NASA STEP for Aerospace Workshop
Jet Propulsion Lab ◆ Pasadena CA
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Automating Product Data-Driven Analysis Using Multifidelity Multidirectional Constrained Objects

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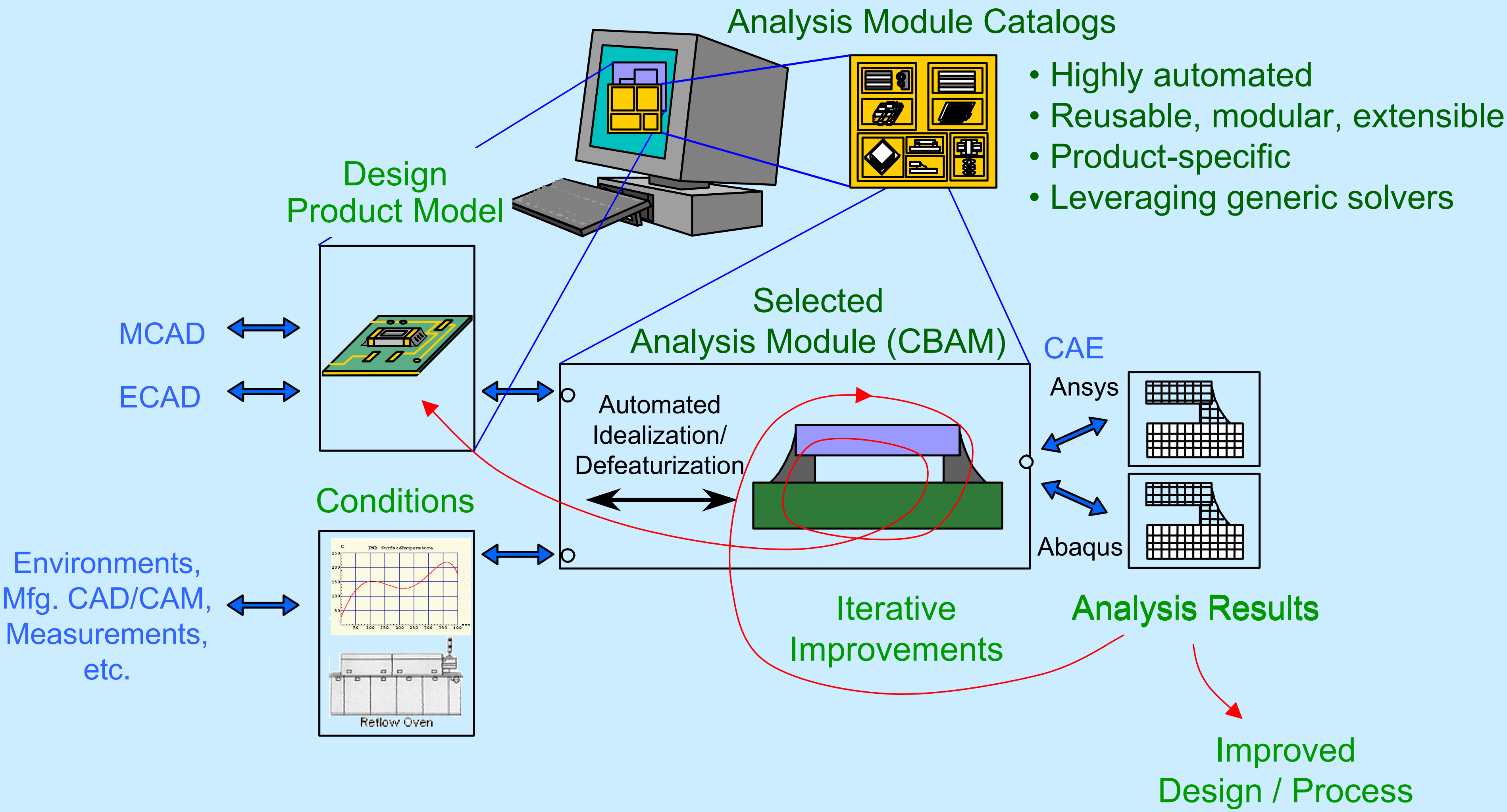
Outline

- Analysis Integration Objectives & Challenges
- Technique Highlights and Applications
- Constrained Objects (COBs) Overview
    - Usage for Analysis Integration
- Summary

Analysis Integration Objectives for Simulation-based Design



Analysis Module Catalogs

- Highly automated
- Reusable, modular, extensible
- Product-specific
- Leveraging generic solvers

Design Product Model

MCAD

ECAD

Conditions

Environments, Mfg. CAD/CAM, Measurements, etc.

Selected Analysis Module (CBAM)

Automated Idealization/ Defeaturization

CAE

Ansys

Abaqus

Iterative Improvements

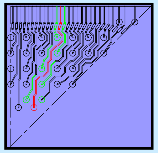
Analysis Results

Improved Design / Process

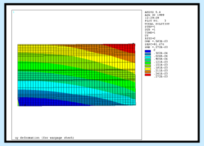
CBAM= context-based analysis model

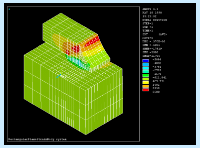
Analysis Integration Challenges: Diverse Disciplines

Electromagnetic

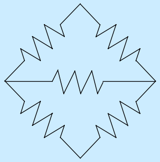


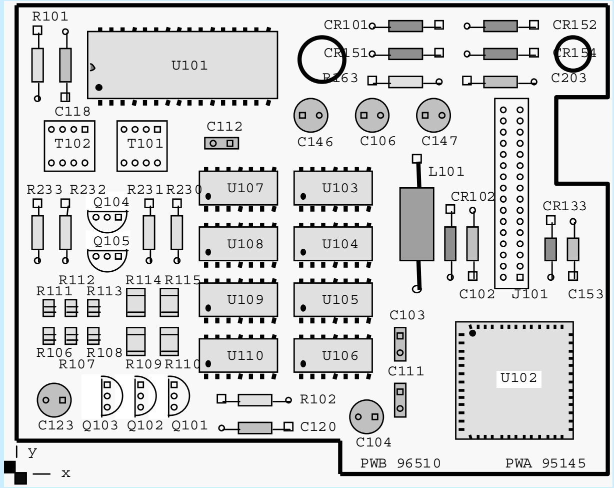
Thermomechanical



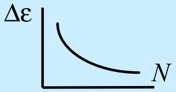


Electrical

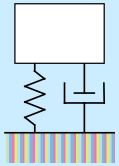




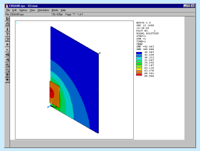
Fatigue



Vibration



Thermal



Analysis Integration Challenges: Heterogeneous Transformations

- Homogeneous Transformation

Design Model A

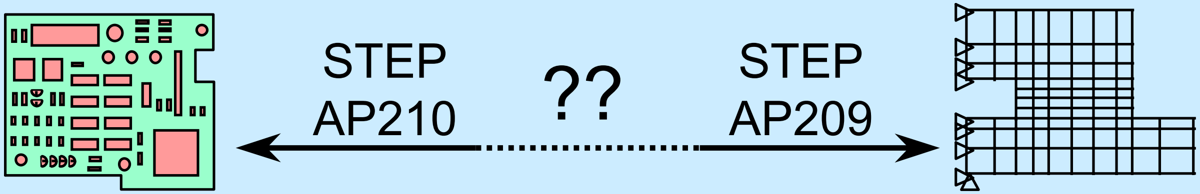
STEP AP210

Design Model B

Mentor Graphics

Cadence

- Heterogeneous Transformation



Design Model A

STEP AP210

??

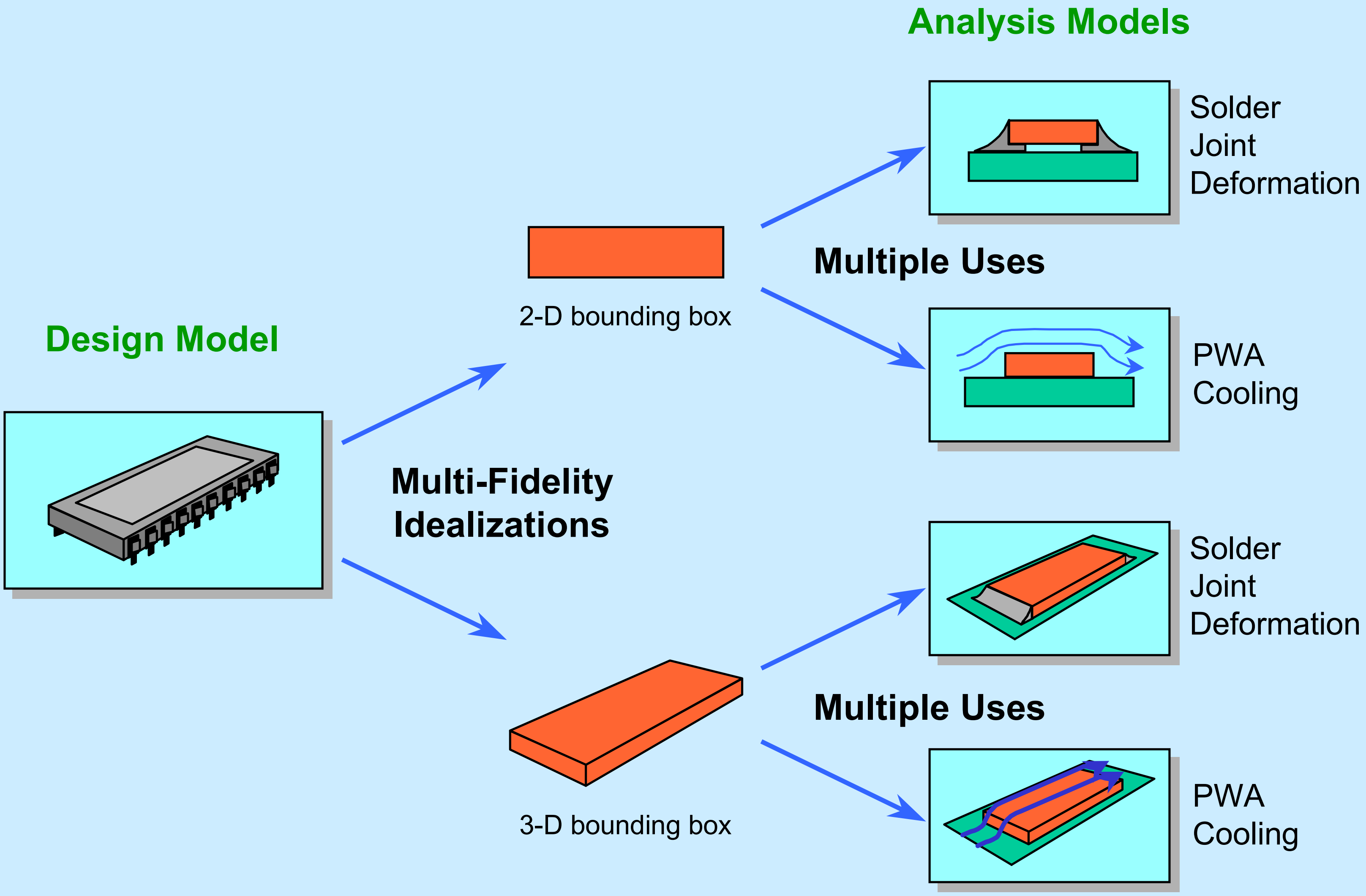
STEP AP209

Analysis Model A

Mentor Graphics

Ansys

Multi-Fidelity Reusable Idealizations



Analysis Models

Design Model

Multi-Fidelity Idealizations

2-D bounding box

3-D bounding box

Multiple Uses

Solder Joint Deformation

PWA Cooling

Multiple Uses

Solder Joint Deformation

PWA Cooling

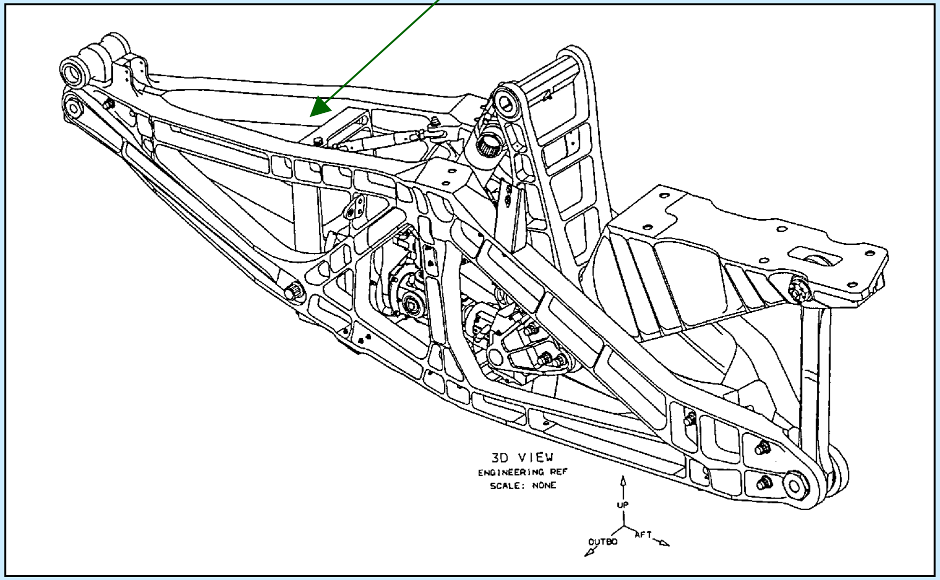
Multi-Fidelity Idealizations

Design Model (MCAD)

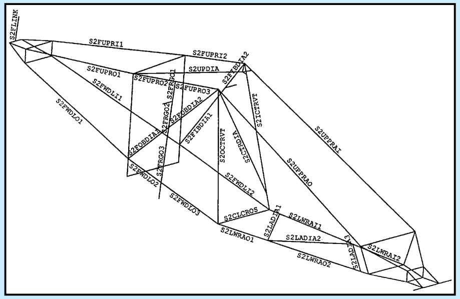
Analysis Models (MCAE)

flap support assembly

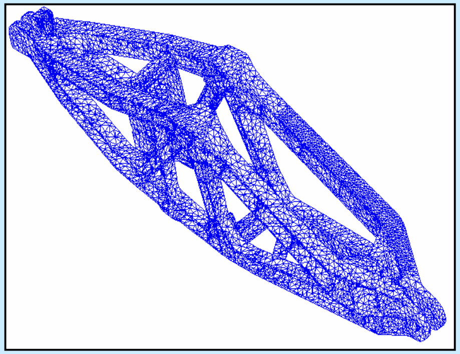
inboard beam



1D Beam/Stick Model

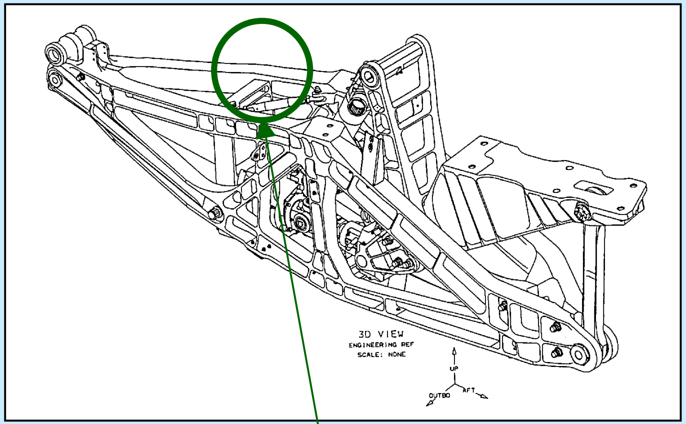


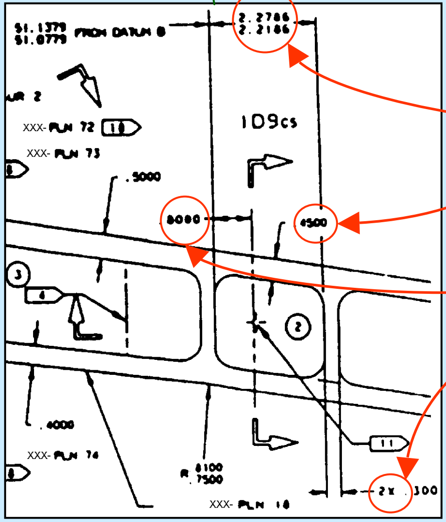
3D Continuum/Brick Model



Design Geometry - Analysis Geometry Mismatch

Detailed Design Model





Missing: Explicit idealization relations

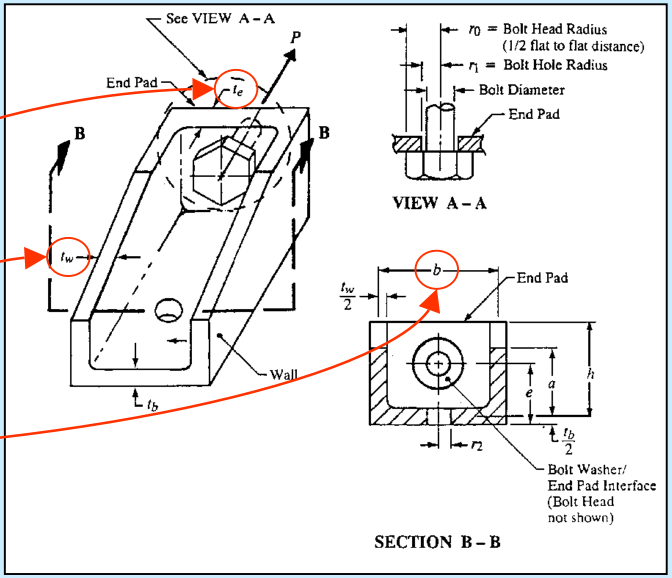
Γ_1 : `b = cavity3.inner_width + rib8.thickness/2`
`+ rib9.thickness/2`

…

Γ

Idealizations

Analysis Model
(with Idealized Features)



Channel Fitting Analysis

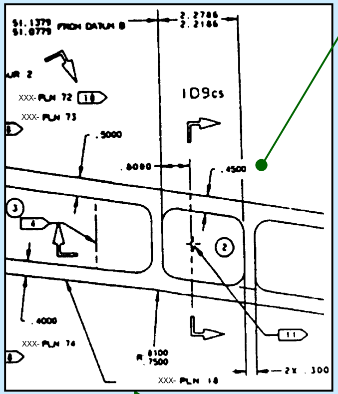
> *"It is no secret that CAD models are driving more of today's product development processes ... With the growing number of design tools on the market, however, the interoperability gap with downstream applications, such as finite element analysis, is a very real problem. As a result, CAD models are being recreated at unprecedented levels."*
>
> Ansys/ITI press Release, July 6 1999
> http://www.ansys.com/webdocs/VisitAnsys/CorpInfo/PR/pr-060799.html

