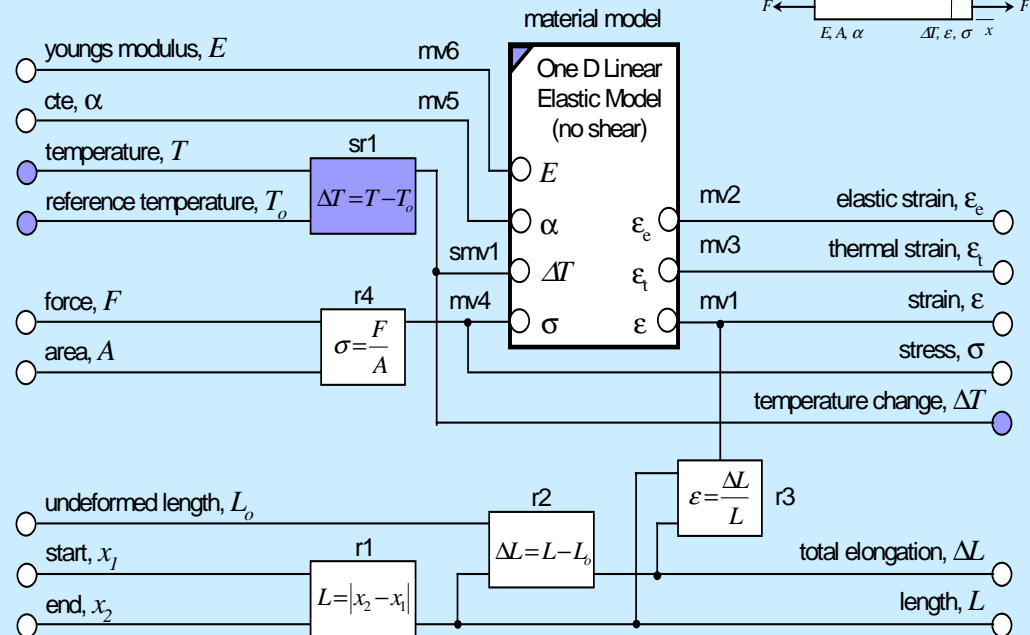


Primitive ABBs

1D Linear Elastic Model



Extensional Rod

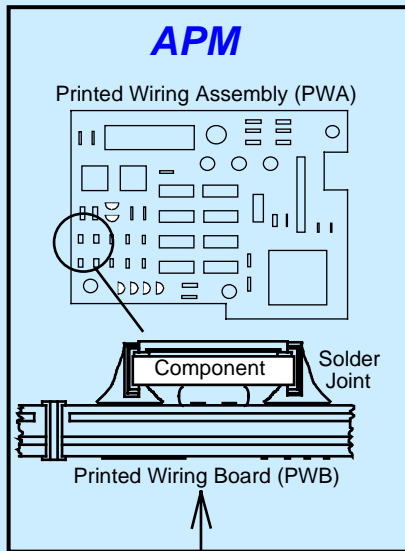


Usage by Flap Link Model

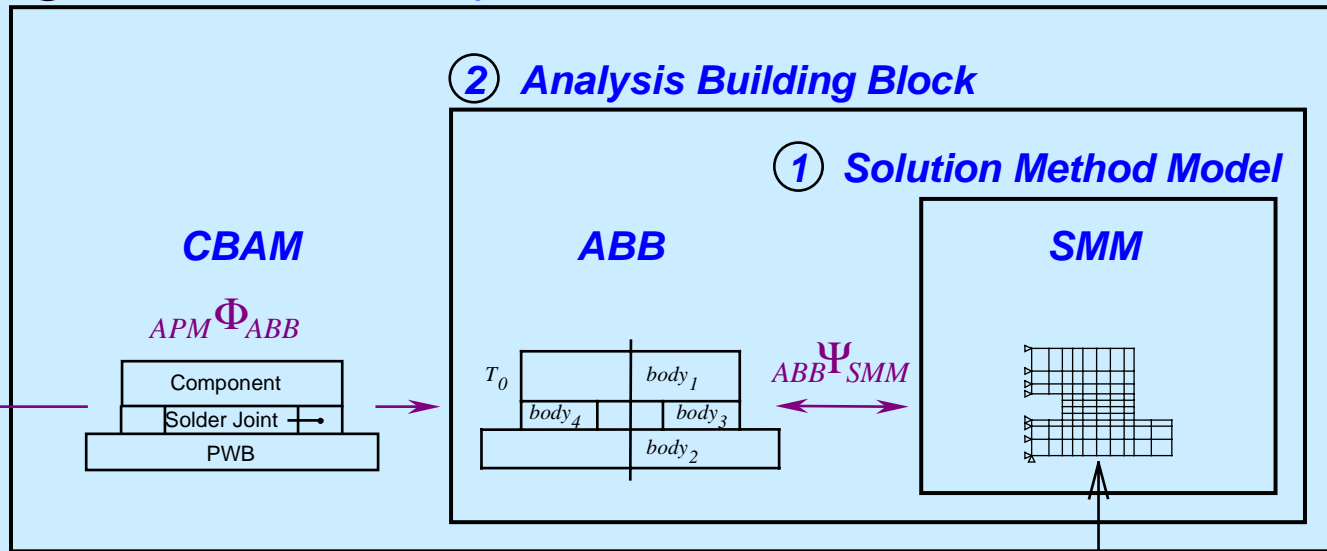
Multi-Representation Architecture for Design-Analysis Integration



③ Analyzable Product Model



④ Context-Based Analysis Model



Design Tools

Solution Tools

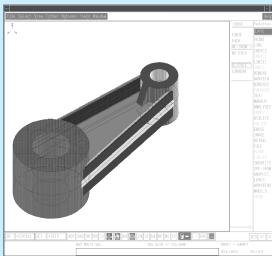
Analyzable Product Models (APMs)

Provide advanced access to design data needed by diverse analyses.

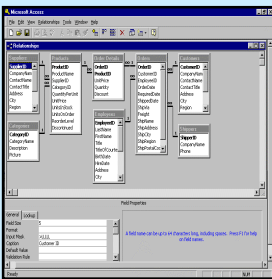
Design Applications

Analysis Applications

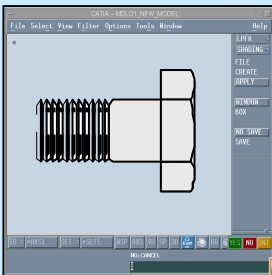
Solid Modeler



Materials Database

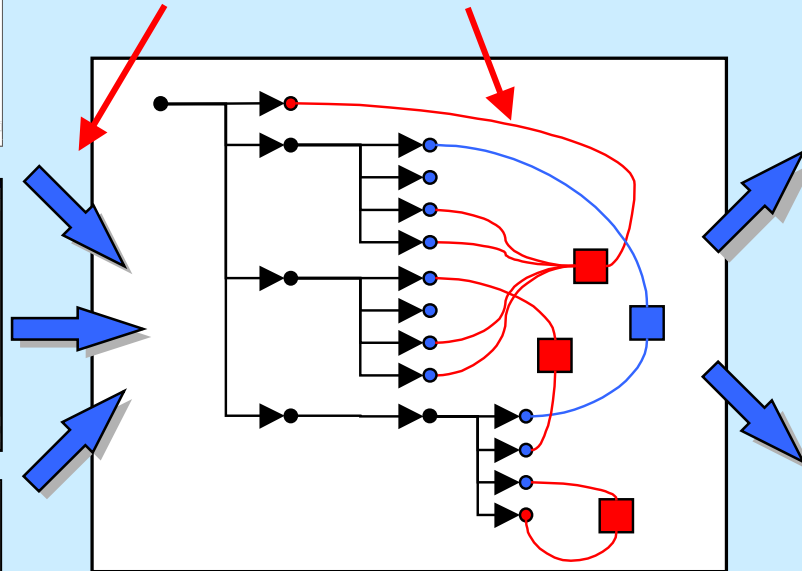


Fasteners Database



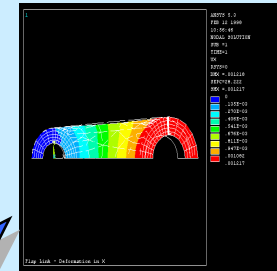
Combine information

Add reusable multifidelity idealizations

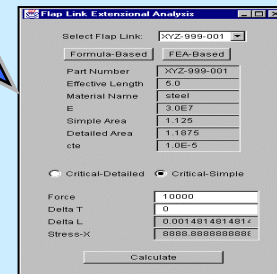


Analyzable Product Model (APM)

Support multidirectionality



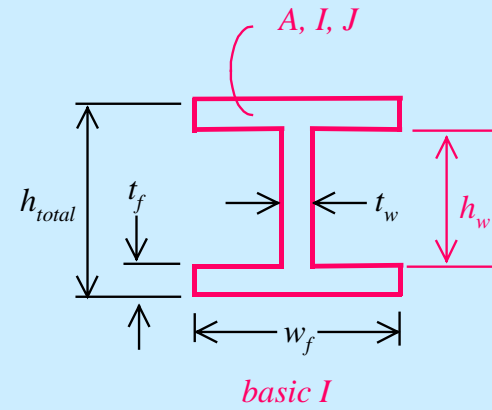
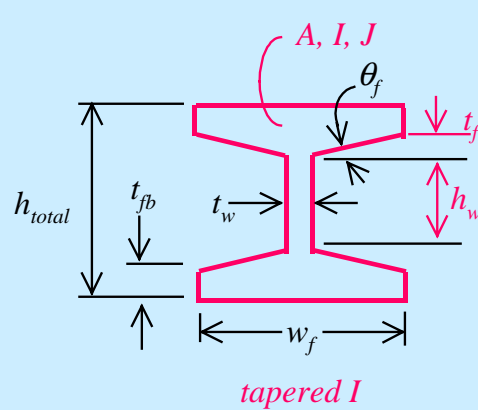
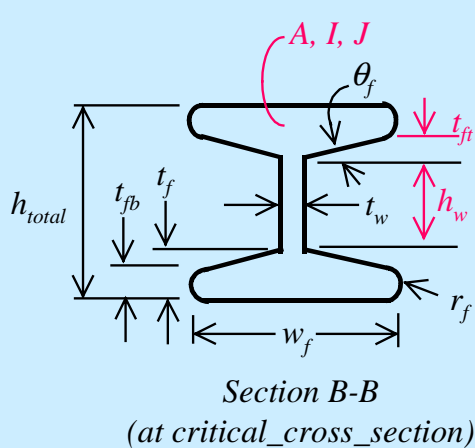
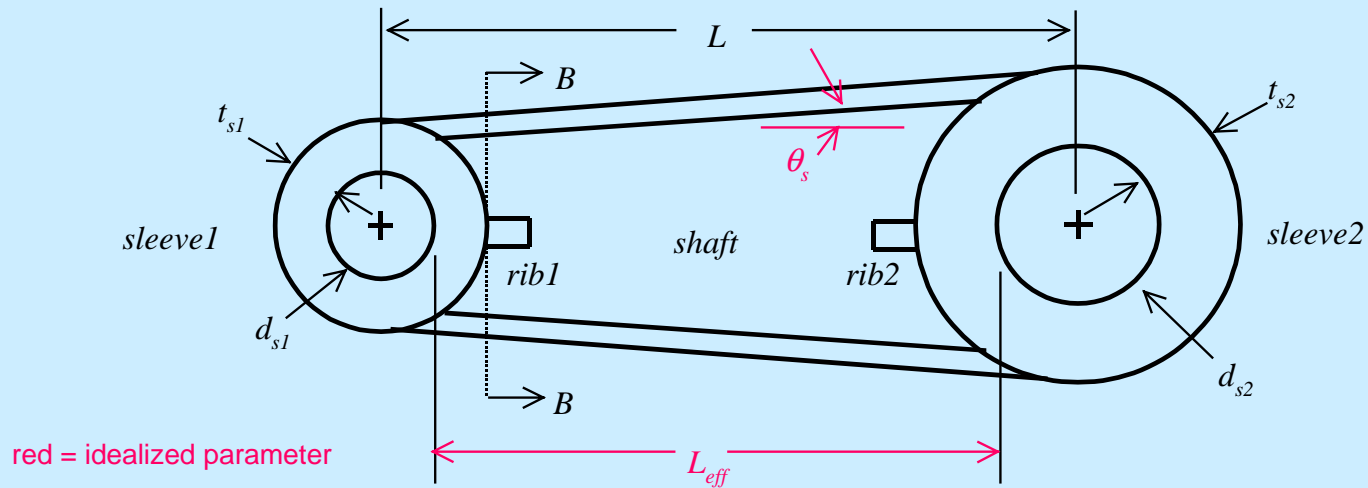
FEA-Based Analysis



Formula-Based Analysis

Flap Link Geometric Model

(with idealizations)

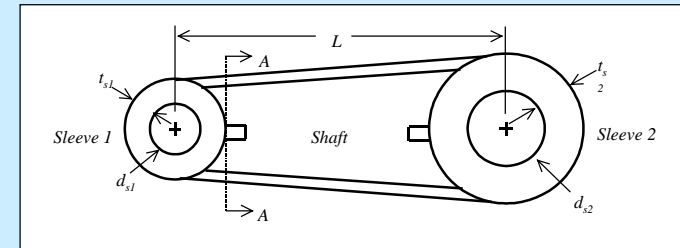
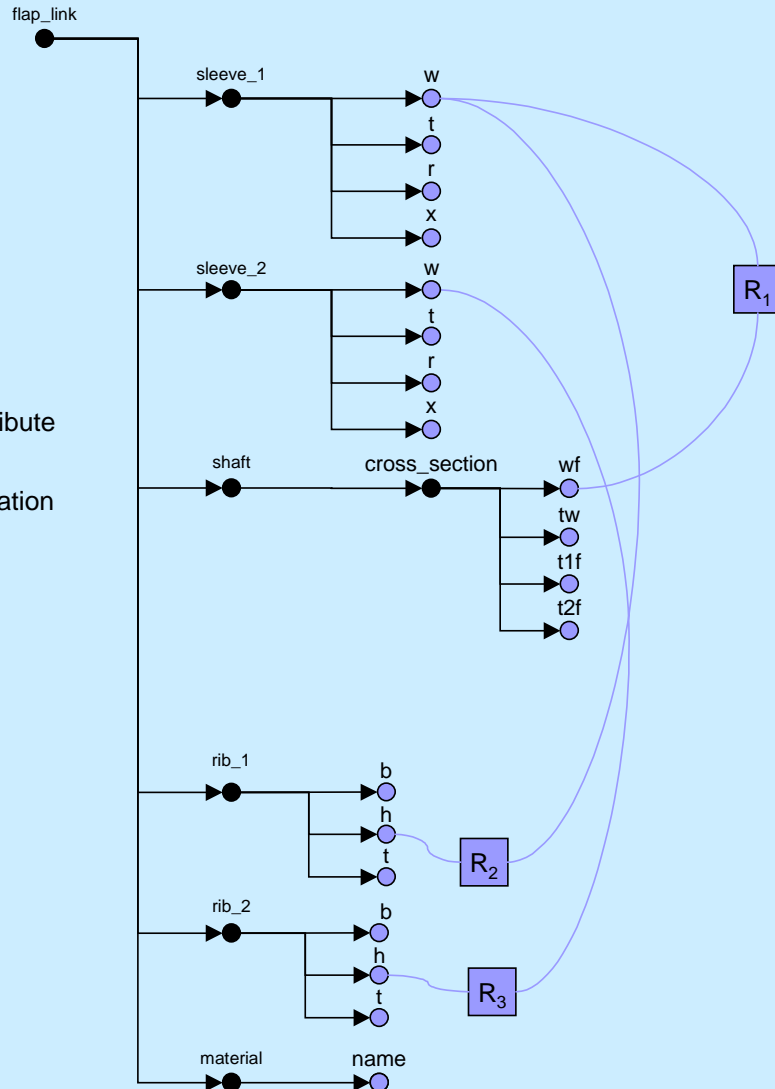


