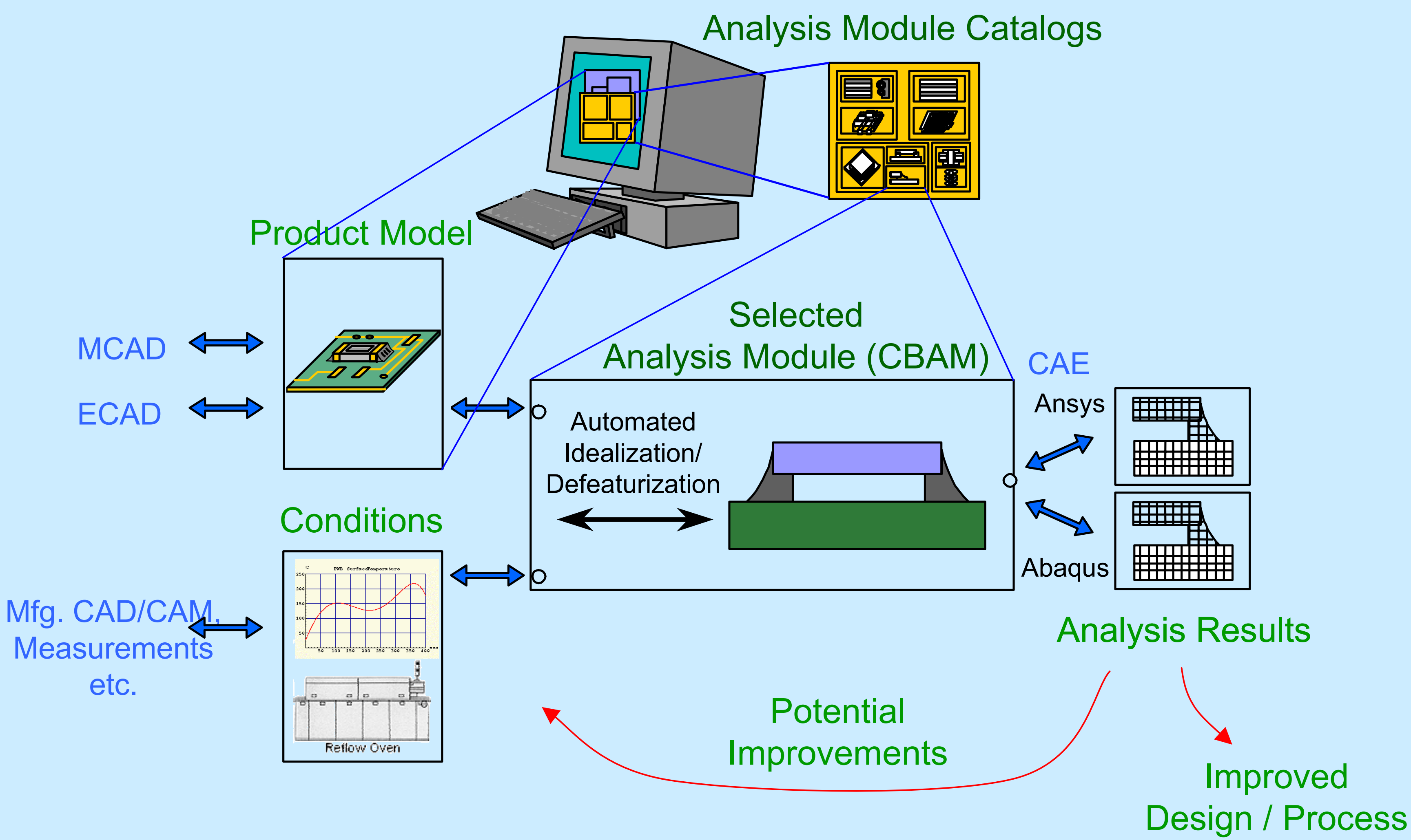
An Introduction to X-Analysis Integration (XAI)

Russell S. Peak
Georgia Tech
Engineering Information Systems Lab
eislab.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



CBAM= context-based analysis model

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

Design Model A

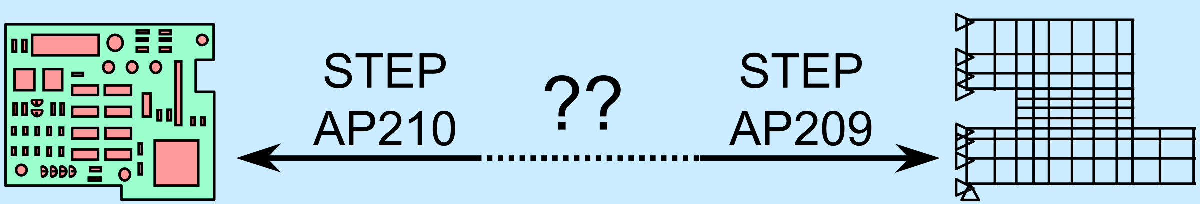
Design Model B

Mentor Graphics

Cadence

- Heterogeneous Transformation

Design Model A



Analysis Model A

Mentor Graphics

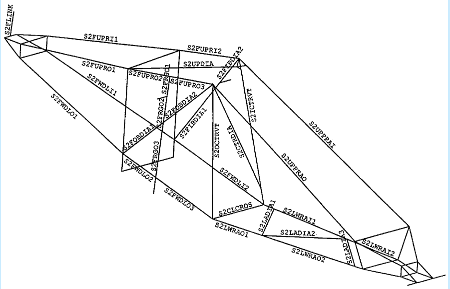
Ansys

Multifidelity Analysis

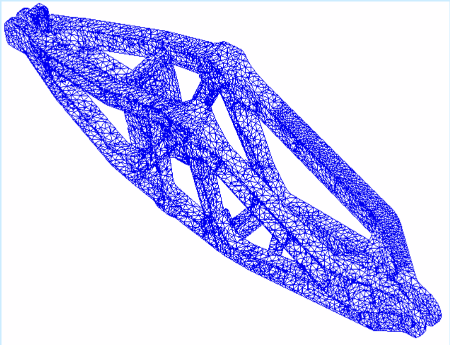
Design Model (MCAD)

Analysis Models (MCAE)

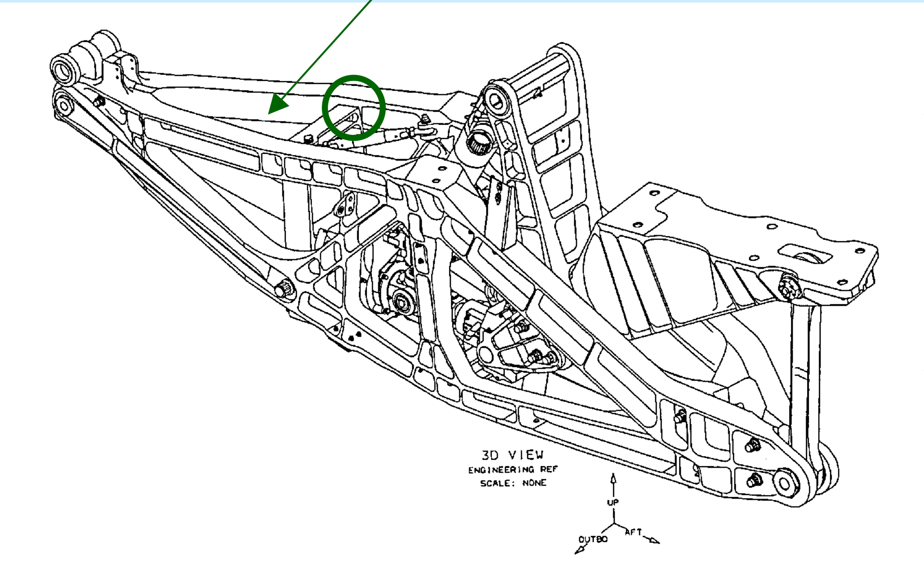
1D Beam/Stick Model



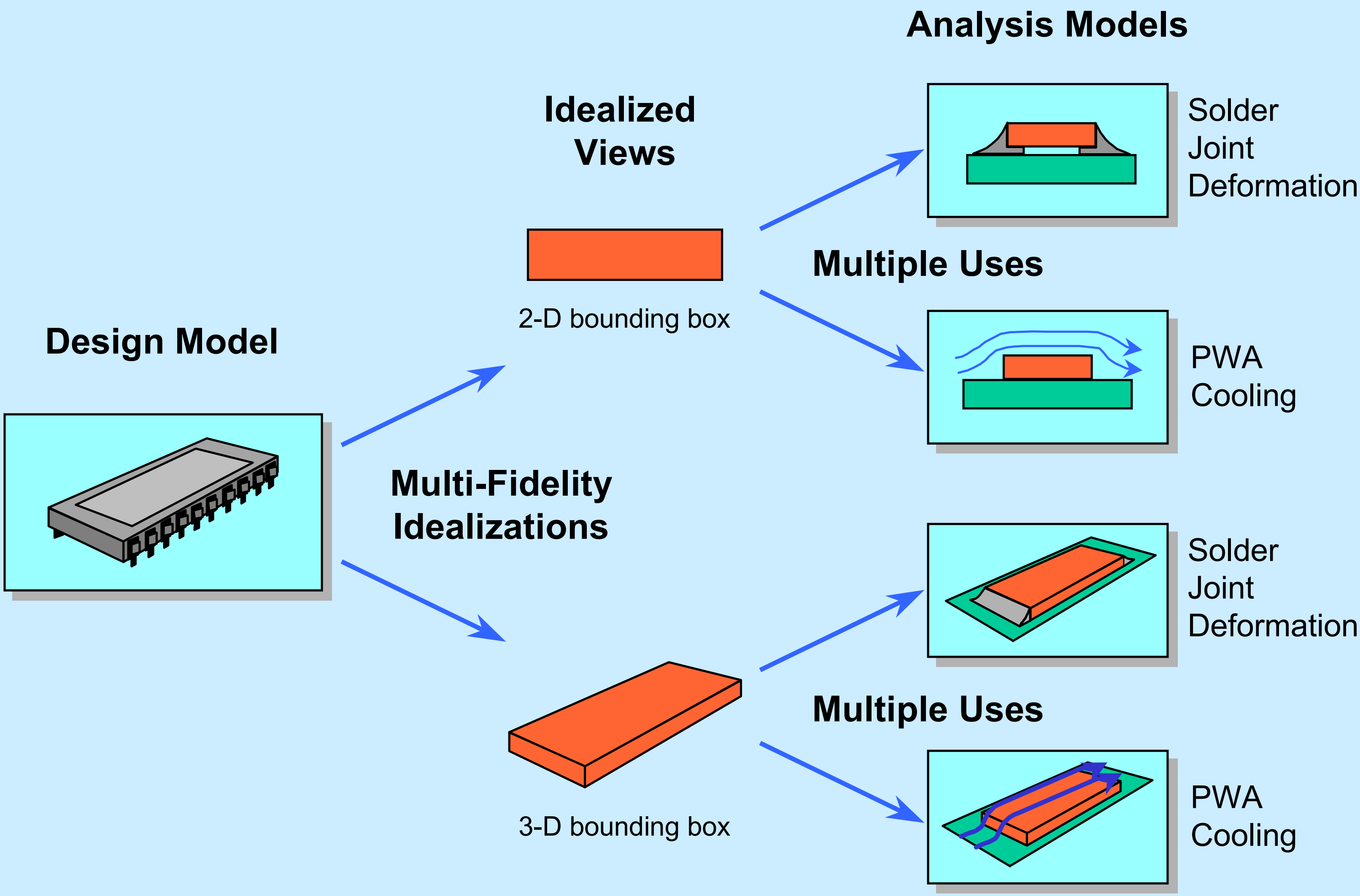
3D Continuum/Brick Model



flap support assembly inboard beam

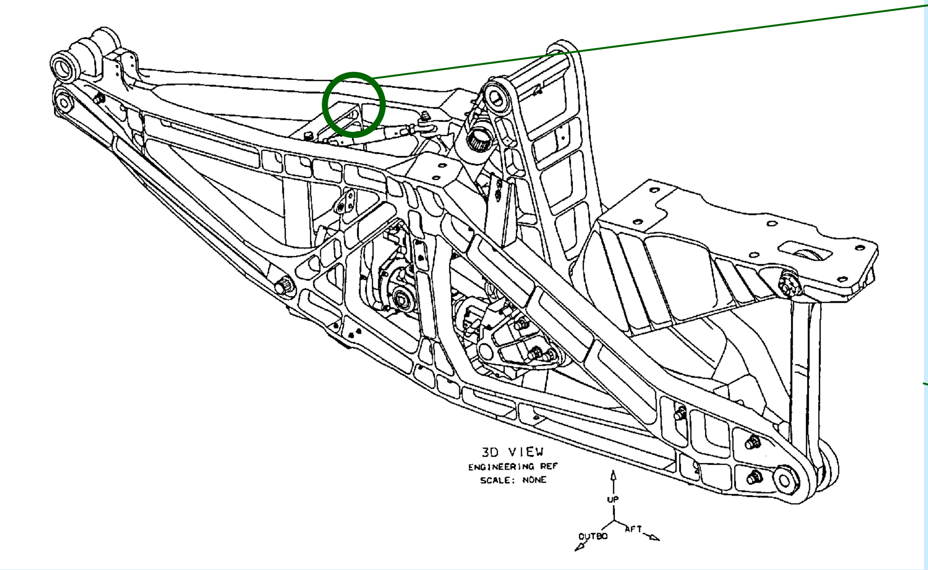


Multi-Fidelity, Multi-Usage Idealizations



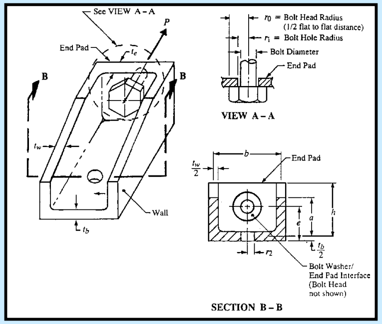
Multilevel Analysis

Design Model (MCAD)

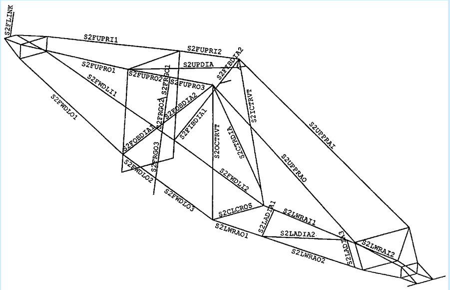


Analysis Models (MCAE)

Part Feature Level Model

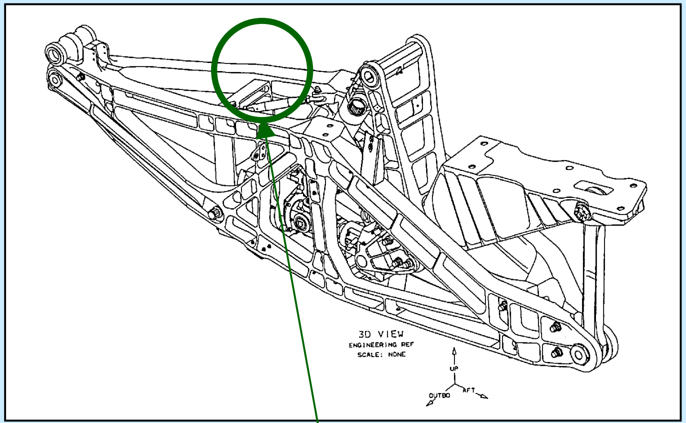


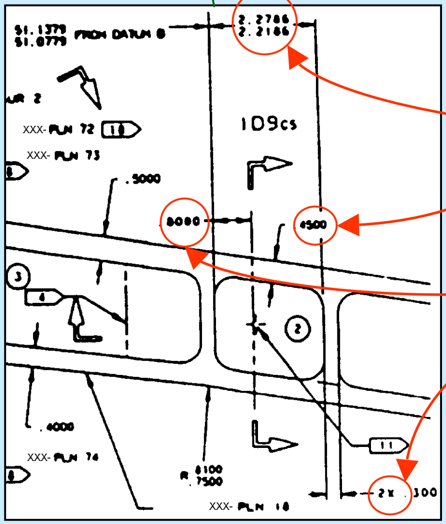
Assembly Level Model



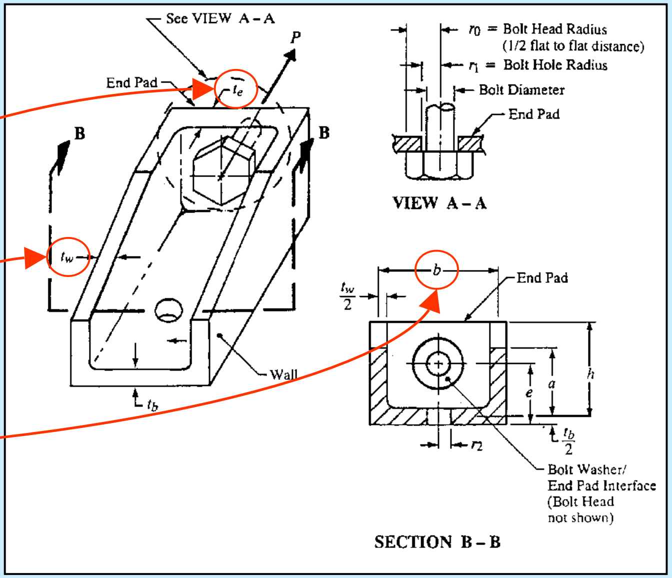
Design Geometry - Analysis Geometry Mismatch

Detailed Design Model





Analysis Model (with Idealized Features)



Γ

Idealizations

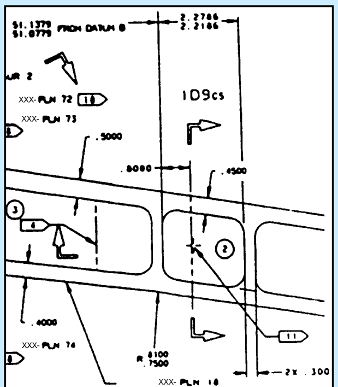
Tension Fitting Analysis

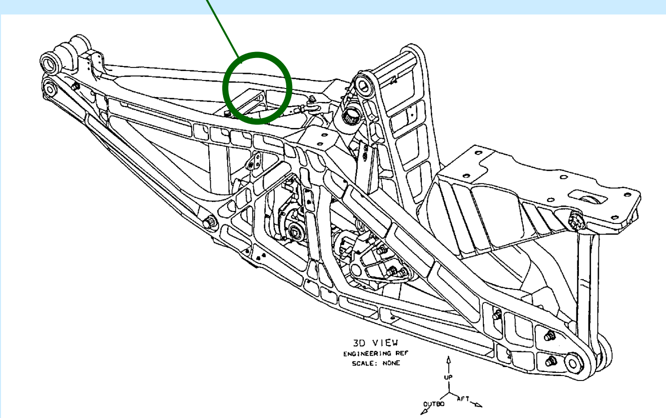
"It is no secret that CAD models are driving more of today's product development processes ... With the growing number of design tools on the market, however, the interoperability gap with downstream applications, such as finite element analysis, is a very real problem. As a result, CAD models are being recreated at unprecedented levels."

Ansys/ITI press Release, July 6 1999
http://www.ansys.com/webdocs/VisitAnsys/CorpInfo/PR/pr-060799.html

Explicit Design-Analysis Associativity

bulkhead assembly attach point CAD model





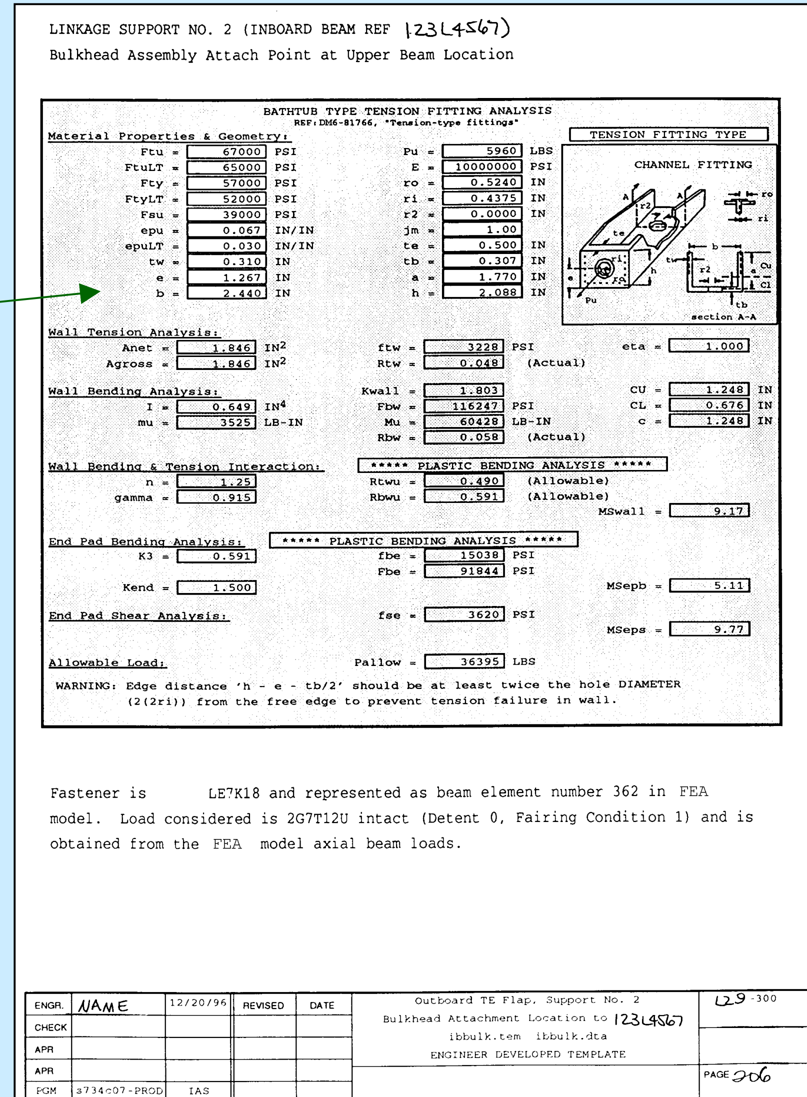
channel fitting analysis

material properties

idealized geometric attributes

Missing CAD-CAE associativity

analysis results



LINKAGE SUPPORT NO. 2 (INBOARD BEAM REF 1234567)
Bulkhead Assembly Attach Point at Upper Beam Location

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

Material Properties & Geometry:

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

TENSION FITTING TYPE
CHANNEL FITTING
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:

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

Wall Bending & Tension Interaction: ***** PLASTIC BENDING ANALYSIS *****

n =	1.25	Rtwu =	0.490	(Allowable)		
gamma =	0.915	Rbwu =	0.591	(Allowable)		
					MSwall =	9.17

End Pad Bending Analysis: ***** PLASTIC BENDING ANALYSIS *****

K3 =	0.591	fbe =	15038	PSI		
		Fbe =	91844	PSI		
Kend =	1.500				MSepb =	5.11

End Pad Shear Analysis:

fse =	3620	PSI		
			MSeps =	9.77

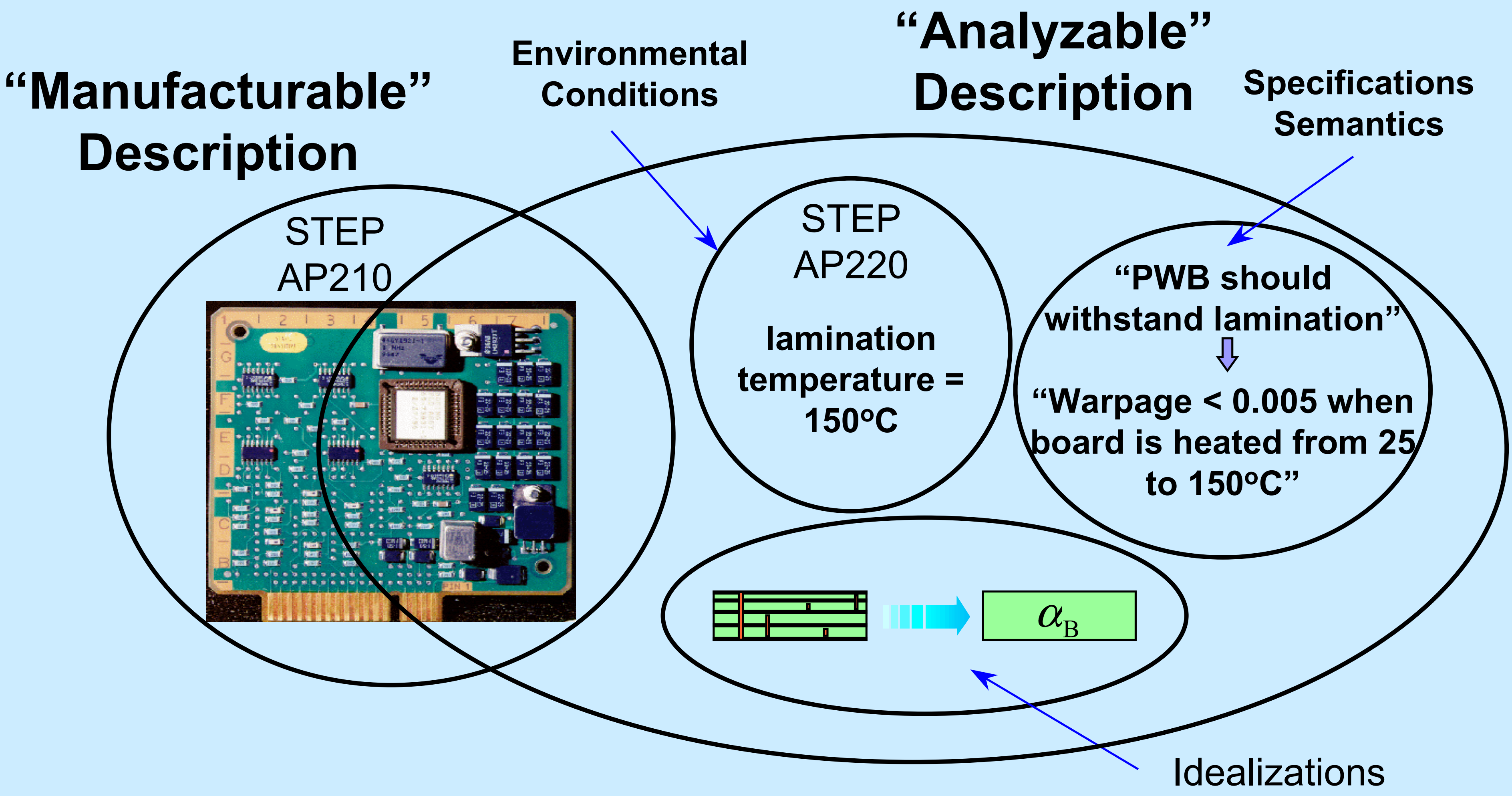
Allowable Load: Pallow = 36395 LBS

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 1234567 ibbulk.tem ibbulk.dta ENGINEER DEVELOPED TEMPLATE	129-300
CHECK						
APR						
APR						PAGE 206
PGM	s734c07-PROD	IAS				

Analysis Integration Challenges: Information Diversity



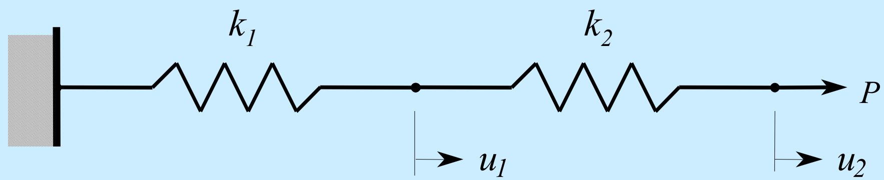
Outline

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

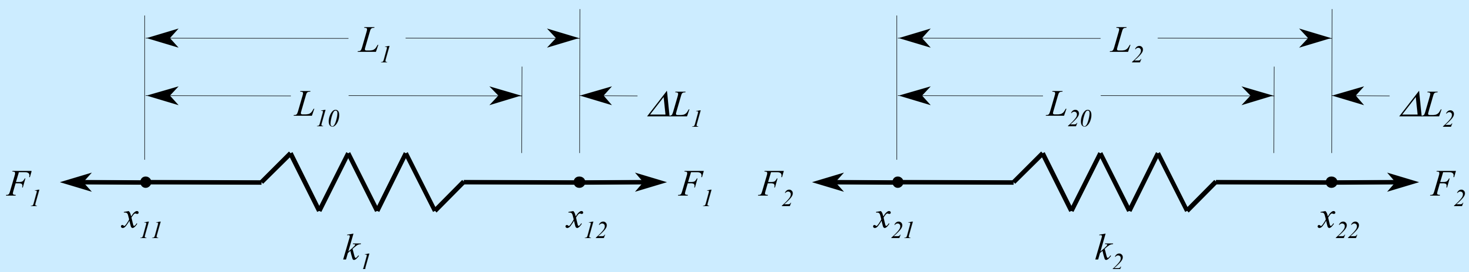
Traditional Mathematical Representation

Two Spring System

System Figure



Free Body Diagrams



Variables and Relations

Kinematic Relations

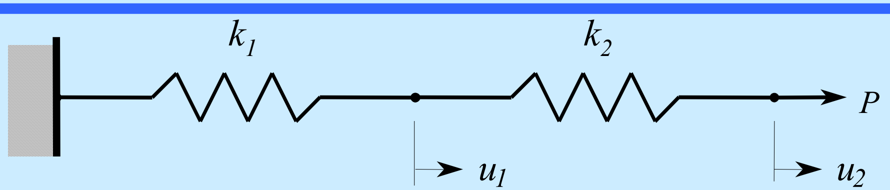
Constitutive Relations

Boundary Conditions

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

Constraint Graph

Two Spring System



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

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

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

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

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

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

$bc_1 : x_{11} = 0$

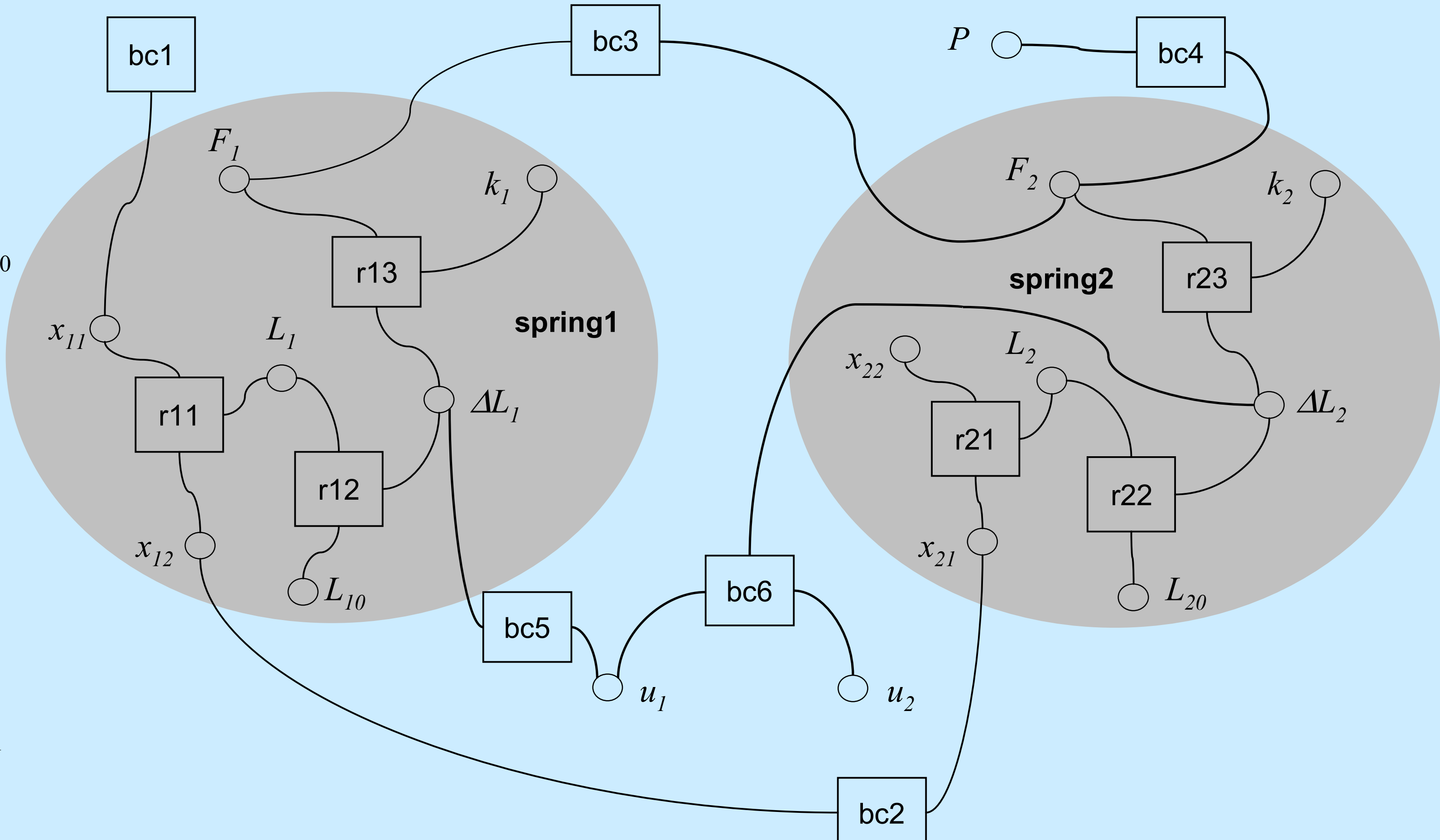
$bc_2 : x_{12} = x_{21}$

$bc_3 : F_1 = F_2$

$bc_4 : F_2 = P$

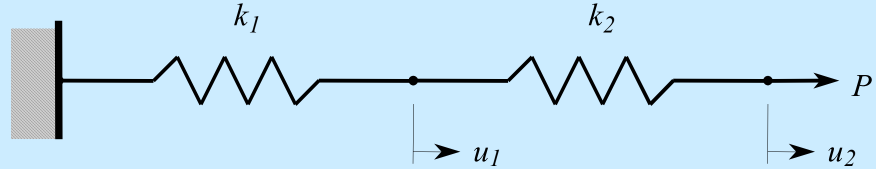
$bc_5 : u_1 = \Delta L_1$

$bc_6 : u_2 = \Delta L_2 + u_1$



COB Constraint Schematic

Two Spring System



Analysis Primitives
with
Encapsulated Relations

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

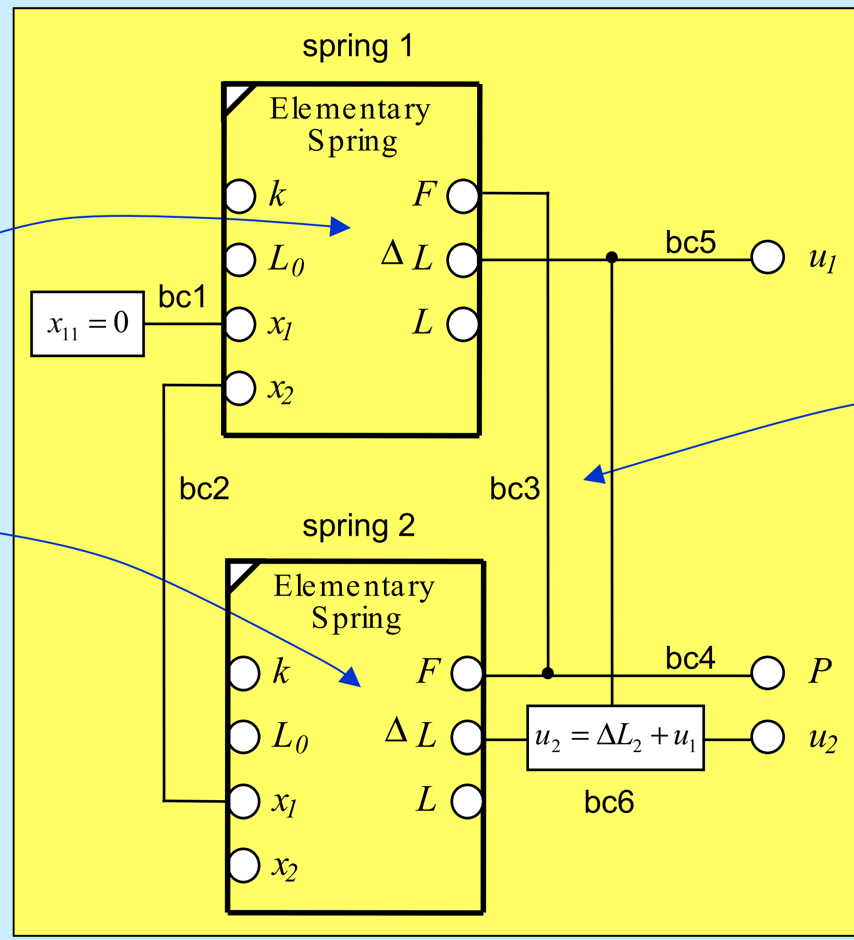
$r_{12} : \Delta L_1 = L_1 - L_{10}$

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

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

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

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



System-Level Relations
(Boundary Conditions)