Missing Today: Explicit Design-Analysis Associativity

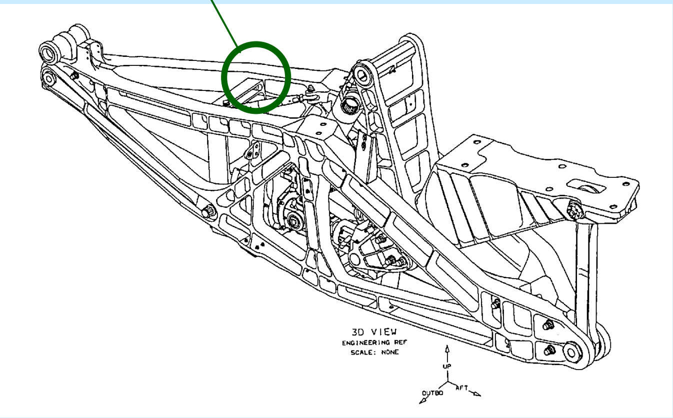
CAD Model

bulkhead assembly attach point

detailed design geometry



No explicit fine-grained CAD-CAE associativity

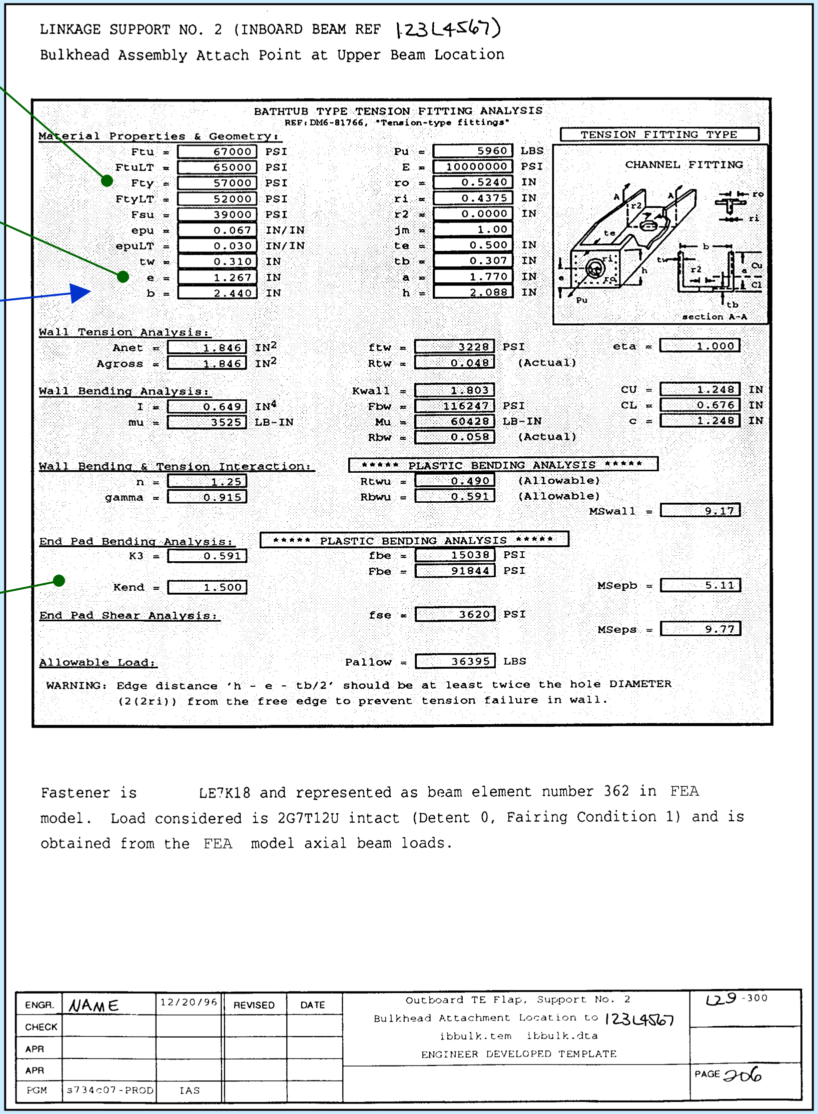


CAE Model channel fitting analysis

material properties

<u>idealized</u> analysis geometry

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"

TENSION FITTING TYPE

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	L29 -300
CHECK						
APR						
APR						PAGE 206
PGM	s734c07-PROD	IAS				

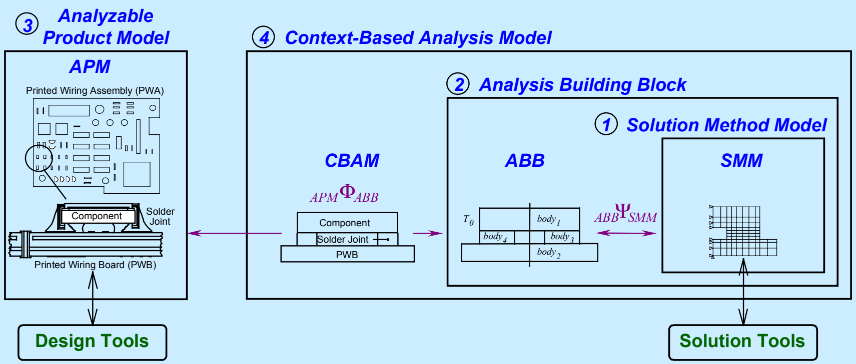
Multi-Directional Relations

"The Big Switch"

- Sizing/synthesis during early design stages
  - *Input:* Desired results - Ex. fatigue life, margin of safety
  - *Output:* Idealized design parameters
  - Outputs then used as targets to guide detailed design
- Analysis/req. checking during later design stages
  - *Input:* Detailed design parameters
  - *Intermediate results:* Idealized design parameters
  - *Output:* Analysis results - Ex. fatigue life, margin of safety
  - Outputs then compared with requirements

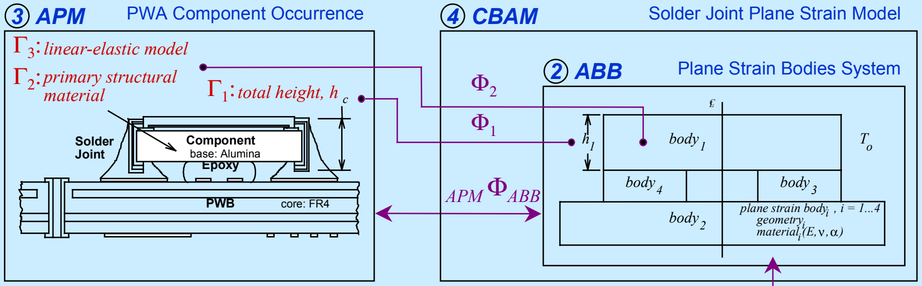
X-Analysis Integration Techniques

Multi-Representation Architecture (MRA)

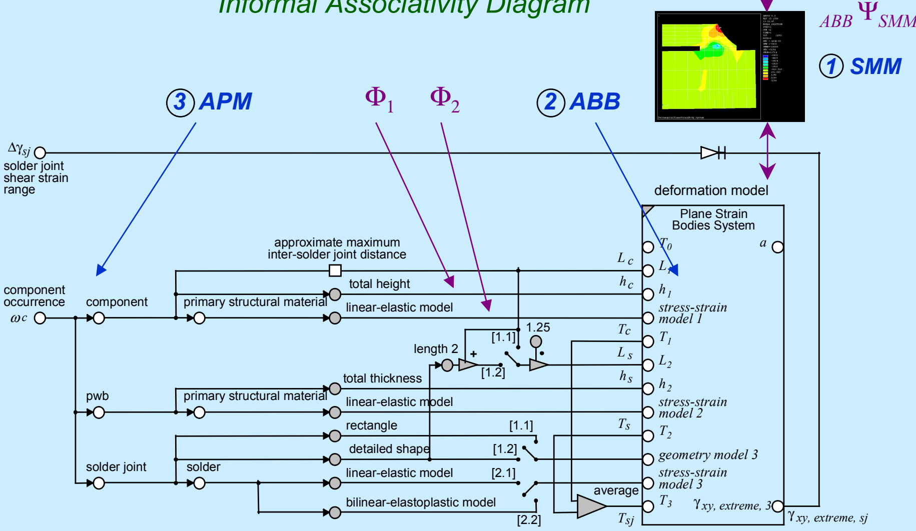


Explicit Design-Analysis Associativity

Design Model *Analysis Model*

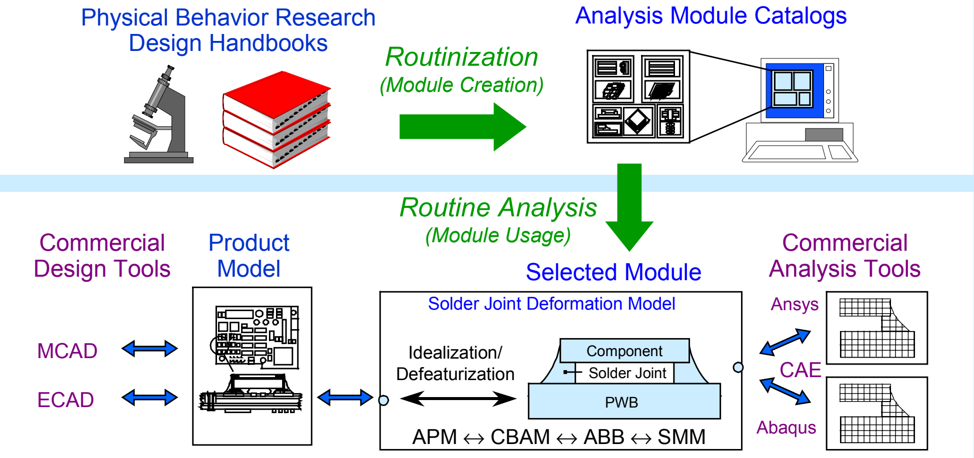


Informal Associativity Diagram



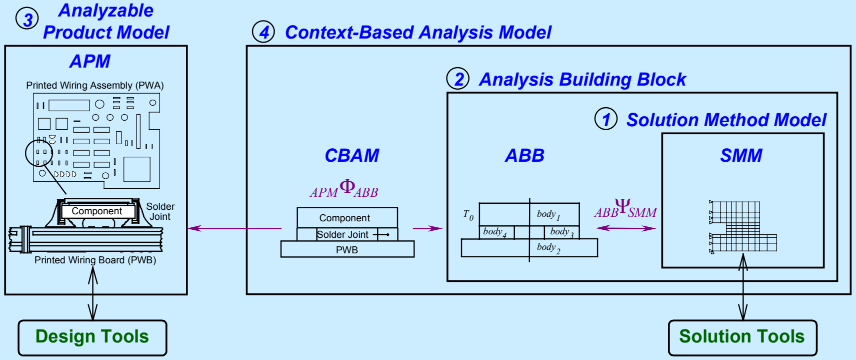
Constraint Schematic (Information Model)

Analysis Module Creation Methodology

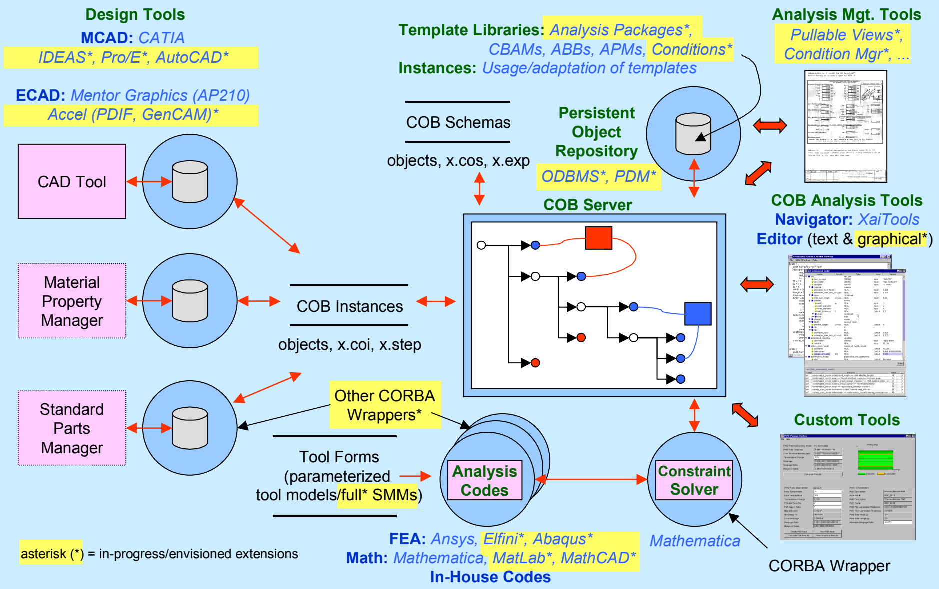


XaiTools™
X-Analysis Integration Toolkit

Multi-Representation Architecture (MRA) Implementation

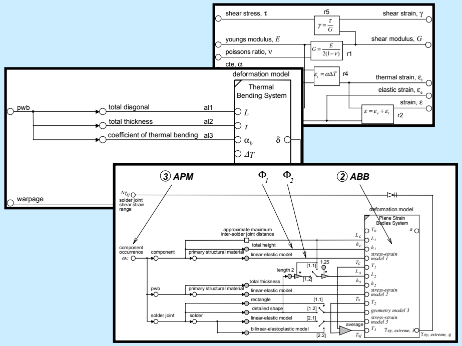


CAD/E Framework Architecture

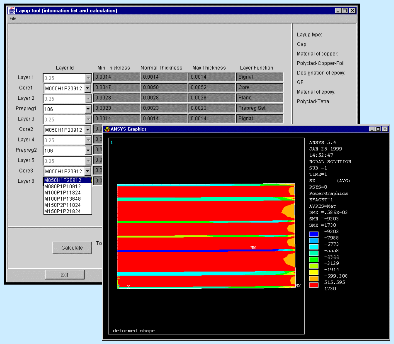


Analysis Modules & Building Blocks

Constraint Schematics



Implementations



	Layer Id	Min Thickness	Normal Thickness	Max Thickness	Layer Function
Layer 1	0.25	0.0014	0.0014	0.0014	Signal
Core1	M050H1P20912	0.0047	0.0050	0.0052	Core
Layer 2	0.25	0.0028	0.0028	0.0028	Plane
Prepreg1	106	0.0023	0.0023	0.0023	Prepreg Set
Layer 3	0.25	0.0014	0.0014	0.0014	Signal
Core2	M050H1P20912				
Layer 4	0.25				
Prepreg2	106				
Layer 5	0.25				
Core3	M050H1P20912				
Layer 6	M050H1P20912 M080P1P10912 M100P1P11824 M100P1P13648 M150P2P11824 M150P1P21824				

Layup type:
Cap
Material of copper:
Polyclad-Copper-Foil
Designation of epoxy:
GF
Material of epoxy:
Polyclad-Tetra

```
ANSYS 5.4
JAN 25 1999
14:52:47
NODAL SOLUTION
SUB =1
TIME=1
SX       (AVG)
RSYS=0
PowerGraphics
EFACET=1
AVRES=Mat
DMX =.586E-03
SMN =-9203
SMX =1730
-9203
-7988
-6773
-5558
-4344
-3129
-1914
-699.208
515.595
1730
```

deformed shape

Product-Specific Applications

- ◆ Aerospace structural analysis
- ◆ PWA-B thermomechanical analysis & design

  XaiTools PWA-B™
- ◆ Electronic package thermal analysis

  XaiTools ChipPackage™

Example Projects

- Team Integrated Electronic Response (TIGER)
  - *Sponsor:* Defense Advanced Research Prog. Admin. (DARPA) *(SCRA subcontract)*
  - *Domain:* PWA/B thermomechanical analysis
- Product Data-Driven Analysis in a Missile Supply Chain (ProAM)
  - *Sponsor:* U. S. DoD JECPO National ECRC Program *(CTC subcontract)*
  - *Stakeholder:* U. S. Army Missile Command (AMCOM)
  - *Domain:* PWA/B thermomechanical analysis
- Design-Analysis Associativity Technology for PSI (PSI-DANTE)
  - *Sponsor:* Boeing
  - *Domain:* Structural analysis
- Design-Analysis Integration Research for Electronic Packaging
  - *Sponsor:* Shinko Electric
  - *Domain:* Chip package thermal resistance analysis

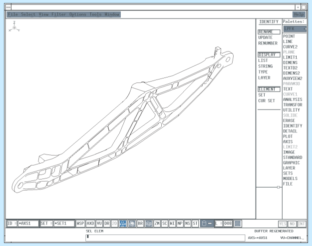
Flexible High Diversity Design-Analysis Integration

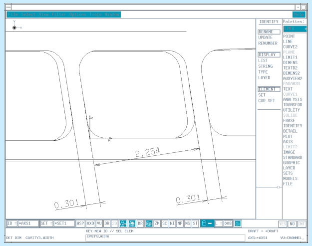
Aerospace Examples:
“Bike Frame” / Flap Support Inboard Beam

Design Tools

MCAD Tools

CATIA





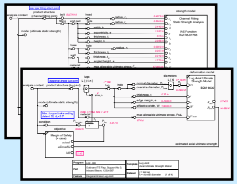
Materials DB

MATDB-like

Fasteners DB

FASTDB-like

Image API
(CATGEO)



Modular, Reusable Template Libraries

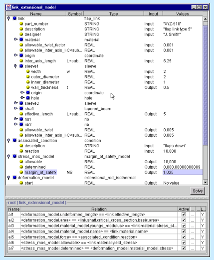
Analyzable Product Model

XaiTools

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

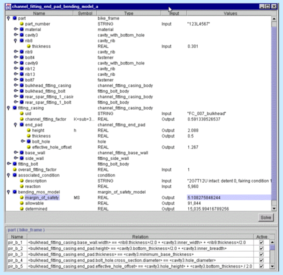
1.5D

Lug: Axial/Oblique; Ultimate/Shear



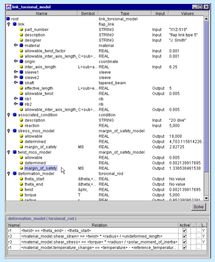
1.5D

Fitting: Bending/Shear



3D

Assembly: Ultimate/ FailSafe/Fatigue*



XaiTools

Analysis Tools

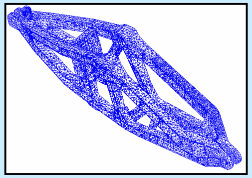
General Math

Mathematica

In-House Codes

FEA

*Elfini**



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

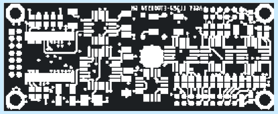
ProAM Design-Analysis Integration

Electronic Packaging Examples: PWA/B

Design Tools

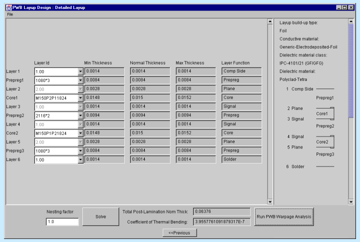
ECAD Tools

*Mentor Graphics, Accel**



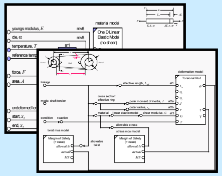
PWB Layup Tool

XaiTools PWA-B



Laminates DB

Materials DB



Modular, Reusable Template Libraries

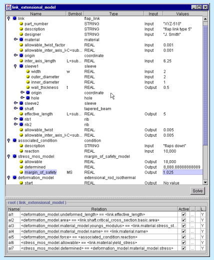
STEP AP210‡
GenCAM**,
PDIF*

Analyzable Product Model

XaiTools PWA-B

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

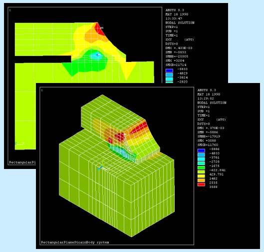
XaiTools PWA-B



Analysis Tools

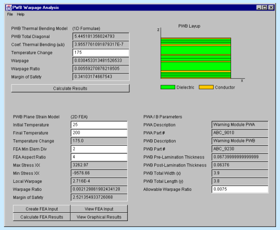
General Math *Mathematica*

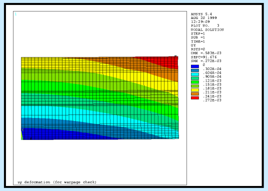
FEA *Ansys*



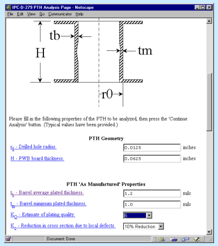
Solder Joint Deformation* — **1D, 2D, 3D**