Detailed Design

Multifidelity Idealizations

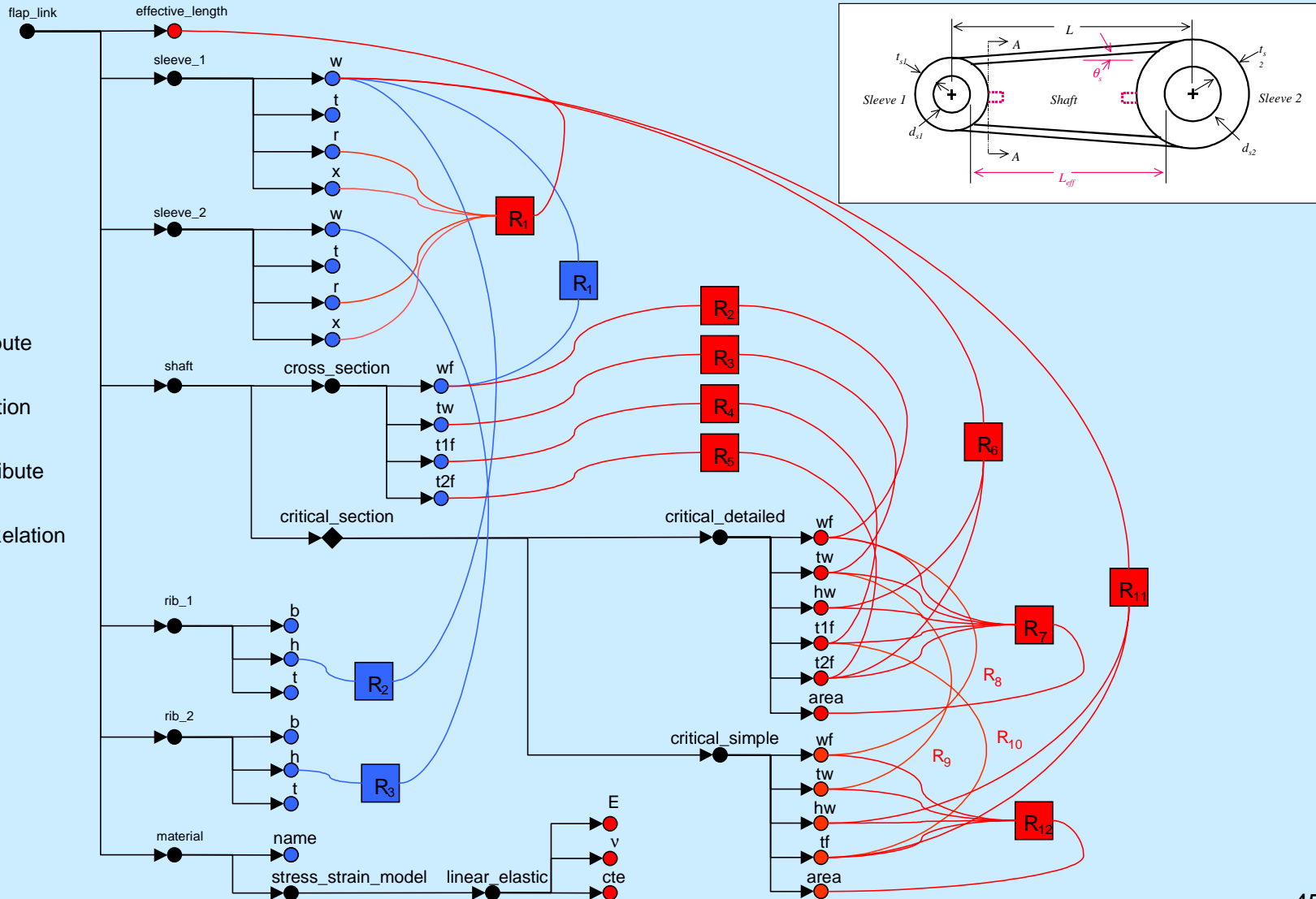
Flap Linkage Example

Manufacturable Product Model (MPM) = Design Description



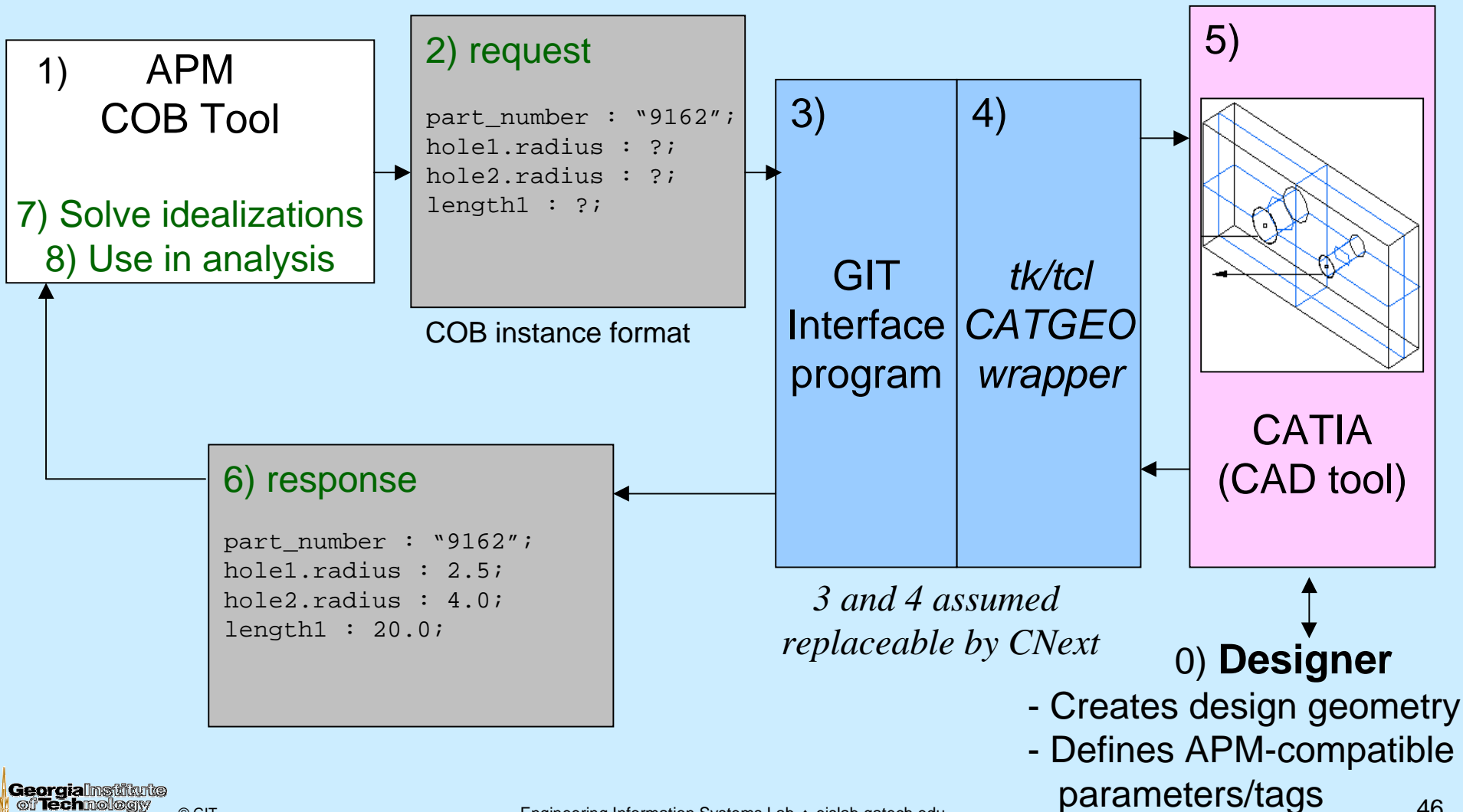
Flap Linkage Example

Analyzable Product Model (APM) = MPM Subset + Idealizations



- Product Attribute
- R_i Product Relation
- Idealized Attribute
- R_i Idealization Relation

APM Interface with Tagged CAD Models



Flap Link Tagging

The screenshot displays a CAD software window with a menu bar (File, Select, View, Filter, Options, Tools, Window, Help) and a toolbar. The main workspace contains a technical drawing of a flap link. The drawing includes a top view and a side view. Key dimensions and annotations are as follows:

- Top View:** Shows two circular holes. The top hole has an outer diameter of $\varnothing 2$ and an inner diameter of $\varnothing 1.5$. The bottom hole has an outer diameter of $\varnothing 2.7$. A dimension line indicates the distance between the centers of the two holes is 6.25 .
- Side View:** Shows the thickness of the link is 2.5 . The angle of the link's taper is 3.2102° .
- Annotations:** Blue text labels include "sleeve2.inner_diameter" pointing to the inner diameter of the top hole, "sleeve2.width" pointing to the thickness of the link, and "inter_axis_length" pointing to the distance between the hole centers.

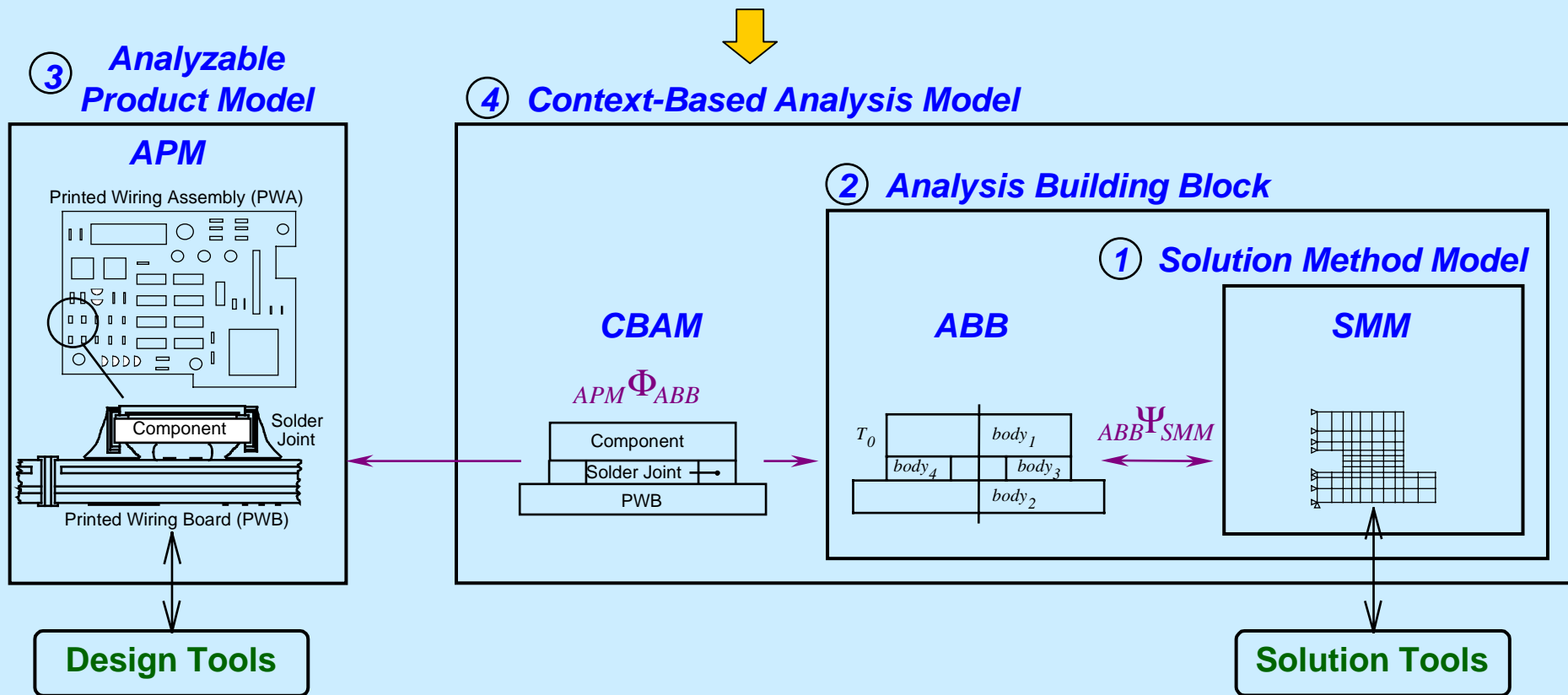
On the right side, there is a "Palettes:" panel with a list of tools and options:

- DIMENS:** CREATE, MODIFY, ISOLATE, STANDARD, VERIFY, DISTANCE, OBLIQUE, CUMULATE, CURVE, ANGLE, OFFSET, COORD, HORIZONTAL, VERTICAL, NORMAL, PARALLEL, NO TOL, STD TOL, KEY TOL.
- Palettes:** LPFK, POINT, LINE, CURVE2, PLANE, LIMIT1, DIMENS, TEXTD2, DIMENS2, AUXVIEW2, PARAM3D, TEXT, CURVE1, ANALYSIS, TRANSFOR, UTILITY, SOLIDE, ERASE, IDENTIFY, DETAIL, PLOT, AXIS, LIMIT2, IMAGE, STANDARD, GRAPHIC, LAYER, SETS, MODELS, FILE.

At the bottom, there is a status bar with the following information:

- ID = *AXS1
- SET = *SET1
- WSP AXD VU DR 3D
- SEL ELEM // YES:START PROCESS
- DRAFT = *DRAFT
- AXS=*AXS1 VU=TOP

Multi-Representation Architecture for Design-Analysis Integration



Tutorial Example: Flap Link Analysis Problems/CBAMs

Flap Link SCN

(2) Torsion Analysis

(1) Extension Analysis a. 1D Extensional Rod b. 2D Plane Stress FEA

1. Mode: **Shaft Tension**

2. BC Objects

Flaps down : $F = 10000$ lbs

3. Part Feature (idealized)

$L_{eff} = 5.0$ in **1020 HR Steel**

$A = 1.13$ in² $E = 30e6$ psi

$\sigma_{allowable} = 18000$ psi

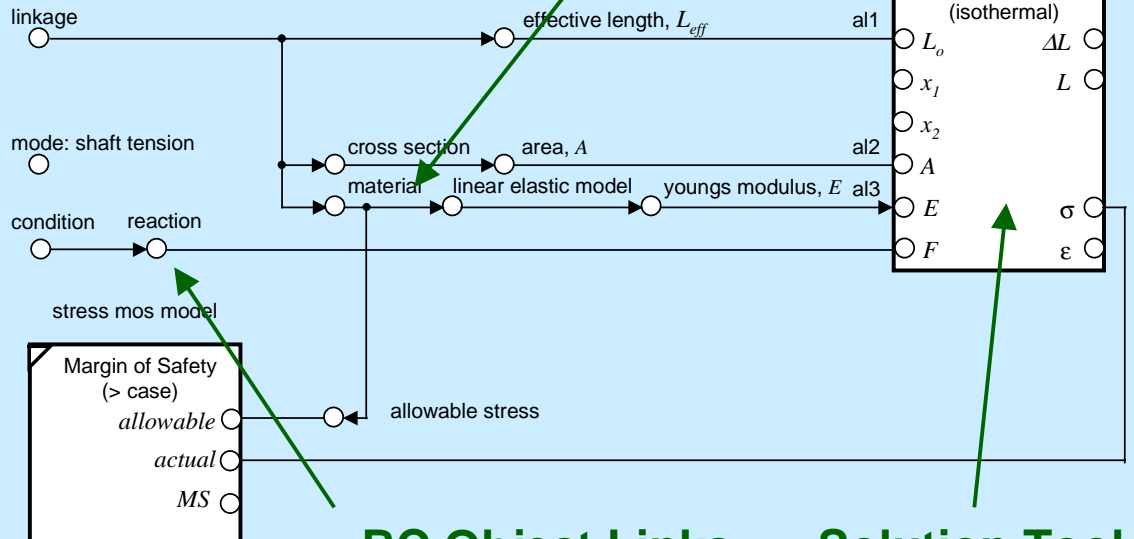
4. Analysis Calculations

$$\sigma = \frac{F}{A} \quad \Delta L = L_{eff} \frac{\sigma}{E}$$

5. Objective

$$MS = \frac{\sigma_{allowable}}{\sigma} - 1 = 1.03$$

(1a) Analysis Problem for 1D Extension Analysis



Pullable Views*

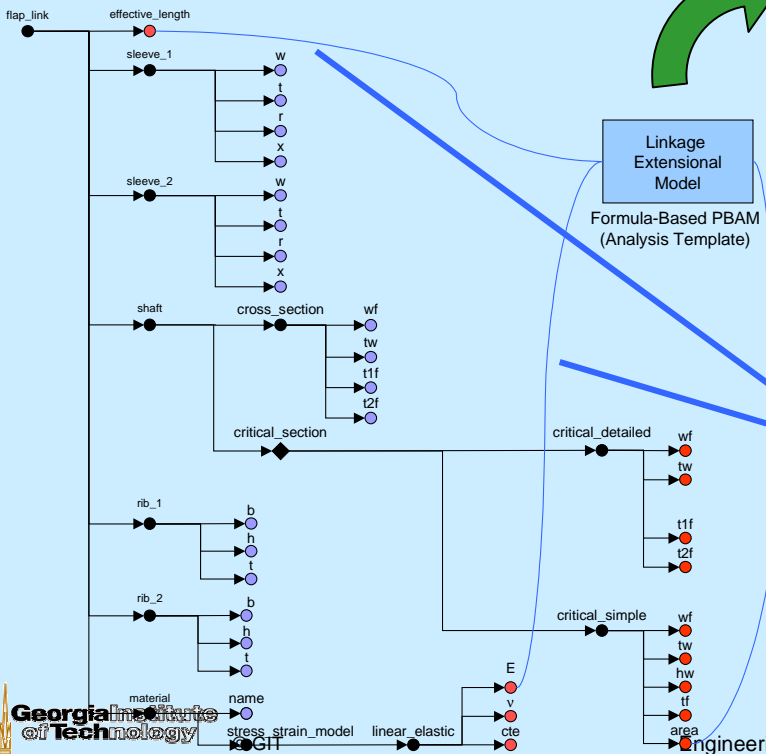
**BC Object Links
(other analyses)***

**Solution Tool
Links**

* Boundary condition objects & pullable views are WIP*

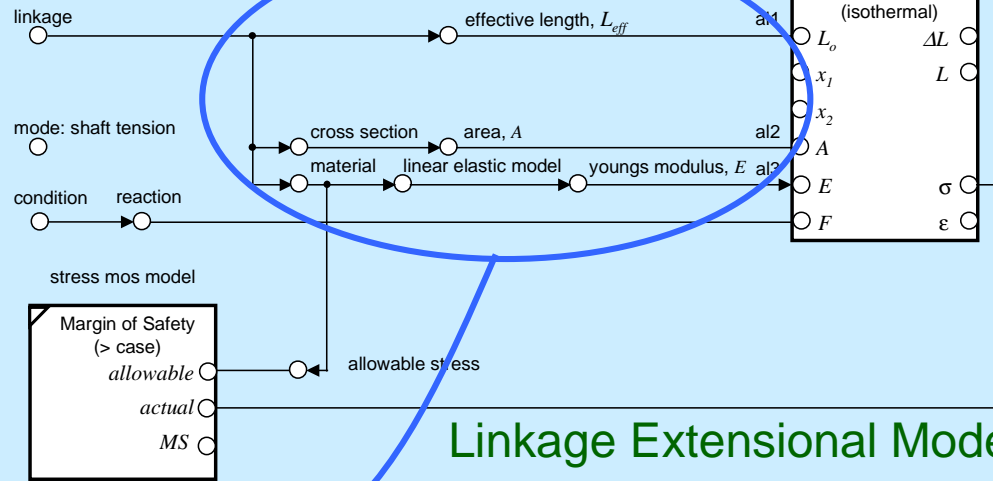
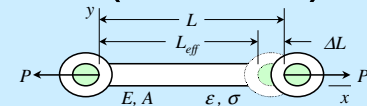
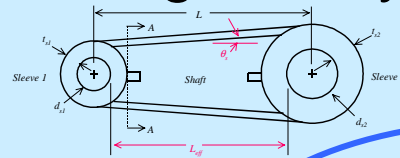
Analysis Template Usage of APM Idealized Attributes

