Static Analysis of a Clothes Hanger

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Bajinder Singh, Misbah Syeda

AGENDA:

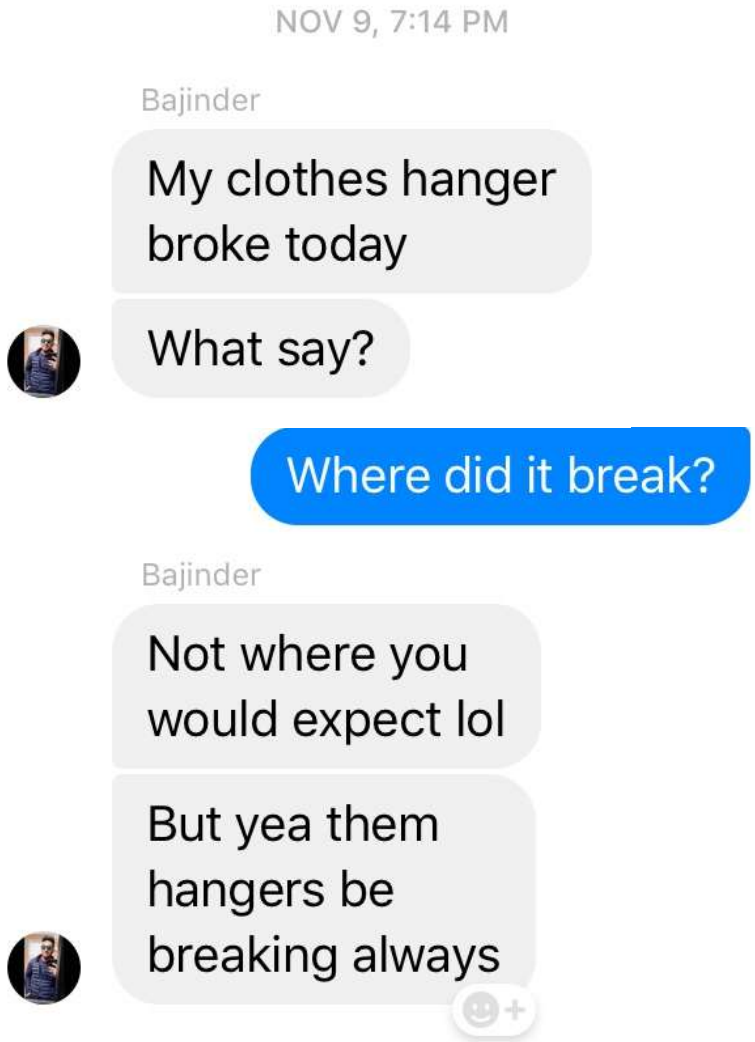
Introduction, Experiments
Jamaal

Geometry, Boundary Conditions, Mesh, Results
Misbah

Results, Geometry Adjustment
Alisa

Sources of Problems, Design Implications, Conclusion
Bajinder

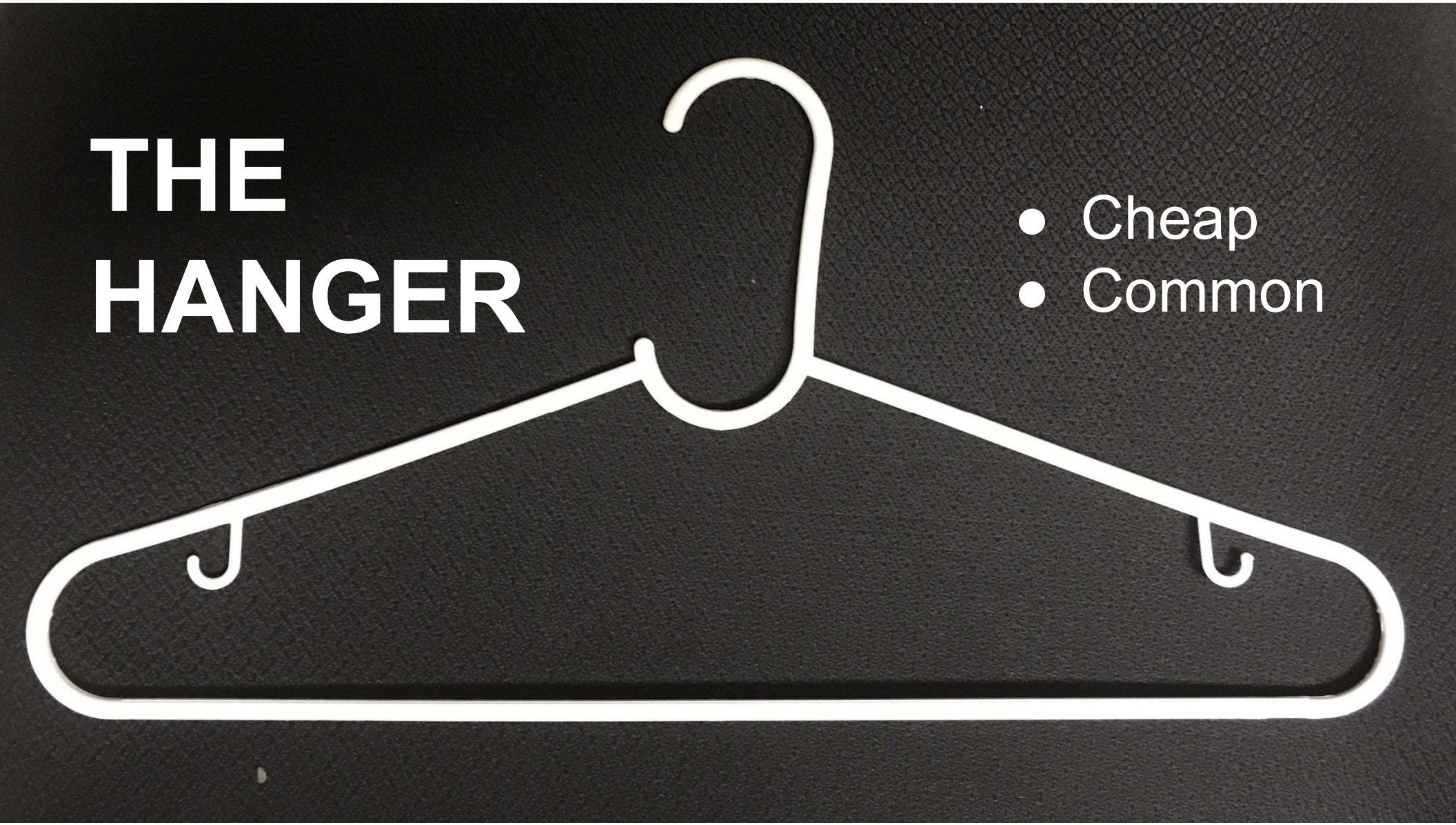
It all started when Bajinder broke his hanger…



PROBLEM STATEMENT

Do hangers break very easily or are we just bad users of hangers?

THE HANGER



- Cheap
- Common

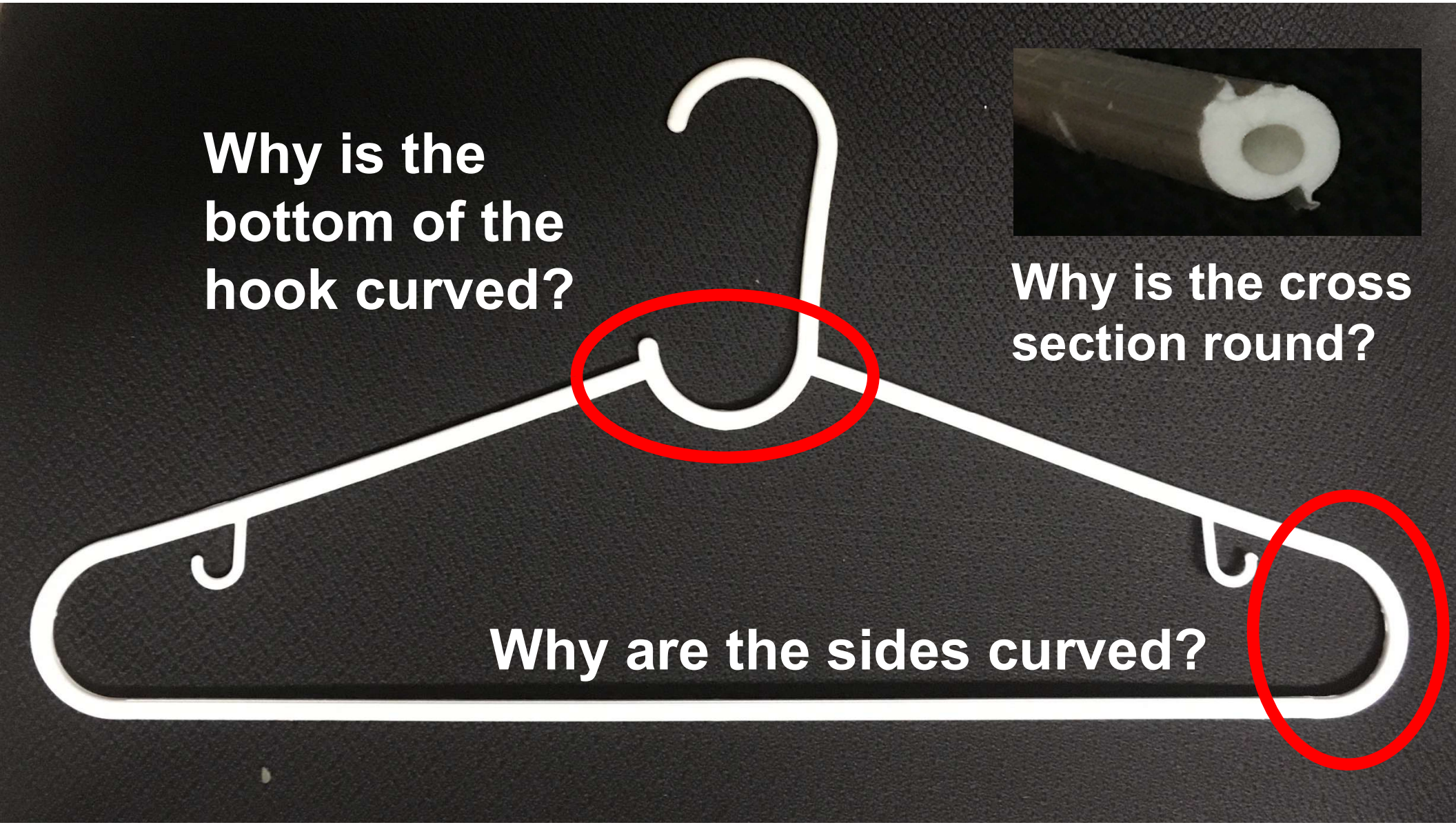
Material Properties

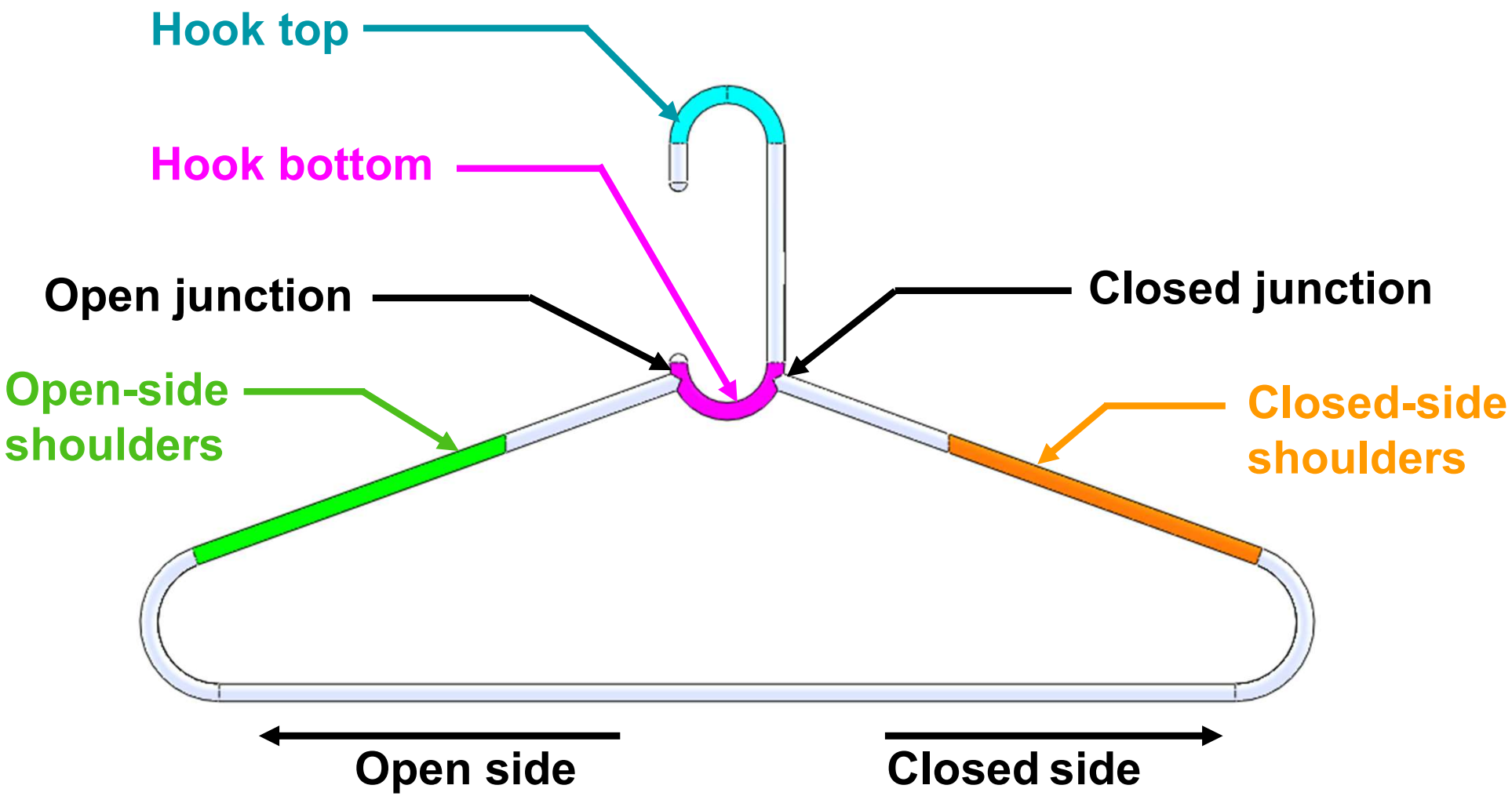
POLYSTYRENE

- Cheap, Hard, Easy to mold
- Brittle: fails by fracture
- Tensile Strength (MatWeb): 35 MPa

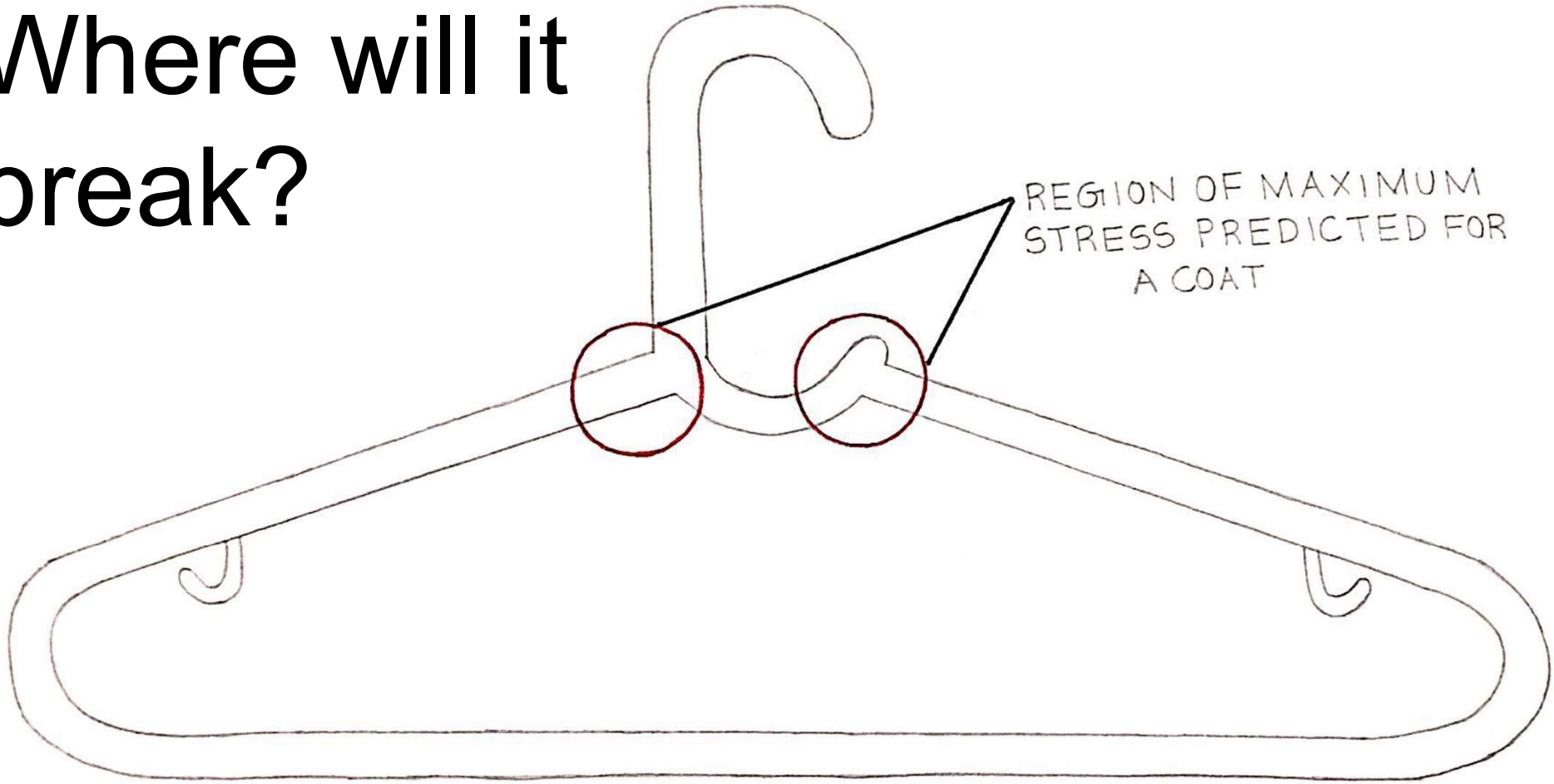
HANGER USER MANUAL

Operating weight:
(1 Heavy Jacket ≈ 2 kg)


Why is the bottom of the hook curved?
Why is the cross section round?
Why are the sides curved?


Hook top
Hook bottom
Open junction
Closed junction
Open-side shoulders
Closed-side shoulders
Open side
Closed side

Where will it break?

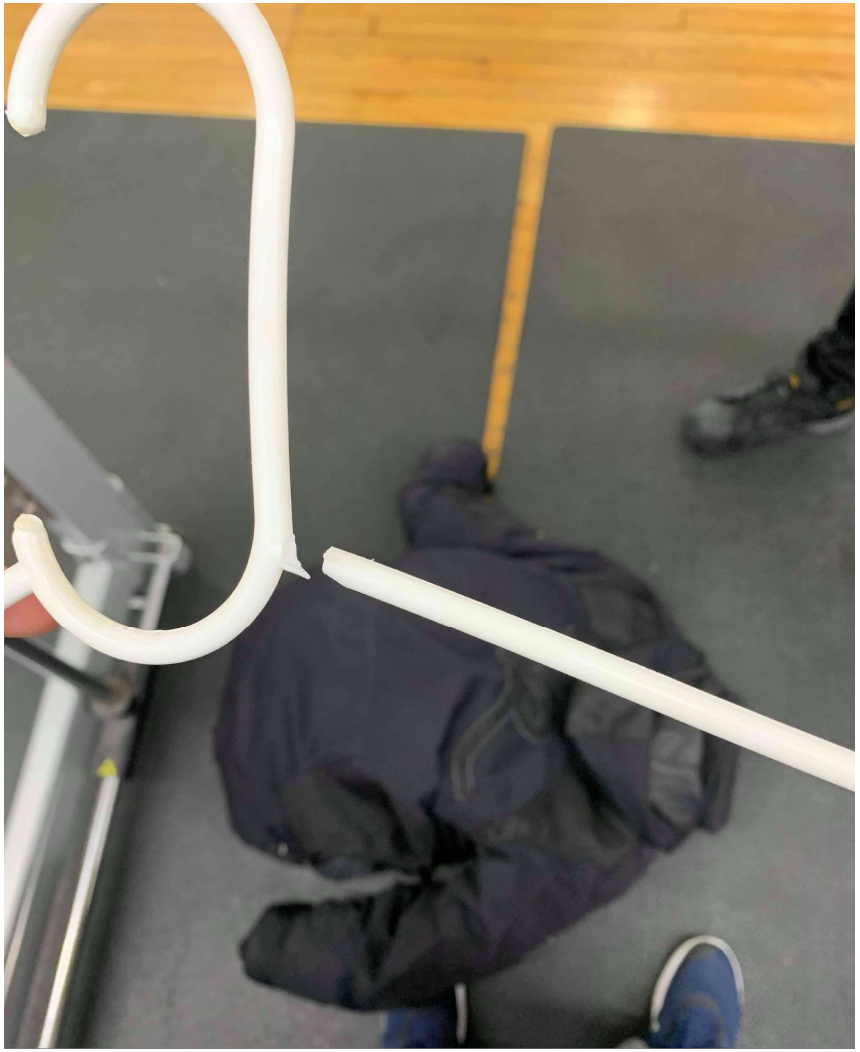


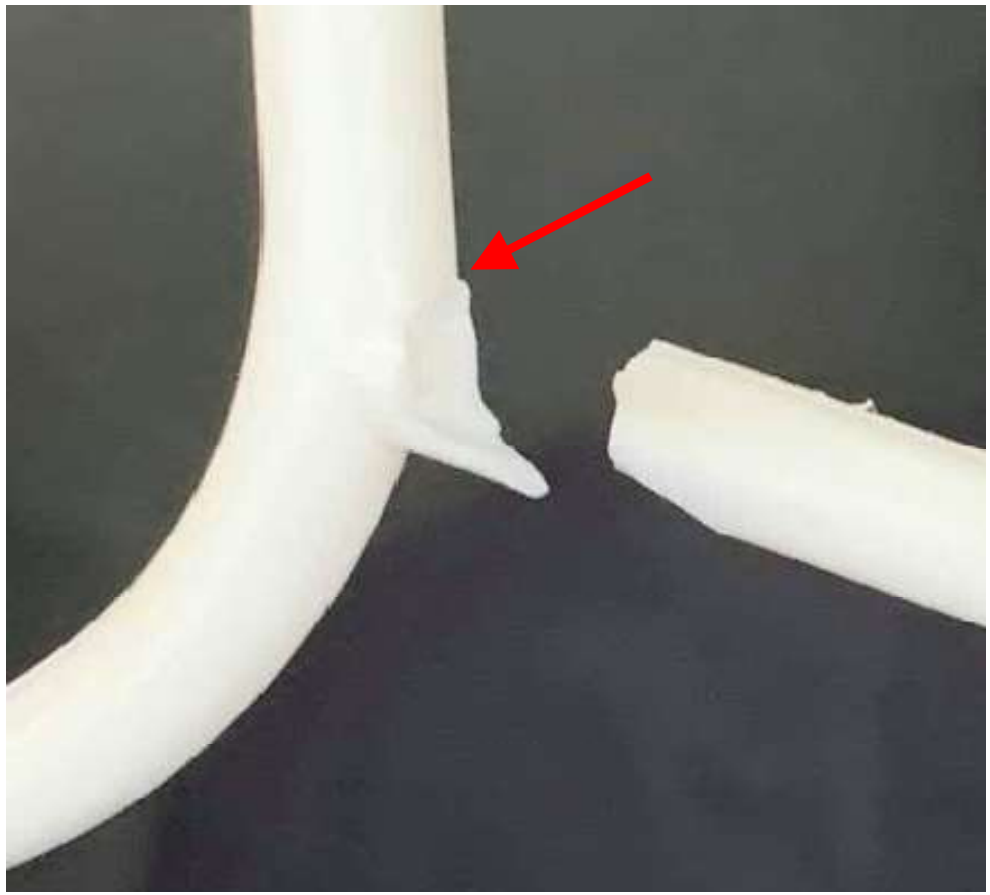
Experiments

Uneven load to balance hanger

Jacket (1.7 kg)