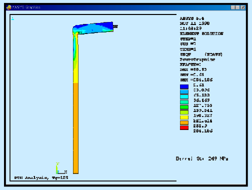
PWB Warpage — **1D, 2D**





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





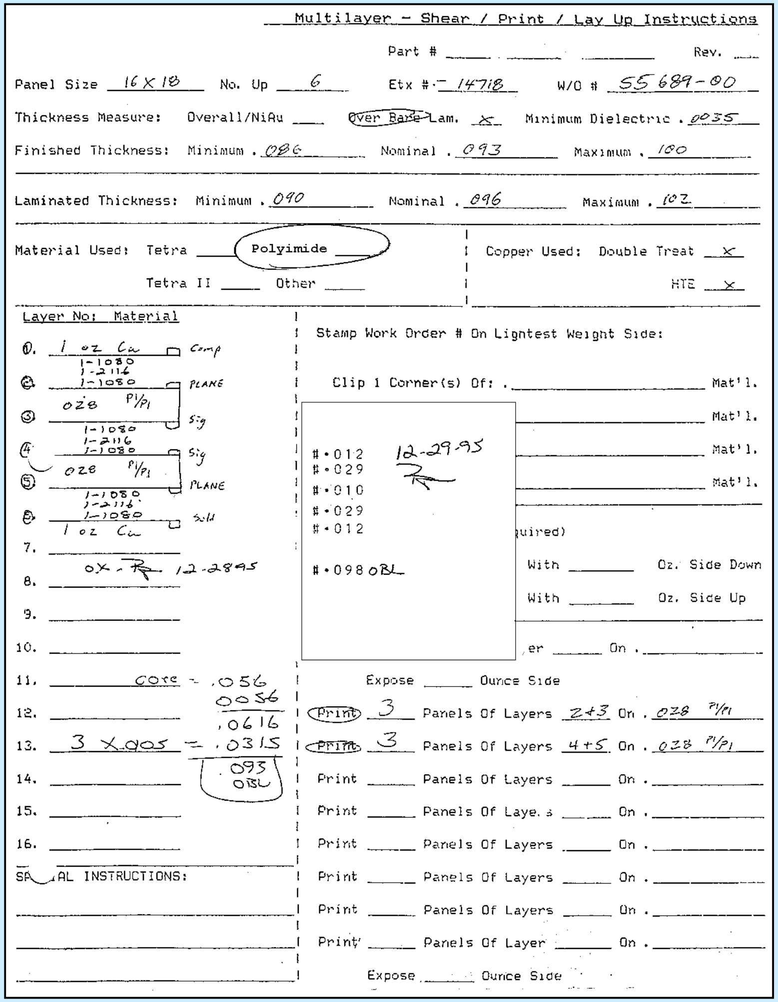
‡ AP210 DIS WD1.7 * = Item not yet available in toolkit (all others have working examples) ** = Item available via U-Engineer.com

Design Automation

Post-Lamination Thickness Calculation

Before: Typical Manual Worksheet

(as much as 1 hour engr. time)



Multilayer - Shear / Print / Lay Up Instructions

Part # ______ ______ ________ Rev. ___

Panel Size 16 X 18 No. Up 6 Etx #- 14718 W/O # 55689-00

Thickness Measure: Overall/NiAu ____ [✓ Over Bare Lam.] X Minimum Dielectric .0035

Finished Thickness: Minimum .086 Nominal .093 Maximum .100

Laminated Thickness: Minimum .090 Nominal .096 Maximum .102

Material Used: Tetra ____ [✓ Polyimide] ____

Tetra II ____ Other ____

Copper Used: Double Treat X

HTE X

Layer No: Material

①. 1 oz Cu Comp

1-1080
1-2116
1-1080

②. PLANE

028 PI/PI

③. Sig

1-1080
1-2116
1-1080

④. Sig

028 PI/PI

⑤. PLANE

1-1080
1-2116
1-1080

⑥. Sold

1 oz Cu

7. ____________

OK - R 12-28-95

8. ____________

9. ____________

10. ____________

11. core - .056

12. ____________ .0056

.0616

13. 3 X .005 = .0315

.093

OBL

14. ____________

15. ____________

16. ____________

SP AL INSTRUCTIONS:

Stamp Work Order # On Lightest Weight Side:

Clip 1 Corner(s) Of: . ____________ Mat'l.

____________ Mat'l.

____________ Mat'l.

____________ Mat'l.

#.012
#.029
#.010
#.029
#.012

#.098 OBL

12-29-95 R

uired)

With ______ Oz. Side Down

With ______ Oz. Side Up

er ______ On . ______

Expose ______ Ounce Side

[✓ Print] 3 Panels Of Layers 2+3 On .028 PI/PI

[✓ Print] 3 Panels Of Layers 4+5 On .028 PI/PI

Print ______ Panels Of Layers ______ On . ______

Print ______ Panels Of Laye. s ______ On . ______

Print ______ Panels Of Layers ______ On . ______

Print ______ Panels Of Layers ______ On . ______

Print ______ Panels Of Layers ______ On . ______

Print ______ Panels Of Layer ______ On . ______

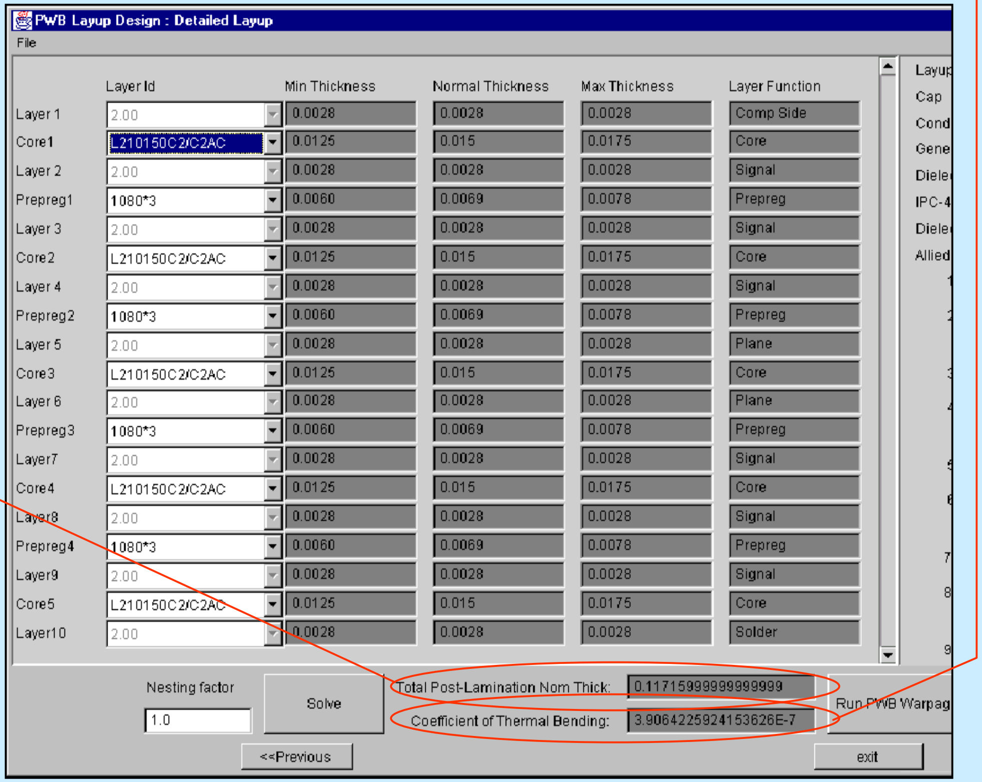
Expose ______ Ounce Side

After: Tool-Aided Design

$$post\_lamination\_thickness = \sum_{1}^{n} nested\_thickess_i$$

$$nested\_thickness_{prepreg\_set} = \sum_{1}^{p} k_n t_{sf_i} - resin\_to\_fill$$

$$\alpha_B = C_1 \frac{\sum_{1}^{n} t_i \alpha_i y_i}{\left(t^2/2\right)} + C_2 \frac{\sum_{1}^{n} \left|t_i \alpha_i y_i\right|}{\left(t^2/2\right)} + C_3$$



PWB Layup Design : Detailed Layup

	Layer Id	Min Thickness	Normal Thickness	Max Thickness	Layer Function
Layer 1	2.00	0.0028	0.0028	0.0028	Comp Side
Core1	L210150C2/C2AC	0.0125	0.015	0.0175	Core
Layer 2	2.00	0.0028	0.0028	0.0028	Signal
Prepreg1	1080*3	0.0060	0.0069	0.0078	Prepreg
Layer 3	2.00	0.0028	0.0028	0.0028	Signal
Core2	L210150C2/C2AC	0.0125	0.015	0.0175	Core
Layer 4	2.00	0.0028	0.0028	0.0028	Signal
Prepreg2	1080*3	0.0060	0.0069	0.0078	Prepreg
Layer 5	2.00	0.0028	0.0028	0.0028	Plane
Core3	L210150C2/C2AC	0.0125	0.015	0.0175	Core
Layer 6	2.00	0.0028	0.0028	0.0028	Plane
Prepreg3	1080*3	0.0060	0.0069	0.0078	Prepreg
Layer7	2.00	0.0028	0.0028	0.0028	Signal
Core4	L210150C2/C2AC	0.0125	0.015	0.0175	Core
Layer8	2.00	0.0028	0.0028	0.0028	Signal
Prepreg4	1080*3	0.0060	0.0069	0.0078	Prepreg
Layer9	2.00	0.0028	0.0028	0.0028	Signal
Core5	L210150C2/C2AC	0.0125	0.015	0.0175	Core
Layer10	2.00	0.0028	0.0028	0.0028	Solder

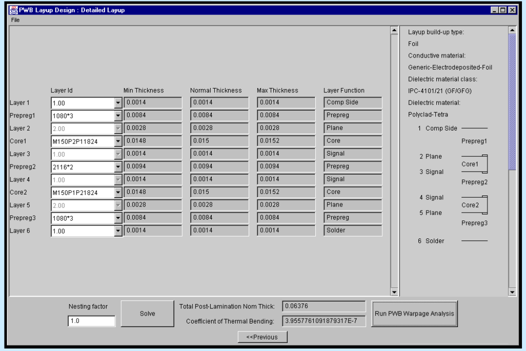
Nesting factor: 1.0

Total Post-Lamination Nom Thick: 0.11715999999999999

Coefficient of Thermal Bending: 3.9064225924153626E-7

Iterative Design & Analysis using *XaiTools PWA-B*

PWB Layup Design Tool



PWB Layup Design : Detailed Layup

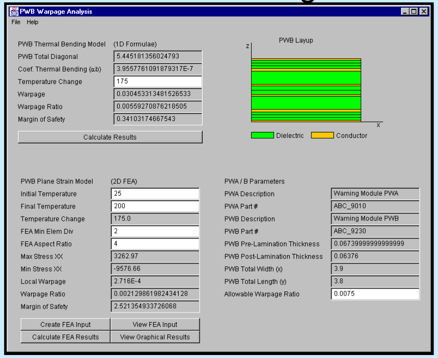
	Layer Id	Min Thickness	Normal Thickness	Max Thickness	Layer Function
Layer 1	1.00	0.0014	0.0014	0.0014	Comp Side
Prepreg1	1080*3	0.0084	0.0084	0.0084	Prepreg
Layer 2	2.00	0.0028	0.0028	0.0028	Plane
Core1	M150P2P11824	0.0148	0.015	0.0152	Core
Layer 3	1.00	0.0014	0.0014	0.0014	Signal
Prepreg2	2116*2	0.0094	0.0094	0.0094	Prepreg
Layer 4	1.00	0.0014	0.0014	0.0014	Signal
Core2	M150P1P21824	0.0148	0.015	0.0152	Core
Layer 5	2.00	0.0028	0.0028	0.0028	Plane
Prepreg3	1080*3	0.0084	0.0084	0.0084	Prepreg
Layer 6	1.00	0.0014	0.0014	0.0014	Solder

Layup build-up type:
Foil
Conductive material:
Generic-Electrodeposited-Foil
Dielectric material class:
IPC-4101/21 (GF/GFG)
Dielectric material:
Polyclad-Tetra

Nesting factor: 1.0
Total Post-Lamination Nom Thick: 0.06376
Coefficient of Thermal Bending: 3.9557761091879317E-7

Layup
Re-design

1D Thermal Bending Model



PWB Warpage Analysis

PWB Thermal Bending Model (1D Formulae)
PWB Total Diagonal: 5.445181356024793
Coef. Thermal Bending (αb): 3.9557761091879317E-7
Temperature Change: 175
Warpage: 0.030453313481526533
Warpage Ratio: 0.00559270876218505
Margin of Safety: 0.34103174667543

PWB Plane Strain Model (2D FEA)
Initial Temperature: 25
Final Temperature: 200
Temperature Change: 175.0
FEA Min Elem Div: 2
FEA Aspect Ratio: 4
Max Stress XX: 3262.97
Min Stress XX: -9576.66
Local Warpage: 2.716E-4
Warpage Ratio: 0.002129861982434128
Margin of Safety: 2.521354933726068

PWA / B Parameters
PWA Description: Warning Module PWA
PWA Part #: ABC_9010
PWB Description: Warning Module PWB
PWB Part #: ABC_9230
PWB Pre-Lamination Thickness: 0.06739999999999999
PWB Post-Lamination Thickness: 0.06376
PWB Total Width (x): 3.9
PWB Total Length (y): 3.8
Allowable Warpage Ratio: 0.0075

Quick Formula-based Check

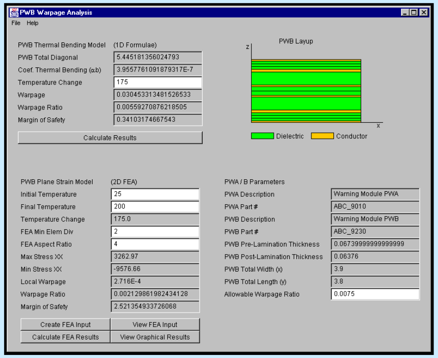
$$\delta = \frac{\alpha_b L^2 \Delta T}{t}$$

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

Analyzable Product Model

PWB Warpage Modules

2D Plane Strain Model



PWB Warpage Analysis

PWB Thermal Bending Model (1D Formulae)
PWB Total Diagonal: 5.445181356024793
Coef. Thermal Bending (αb): 3.9557761091879317E-7
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Margin of Safety: 0.34103174667543

PWB Plane Strain Model (2D FEA)
Initial Temperature: 25
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FEA Min Elem Div: 2
FEA Aspect Ratio: 4
Max Stress XX: 3262.97
Min Stress XX: -9576.66
Local Warpage: 2.716E-4
Warpage Ratio: 0.002129861982434128
Margin of Safety: 2.521354933726068

PWA / B Parameters
PWA Description: Warning Module PWA
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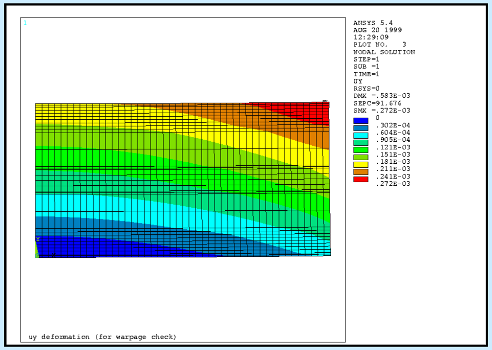
PWB Pre-Lamination Thickness: 0.06739999999999999
PWB Post-Lamination Thickness: 0.06376
PWB Total Width (x): 3.9
PWB Total Length (y): 3.8
Allowable Warpage Ratio: 0.0075

Detailed FEA Check



```
ANSYS 5.4
AUG 20 1999
12:29:09
PLOT NO.    3
NODAL SOLUTION
STEP=1
SUB =1
TIME=1
UY
RSYS=0
DMX =.583E-03
SEPC=91.676
SMX =.272E-03
```

Flexible High Diversity Design-Analysis Integration

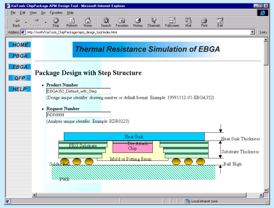
Electronic Packaging Examples: Chip Packages/Mounting

(work-in-progress for Shinko Electric)