Linkage APM



Linkage Extensional Model
Formula-Based PBAM
(Analysis Template)

Linkage Analysis Template (CBAM)



Linkage Extensional Model

Flap Linkage Extensional Model: Lexical COB Structure

```
COB link_extensional_model SUBTYPE_OF link_analysis_model;
```

```
DESCRIPTION
```

```
"Represents 1D formula-based extensional model.";
```

```
ANALYSIS_CONTEXT
```

```
PART_FEATURE
```

```
link : flap_link
```

```
BOUNDARY_CONDITION_OBJECTS
```

```
associated_condition : condition;
```

```
MODE
```

```
"tension";
```

```
OBJECTIVES
```

```
stress_mos_model : margin_of_safety_model;
```

```
ANALYSIS_SUBSYSTEMS */
```

```
deformation_model : extensional_rod_isothermal;
```

```
RELATIONS
```

```
a1 : "<deformation_model.undeformed_length> == <link.effective_length>";
```

```
a2 : "<deformation_model.area> == <link.shaft.critical_cross_section.basic.area>";
```

```
a3 : "<deformation_model.material_model.youngs_modulus> ==  
      <link.material.stress_strain_model.linear_elastic.youngs_modulus>";
```

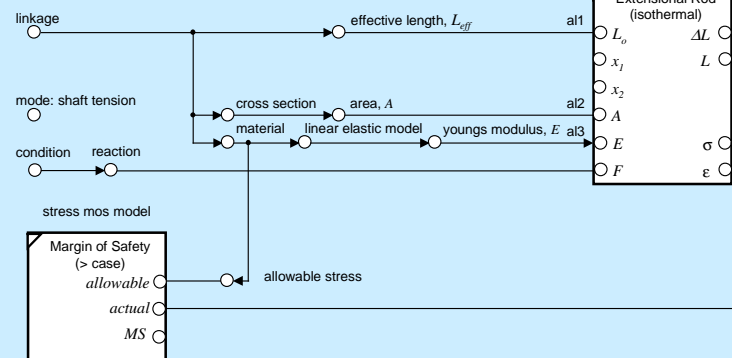
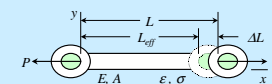
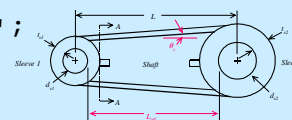
```
a4 : "<deformation_model.material_model.name> == <link.material.name>";
```

```
a5 : "<deformation_model.force> == <associated_condition.reaction>";
```

```
a6 : "<stress_mos_model.allowable> == <link.material.yield_stress>";
```

```
a7 : "<stress_mos_model.determined> == <deformation_model.material_model.stress>";
```

```
END_COB;
```



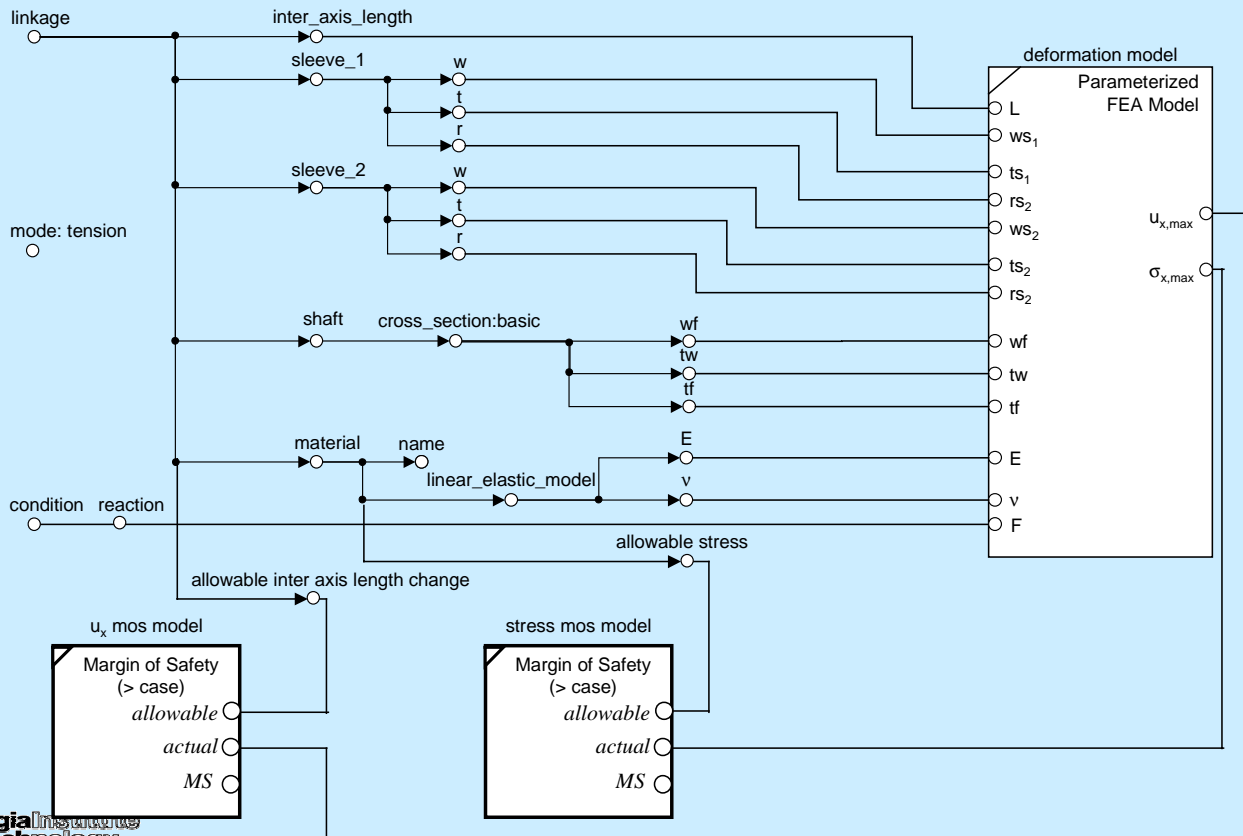
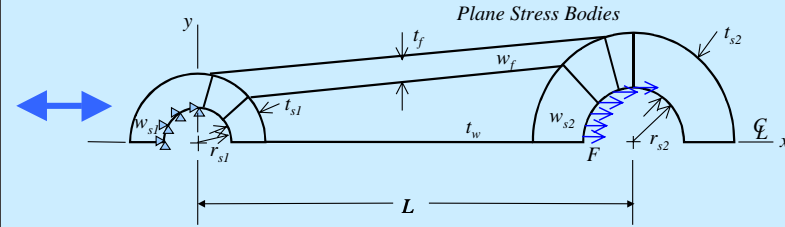
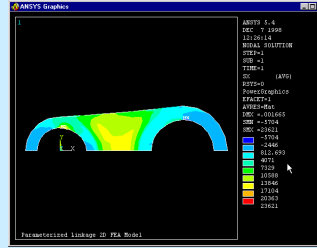
Desired categorization of attributes is shown above (as manually inserted) to support pullable views.

Categorization capabilities is a planned XaiTools extension.

FEA-based Analysis Subsystem

Used in Linkage Plane Stress Model (2D Analysis Problem)

Higher fidelity version
vs. Linkage Extensional Model

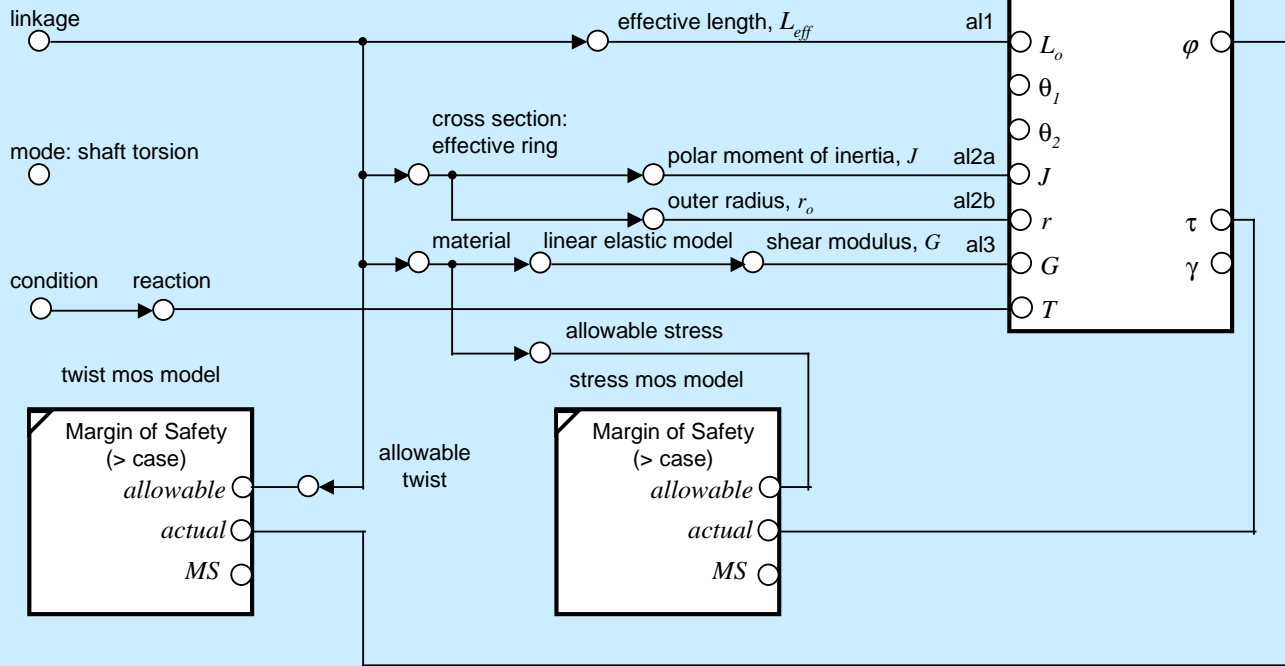
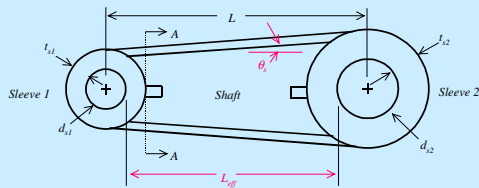


Name	Symbol	Type	Input	Values
root		link_plane_stress_model		
link		link_plane_stress_model		
part_number	STRING	Input	"NYZ-510"	
description	STRING	Input	"flap link type 5"	
designer	STRING	Input	"J. Smrtn"	
material	material	Input		
origin	coordinate	Input		
inter_axis_length	REAL	Input	6.25	
sleeve1	sleeve	Input		
width	REAL	Input	2	
outer_diameter	REAL	Input	2	
inner_diameter	REAL	Input	1	
wall_thickness t	REAL	Output		0.5
origin	coordinate	Input		
hole	hole	Input		
sleeve2	sleeve	Input		
shaft	tapered_beam	Input		
effective_length	REAL	Output		5
rib1	rib	Input		
rib2	rib	Input		
mx_mos_model	margin_of_safety_model	Input		
margin_of_safety	REAL	Output		0.23797207632
allowable	REAL	Output		18.000
determined	REAL	Output		23,621.18164
ux_mos_model	margin_of_safety_model	Input		
margin_of_safety	REAL	Output		2.003021219528
allowable	REAL	Output		0.005
determined	REAL	Output		0.0016649899
associated_condition	condition	Input		"flaps down"
description	STRING	Input		10,002
reaction	REAL	Input		
deformation_model	link_plane_stress_abb	Input		
ex	REAL	Output		30,000,000
nuxy	REAL	Output		0.3
l	REAL	Output		5
suet	REAL	Output		7

Name	Local	Onevaly	Relation	Active
r1	Y	Y	<ux> = AnsysFlapLink[ux_part_number,<ex,<nuxy,<l,<ws1>,<...	✓
r2	Y	Y	<sx> = AnsysFlapLink[sx_part_number,<ex,<nuxy,<l,<ws1>,<...	✓

Flap Linkage Torsional Model

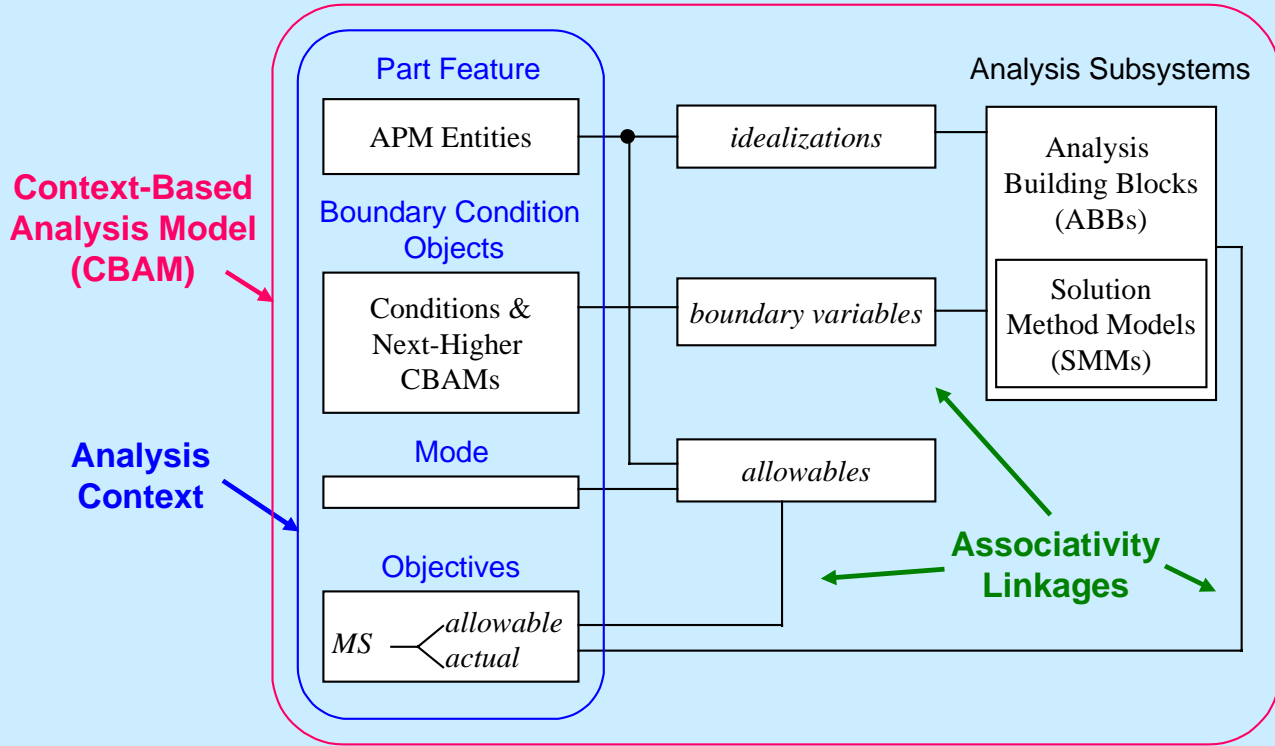
Diverse Mode (Behavior) vs. Linkage Extensional Model



Name	Symbol	Type	Input	Values
root		link_torsional_model		
link		flap_link		
part_number		STRING	Input	"XYZ-510"
description		STRING	Input	"flap link type 5"
designer		STRING	Input	"J. Smith"
material		material		
allowable_twist_factor		REAL	Input	0.001
allowable_inter_axis_length_C_{...}		REAL	Input	0.001
origin		coordinate		
inter_axis_length		REAL	Input	6.25
sleeve1		sleeve		
sleeve2		sleeve		
shaft		tapered_beam		
effective_length		REAL	Output	5
allowable_twist		REAL	Output	0.005
rib1		rib		
rib2		rib		
allowable_inter_axis_length_C_{...}		REAL	Output	0.005
associated_condition		condition		
description		STRING	Input	"2G drive"
reaction		REAL	Input	5,000
stress_mos_model		margin_of_safety_model		
allowable		REAL	Output	18,000
determined		REAL	Output	4,703.115814226
margin_of_safety	MS	REAL	Output	2.82725
twist_mos_model		margin_of_safety_model		
allowable		REAL	Output	0.005
determined		REAL	Output	0.002139917695
margin_of_safety	MS	REAL	Output	1.336538461538
deformation_model		torsional_rod		
theta_start	θ<...</td>	REAL	Output	No value
theta_end	θ<...</td>	REAL	Output	No value
twist	φ<...</td>	REAL	Output	0.002139917695
torque	T	REAL	Output	5,000
radius	r	REAL	Output	0.951380053284

Name	Relation	Active
r1	<twist> == <theta_end> - <theta_start>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Y
r2	<material_model.shear_strain> == <twist> * <radius> / <undeformed_length>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Y
r3	<material_model.shear_stress> == <torque> * <radius> / <polar_moment_of_inertia>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Y
r1	<material_model.temperature_change> == <temperature> - <reference_temperatur...	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Y

Major Types of Analysis Objects



Analysis Context

- Analysis specification (why vs. how)
- Definable during early planning stages

analysis problem a.k.a: template, context-based analysis model (CBAM), analysis module

CBAM = why + how


= **Analysis Context**

+ Analysis Subsystems (ABBs, etc.)