$bc_1 : x_{11} = 0$

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

$bc_3 : F_1 = F_2$

$bc_4 : F_2 = P$

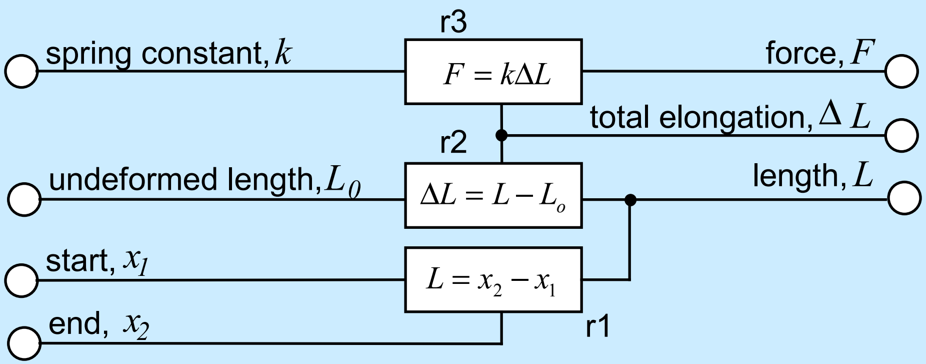
$bc_5 : u_1 = \Delta L_1$

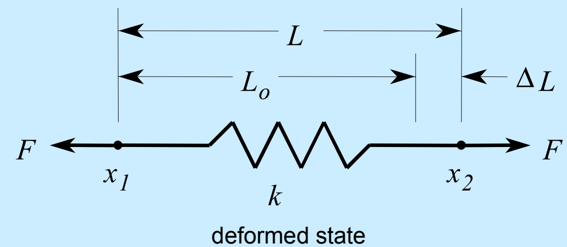
$bc_6 : u_2 = \Delta L_2 + u_1$

COB Structure: Graphical Forms

Spring Primitive

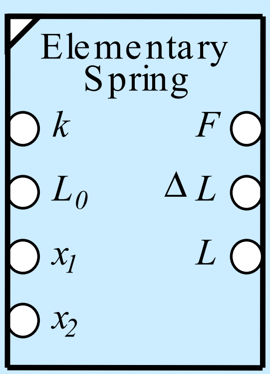
Constraint Schematic





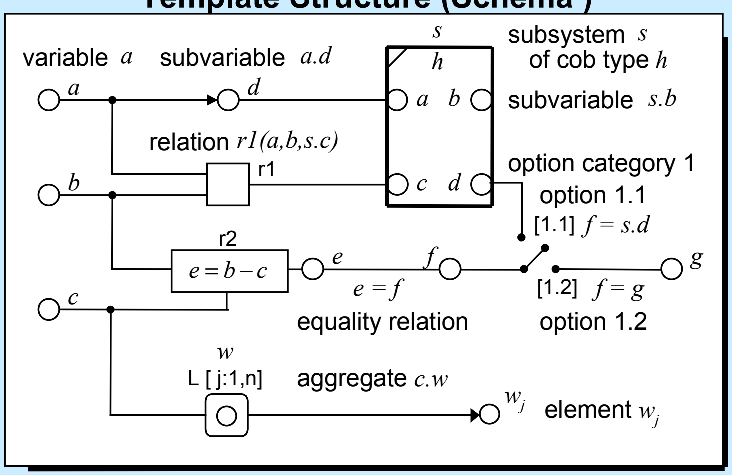
Subsystem View

(for reuse by other COBs)



Basic Constraint Schematic Notation

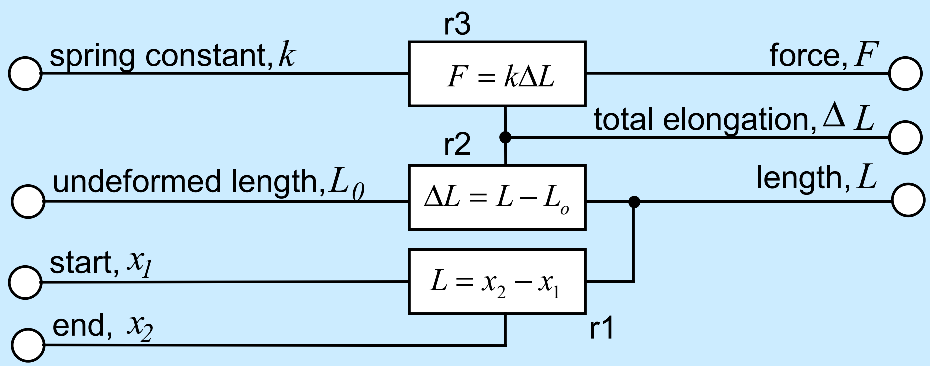
Template Structure (Schema)



COB Structure: Lexical Form

Spring Primitive

Constraint Schematic

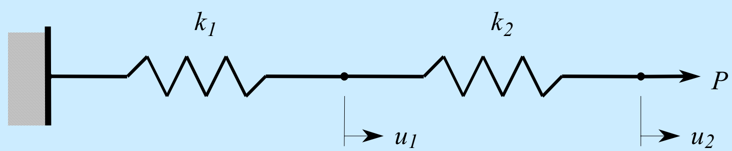


Lexical COB Schema Template

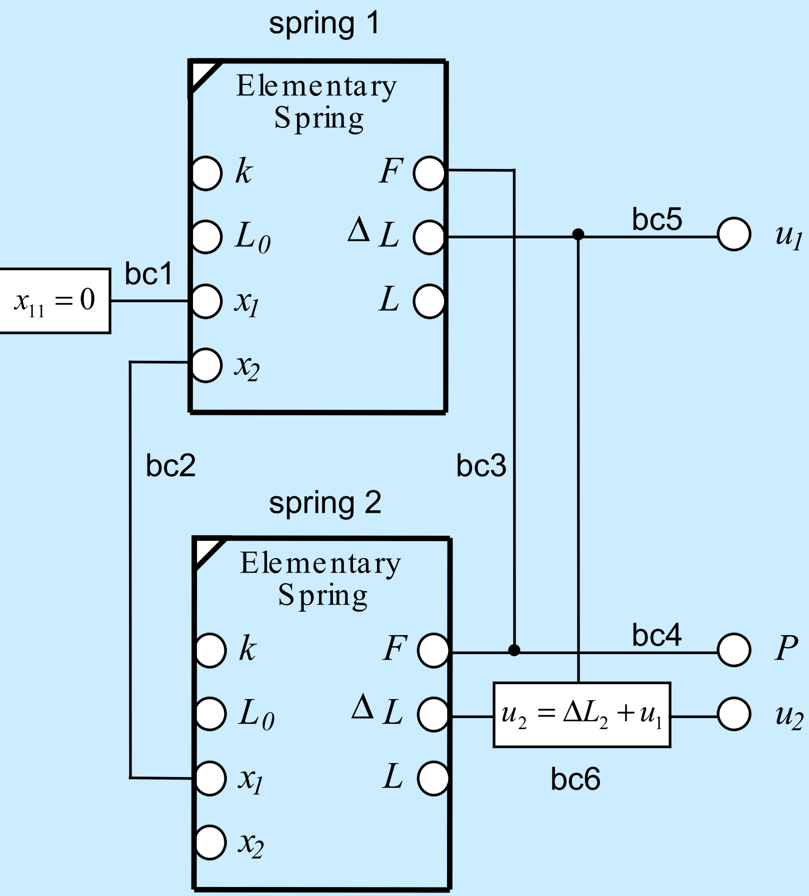
```
COB spring SUBTYPE_OF abb;
   undeformed_length, L<sub>0</sub> : REAL;
   spring_constant, k : REAL;
   start, x<sub>1</sub> : REAL;
   end, x<sub>2</sub> : REAL;
   length, L : REAL;
   total_elongation, &Delta;L : REAL;
   force, F : REAL;
 RELATIONS
   r1 : "<length> == <end> - <start>";
   r2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

COBs as Building Blocks

Two Spring System



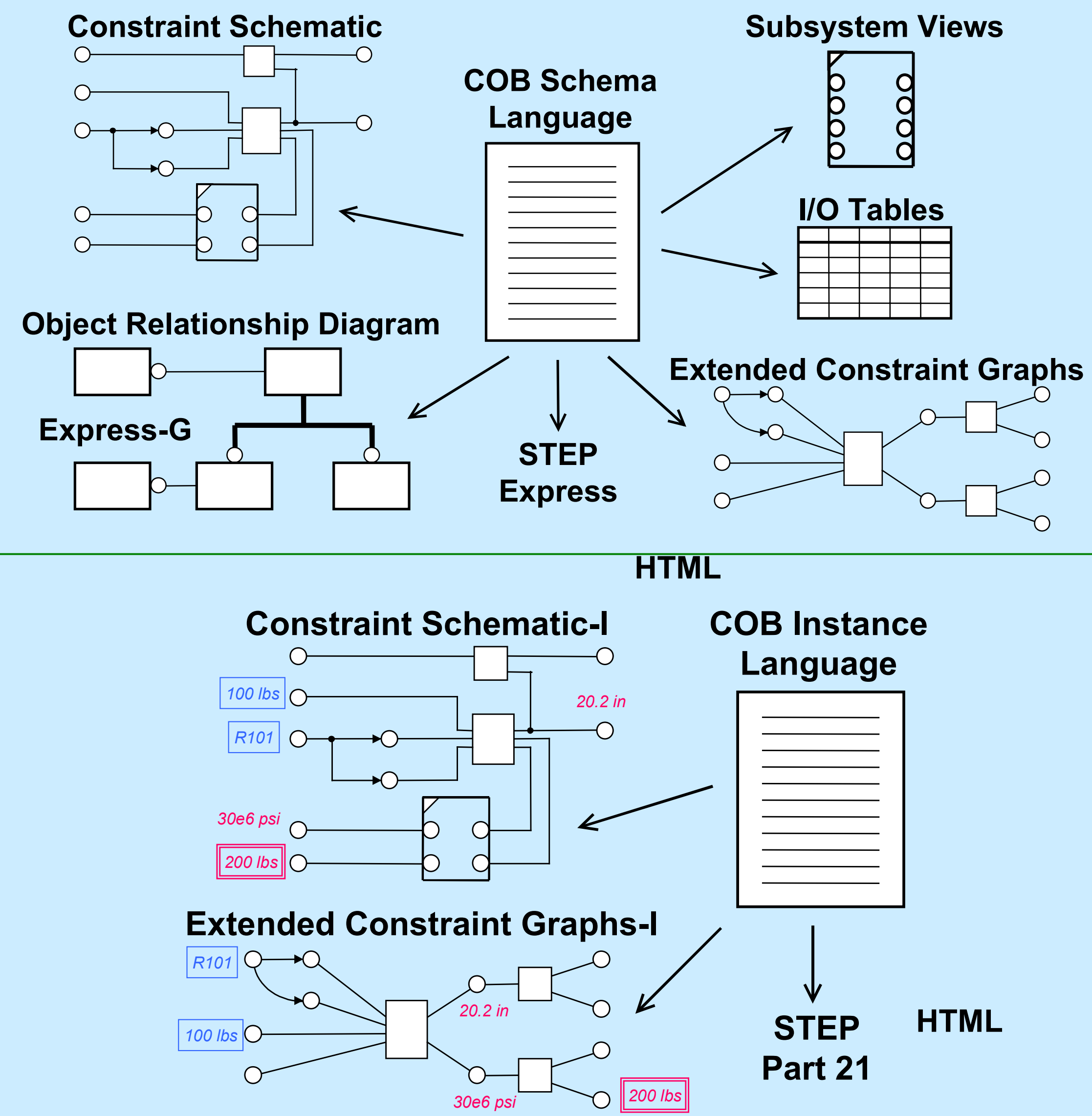
Constraint Schematic



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

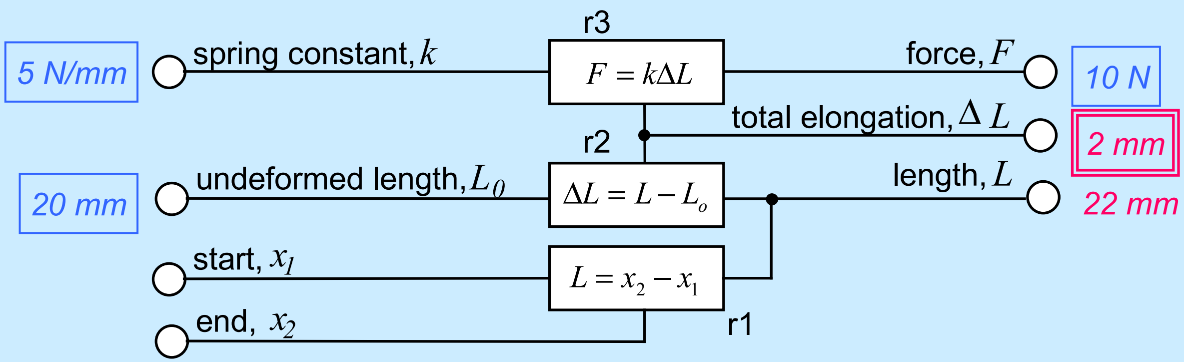


Example COB Instance

Spring Primitive

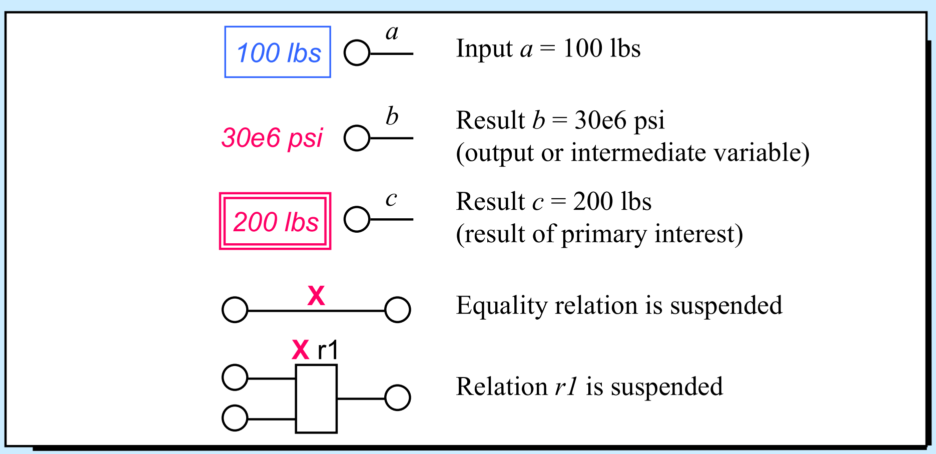
Constraint Schematic Instance Views

example 1, state 1



Basic Constraint Schematic Notation

Instances



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;
```

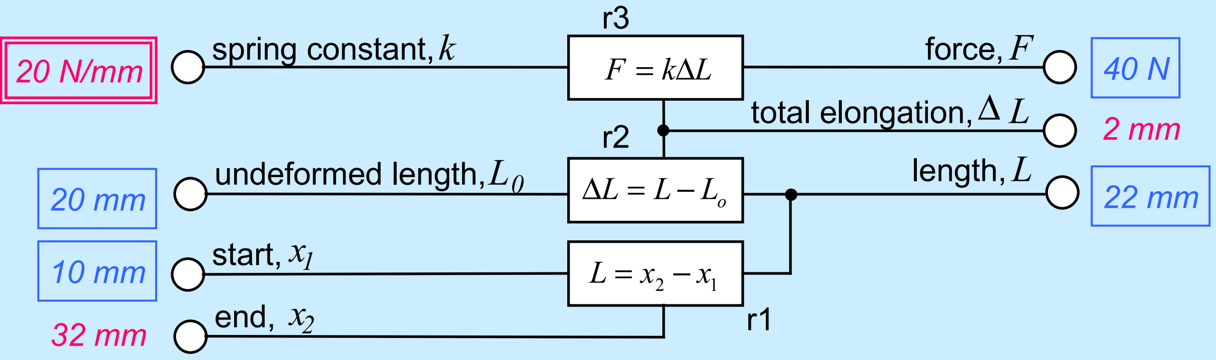
```
result (reconciled):

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;
```

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	L₀	REAL	Input	20
spring_constant	k	REAL	Input	5
start	x₁	REAL	Output	No value
end0	x₂	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		<length> == <end0> - <start>	✔
r2	Y		<total_elongation> == <length> - <undeformed_length>	✔
r3	Y		<force> == <spring_constant> * <total_elongation>	✔

spring

Name	Symbol	Type	Input	Values
root		spring		
undeformed_length	L₀	REAL	Input	20
spring_constant	k	REAL	Output	20
start	x₁	REAL	Input	10
end0	x₂	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		<length> == <end0> - <start>	✔
r2	Y		<total_elongation> == <length> - <undeformed_length>	✔
r3	Y		<force> == <spring_constant> * <total_elongation>	✔

spring_system

Name	Symbol	Type	Input	Values
root		spring_system		
spring1		spring		
undeformed_length	L₀	REAL	Input	8
spring_constant	k	REAL	Input	5
start	x₁	REAL	Output	0
end0	x₂	REAL	Output	10
length	L	REAL	Output	10
total_elongation	ΔL	REAL	Output	2
force	F	REAL	Output	10
spring2		spring		
undeformed_length	L₀	REAL	Input	8
spring_constant	k	REAL	Input	20
start	x₁	REAL	Output	10
end0	x₂	REAL	Output	18.5
length	L	REAL	Output	8.5
total_elongation	ΔL	REAL	Output	0.5
force	F	REAL	Output	10
deformation1	u₁	REAL	Output	2
deformation2	u₂	REAL	Output	2.5
load	P	REAL	Input	10

Solve

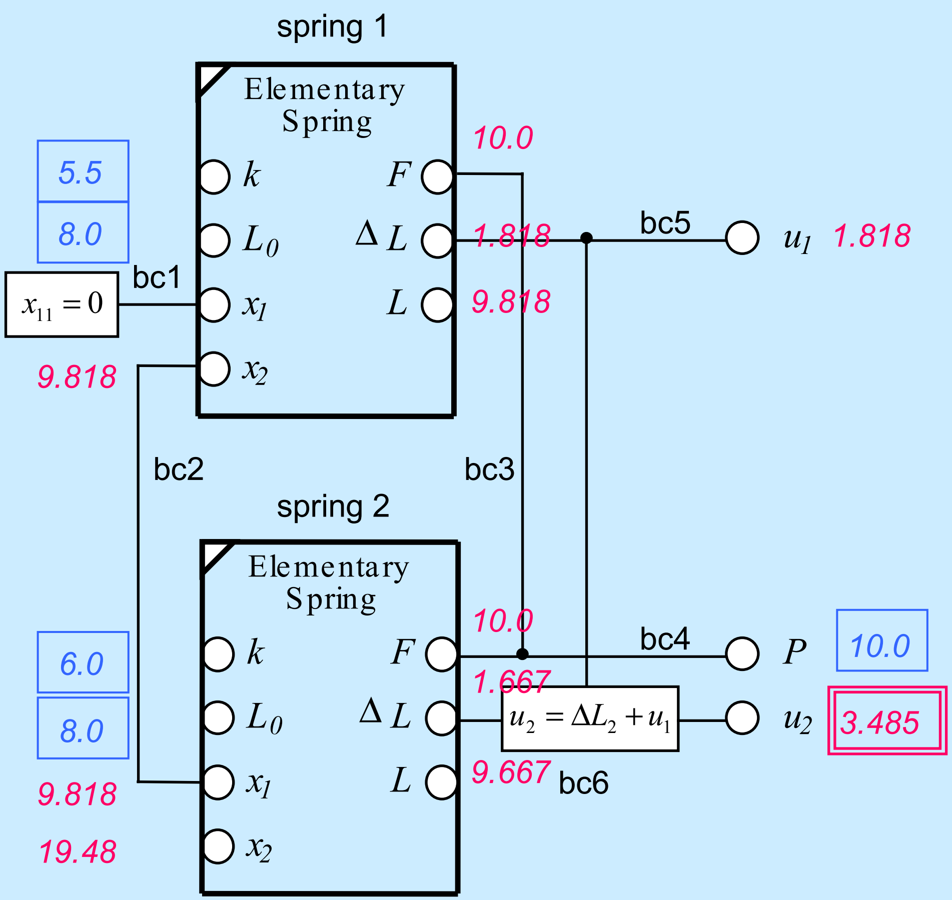
root (spring_system)

Name	Local	Oneway	Relation	Active
r1	Y		<spring1.start> == 0.0	✔
r2	Y		<spring1.end0> == <spring2.start>	✔
r3	Y		<spring1.force> == <spring2.force>	✔
r4	Y		<spring2.force> == <load>	✔
r5	Y		<deformation1> == <spring1.total_elongation>	✔
r6	Y		<deformation2> == <spring2.total_elongation> + <deformation1>	✔

Analysis System Instance

Two Spring System

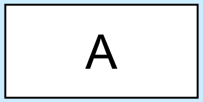
Constraint Schematic Instance View



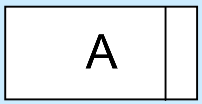
Lexical COB Instance

```
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 : 1.81818181818181818;
   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 : 1.66666666666666;
   spring2.length : 9.66666666666667;
   spring2.end0 : 19.48484848484848;
   load : 10.0;
   deformation1 : 1.81818181818181818;
   deformation2 : 3.48484848484848484;
END_INSTANCE;
```

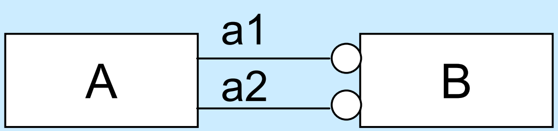
Basic EXPRESS-G notation



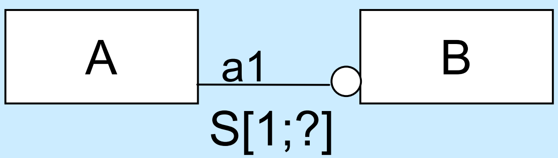
A is an entity (class)
Instance of A are objects



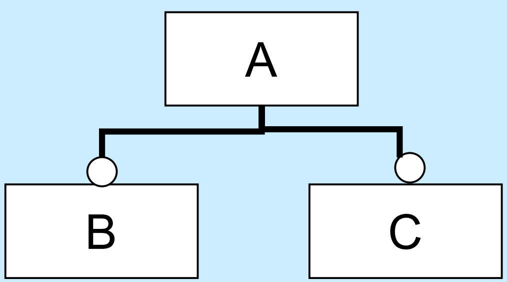
A is a simple type
(BOOLEAN, LOGICAL, BINARY, NUMBER, INTEGER, REAL, STRING)



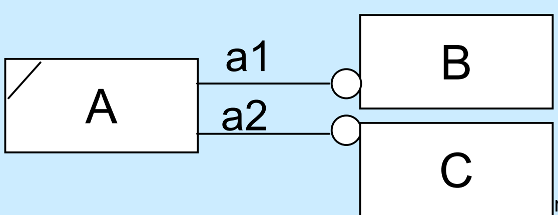
A has two attribute, a1 and a2, that are both type B



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

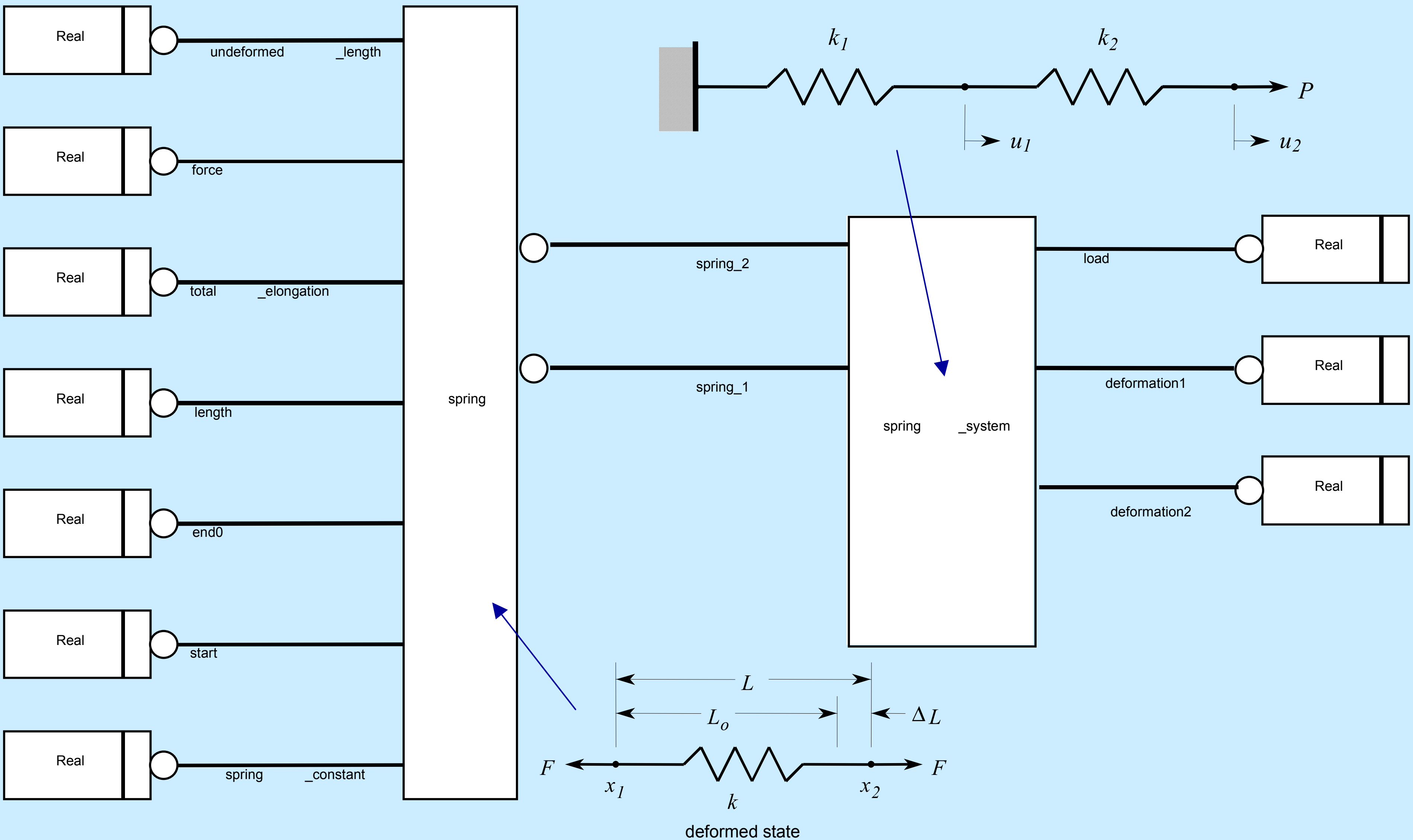


A is a supertype of B and C.
(B and C are subtype of A)



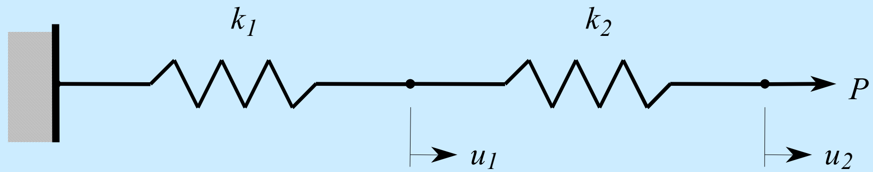
<u>Unofficial extensions:</u>
A has two levels, a1 and a2.
a1 is type B. a2 is type C.