Design Tools

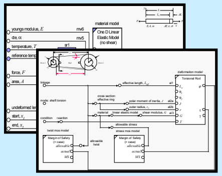
Prelim/APM Design Tool

XaiTools ChipPackage



PWB Laminates DB

Materials DB*

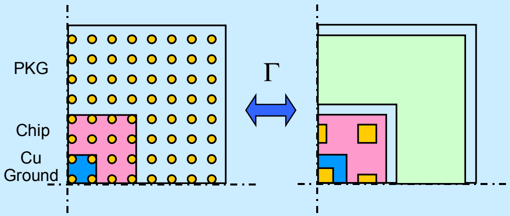


Modular, Reusable Template Libraries

Analyzable Product Model

XaiTools

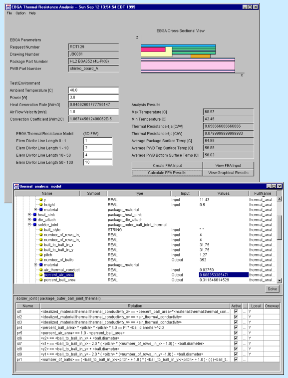
EBGA, PBGA, QFP



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

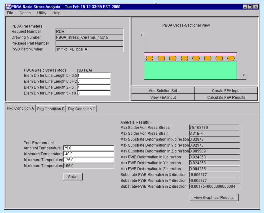
Thermal Resistance

3D



Thermal Stress

Basic 3D*



Analysis Tools

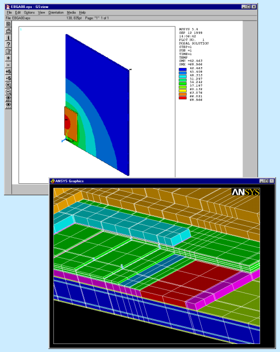
XaiTools ChipPackage

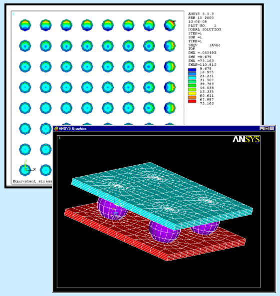
General Math

Mathematica

FEA

Ansys

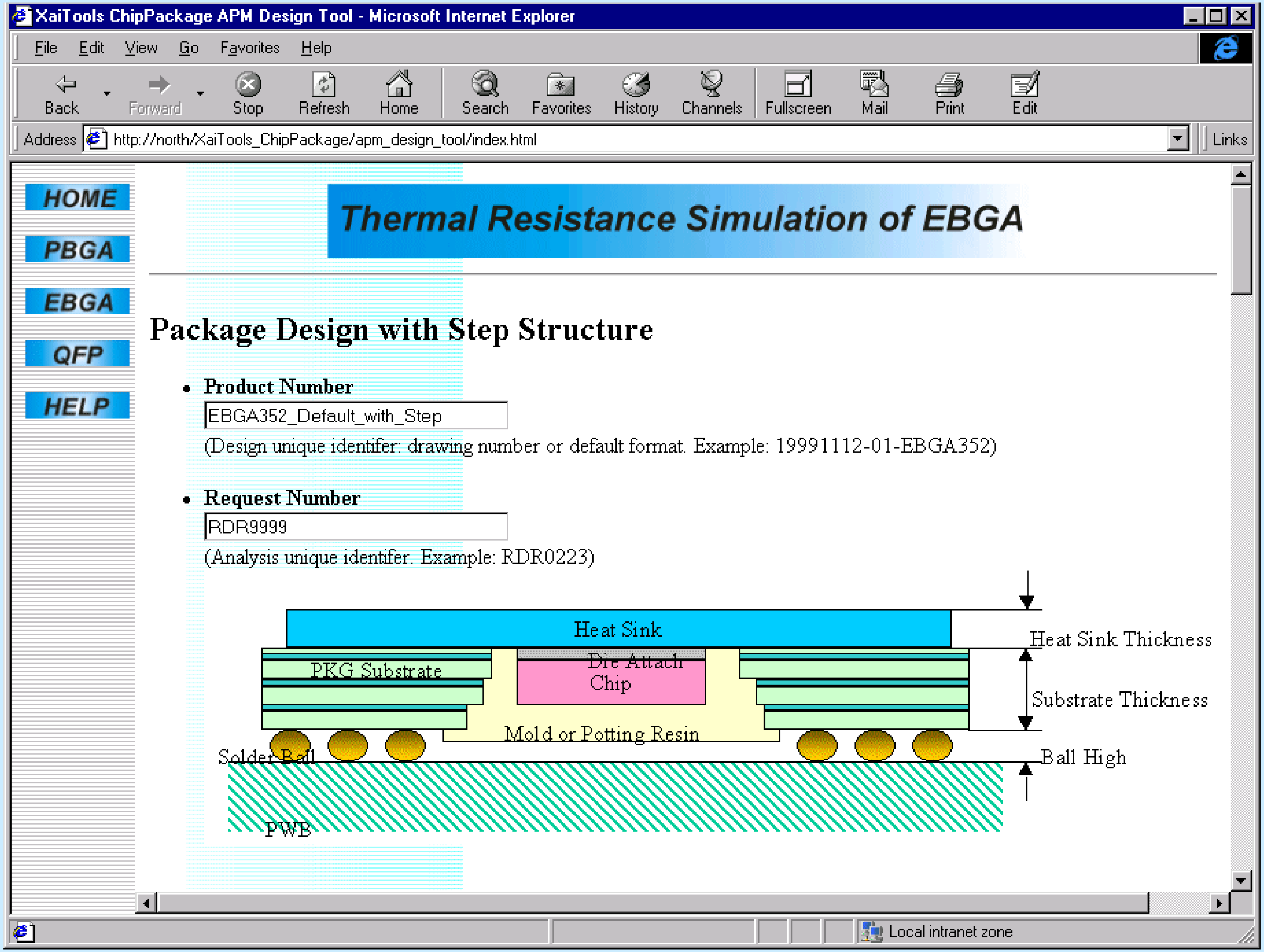




** = Demonstration module

APM Design Tool

Preliminary Design of Packages



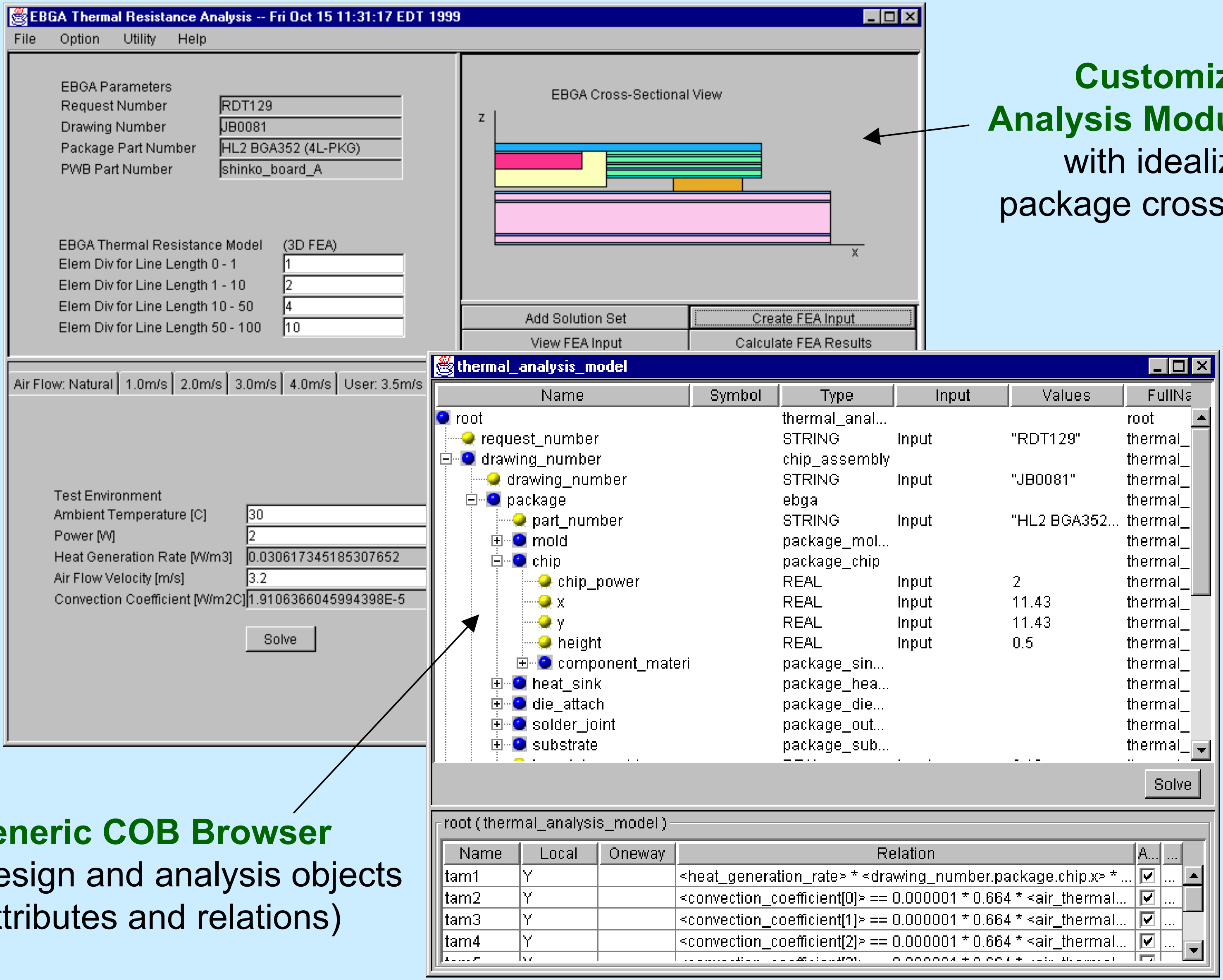
Thermal Resistance Simulation of EBGA

Package Design with Step Structure

- **Product Number**
  EBGA352_Default_with_Step
  (Design unique identifer: drawing number or default format. Example: 19991112-01-EBGA352)
- **Request Number**
  RDR9999
  (Analysis unique identifer. Example: RDR0223)

COB-based Analysis Tools

Typical Input Objects



EBGA Parameters
Request Number: RDT129
Drawing Number: JB0081
Package Part Number: HL2 BGA352 (4L-PKG)
PWB Part Number: shinko_board_A

EBGA Thermal Resistance Model (3D FEA)
Elem Div for Line Length 0 - 1: 1
Elem Div for Line Length 1 - 10: 2
Elem Div for Line Length 10 - 50: 4
Elem Div for Line Length 50 - 100: 10

Test Environment
Ambient Temperature [C]: 30
Power [W]: 2
Heat Generation Rate [W/m3]: 0.030617345185307652
Air Flow Velocity [m/s]: 3.2
Convection Coefficient [W/m2C]: 1.9106366045994398E-5

Name	Symbol	Type	Input	Values	FullNa
root		thermal_anal...			root
request_number		STRING	Input	"RDT129"	thermal_
drawing_number		chip_assembly			thermal_
drawing_number		STRING	Input	"JB0081"	thermal_
package		ebga			thermal_
part_number		STRING	Input	"HL2 BGA352...	thermal_
mold		package_mol...			thermal_
chip		package_chip			thermal_
chip_power		REAL	Input	2	thermal_
x		REAL	Input	11.43	thermal_
y		REAL	Input	11.43	thermal_
height		REAL	Input	0.5	thermal_
component_materi		package_sin...			thermal_
heat_sink		package_hea...			thermal_
die_attach		package_die...			thermal_
solder_joint		package_out...			thermal_
substrate		package_sub...			thermal_

root (thermal_analysis_model)

Name	Local	Oneway	Relation	A...	...
tam1	Y		<heat_generation_rate> * <drawing_number.package.chip.x> * ...	☑	...
tam2	Y		<convection_coefficient[0]> == 0.000001 * 0.664 * <air_thermal...	☑	...
tam3	Y		<convection_coefficient[1]> == 0.000001 * 0.664 * <air_thermal...	☑	...
tam4	Y		<convection_coefficient[2]> == 0.000001 * 0.664 * <air_thermal...	☑	...

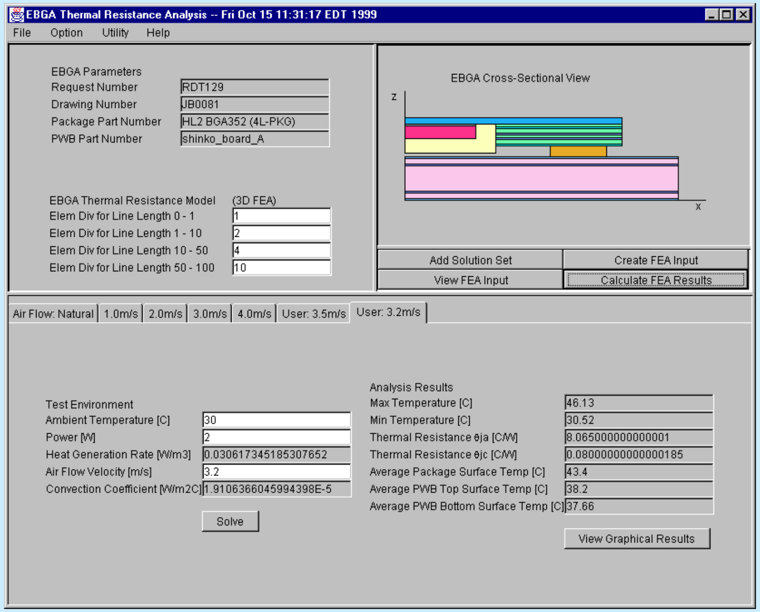
Customized Analysis Module Tool
with idealized
package cross-section

Generic COB Browser
with design and analysis objects
(attributes and relations)

COB-based Analysis Tools

Typical Highly Automated Results

Analysis Module Tool with Results Summaries



EBGA Thermal Resistance Analysis -- Fri Oct 15 11:31:17 EDT 1999

EBGA Parameters

Request Number	RDT129
Drawing Number	JB0081
Package Part Number	HL2 BGA352 (4L-PKG)
PWB Part Number	shinko_board_A

EBGA Thermal Resistance Model (3D FEA)

Elem Div for Line Length 0 - 1	1
Elem Div for Line Length 1 - 10	2
Elem Div for Line Length 10 - 50	4
Elem Div for Line Length 50 - 100	10

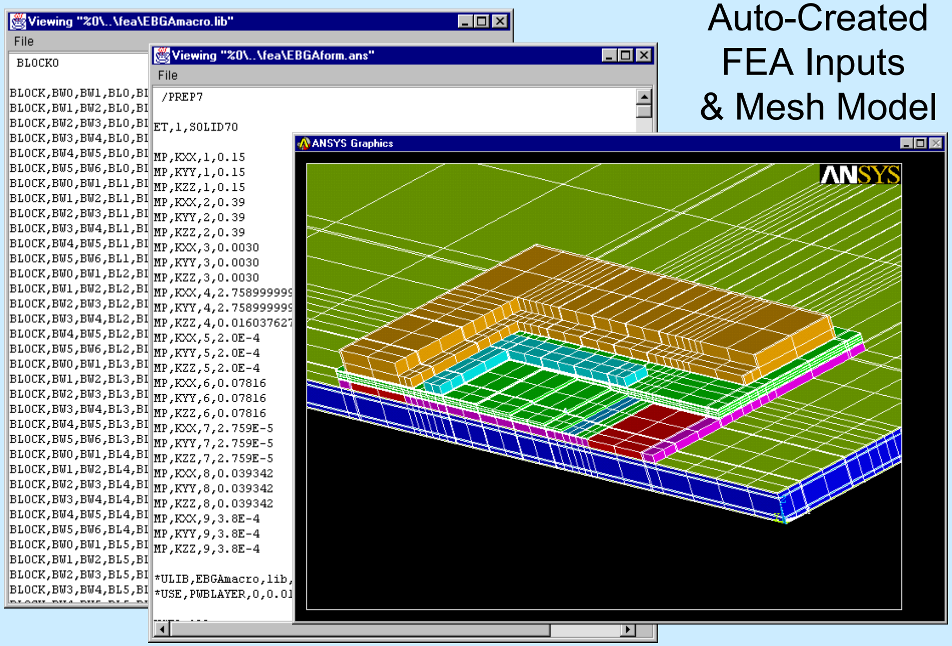
Test Environment

Ambient Temperature [C]	30
Power [W]	2
Heat Generation Rate [W/m3]	0.030617345185307652
Air Flow Velocity [m/s]	3.2
Convection Coefficient [W/m2C]	1.9106366045994398E-5

Analysis Results

Max Temperature [C]	46.13
Min Temperature [C]	30.52
Thermal Resistance θja [C/W]	8.065000000000001
Thermal Resistance θjc [C/W]	0.08000000000000185
Average Package Surface Temp [C]	43.4
Average PWB Top Surface Temp [C]	38.2
Average PWB Bottom Surface Temp [C]	37.66

Auto-Created FEA Inputs & Mesh Model

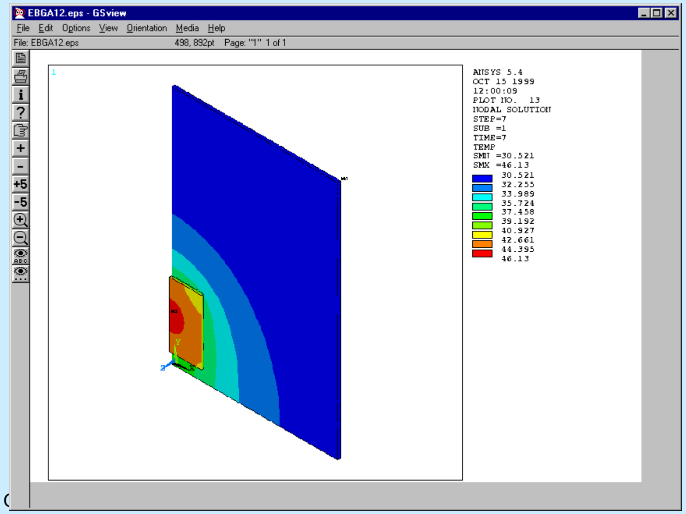


Viewing "%0\..\fea\EBGAmacro.lib"

```
BLOCK0

BLOCK,BW0,BW1,BL0,BI
BLOCK,BW1,BW2,BL0,BI
BLOCK,BW2,BW3,BL0,BI
BLOCK,BW3,BW4,BL0,BI
BLOCK,BW4,BW5,BL0,BI
BLOCK,BW5,BW6,BL0,BI
BLOCK,BW0,BW1,BL1,BI
BLOCK,BW1,BW2,BL1,BI
BLOCK,BW2,BW3,BL1,BI
BLOCK,BW3,BW4,BL1,BI
BLOCK,BW4,BW5,BL1,BI
BLOCK,BW5,BW6,BL1,BI
BLOCK,BW0,BW1,BL2,BI
BLOCK,BW1,BW2,BL2,BI
BLOCK,BW2,BW3,BL2,BI
BLOCK,BW3,BW4,BL2,BI
BLOCK,BW4,BW5,BL2,BI
BLOCK,BW5,BW6,BL2,BI
BLOCK,BW0,BW1,BL3,BI
BLOCK,BW1,BW2,BL3,BI
BLOCK,BW2,BW3,BL3,BI
BLOCK,BW3,BW4,BL3,BI
BLOCK,BW4,BW5,BL3,BI
BLOCK,BW5,BW6,BL3,BI
BLOCK,BW0,BW1,BL4,BI
BLOCK,BW1,BW2,BL4,BI
BLOCK,BW2,BW3,BL4,BI
BLOCK,BW3,BW4,BL4,BI
BLOCK,BW4,BW5,BL4,BI
BLOCK,BW5,BW6,BL4,BI
BLOCK,BW0,BW1,BL5,BI
BLOCK,BW1,BW2,BL5,BI
BLOCK,BW2,BW3,BL5,BI
BLOCK,BW3,BW4,BL5,BI
```

Viewing "%0\..\fea\EBGAform.ans"

```
/PREP7

ET,1,SOLID70

MP,KXX,1,0.15
MP,KYY,1,0.15
MP,KZZ,1,0.15
MP,KXX,2,0.39
MP,KYY,2,0.39
MP,KZZ,2,0.39
MP,KXX,3,0.0030
MP,KYY,3,0.0030
MP,KZZ,3,0.0030
MP,KXX,4,2.758999999
MP,KYY,4,2.758999999
MP,KZZ,4,0.016037627
MP,KXX,5,2.0E-4
MP,KYY,5,2.0E-4
MP,KZZ,5,2.0E-4
MP,KXX,6,0.07816
MP,KYY,6,0.07816
MP,KZZ,6,0.07816
MP,KXX,7,2.759E-5
MP,KYY,7,2.759E-5
MP,KZZ,7,2.759E-5
MP,KXX,8,0.039342
MP,KYY,8,0.039342
MP,KZZ,8,0.039342
MP,KXX,9,3.8E-4
MP,KYY,9,3.8E-4
MP,KZZ,9,3.8E-4

*ULIB,EBGAmacro,lib,
*USE,PWBLAYER,0,0.01
```

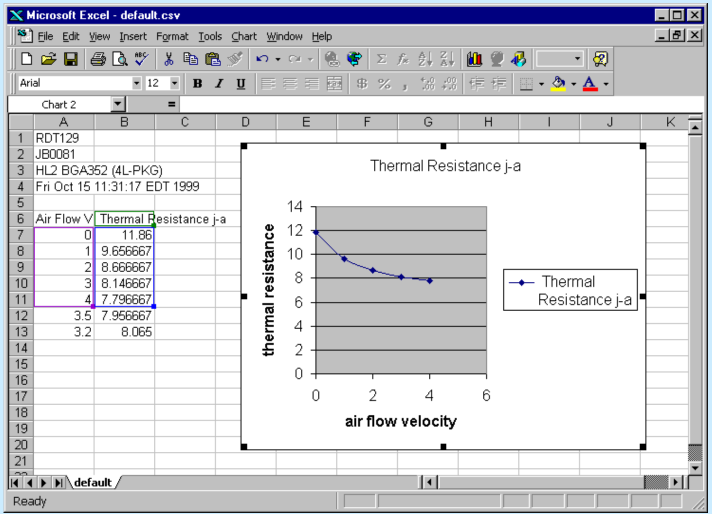


EBGA12.eps - GSview

```
ANSYS 5.4
OCT 15 1999
12:00:09
PLOT NO.  13
NODAL SOLUTION
STEP=7
SUB =1
TIME=7
TEMP
SMN =30.521
SMX =46.13
```