+ **Associativity Linkages**

- Can be new, reused, or adapted template
- Instance can contain one or more runs

Outline

- ◆ Analysis Integration Challenges
- ◆ Introduction to Constrained Objects (COBs)
- ◆ Overview of COB-based XAI
- ◆ Example Applications 
 - ◆ Electronic Packaging Thermomechanical Analysis
 - ◆ Aerospace Structural Analysis
- ◆ Summary

STEP AP 210

PWA/B Design Information

Physical

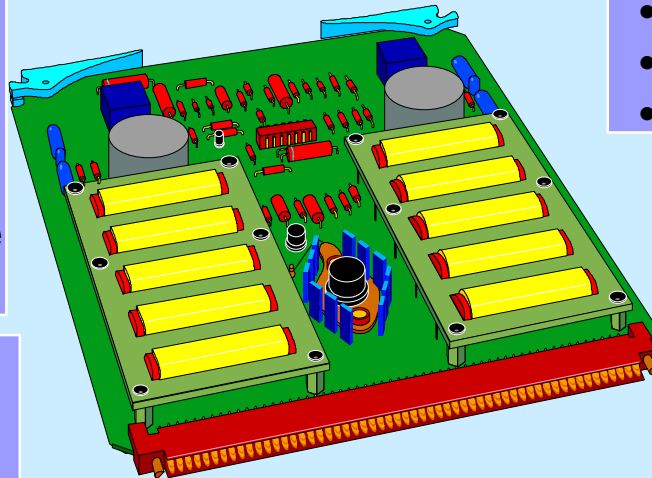
- Component Placement
- Bare Board Geometry
- Layout items
- Layers non-planar, conductive & non-conductive
- Material product

Geometry

- Geometrically Bounded 2-D Shape
- Wireframe with Topology
- Advanced BREP Solids
- Constructive Solid Geometry

Product Structure/Connectivity

- Functional
- Packaged



Part

- Functionality
- Termination
- Shape 2D, 3D
- Single Level Decomposition
- Material Product
- Characteristics

Configuration Mgmt

- Identification
- Authority
- Effectivity
- Control
- Requirement Traceability
- Analytical Model
- Document References

Requirements

- Design
- Allocation
- Constraints
- Interface

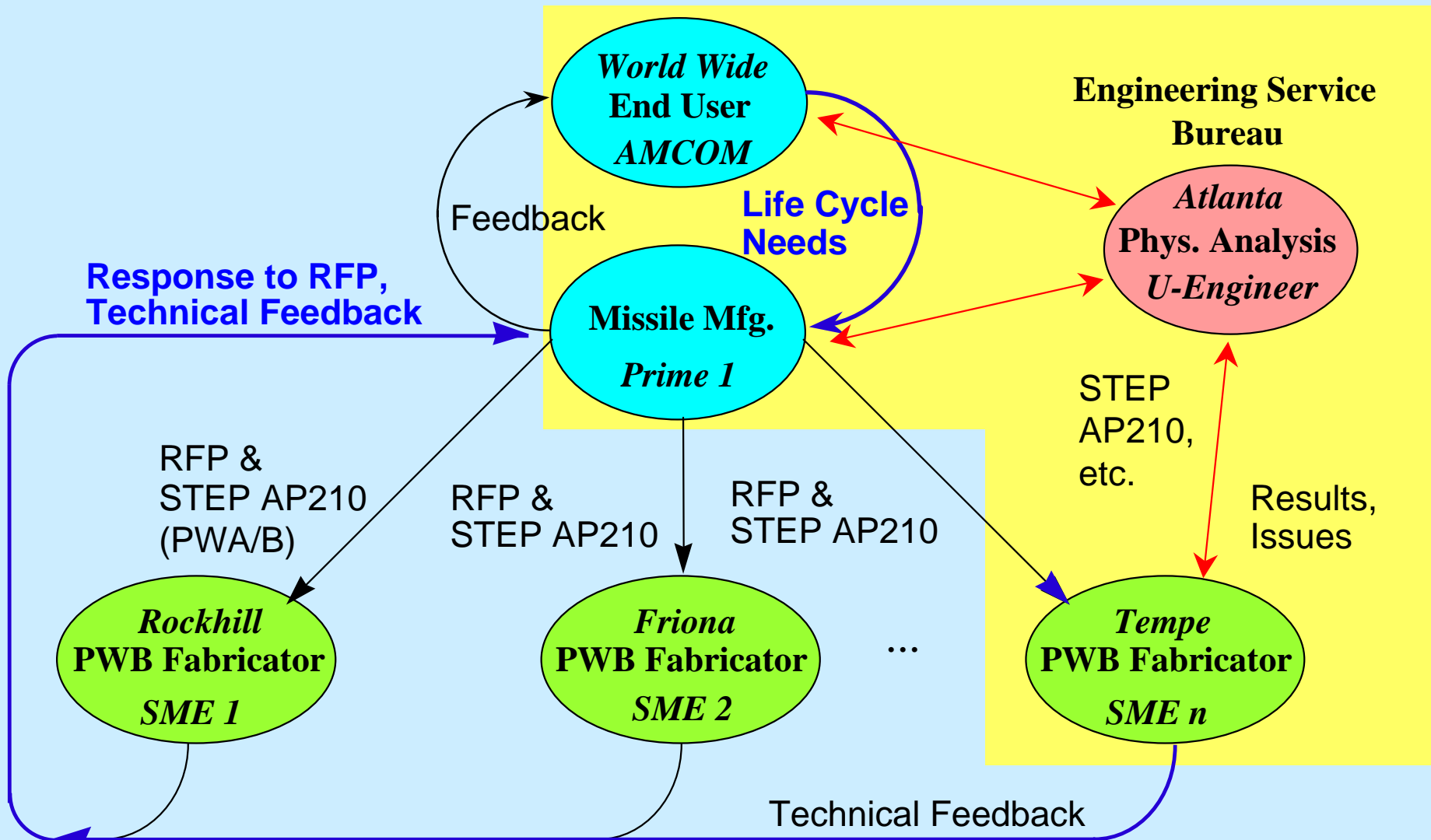
Technology

- Fabrication Design Rules
- Product Design Rules

ProAM Scenario

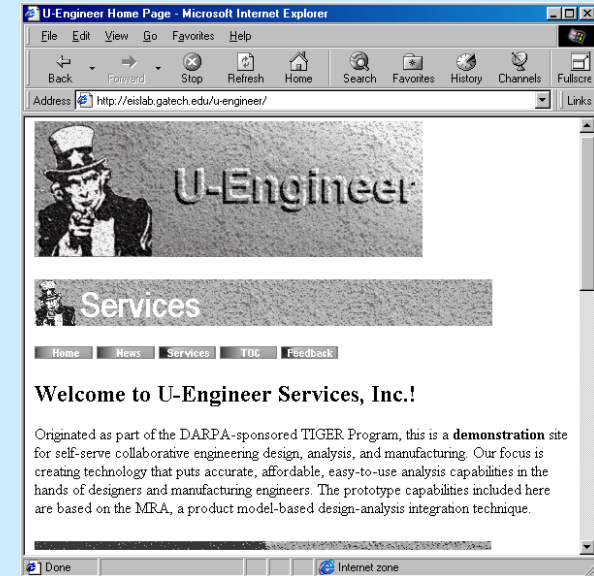
Highly Automated Internet-based Analysis Modules

ProAM Focus



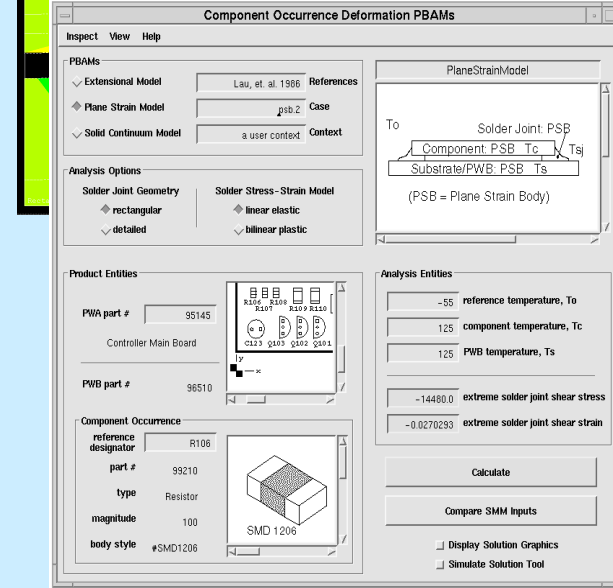
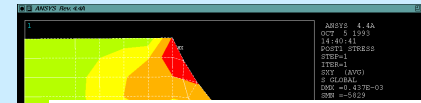
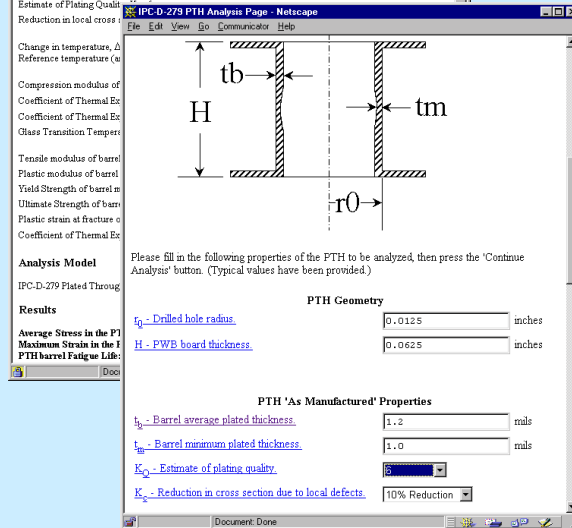
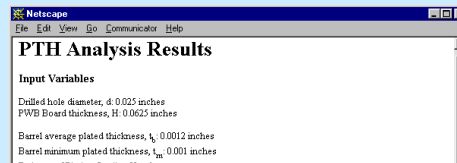
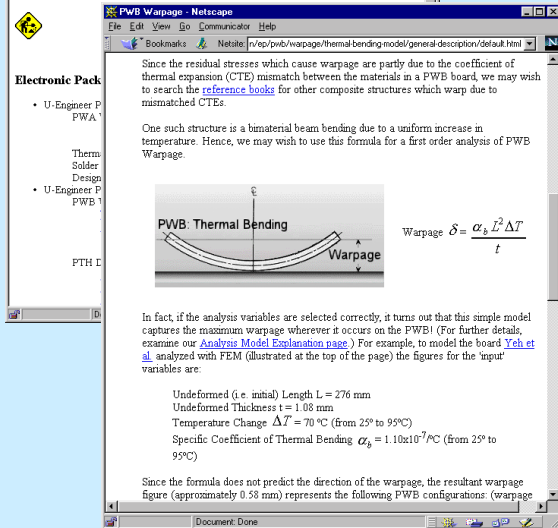
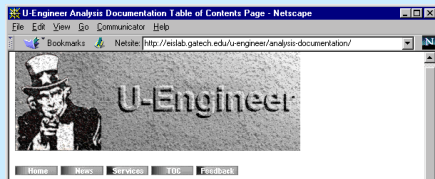
Internet-based Engineering Service Bureaus (ESBs)

- ◆ Self-serve analysis
 - Pre-developed analysis modules in product & process contexts
 - Available via the Internet
 - Standards-driven (STEP, GenCAM ...):
 - » Reduce manual data entry
 - » Highly automated plug-and-play usage
 - Enabled by X-analysis integration technology
- ◆ Pay-per-use and/or period
 - Costs averaged across customer base
- ◆ Full-serve analysis as needed



u-engineer.com

ProAM Pilot Commercial ESB

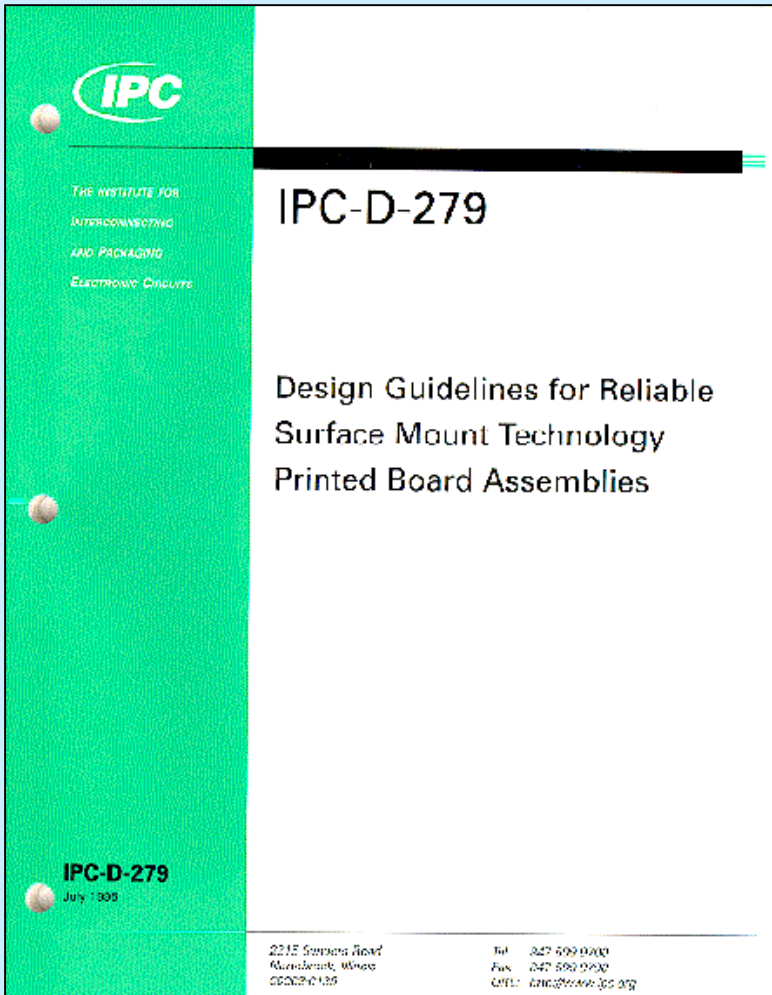


Analysis Documentation

Ready-to-Use Analysis Modules

Lower cost, better quality, fewer delays in supply chain

IPC-D-279 Plated Through Holes/Vias Analysis Guide



PTH/PTV Fatigue Life Estimation

$$\sigma_{avg} = \frac{\left[(\alpha_E - \alpha_{Cu}) \Delta T + S_y \cdot \frac{E_{Cu} - E_{Cu}'}{E_{Cu} \cdot E_{Cu}'} \right] \cdot A_E \cdot E_E \cdot E_{Cu}'}{A_E \cdot E_E + A_{Cu} \cdot E_{Cu}'}$$

$$\Delta \epsilon_{avg} = \frac{(\alpha_E - \alpha_{Cu}) \Delta T \cdot A_E \cdot E_E - S_y \cdot A_{Cu} \cdot \frac{E_{Cu} - E_{Cu}'}{E_{Cu}}}{A_E \cdot E_E + A_{Cu} \cdot E_{Cu}'}$$

$$N_f^{-0.6} D_f^{0.75} + 0.9 \frac{S_u}{E} \left[\frac{e^{D_f}}{0.36} \right]^{0.1785 \log \frac{10^5}{N_f}} - \Delta \epsilon = 0$$

$$N_f(x\%) = N_f(50\%) \left[\frac{\ln(1 - 0.01x)}{\ln(0.5)} \right]^{\frac{1}{\beta}}$$

Product Data-Driven IPC-D-279 PTH Analysis Module

<?XML!>

GenCAM/GenX



Xparse

JavaScript
parsing

IPC-D-279 PTH Analysis Module

File Edit View

Back Forward

Address <C:\Data\genx\ver05genx\pwr\pwrpth.htm>

Edit this GenX File if desired and hit Process!

```
<?xml version="1.0"?>
<!DOCTYPE GenX SYSTEM "genx.dtd">
<GenX>
  <HEADER GENX_VERSION="0.h"
  GENERATEDBY_SOFTWARE="GTXML"
  GENERATEDBY_SOFTWARE_VERSION="Andy1"
  DIMENSION="THOU" GRID_VALUE="50"
  ANGLEUNITS="DEGREES" HISTORY="1" >
    <ASSEMBLY_DEF
  USEDIN_NAME="C100" NAME="Modem C100
  mrboard" NUMBER="11149-14811" REVISION="Rev
  566g 20">
      <ATTRIBUTE GROUP="alpha"
  NAME="m_part" VALUE="BIS 9600" />
      <ATTRIBUTE GROUP="alpha"
```

Process! (May take some time on large GenX files)

PTH Geometry

led	0.0125	inc
us.		
H - PWB		
board	0.0625	inc
thickness.		