COB Object Model View (EXPRESS-G) Spring Schema



Declarative Knowledge / Derivable Behavior

Two Spring System



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

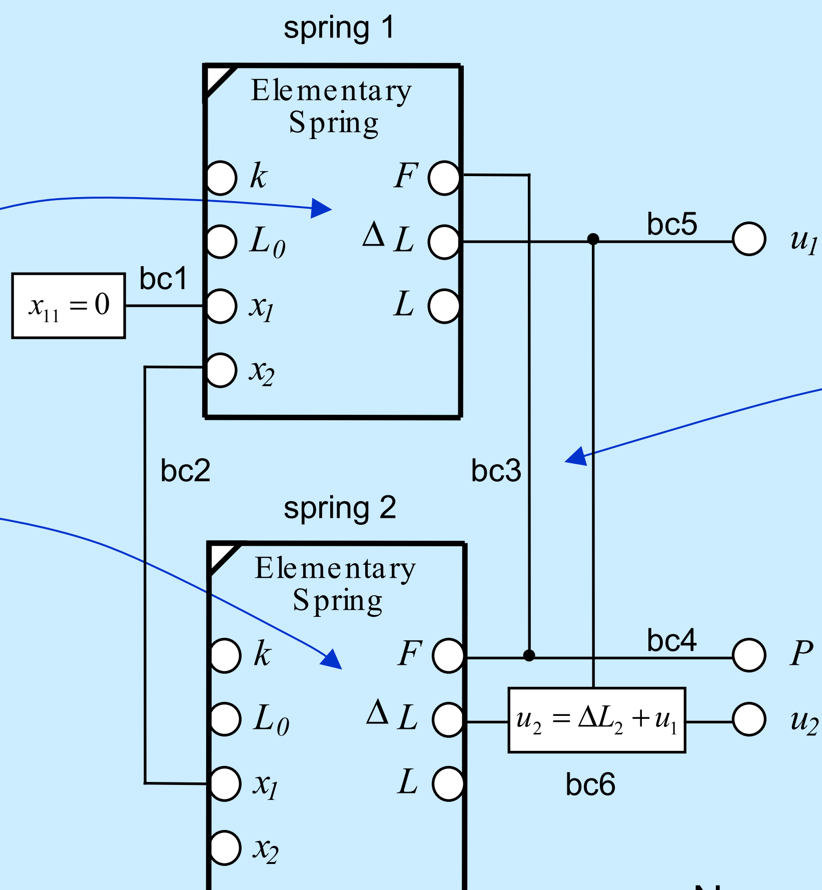
$r_{12} : \Delta L_1 = L_1 - L_{10}$

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

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

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

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



$bc_1 : x_{11} = 0$

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

$bc_3 : F_1 = F_2$

$bc_4 : F_2 = P$

$bc_5 : u_1 = \Delta L_1$

$bc_6 : u_2 = \Delta L_2 + u_1$

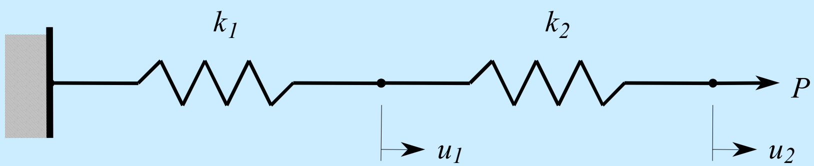
Derivable Behavior

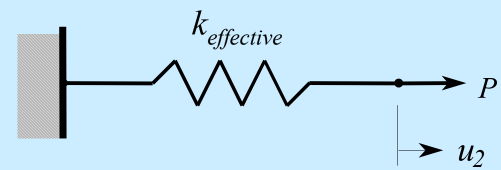
$dr_1 : u_1 = \dfrac{P}{k_1}$

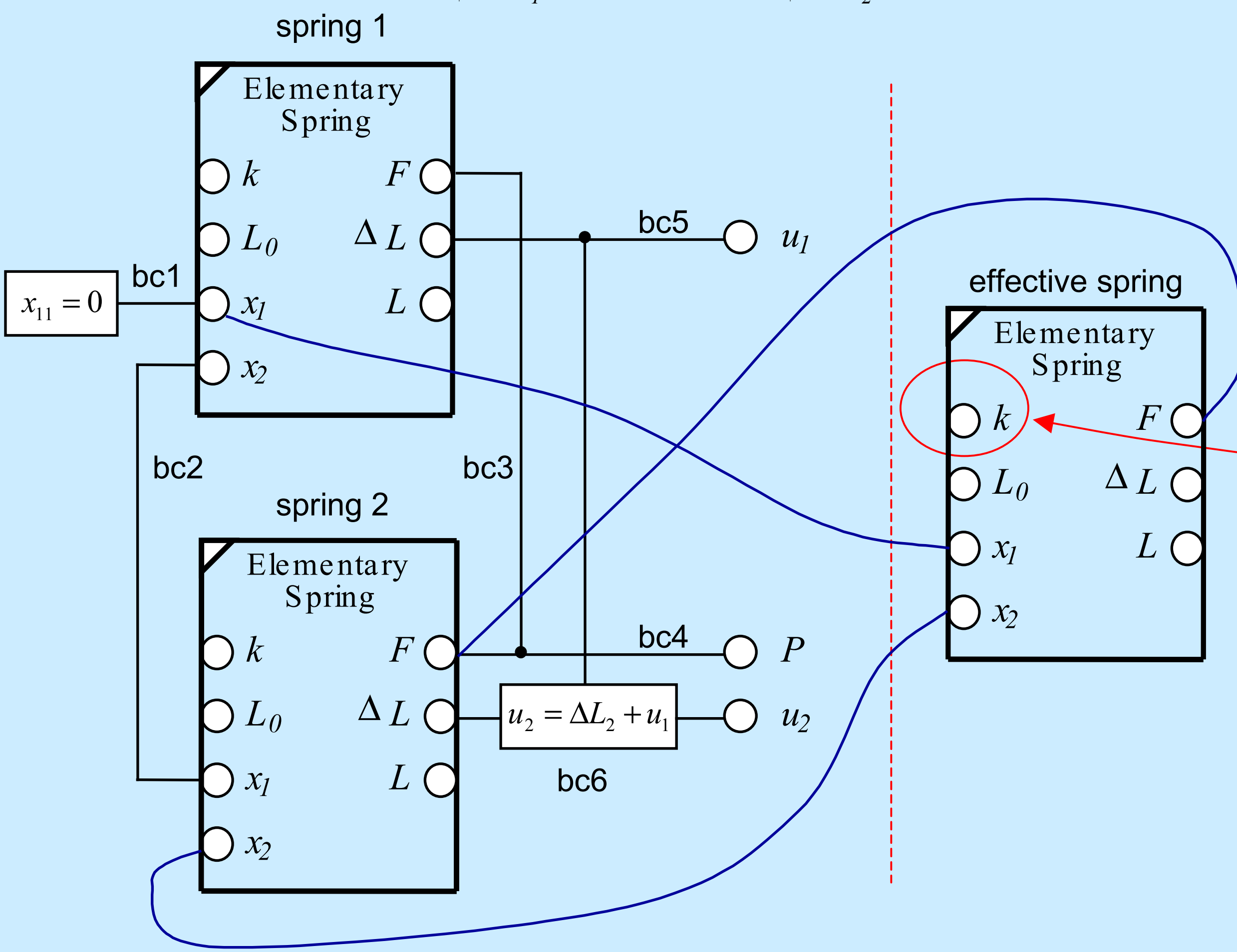
$dr_2 : u_2 = P\dfrac{k_1 + k_2}{k_1 k_2}$

$\Rightarrow$ No need to include explicitly (redundant)

Achieving Effective System Properties via Semantically Rich COBs







Derivable System Level Properties

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

$$dr2 : \Delta L_{effective} = \Delta L_1 + \Delta L_2$$

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

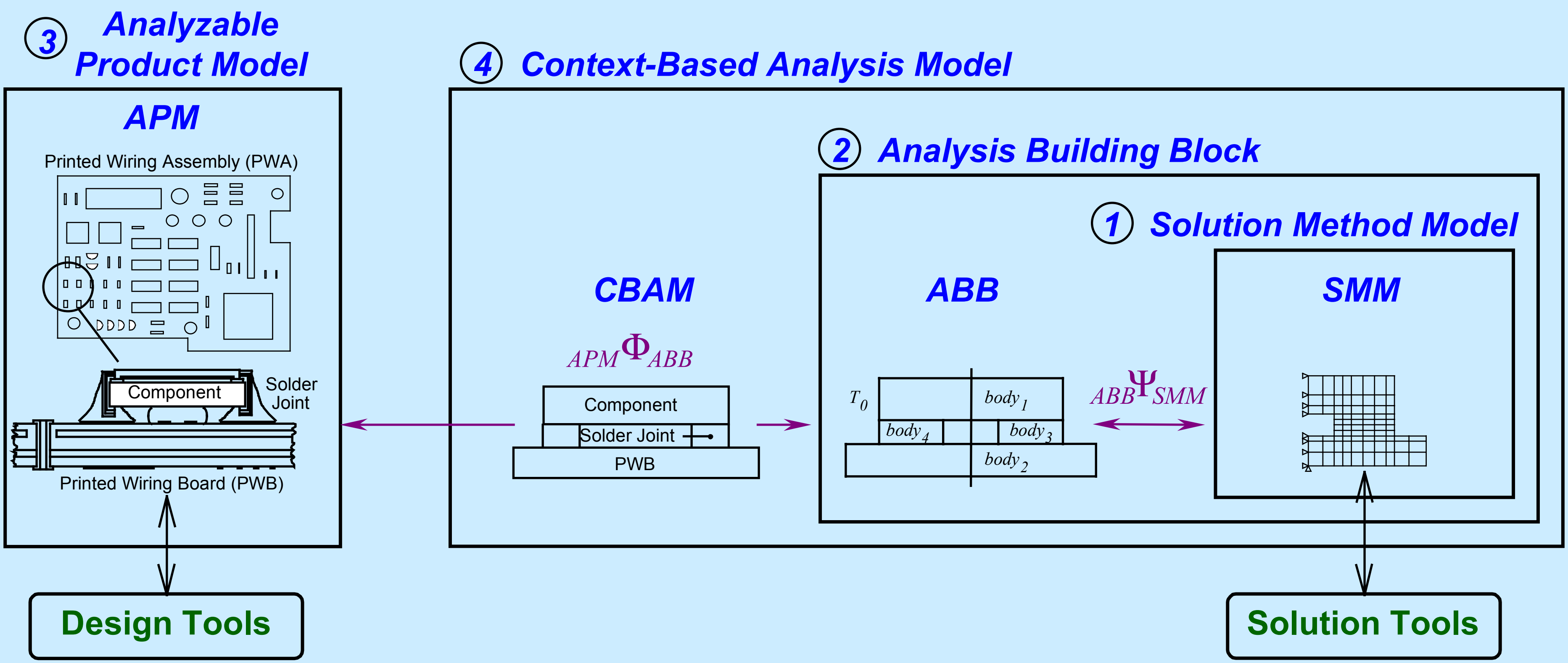
- Analysis Integration Challenges
- Introduction to Constrained Objects (COBs)
- Overview of COB-based XAI
- Example Applications
  - Electronic Packaging Thermomechanical Analysis
  - Aerospace Structural Analysis
- Summary

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://eislab.gatech.edu/ for references

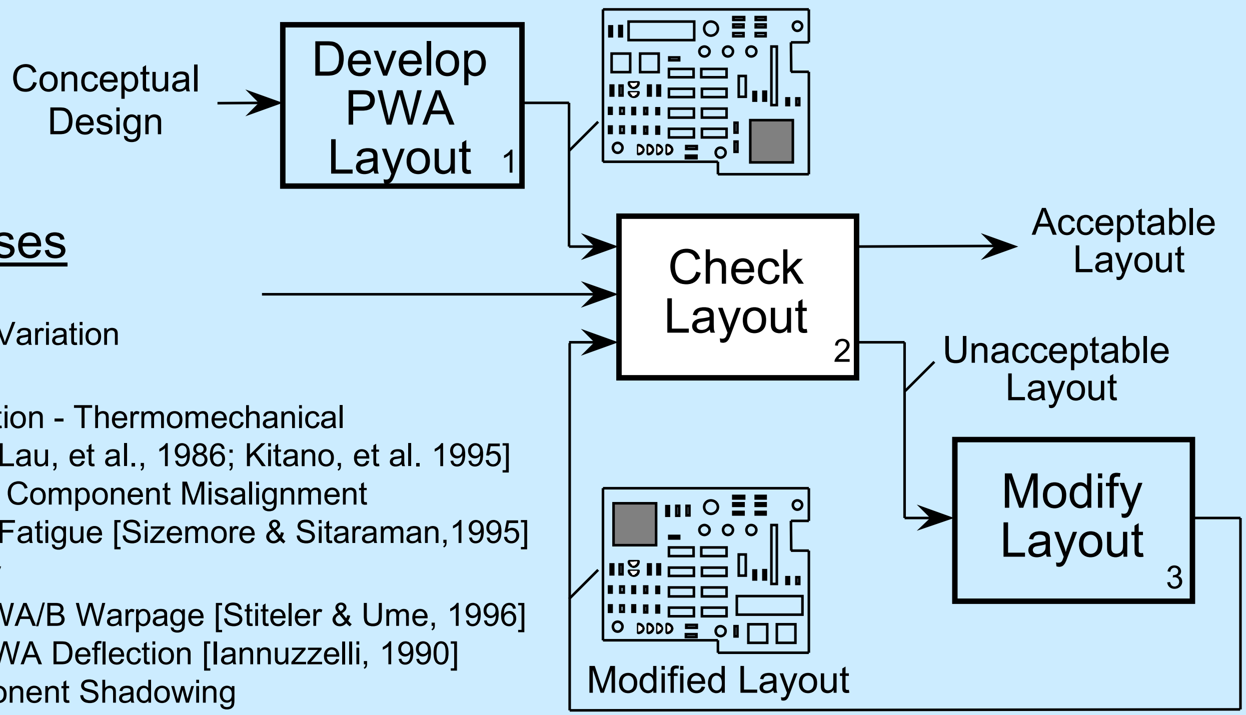
Multi-Representation Architecture for Design-Analysis Integration



- 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

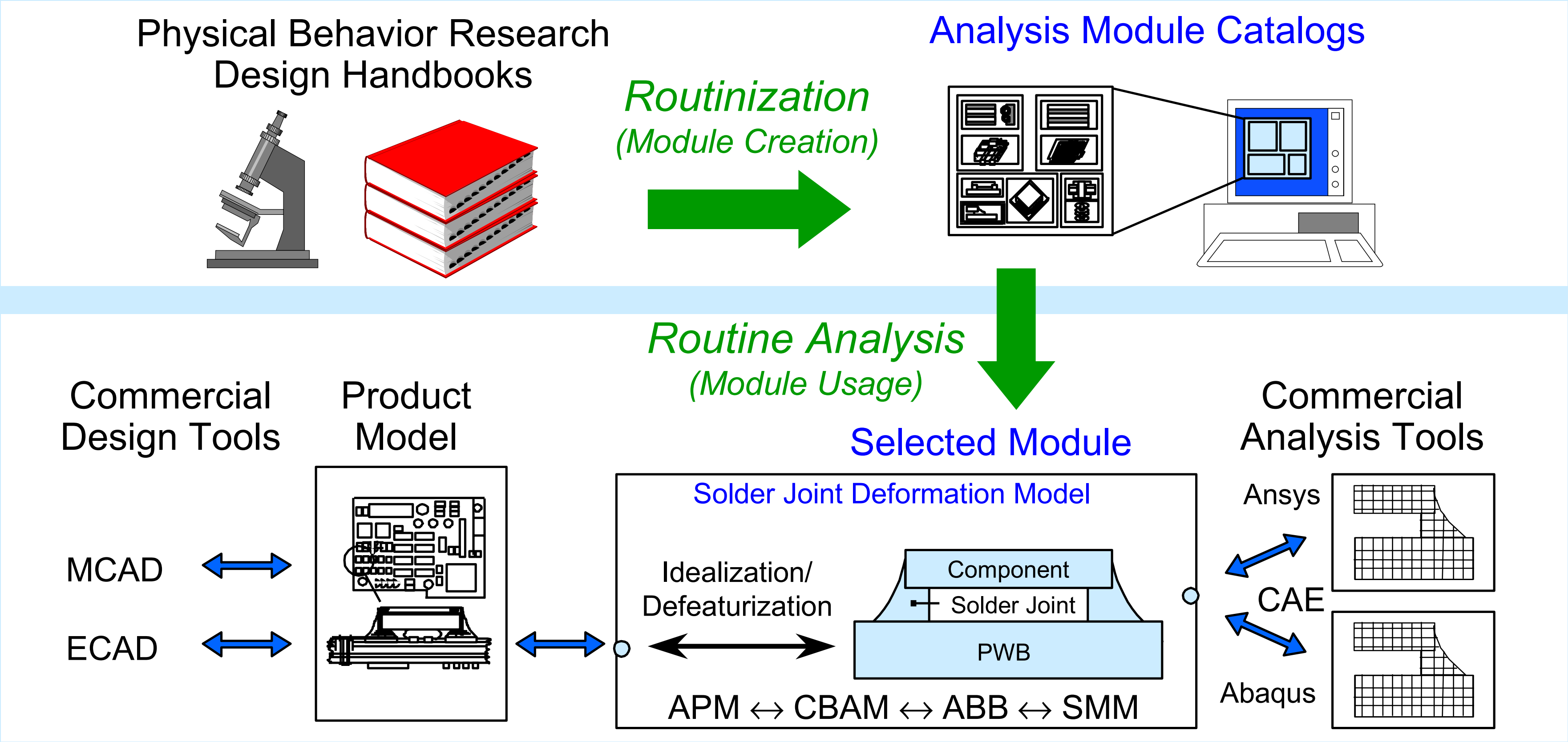
Reliability

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



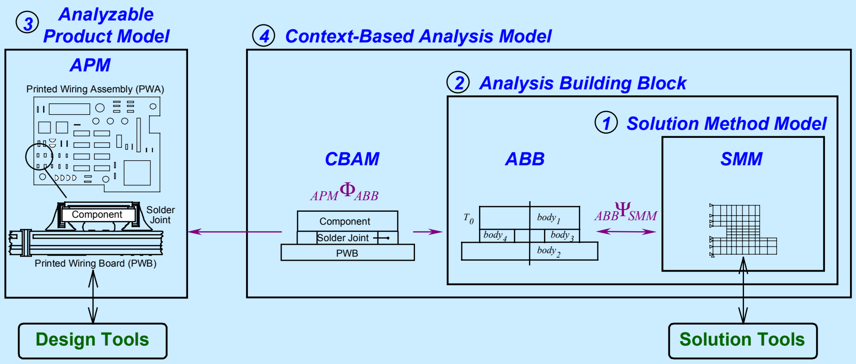
- Provides technique to bridge CAD-CAE gap
- Uses AI & info. technology: objects, constraints, STEP

XaiTools

Prototype X-Analysis Integration Toolkit

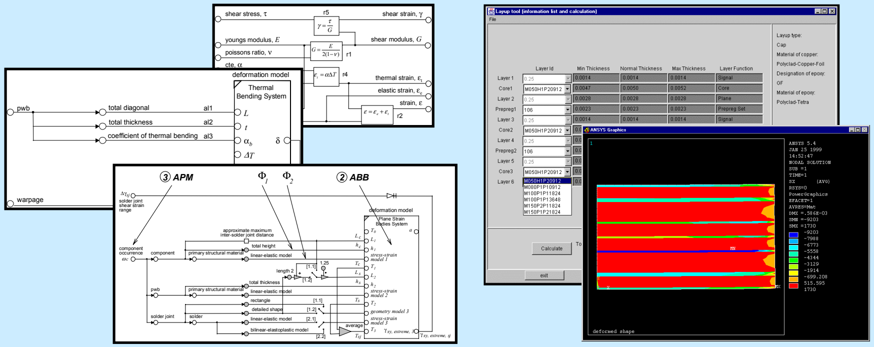
Second Generation - Java-based

Multi-Representation Architecture (MRA)



Analysis Modules & Building Blocks

Constraint Schematics | Implementations

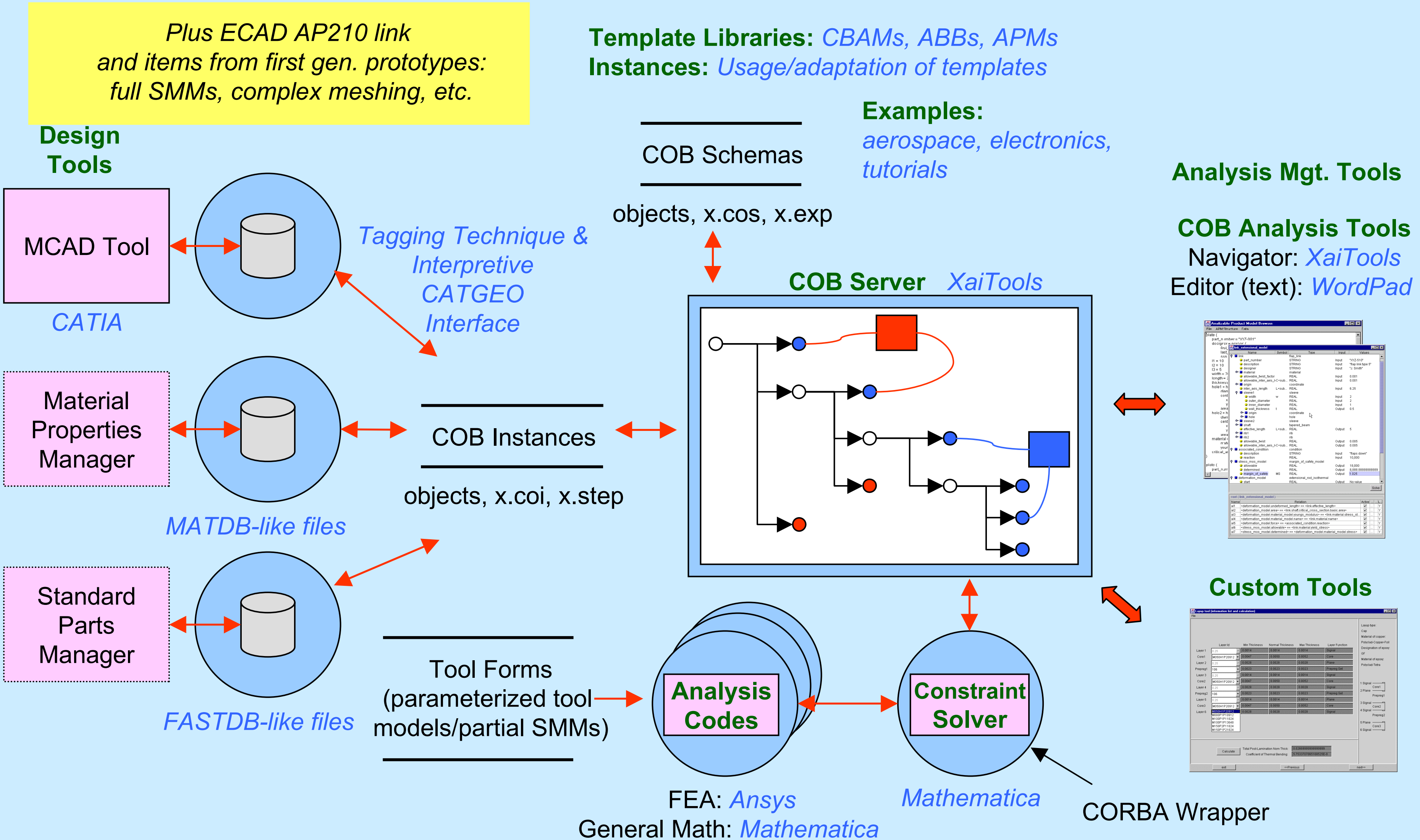


- Product-independent MRA toolkit
- Lexical constrained objects (COBs)
  - Data-driven creation
  - User-adaptable
- Mathematica constraint solver
  - More capabilities
- SMM-type wrappings:
  - FEA tools: Ansys, Abaqus*
  - Symbolic Eqn. Solver: Mathematica
- Extended APM technique for design links:
  - 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.

XaiTools Tool Architecture

Company/Product-Independent View

Capabilities as of 12/98



XaiTools Tool Architecture

Company/Product-Independent View

In-Progress & Potential Extensions as of 6/99

Design Tools

MCAD: *CATIA*
IDEAS, Pro/E*, AutoCAD**

ECAD: *Mentor Graphics (AP210)*
*Accel (PDIF, GenCAM)**

CAD Tool

Material Property Manager

Standard Parts Manager

Template Libraries: *Analysis Packages*, CBAMs, ABBs, APMs, Conditions**
Instances: *Usage/adaptation of templates*

COB Schemas

objects, x.cos, x.exp

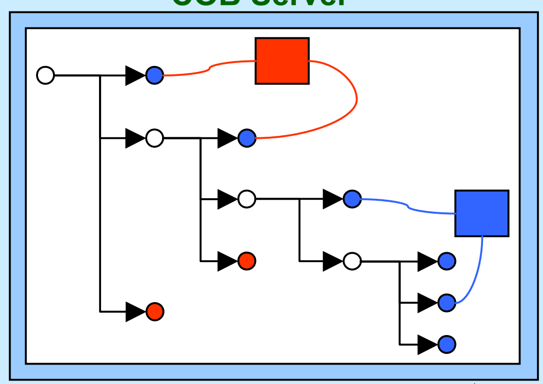
Persistent Object Repository

ODBMS, PDM**

COB Instances

objects, x.coi, x.step

COB Server



Other CORBA Wrappers*

Tool Forms (parameterized tool models/full* SMMs)

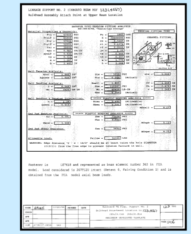
Analysis Codes

Constraint Solver

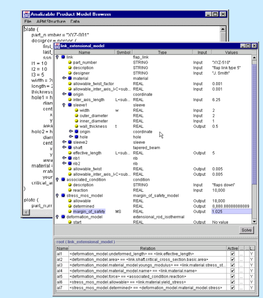
Mathematica

Analysis Mgt. Tools

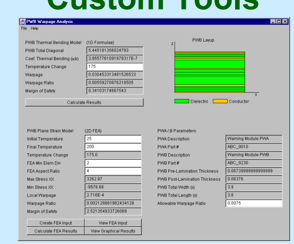
Pullable Views, Condition Mgr*, ...*



COB Analysis Tools
Navigator: *XaiTools*
Editor (text & graphical*)



Custom Tools



CORBA Wrapper

FEA: *Ansys, Elfini*, Abaqus**
Math: *Mathematica, MatLab*, MathCAD**
In-House Codes

asterisk (*) = in-progress/envisioned extensions

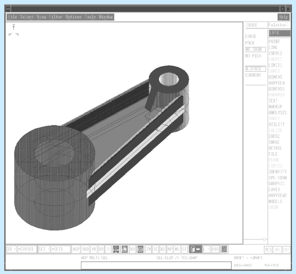
Flexible High Diversity Design-Analysis Integration

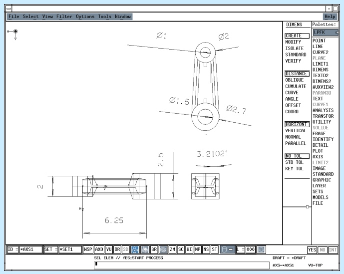
Tutorial Examples: Flap Link (Mechanical/Structural Analysis)

Design Tools

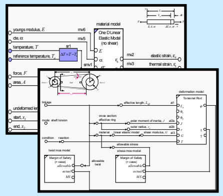
MCAD Tools

CATIA





Materials DB



Modular, Reusable Template Libraries

Analyzable Product Model

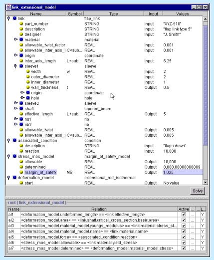
XaiTools

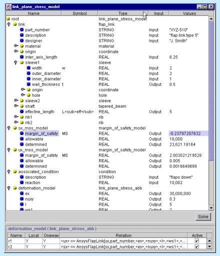
Analysis Modules (CBAMs) of Diverse Mode & *Fidelity*

XaiTools

Extension

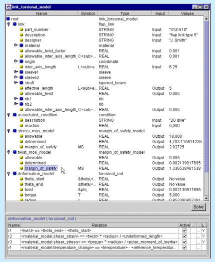
1D, 2D, 3D*





Torsion

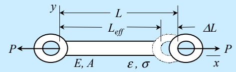
1D



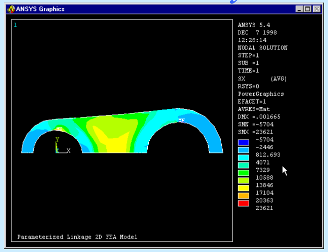
Analysis Tools

General Math

Mathematica

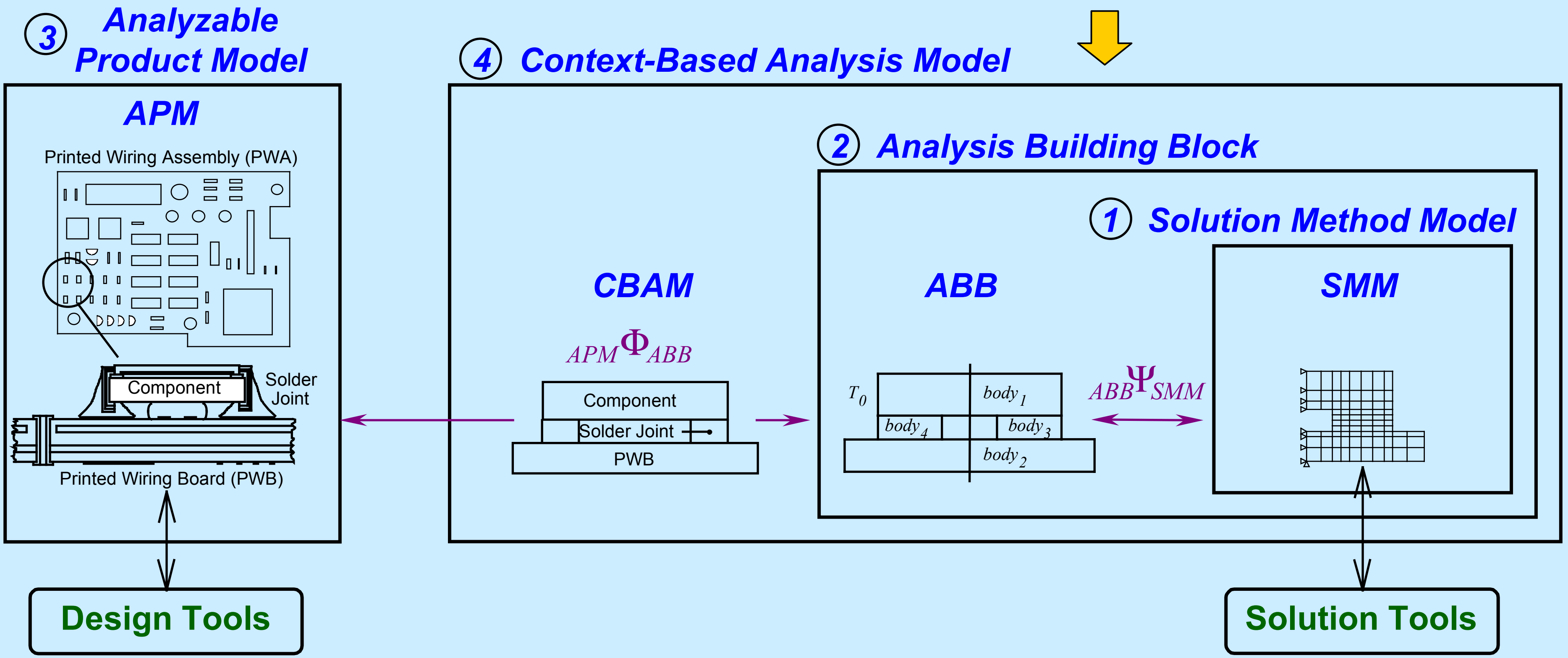


FEA *Ansys*



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

Multi-Representation Architecture for Design-Analysis Integration

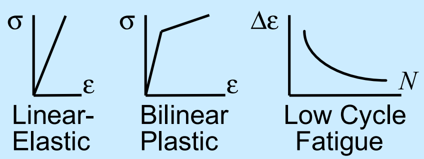


Analysis Building Blocks (ABBs)

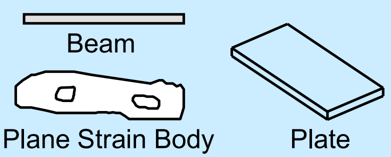
Object representation of product-independent analytical engineering concepts

Analysis Primitives
- Primitive building blocks

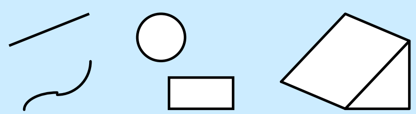
Material Models



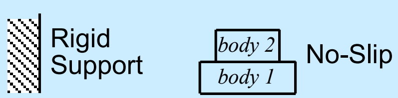
Continua



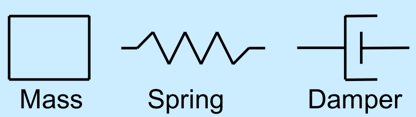
Geometry



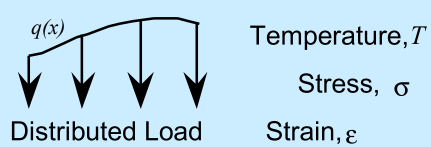
Interconnections



Discrete Elements

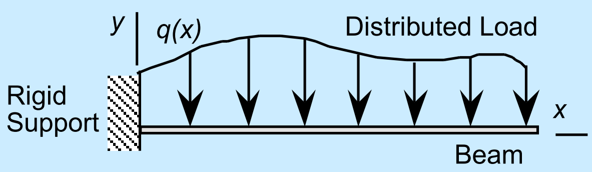


Analysis Variables



Analysis Systems
- Containers of ABB "assemblies"