Jacket + weights in pocket (6.1 kg)





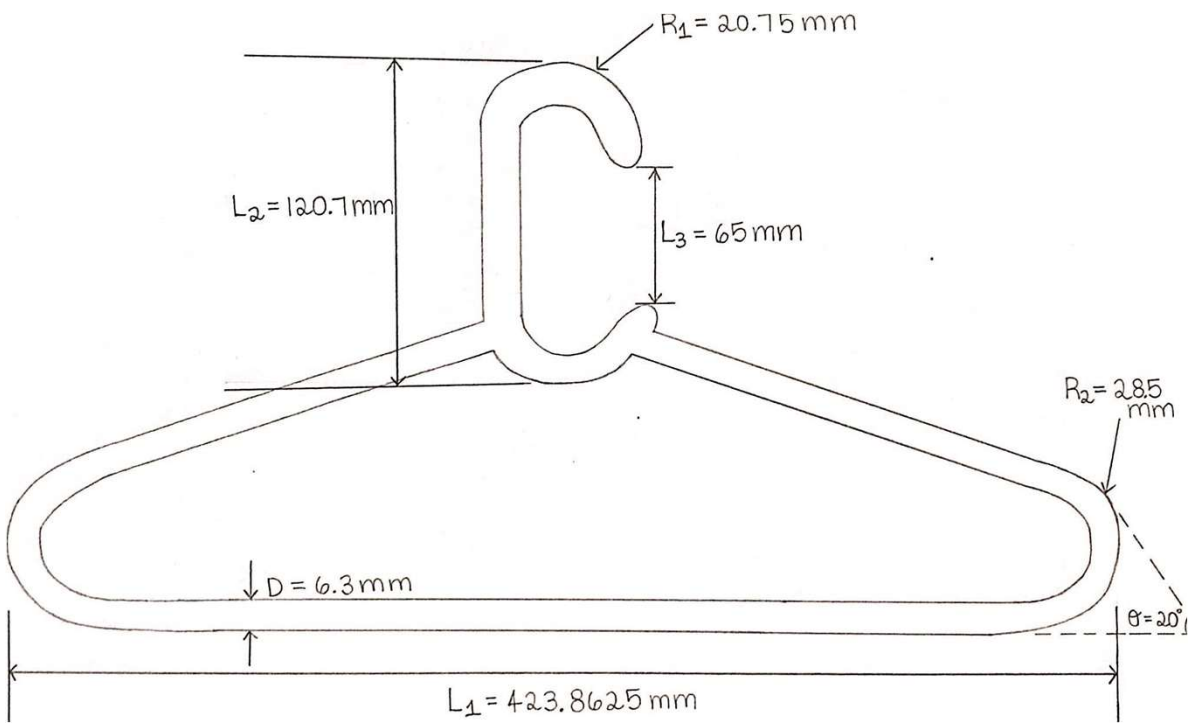
Brittle fracture by tension

Why use computer simulations if we can experiment in real life?

- We can determine the stress
- We can make design changes

Geometry

MEASUREMENTS

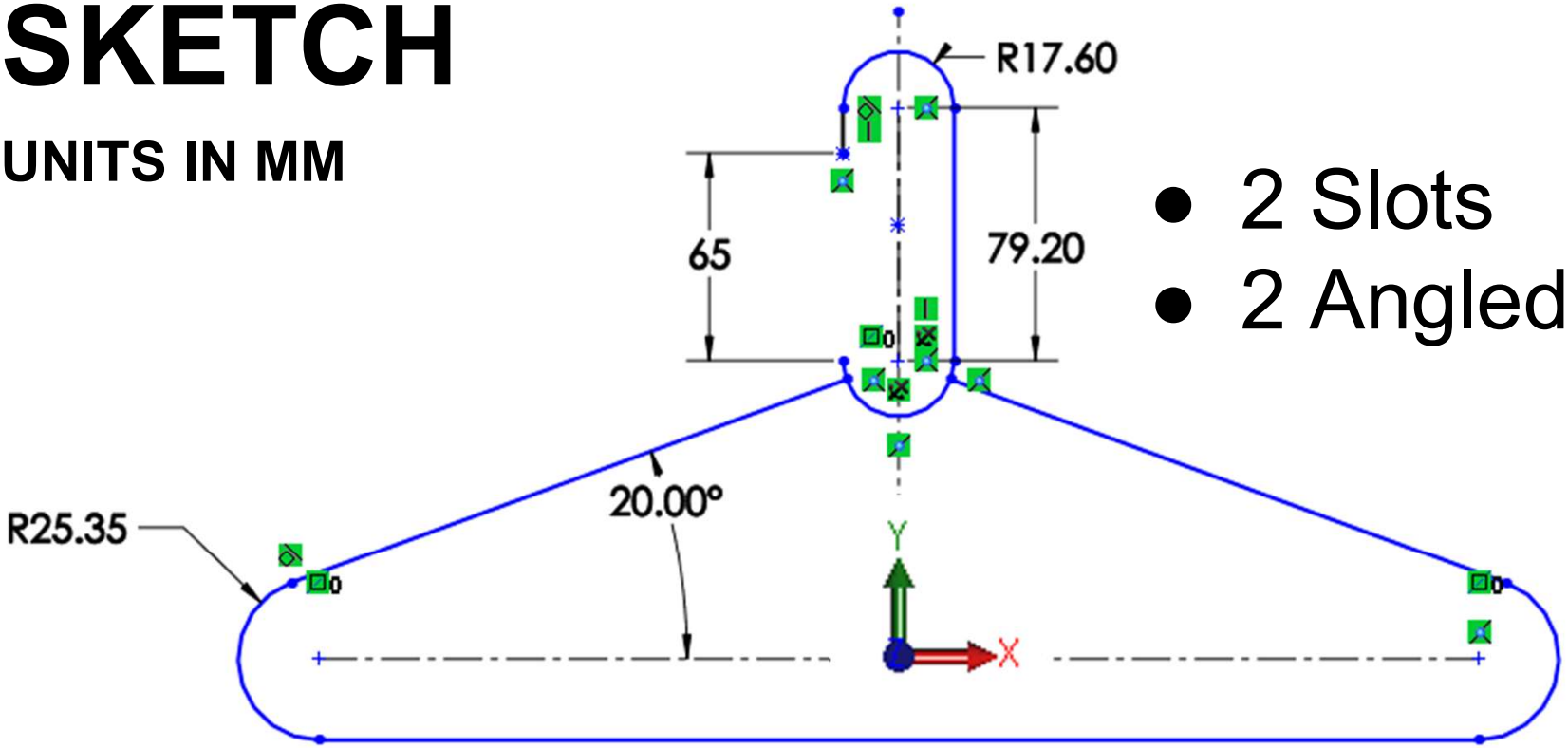


ASSUMPTION

- Vertically symmetric (except for the hook opening)

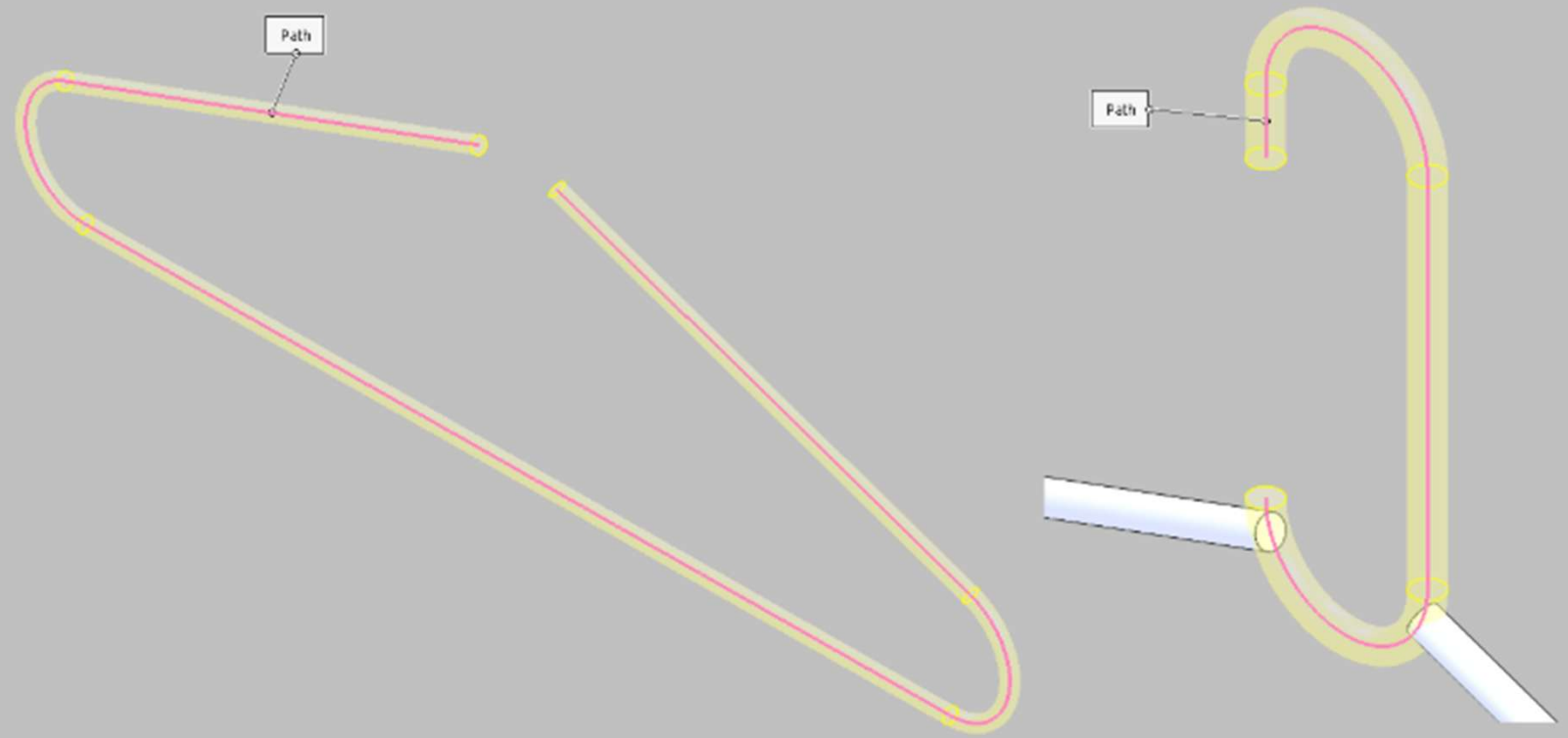
SKETCH

UNITS IN MM

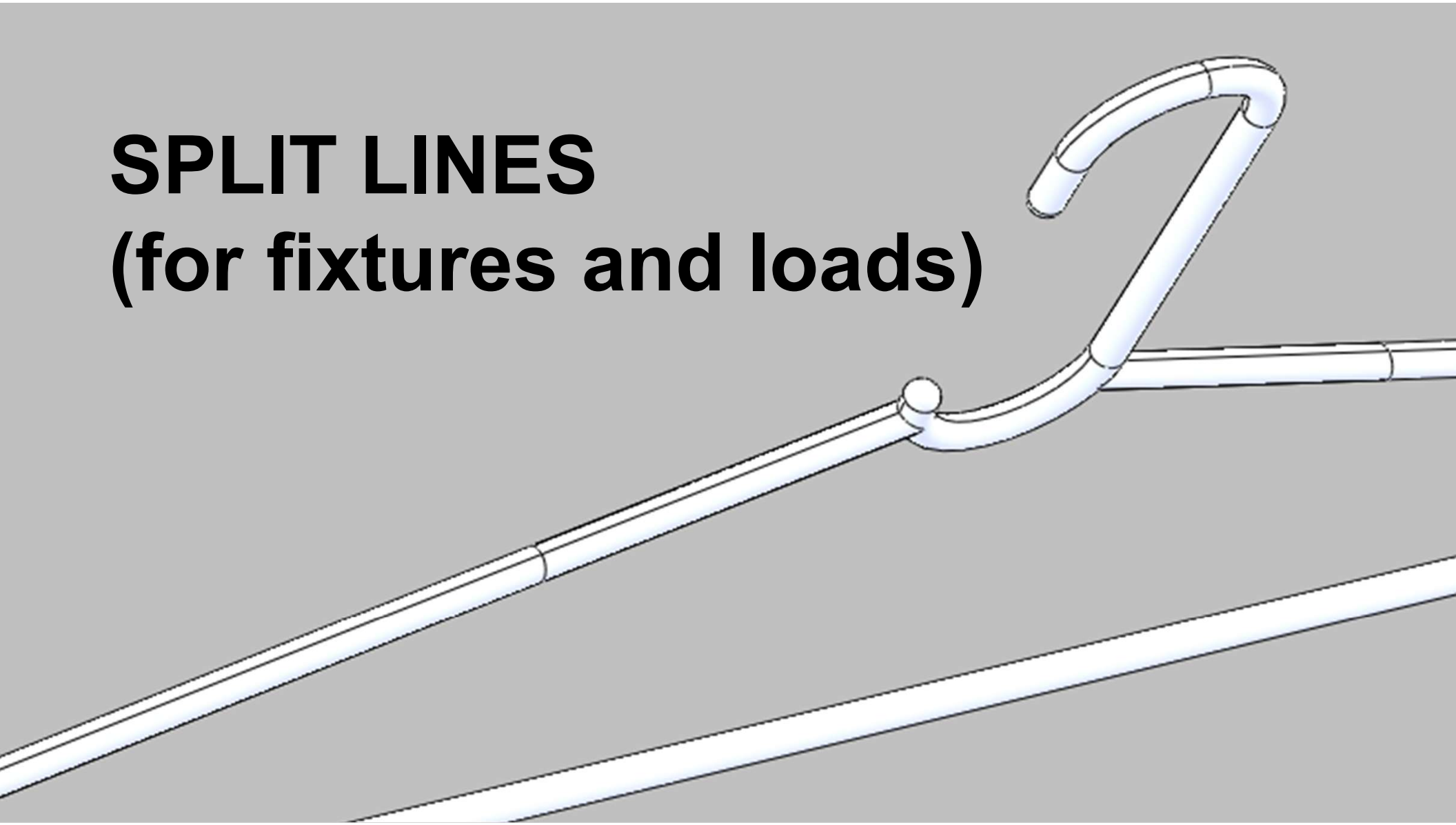


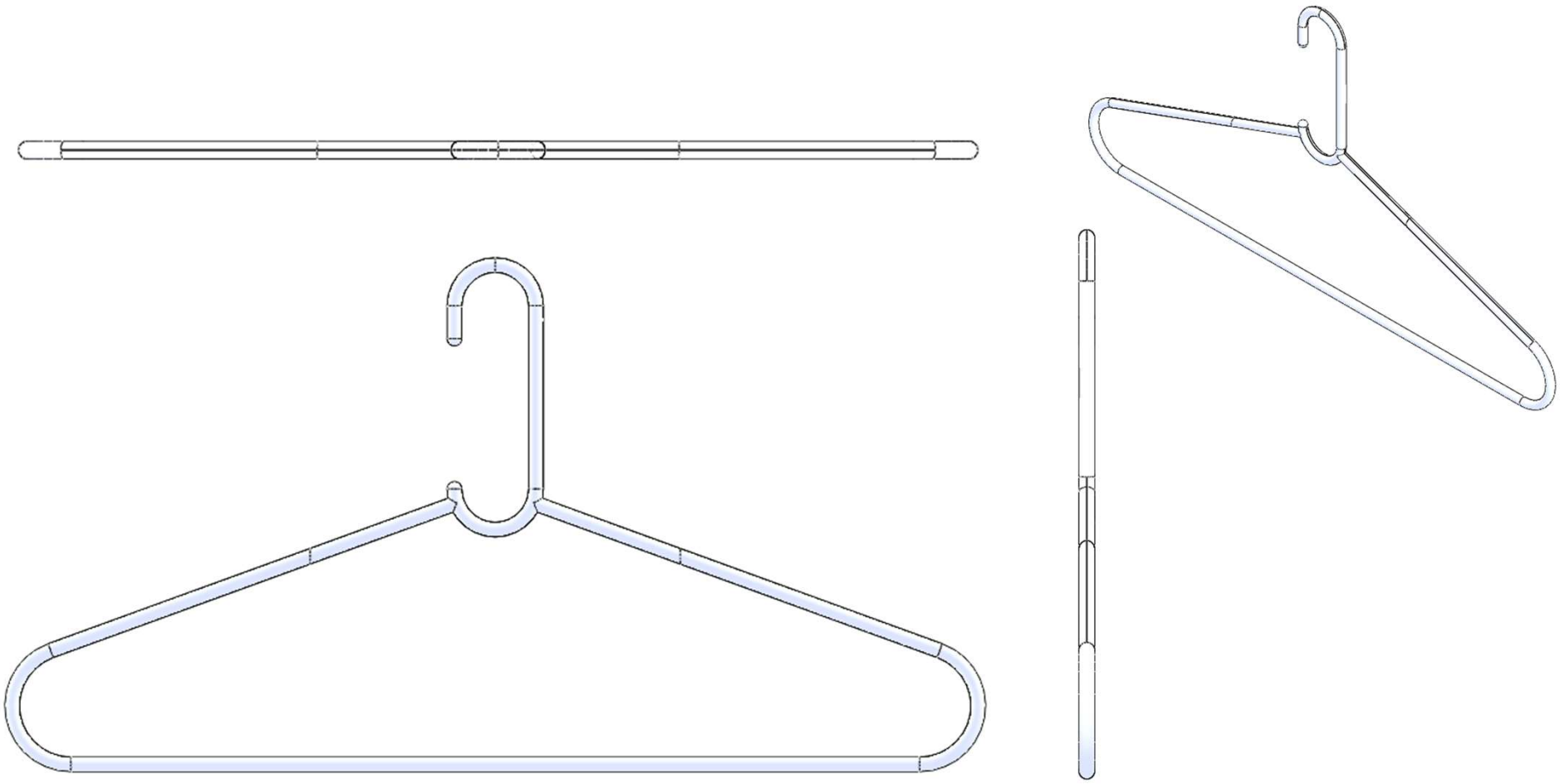
- 2 Slots
- 2 Angled lines

CIRCULAR SWEEP

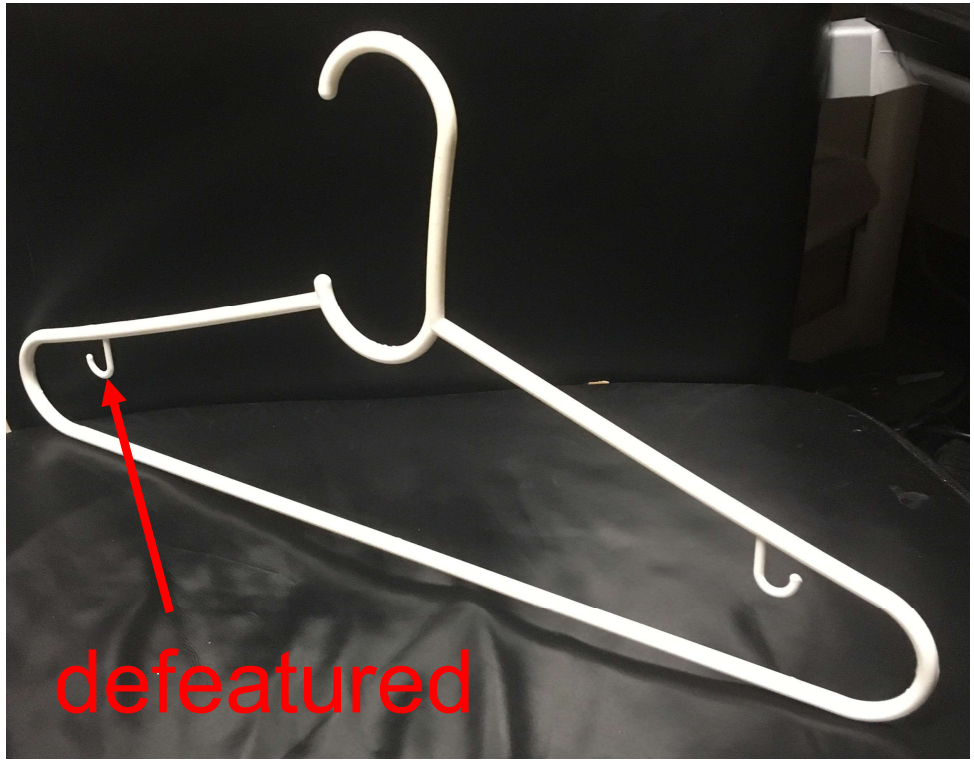


SPLIT LINES
(for fixtures and loads)