PTH "As Manufactured" Properties

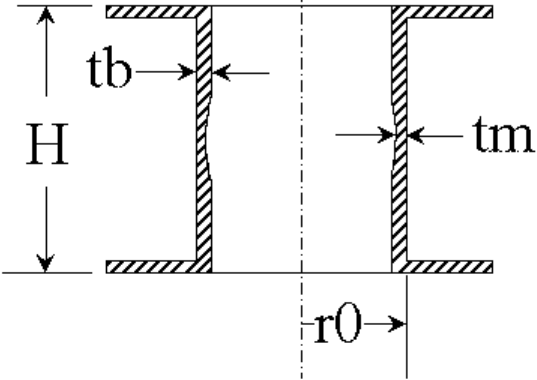
t ₂ - Barrel		
average	1.2	mi
plated		

My Computer

- ◆ Data Driven aspect:
 - Web Browser
 - Processes Neutral File
 - + Local Browser Computation
 - + Less Errors than manual entry
 - + Exhaustive search
 - + Data Compression (e.g. 100x)
 - + Security

Web-based Analysis Results

IPC-D-279 PTH Analysis Page - Netscape



Please fill in the following properties of the PTH to be analyzed, then press the 'Continue Analysis' button. (Typical values have been provided.)

PTH Geometry

[r₀ - Drilled hole radius.](#) inches

[H - PWB board thickness.](#) inches

PTH 'As Manufactured' Properties

[t_b - Barrel average plated thickness.](#) mils

[t_m - Barrel minimum plated thickness.](#) mils

[K_Q - Estimate of plating quality.](#)

[K_c - Reduction in cross section due to local defects.](#)

Netscape

PTH Analysis Results

Input Variables

Drilled hole diameter, d : 0.025 inches
PWB Board thickness, H : 0.0625 inches

Barrel average plated thickness, t_b : 0.0012 inches
Barrel minimum plated thickness, t_m : 0.001 inches
Estimate of Plating Quality, K_Q : 6
Reduction in local cross sectional area due to plating or drilling defects, K_c : 10 %

Change in temperature, ΔT : 200°C
Reference temperature (ambient), T_{ref} : 25°C

Compression modulus of resin, E_r : 500000 psi
Coefficient of Thermal Expansion of resin, α_r below T_g : 0.000067 /°C
Coefficient of Thermal Expansion of resin, α_r above T_g : 0.000315 /°C
Glass Transition Temperature, T_g : 137 °C

Tensile modulus of barrel material, E_b : 3000000 psi
Plastic modulus of barrel material, E_b^p : 100000 psi
Yield Strength of barrel material, S_y : 25000 psi
Ultimate Strength of barrel material, S_u : 41000 psi
Plastic strain at fracture of barrel material, D_f : 0.203
Coefficient of Thermal Expansion of barrel material, α_b : 0.000017 /°C

Analysis Model

IPC-D-279 Plated Through Hole Model

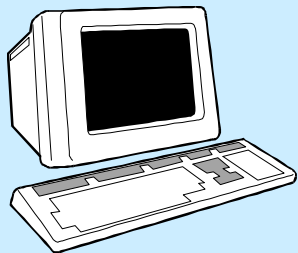
Results

Average Stress in the PTH barrel: 30.0317e3 psi
Maximum Strain in the PTH barrel: 0.121682
PTH barrel Fatigue Life: 10.61e3 cycles to 50% failure probability.

Analysis Data Flow

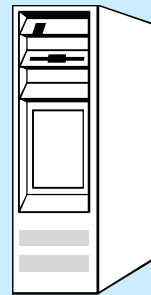
Web-based Approach

**SME
Client**



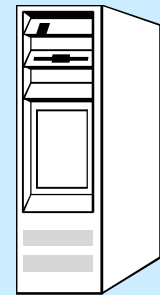
Pentium PC
Web Browser

**ESB Web
Server**



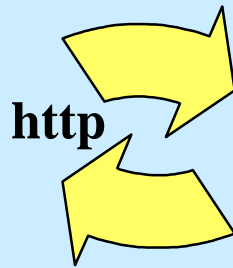
Pentium PC
httpd, etc.

**ESB Analysis
Server**



Sun SPARCstation
Mathematica

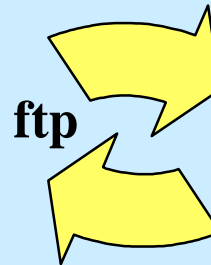
html form



http

html page

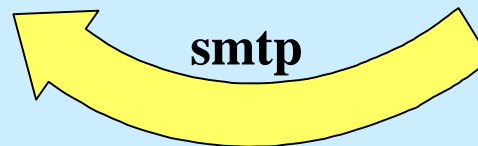
**Analysis Tool
script**



ftp

html page

**email
notification**

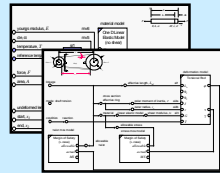


smtp

ProAM Design-Analysis Integration

Electronic Packaging Examples: PWA/B

ECAD Tools
Mentor Graphics,
Accel*



**Modular, Reusable
Template Libraries**

**Analysis Modules (CBAMs)
of Diverse Mode & Fidelity**

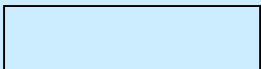


STEP AP210,
GenCAM**,
PDF*

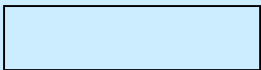
PWB Layup Tool

LayerID	Min Thickness	Normal Thickness	Max Thickness	Layer Function
Core1	0.0000	0.0000	0.0000	Core
Prepreg1	0.0000	0.0000	0.0000	Prepreg
Core2	0.0000	0.0000	0.0000	Core
Prepreg2	0.0000	0.0000	0.0000	Prepreg
Core3	0.0000	0.0000	0.0000	Core
Prepreg3	0.0000	0.0000	0.0000	Prepreg
Core4	0.0000	0.0000	0.0000	Core
Prepreg4	0.0000	0.0000	0.0000	Prepreg
Core5	0.0000	0.0000	0.0000	Core
Prepreg5	0.0000	0.0000	0.0000	Prepreg

Laminates DB



Materials DB



**Analyzable
Product Model**



**Solder Joint
Deformation**

1D,
2D,
3D

**PWB
Warpage**

1D,
2D

**PTH
Deformation
& Fatigue****

1D,
2D

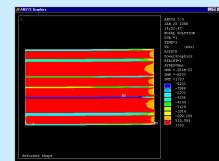
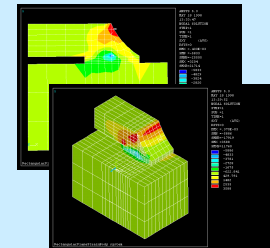
Analysis Tools

**General Math
Mathematica**

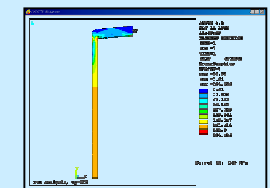
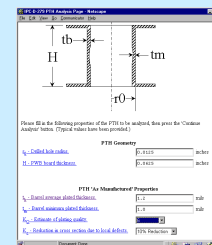
FEA Ansys

XaiTools

Module Name	Mode	Fidelity
Solder Joint Deformation	1D, 2D, 3D	High
PWB Warpage	1D, 2D	High
PTH Deformation & Fatigue	1D, 2D	High



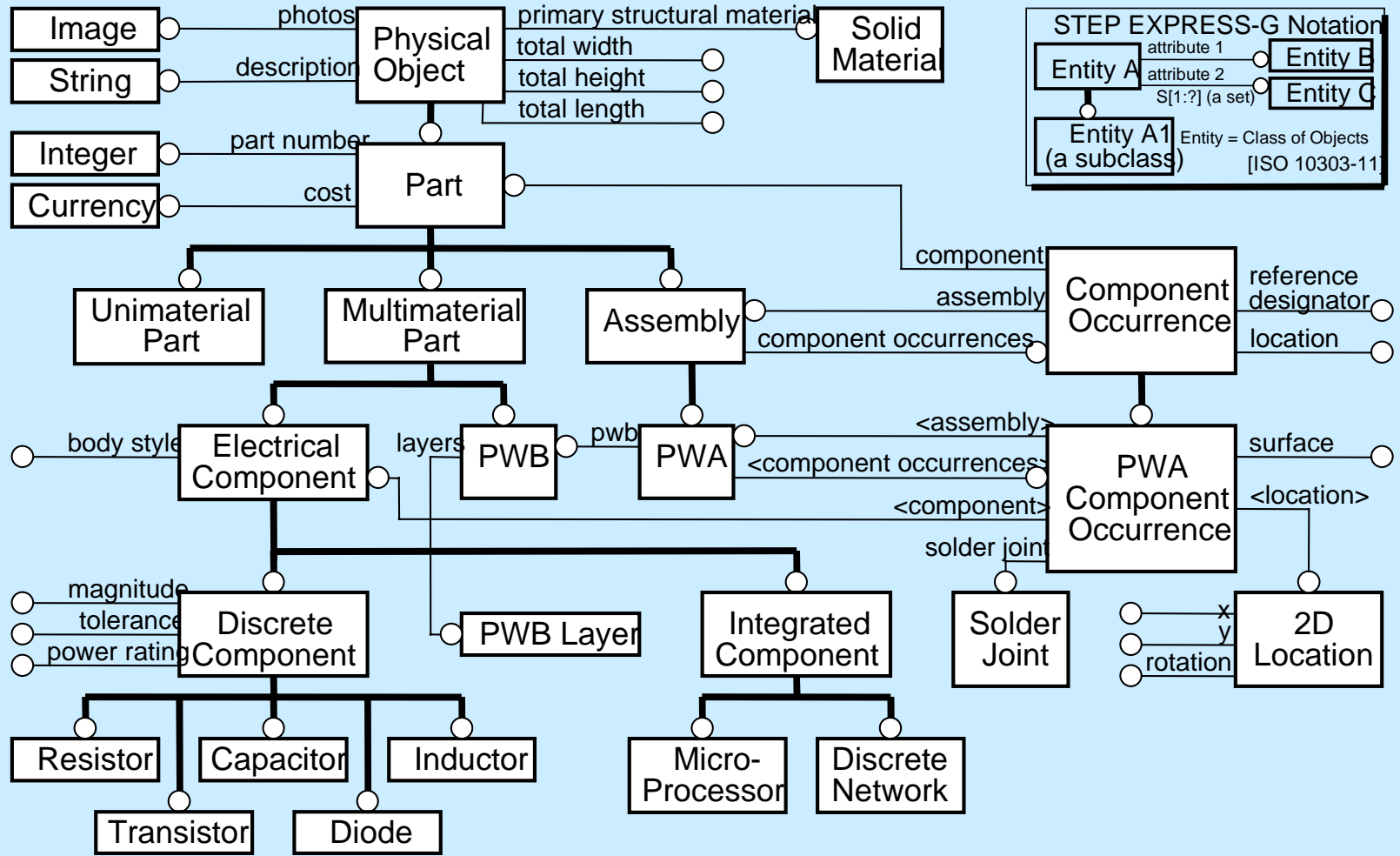
Parameter	Value
Print Temperature	150 (C)
Prepreg Temperature	150 (C)
Prepreg Moisture	0.01 (g/g)
Prepreg Thickness	0.125 (mm)
Prepreg Density	1.2 (g/cm3)
Prepreg Modulus	1.5e9 (Pa)
Prepreg Poisson's Ratio	0.3
Prepreg Thermal Expansion	15 (ppm/C)
Prepreg Thermal Contraction	15 (ppm/C)
Prepreg Thermal Shrinkage	15 (ppm/C)
Prepreg Thermal Growth	15 (ppm/C)
Prepreg Thermal Anisotropy	15 (ppm/C)
Prepreg Thermal Hysteresis	15 (ppm/C)
Prepreg Thermal Relaxation	15 (ppm/C)
Prepreg Thermal Creep	15 (ppm/C)
Prepreg Thermal Aging	15 (ppm/C)
Prepreg Thermal Fatigue	15 (ppm/C)
Prepreg Thermal Strain	15 (ppm/C)
Prepreg Thermal Stress	15 (ppm/C)
Prepreg Thermal Strain Rate	15 (ppm/C)
Prepreg Thermal Stress Rate	15 (ppm/C)
Prepreg Thermal Strain Rate	15 (ppm/C)
Prepreg Thermal Stress Rate	15 (ppm/C)



* = Item not available in XaiTools prototype (all others have working examples)

** = Item available via U-Engineer.com, but not in XaiTools prototype

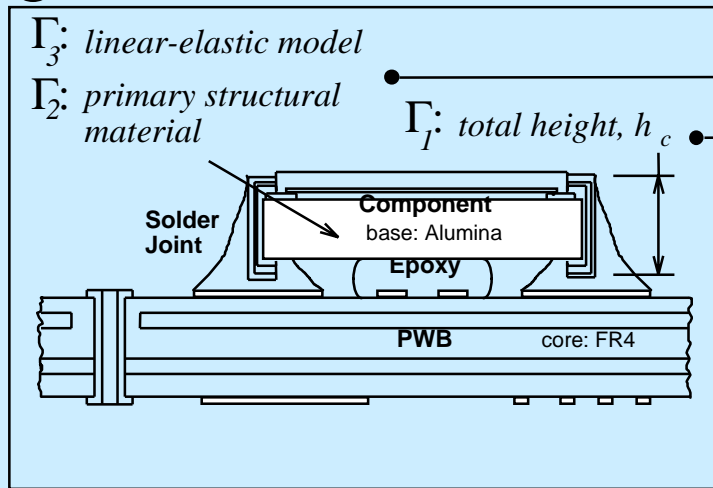
PWA/B Analyzable Product Model (partial)