Specialized
- Predefined templates

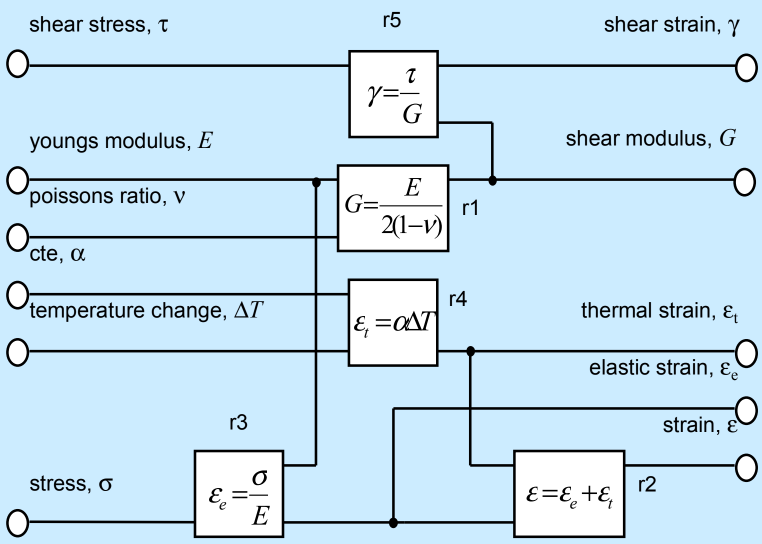


Cantilever Beam System

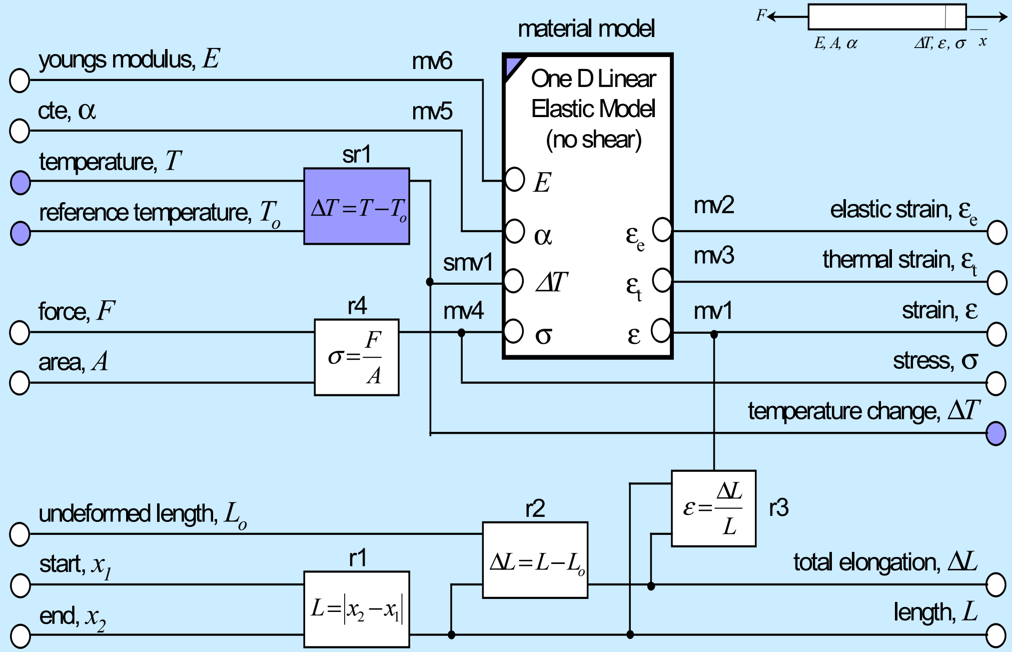
General
- User-defined systems

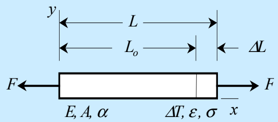
Primitive ABBs

1D Linear Elastic Model



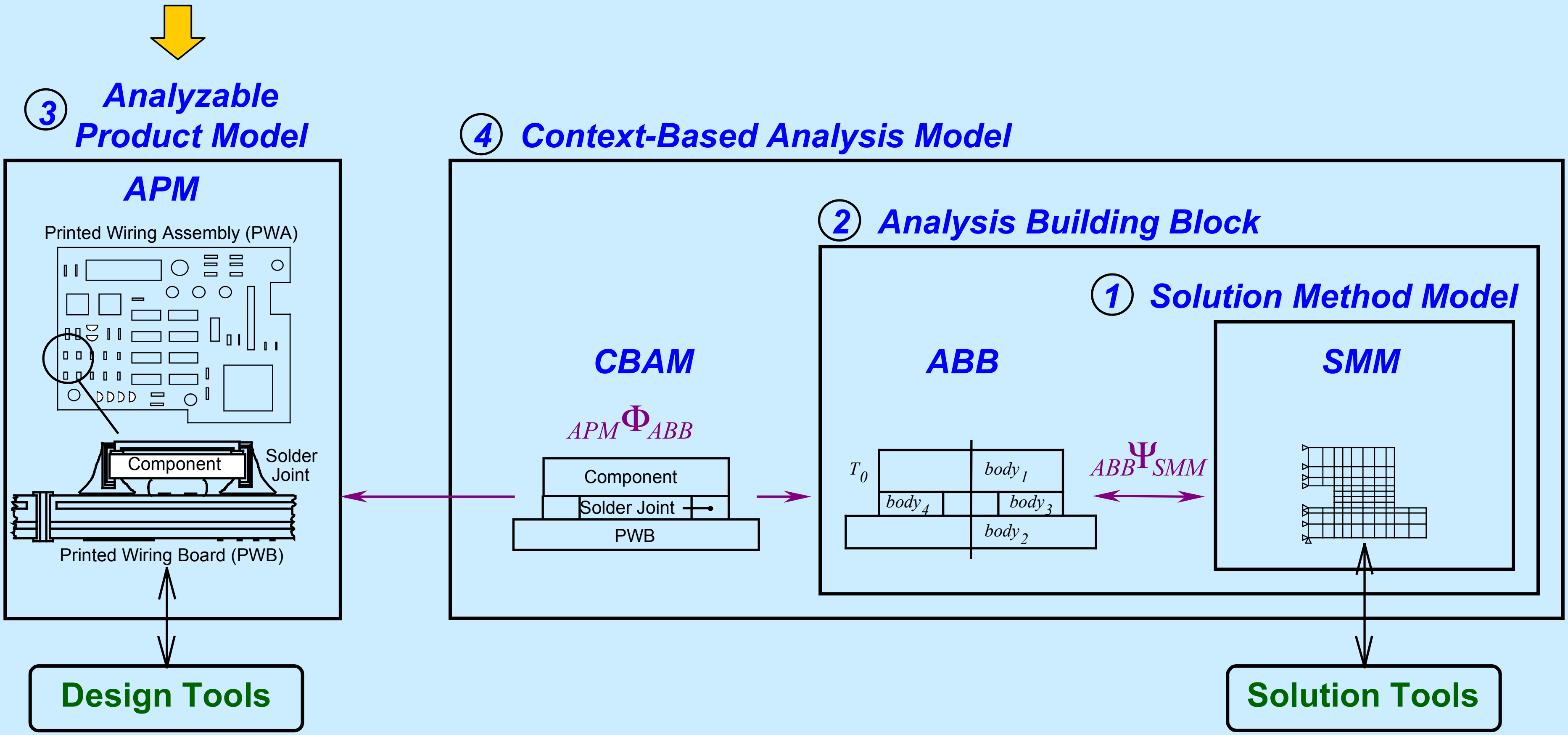
Extensional Rod





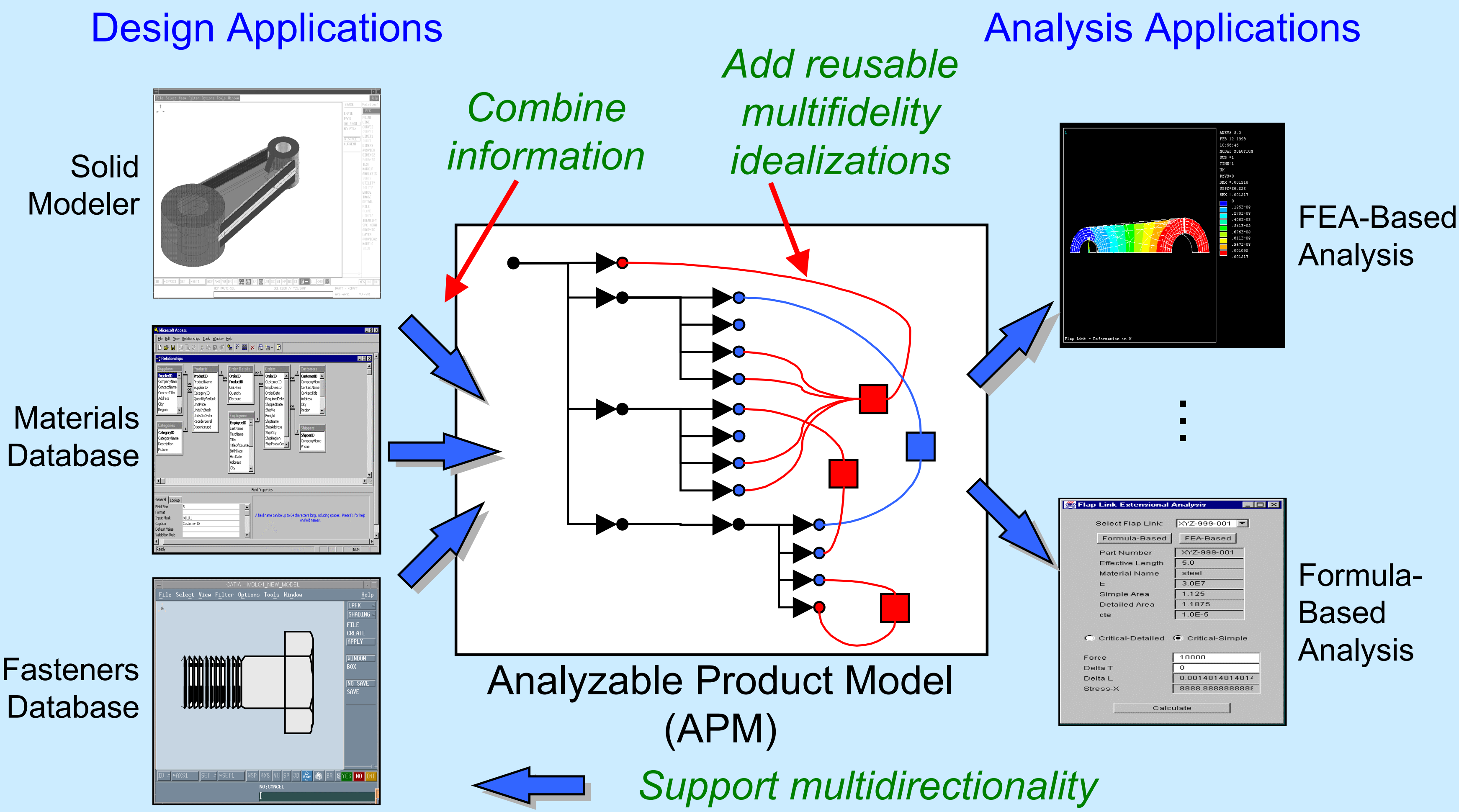
Usage by Flap Link Model

Multi-Representation Architecture for Design-Analysis Integration



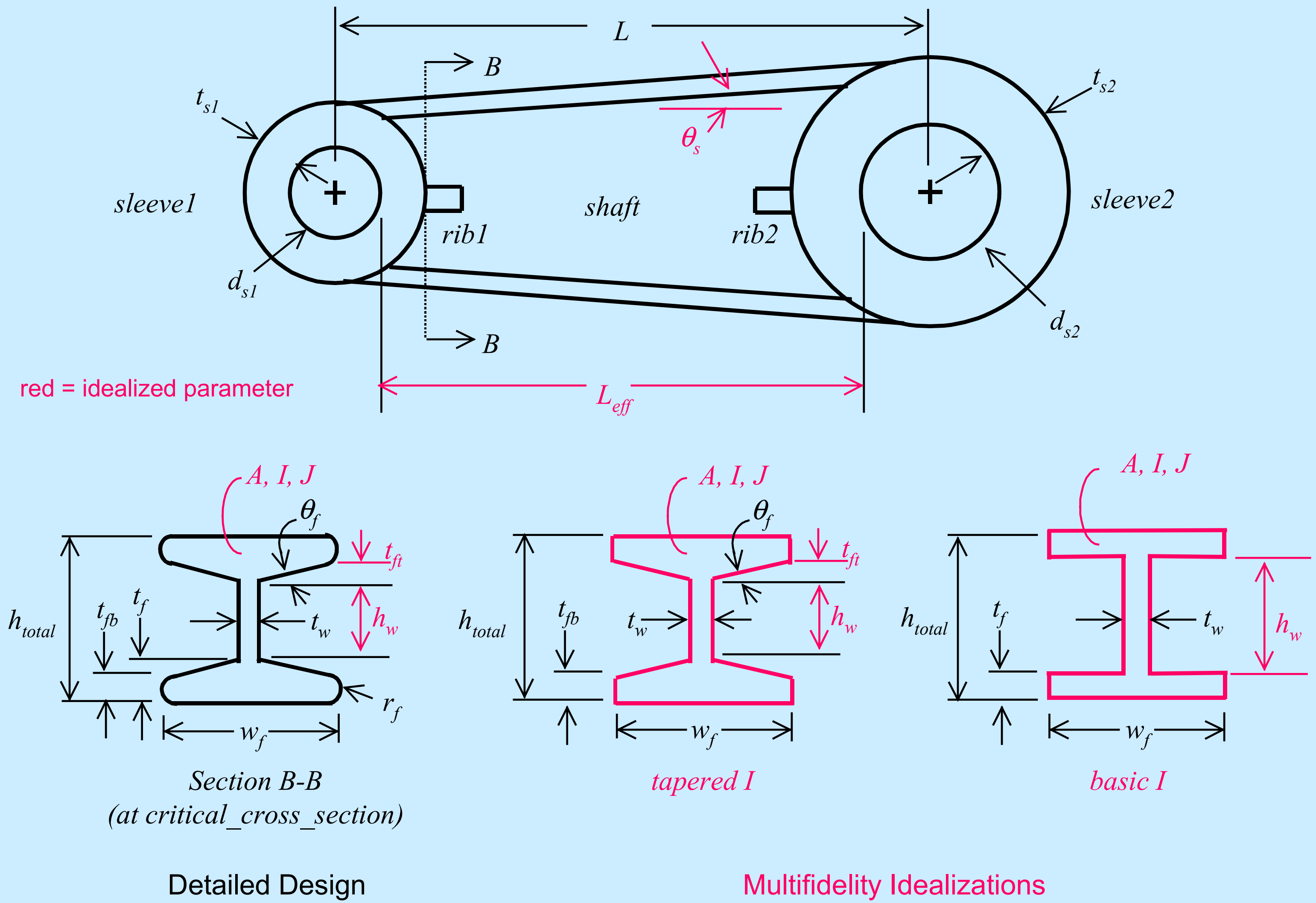
Analyzable Product Models (APMs)

Provide advanced access to design data needed by diverse analyses.



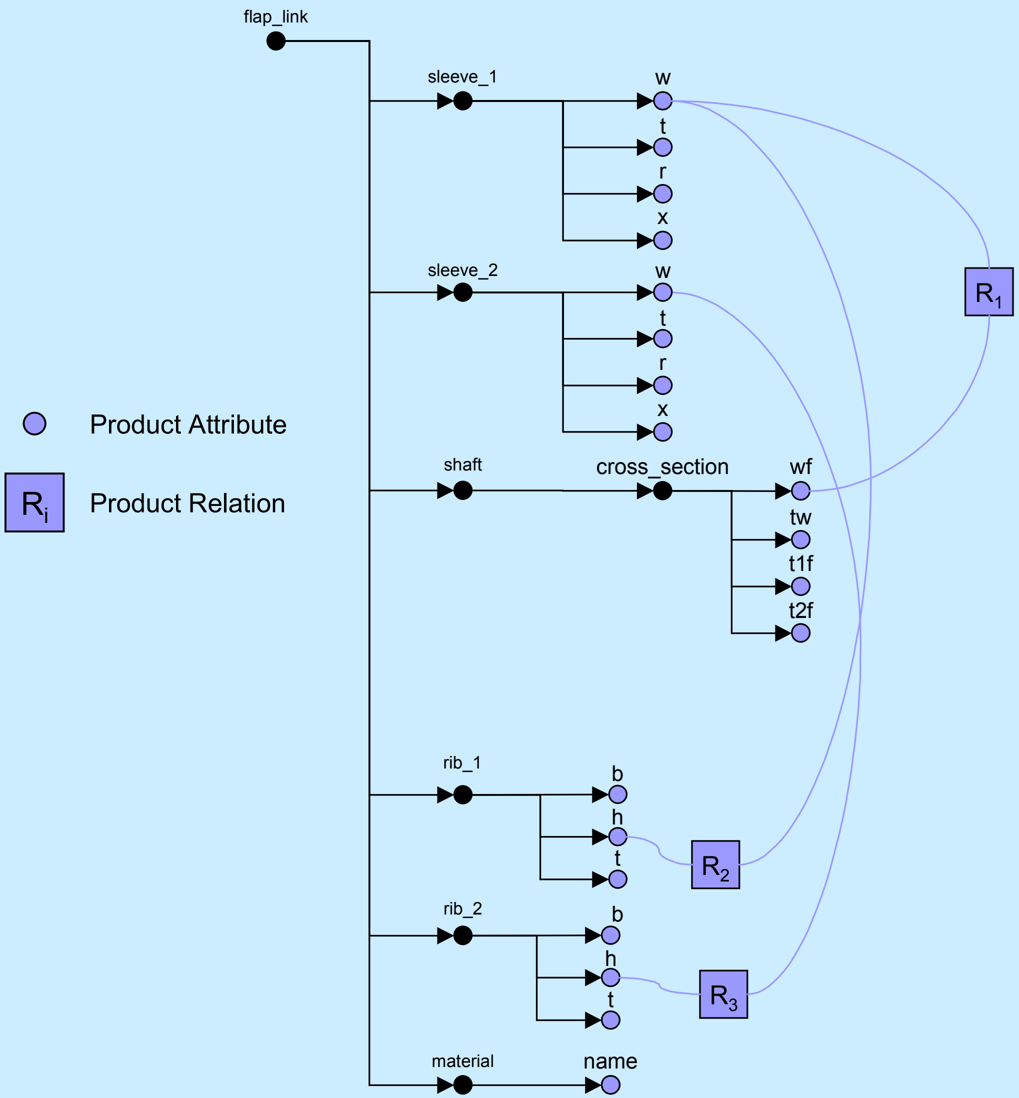
Flap Link Geometric Model

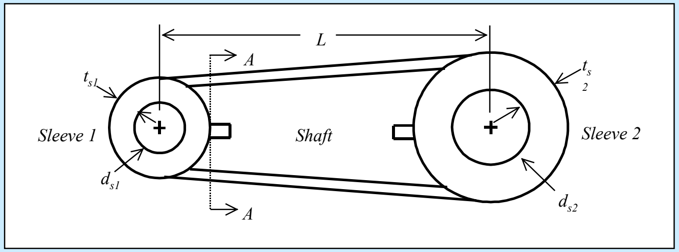
(with idealizations)



Flap Linkage Example

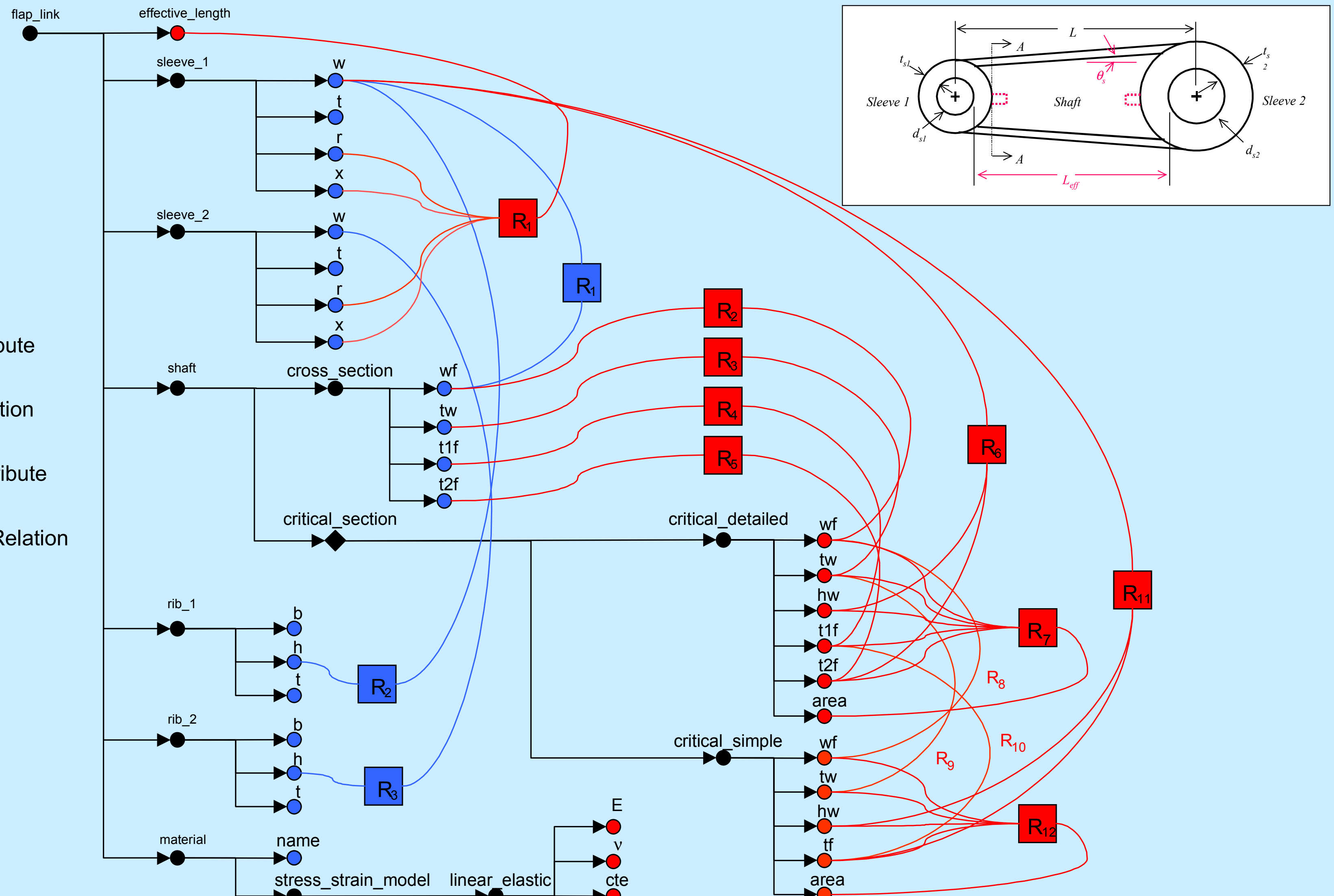
Manufacturable Product Model (MPM) = Design Description





Flap Linkage Example

Analyzable Product Model (APM) = MPM Subset + Idealizations



Product Attribute

Ri Product Relation

Idealized Attribute

Ri Idealization Relation

APM Interface with Tagged CAD Models

1) APM COB Tool

7) Solve idealizations

8) Use in analysis

2) request

```
part_number : "9162";
hole1.radius : ?;
hole2.radius : ?;
length1 : ?;
```

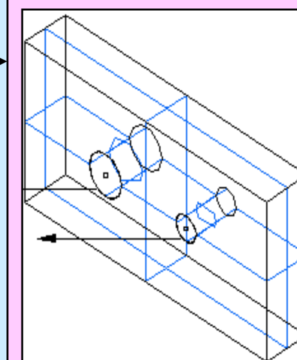
COB instance format

3) GIT Interface program

4) *tk/tcl CATGEO wrapper*

3 and 4 similar to other CAD APIs

5)



CATIA (CAD tool)

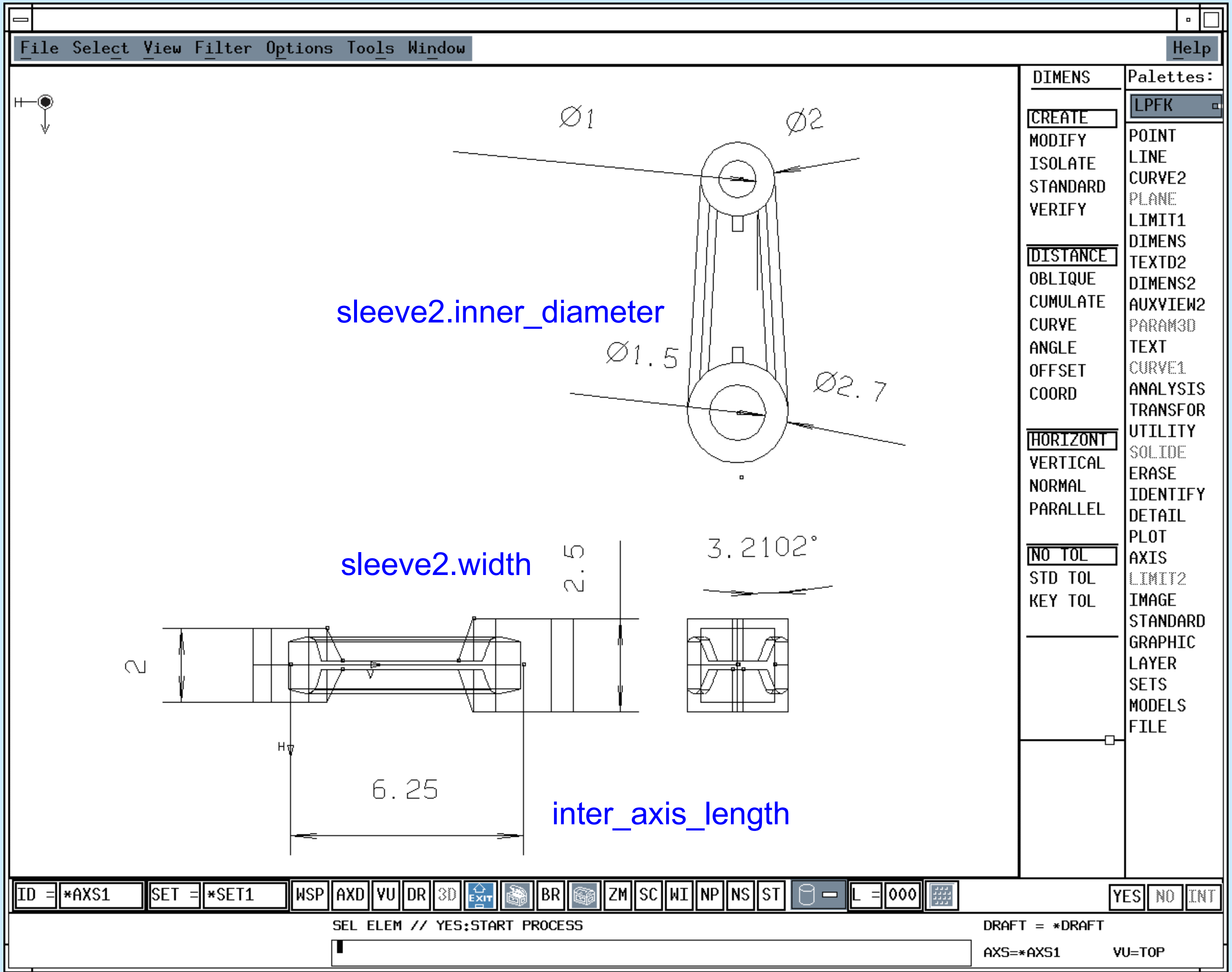
6) response

```
part_number : "9162";
hole1.radius : 2.5;
hole2.radius : 4.0;
length1 : 20.0;
```