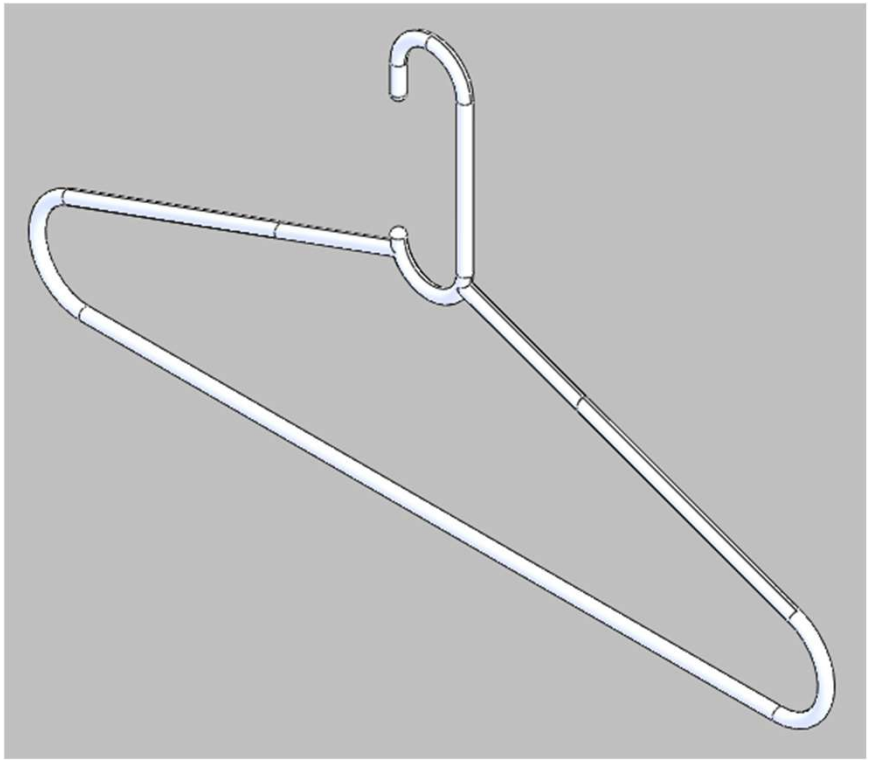




Real Object

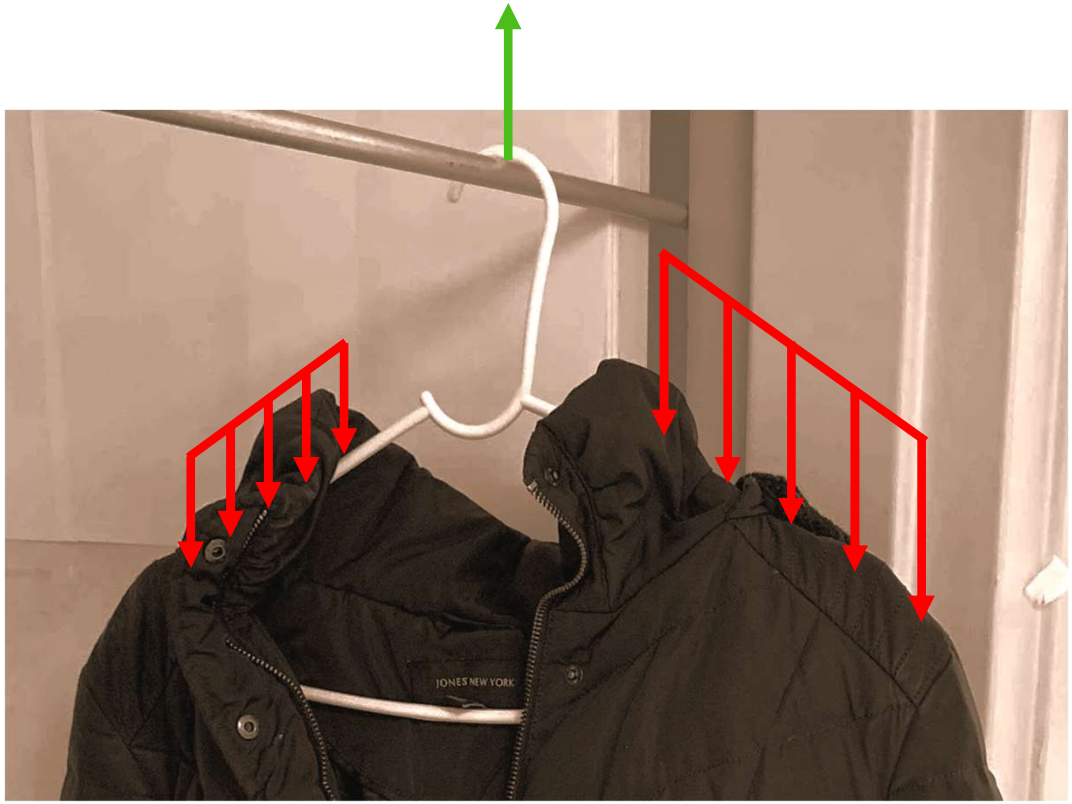


Model

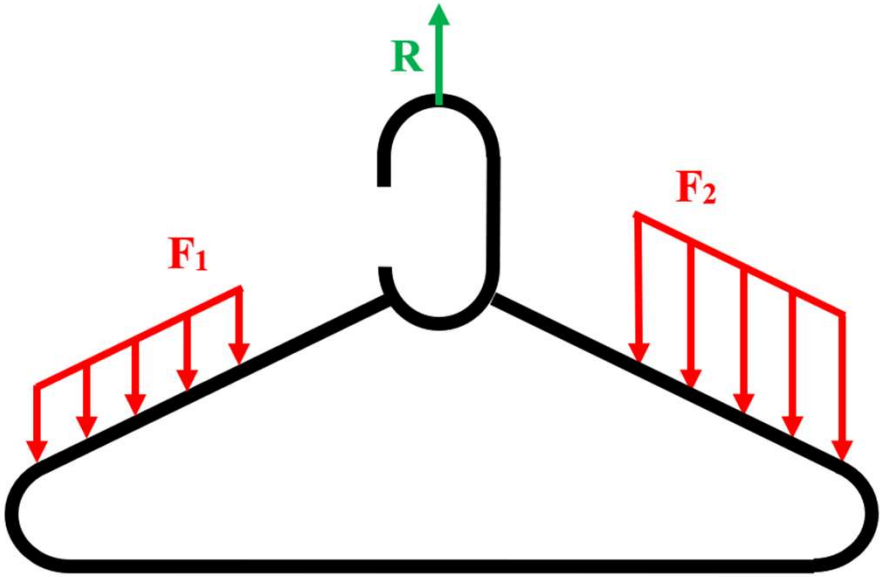


Boundary Conditions

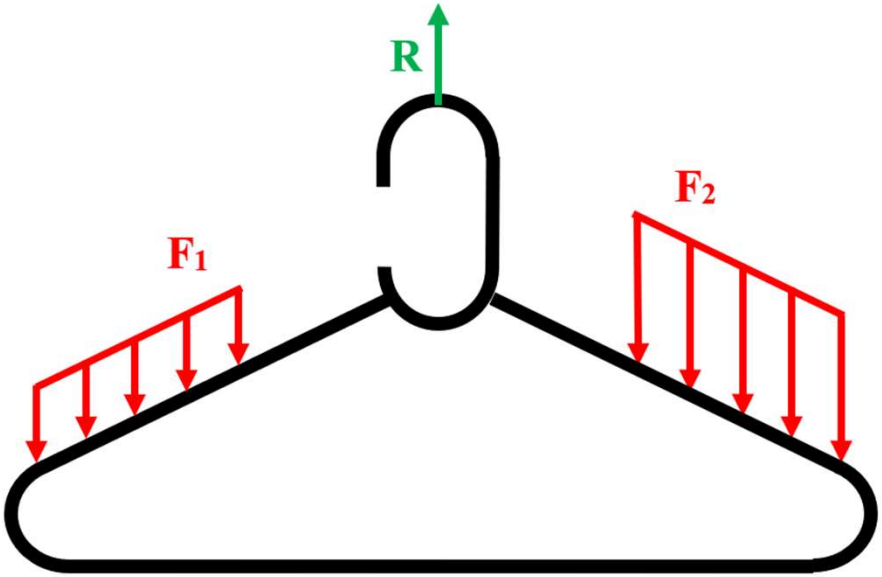
REAL-LIFE



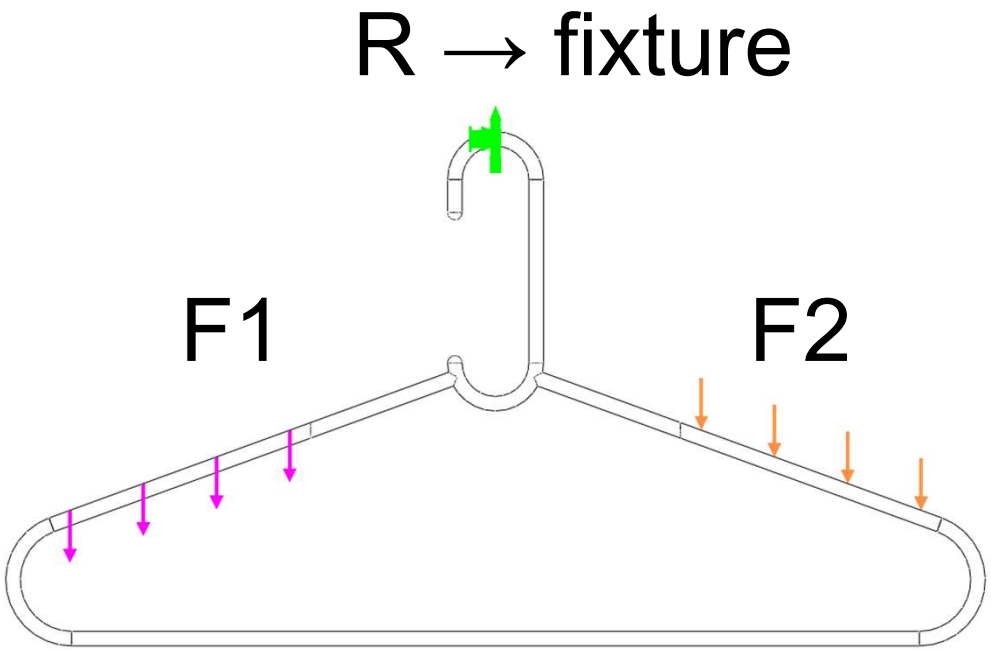
FREE-BODY DIAGRAM



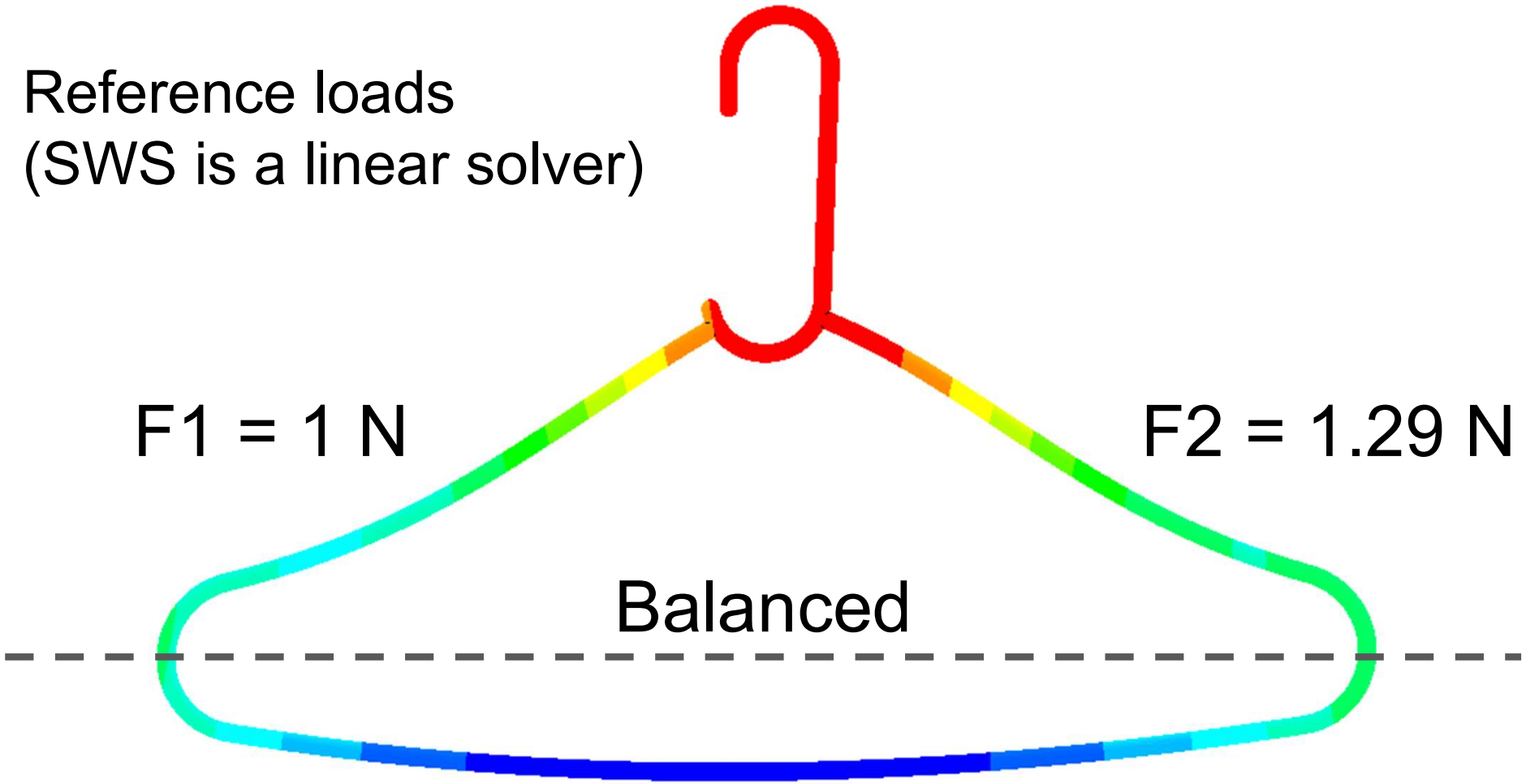
FREE-BODY DIAGRAM



SOLIDWORKS SIMULATION

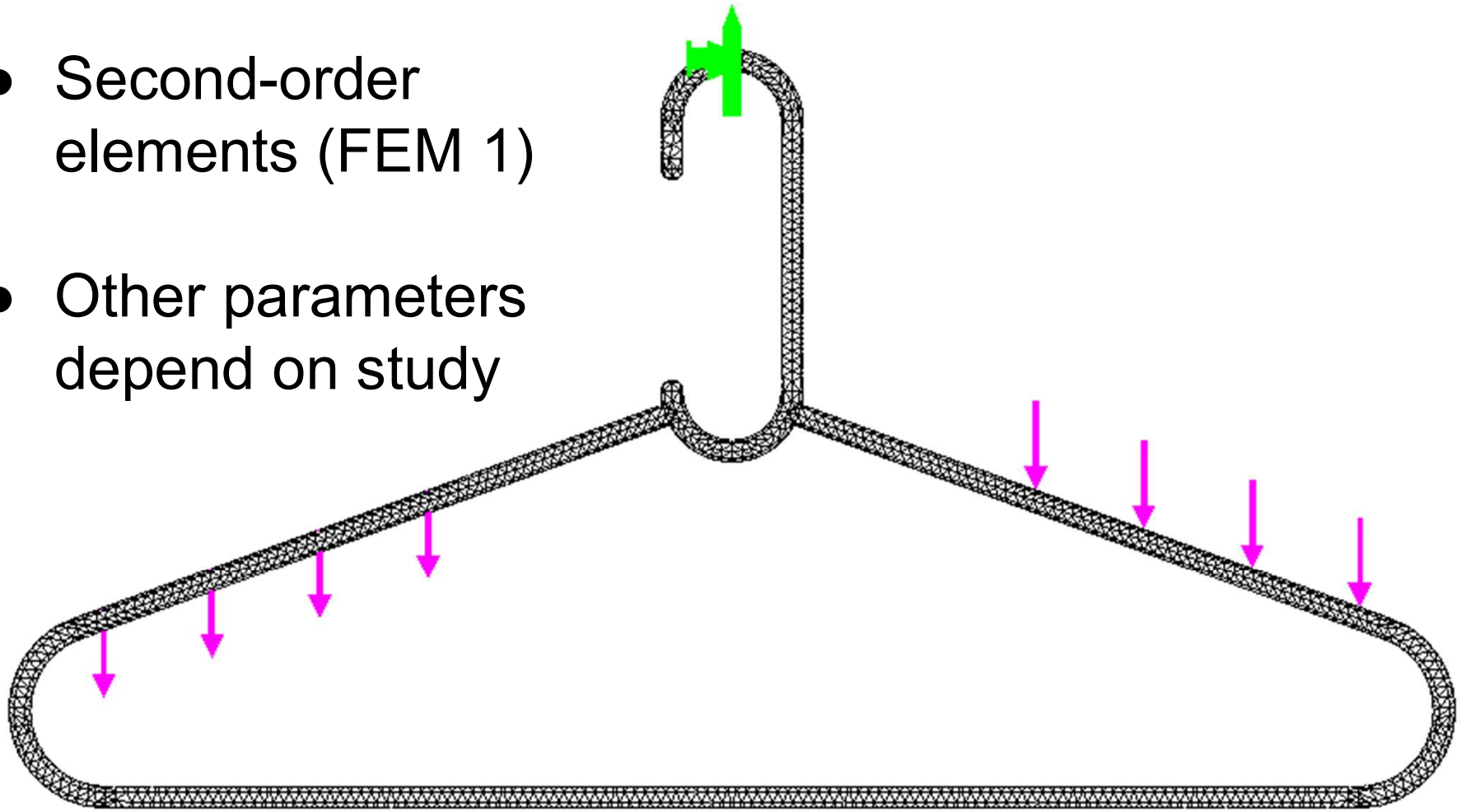


Reference loads
(SWS is a linear solver)



Mesh

- Second-order elements (FEM 1)
- Other parameters depend on study



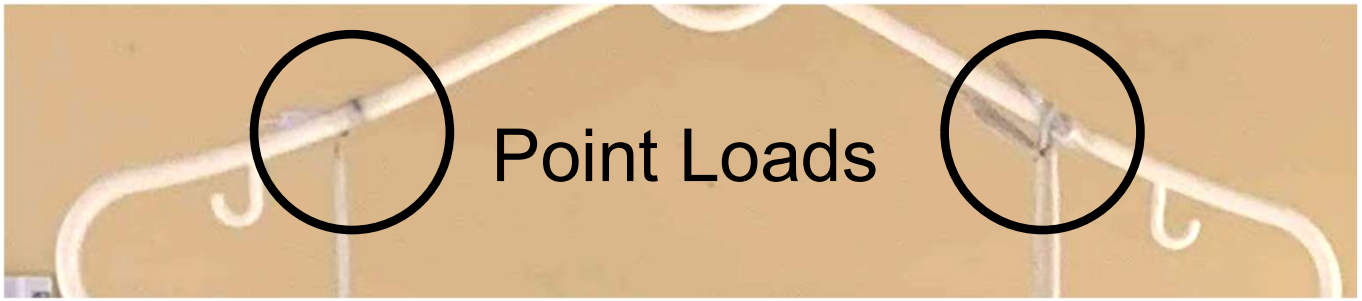
Results

Is our results valid?

Evaluation of	Method	Remedy	Valid?
Model	Displacement	Boundary Condition	
Solution	Convergence Analytical Sensitivity	Geometry	
Design	Failure Theory Factor of Safety	Geometry Loading Material	

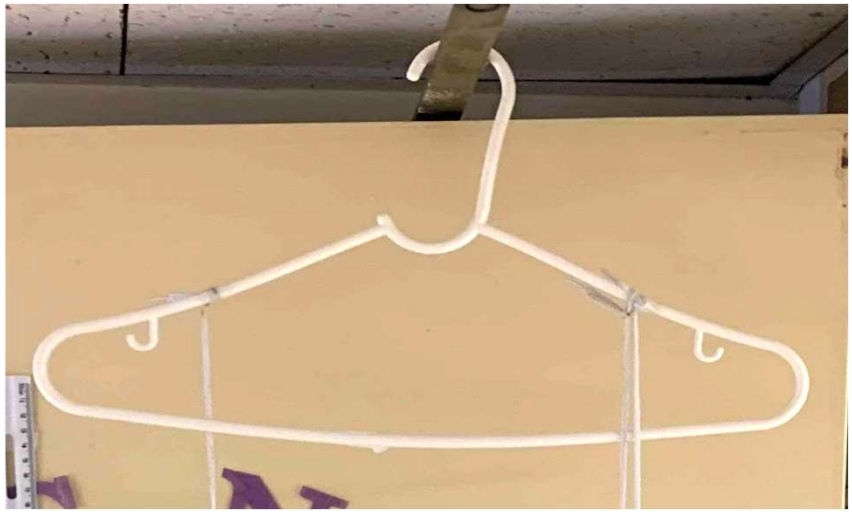
Is our results valid?

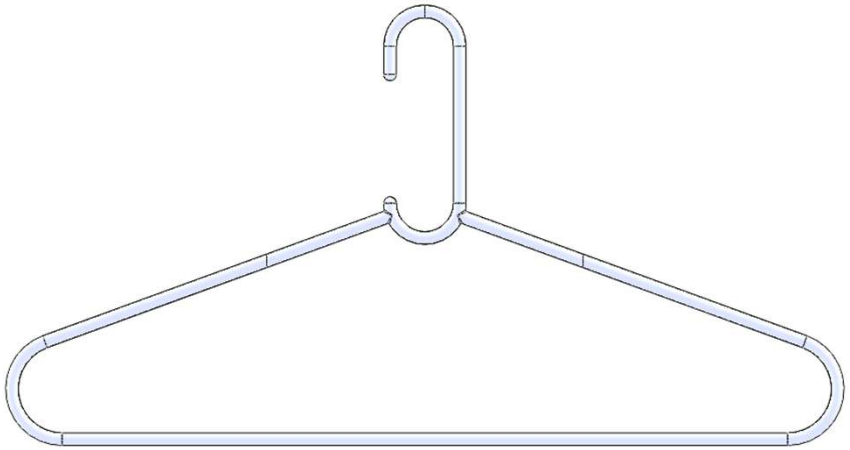
Evaluation of	Method	Remedy	Valid?
Model	Displacement	Boundary Condition	
Solution	Convergence Analytical Sensitivity	Geometry	
Design	Failure Theory Factor of Safety	Geometry Loading Material	

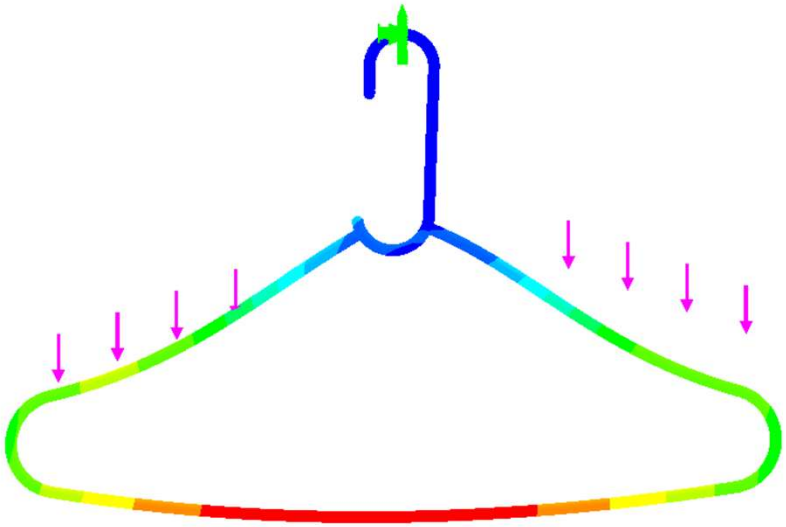


Water Bottle
(0.5 kg)

Water Bottle +
Tape Dispenser
(0.85 kg)







Is our MODEL valid?