FEA
Temperature
Distribution

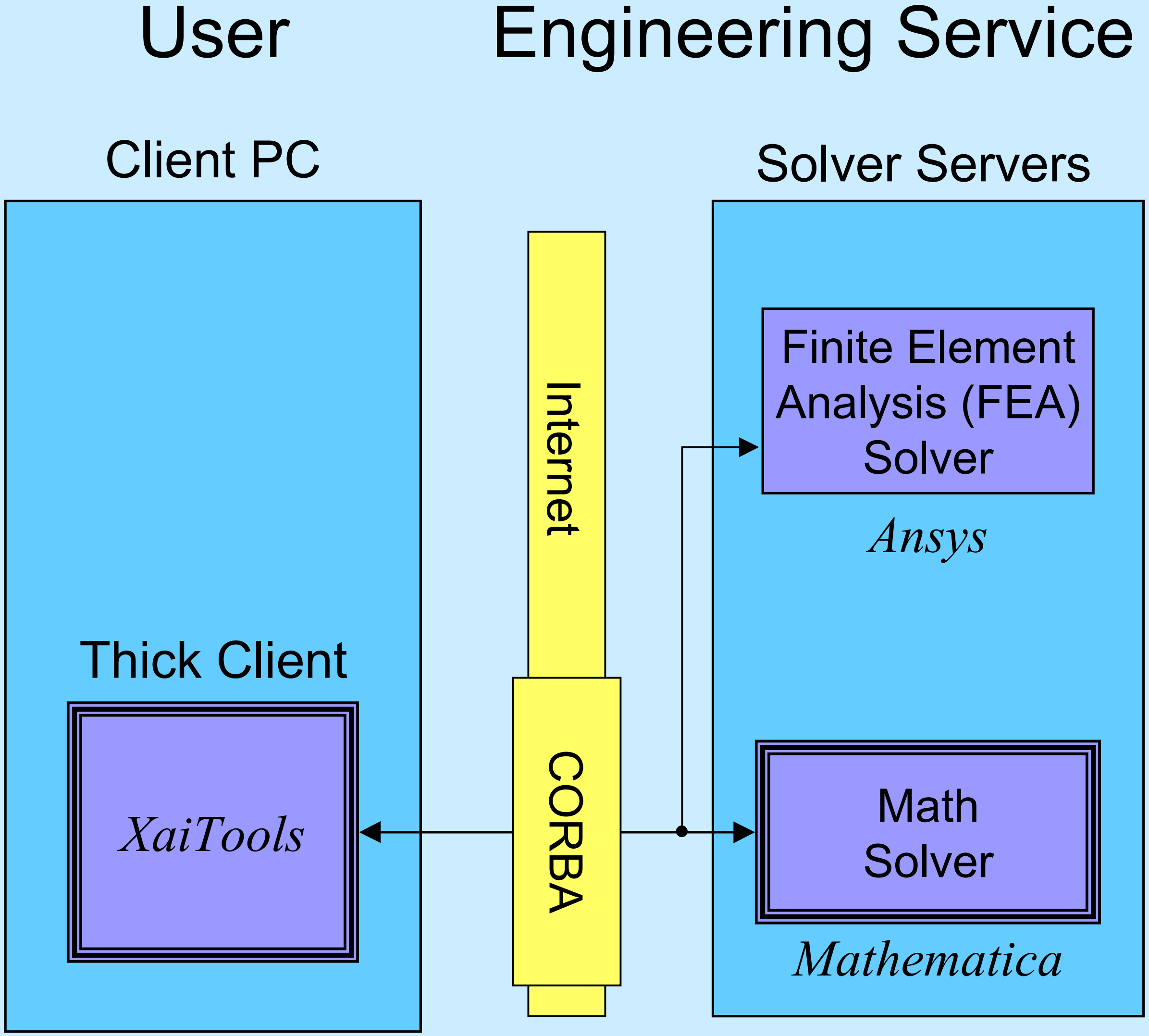
Thermal Resistance
vs.
Air Flow Velocity



Microsoft Excel - default.csv

	A	B	C
1	RDT129		
2	JB0081		
3	HL2 BGA352 (4L-PKG)		
4	Fri Oct 15 11:31:17 EDT 1999		
5			
6	Air Flow V	Thermal Resistance j-a	
7	0	11.86	
8	1	9.656667	
9	2	8.666667	
10	3	8.146667	
11	4	7.796667	
12	3.5	7.956667	
13	3.2	8.065	

Using Internet-based Analysis Solvers



Current:
U-Engineer.com
Pilot Demo

Future:
Company Internal
or
U-Engineer.com

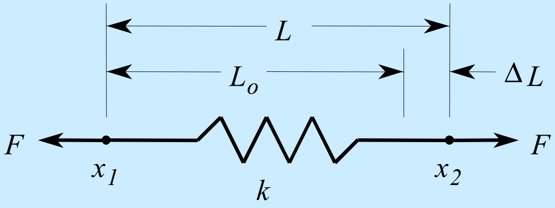
Outline

- Objectives & Challenges
- Technique Highlights and Applications
- ➡ Constrained Objects (COBs) Overview
  - Usage for Analysis Integration
- Summary

COB Structure: Graphical Forms

Spring Primitive

Figure



deformed state

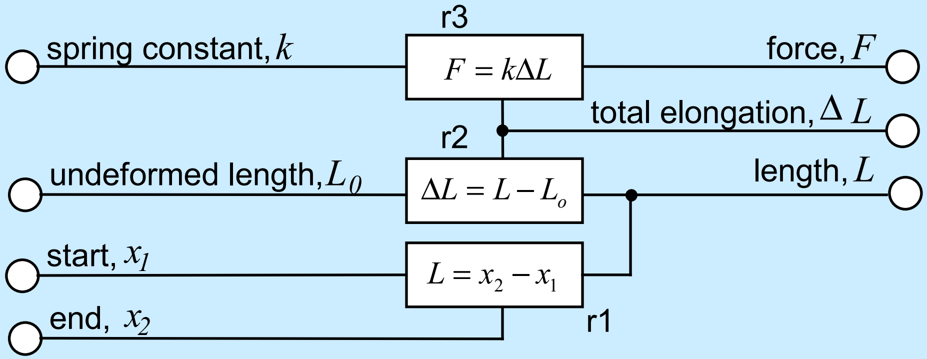
Relations

$$r_1 : L = x_2 - x_1$$

$$r_2 : \Delta L = L - L_0$$

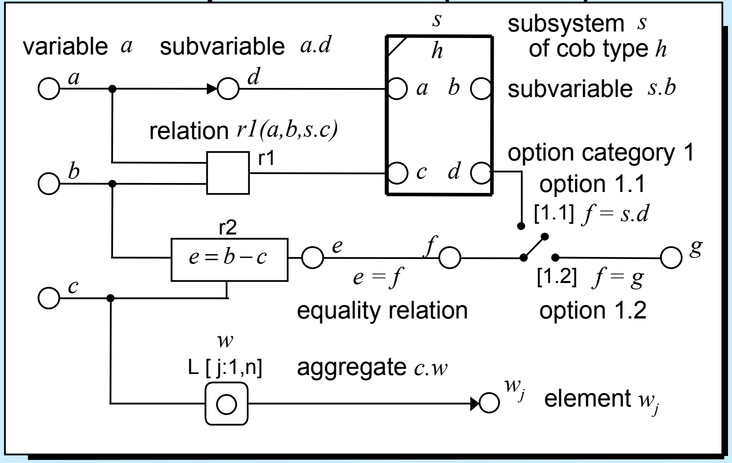
$$r_3 : F = k\Delta L$$

Constraint Schematic



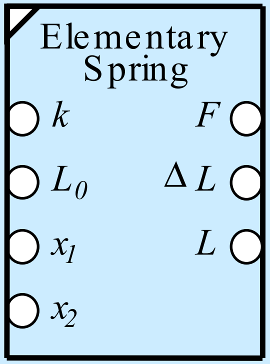
Basic Constraint Schematic Notation

Template Structure (Schema)



Subsystem View

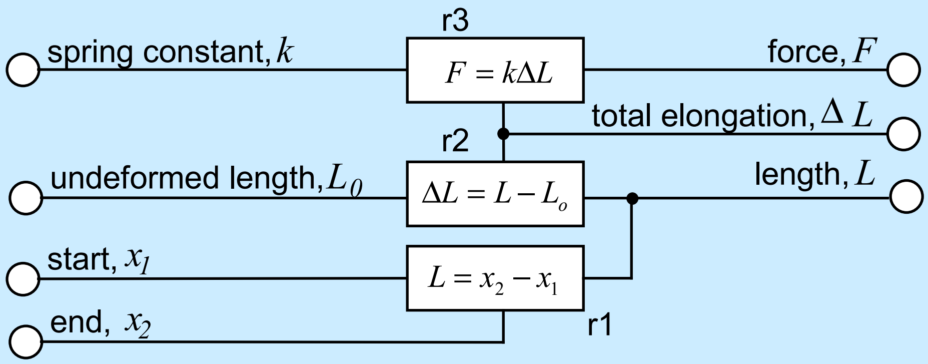
(for reuse by other COBs)



COB Structure: Lexical Form

Spring Primitive

Constraint Schematic



Lexical COB Schema Template

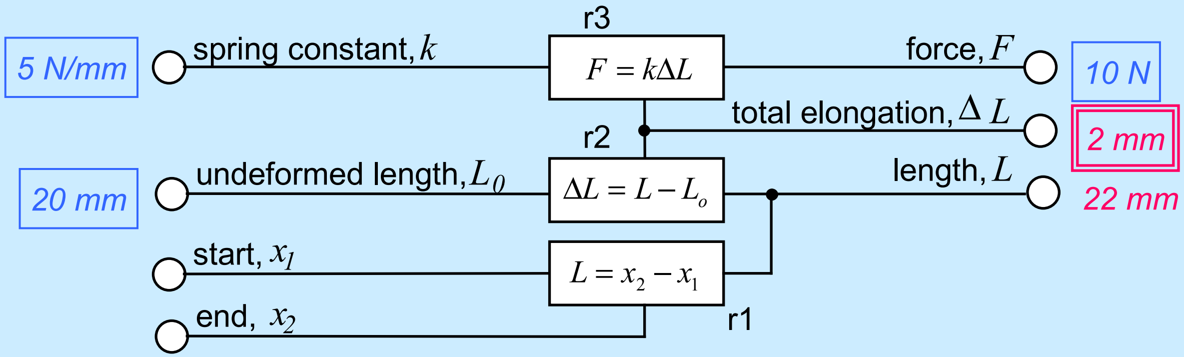
```
COB spring SUBTYPE_OF abb;
   undeformed_length, L<sub>0</sub> : REAL;
   spring_constant, k : REAL;
   start, x<sub>1</sub> : REAL;
   end, x<sub>2</sub> : REAL;
   length, L : REAL;
   total_elongation, &Delta;L : REAL;
   force, F : REAL;
 RELATIONS
   r1 : "<length> == <end> - <start>";
   r2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

Example COB Instance

Spring Primitive

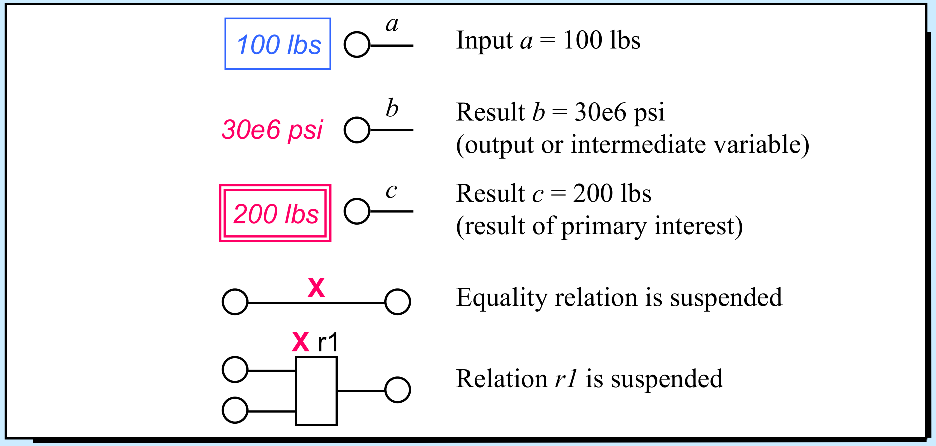
Constraint Schematic Instance Views

example 1, state 1



Basic Constraint Schematic Notation

Instances



Input a = 100 lbs

Result b = 30e6 psi
(output or intermediate variable)

Result c = 200 lbs
(result of primary interest)

Equality relation is suspended

Relation $r1$ is suspended

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;
```

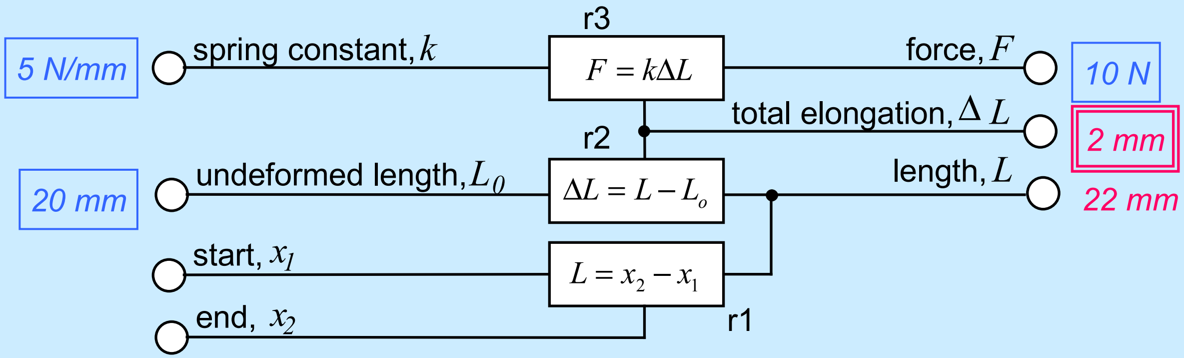
Multi-Directional I/O (non-causal)

Spring Primitive

Constraint Schematic Instance View

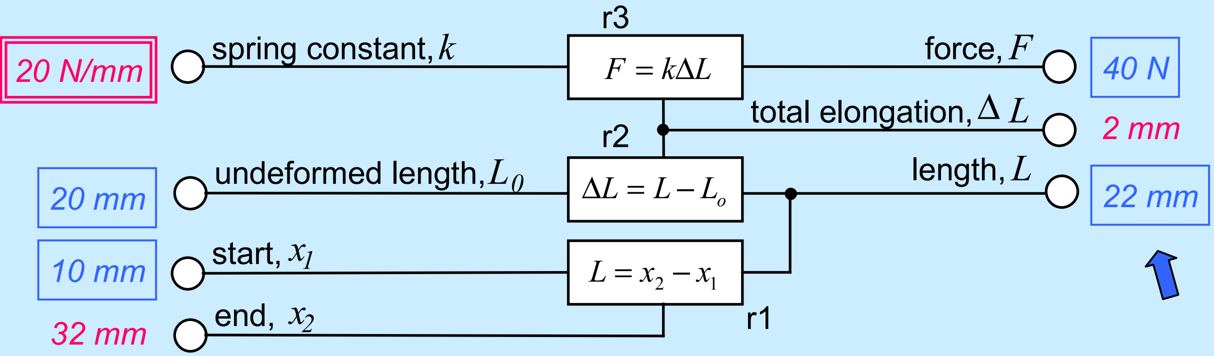
Design check

example 1, state 1



Design synthesis

example 1, state 5



Lexical COB Instance

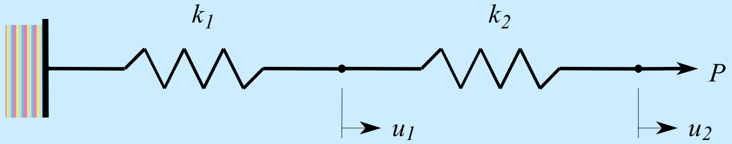
(state 5)

```
input:

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

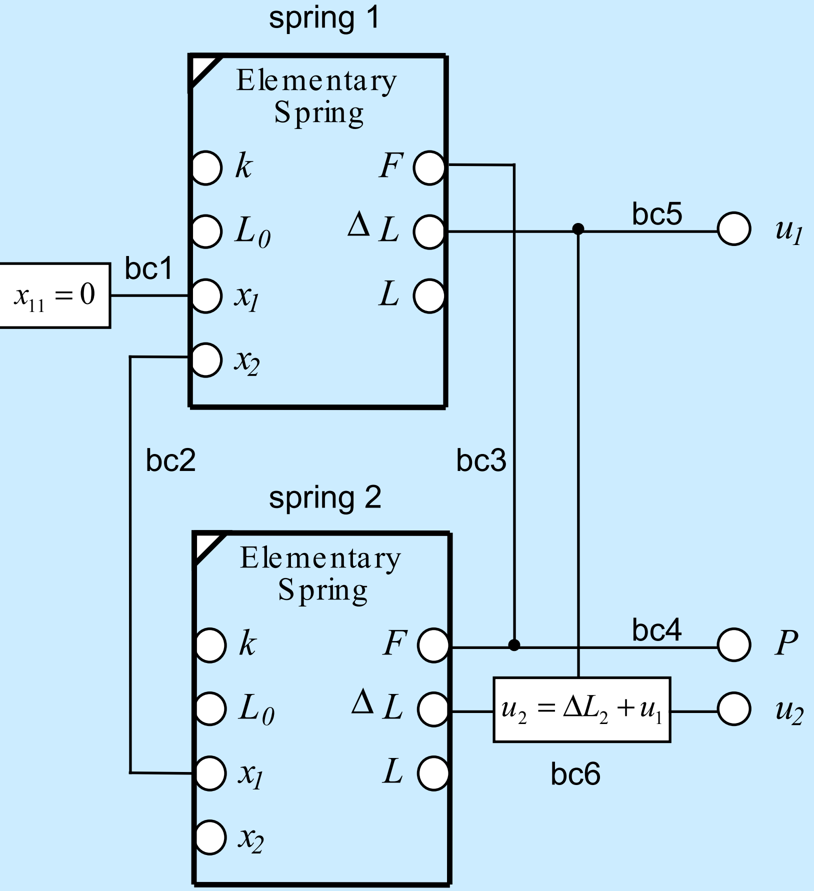
```
result:

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;
```

COBs as Building Blocks

Two Spring System



Constraint Schematic



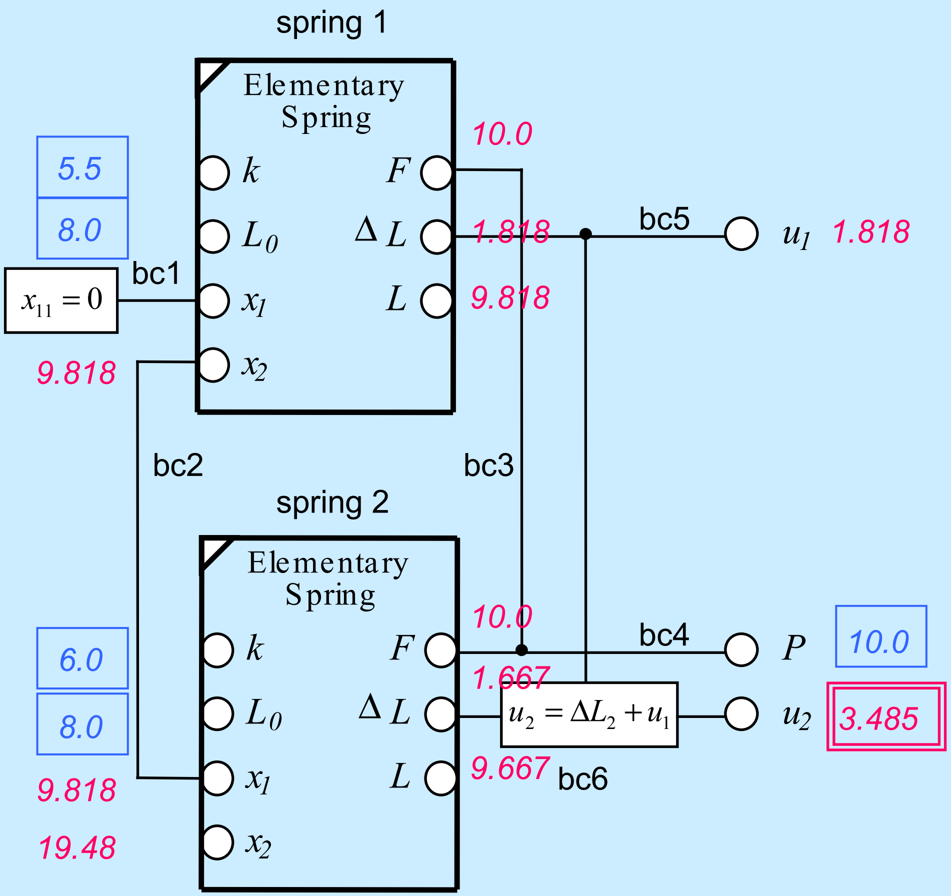
Lexical COB Schema Template

```
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;
```

Analysis System Instance

Two Spring System

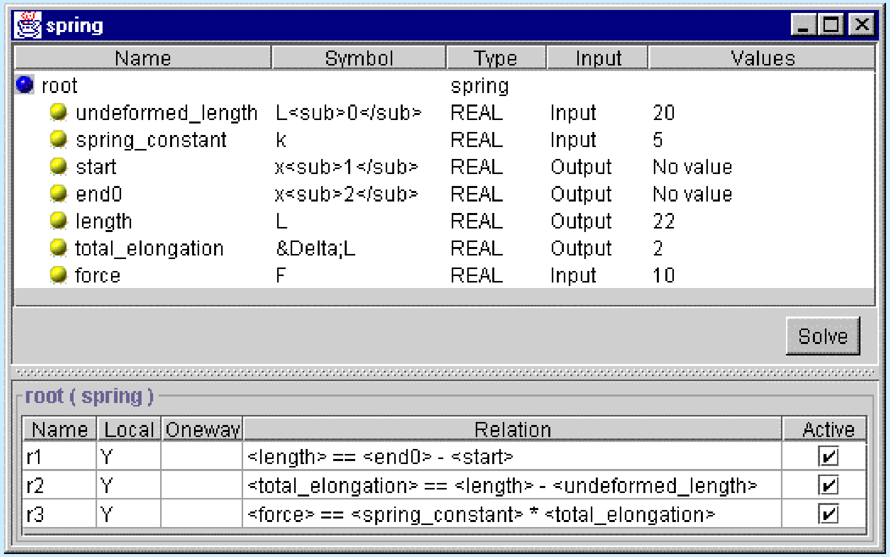
Constraint Schematic Instance View



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;
```

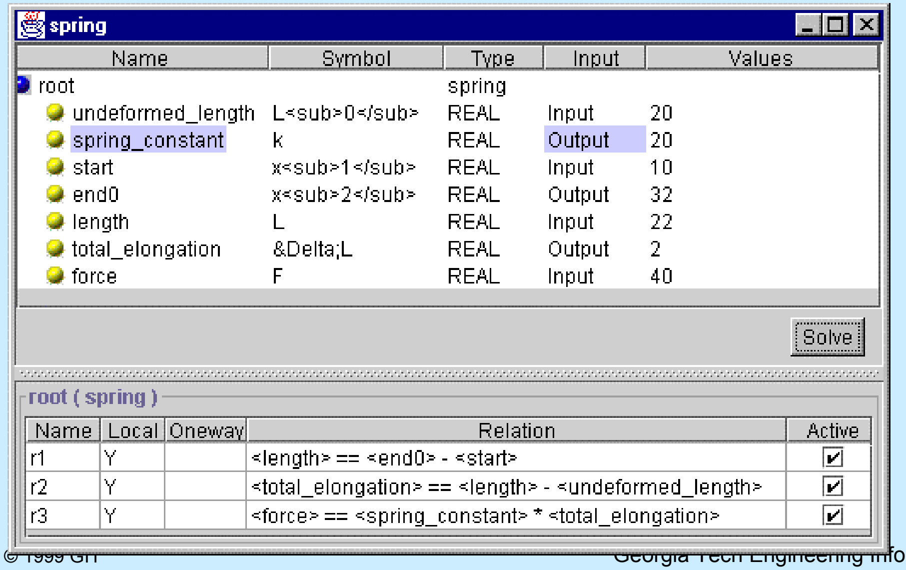
Spring Examples Implemented in *XaiTools* X-Analysis Integration Toolkit



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

root (spring)

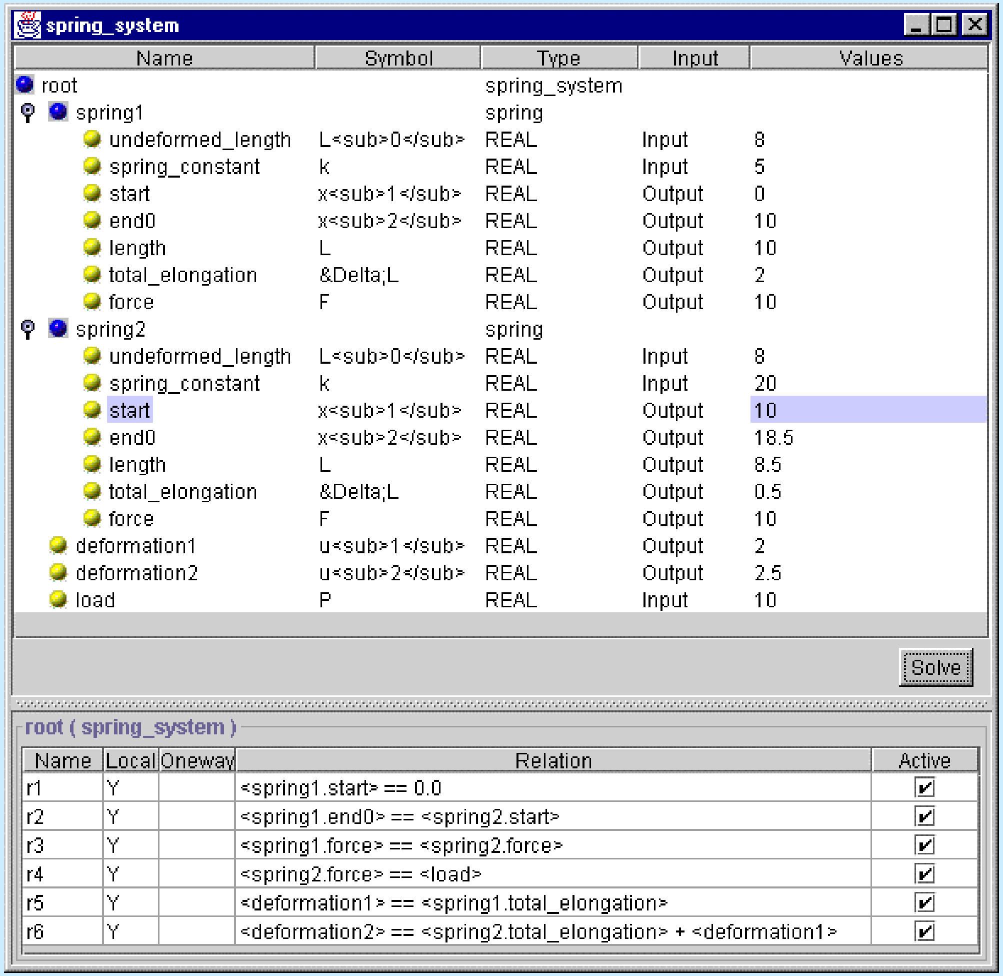
Name	Local	Oneway	Relation	Active
r1	Y		<length> == <end0> - <start>	☑
r2	Y		<total_elongation> == <length> - <undeformed_length>	☑
r3	Y		<force> == <spring_constant> * <total_elongation>	☑



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

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>	☑

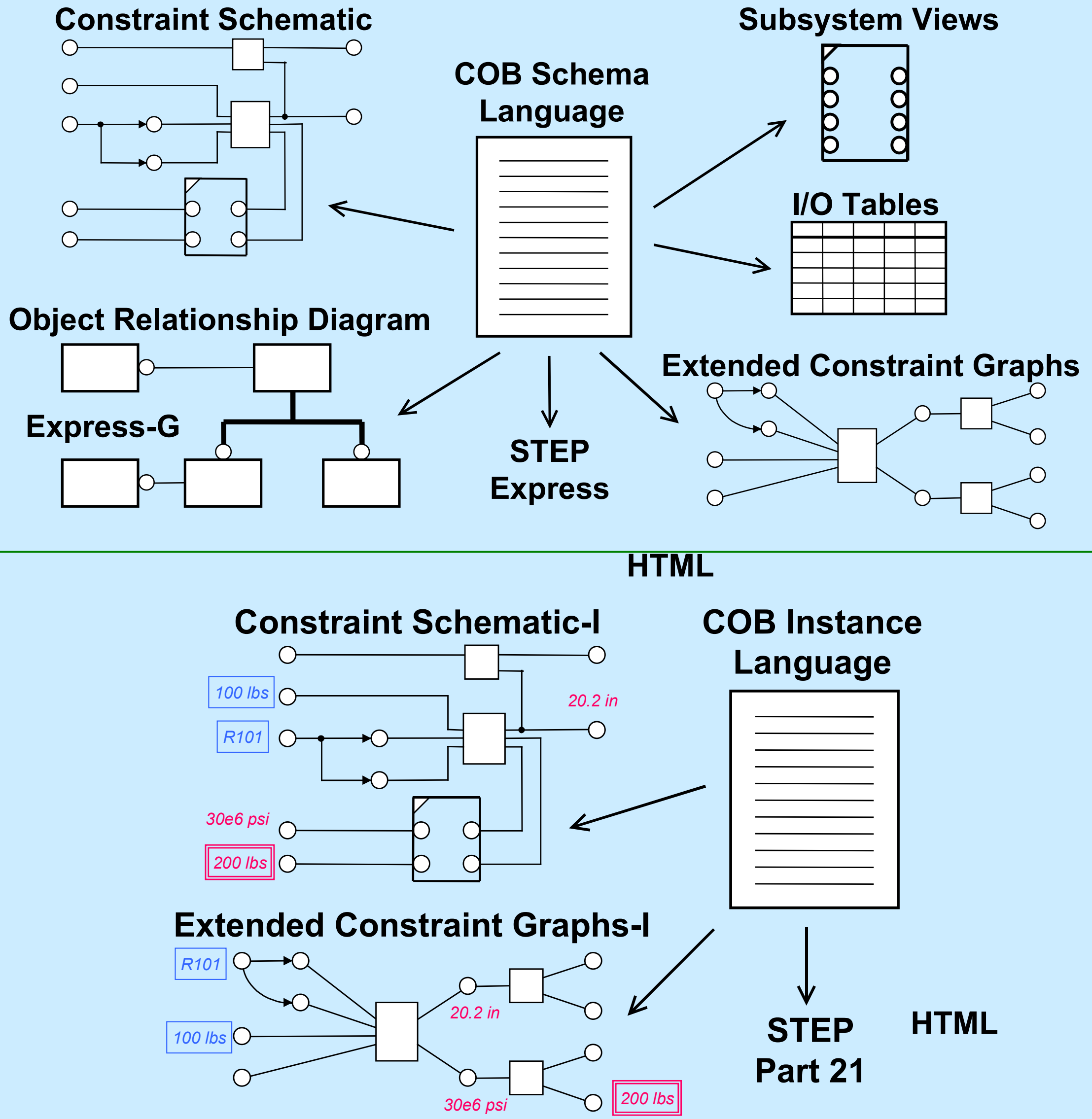


Name	Symbol	Type	Input	Values
root		spring_system		
spring1		spring		
undeformed_length	L₀	REAL	Input	8
spring_constant	k	REAL	Input	5
start	x₁	REAL	Output	0
end0	x₂	REAL	Output	10
length	L	REAL	Output	10
total_elongation	ΔL	REAL	Output	2
force	F	REAL	Output	10
spring2		spring		
undeformed_length	L₀	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

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>	☑

COB Modeling Views



Constraint Schematic

COB Schema Language

Subsystem Views

I/O Tables

Object Relationship Diagram

Express-G

STEP Express

Extended Constraint Graphs

HTML

Constraint Schematic-I

COB Instance Language

Extended Constraint Graphs-I

STEP Part 21

HTML

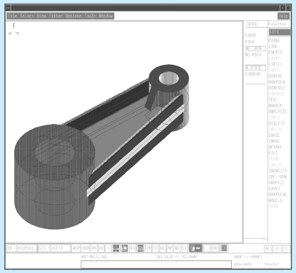
Flexible High Diversity Design-Analysis Integration

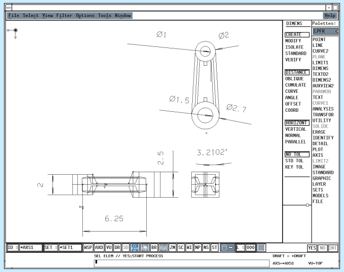
Tutorial Examples: Flap Link (Mechanical/Structural Analysis)

Design Tools

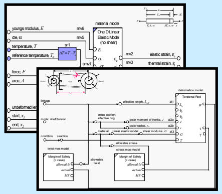
MCAD Tools

CATIA





Materials DB



Modular, Reusable Template Libraries

Analyzable Product Model

XaiTools

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

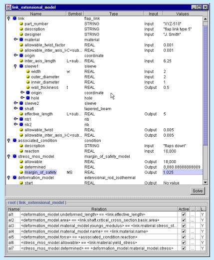
Extension

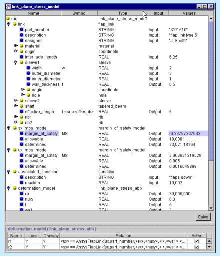
1D, 2D, 3D*

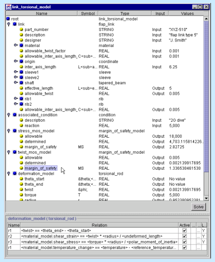
Torsion

1D

XaiTools



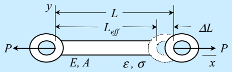




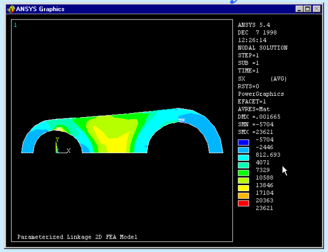
Analysis Tools

General Math

Mathematica



FEA *Ansys*



```
ANSYS 5.4
DEC  7 1998
12:26:14
NODAL SOLUTION
STEP=1
SUB =1
TIME=1
SX        (AVG)
RSYS=0
PowerGraphics
EFACET=1
AVRES=Mat
DMX =.001665
SMN =-5704
SMX =23621
  -5704
  -2446
  812.693
  4071
  7329
  10588
  13846
  17104
  20363
  23621
Parameterized Linkage 2D FEA Model
```