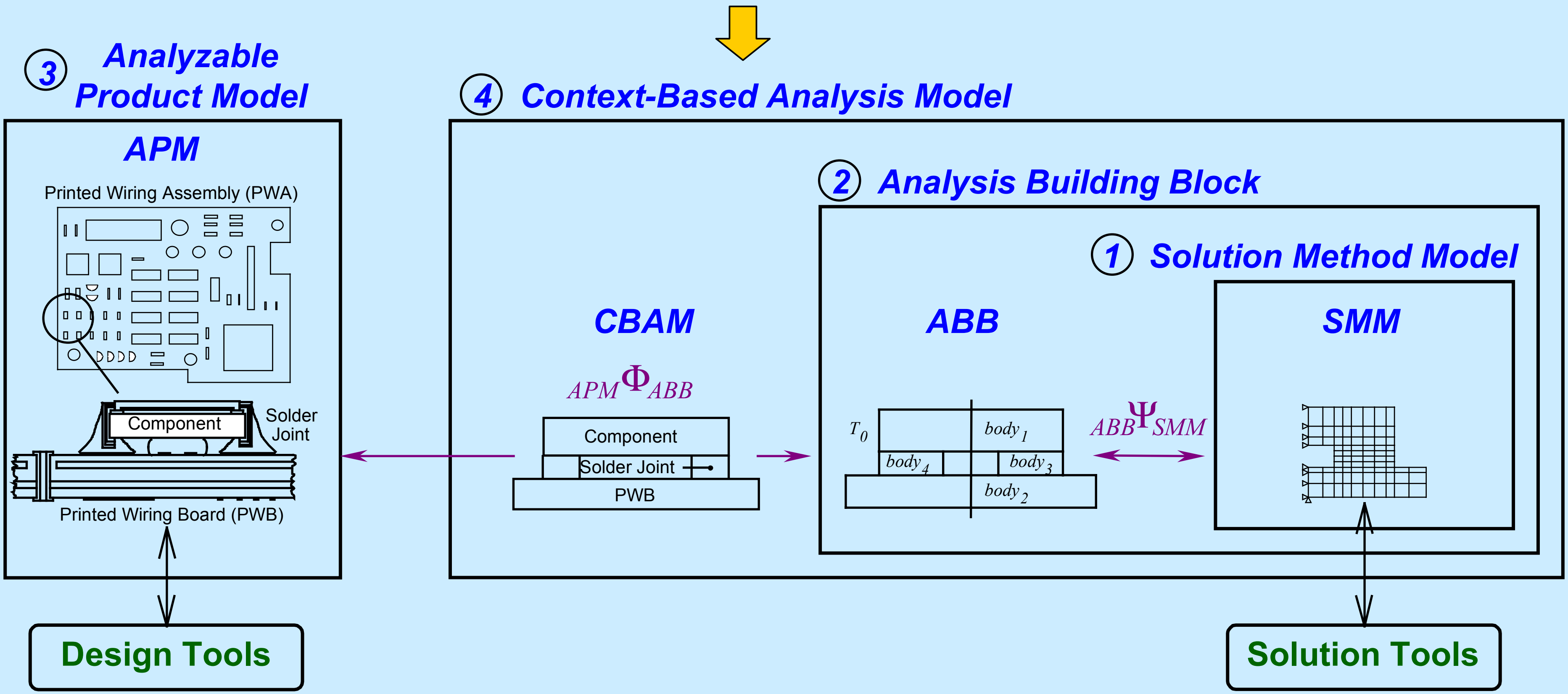
0) **Designer**

- Creates design geometry
- Defines APM-compatible parameters/tags

Flap Link Tagging



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 in^2 — $E =$ 30e6 *psi*

$\sigma_{allowable} =$ 18000 *psi*

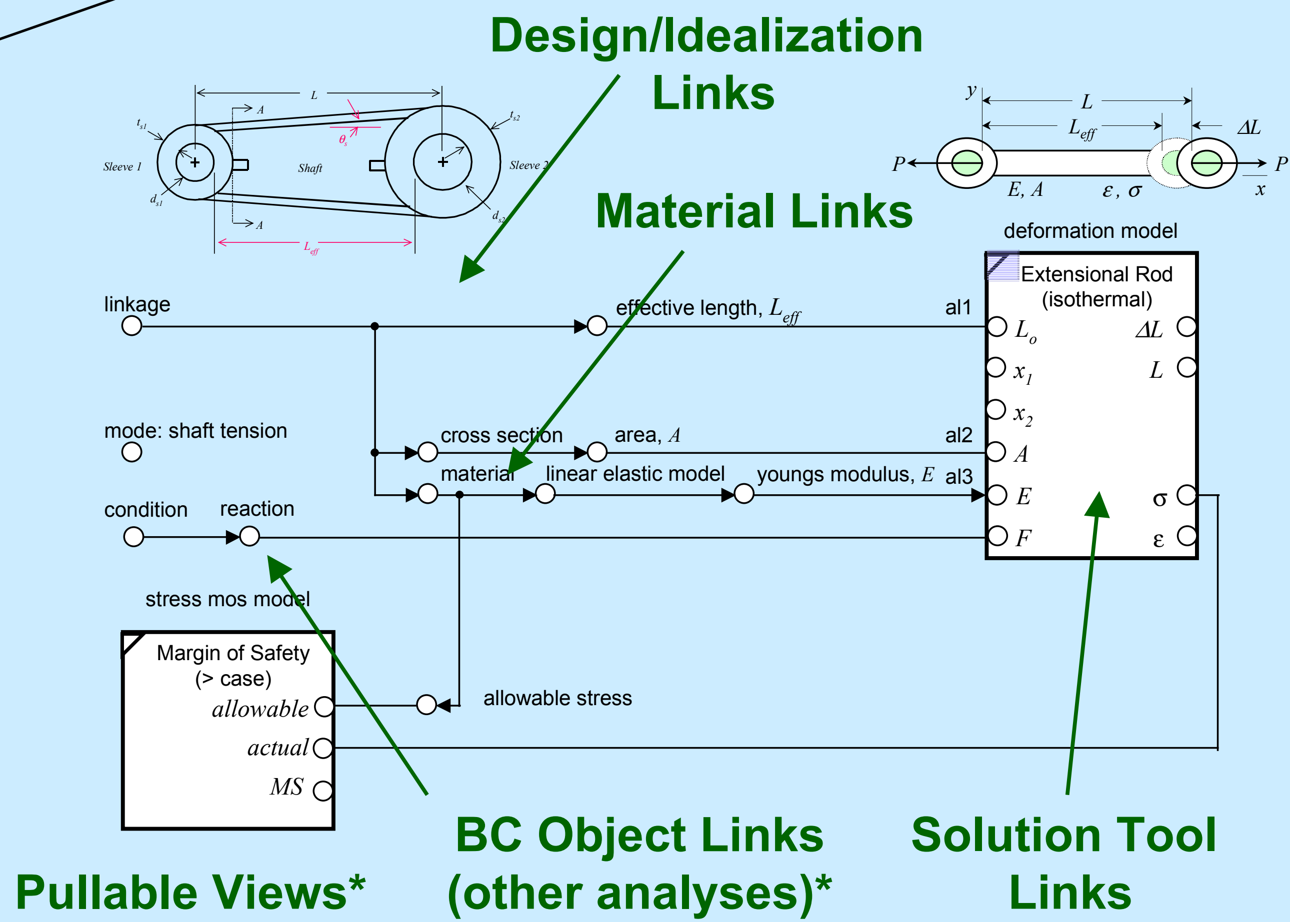
4. Analysis Calculations

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

5. Objective

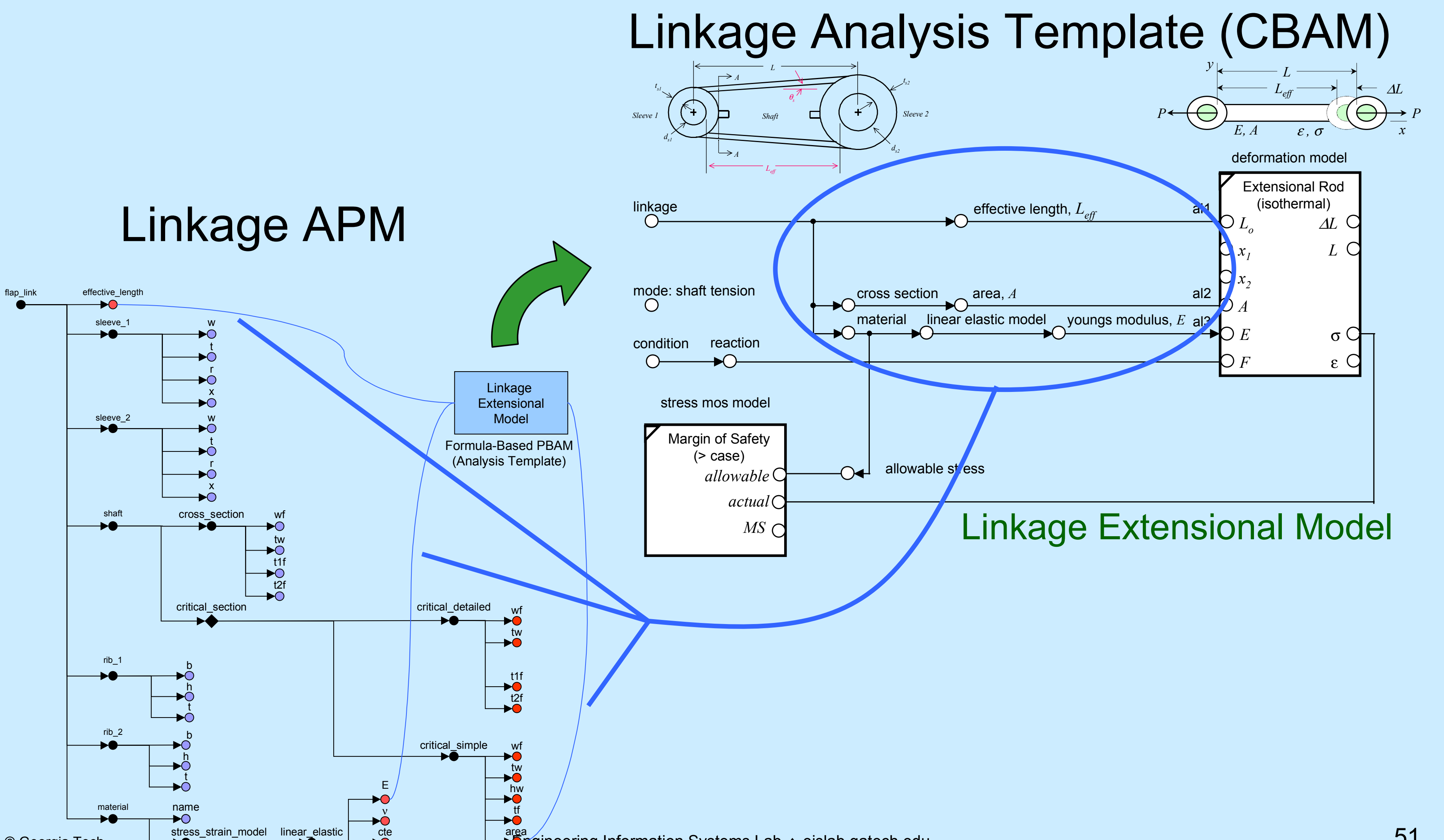
$$MS = \frac{\sigma_{allowable}}{\sigma} - 1 = 1.03$$

(1a) Analysis Problem for 1D Extension Analysis



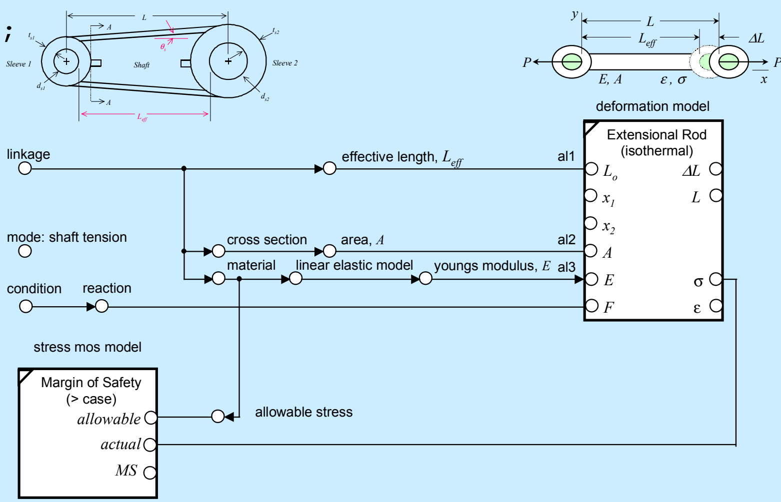
** Boundary condition objects & pullable views are WIP**

Analysis Template Usage of APM Idealized Attributes



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
   al1 : "<deformation_model.undeformed_length> == <link.effective_length>";
   al2 : "<deformation_model.area> == <link.shaft.critical_cross_section.basic.area>";
   al3 : "<deformation_model.material_model.youngs_modulus> ==
             <link.material.stress_strain_model.linear_elastic.youngs_modulus>";

   al4 : "<deformation_model.material_model.name> == <link.material.name>";
   al5 : "<deformation_model.force> == <associated_condition.reaction>";