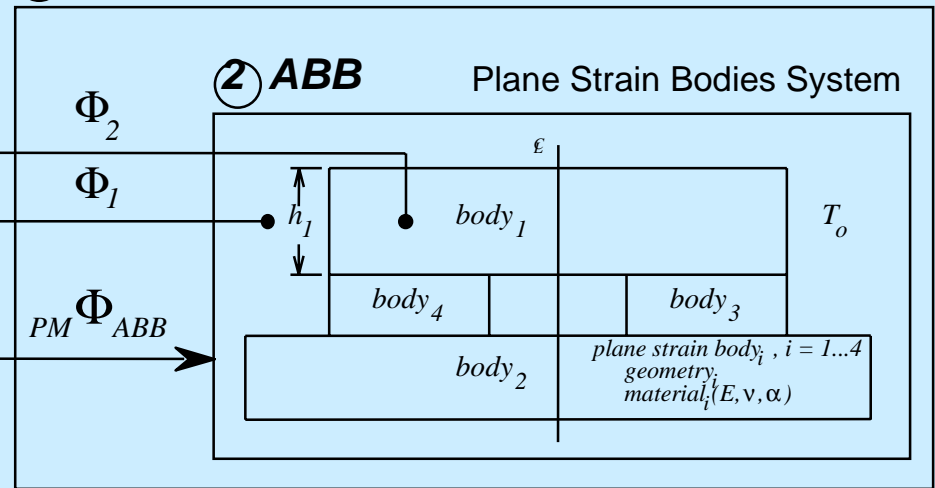
Solder Joint Deformation CBAM

Informal Associativity Mapping

③ APM PWA Component Occurrence

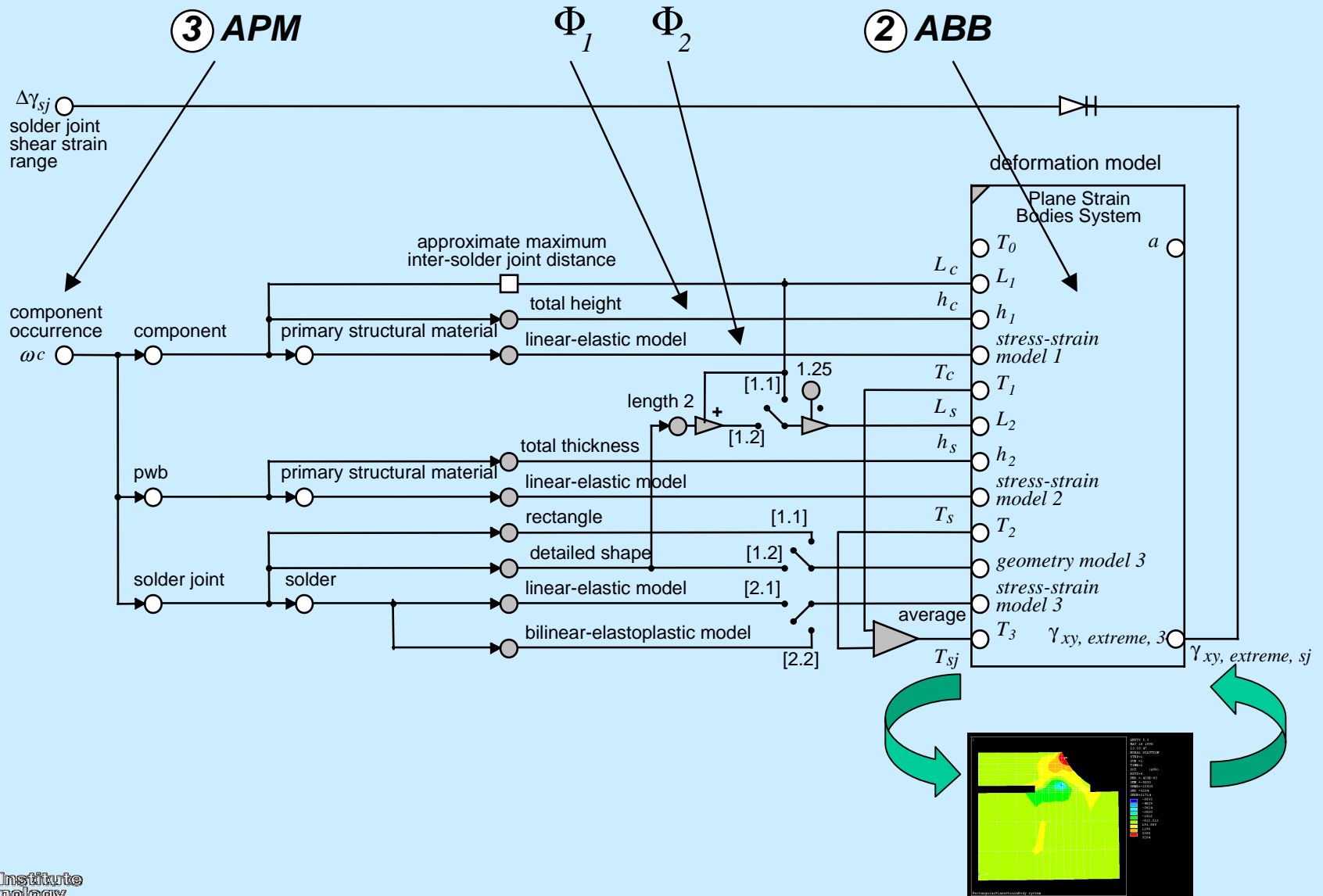


④ CBAM Component Occurrence Plane Strain Model



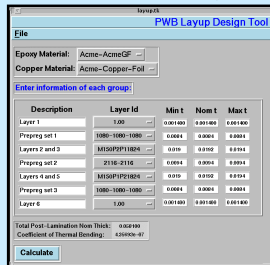
Solder Joint Deformation CBAM

Constraint Schematic

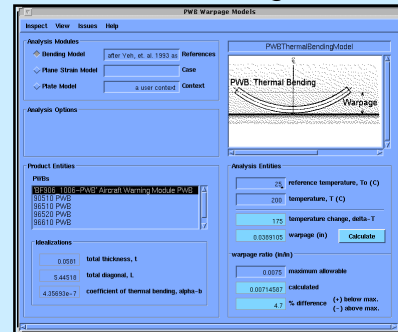


Iterative Design & Analysis with Multifidelity PWB Warpage Modules (CBAMs)

PWB Layup Design Tool



Thermal Bending Model



Quick Formula-based Check

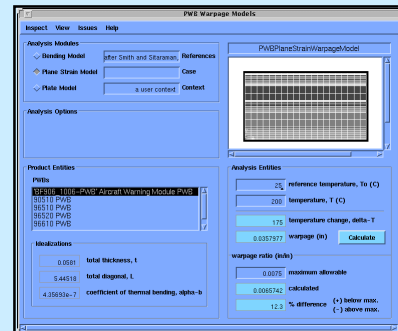
$$\delta = \frac{\alpha_b L^2 \Delta T}{t}$$

$$\alpha_b = \frac{\sum w_i \alpha_i y_i}{t/2 \sum w_i}$$

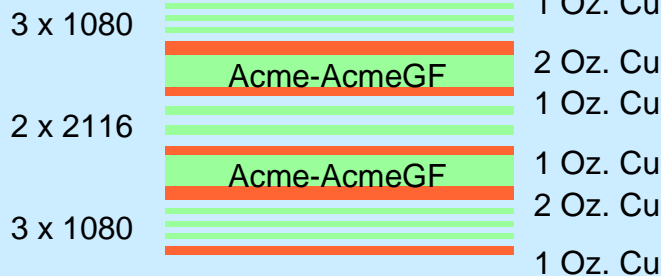
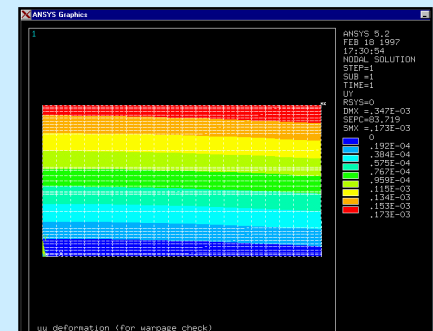
Analyzable
Product
Database

PWB Warpage Modules

Plain Strain Model

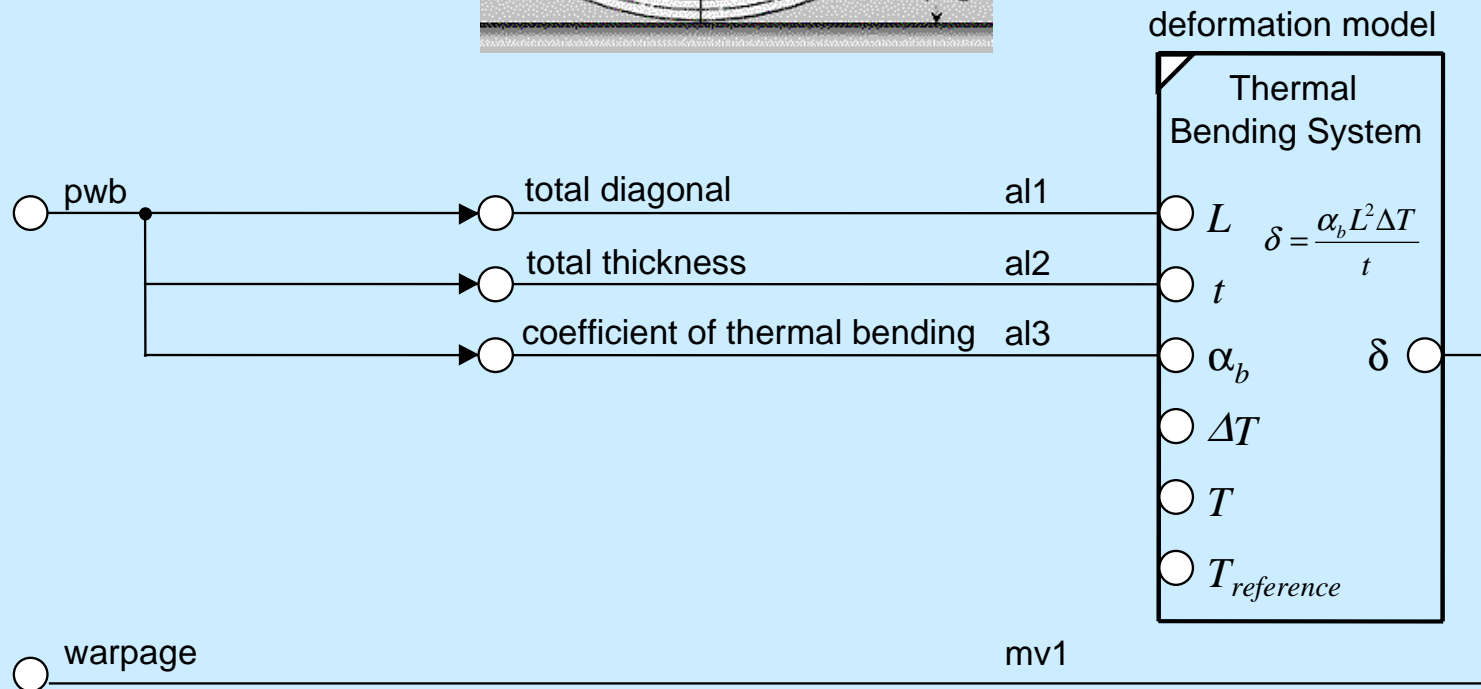
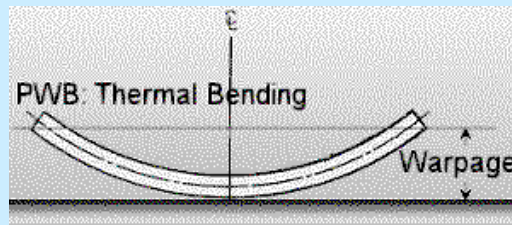


Accurate FEA Check



PWB Warpage CBAM

PWB Thermal Bending Model (1D formula-based)



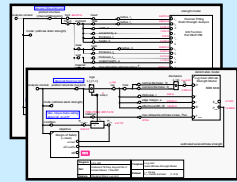
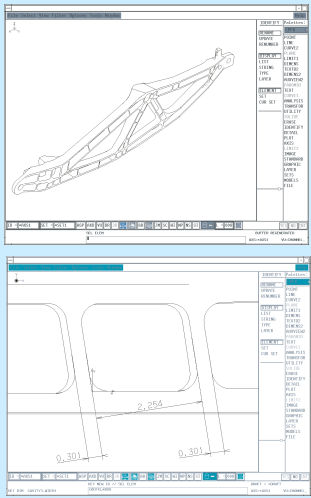
Flexible High Diversity Design-Analysis Integration

Aerospace Examples:

"Bike Frame" / Flap Support Inboard Beam

MCAD Tools

CATIA



Modular, Reusable Template Libraries

Analysis Modules (CBAMs) of Diverse Feature:Mode, & Fidelity

XaiTools

Analysis Tools

In-House Tool Template*
or

General Math
Mathematica

Analyzable Product Model



Materials DB

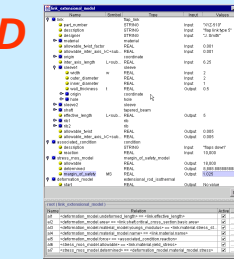
MATDB-like

Fasteners DB

FASTDB-like

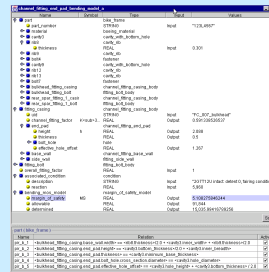
1.5D

Lug:
Axial/Oblique;
Ultimate/Shear



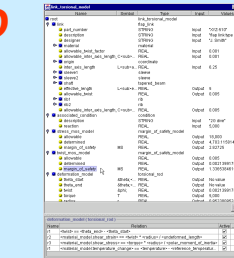
1.5D

Fitting:
Bending/Shear

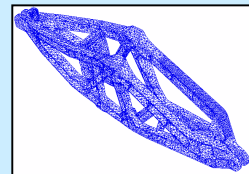


3D

Assembly:
Ultimate/
FailSafe/Fatigue*



FEA
Elfini*



* = Item not available in working prototype yet (all others have working examples)

Today's Fitting Catalog Documentation

from DM 6-81766 Design Manual

Calculation Steps

Categories of Idealized Fittings

End Pad Analysis – Two margins of safety, one from the bending stress and one for the shear stress will be calculated. Unless otherwise noted, do not extrapolate the K_3 curves.

1. End Pad Analysis – Bending

Step 1: Compute $\frac{r_1}{h}$ and $\frac{b}{h}$.

Step 2: From FIGURE 3-3 read K_3 . If b/h is less than 1.0, use the K_3 value for b/h equal to 1.0. If r_1/h is greater than 0.4, use the K_3 value for r_1/h equal to 0.4.

Step 3: Determine the bending stress, f_{be} :

$$f_{be} = K_3 (2e - t_b) \frac{P}{h t_e^2}$$

Step 4: Determine the allowable apparent bending stress, F_b , from the plastic bending curves in the appropriate DM-4XXX using $K = 1.5$ and an actual extreme fiber stress equal to F_{lu} .

Step 5: The margin of safety is

$$M.S. = \frac{F_b}{j_m f_{be}} - 1$$

2. End Pad Analysis – Shear

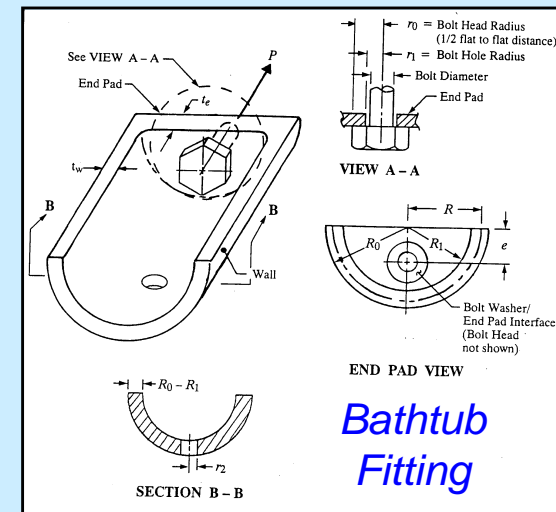
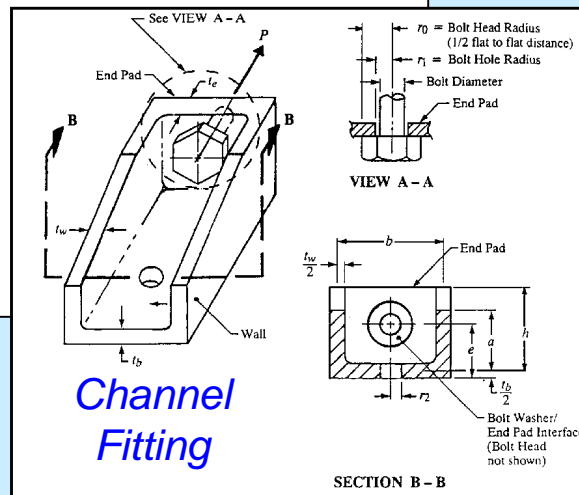
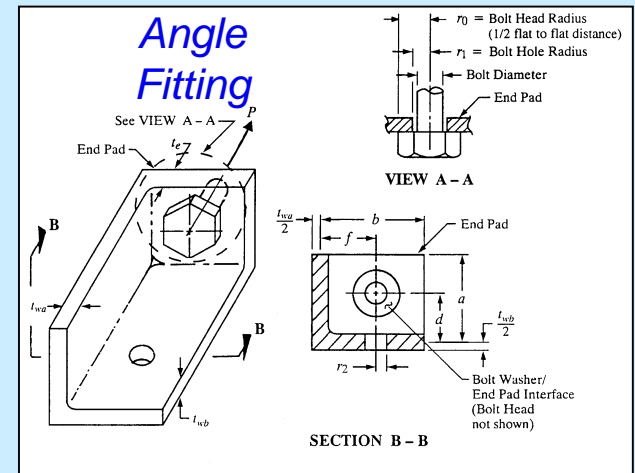
Step 1: Actual shear stress is

$$f_{se} = \frac{P}{2\pi r_0 t_e}$$

Step 2: The margin of safety is

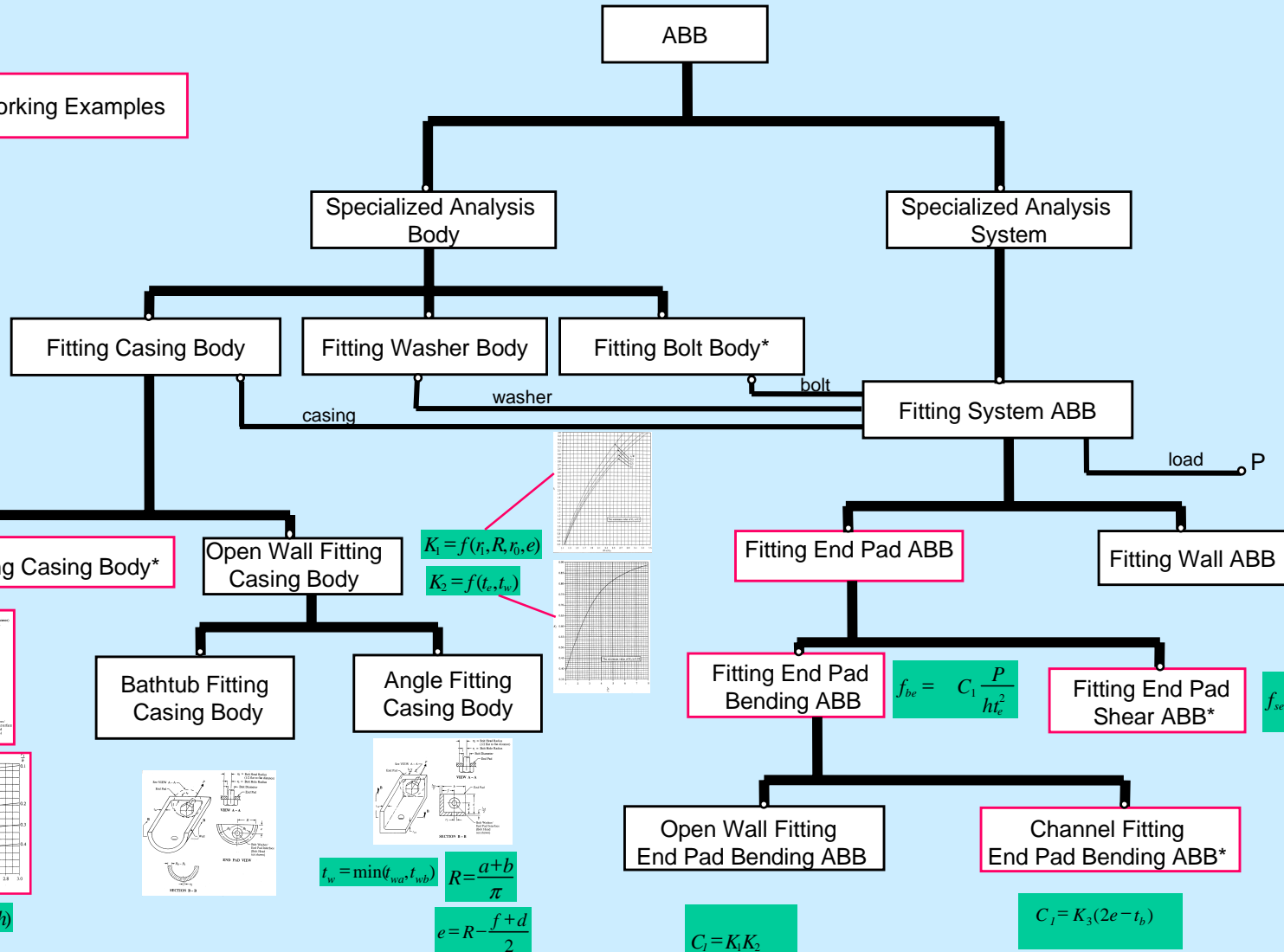
$$M.S. = \frac{F_{su}}{j_m f_{se}} - 1$$