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

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*

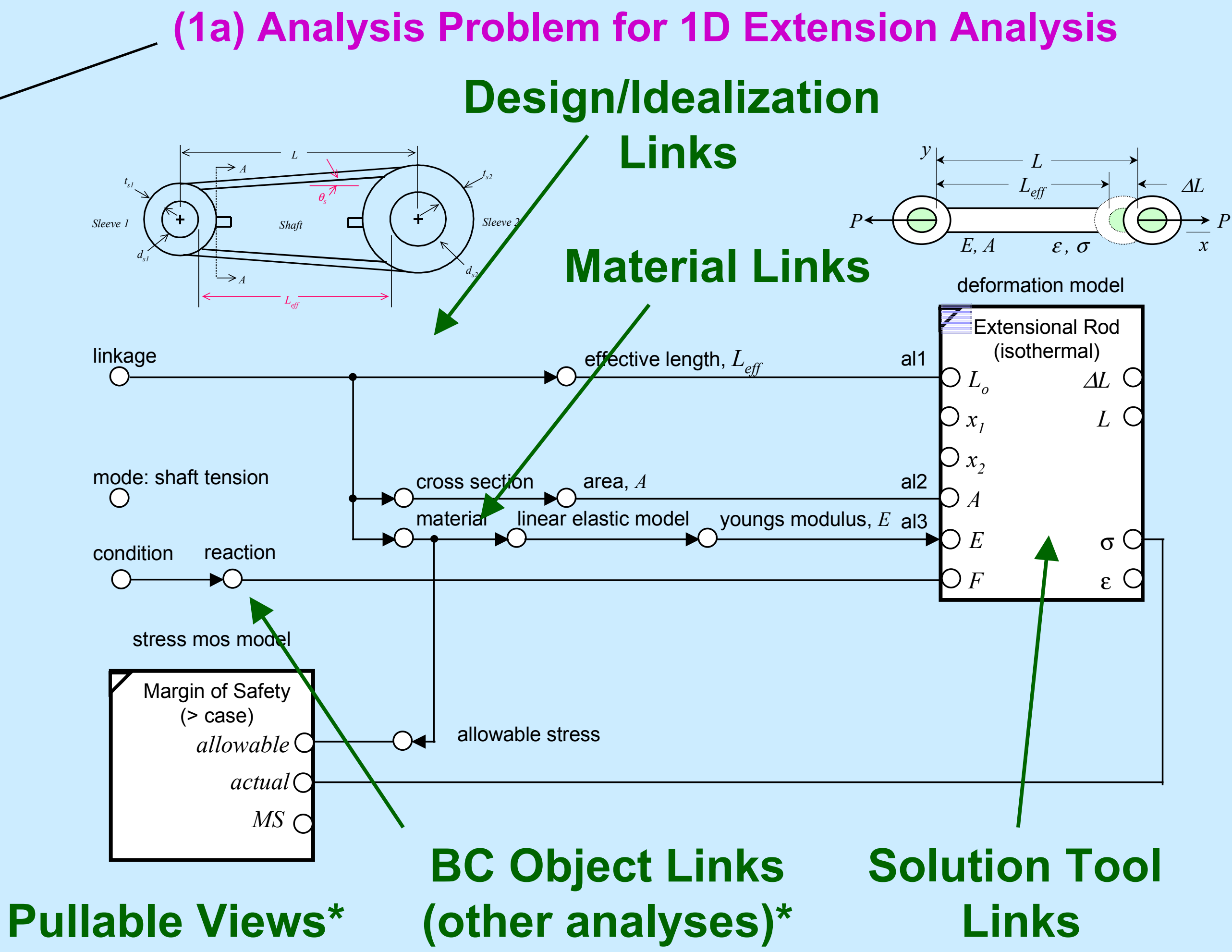
$\sigma_{allowable} =$ 18000 *psi*

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

Design/Idealization Links

Material Links

BC Object Links (other analyses)*

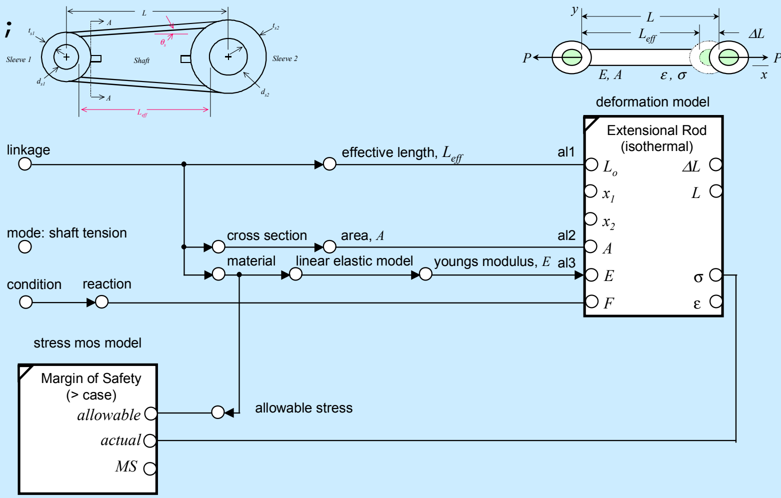
Pullable Views*

Solution Tool Links

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

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;
```

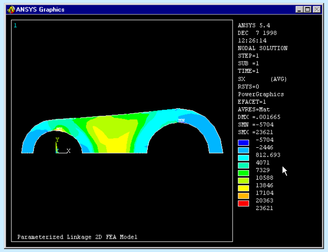


Desired categorization of attributes is shown above (as manually inserted) to support pullable views. Categorization capabilities is a planned XaiTools extension.

FEA-based Analysis Subsystem

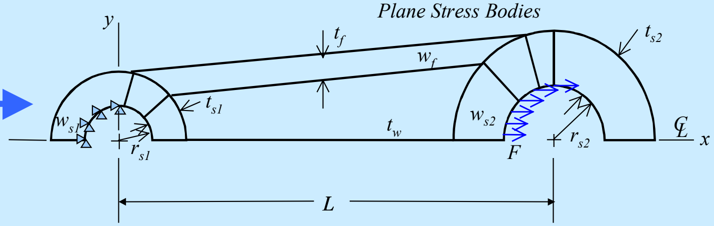
Used in Linkage Plane Stress Model (2D Analysis Problem)

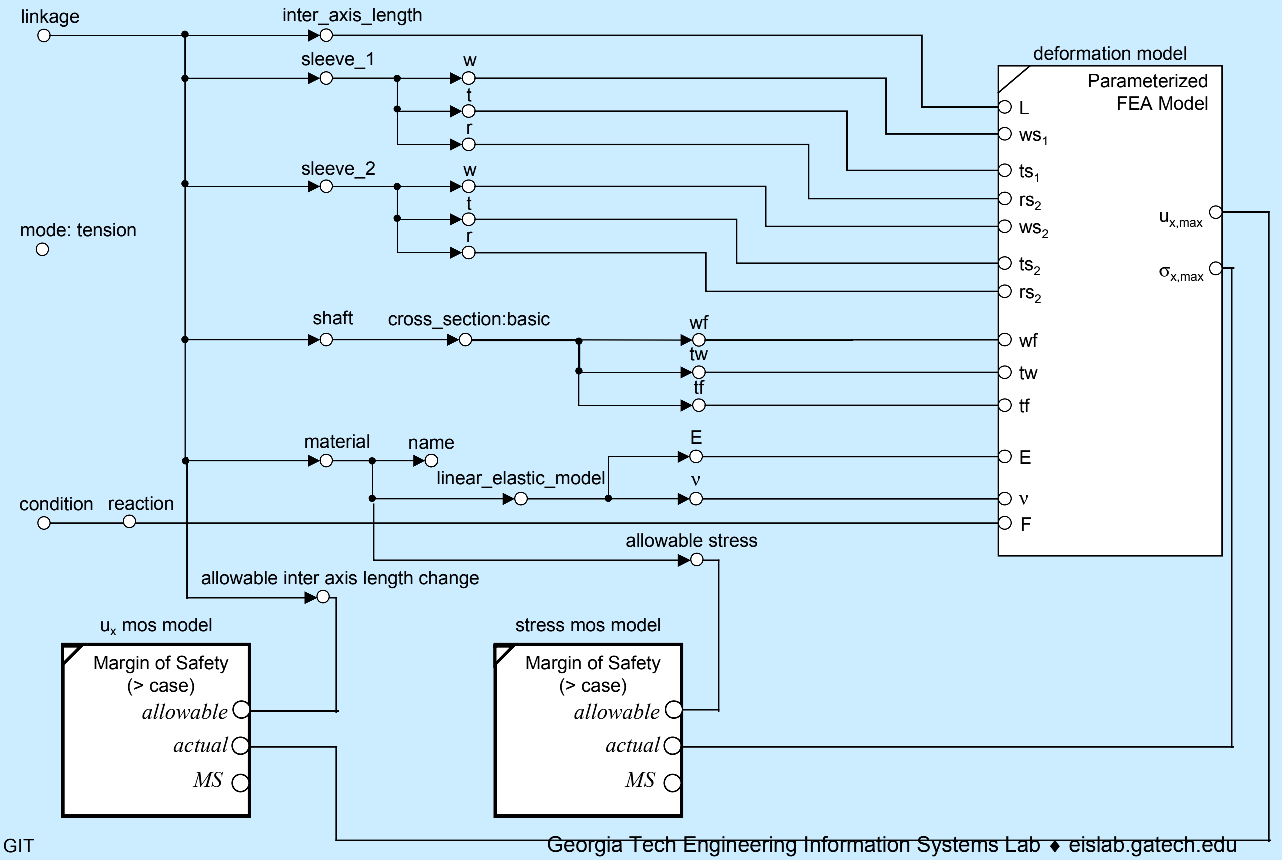
Higher fidelity version
vs. Linkage Extensional Model