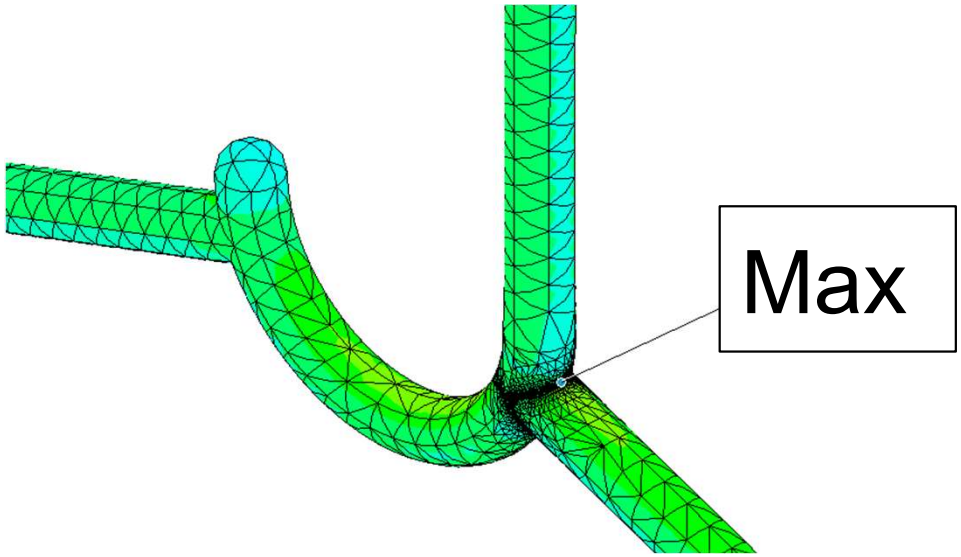
Evaluation of	Method	Remedy	Valid?
Model	Displacement	Boundary Condition	
Solution	Convergence Analytical Sensitivity	Geometry	
Design	Failure Theory Factor of Safety	Geometry Loading Material	

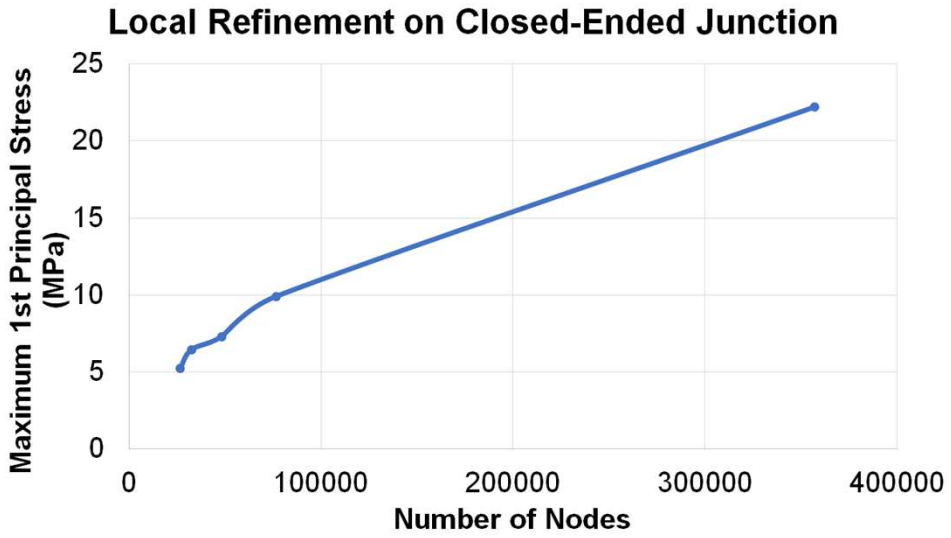
Is our MODEL valid?

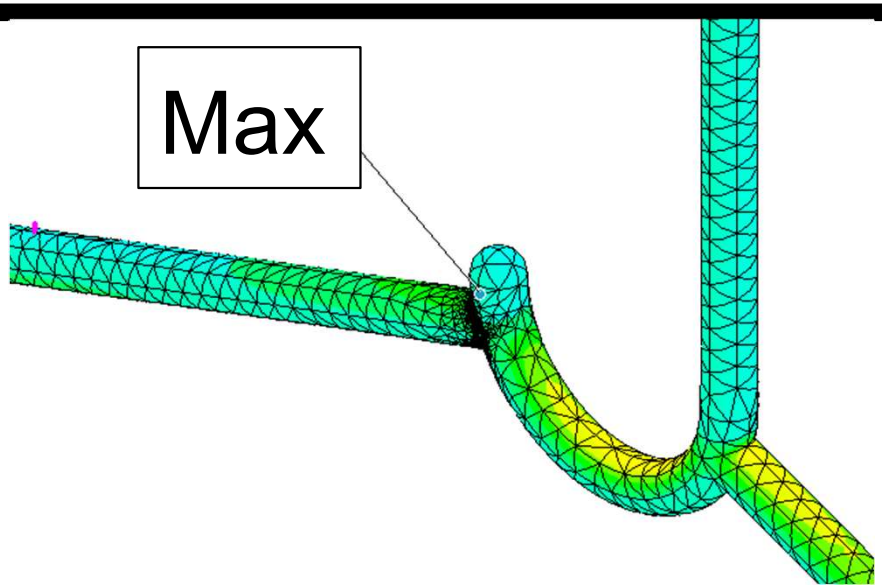
Evaluation of	Method	Remedy	Valid?
Model	Displacement	Boundary Condition	✓
Solution	Convergence Analytical Sensitivity	Geometry	
Design	Failure Theory Factor of Safety	Geometry Loading Material	

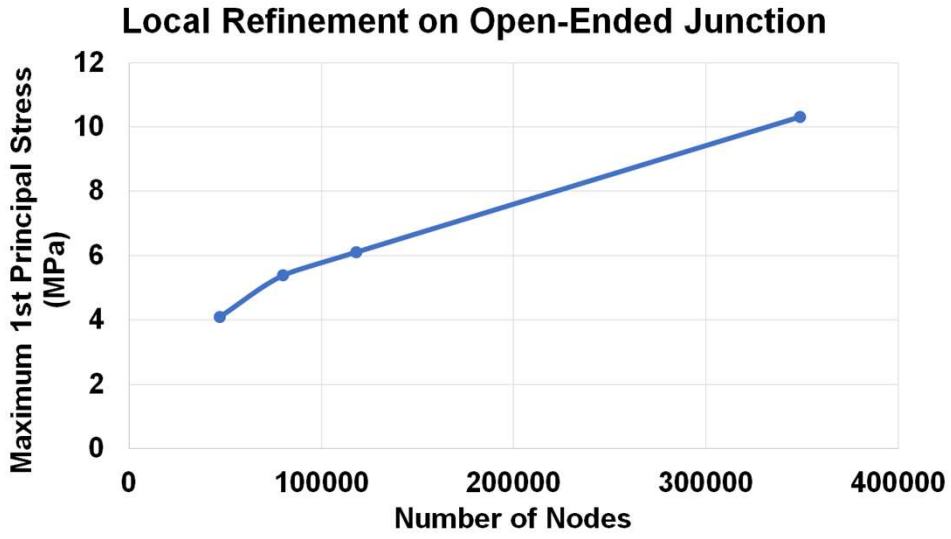
Is our SOLUTION valid?

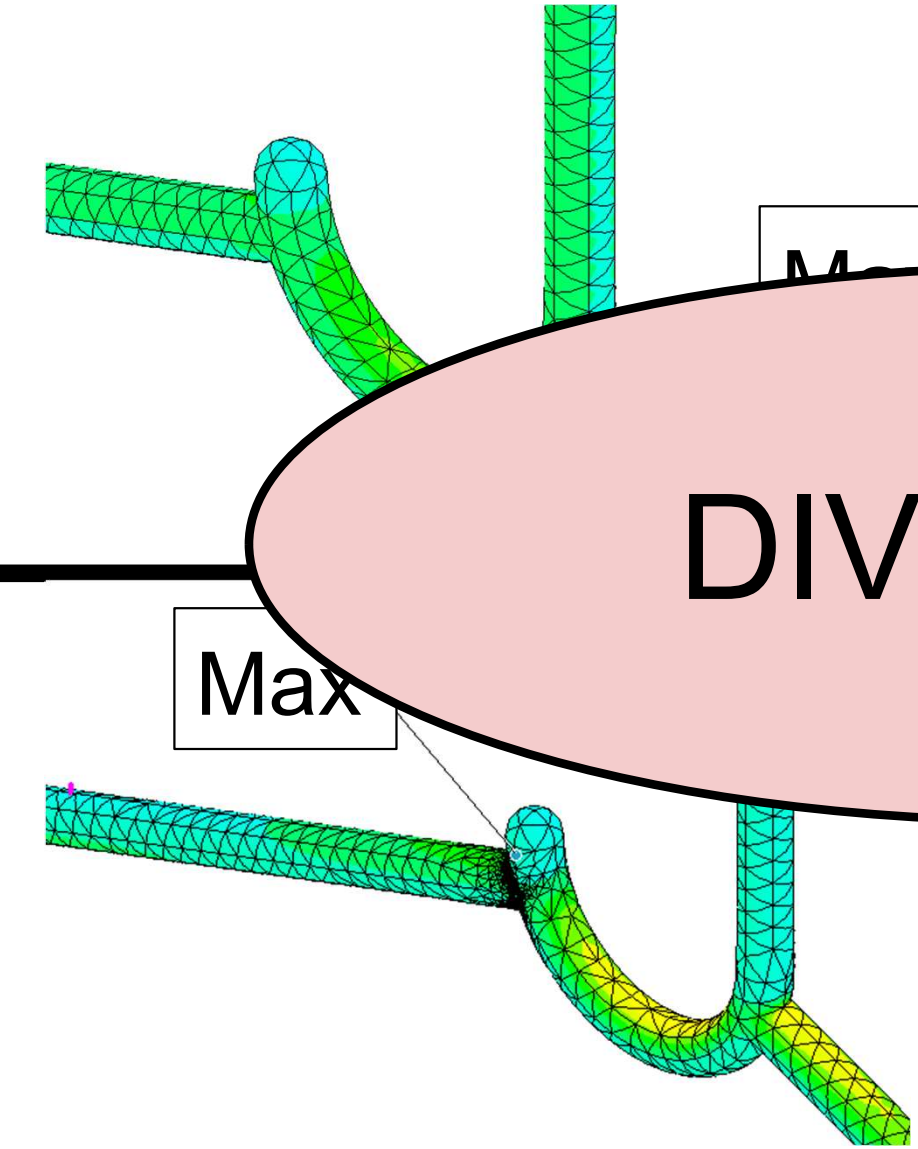
Evaluation of	Method	Remedy	Valid?
Model	Displacement	Boundary Condition	✓
Solution	Convergence Analytical Sensitivity	Geometry	
Design	Failure Theory Factor of Safety	Geometry Loading Material	


Max

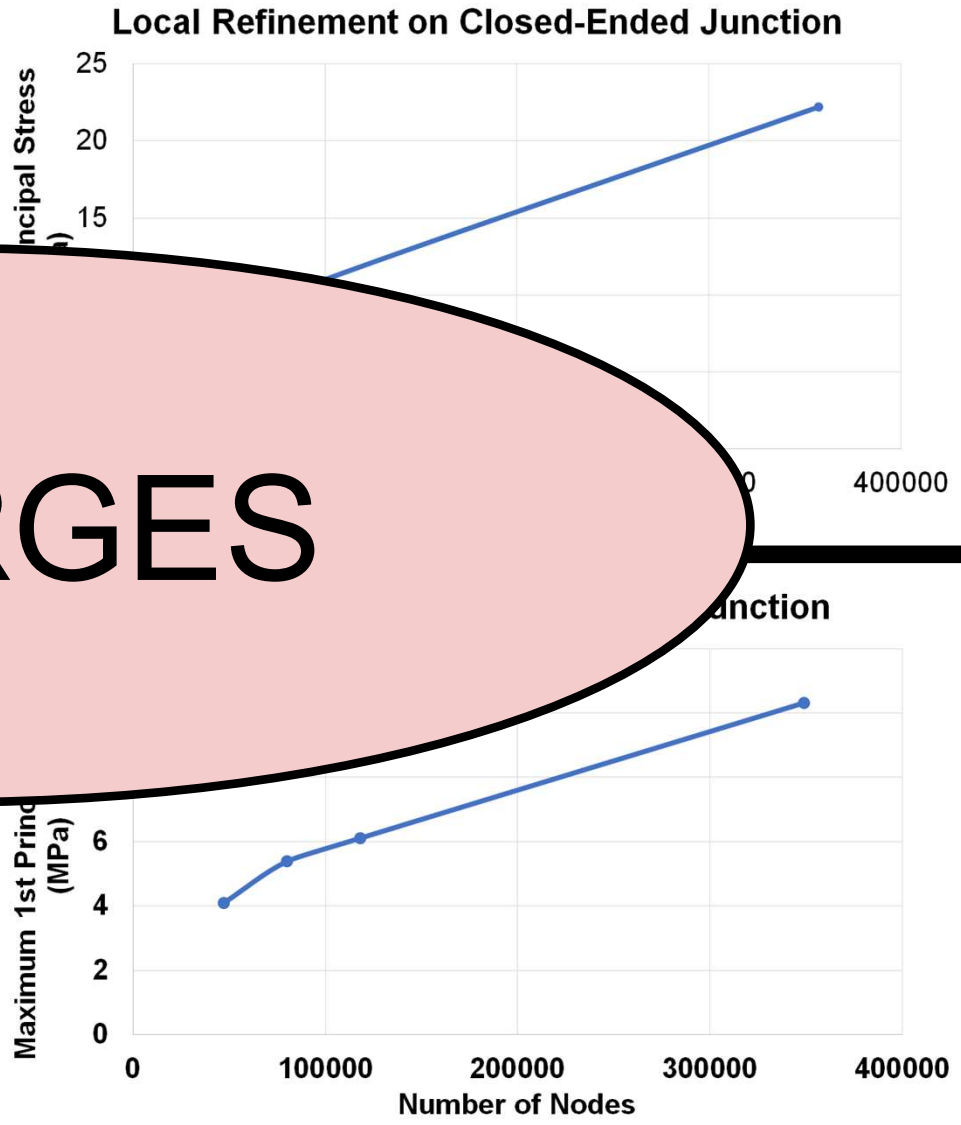

Local Refinement on Closed-Ended Junction
Maximum 1st Principal Stress (MPa)
25
20
15
10
5
0
0
100000
200000
300000
400000
Number of Nodes


Max


Local Refinement on Open-Ended Junction
Maximum 1st Principal Stress (MPa)
12
10
8
6
4
2
0
0
100000
200000
300000
400000
Number of Nodes



Max



DIVERGES

Is our SOLUTION valid?

Evaluation of	Method	Remedy	Valid?
Model	Displacement	Boundary Condition	✓
Solution	Convergence Analytical Sensitivity	Geometry	
Design	Failure Theory Factor of Safety	Geometry Loading Material	

Is our SOLUTION valid?

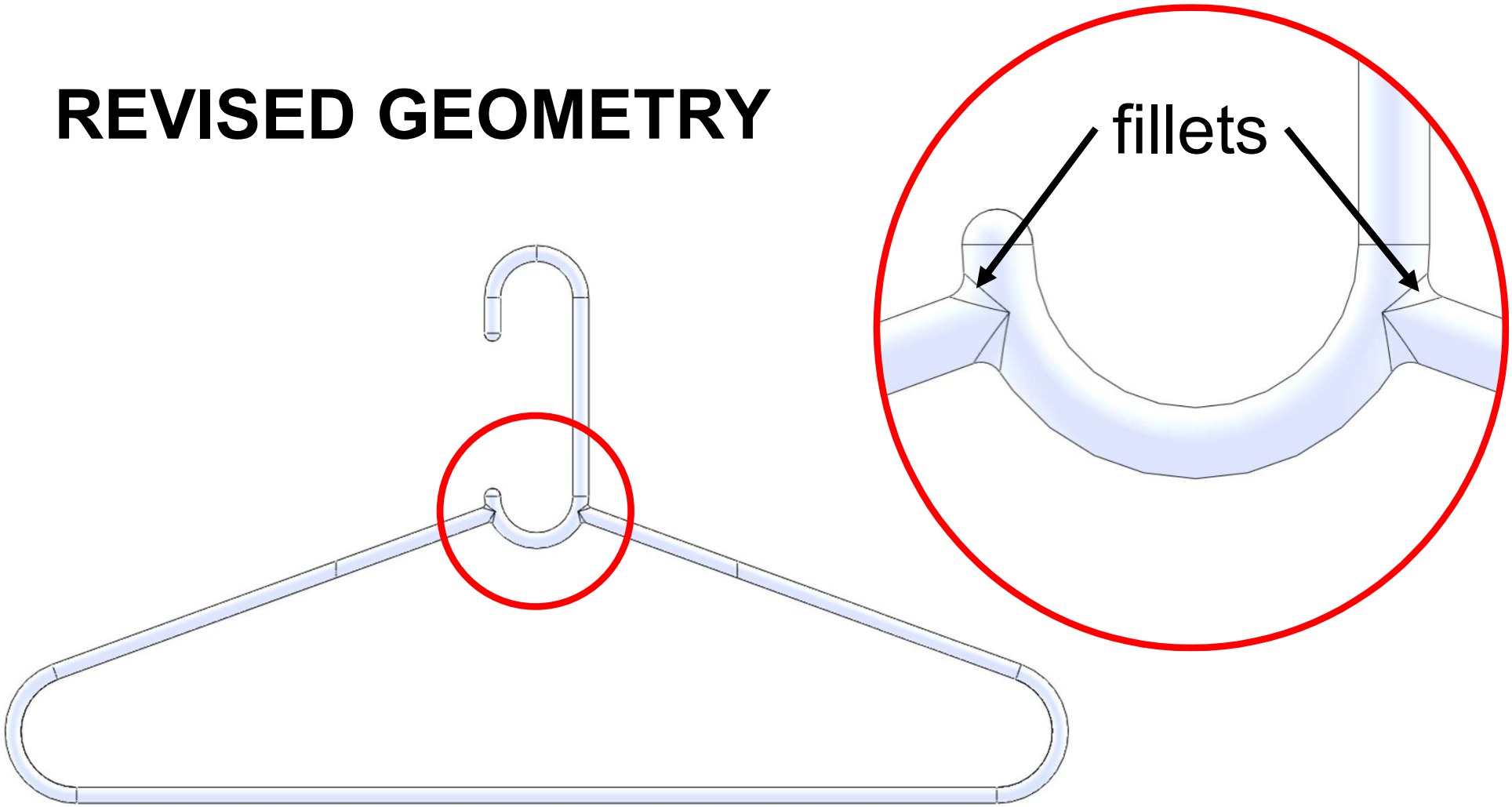
Evaluation of	Method	Remedy	Valid?
Model	Displacement	Boundary Condition	✓
Solution	Convergence Analytical Sensitivity	Geometry	X
Design	Failure Theory Factor of Safety	Geometry Loading Material	

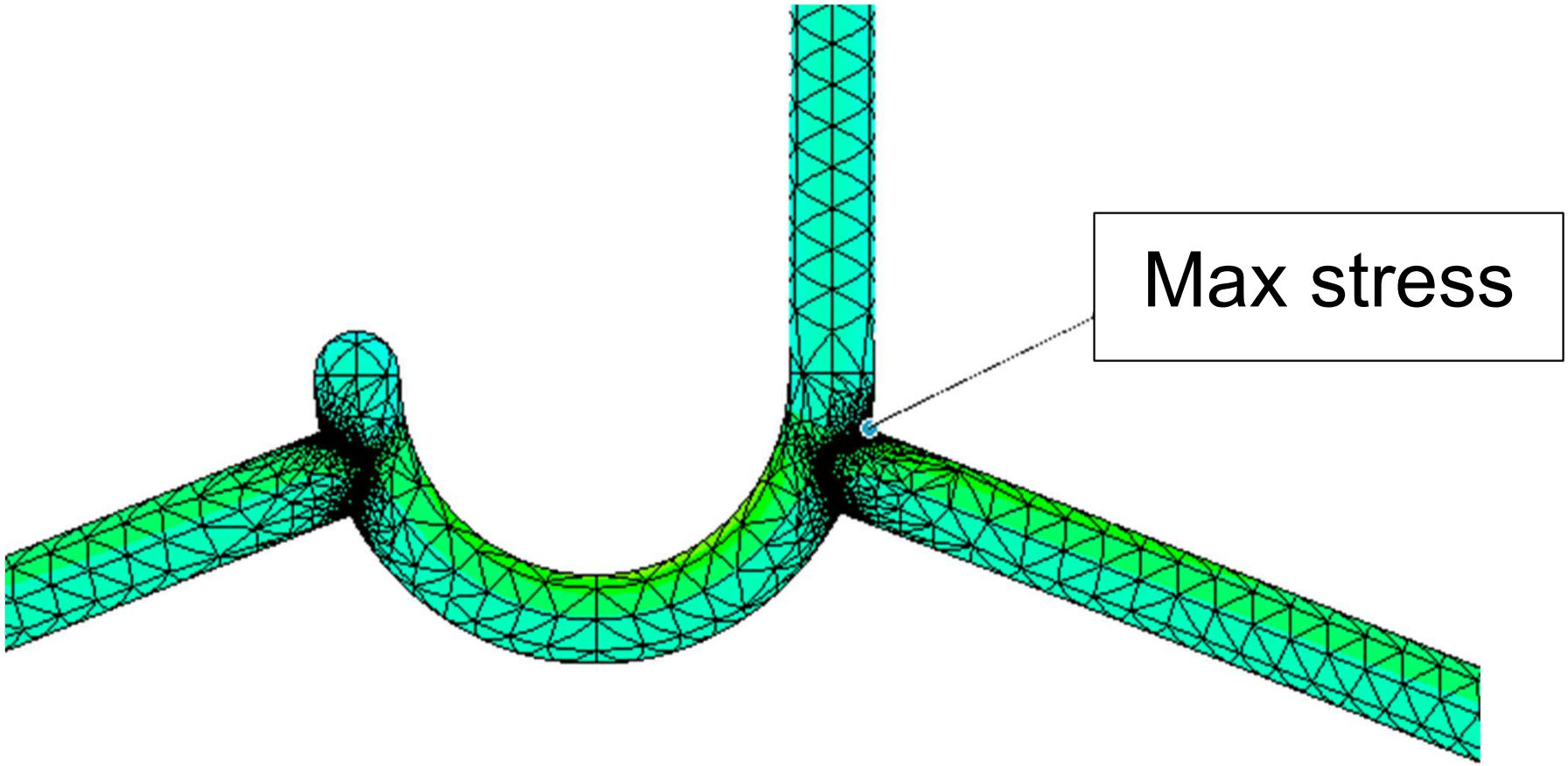
Is our SOLUTION valid?