Channel Fitting End Pad Bending Analysis



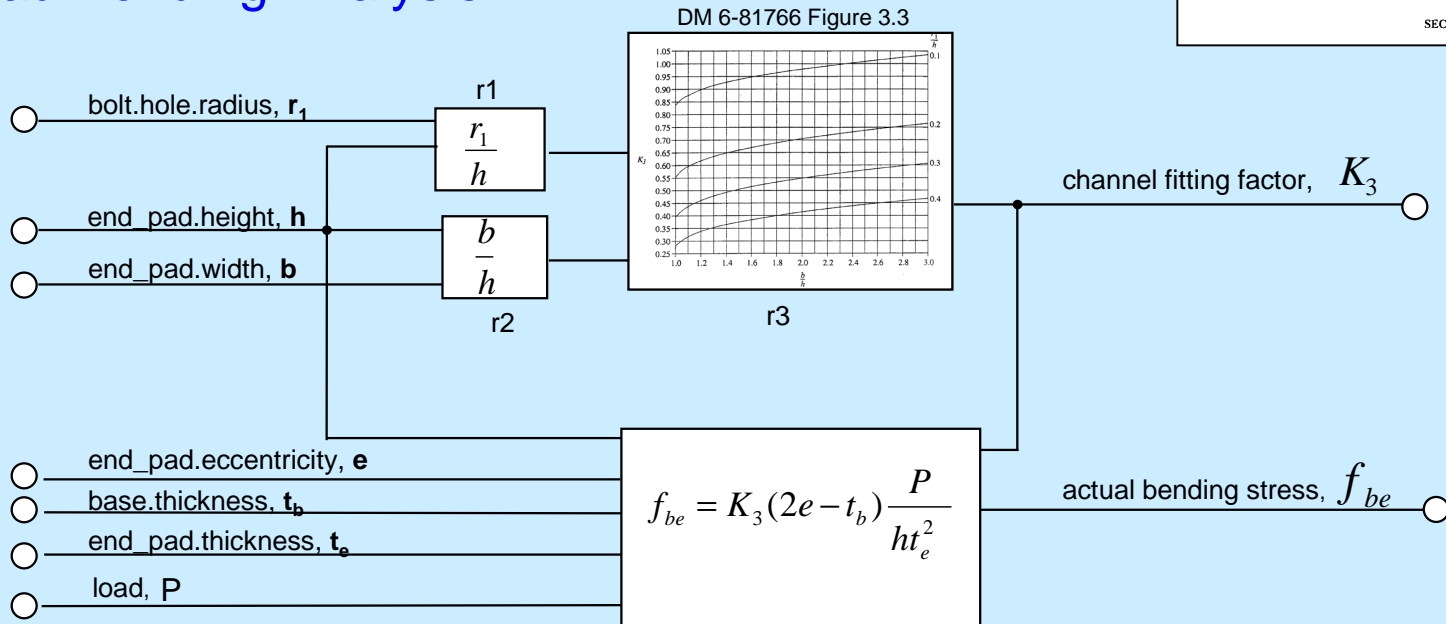
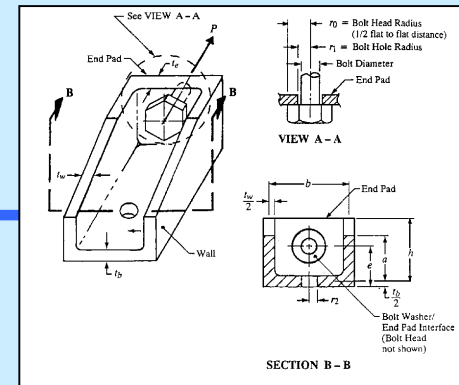
Object-Oriented Hierarchy of Fitting ABBs

* = Working Examples

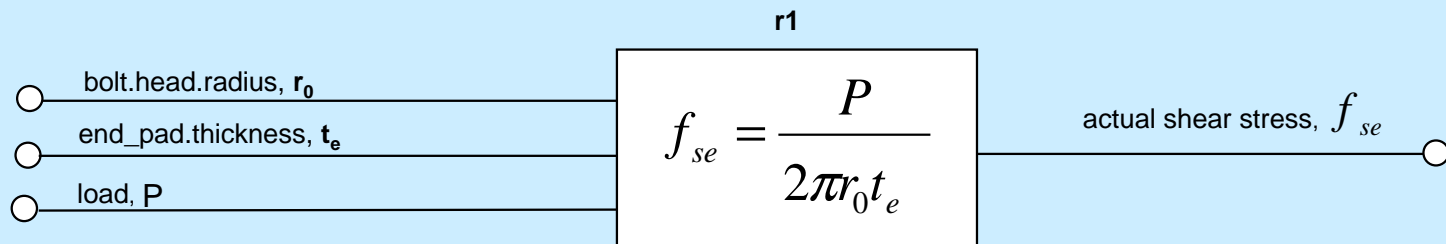


Channel Fitting System ABBs

End Pad Bending Analysis

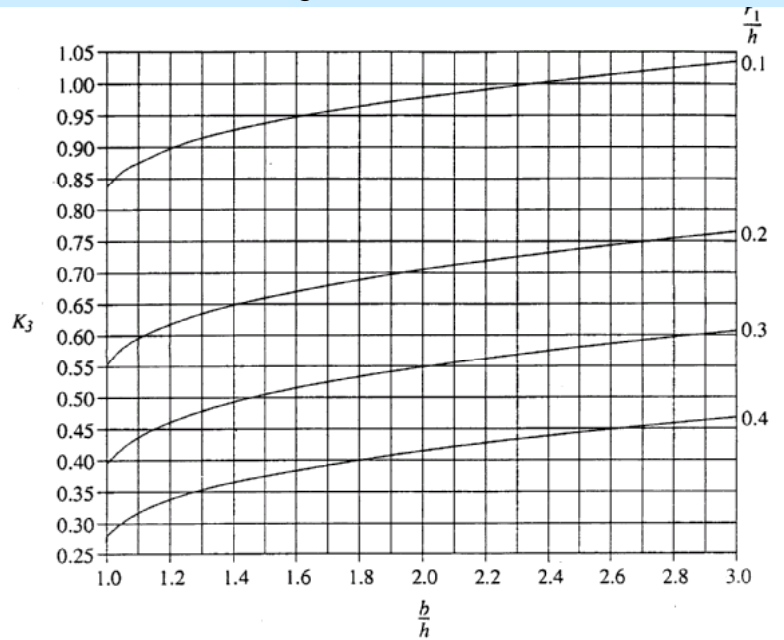


End Pad Shear Analysis

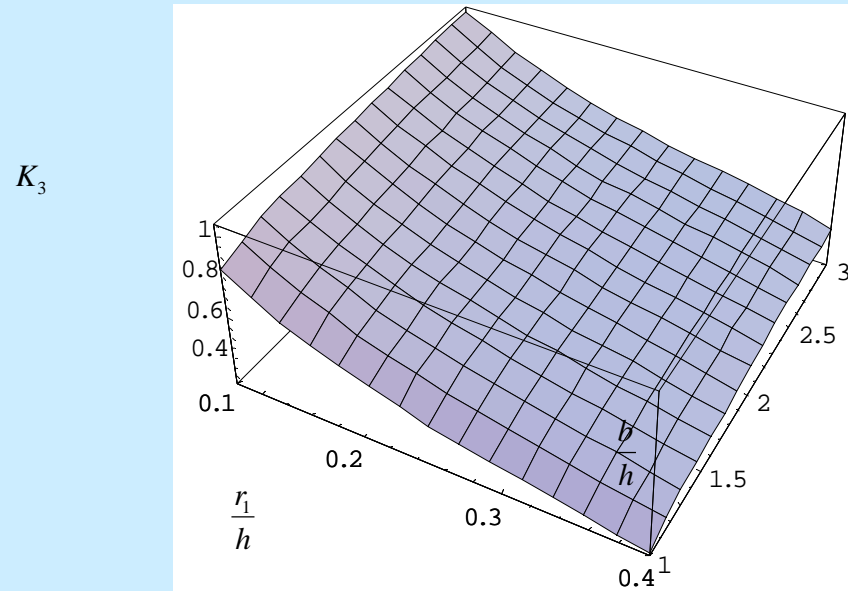


Implementation of Channel Fitting Factor, K_3 as a Reusable Relation in an External Tool

Design Manual Curves

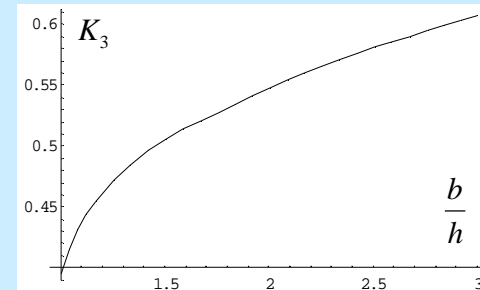
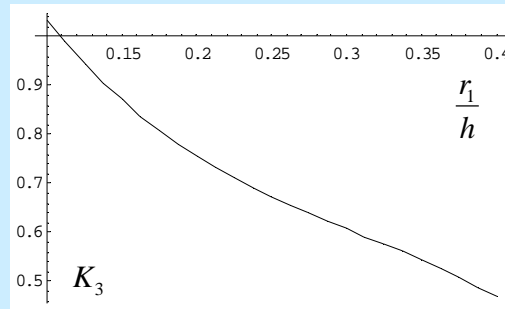


Mathematica Implementation

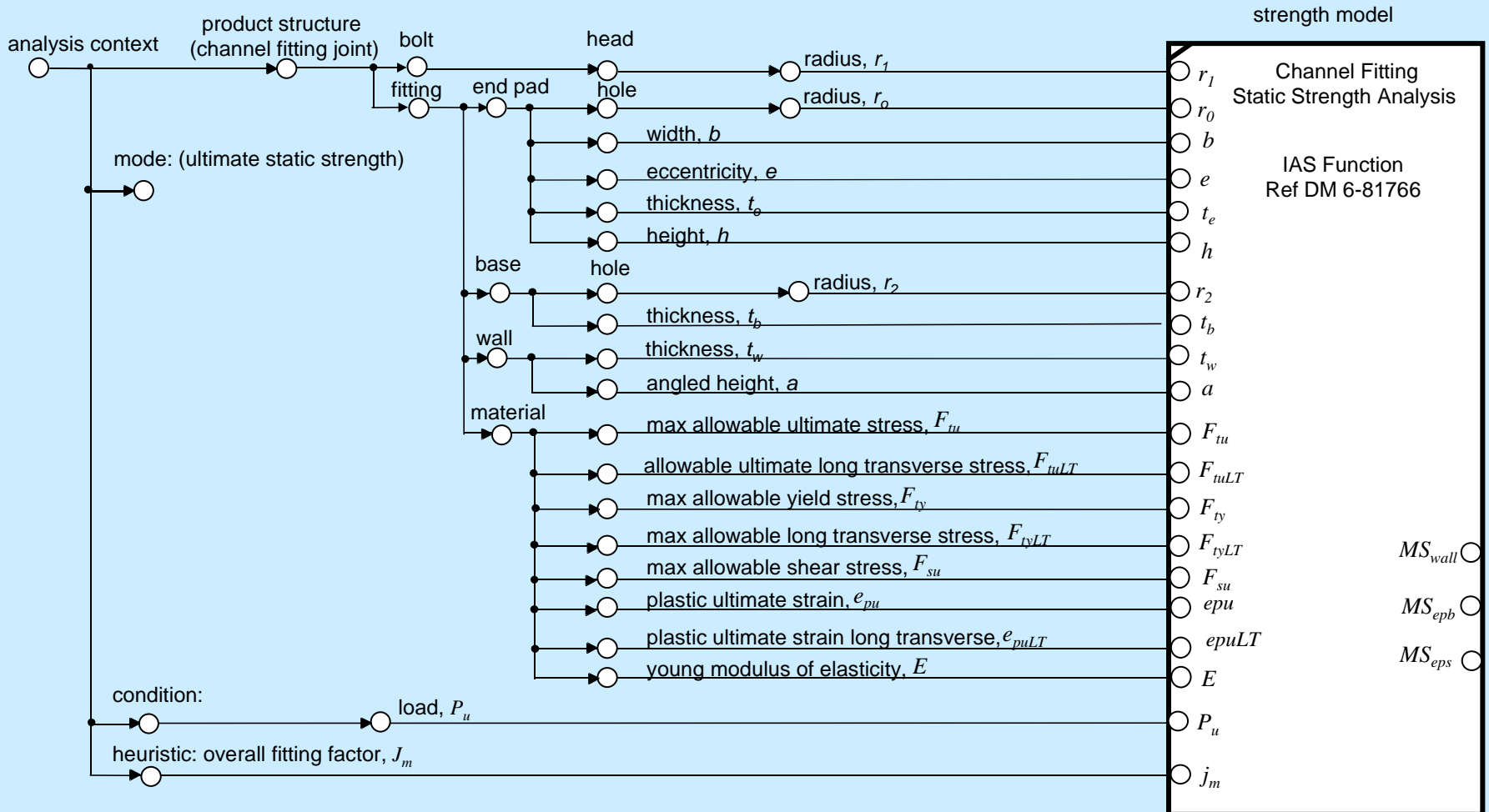


$r_1/h = 0.1$		$r_1/h = 0.2$		$r_1/h = 0.3$		$r_1/h = 0.4$	
b/h	K_3	b/h	K_3	b/h	K_3	b/h	K_3
1.0	0.836	1.0	0.5525	1.0	0.395	1.0	0.28
1.04	0.8575	1.04	0.575	1.04	0.415	1.04	0.2975
1.1	0.8752	1.1	0.596	1.1	0.437	1.1	0.317
1.2	0.898	1.2	0.618	1.2	0.461	1.18	0.335
1.34	0.92	1.34	0.641	1.34	0.485	1.34	0.359
1.5	0.938	1.5	0.66	1.5	0.505	1.5	0.375
1.8	0.9645	2.0	0.705	2.02	0.55	2.0	0.415
2.1	0.985	2.54	0.74	2.4	0.575	2.52	0.445
3.0	1.035	3.0	0.756	3.0	0.607	3.0	0.468

DM 6-81766 Graph (Figure 3.3)



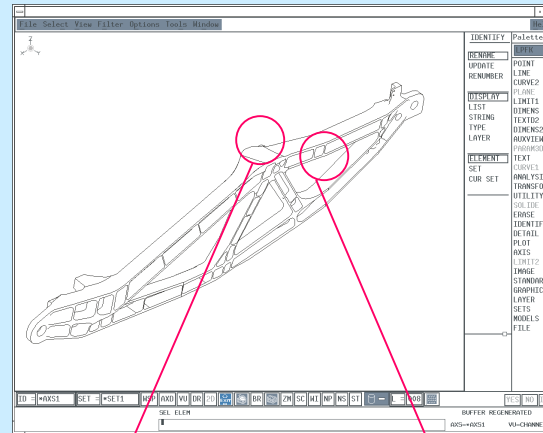
Reusable Channel Fitting Analysis Module (CBAM)