   al6 : "<stress_mos_model.allowable> == <link.material.yield_stress>";
   al7 : "<stress_mos_model.determined> == <deformation_model.material_model.stress>";
END_COB;
```

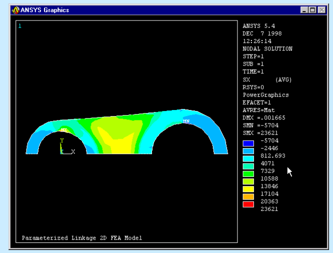


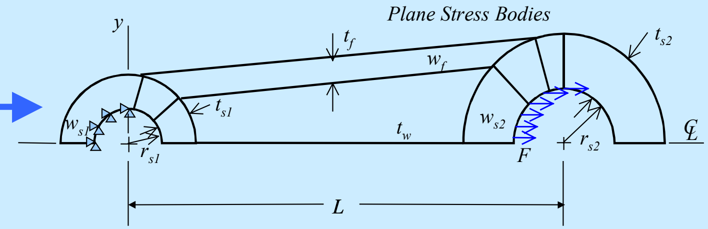
Desired categorization of attributes is shown above (as manually inserted) to support pullable views. Categorization capabilities is a planned XaiTools extension.

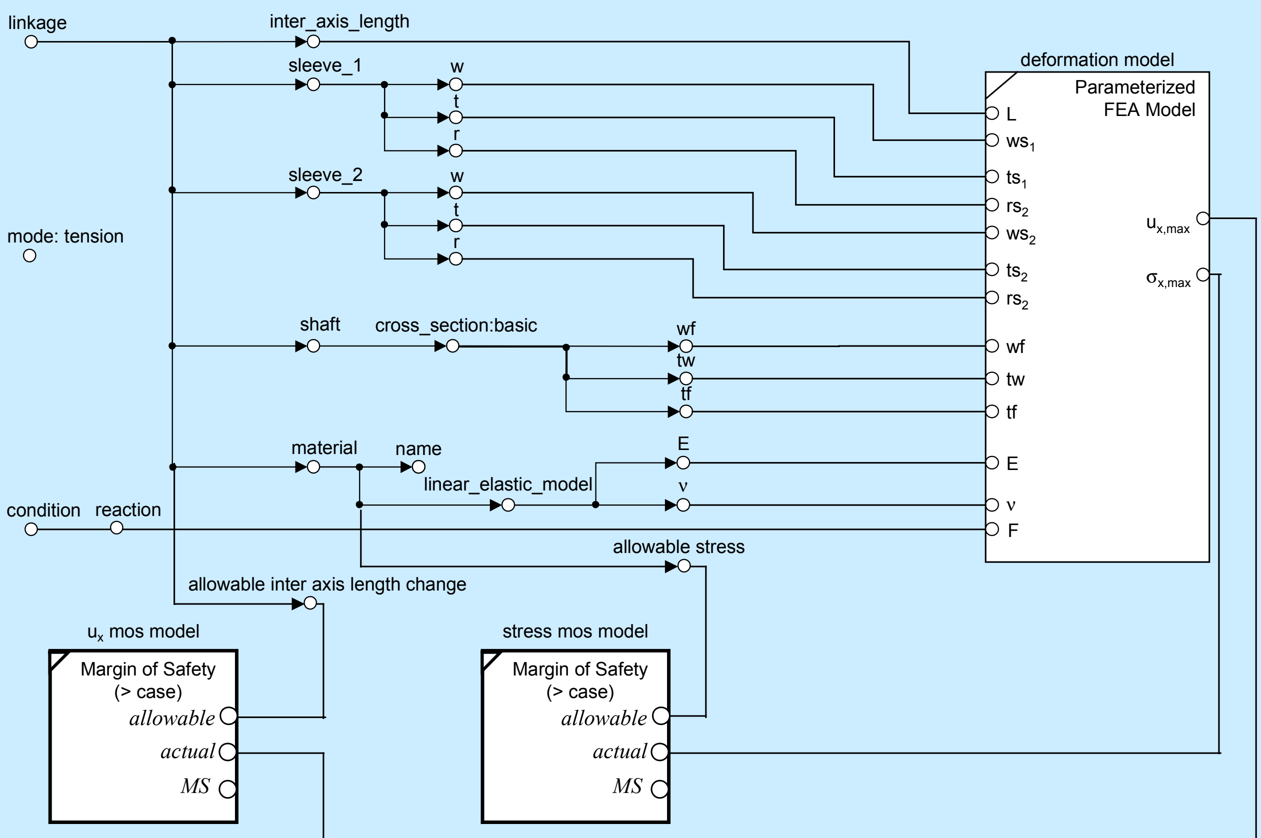
FEA-based Analysis Subsystem

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

Higher fidelity version
vs. Linkage Extensional Model

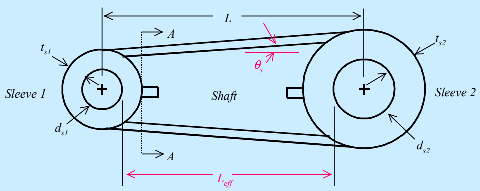


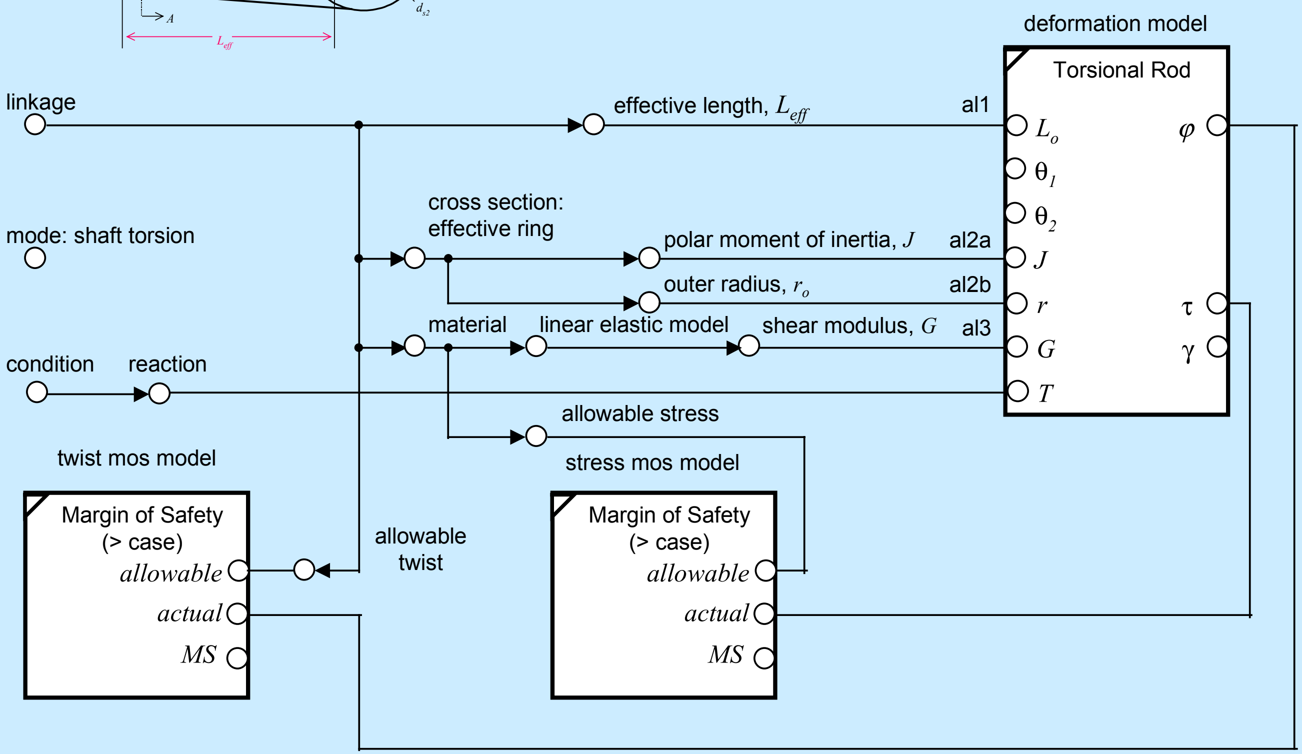


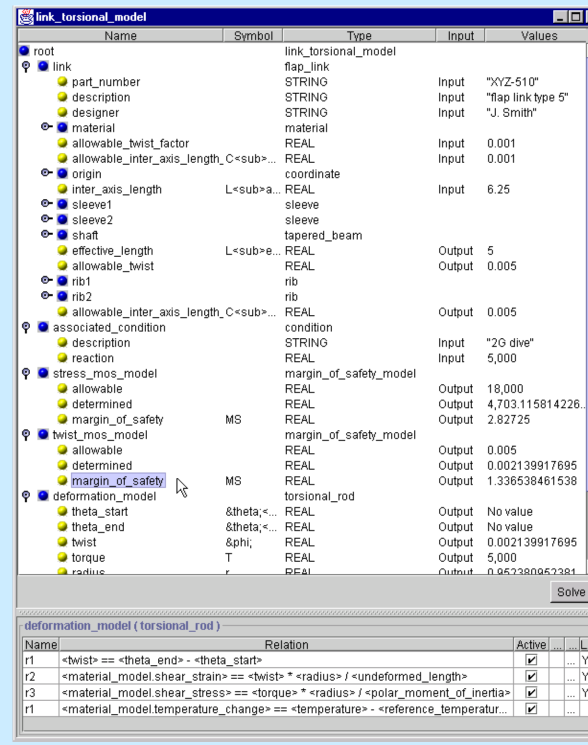


Flap Linkage Torsional Model

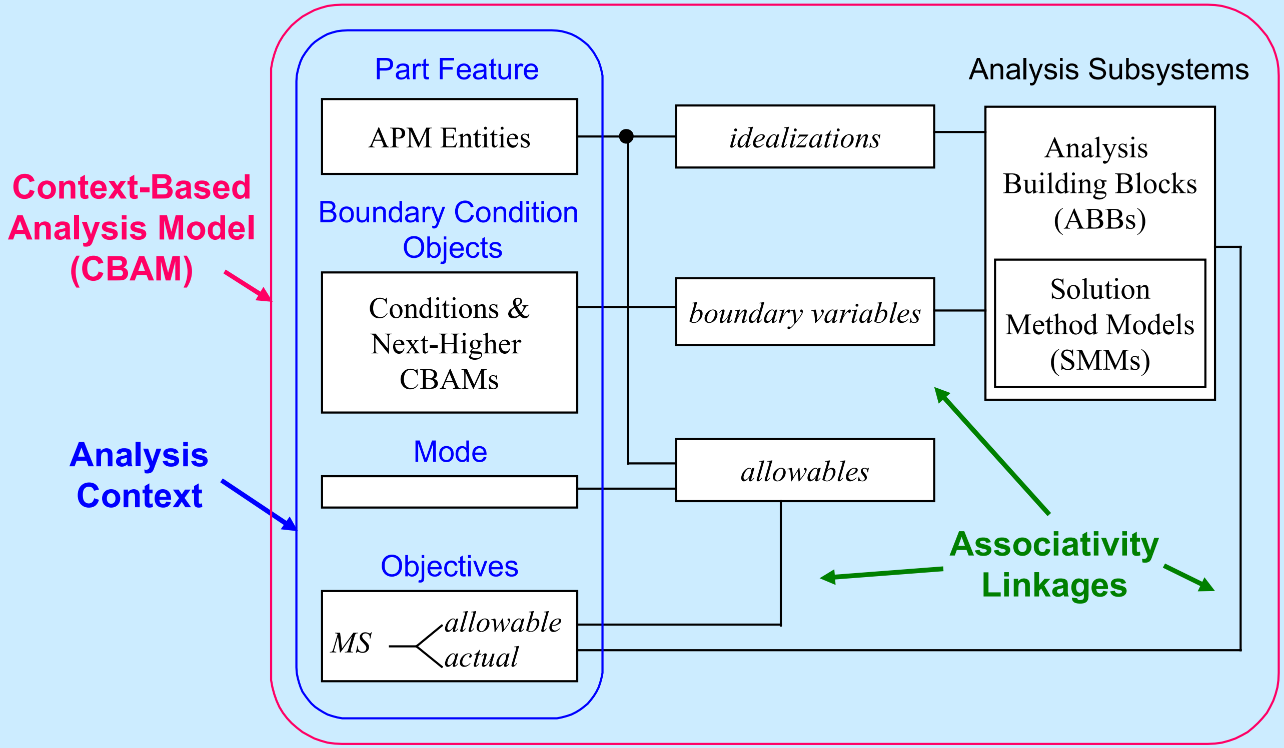
Diverse Mode (Behavior) vs. Linkage Extensional Model







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

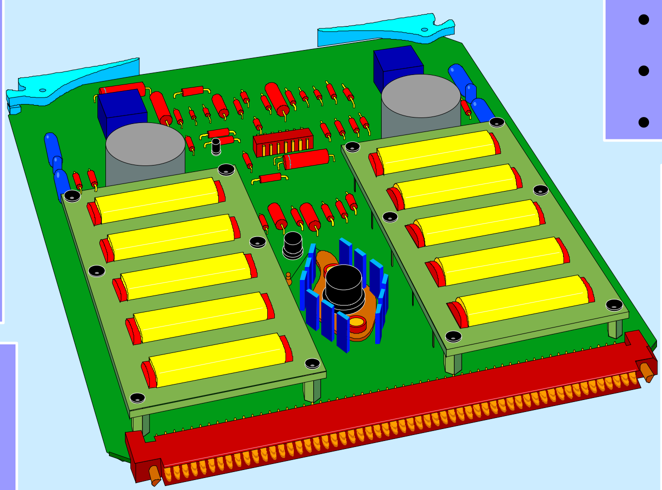
- Analysis Integration Challenges
- Introduction to Constrained Objects (COBs)
- Overview of COB-based XAI
- Example Applications
  - Electronic Packaging Thermomechanical Analysis
  - Aerospace Structural Analysis
- Summary

STEP AP 210
PWA/B Design Information

Product Structure/ Connectivity
- Functional
- Packaged

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

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



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

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

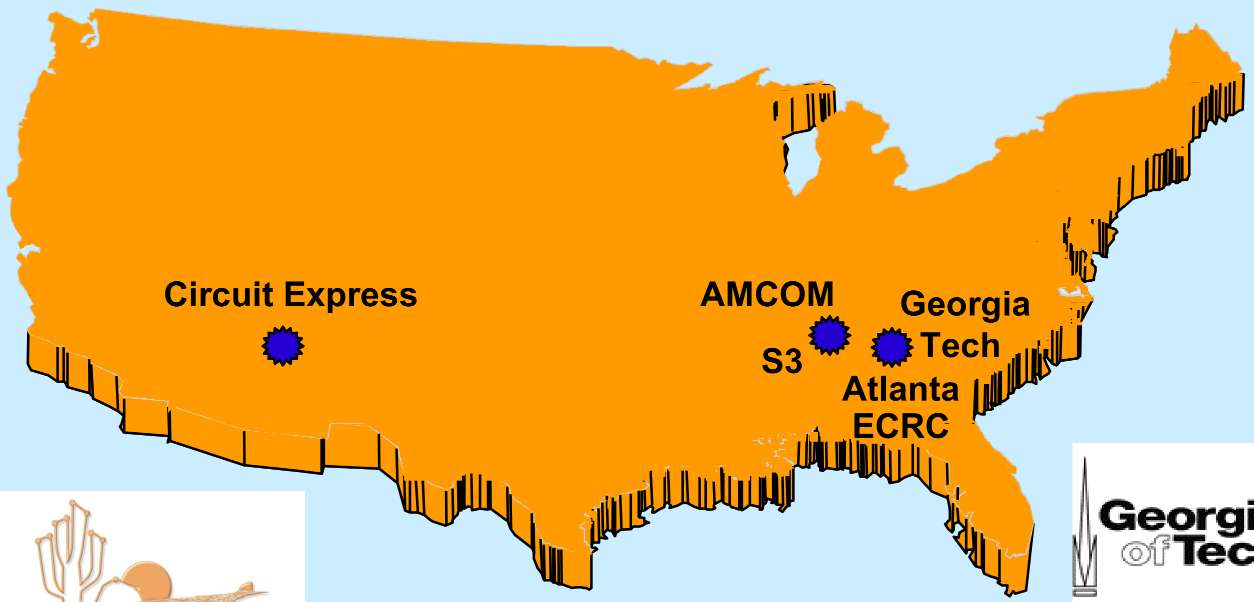
Requirements
- Design
- Allocation
- Constraints
- Interface

Technology
- Fabrication Design Rules
- Product Design Rules

ProAM Technical Team

SYSTEM STUDIES & SIMULATION, Inc

Providing Technical Products and Services to the Defense, Space, and the Intelligence communities



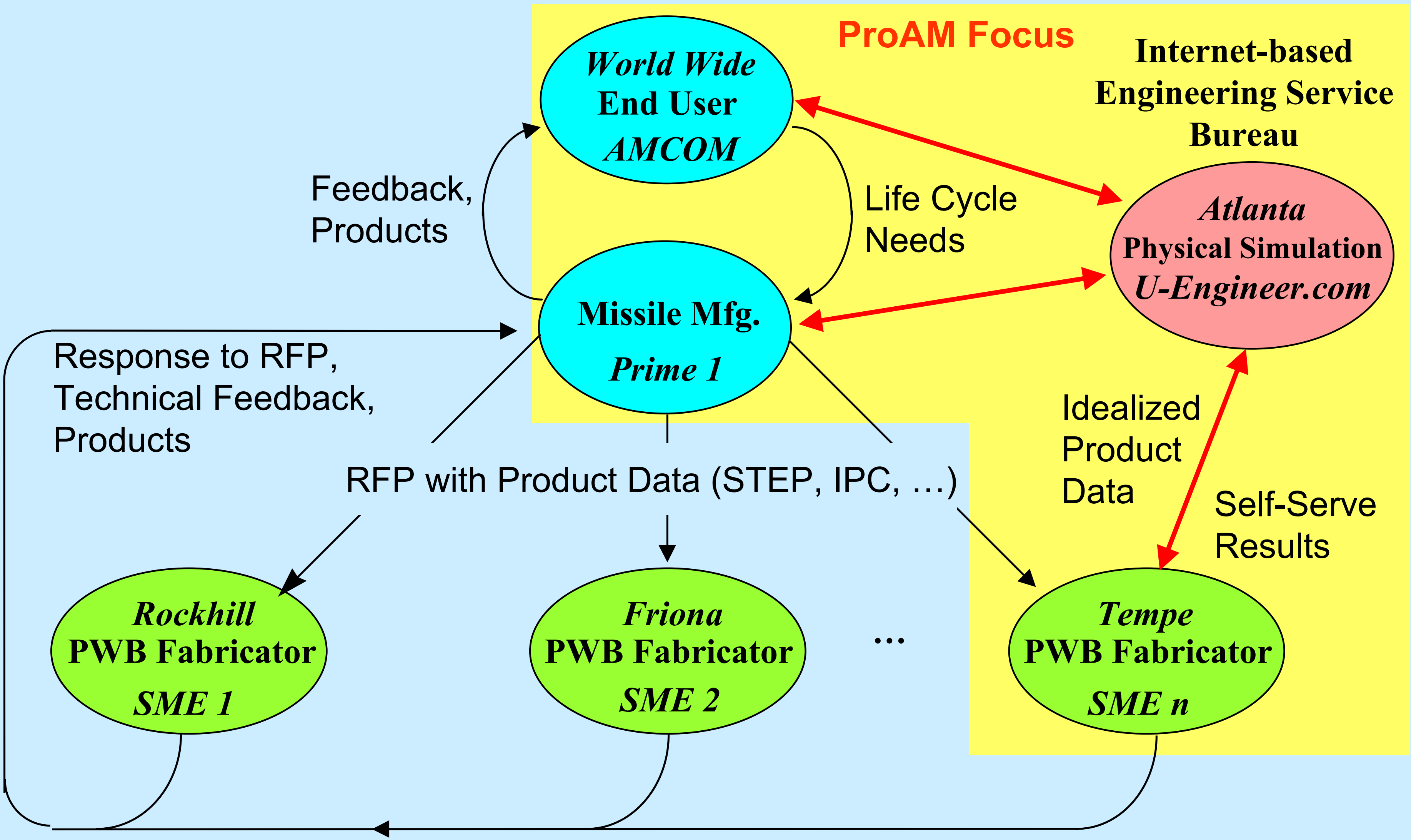
CIRCUIT EXPRESS, INC.
"Quality in Every Process"

Atlanta ECRC
Electronic Commerce Resource Center

Georgia Institute of Technology

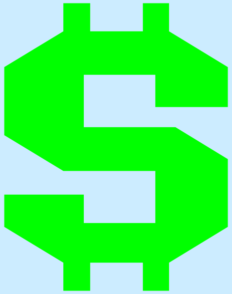
ProAM Focus

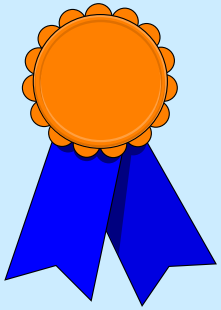
Highly Automated Internet-based Analysis Modules



Why Do SME Manufacturers Need Analysis?

- Typically niche-experts
  - Precise mfg. process knowledge
  - Specialized product design knowledge (ex. PWB laminates)
- SME analysis needs
  - Product improvements (DFM)
  - Mfg. process troubleshooting
  - Mfg. process optimization
- More accurate data $\rightarrow$ Better analysis
- Bottom line drivers:



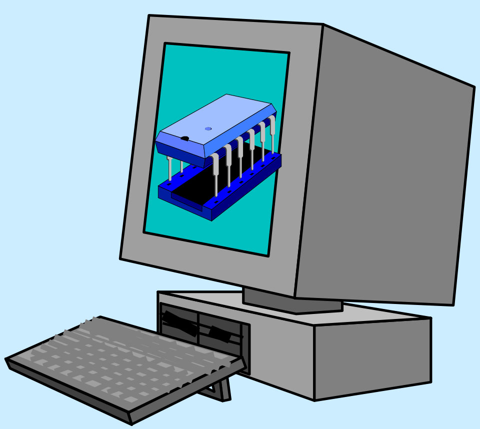


Higher Yields, Lower Cost, Better Quality, Fewer Delays

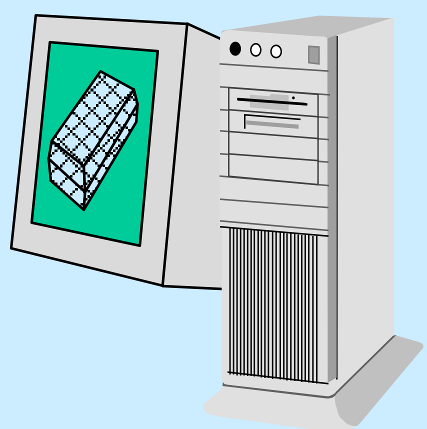
Barriers to SME Analysis

- Lack of awareness
- High costs of traditional analysis capability
  - Secondary: Specialized Software, Training, Hardware
  - Primary: Model Access/Development, Validation, Usage
- Lack of domain-specific integrated tools

Product Model

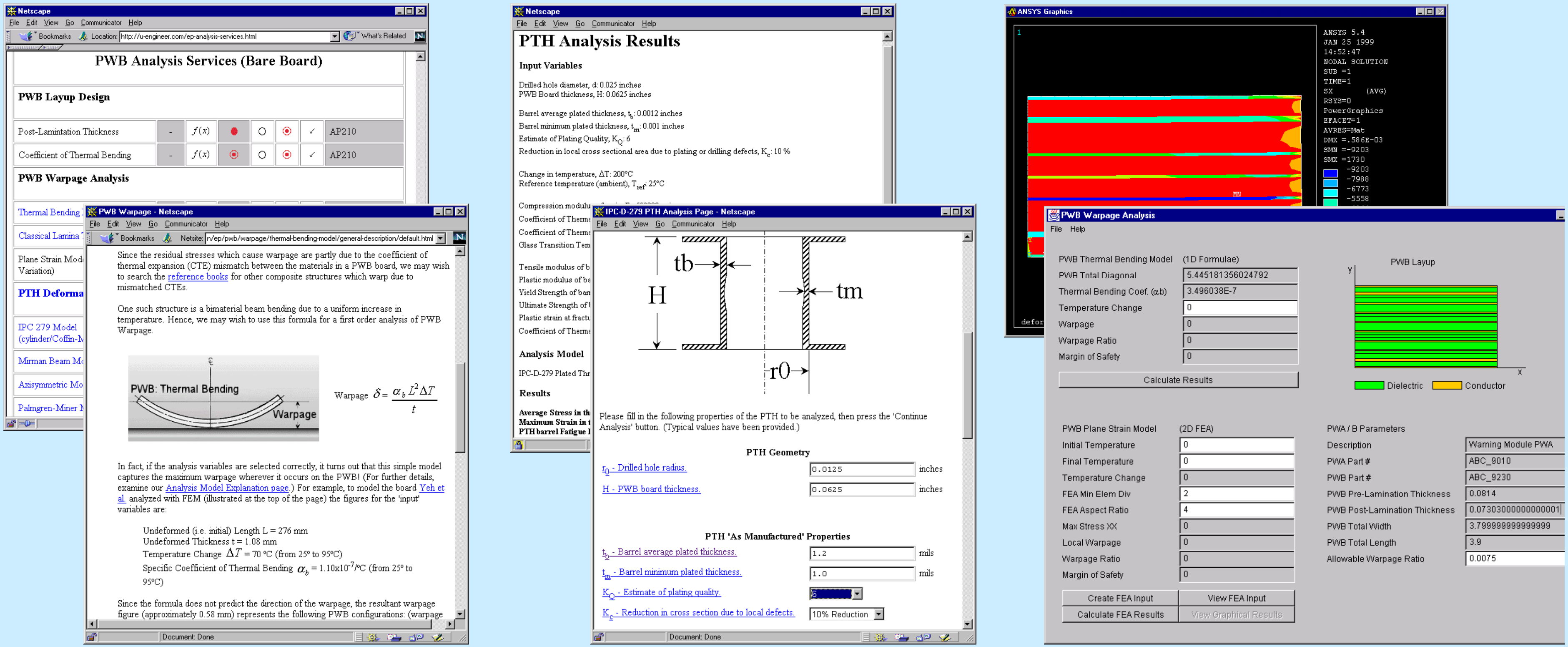


Analysis Model



Skilled Personnel

Internet-based Engineering Service Bureau (ESB) Tools



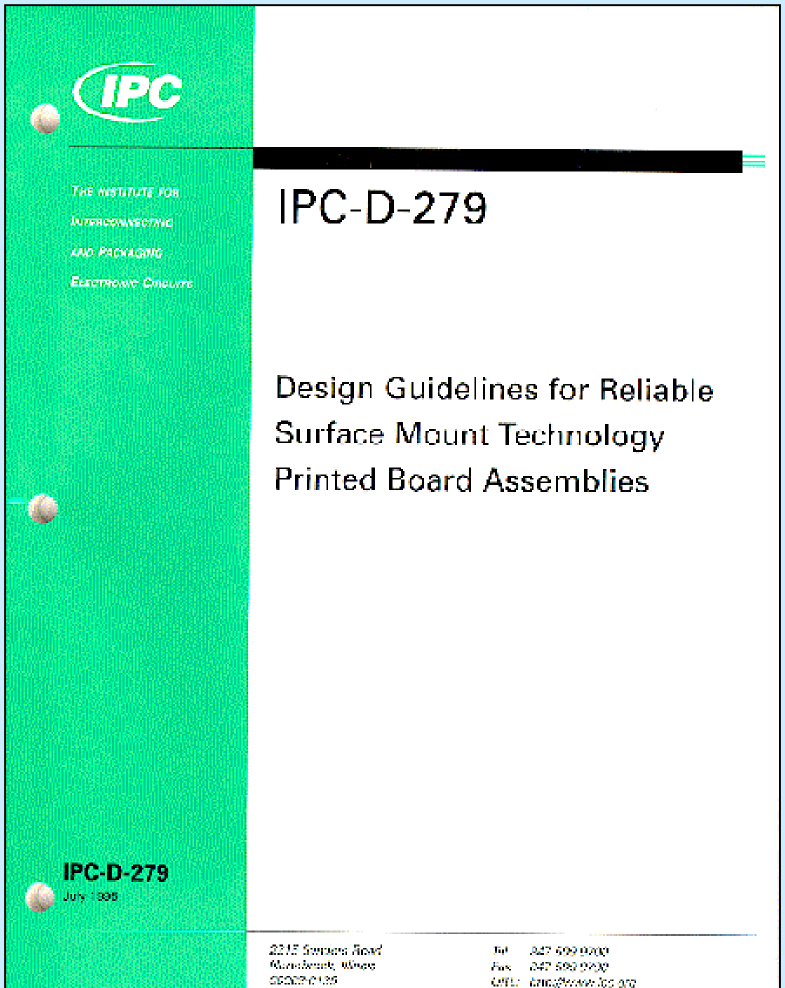
Analysis Documentation

Ready-to-Use Analysis Modules

Lower cost, better quality, fewer delays in supply chain

Paper-based IPC-D-279 Plated Through Hole Fatigue Analysis

Tedious to Use



PTH/PTV Fatigue Life Estimation

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

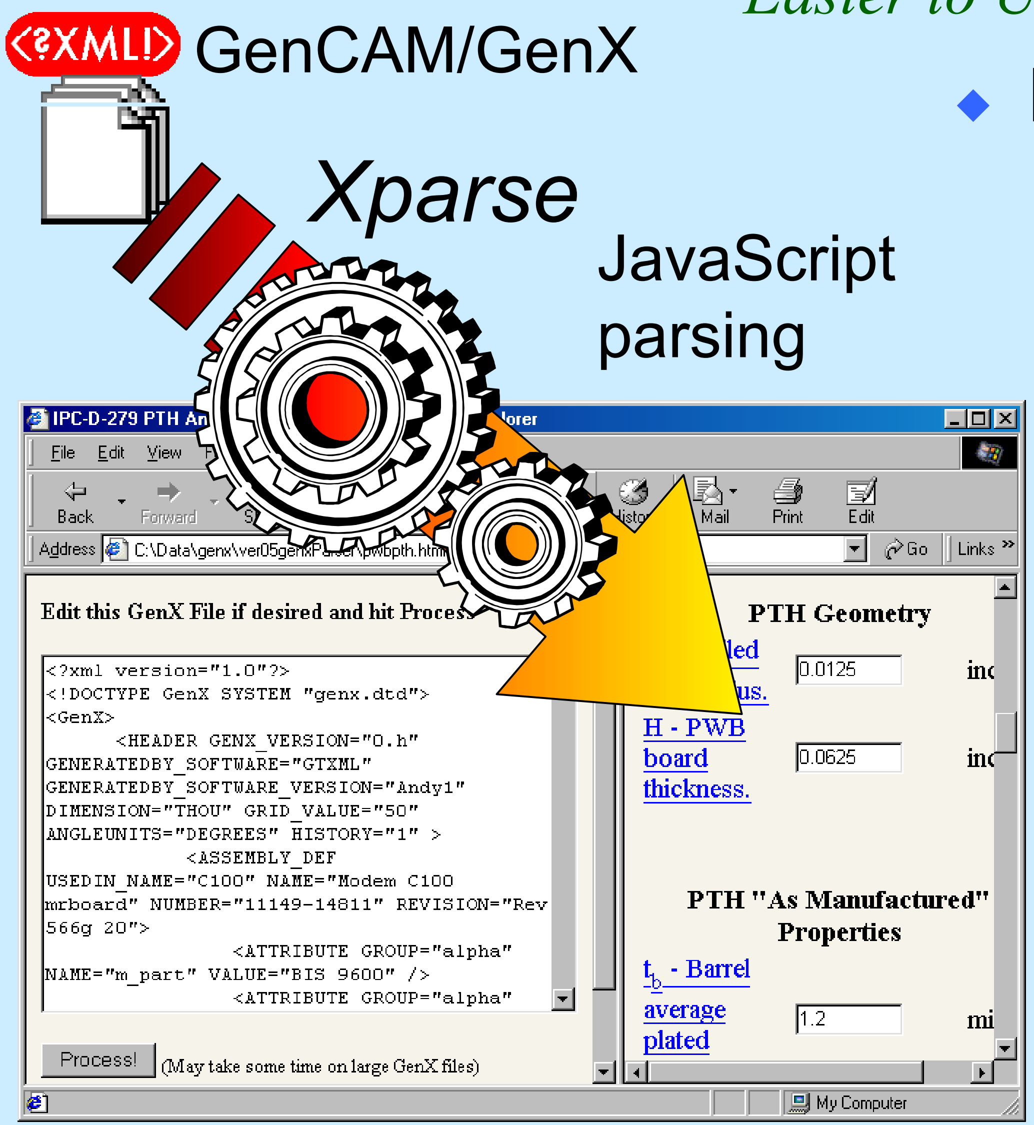
$$\Delta\varepsilon_{avg} = \frac{(\alpha_E - \alpha_{Cu})\Delta T \cdot A_E \cdot E_E - S_y \cdot A_{Cu} \cdot \frac{E_{Cu} - E_{Cu}'}{E_{Cu}}}{A_E \cdot E_E + A_{Cu} \cdot E_{Cu}'}$$

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

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

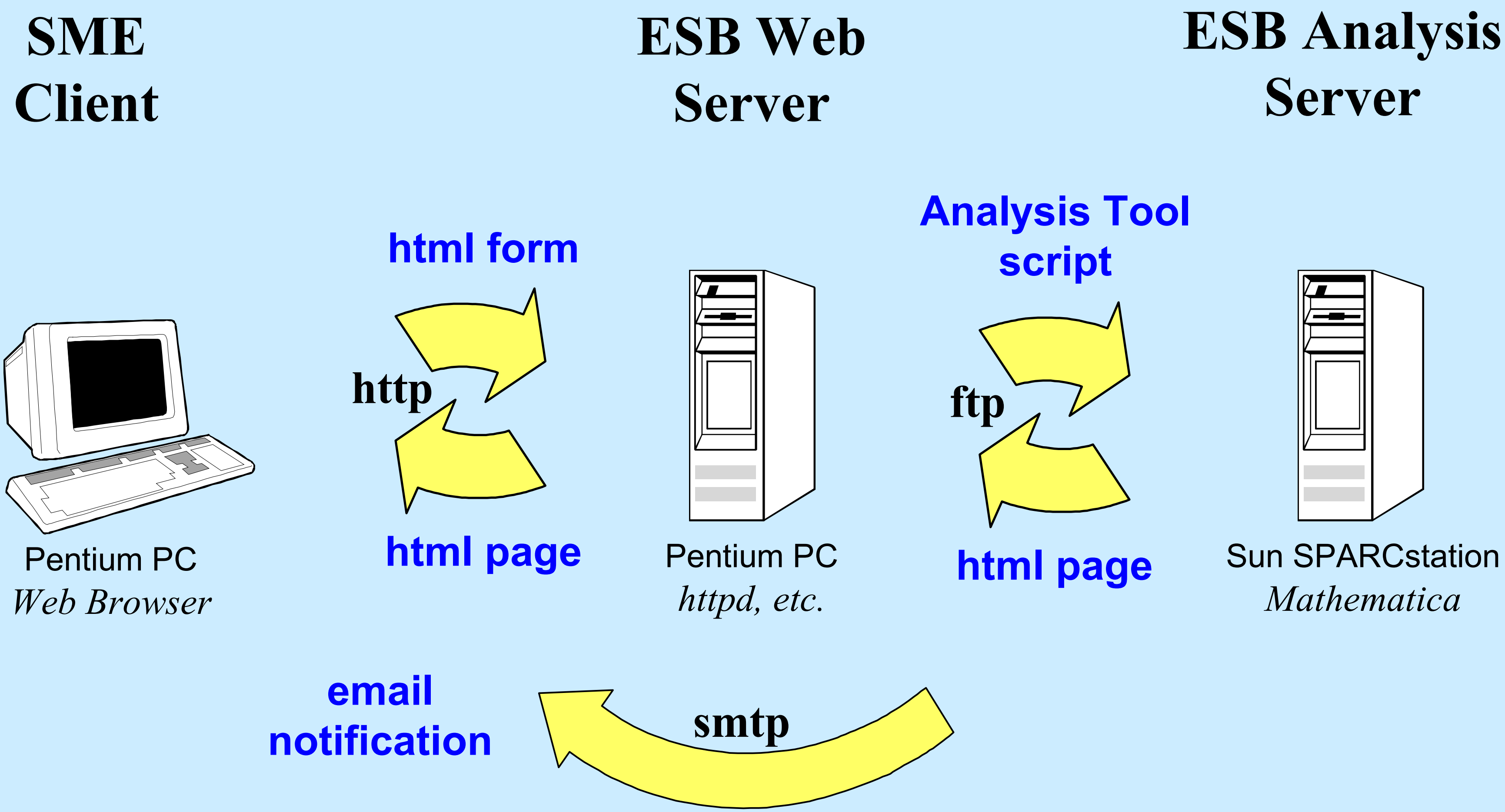
Product Data-Driven IPC-D-279 PTH Analysis Module

Easier to Use

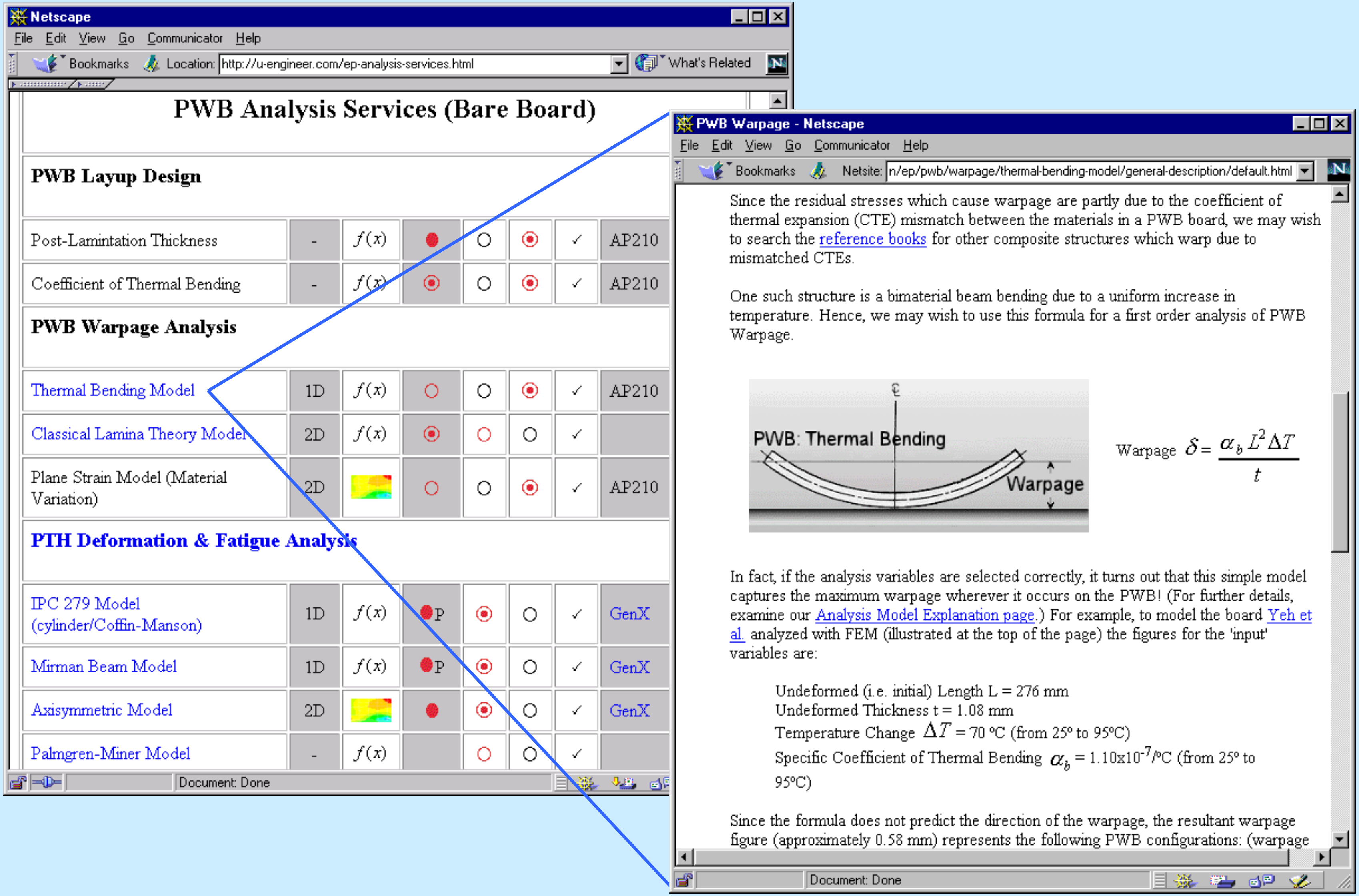


- Data Driven aspect: Web
  - + Local Browser Compu
  - + Less Errors than manu
  - + Exhaustive search
  - + Data Compression (e.g. 100x)
  - + Security

Analysis Data Flow
Web-based Approach



ESB Analysis Module
Catalogs & Documentation



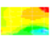
Analysis Modules Attributes

Netscape

File Edit View Go Communicator Help

Solution Method - An indication of model computational cost.

$f(x)$ Formula Based

 Finite Element

Utility Ranking - A measure of analysis model validity.

○ (black) Demonstration

○ (red) Trends

◉ Magnitude Relative

● Absolute

A "P" suffix indicates the ranking is backed by physical measurements.

Tool Availability - A measure of implementation maturity.

○ (black) Concept

○ (red) Prototype

◉ Pilot

● Production

	Dimensionality	Solution Method	Utility Ranking	Availability			Supported Design Formats
				Self - Serve Web	Self - Serve Toolkit	Full - Serve	

Document: Done

Netscape

File Edit View Go Communicator Help

Bookmarks Location: http://u-engineer.com/ep-analysis-services.html What's Related

PWB Analysis Services (Bare Board)

	Dimensionality	Solution Method	Utility Ranking	Self - Serve Web	Self - Serve Toolkit	Full - Serve	Supported Design Formats
PWB Layup Design							
Post-Lamintation Thickness	-	$f(x)$	●	○ (black)	◉	✓	AP210
Coefficient of Thermal Bending	-	$f(x)$	◉	○ (black)	◉	✓	AP210
PWB Warpage Analysis							
Thermal Bending Model	1D	$f(x)$	○ (red)	○ (black)	◉	✓	AP210
Classical Lamina Theory Model	2D	$f(x)$	◉	○ (red)	○ (black)	✓	
Plane Strain Model (Material Variation)	2D		○ (red)	○ (black)	◉	✓	AP210
PTH Deformation & Fatigue Analysis							
IPC 279 Model (cylinder/Coffin-Manson)	1D	$f(x)$	●P	◉	○ (black)	✓	GenX
Mirman Beam Model	1D	$f(x)$	●P	◉	○ (black)	✓	GenX
Axisymmetric Model	2D		●	◉	○ (black)	✓	GenX
Palmgren-Miner Model	-	$f(x)$		○ (red)	○ (black)	✓	

Document: Done

ESB Characteristics

- **Self-serve analysis**
  – Pre-developed analysis modules presented in product & process contexts
  – Available via the Internet
  – Optionally standards-driven (STEP, GenCAM ...):