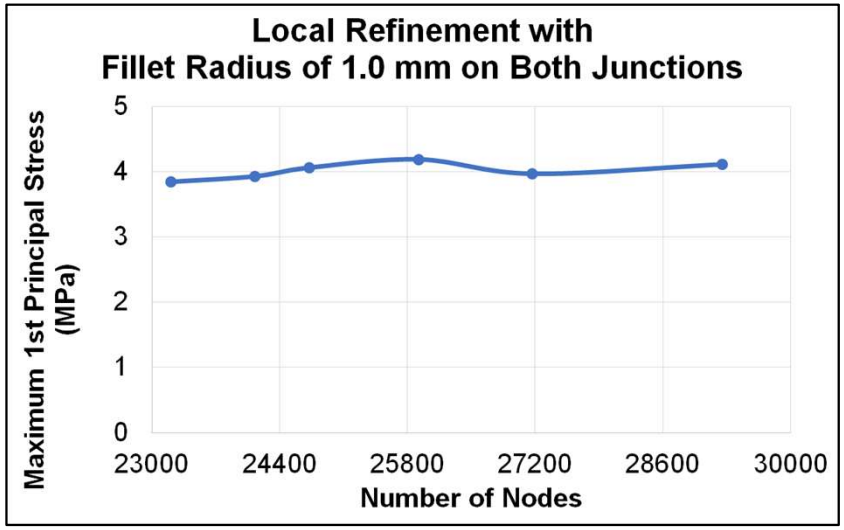
Evaluation of	Method	Remedy	Valid?
Model	Displacement	Boundary Condition	✓
Solution	Convergence Analytical Sensitivity	**GEOMETRY**	X
Design	Failure Theory Factor of Safety	Geometry Loading Material	

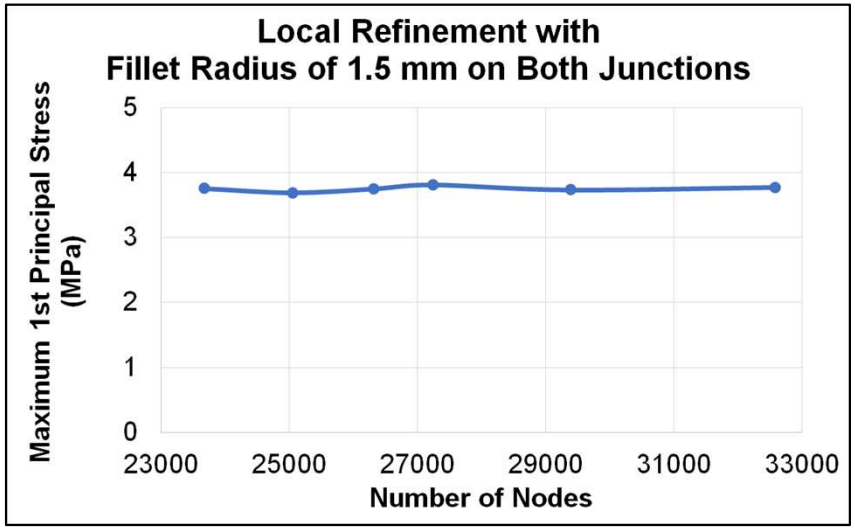
Changing Geometry

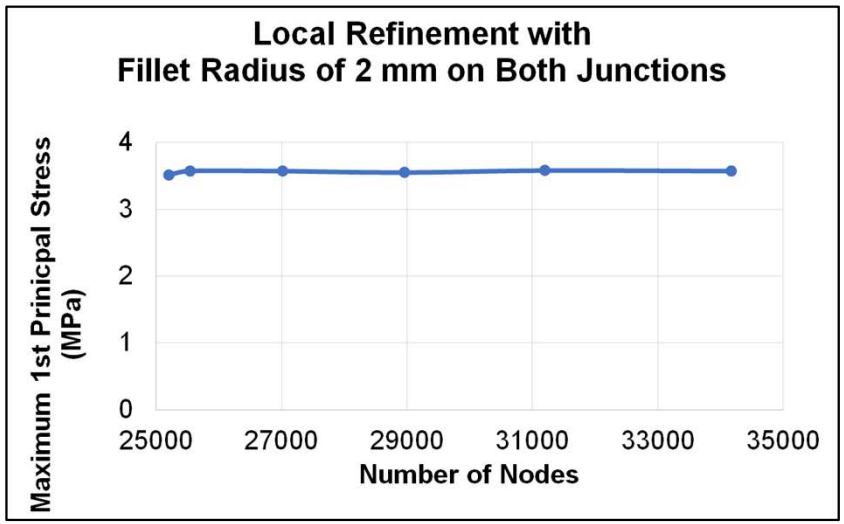
REVISED GEOMETRY

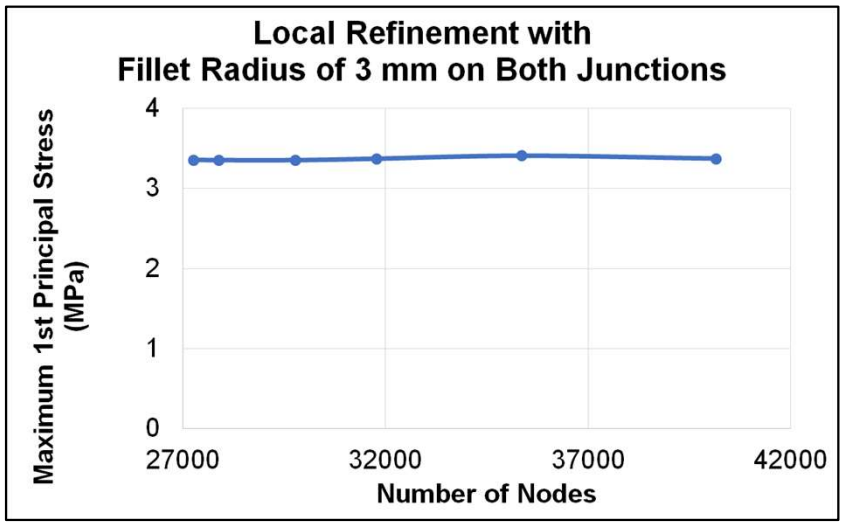


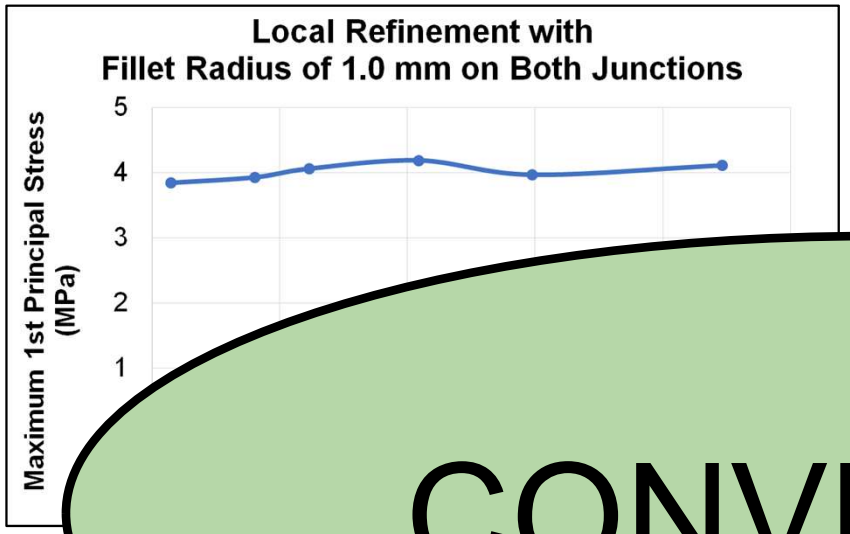

Max stress

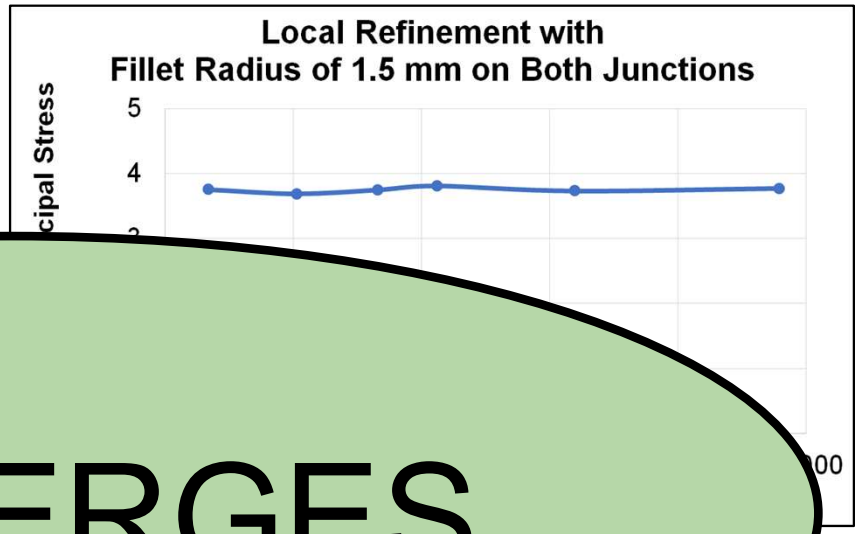

Local Refinement with
Fillet Radius of 1.0 mm on Both Junctions
Maximum 1st Principal Stress (MPa)
0
1
2
3
4
5
23000
24400
25800
27200
28600
30000
Number of Nodes


Local Refinement with
Fillet Radius of 1.5 mm on Both Junctions
Maximum 1st Principal Stress (MPa)
0
1
2
3
4
5
23000
25000
27000
29000
31000
33000
Number of Nodes

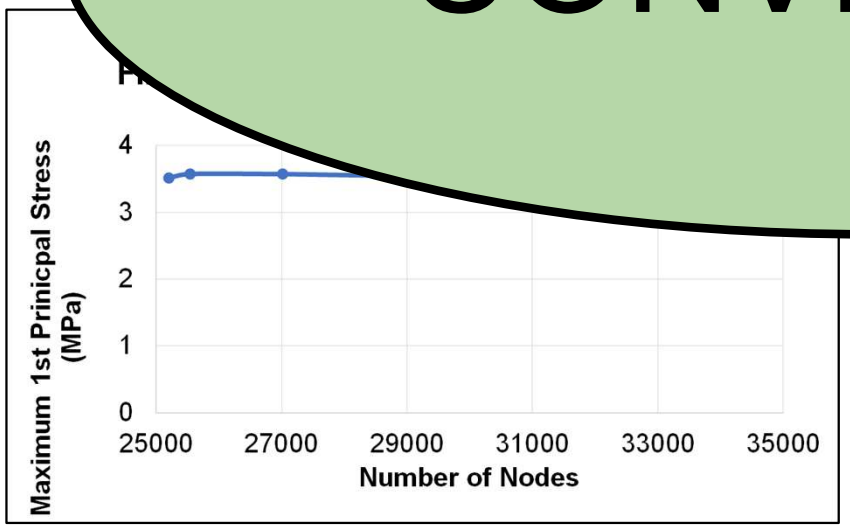

Local Refinement with
Fillet Radius of 2 mm on Both Junctions
Maximum 1st Prinicpal Stress (MPa)
0
1
2
3
4
25000
27000
29000
31000
33000
35000
Number of Nodes

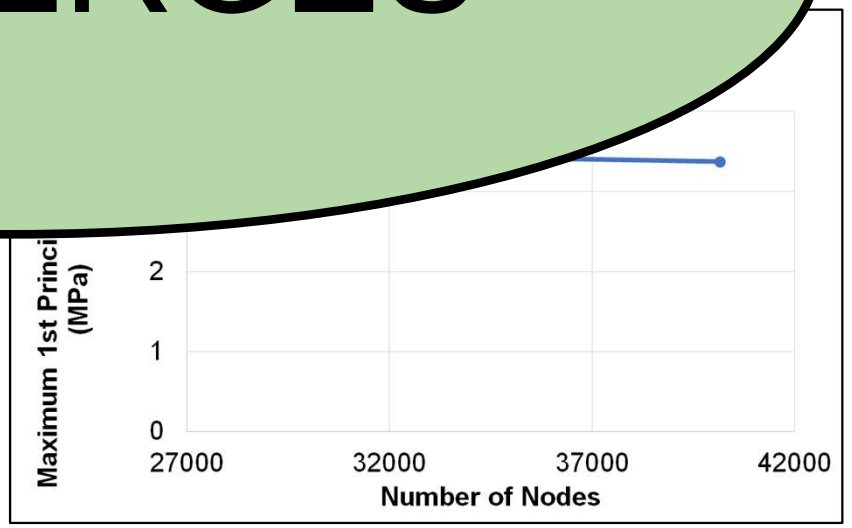

Local Refinement with
Fillet Radius of 3 mm on Both Junctions
Maximum 1st Principal Stress (MPa)
0
1
2
3
4
27000
32000
37000
42000
Number of Nodes

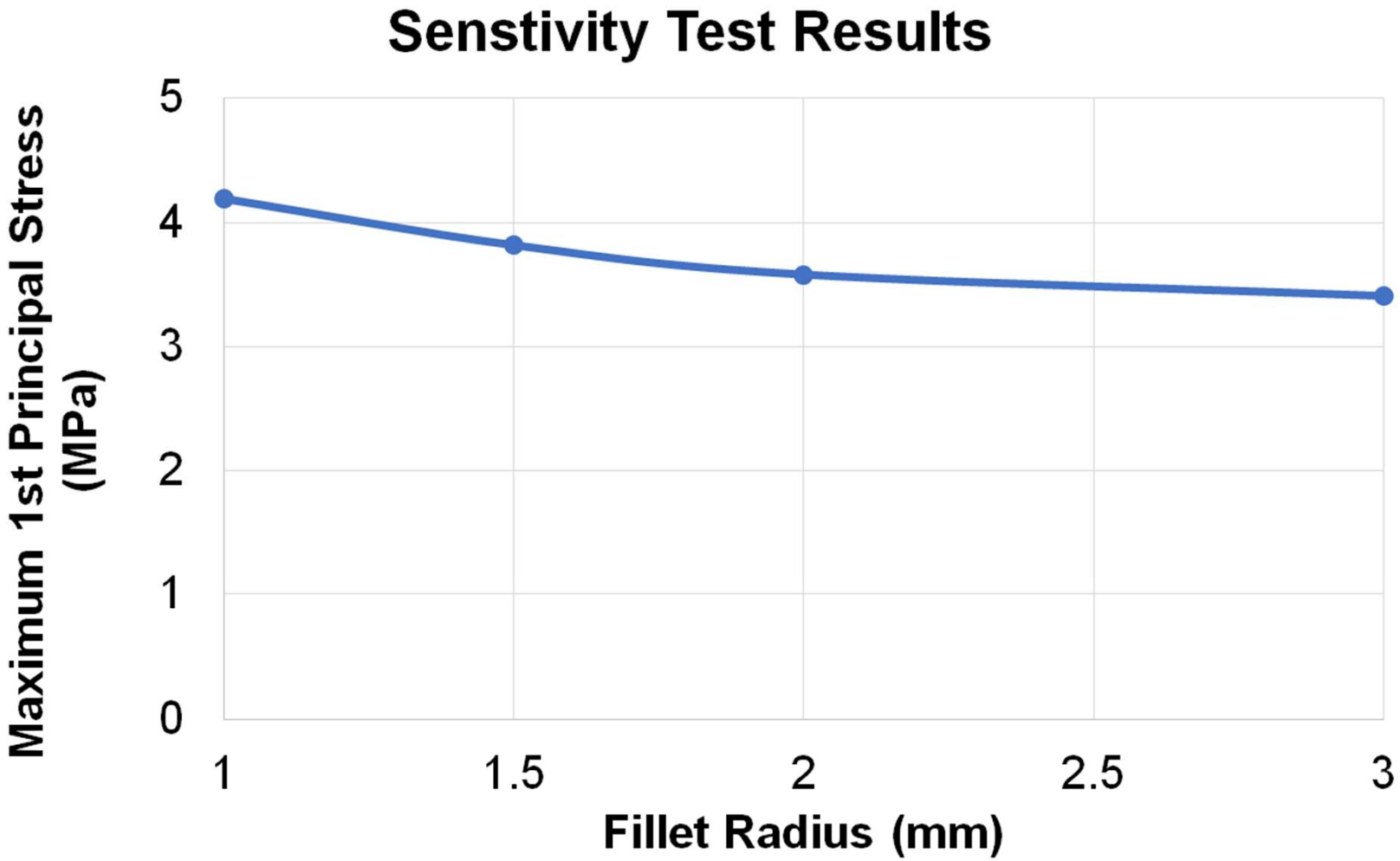

Local Refinement with
Fillet Radius of 1.0 mm on Both Junctions
Maximum 1st Principal Stress (MPa)
5
4
3
2
1

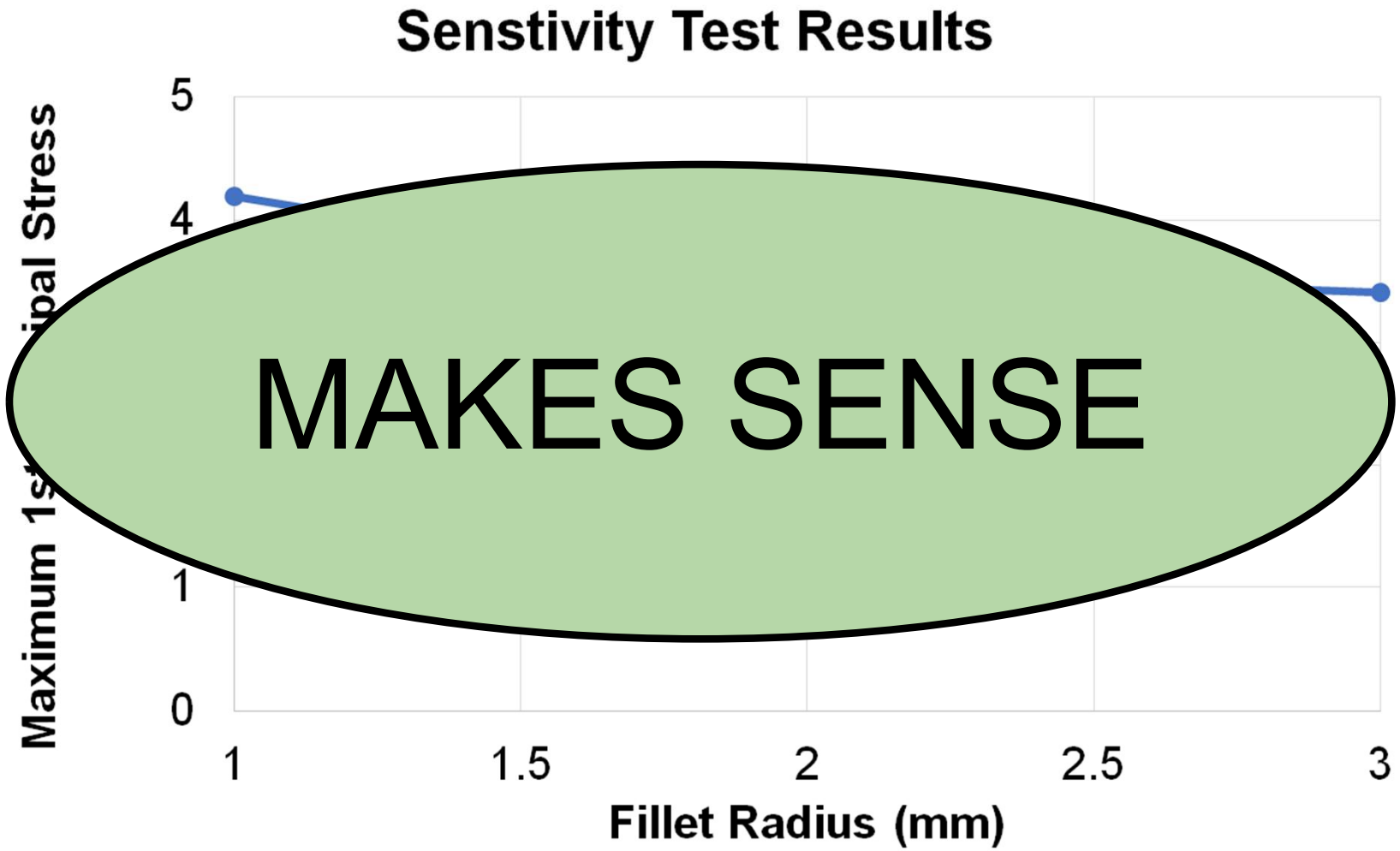

Local Refinement with
Fillet Radius of 1.5 mm on Both Junctions
5
4

CONVERGES

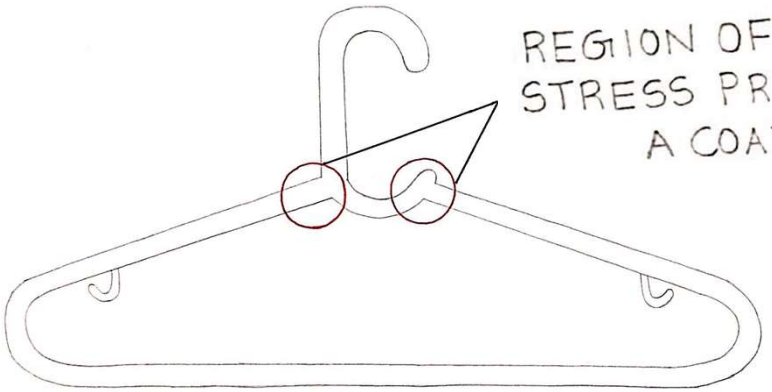

Maximum 1st Prinicpal Stress (MPa)
4
3
2
1
0
25000
27000
29000
31000
33000
35000
Number of Nodes

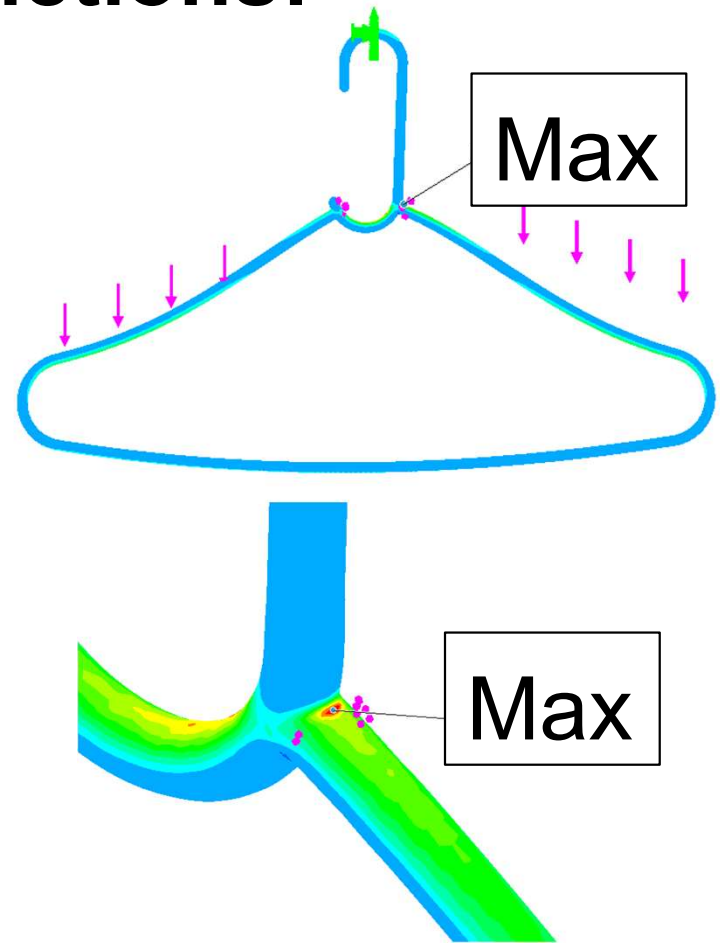

Maximum 1st Princi (MPa)
2
1
0
27000
32000
37000
42000
Number of Nodes


Senstivity Test Results
Maximum 1st Principal Stress (MPa)
5
4
3
2
1
0
1
1.5
2
2.5
3
Fillet Radius (mm)


Senstivity Test Results
5
4
1
0
1
1.5
2
2.5
3
Fillet Radius (mm)
MAKES SENSE

And it did match our predictions!