Application to an Aerospace Part

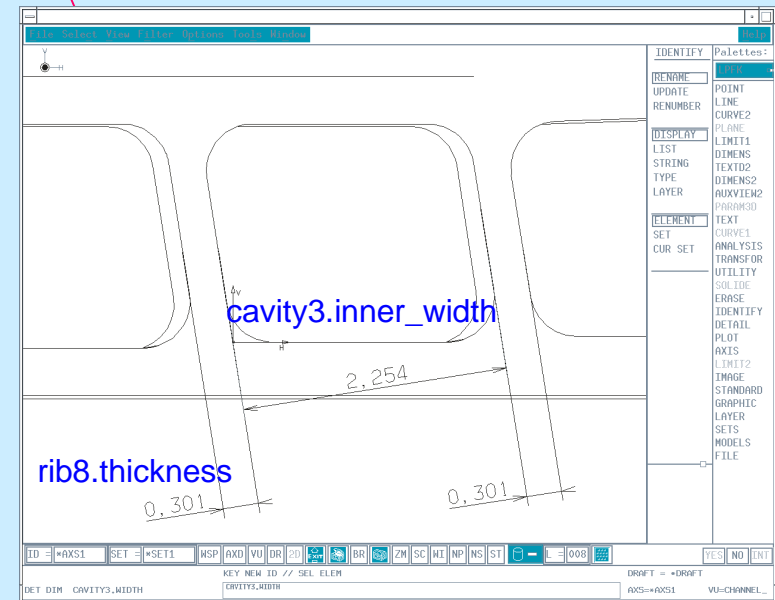
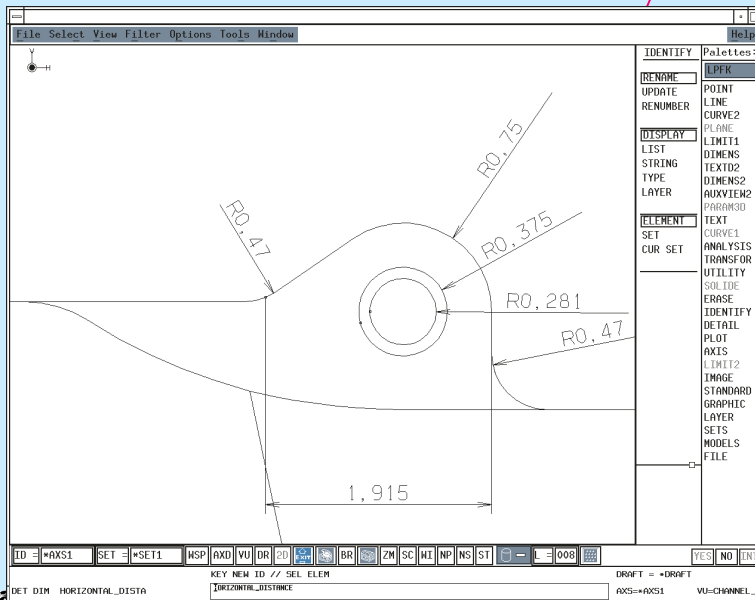
APM Associativity with Tagged CATIA Model

Bike Frame
CATIA CAD Model



Diagonal Brace Lug

Bulkhead Fitting Casing

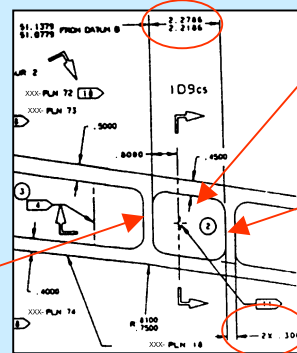
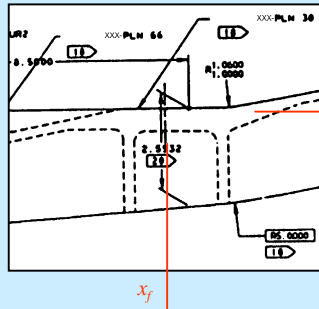
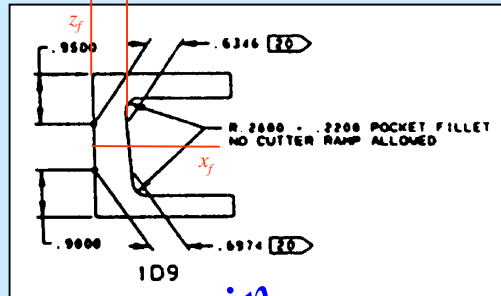


Explicit Capture of Idealizations

(part-specific template adaptation in bike frame case)

Features/Parameters Tagged in CAD Model (CATIA)

cavity3.base.minimum_thickness



cavity3.width, w_3

cavity 3

rib9

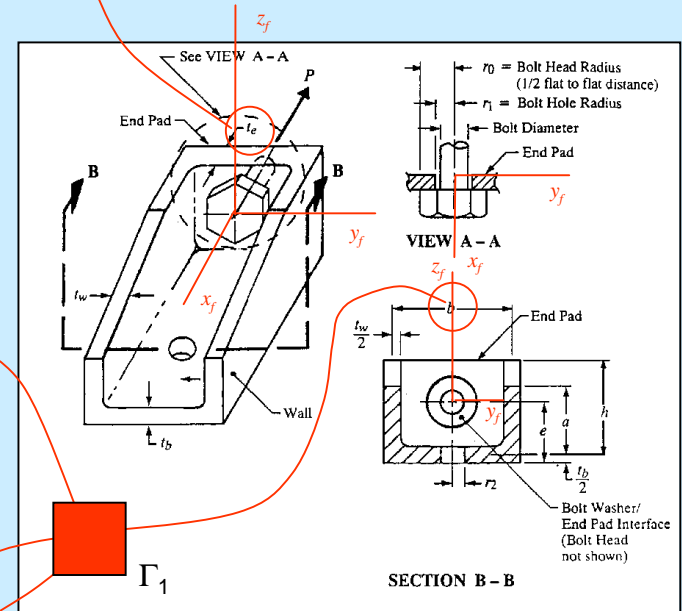
rib8

$= t_8, t_9$

rib8.thickness

rib9.thickness

Idealized Features



Tension Fitting Analysis

Γ_i - Relations between CAD parameters and idealized parameters

$$\Gamma_1 : b = \text{cavity3.inner_width} + \text{rib8.thickness}/2 + \text{rib9.thickness}/2$$

$$\Gamma_2 : t_e = \text{cavity3.base.minimum_thickness}$$

Missing in Today's Process

Today's Typical Fitting Analysis

Idealized CAD data manually transformed and input

Missing Design-Analysis Associativity

LINKAGE SUPPORT NO. 2 (INBOARD BEAM REF 123L4S67)
Bulkhead Assembly Attach Point at Upper Beam Location

BATHTUB TYPE TENSION FITTING ANALYSIS
REF: DM6-81766, "Tension-type fittings"

Material Properties & Geometry:		TENSION FITTING TYPE	
Ftu =	67000 PSI	Pu =	5960 LBS
FtuLT =	65000 PSI	E =	10000000 PSI
Fty =	57000 PSI	ro =	0.5240 IN
FtyLT =	52000 PSI	ri =	0.4375 IN
Fsu =	39000 PSI	r2 =	0.0000 IN
epu =	0.067 IN/IN	jm =	1.00
epuLT =	0.030 IN/IN	te =	0.500 IN
tw =	0.310 IN	tb =	0.307 IN
e =	1.267 IN	a =	1.770 IN
b =	2.440 IN	h =	2.088 IN

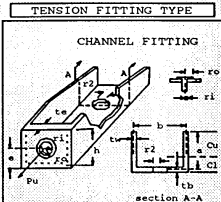


Diagram labels: A, A', r1, r2, b, t, cu, pu, fs, section A-A

Wall Tension Analysis:					
Anet =	1.846 IN ²	ftw =	3228 PSI	eta =	1.000
Agross =	1.846 IN ²	Rtw =	0.048 (Actual)		

Wall Bending Analysis:					
I =	0.649 IN ⁴	Kwall =	1.803	CU =	1.248 IN
mu =	3525 LB-IN	Fbw =	116247 PSI	CL =	0.676 IN
		Mu =	60428 LB-IN	c =	1.248 IN
		Rbw =	0.058 (Actual)		

Wall Bending & Tension Interaction:					
n =	1.25	***** PLASTIC BENDING ANALYSIS *****			
gamma =	0.915	Rtwu =	0.490 (Allowable)		
		Rbwu =	0.591 (Allowable)		
		Mswall =	9.17		

End Pad Bending Analysis:					
K3 =	0.591	***** PLASTIC BENDING ANALYSIS *****			
Kend =	1.500	fbe =	15038 PSI		
		Fbe =	91844 PSI	Msepb =	5.11

End Pad Shear Analysis:					
		fse =	3620 PSI	Mseps =	9.77

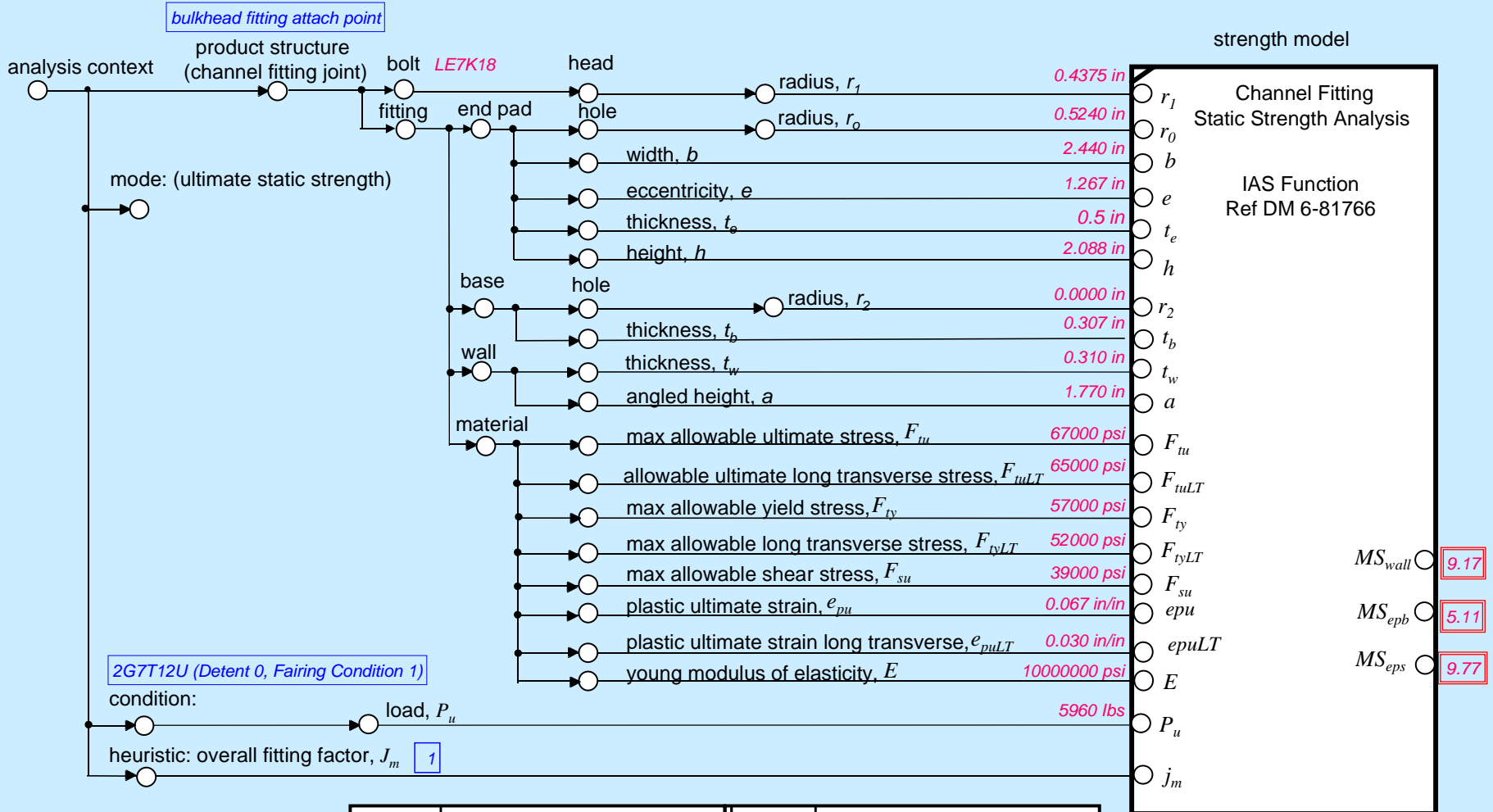
Allowable Load:			
		Pallow =	36395 LBS

WARNING: Edge distance 'h - e - tb/2' should be at least twice the hole DIAMETER (2(2ri)) from the free edge to prevent tension failure in wall.

Fastener is LE7K18 and represented as beam element number 362 in FEA model. Load considered is 2G7T12U intact (Detent 0, Fairing Condition 1) and is obtained from the FEA model axial beam loads.

ENGR.	NAME	12/20/96	REVISED	DATE	Outboard TE Flap, Support No. 2 Bulkhead Attachment Location to 123L4S67 ibbulk.tem ibbulk.dta ENGINEER DEVELOPED TEMPLATE	09-300
CHECK						
APR						
APR						PAGE 206
FCM	3734007-PROD	IAS				

CBAM Instance for Channel Fitting Analysis



Program	L29 -300	Template	Channel Fitting Static Strength Analysis
Part	Outboard TE Flap, Support No 2; Inboard Beam, 123L4567	Dataset	1 of 1
Feature	Bulkhead Fitting Joint		

Fitting Analysis

Using COB-based CBAMs

channel_fitting_end_pad_bending_model_a

Name	Symbol	Type	Input	Values
part		bike_frame		
part_number		STRING	Input	"123L4567"
material		material		
cavity3		cavity_with_bottom_hole		
rib8		cavity_rib		
thickness		REAL	Input	0.301
rib9		cavity_rib		
bolt4		fastener		
cavity9		cavity_with_bottom_hole		
rib12		cavity_rib		
rib13		cavity_rib		
bolt7		fastener		
bulkhead_fitting_casing		channel_fitting_casing_body		
bulkhead_fitting_bolt		fitting_bolt_body		
rear_spar_fitting_1_casing		channel_fitting_casing_body		
rear_spar_fitting_1_bolt		fitting_bolt_body		
fitting_casing		channel_fitting_casing_body		
uid		STRING	Input	"FC_007_bulkhead"
channel_fitting_factor	K_{3...}	REAL	Output	0.591338526537
end_pad		channel_fitting_end_pad		
height	h	REAL	Output	2.088
thickness		REAL	Output	0.5
bolt_hole		hole		
effective_hole_offset		REAL	Output	1.267
base_wall		channel_fitting_base_wall		
side_wall		fitting_side_wall		
fitting_bolt		fitting_bolt_body		
overall_fitting_factor		REAL	Input	1
associated_condition		condition		
description		STRING	Input	"2G7T12U intact: detent 0, fairing condition 1"
reaction		REAL	Input	5,960
bending_mos_model		margin_of_safety_model		
margin_of_safety	MS	REAL	Output	5.108275846244
allowable		REAL	Output	91,844
determined		REAL	Output	15,035.99416789256

Solve

Detailed CAD data from CATIA

Library data for materials & fasteners

Idealized analysis features in APM


Fitting & MoS ABBs

Explicit multidirectional associativity between detailed CAD data & idealized analysis features

part (bike_frame)

Name	Relation	Active
pir_b_1	<bulkhead_fitting_casing.base_wall.width> == <rib8.thickness>/2.0 + <cavity3.inner_width> + <rib9.thickness>/2.0	<input checked="" type="checkbox"/>
pir_b_2	<bulkhead_fitting_casing.end_pad.height> == <cavity3.bottom_thickness>/2.0 + <cavity3.inner_breadth>	<input checked="" type="checkbox"/>
pir_b_3	<bulkhead_fitting_casing.end_pad.thickness> == <cavity3.minimum_base_thickness>	<input checked="" type="checkbox"/>
pir_b_4	<bulkhead_fitting_casing.end_pad.bolt_hole.cross_section.diameter> == <cavity3.hole_diameter>	<input checked="" type="checkbox"/>
pir_b_5	<bulkhead_fitting_casing.end_pad.effective_hole_offset> == <cavity3.hole_height> + <cavity3.bottom_thickness> / 2.0	<input checked="" type="checkbox"/>

Outline

- ◆ Analysis Integration Challenges
- ◆ Introduction to Constrained Objects (COBs)
- ◆ Overview of COB-based XAI
- ◆ Example Applications
 - ◆ Electronic Packaging Thermomechanical Analysis
 - ◆ Aerospace Structural Analysis
- ◆ Summary 

Analysis Integration Summary

- ◆ Strong emphasis on X-analysis integration (XAI, DAI)
- ◆ Multi-Representation Architecture (MRA)
 - Addressing fundamental XAI issues
 - » Explicit representation of design-analysis associativity
 - General methodology --> Flexibility & broad application
- ◆ Relevant experience and advances
 - TIGER / ProAM product data-driven analysis (STEP AP210, etc.)
 - » Demonstration engineering service bureau (at Atlanta ECRC)
 - Object techniques for next generation aerospace analysis systems
- ◆ Research, applications, and technology transfer
 - Analysis integration toolkit: *XaiTools*
 - Engineering information systems solutions
- ◆ Industry & government collaboration

For Further Information ...

- ◆ EIS Lab web site:
 - <http://eislabs.gatech.edu/>
 - Publications, project overviews, etc.
 - See Publications, DAI/XAI, Suggested Starting Points