    » Reduce manual data transformation & re-entry
    » Highly automated plug-and-play usage
  – Enabled by X-analysis integration technology
- **Full-serve analysis as needed**
- **Possible business models:** (beyond ProAM scope)
  – Pay-per-use and/or Pay-per-period

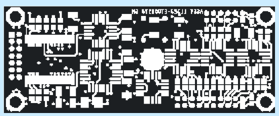
ProAM Design-Analysis Integration

Electronic Packaging Examples: PWA/B

Design Tools

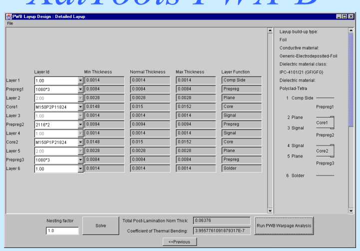
ECAD Tools

*Mentor Graphics, Accel**



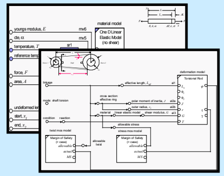
PWB Layup Tool

XaiTools PWA-B



Laminates DB

Materials DB



Modular, Reusable Template Libraries

STEP AP210, GenCAM**, PDIF*

Analyzable Product Model

XaiTools PWA-B

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

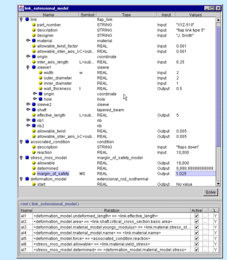
Solder Joint Deformation* — *1D, 2D, 3D*

PWB Warpage — *1D, 2D*

PTH Deformation & Fatigue** — *1D, 2D*

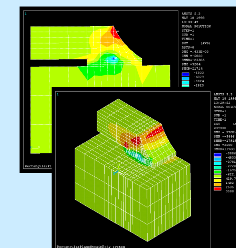
Analysis Tools

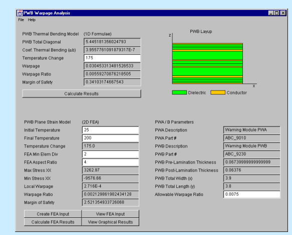
XaiTools PWA-B

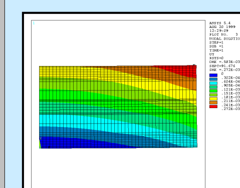


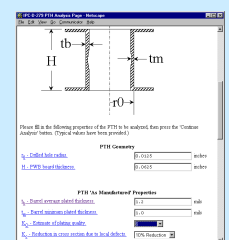
General Math *Mathematica*

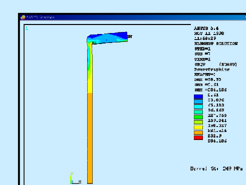
FEA *Ansys*







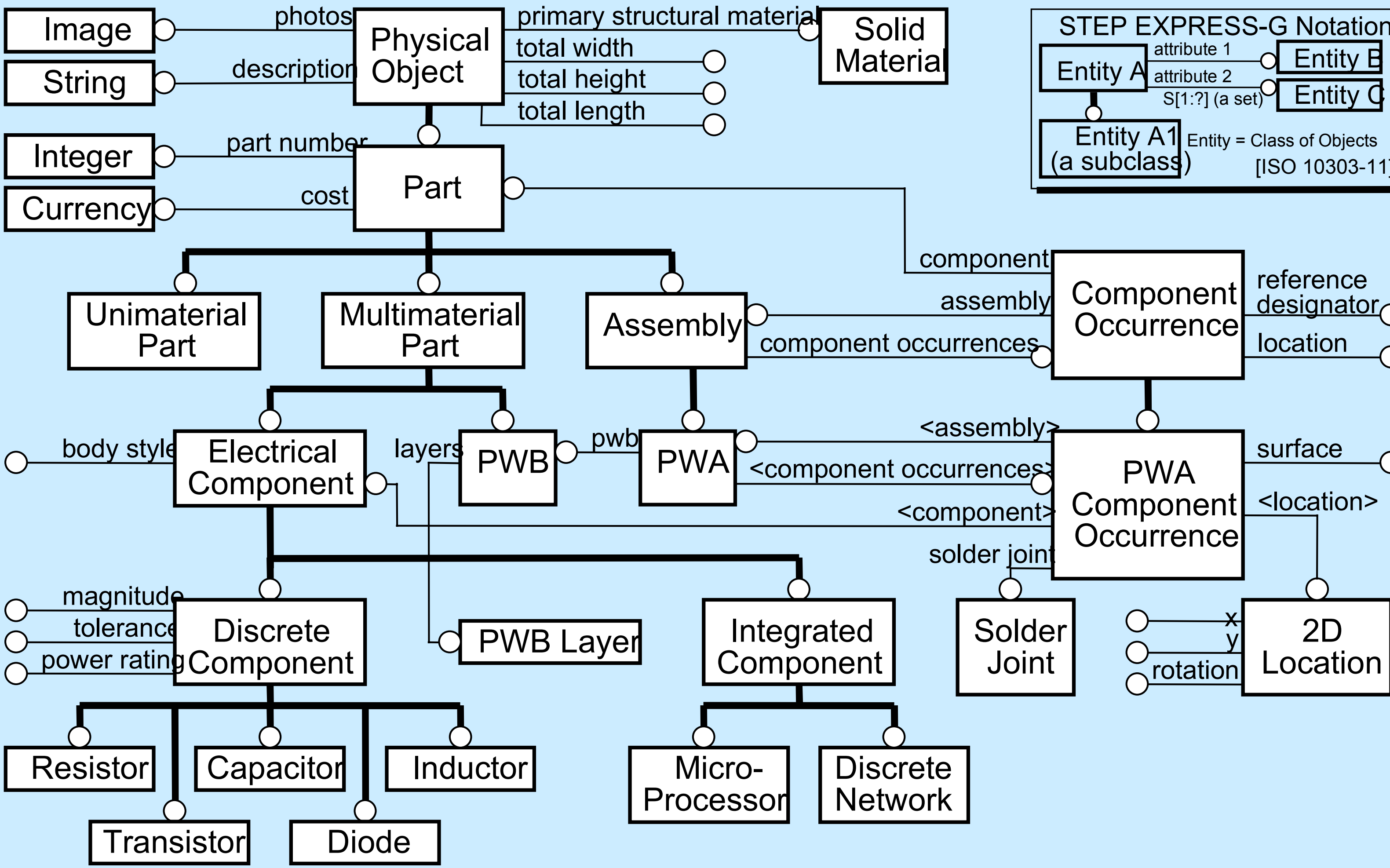




* = Item not yet available in toolkit (all others have working examples) ** = Item available via U-Engineer.com

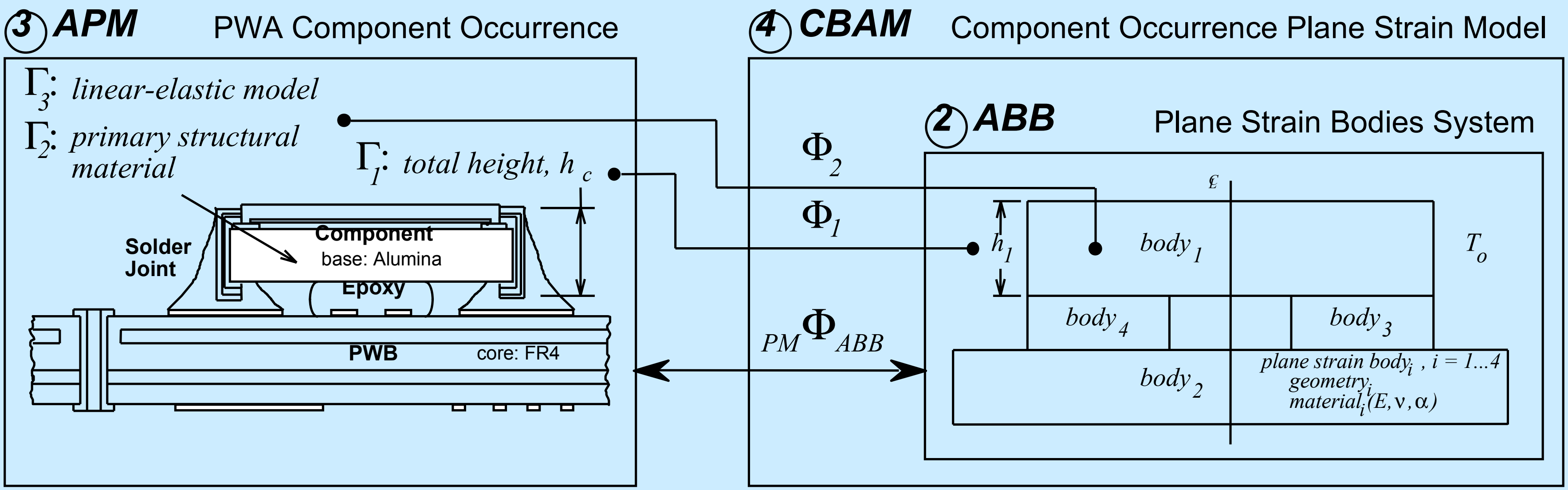
PWA/B Analyzable Product Model

(partial)



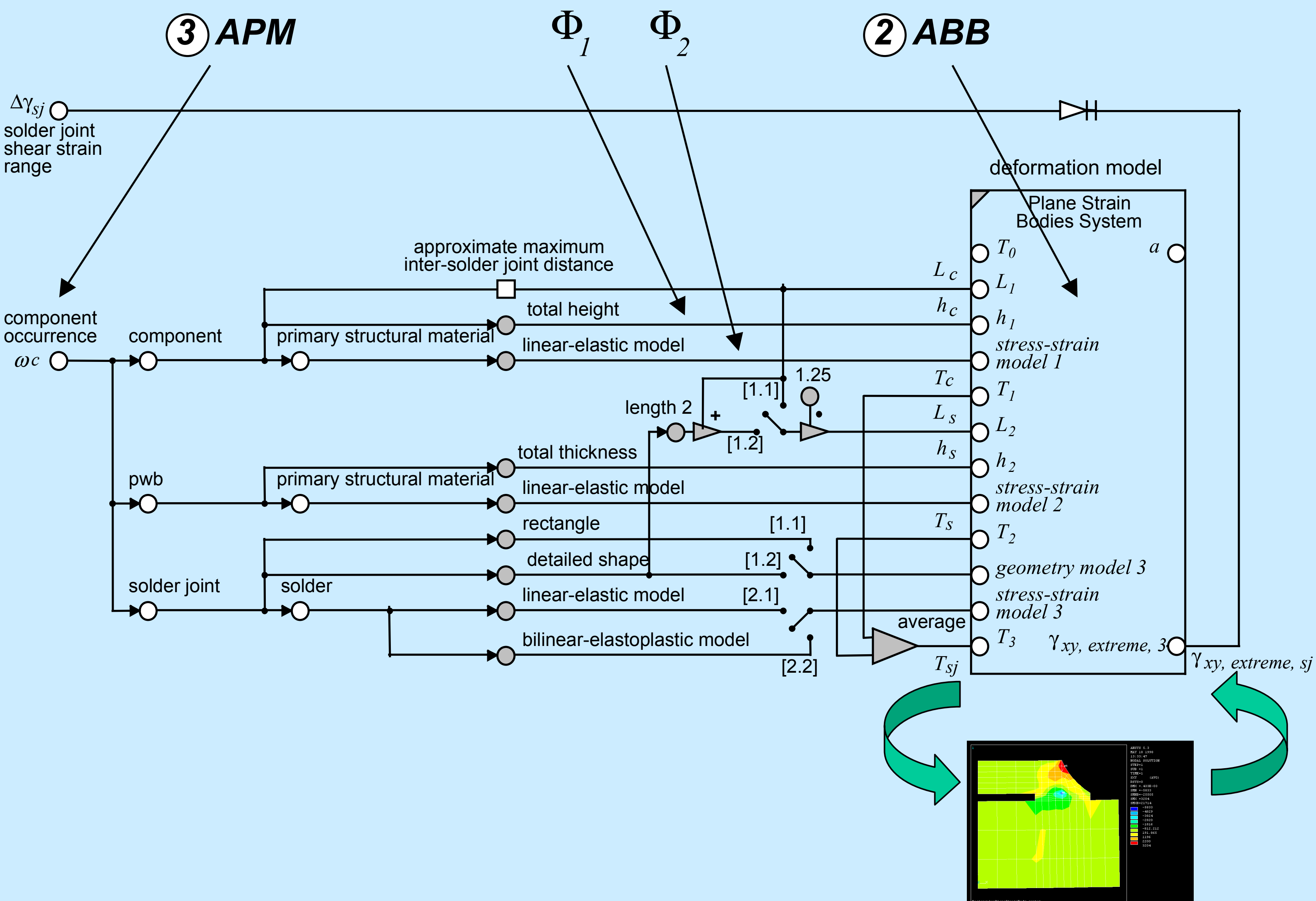
Solder Joint Deformation CBAM

Informal Associativity Mapping



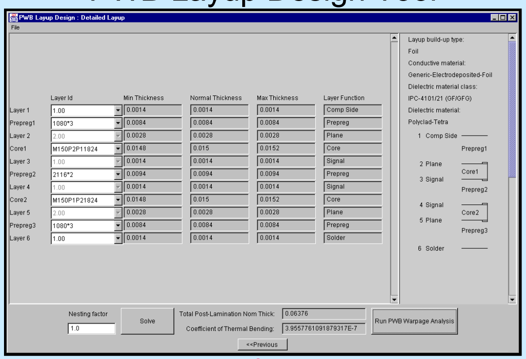
Solder Joint Deformation CBAM

Constraint Schematic



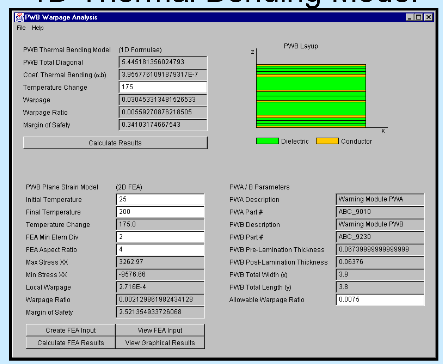
Iterative Design & Analysis

PWB Layup Design Tool



Layup
Re-design

1D Thermal Bending Model



Quick Formula-based Check

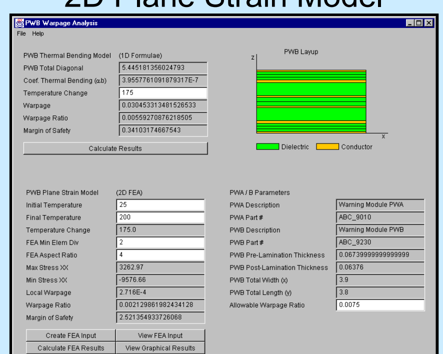
$$\delta = \frac{\alpha_b L^2 \Delta T}{t}$$

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

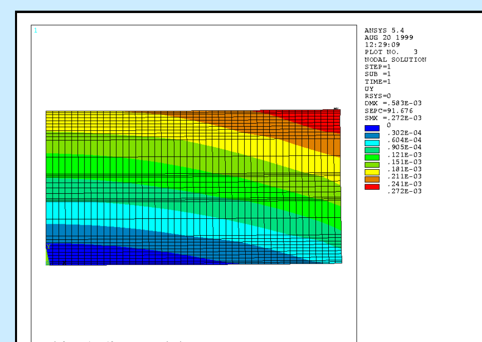
PWB Warpage Modules

Analyzable
Product Model

2D Plane Strain Model

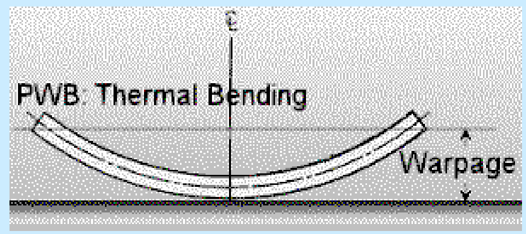


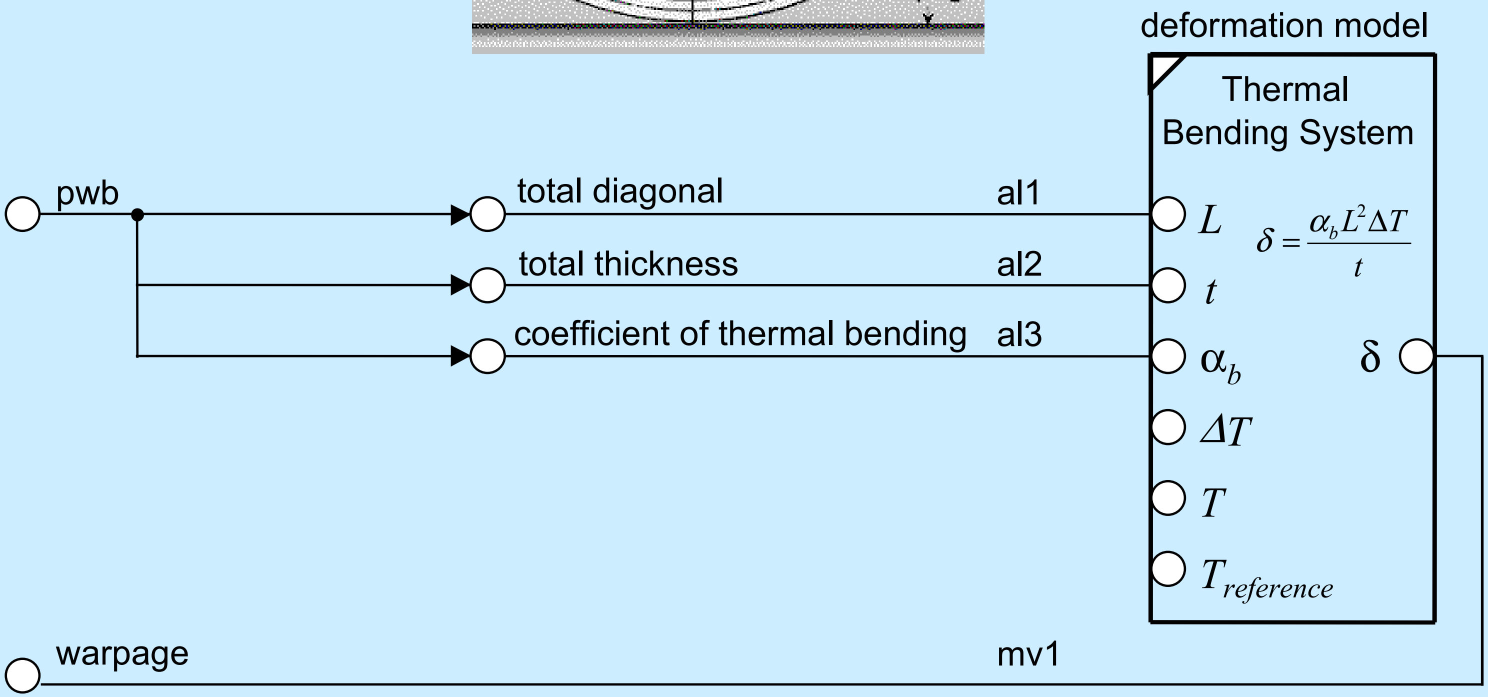
Detailed FEA Check



PWB Warpage CBAM

PWB Thermal Bending Model (1D formula-based)





Aerospace Structural Analysis Test Case

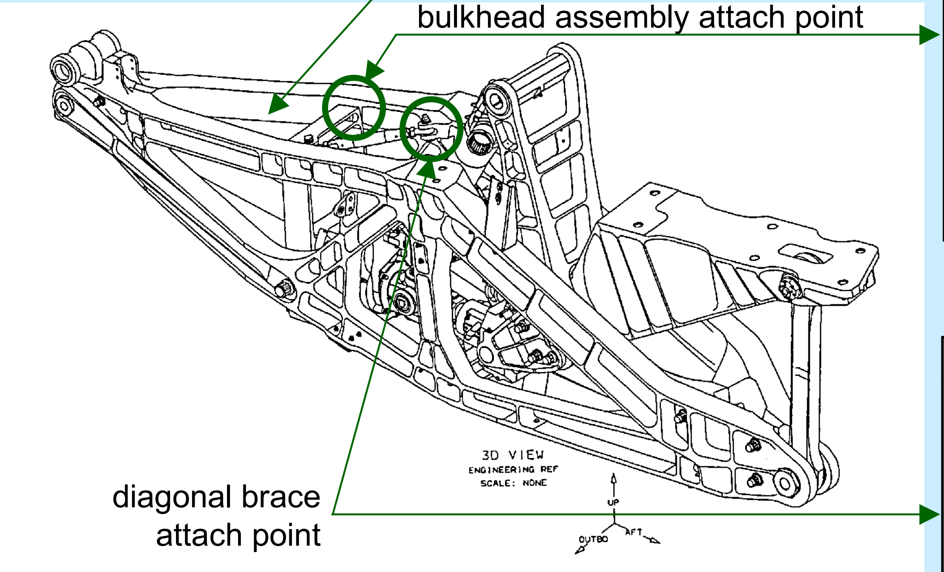
GIT Work in Boeing PSI Project

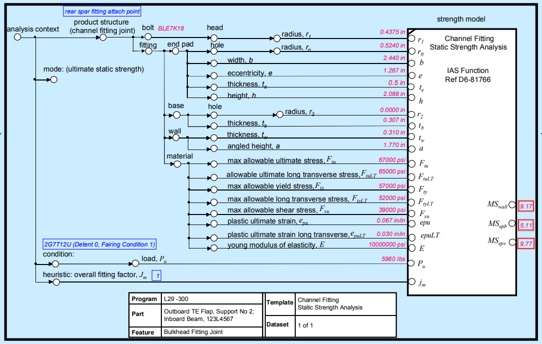
Design Objects

Analysis Objects

Pullable Views

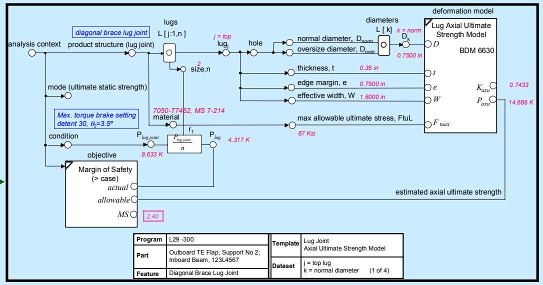
flap support assembly inboard beam (a.k.a. “bike frame”)

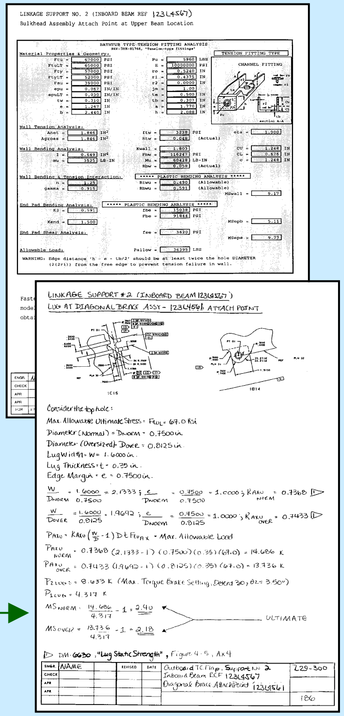




fitting analysis

lug analysis





Modular, Integrated, Active, Multidirectional, Reusable, User-Definable

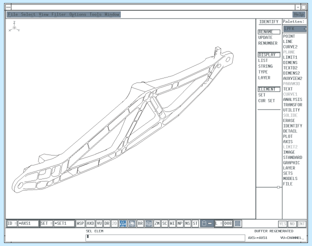
Flexible High Diversity Design-Analysis Integration

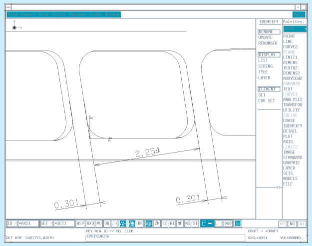
Aerospace Examples:

"Bike Frame" / Flap Support Inboard Beam

Design Tools

MCAD Tools



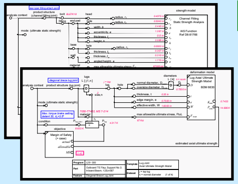


Materials DB

MATDB-like

Fasteners DB

FASTDB-like



Modular, Reusable Template Libraries

Analyzable Product Model

XaiTools

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

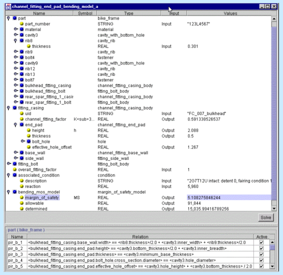
XaiTools

1.5D

Lug: Axial/Oblique; Ultimate/Shear

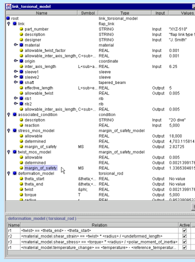
1.5D

Fitting: Bending/Shear



3D

Assembly: Ultimate/ FailSafe/Fatigue*



Analysis Tools

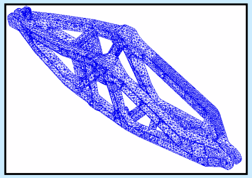
General Math

Mathematica

In-House Codes

FEA

*Elfini**



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

Today's Fitting Catalog Documentation

from DM 6-81766 Design Manual

Calculation Steps

Channel Fitting
End Pad Bending Analysis

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_{tu}.

   Step 5: The margin of safety is

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

2. End Pad Analysis – Shear

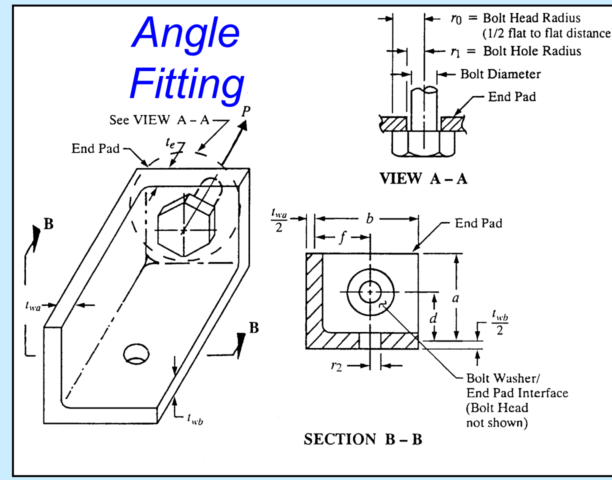
   Step 1: Actual shear stress is

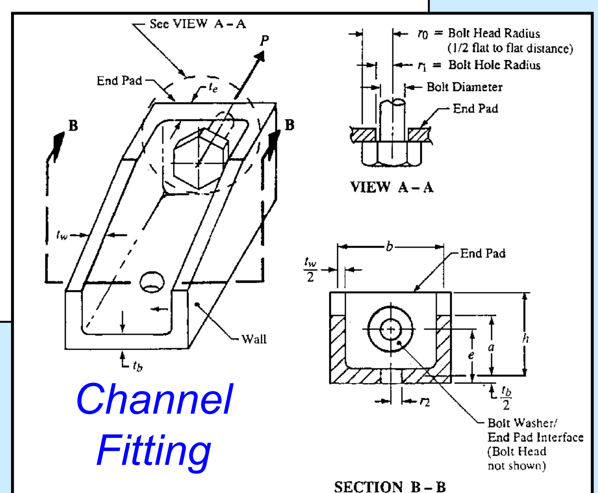
$$f_{se} = \frac{P}{2\pi \, r_0 \, t_e}$$

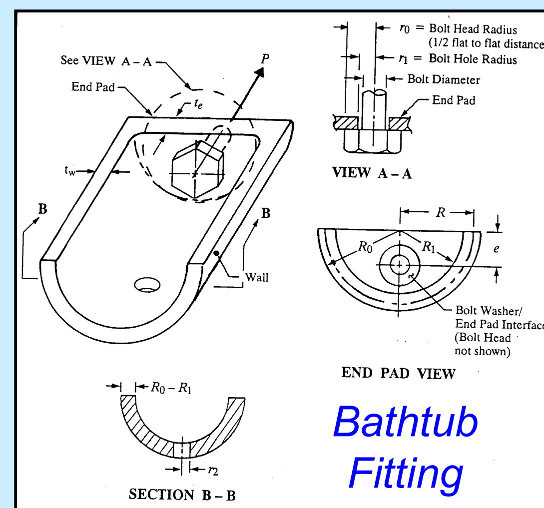
   Step 2: The margin of safety is

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

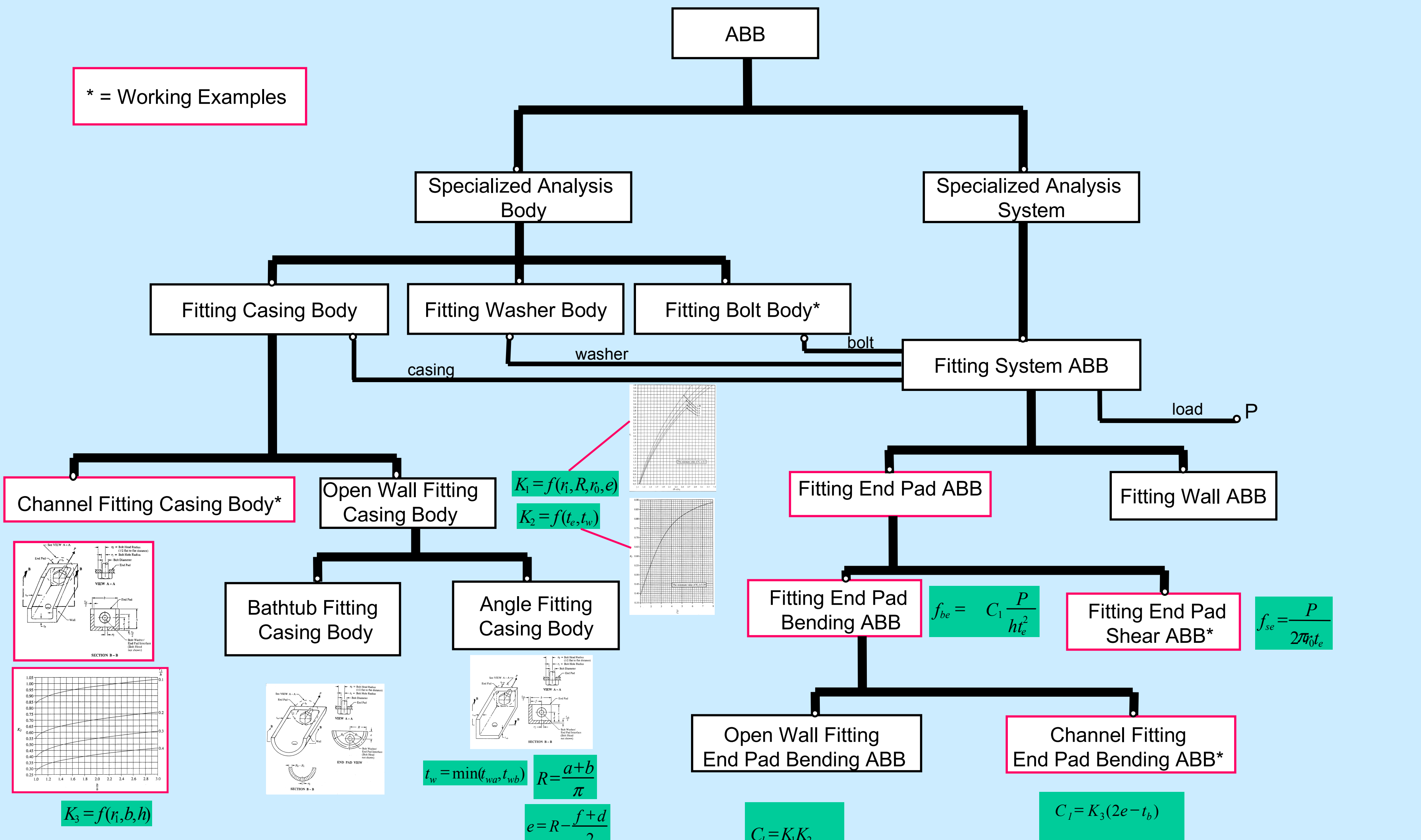
Categories of Idealized Fittings



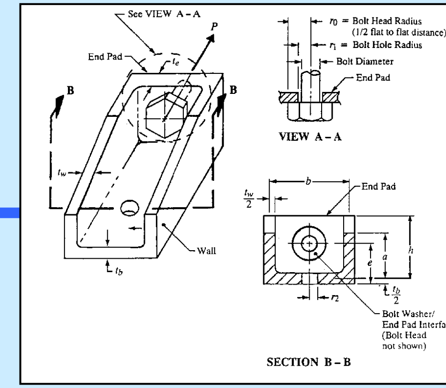




Object-Oriented Hierarchy of Fitting ABBs

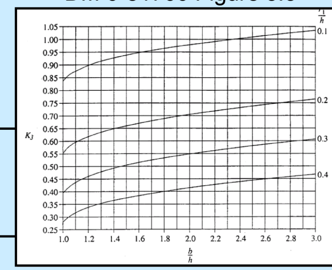


Channel Fitting System ABBs



End Pad Bending Analysis

DM 6-81766 Figure 3.3



r3

Inputs:

- bolt.hole.radius, $\mathbf{r_1}$
- end_pad.height, **h**
- end_pad.width, **b**
- end_pad.eccentricity, **e**
- base.thickness, $\mathbf{t_b}$
- end_pad.thickness, $\mathbf{t_e}$
- load, P

r1: $\frac{r_1}{h}$

r2: $\frac{b}{h}$

channel fitting factor, K_3

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

actual bending stress, f_{be}

End Pad Shear Analysis

r1

Inputs:

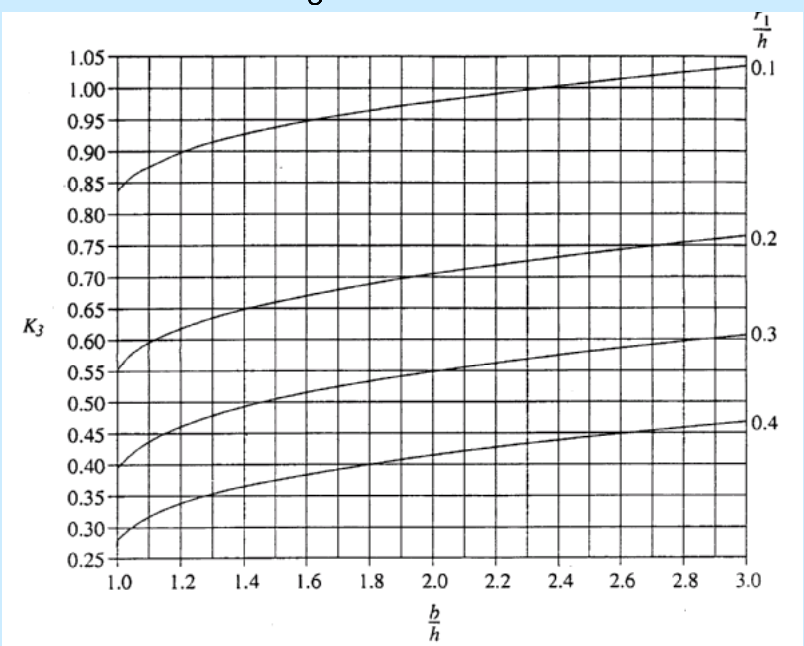
- bolt.head.radius, $\mathbf{r_0}$
- end_pad.thickness, $\mathbf{t_e}$
- load, P

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

actual shear stress, f_{se}

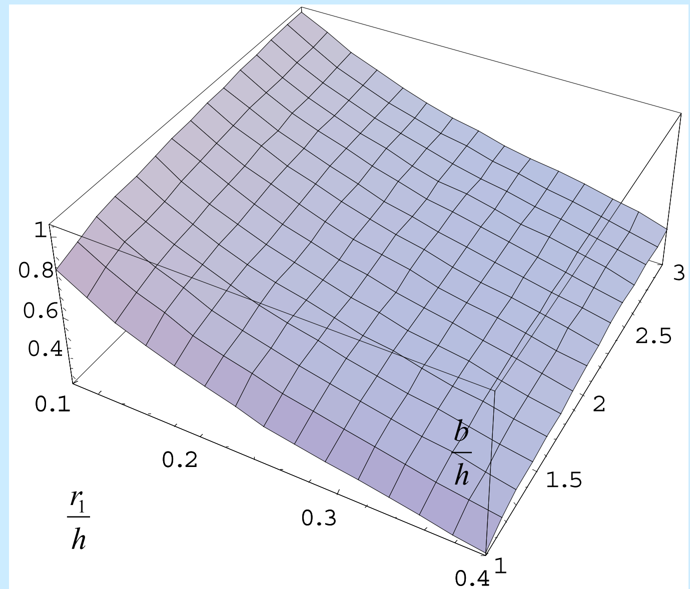
Implementation of Channel Fitting Factor, K3 as a Reusable Relation in an External Tool

Design Manual Curves



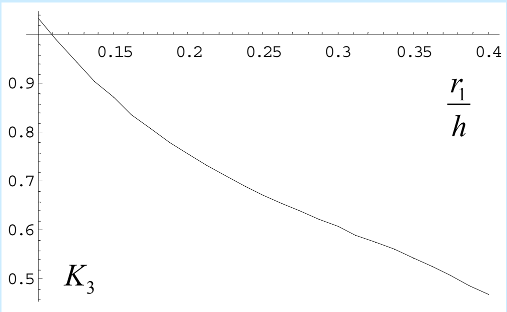
Mathematica Implementation

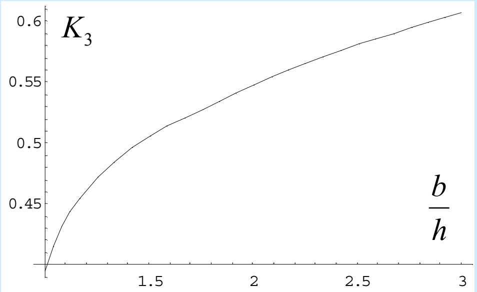
K_3



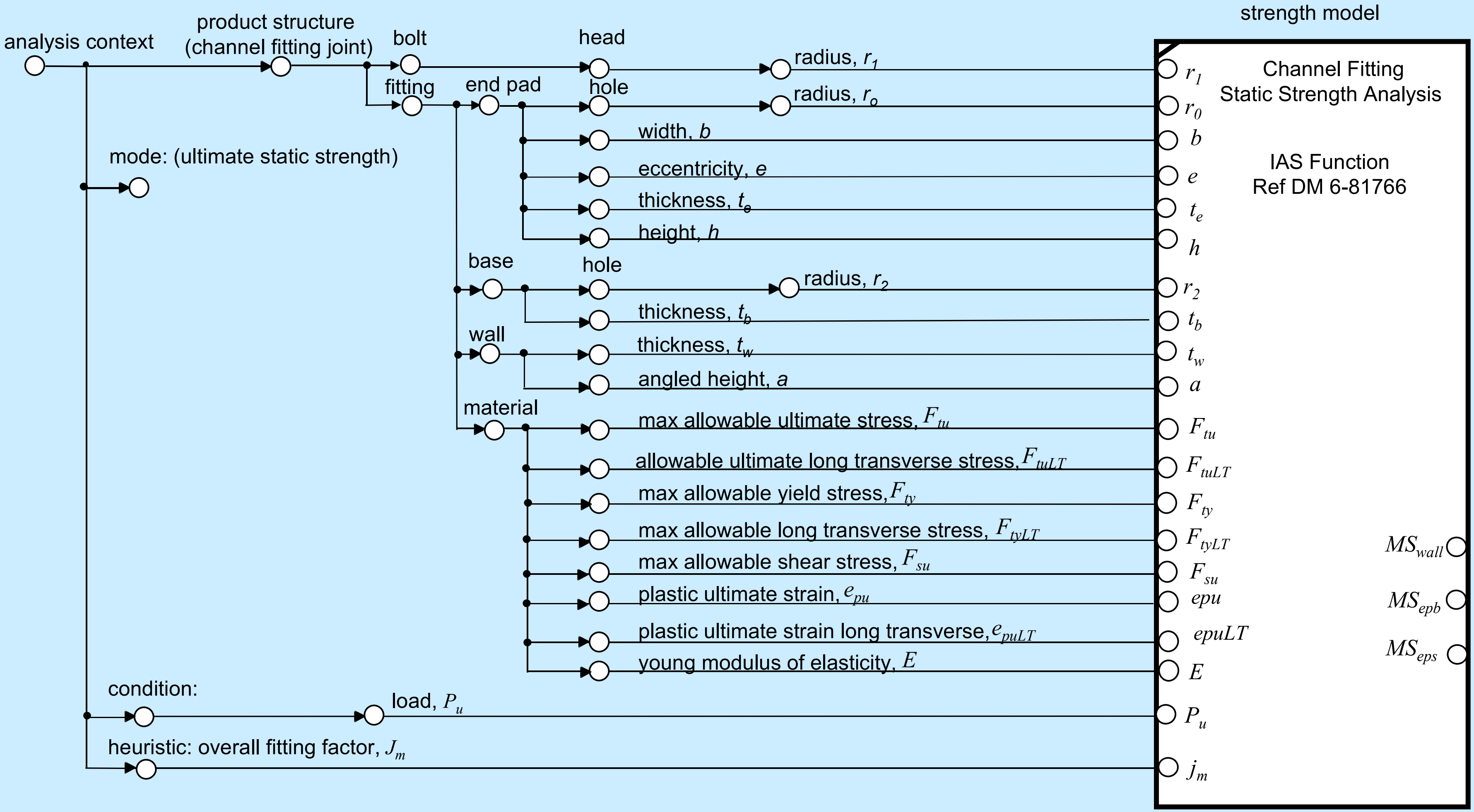
r_1/h = 0.1		r_1/h = 0.2		r_1/h = 0.3		r_1/h = 0.4	
b/h	K_3	b/h	K_3	b/h	K_3	b/h	K_3
1.0	0.836	1.0	0.5525	1.0	0.395	1.0	0.28
1.04	0.8575	1.04	0.575	1.04	0.415	1.04	0.2975
1.1	0.8752	1.1	0.596	1.1	0.437	1.1	0.317
1.2	0.898	1.2	0.618	1.2	0.461	1.18	0.335
1.34	0.92	1.34	0.641	1.34	0.485	1.34	0.359
1.5	0.938	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)





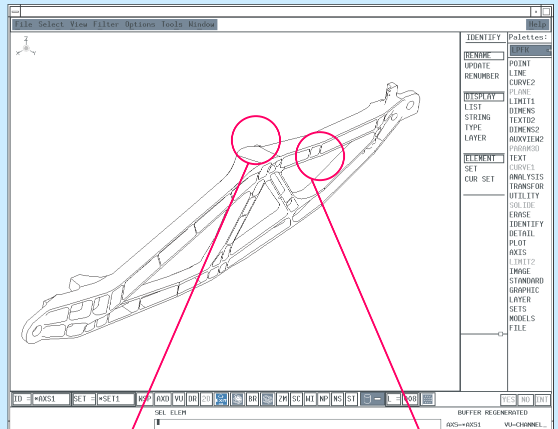
Reusable Channel Fitting Analysis Module (CBAM)



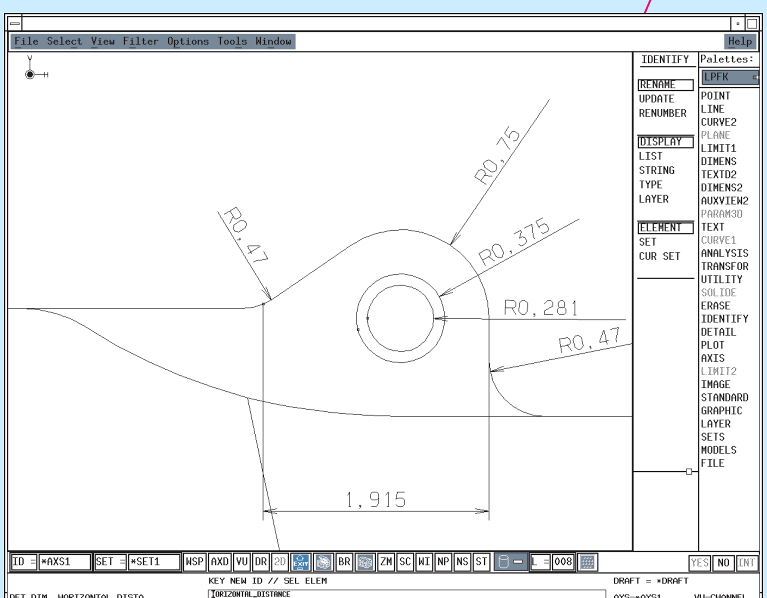
Application to an Aerospace Part

APM Associativity with Tagged CATIA Model

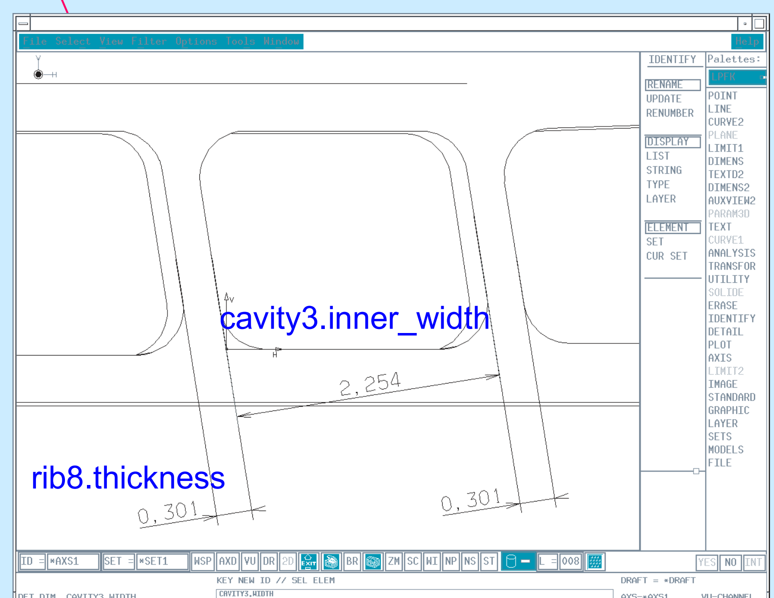
Bike Frame
CATIA CAD Model