Is our SOLUTION valid? (With fillets)

Evaluation of	Method	Remedy	Valid?
Model	Displacement	Boundary Condition	✓
Solution	Convergence Analytical Sensitivity	Geometry	
Design	Failure Theory Factor of Safety	Geometry Loading Material	

Is our SOLUTION valid? (With fillets)

Evaluation of	Method	Remedy	Valid?
Model	Displacement	Boundary Condition	✓
Solution	Convergence Analytical (N/A) Sensitivity	Geometry	✓
Design	Failure Theory Factor of Safety	Geometry Loading Material	

Is our DESIGN valid? (With fillets)

Evaluation of	Method	Remedy	Valid?
Model	Displacement	Boundary Condition	✓
Solution	Convergence Analytical (N/A) Sensitivity	Geometry	✓
Design	Failure Theory Factor of Safety	Geometry Loading Material	

MAXIMUM STRESS FRACTURE THEORY:

Fracture occurs if...

First Principal Stress > Tensile Strength

MAXIMUM STRESS FRACTURE THEORY:

Fracture occurs if...

First Principal Stress > **35 MPa**

JACKET AND WEIGHTS (FRACTURES)

	Experiment	FEA
Load (N)	61	2.29
Stress (MPa)		

JACKET AND WEIGHTS (FRACTURES)

	Experiment	FEA
Load (N)	61	2.29
Stress (MPa)		

$$\frac{61}{2.29} = 27$$

JACKET AND WEIGHTS (FRACTURES)

	Experiment	FEA
Load (N)	61	2.29
Stress (MPa)	35	

$$\frac{61}{2.29} = 27$$

JACKET AND WEIGHTS (FRACTURES)

	Experiment	FEA
Load (N)	61	2.29
Stress (MPa)	35	

$$\frac{61}{2.29} = 27$$

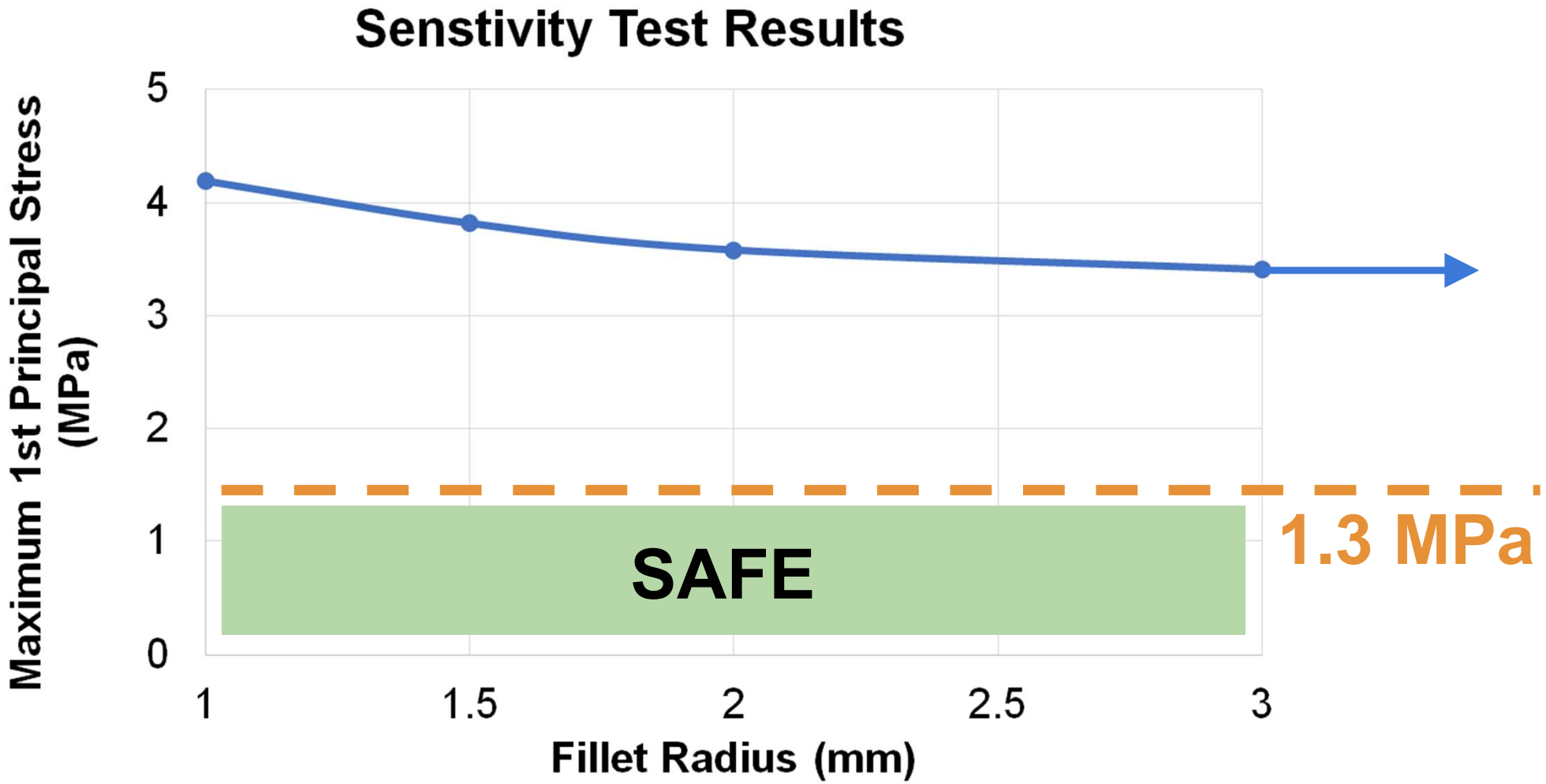
$$\frac{35}{27} = 1.3$$

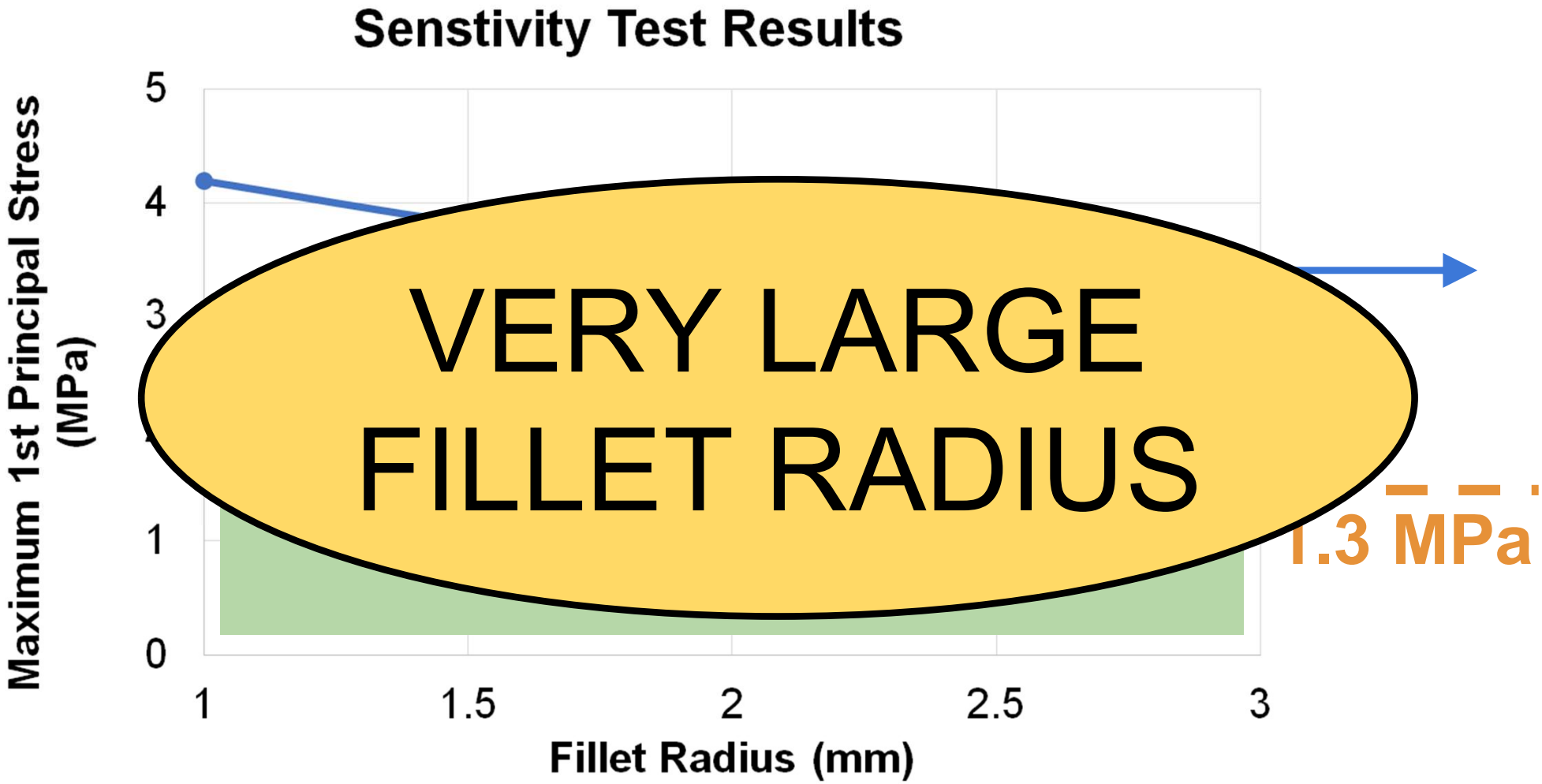
JACKET AND WEIGHTS (FRACTURES)

	Experiment	FEA
Load (N)	61	2.29
Stress (MPa)	35	1.3

$$\frac{61}{2.29} = 27$$

$$\frac{35}{27} = 1.3$$


Senstivity Test Results
Maximum 1st Principal Stress (MPa)
5
4
3
2
1
0
1
1.5
2
2.5
3
Fillet Radius (mm)
SAFE
1.3 MPa


Senstivity Test Results
Maximum 1st Principal Stress (MPa)
5
4
3
1
0
1
1.5
2
2.5
3
Fillet Radius (mm)
VERY LARGE FILLET RADIUS
1.3 MPa

Experiment	FEA
61 N	61 N
35 MPa	35 MPa
No fillet	Large fillet

Experiment	FEA
61 N	61 N
35 MPa	35 MPa
No fillet	Large fillet

Experiment	FEA
61 N	61 N
35 MPa	35 MPa
No fillet	Large fillet

Experiment	FEA
61 N	61 N
35 MPa	35 MPa
No fillet	Large fillet

FEA is not matching with real life!

Is our DESIGN valid? (With fillets)

Evaluation of	Method	Remedy	Valid?
Model	Displacement	Boundary Condition	✓
Solution	Convergence Analytical (N/A) Sensitivity	Geometry	✓
Design	Failure Theory Factor of Safety	Geometry Loading Material	

Doesn’t really make sense! (With fillets)

Evaluation of	Method	Remedy	Valid?
Model	Displacement	Boundary Condition	✓
Solution	Convergence Analytical (N/A) Sensitivity	Geometry	✓
Design	Failure Theory Factor of Safety (N/A)	Geometry Loading Material	X

Doesn’t really make sense! (With fillets)

Evaluation of	Method	Remedy	Valid?
Model	Displacement	Boundary Condition	✓
Solution	Convergence Analytical (N/A) Sensitivity	Geometry	✓
Design	Failure Theory Factor of Safety (N/A)	**Geometry** **Loading** **Material**	X

Geometry	Can’t think of other ways to avoid stress singularity
Loading	Can’t think of other loading possibilities
Material	Can’t think of other materials

Doesn’t really make sense! (With fillets)

Evaluation of	Method	Remedy	Valid?
Model	Displacement	Boundary Condition	✓
Solution	Convergence Analytical (N/A) Sensitivity	Geometry	✓
Design	Failure Theory Factor of Safety (N/A)	Geometry Loading Material	X

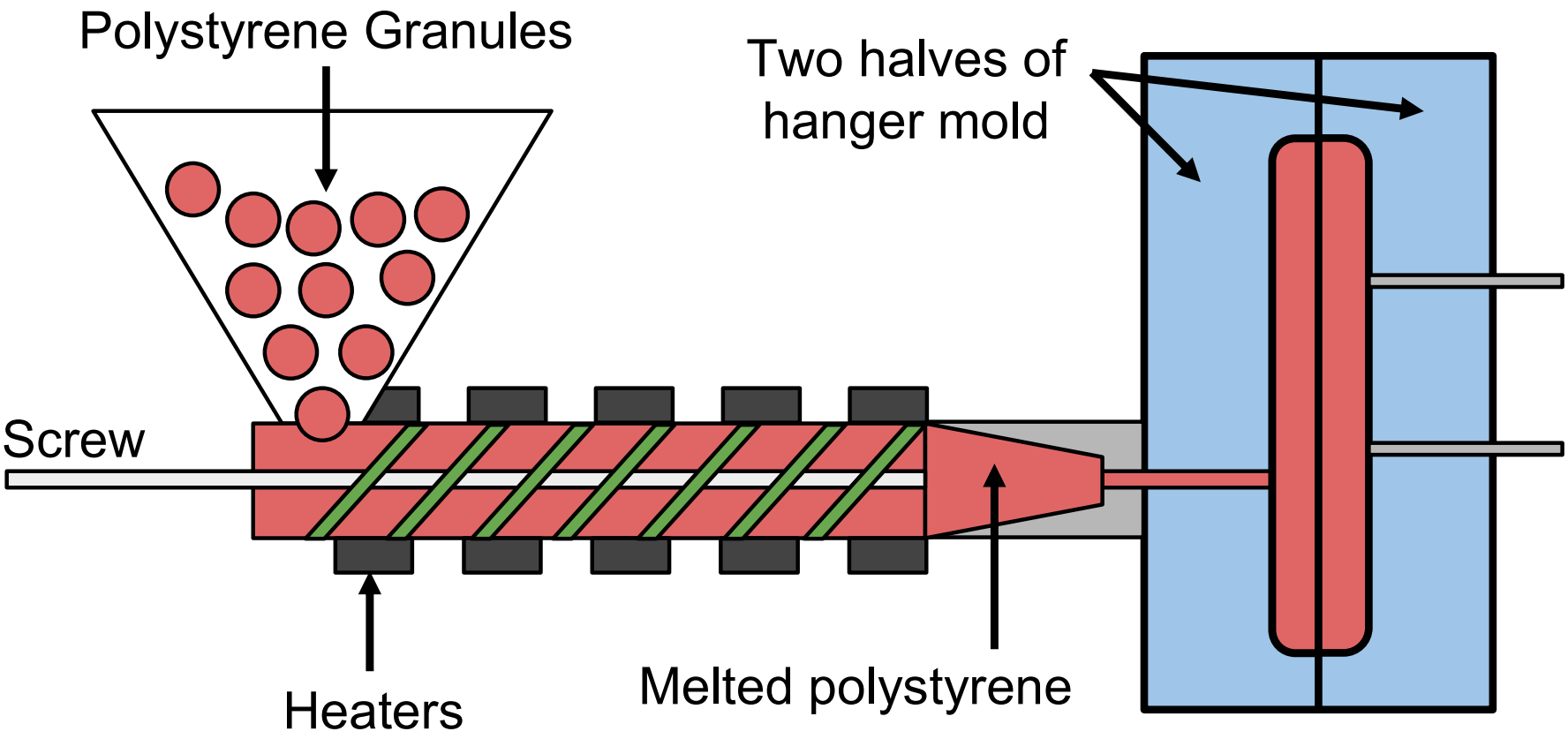
Doesn’t really make sense! (With fillets)

Evaluation of	Mat…	…medy	Valid?
Mod…			✓
S…			
Design	Failure Theory Factor of Safety (N/A)	Geometry Loading Material	X

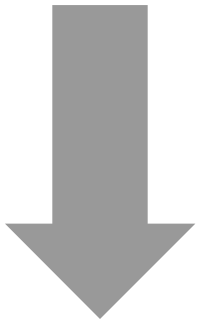
DIFFICULT TO VALIDATE

Sources of Problems

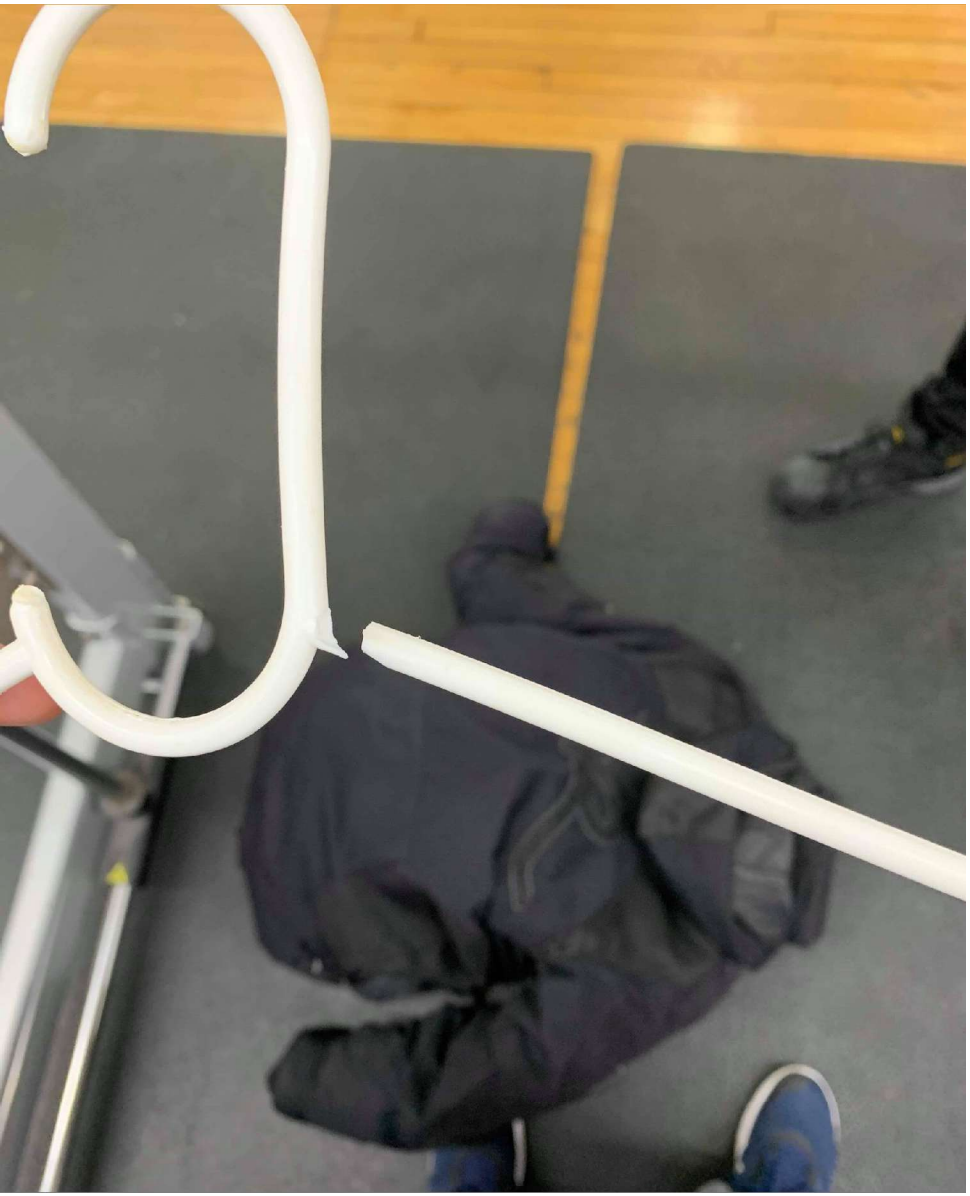
INJECTION MOLDING



Simulation does not work out



Rely on **experiments**!



6.1 kg

Jacket + weights

6.1 kg ≈ 3 Heavy Jackets

6.1 kg ≈ 3 Heavy Jackets

GOOD DESIGN!