```
ANSYS 5.4
DEC  7 1998
12:26:14
NODAL SOLUTION
STEP=1
SUB =1
TIME=1
SX       (AVG)
RSYS=0
PowerGraphics
EFACET=1
AVRES=Mat
DMX =.001665
SMN =-5704
SMX =23621
  -5704
  -2446
  812.693
  4071
  7329
  10588
  13846
  17104
  20363
  23621
```

Parameterized Linkage 2D FEA Model



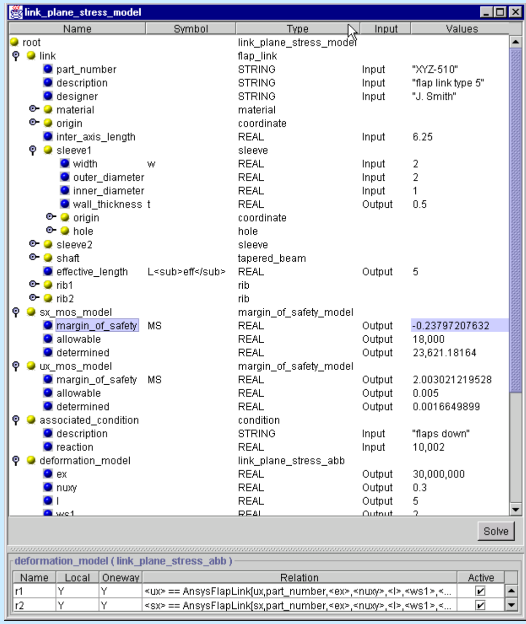


linkage
inter_axis_length
sleeve_1
w
t
r
sleeve_2
w
t
r
mode: tension
shaft
cross_section:basic
wf
tw
tf
material
name
linear_elastic_model
E
ν
condition
reaction
allowable stress
allowable inter axis length change

deformation model
Parameterized FEA Model
L
ws_1
ts_1
rs_2
ws_2
ts_2
rs_2
wf
tw
tf
E
ν
F
$u_{x,max}$
$\sigma_{x,max}$

u_x mos model
Margin of Safety
(> case)
allowable
actual
MS

stress mos model
Margin of Safety
(> case)
allowable
actual
MS



link_plane_stress_model

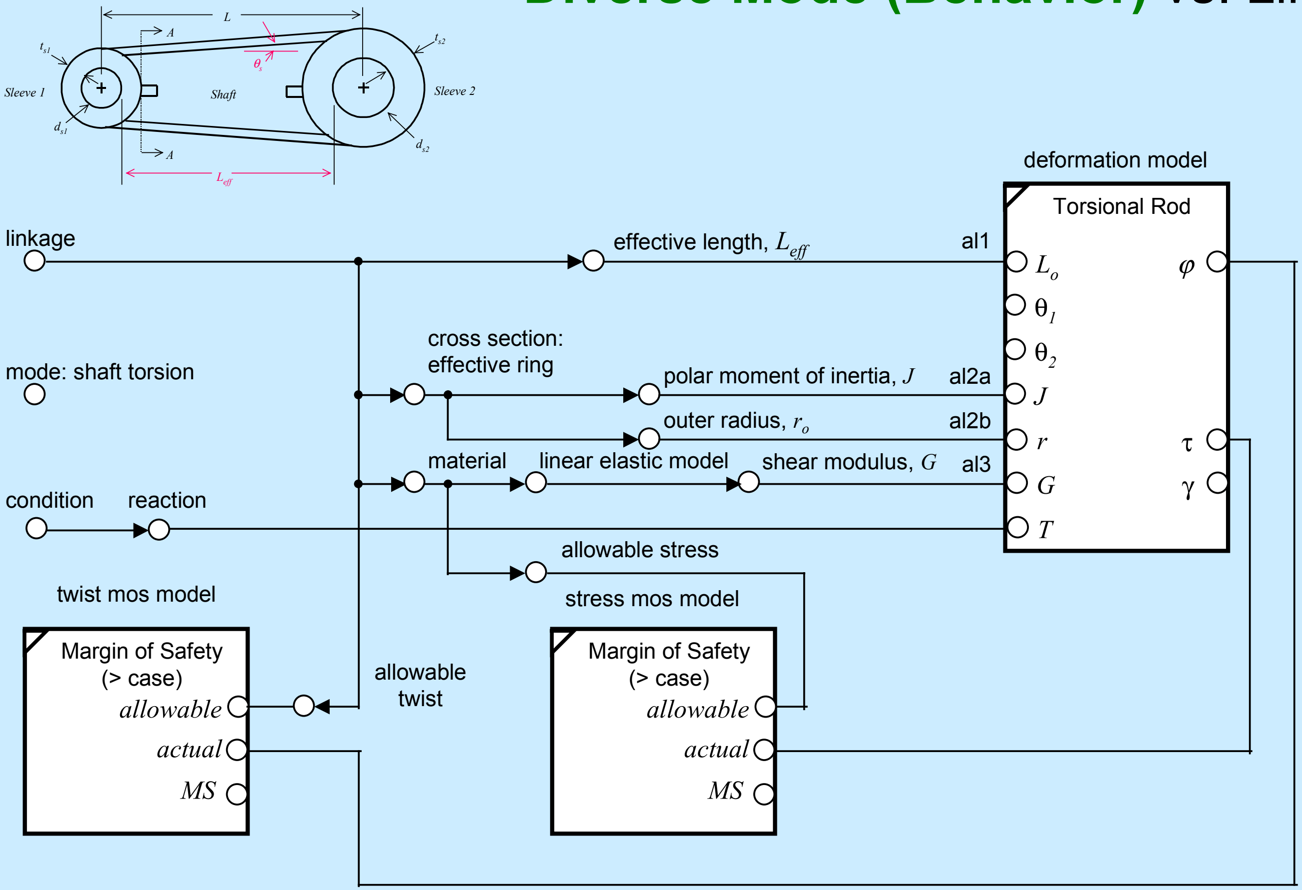
Name	Symbol	Type	Input	Values
root		link_plane_stress_model		
link		flap_link		
part_number		STRING	Input	"XYZ-510"
description		STRING	Input	"flap link type 5"
designer		STRING	Input	"J. Smith"
material		material		
origin		coordinate		
inter_axis_length		REAL	Input	6.25
sleeve1		sleeve		
width	w	REAL	Input	2
outer_diameter		REAL	Input	2
inner_diameter		REAL	Input	1
wall_thickness	t	REAL	Output	0.5
origin		coordinate		
hole		hole		
sleeve2		sleeve		
shaft		tapered_beam		
effective_length	L_{eff}	REAL	Output	5
rib1		rib		
rib2		rib		
sx_mos_model		margin_of_safety_model		
margin_of_safety	MS	REAL	Output	-0.23797207632
allowable		REAL	Output	18,000
determined		REAL	Output	23,621.18164
ux_mos_model		margin_of_safety_model		
margin_of_safety	MS	REAL	Output	2.003021219528
allowable		REAL	Output	0.005
determined		REAL	Output	0.0016649899
associated_condition		condition		
description		STRING	Input	"flaps down"
reaction		REAL	Input	10,002
deformation_model		link_plane_stress_abb		
ex		REAL	Output	30,000,000
nuxy		REAL	Output	0.3
l		REAL	Output	5
ws1		REAL	Output	2

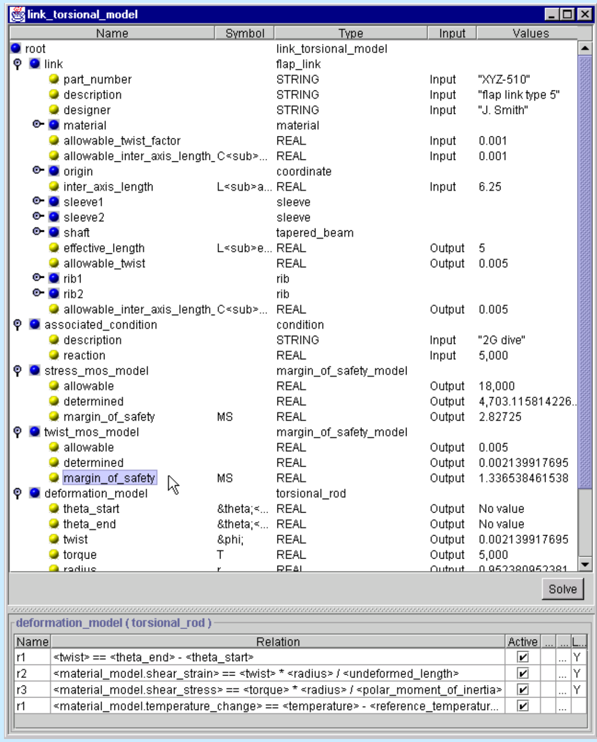
deformation_model (link_plane_stress_abb)

Name	Local	Oneway	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<sub>...	REAL	Input	0.001
origin		coordinate		
inter_axis_length	L<sub>a...	REAL	Input	6.25
sleeve1		sleeve		
sleeve2		sleeve		
shaft		tapered_beam		
effective_length	L<sub>e...	REAL	Output	5
allowable_twist		REAL	Output	0.005
rib1		rib		
rib2		rib		
allowable_inter_axis_length_	C<sub>...	REAL	Output	0.005
associated_condition		condition		
description		STRING	Input	"2G dive"
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<...	REAL	Output	No value
theta_end	θ<...	REAL	Output	No value
twist	φ	REAL	Output	0.002139917695
torque	T	REAL	Output	5,000
radius	r	REAL	Output	0.952380952381

deformation_model (torsional_rod)

Name	Relation	Active	...	...	L...
r1	<twist> == <theta_end> - <theta_start>	☑		...	Y
r2	<material_model.shear_strain> == <twist> * <radius> / <undeformed_length>	☑		...	Y
r3	<material_model.shear_stress> == <torque> * <radius> / <polar_moment_of_inertia>	☑		...	Y
r1	<material_model.temperature_change> == <temperature> - <reference_temperatur...	☑		...	

Today’s Typical Analysis Catalogs

paper-oriented, no associativity

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

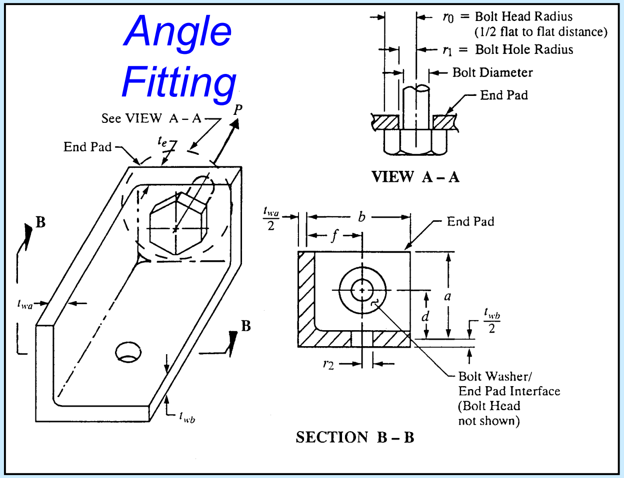
Step 1: Actual shear stress is

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

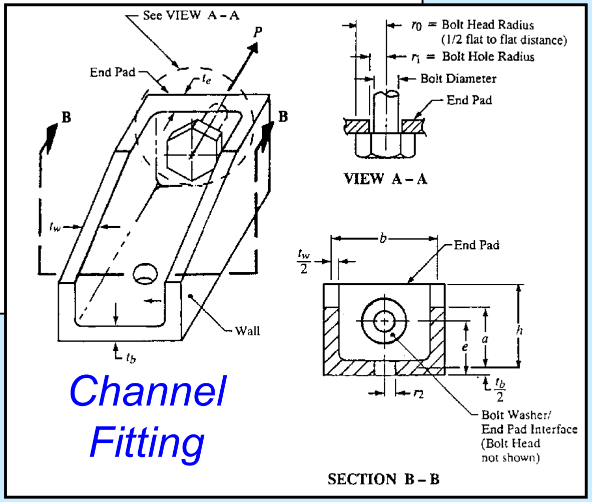
Step 2: The margin of safety is

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

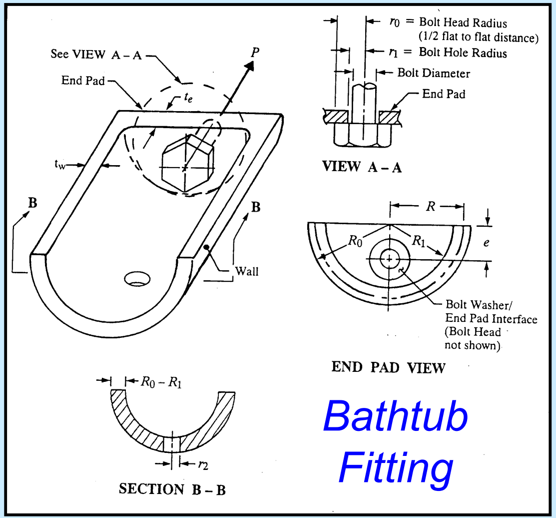
Categories of Idealized Fittings



Angle Fitting



Channel Fitting



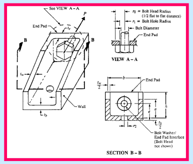
Bathtub Fitting

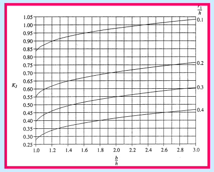
Transformation into Object-Oriented Hierarchy of ABBs

* = Working Examples

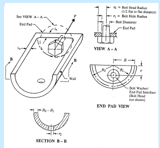
- ABB
  - Specialized Analysis Body
    - Fitting Casing Body
      - Channel Fitting Casing Body*
      - Open Wall Fitting Casing Body
        - Bathtub Fitting Casing Body
        - Angle Fitting Casing Body
    - Fitting Washer Body
    - Fitting Bolt Body*
  - Specialized Analysis System
    - Fitting System ABB
      - Fitting End Pad ABB
        - Fitting End Pad Bending ABB
          - Open Wall Fitting End Pad Bending ABB
          - Channel Fitting End Pad Bending ABB*
        - Fitting End Pad Shear ABB*
      - Fitting Wall ABB

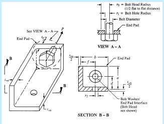
Fitting System ABB: casing → Fitting Casing Body; washer → Fitting Washer Body; bolt → Fitting Bolt Body*; load → P





$K_3 = f(r_1, b, h)$

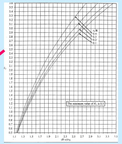




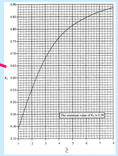
$t_w = \min(t_{wa}, t_{wb})$

$R = \frac{a+b}{\pi}$

$e = R - \frac{f+d}{2}$



$K_1 = f(r_1, R, r_0, e)$



$K_2 = f(t_e, t_w)$

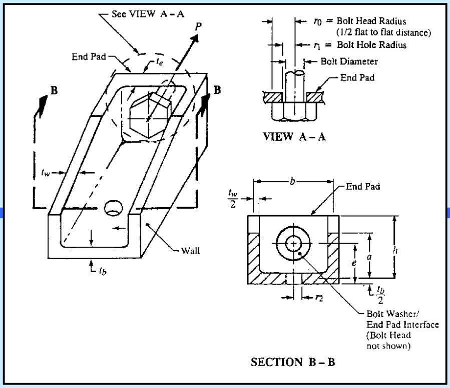
$f_{be} = C_1 \frac{P}{h t_e^2}$

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

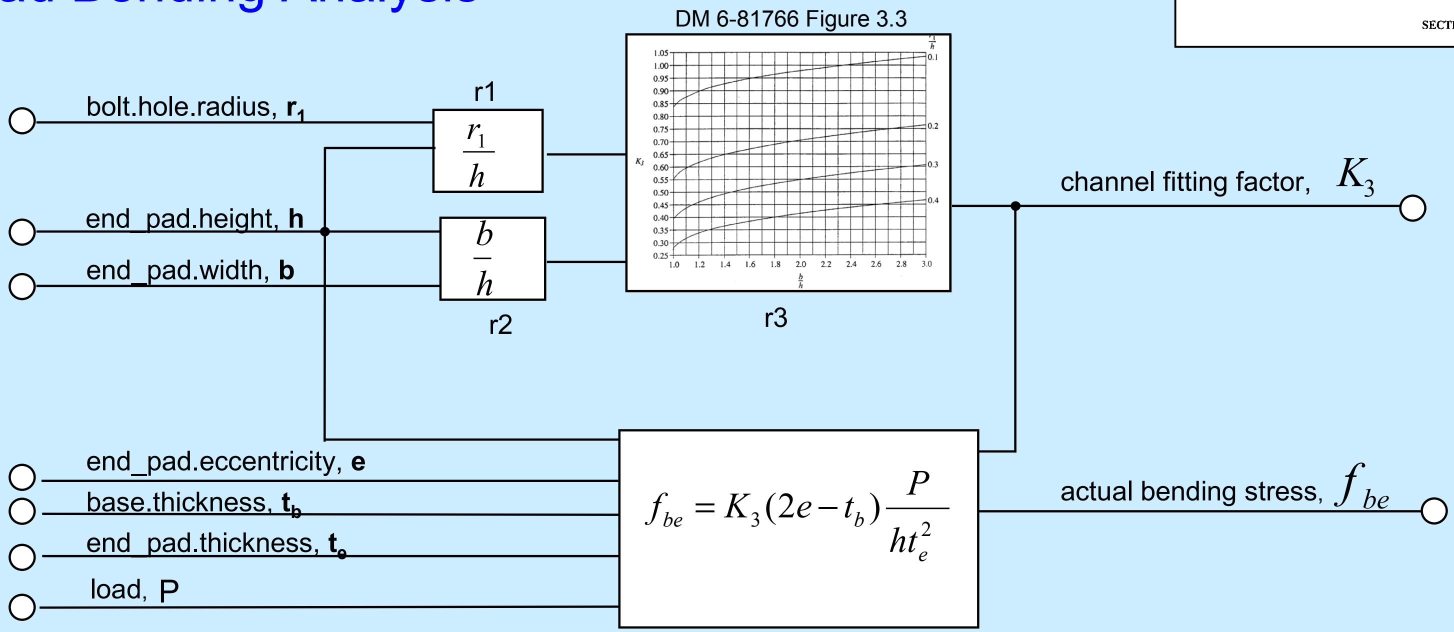
$C_l = K_1 K_2$

$C_l = K_3(2e - t_b)$

Channel Fitting System ABBs



End Pad Bending Analysis



bolt.hole.radius, $\mathbf{r_1}$

end_pad.height, **h**

end_pad.width, **b**

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

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

r3

channel fitting factor, K_3

end_pad.eccentricity, **e**

base.thickness, $\mathbf{t_b}$

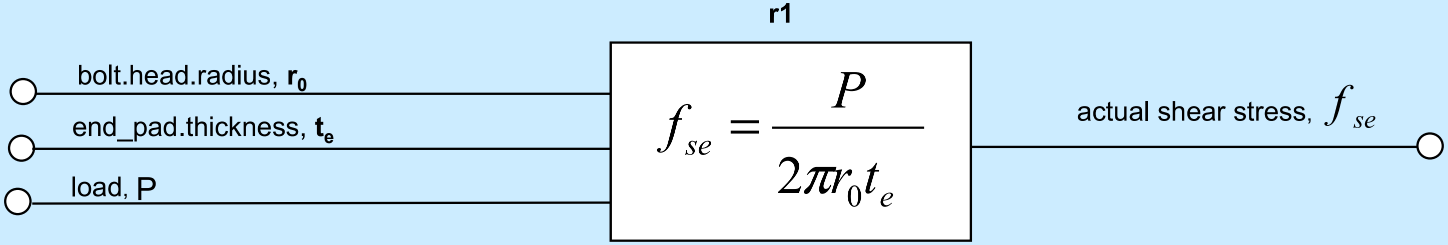
end_pad.thickness, $\mathbf{t_e}$

load, P

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

actual bending stress, f_{be}

End Pad Shear Analysis



r1

bolt.head.radius, $\mathbf{r_0}$

end_pad.thickness, $\mathbf{t_e}$

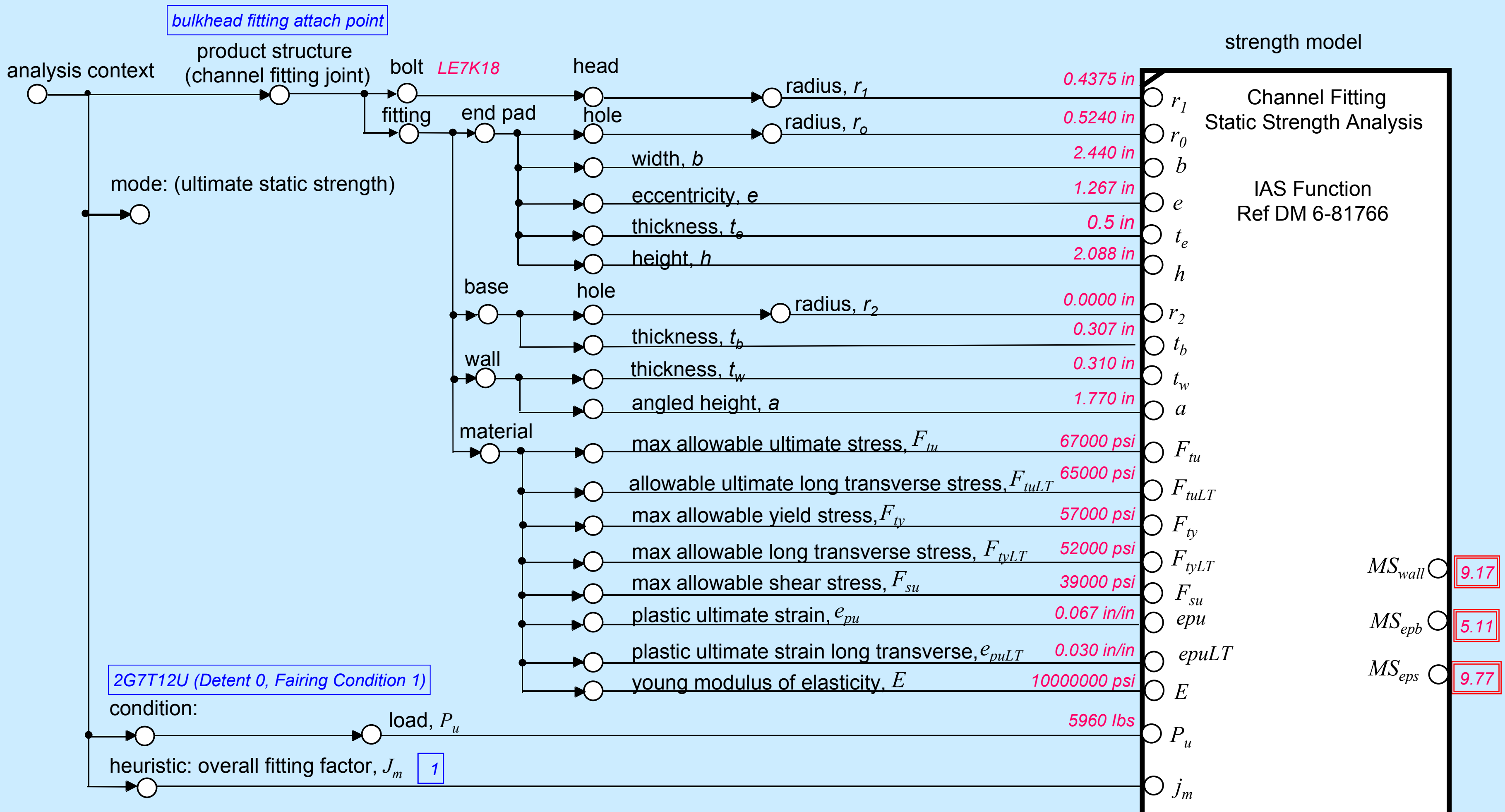
load, P

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

actual shear stress, f_{se}

Reusable Fitting Analysis Module (CBAM)

with explicit design associativity



bulkhead fitting attach point

analysis context

product structure
(channel fitting joint)

bolt *LE7K18*

head

radius, r_1 — 0.4375 in — r_1

fitting

end pad

hole

radius, r_o — 0.5240 in — r_0

width, b — 2.440 in — b

mode: (ultimate static strength)

eccentricity, e — 1.267 in — e

thickness, t_e — 0.5 in — t_e

height, h — 2.088 in — h

base

hole

radius, r_2 — 0.0000 in — r_2

thickness, t_b — 0.307 in — t_b

wall

thickness, t_w — 0.310 in — t_w

angled height, a — 1.770 in — a

material

max allowable ultimate stress, F_{tu} — 67000 psi — F_{tu}

allowable ultimate long transverse stress, F_{tuLT} — 65000 psi — F_{tuLT}

max allowable yield stress, F_{ty} — 57000 psi — F_{ty}

max allowable long transverse stress, F_{tyLT} — 52000 psi — F_{tyLT}

max allowable shear stress, F_{su} — 39000 psi — F_{su}

plastic ultimate strain, e_{pu} — 0.067 in/in — epu

plastic ultimate strain long transverse, e_{puLT} — 0.030 in/in — epuLT

young modulus of elasticity, E — 10000000 psi — E

2G7T12U (Detent 0, Fairing Condition 1)

condition:

load, P_u — 5960 lbs — P_u

heuristic: overall fitting factor, J_m — 1 — j_m

strength model

Channel Fitting
Static Strength Analysis

IAS Function
Ref DM 6-81766

MS_{wall} — 9.17

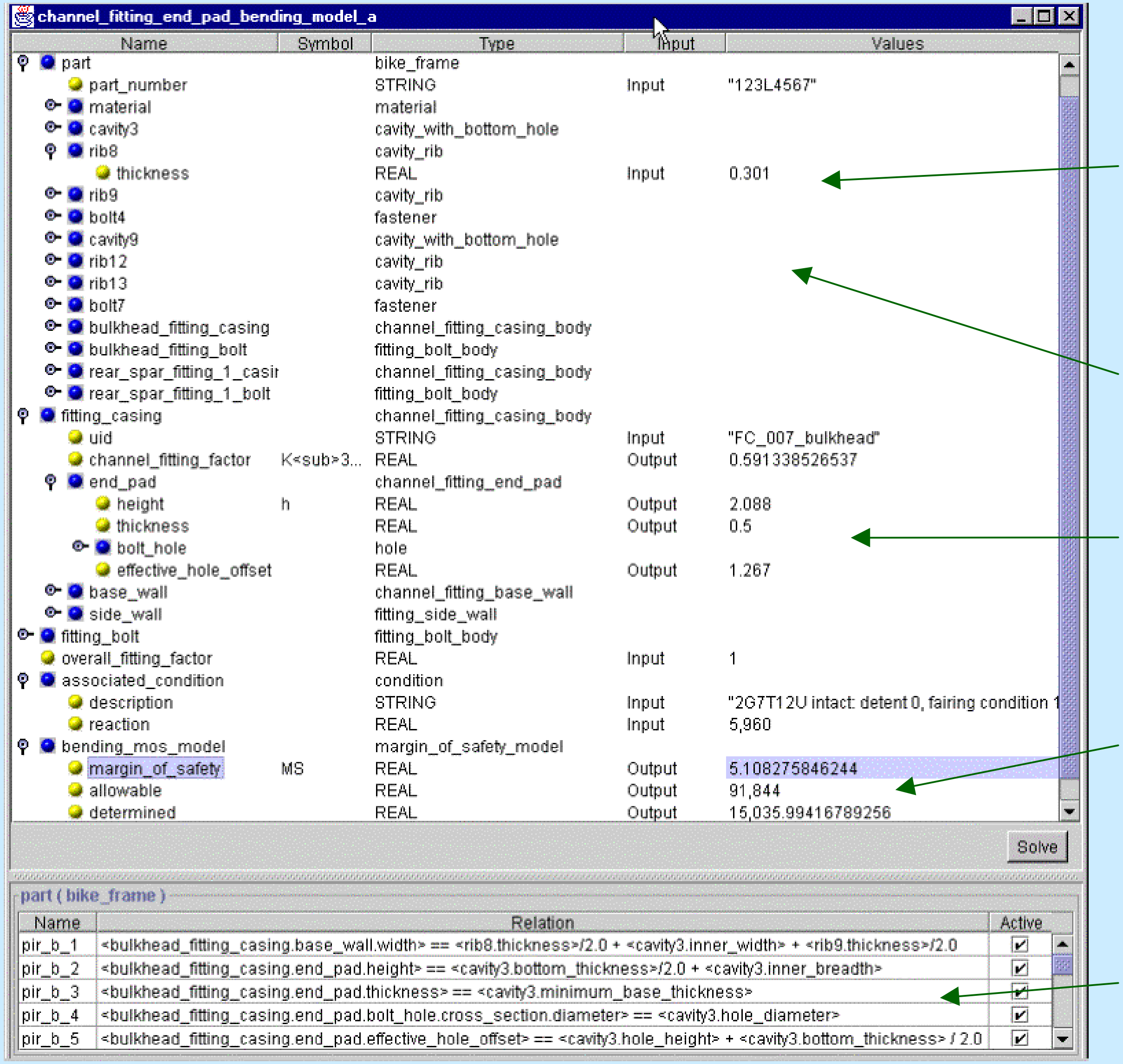
MS_{epb} — 5.11

MS_{eps} — 9.77

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 Module in *XaiTools*

Integration Focal Point



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_casir		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<sub>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

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	☑
pir_b_2	<bulkhead_fitting_casing.end_pad.height> == <cavity3.bottom_thickness>/2.0 + <cavity3.inner_breadth>	☑
pir_b_3	<bulkhead_fitting_casing.end_pad.thickness> == <cavity3.minimum_base_thickness>	☑
pir_b_4	<bulkhead_fitting_casing.end_pad.bolt_hole.cross_section.diameter> == <cavity3.hole_diameter>	☑
pir_b_5	<bulkhead_fitting_casing.end_pad.effective_hole_offset> == <cavity3.hole_height> + <cavity3.bottom_thickness> / 2.0	☑

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

Constrained Object Language (COBs)

- Capabilities & features:
  - Various forms: computable lexical form, graphical form, etc.
  - Sub/supertypes, basic aggregates, multi-fidelity objects
  - Multi-directionality (I/O change)
  - Wrapping external programs as white box relations
- Analysis module/template applications:
  - Product model idealizations
  - Explicit associativity relations with design models & other analyses
  - White box reuse of existing tools (e.g., FEA, in-house codes)
  - Reusable, adaptable analysis building blocks
  - Synthesis (sizing) and verification (analysis)

Constrained Object Language (cont.)

- Overall characteristics
  - Declarative knowledge representation
  - Combining object & constraint graph techniques
  - COBs = (STEP EXPRESS subset) + (constraint concepts & views)
  - Advantages over traditional analysis representations:
    - Greater solution control
    - Richer semantics (e.g., equations wrapped in engineering context)
    - Capture of reusable knowledge
- Further needs …
  - Higher order constraints
  - Hybrid declarative/procedural approaches
  - Etc.

Summary

- Emphasis on X-analysis integration (XAI) for design reuse (DAI,SBD)
- Multi-Representation Architecture (MRA)
  - Addressing fundamental XAI/DAI issues:
    - Multi-fidelity, multi-directional, fine-grained associativity, etc.
  - General methodology --> Flexibility & broad application
- Research advances & applications
  - Product data-driven analysis (STEP AP210, GenCAM, etc.)
  - Internet-based engineering service bureau (ESB) techniques
  - Object techniques for next-generation aerospace analysis systems
  - ~10:1 analysis time reduction in pilot tests (chip packages)
- Tools and development services
  - Analysis integration toolkit: *XaiTools Framework* and applications
  - Pilot commercial ESB: U-Engineer.com
  - Company-tailored engineering information system solutions
- Motivated by industry & government collaboration

Selected Tools and Services

offered via Georgia Tech Research Corp.

http://eislab.gatech.edu/

- *XaiTools Framework*™
  - General-purpose analysis integration toolkit
- Product-Specific Toolkits
  - *XaiTools PWA-B*™
  - *XaiTools ChipPackage*™

- *U-Engineer.com*™
  - Internet-based engineering service bureau (ESB)
  - Self-serve analysis modules ↔ Full-serve consulting
- Research, Development, and Consulting
  - Analysis integration & optimization
  - Product-specific analysis module catalogs
  - Internet-based ESB development
  - Engineering information technology
    - » PDM, STEP, GenCAM, XML, UML, Java, CORBA, Internet, …
  - CAD/CAE/CAM, FEA, thermal & mechanical analysis

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/tools/XaiTools/*
- 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