Diagonal Brace Lug



Bulkhead Fitting Casing

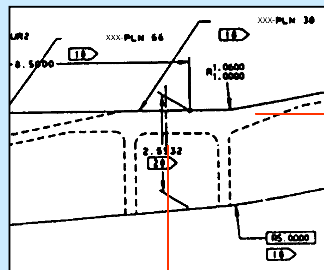


Explicit Capture of Idealizations

(part-specific template adaptation in bike frame case)

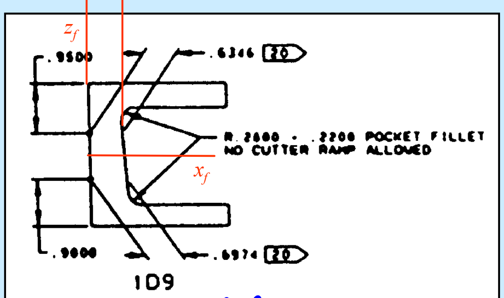
Idealized Features

Features/Parameters Tagged in CAD Model (CATIA)



Γ_2

cavity3.base.minimum_thickness

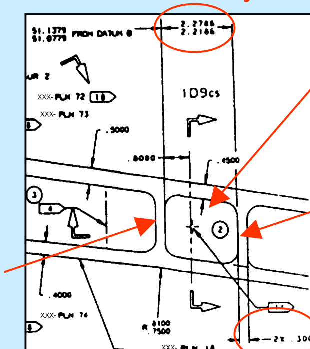


cavity3.width, w_3

cavity 3

rib9

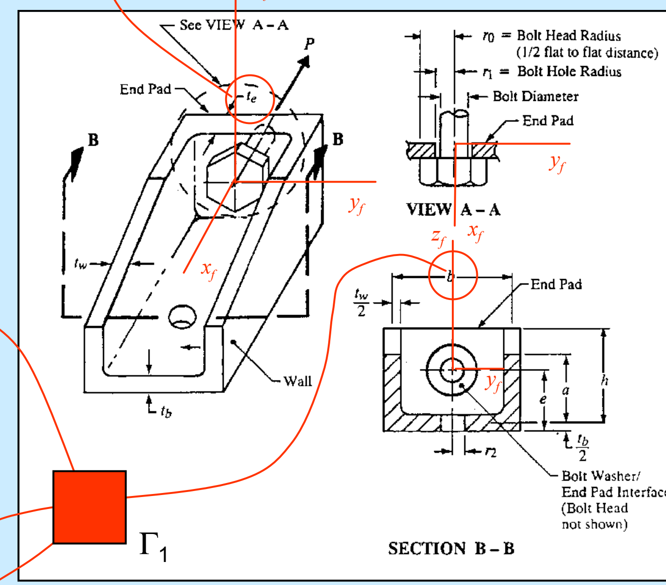
rib8



$= t_8, t_9$

rib8.thickness

rib9.thickness



Γ_1

Tension Fitting Analysis

Missing in Today's Process

Γ_i - Relations between CAD parameters and idealized parameters

Γ_1 : b = cavity3.inner_width + rib8.thickness/2 + rib9.thickness/2

Γ_2 : t_e = cavity3.base.minimum_thickness

Today's Typical Fitting Analysis

Idealized CAD data manually transformed and input

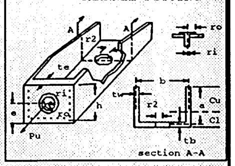
Missing Design-Analysis Associativity

LINKAGE SUPPORT NO. 2 (INBOARD BEAM REF 1234567)
Bulkhead Assembly Attach Point at Upper Beam Location

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

TENSION FITTING TYPE

CHANNEL FITTING



Material Properties & Geometry:

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

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:

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

Wall Bending & Tension Interaction:

***** PLASTIC BENDING ANALYSIS *****

n =	1.25	Rtwu =	0.490	(Allowable)		
gamma =	0.915	Rbwu =	0.591	(Allowable)		
					MSwall =	9.17

End Pad Bending Analysis:

***** PLASTIC BENDING ANALYSIS *****

K3 =	0.591	fbe =	15038	PSI		
		Fbe =	91844	PSI		
Kend =	1.500				MSepb =	5.11

End Pad Shear Analysis:

fse =	3620	PSI		
			MSeps =	9.77

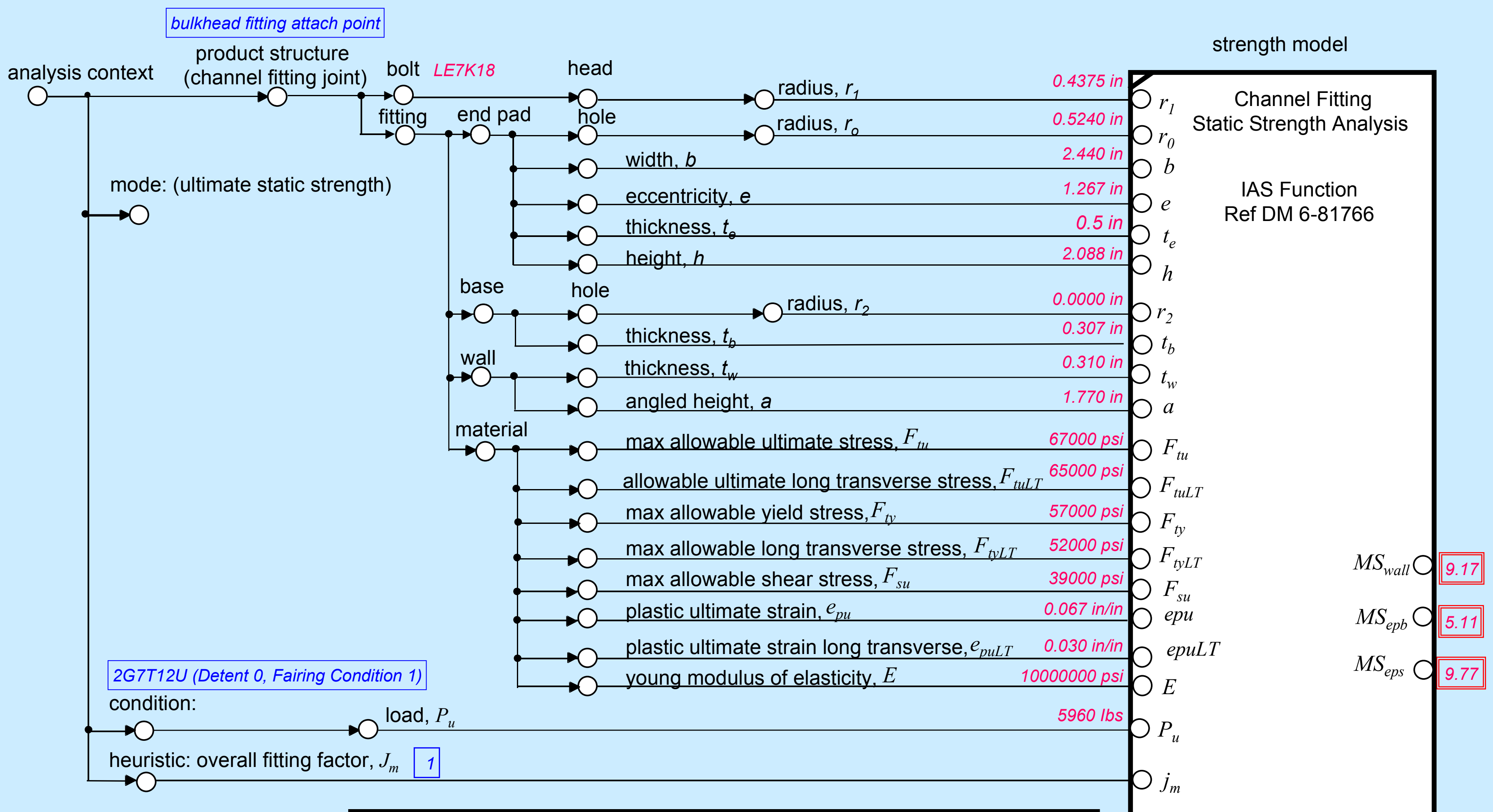
Allowable Load: Pallow = 36395 LBS

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.

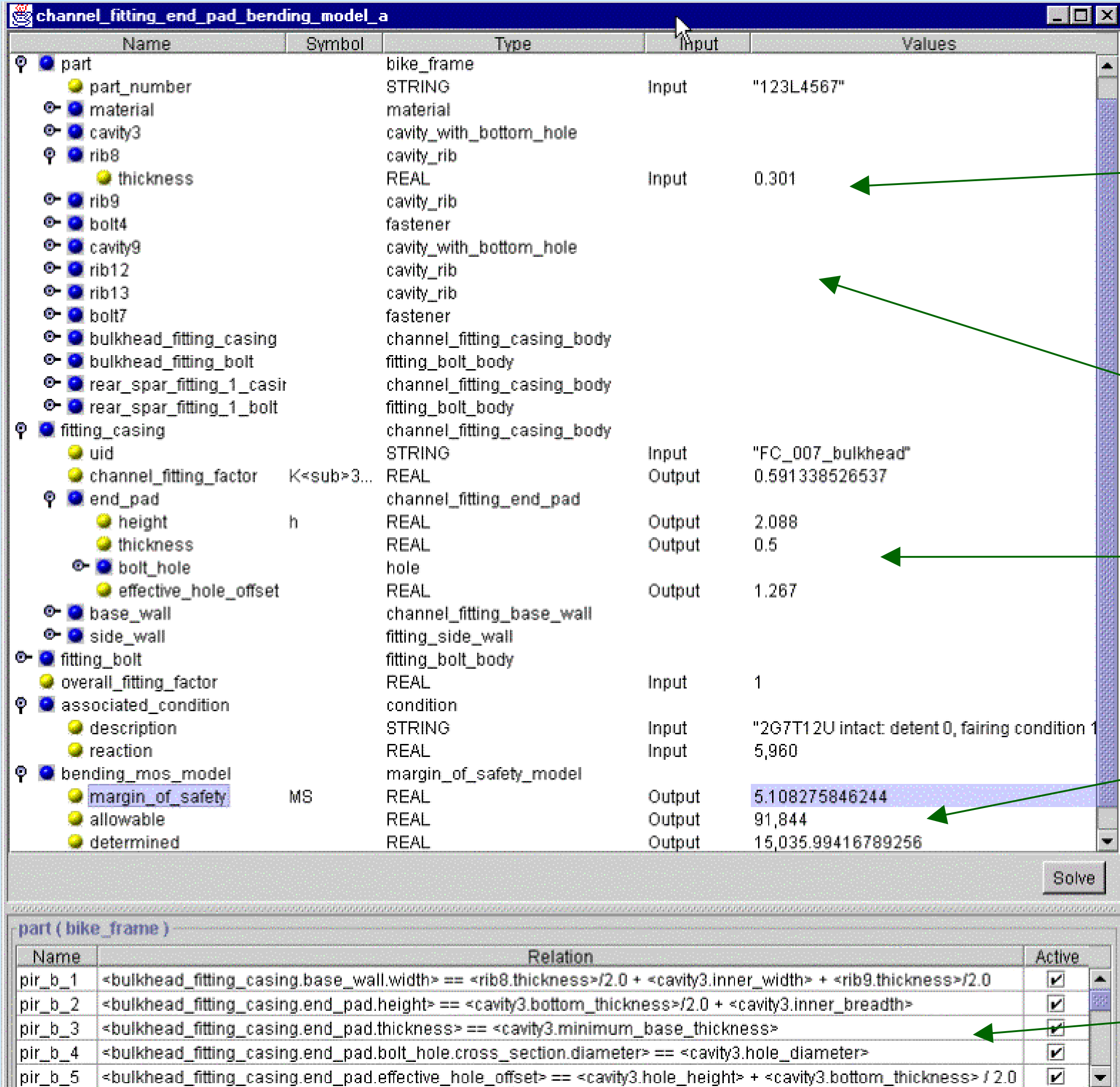
ENGR.	NAME	12/20/96	REVISED	DATE	Outboard TE Flap, Support No. 2 Bulkhead Attachment Location to 1234567 ibbulk.tem ibbulk.dta ENGINEER DEVELOPED TEMPLATE	129-300
CHECK						
APR						
APR						PAGE 206
PGM	3734c07-PROD	IAS				

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		

Bike Frame Bulkhead Fitting Analysis Using COB-based Templates



Detailed CAD data from CATIA

Library data for materials & fasteners

Idealized analysis features in APM

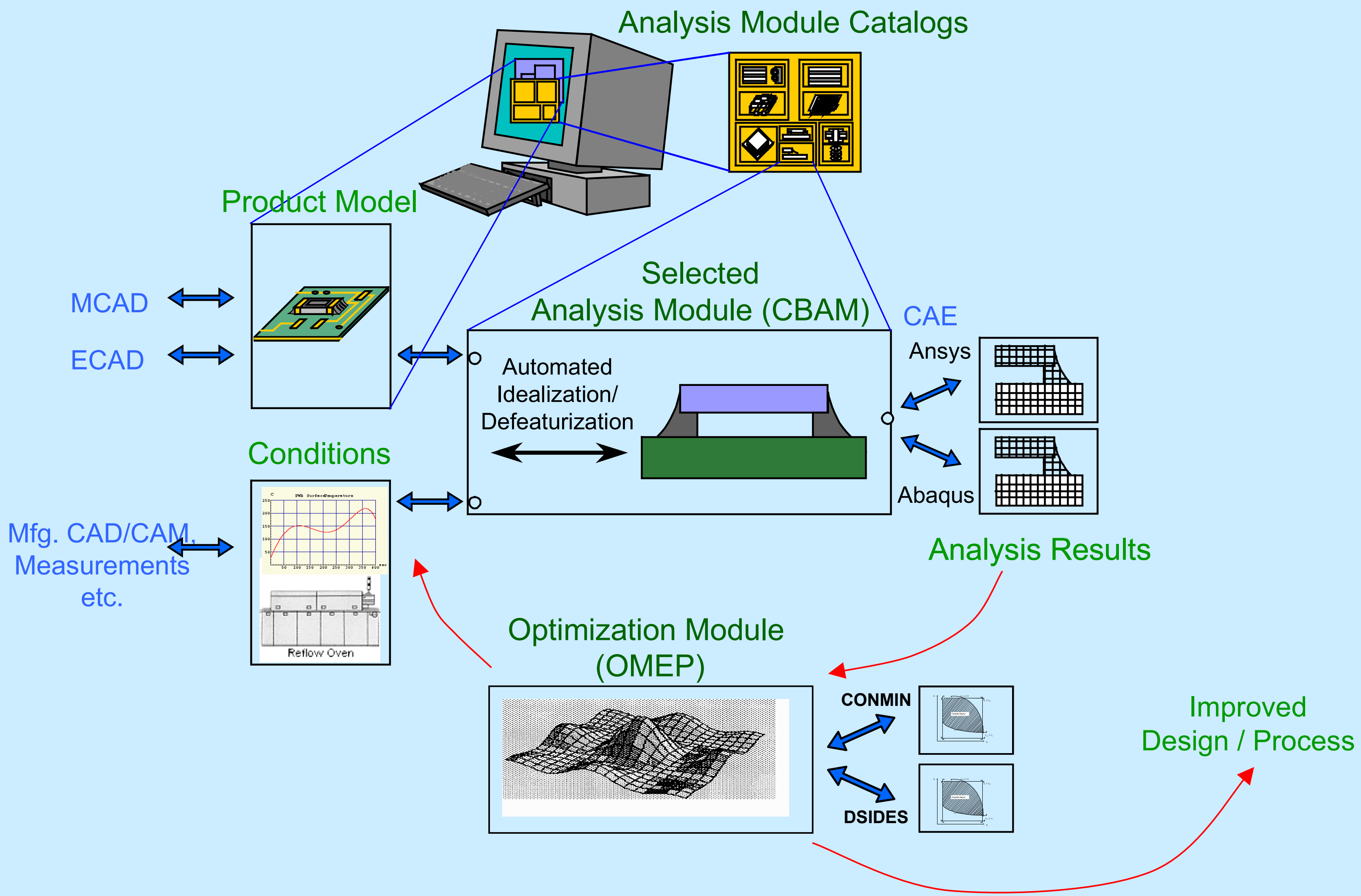
Fitting & MoS ABBs

Explicit multi-directional associativity between detailed CAD data & idealized analysis features

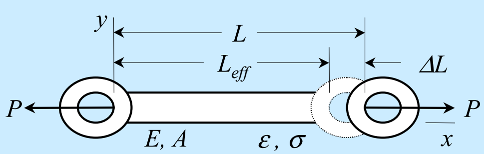
Outline

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

Optimization Integration Thrust (work-in-process)



Optimization Model Diversity



1D EXTENSIONAL STRESS MODEL

OPTIMIZATION MODEL CLASS

Optimization Object 1

Min Weight

subject to
Stress
Design variables
Area

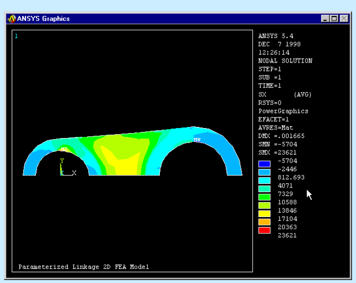
Optimization Object 2

Min Weight

subject to
Stress
Buckling
Design variables
Area, Material

Analysis Model(s)
Enhancement and/or Addition

Objective, design variable, and/or constraint function enhancement



2D PLANE STRAIN MODEL

OPTIMIZATION MODEL CLASS

Optimization Object 1

Min Weight

subject to

X(H)

Optimization Object 2

Min Weight

subject to
g (x)<0
h(x) =0
X(H,LL,LR)

Optimization Object 3

Min Weight, Cost

subject to
g (x)<0
h(x) =0
X(H,LL,LR,Mat)

Optimization Model Enhancement

OPTIMIZATION MODEL I

Minimize

$f_1 = \rho L A$ Weight

Subject to

$g_1 = MS_{stress}(A) \geq 0$ *Normal Stress Margin of Safety*

Design variables

$\mathbf{X} = \{A\}$

OPTIMIZATION MODEL II

Minimize

$f_1 = \rho L A$ Weight

Subject to

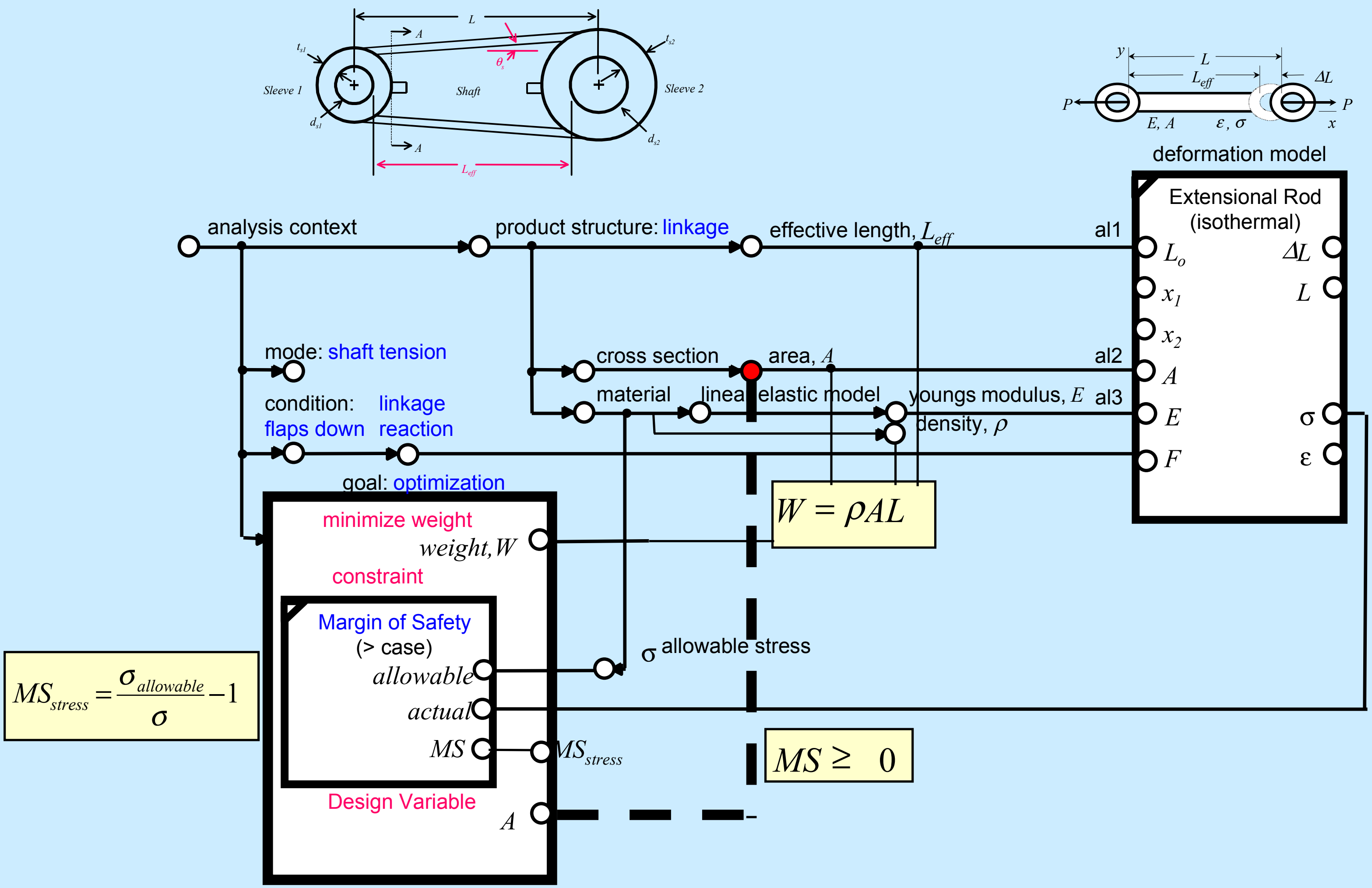
$g_1 = MS_{stress}(A) \geq 0$ *Normal Stress Margin of Safety*

Design variables

$\mathbf{X} = \{A, \text{material}\}$

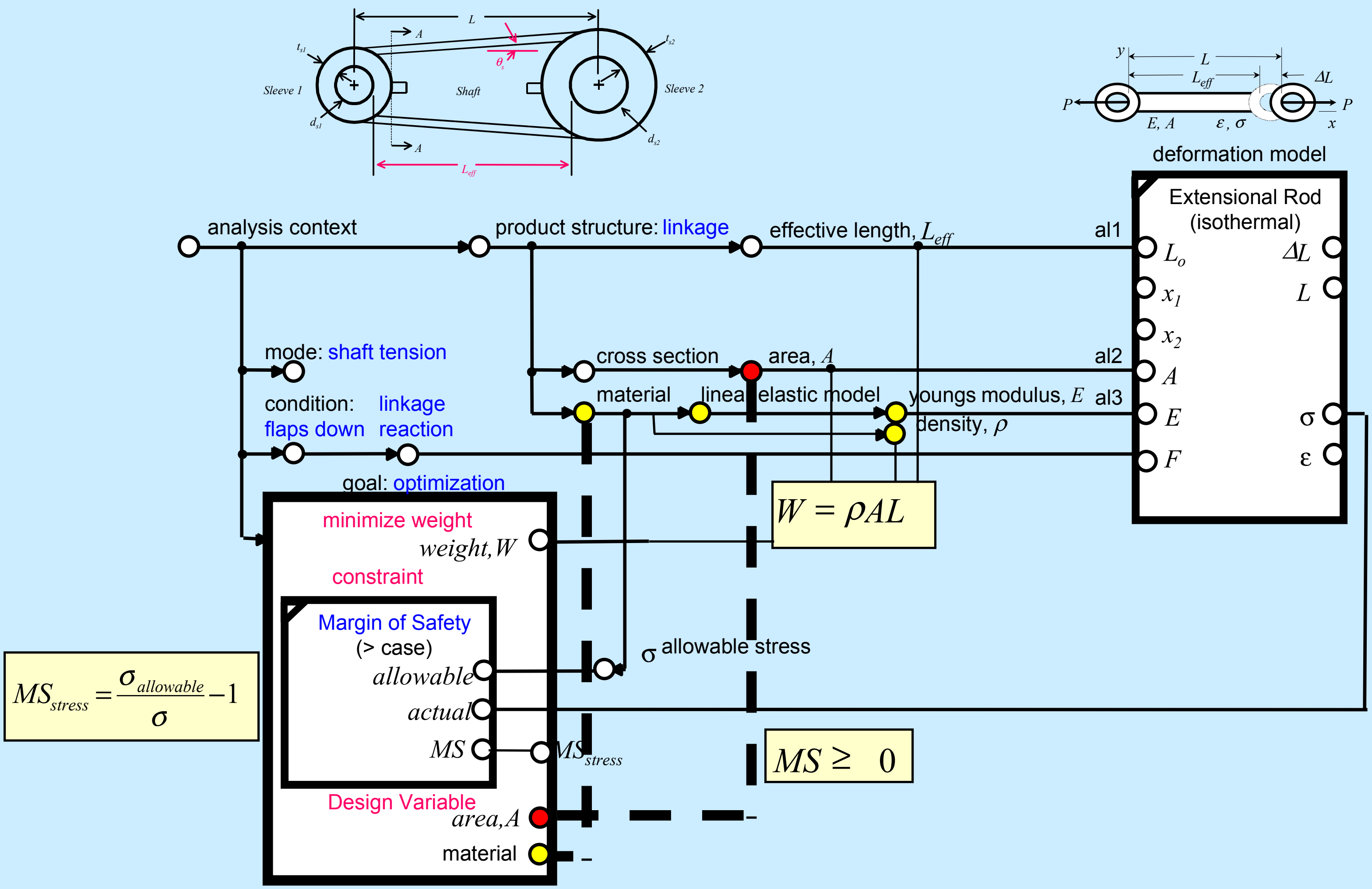
Minimization of Weight of a Linkage

X(area) subject to (extensional stress)



Minimization of Weight of a Linkage

X(area, material) subject to (extensional stress)



Optimization Model Enhancement

OPTIMIZATION MODEL III

Minimize

$f_1 = \rho L A$ — Weight

Subject to

$g_1 = MS_{stress}(A) \geq 0$ — *Normal Stress Margin of Safety*

$g_2 = MS_{buckling}(A) \geq 0$ — *Buckling Margin of Safety*

Design variables

$\mathbf{X}=\{A\}$

OPTIMIZATION MODEL IV

Minimize

$f_1 = \rho L A$ — Weight

Subject to

$g_1 = MS_{stress}(A) \geq 0$ — *Normal Stress Margin of Safety*

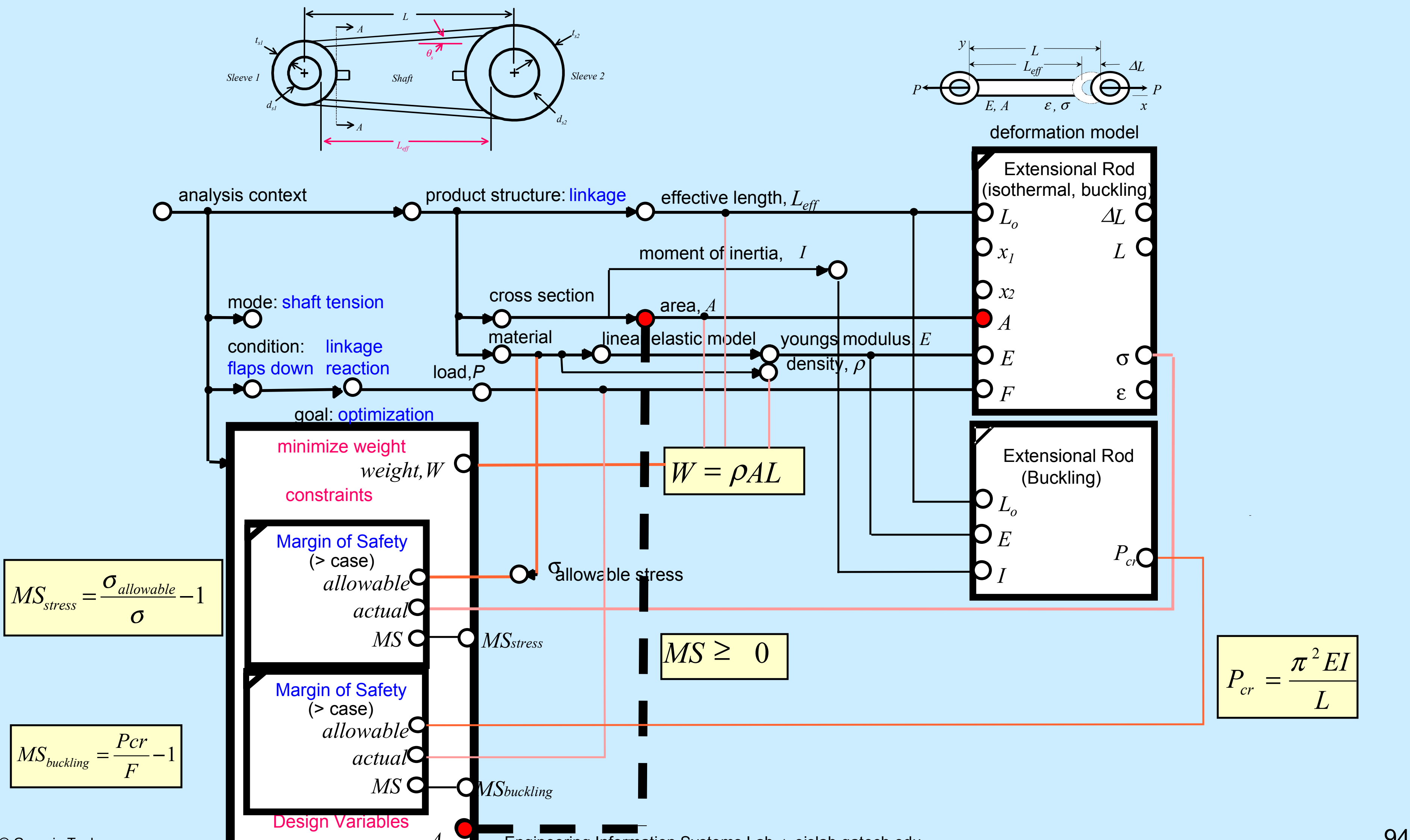
$g_2 = MS_{buckling}(A) \geq 0$ — *Buckling Margin of Safety*

Design variables

$\mathbf{X}=\{\text{A, material}\}$

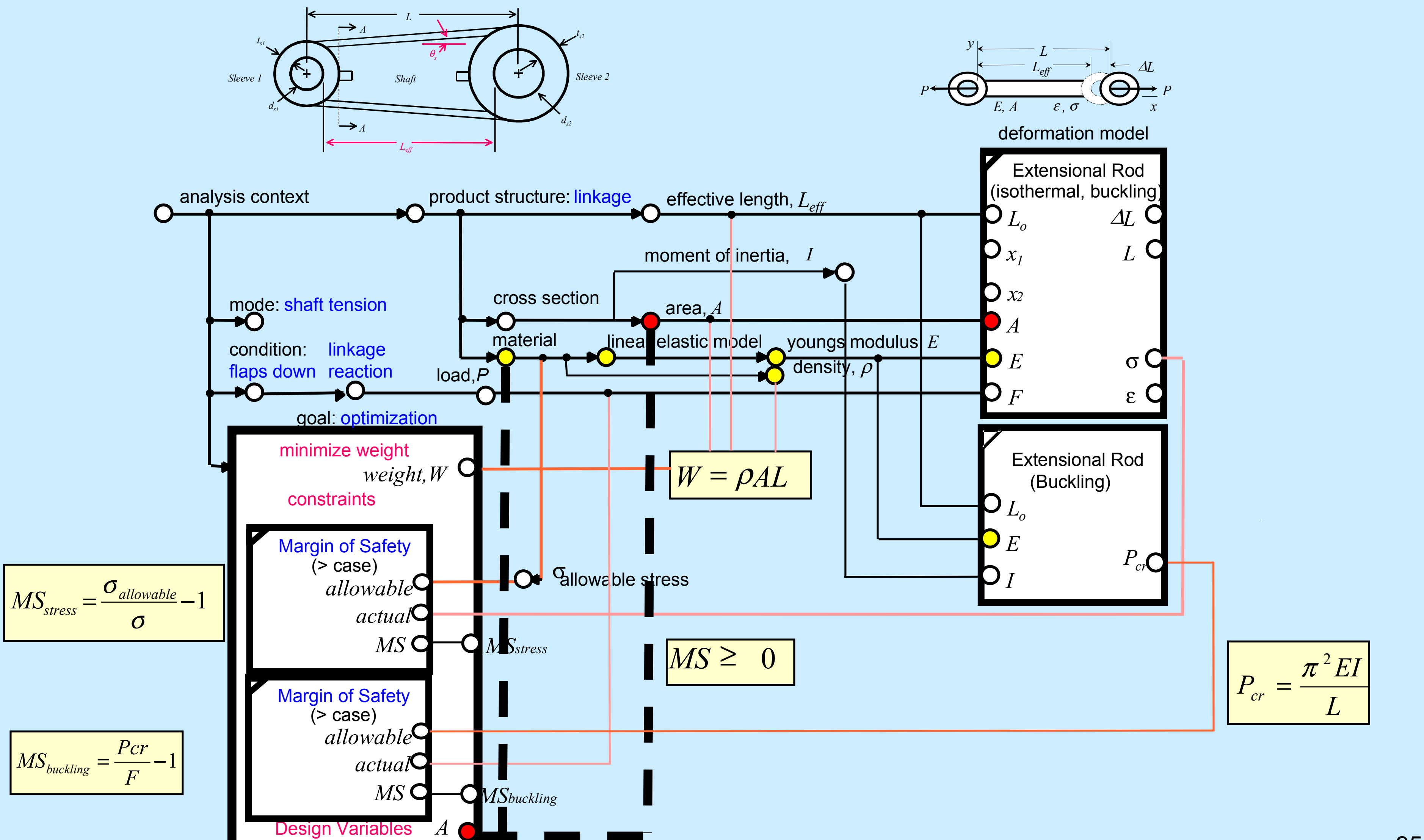
Minimization of Weight of a Linkage

X(area) subject to (extensional stress, buckling load)



Minimization of Weight of a Linkage

X(area, material) subject to (extensional stress, buckling load)



Outline

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

Analysis Integration Summary

- Strong emphasis on X-analysis integration (XAI/DAI)
- Multi-Representation Architecture (MRA)
  - Addressing fundamental XAI/DAI issues
  - General methodology --> Flexibility & broad application
- Relevant project experience and research advances
  - Product data-driven analysis (STEP AP210, GenCAM, etc.)
  - Engineering service bureau (ESB) techniques
  - Object techniques for next generation aerospace analysis systems
- Tools and development services
  - Analysis integration toolkit: *XaiTools*
  - Pilot commercial ESB: U-Engineer.com
  - Company-tailored engineering information system solutions
- Industry & government collaboration

For Further Information ...

- EIS Lab web site: *http://eislab.gatech.edu/*
  - Publications, project overviews, tools, etc.
  - See Publications, DAI/XAI, Suggested Starting Points
- *XaiTools* home page: *http://eislab.gatech.edu/*
- Pilot commercial ESB: *http://www.u-engineer.com/*
  - Internet-based self-serve analysis
  - Analysis module catalog for electronic packaging
  - Highly automated front-ends to general FEA & math tools