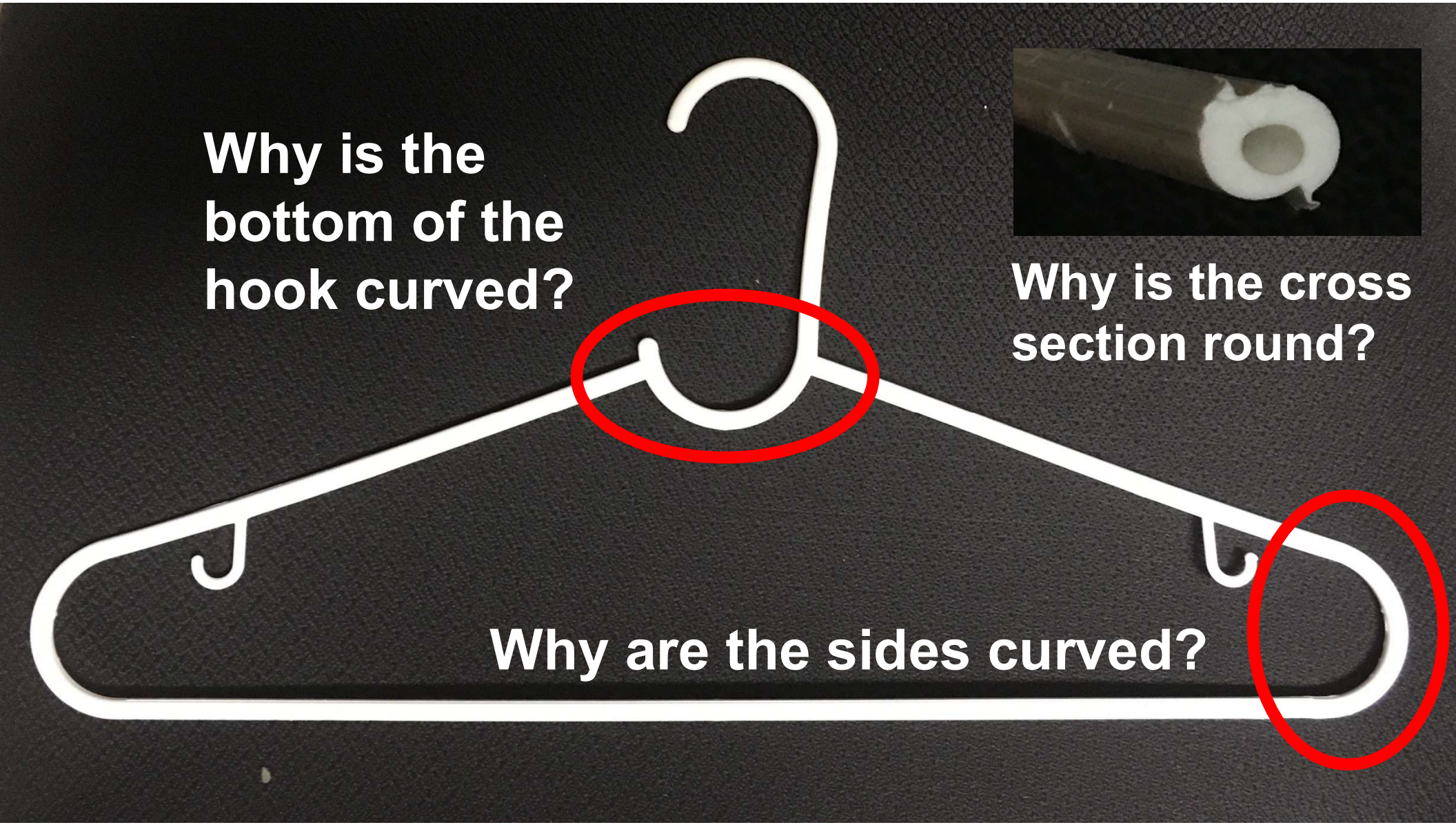
PROBLEM STATEMENT

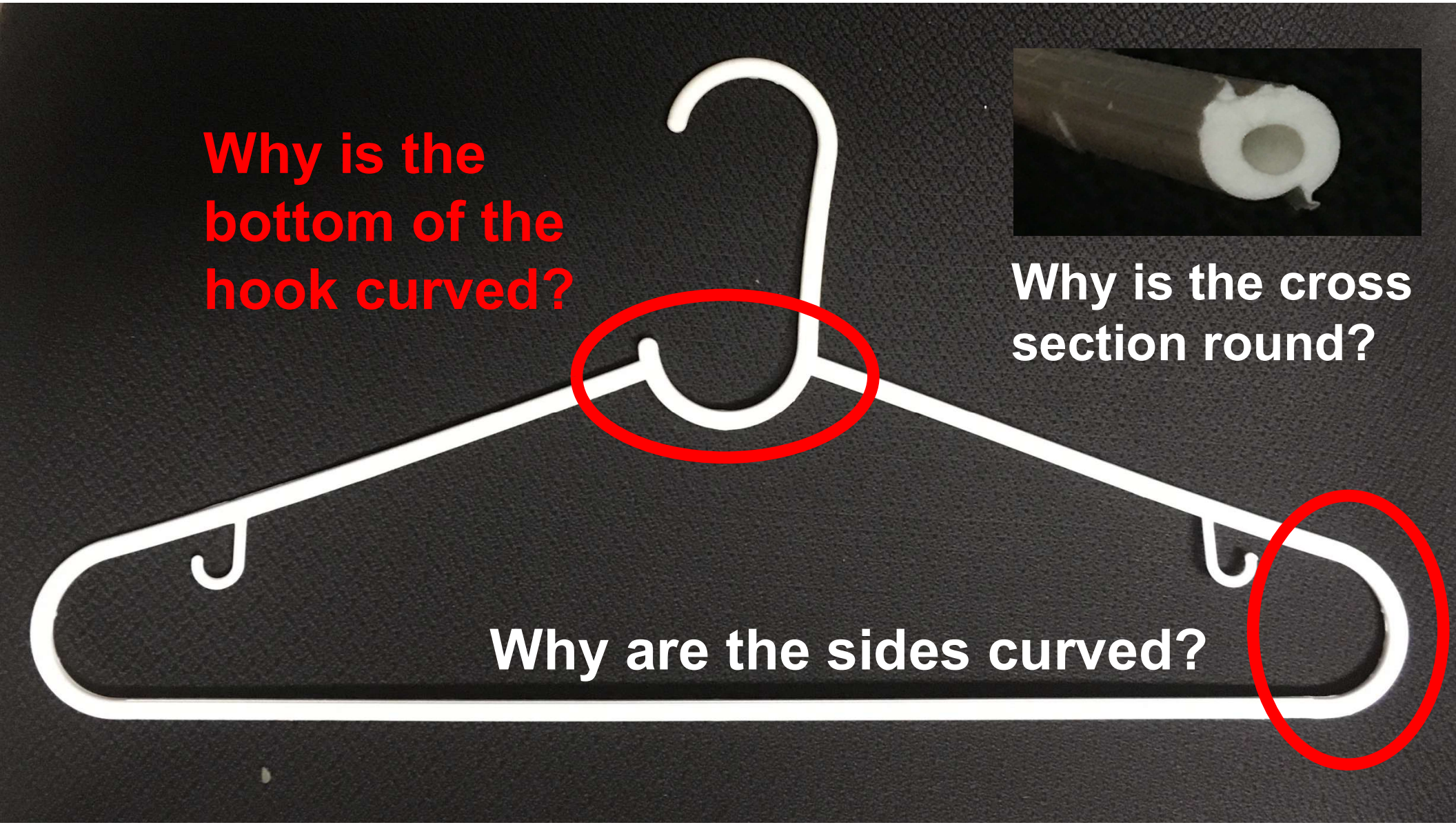
Do hangers break very easily or are we just bad users of hangers?

BY EXPERIMENT:

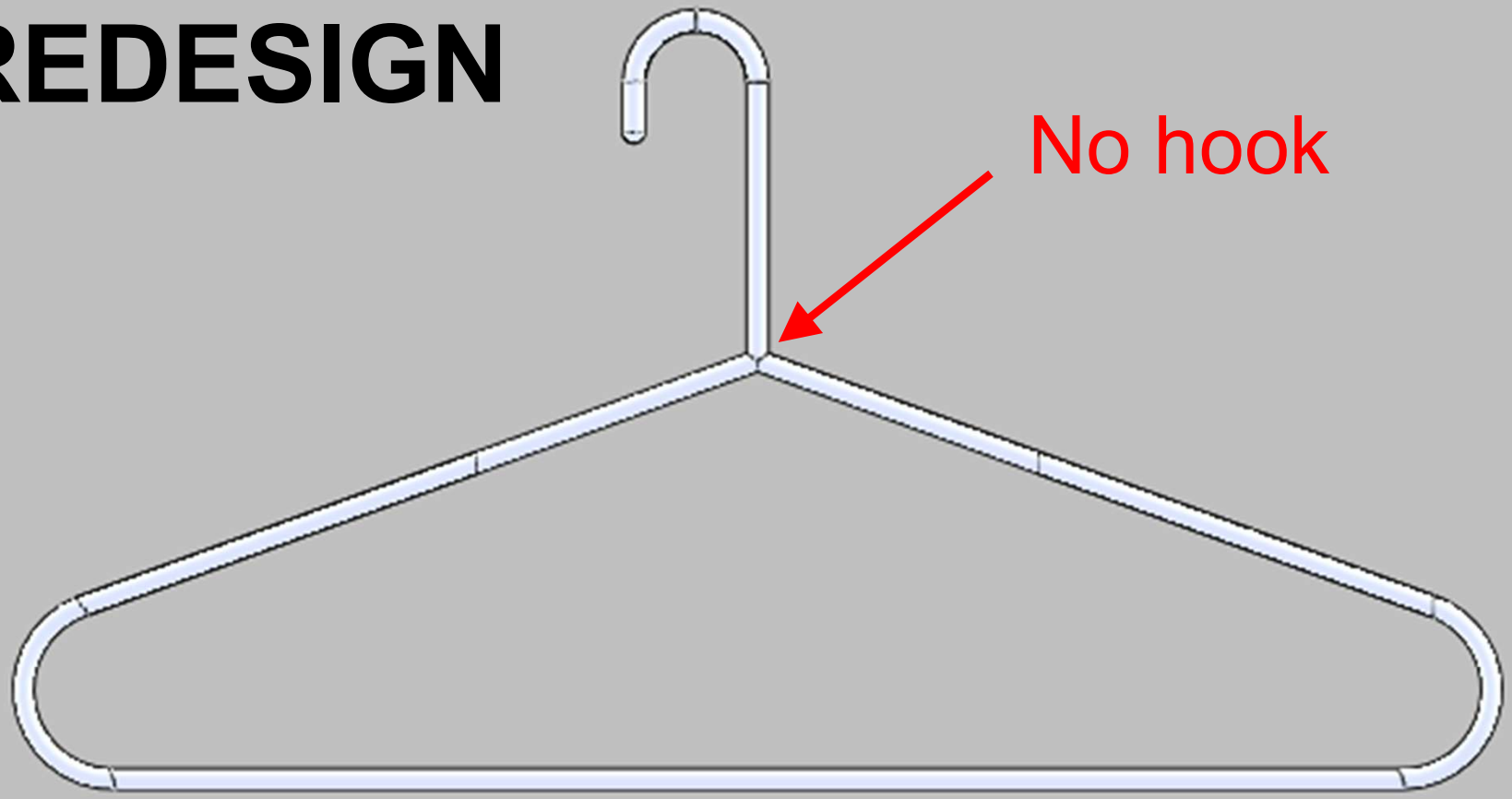
Hangers do not break easily and we are just bad users of hangers

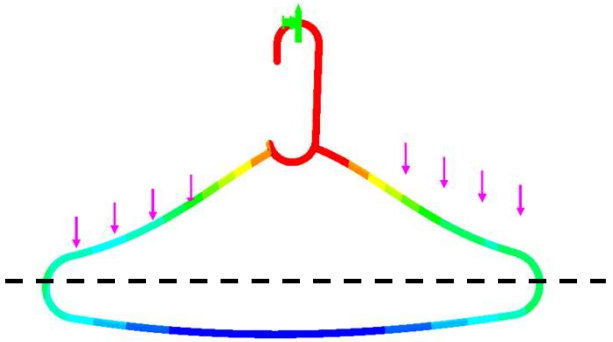
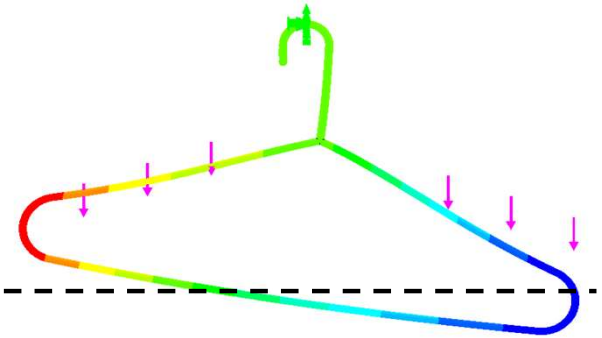
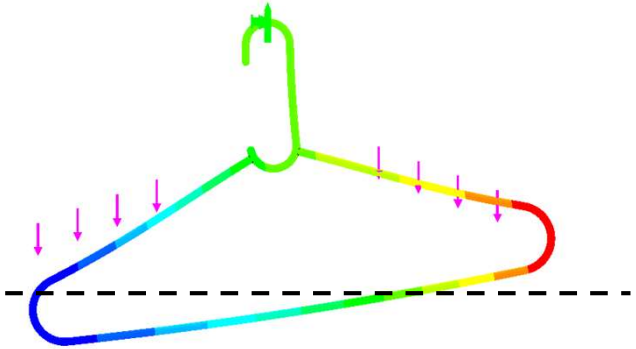
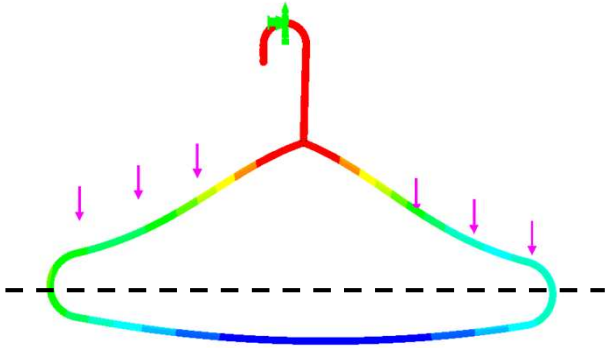
Design Implications

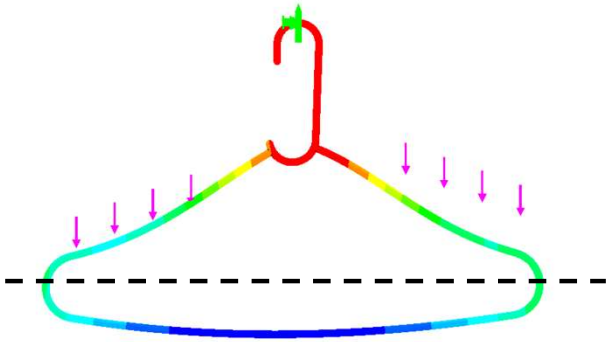
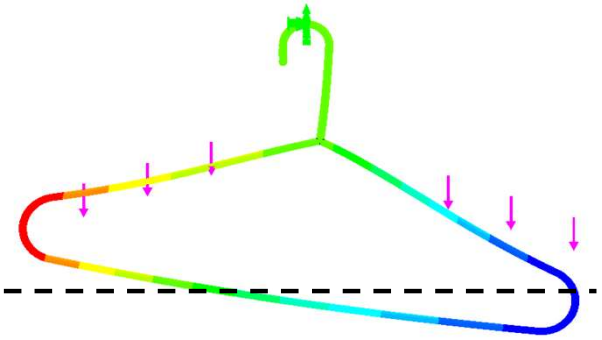
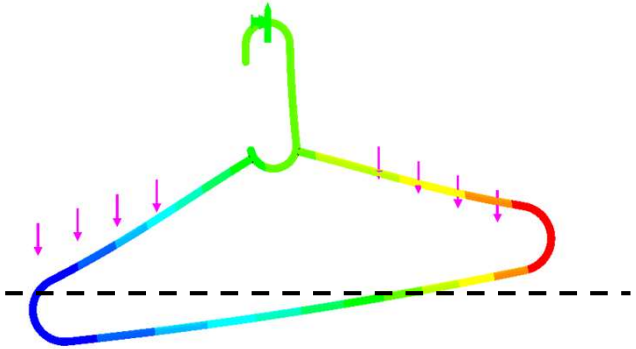
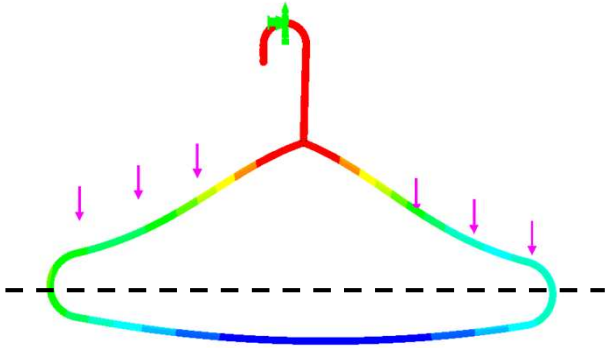

Why is the bottom of the hook curved?
Why is the cross section round?
Why are the sides curved?

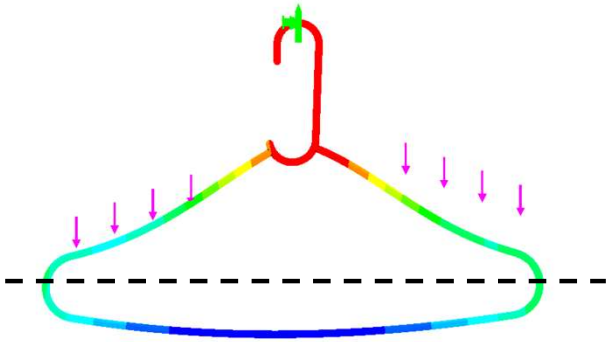
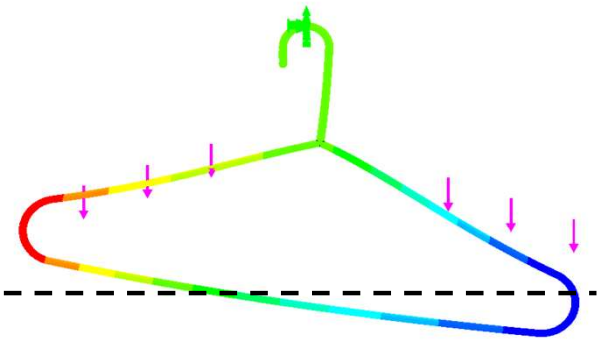
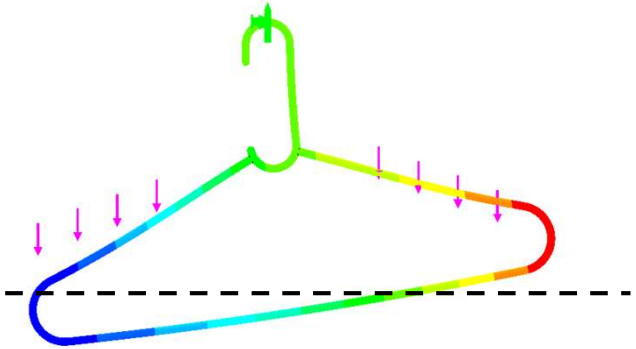
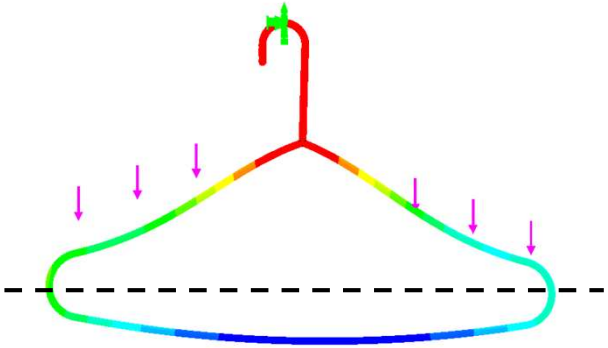

Why is the bottom of the hook curved?
Why is the cross section round?
Why are the sides curved?

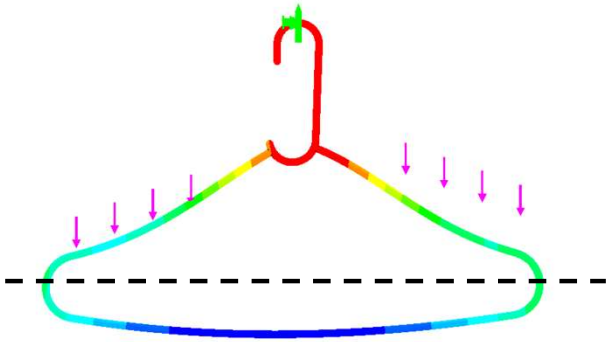
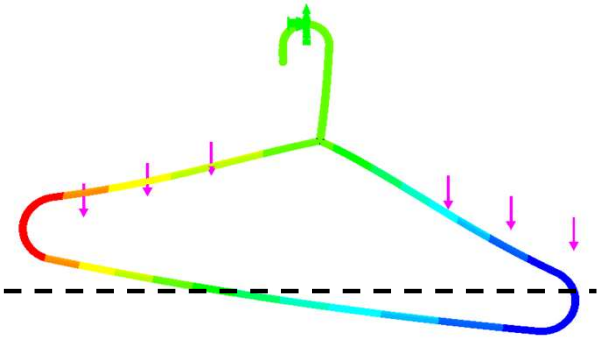
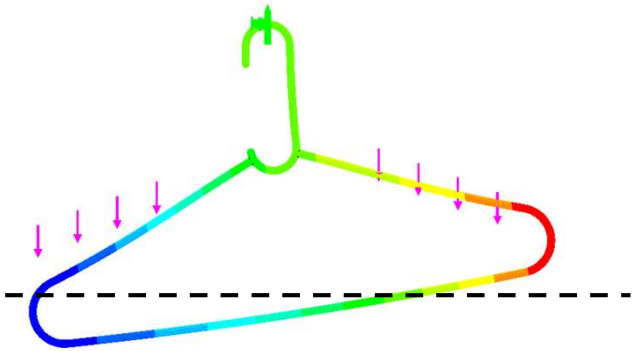
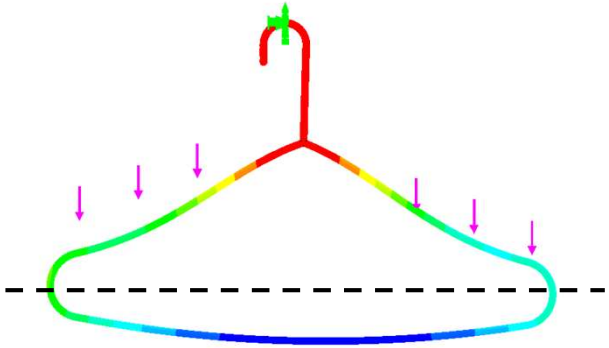
REDESIGN

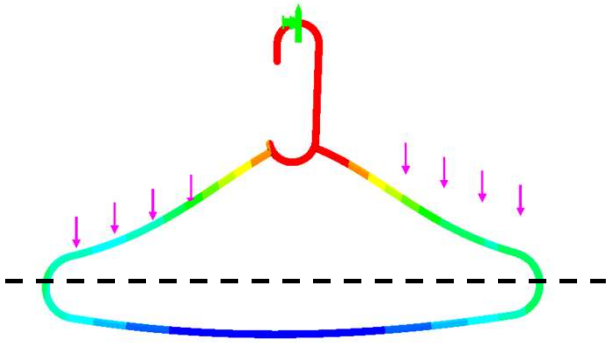
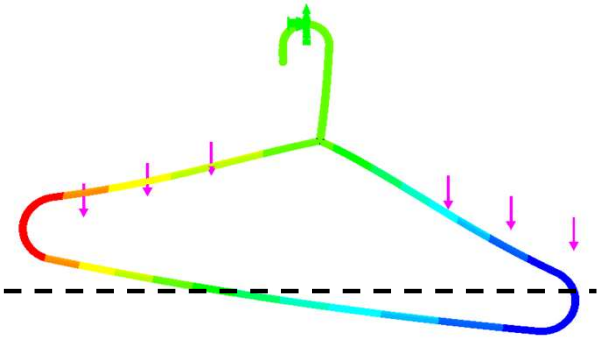
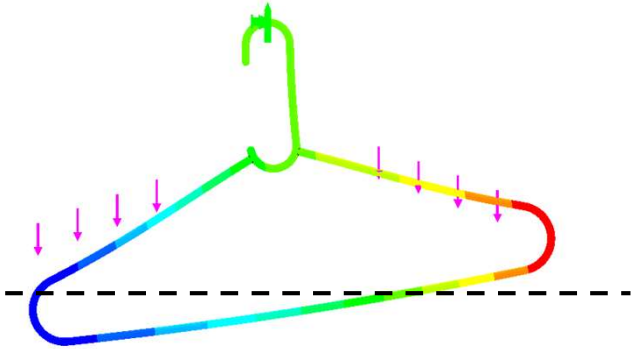
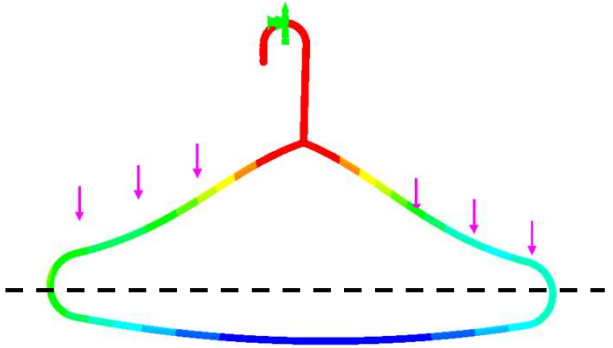


	ORIGINAL	REDESIGN
UNEVEN LOAD (current)		
EVEN LOAD (desired)		

	ORIGINAL	REDESIGN
UNEVEN LOAD (current)		
EVEN LOAD (desired)		

	ORIGINAL	REDESIGN
UNEVEN LOAD (current)		
EVEN LOAD (desired)		

	ORIGINAL	REDESIGN
UNEVEN LOAD (current)		
EVEN LOAD (desired)		

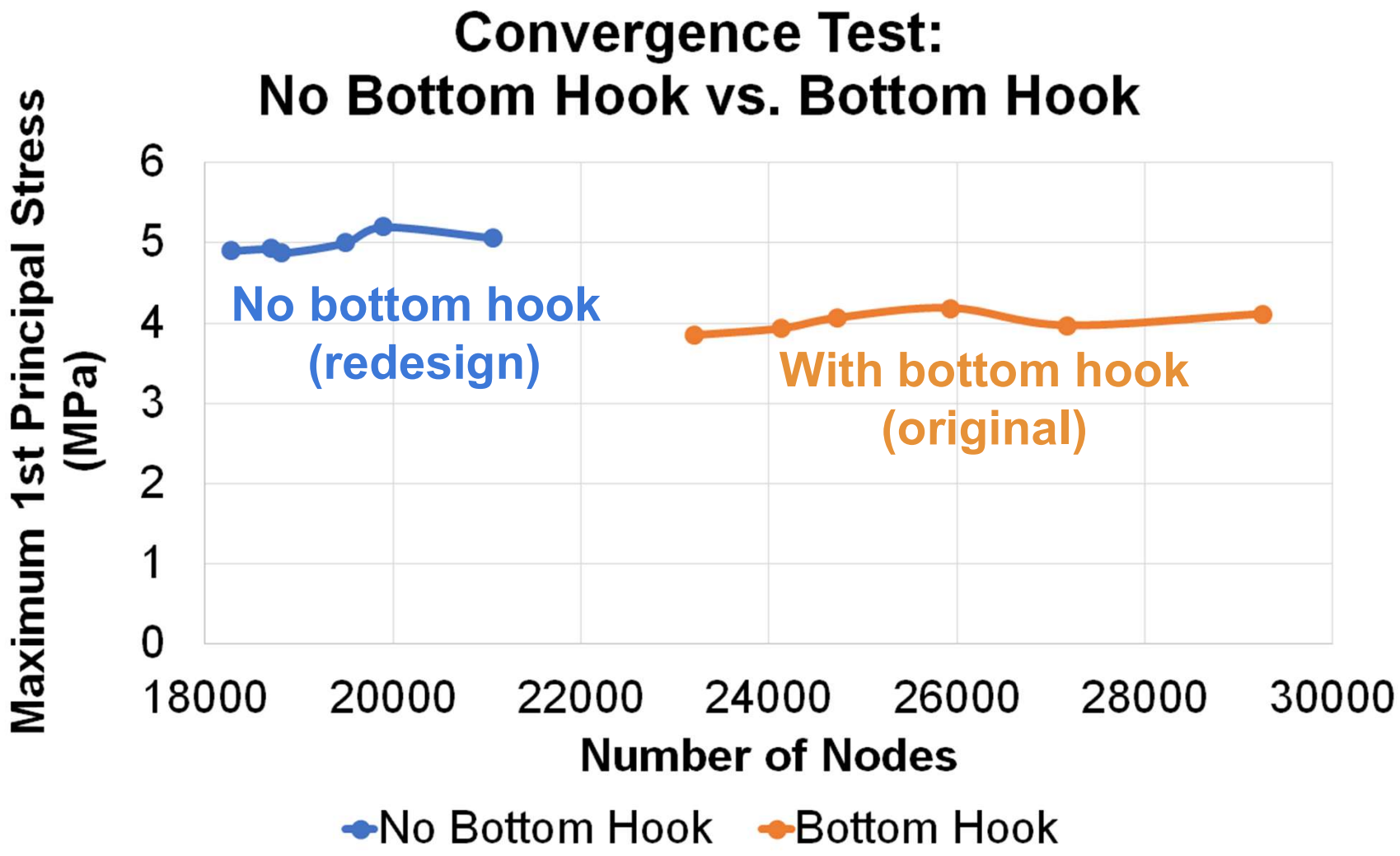
	ORIGINAL	REDESIGN
UNEVEN LOAD (current)		
EVEN LOAD (desired)		

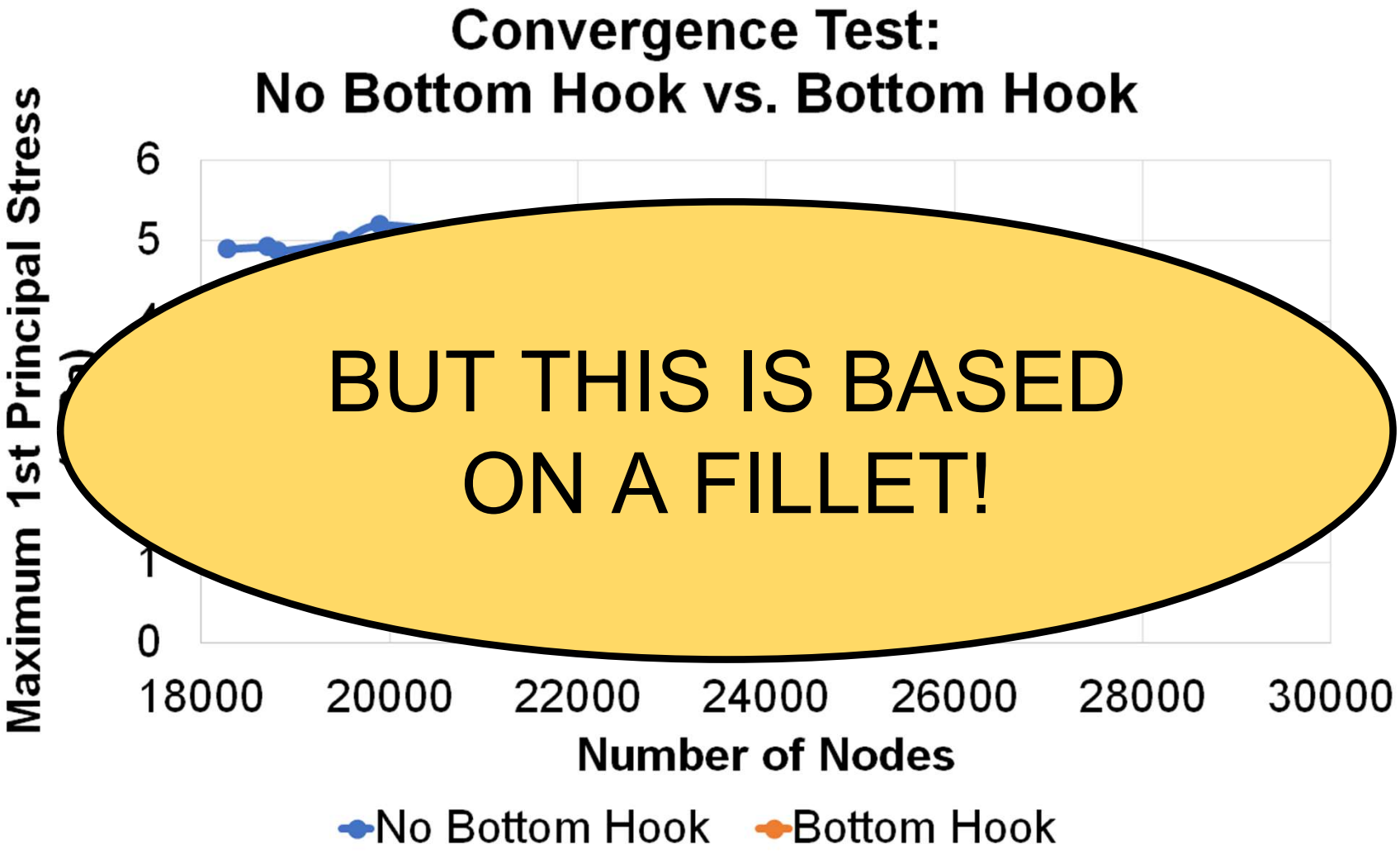
	ORIGINAL	REDESIGN
UNEVEN LOAD (cur		
EVEN LOAD (desired)		

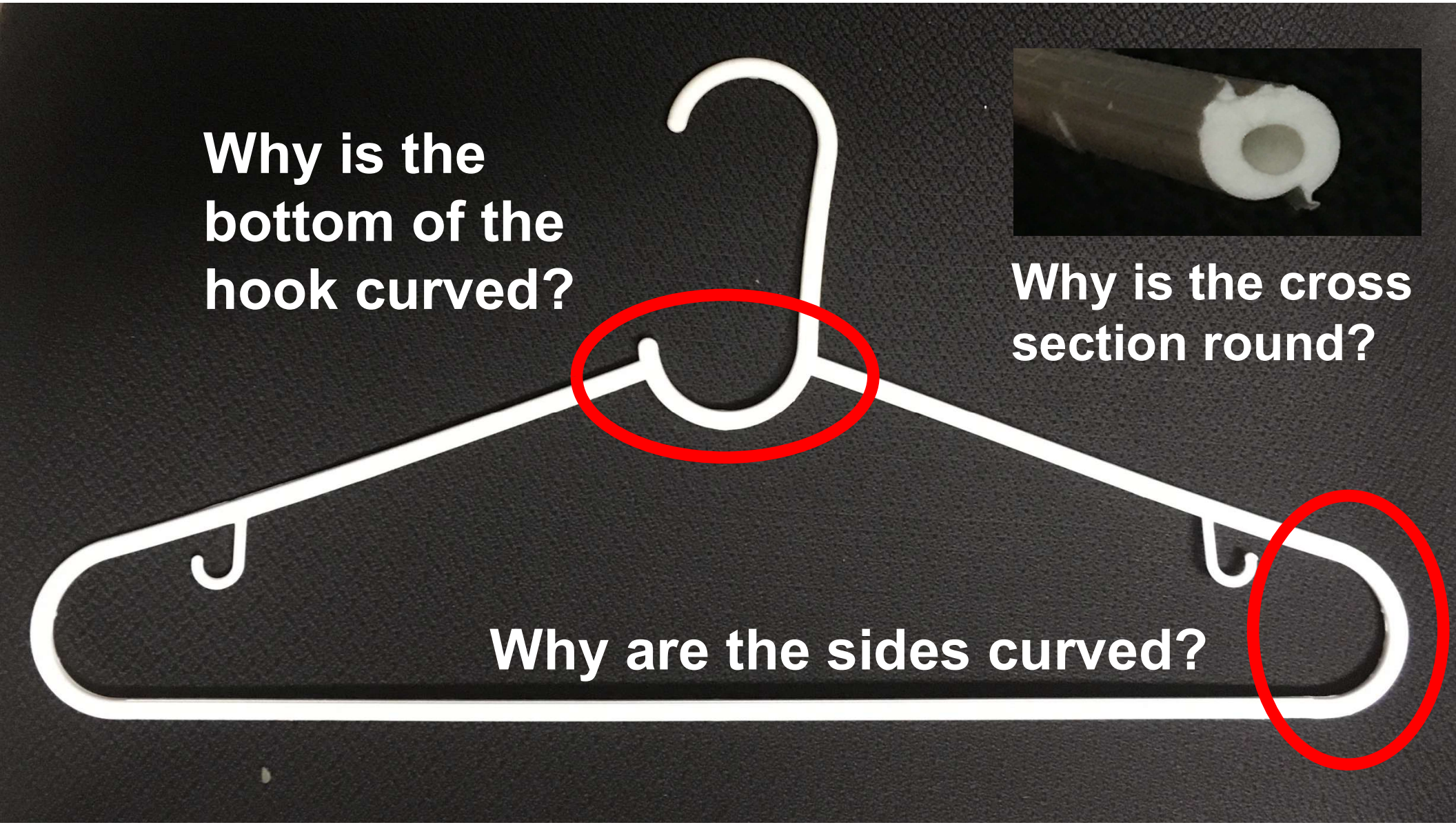
DISPLACEMENT IS NOT THE REASON

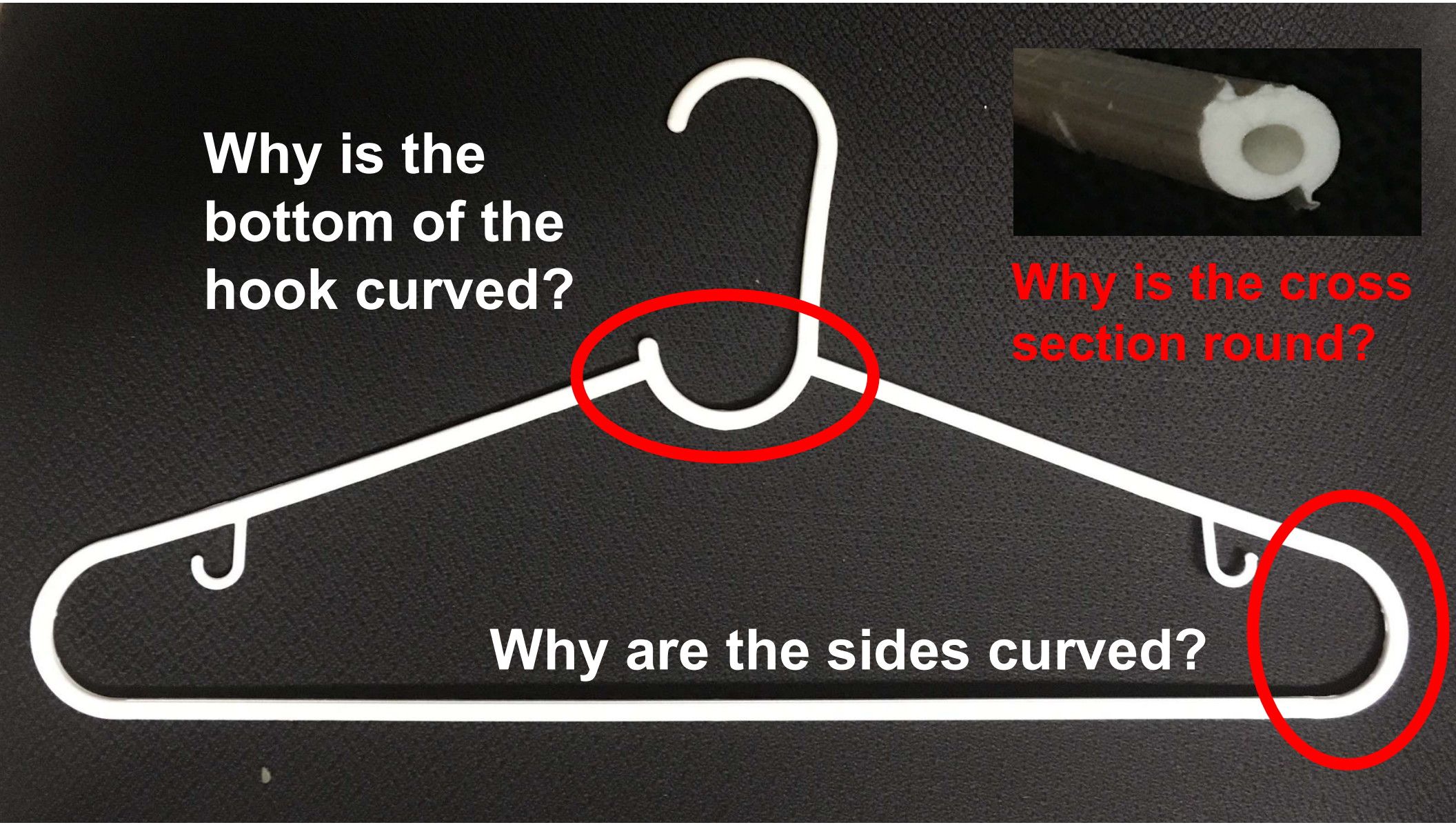
	ORIGINAL	REDESIGN
UNEVEN LOAD (cur		
EVEN LOAD (desired)		

MAYBE STRESS IS THE REASON?

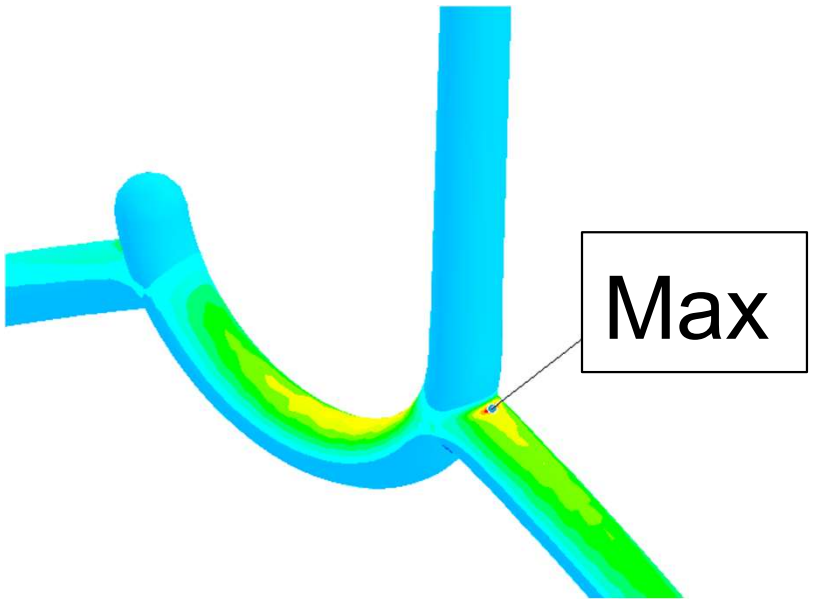

Convergence Test:
No Bottom Hook vs. Bottom Hook
Maximum 1st Principal Stress (MPa)
6
5
4
3
2
1
0
No bottom hook (redesign)
With bottom hook (original)
18000
20000
22000
24000
26000
28000
30000
Number of Nodes
No Bottom Hook
Bottom Hook


Convergence Test:
No Bottom Hook vs. Bottom Hook
Maximum 1st Principal Stress
6
5
0
18000
20000
22000
24000
26000
28000
30000
Number of Nodes
No Bottom Hook
Bottom Hook
BUT THIS IS BASED
ON A FILLET!


Why is the bottom of the hook curved?
Why is the cross section round?
Why are the sides curved?

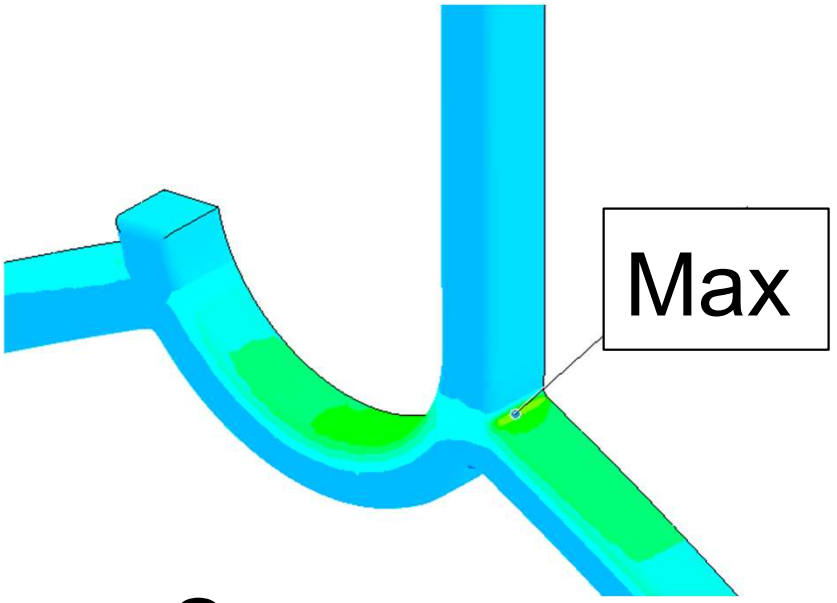

Why is the bottom of the hook curved?
Why is the cross section round?
Why are the sides curved?

FILLET, 1 MM



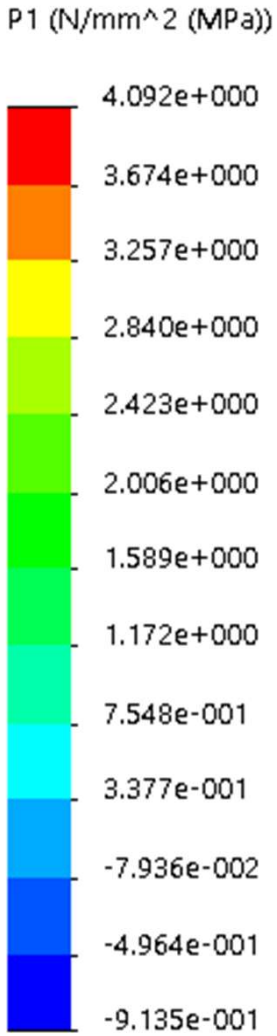
Circle

4 MPa

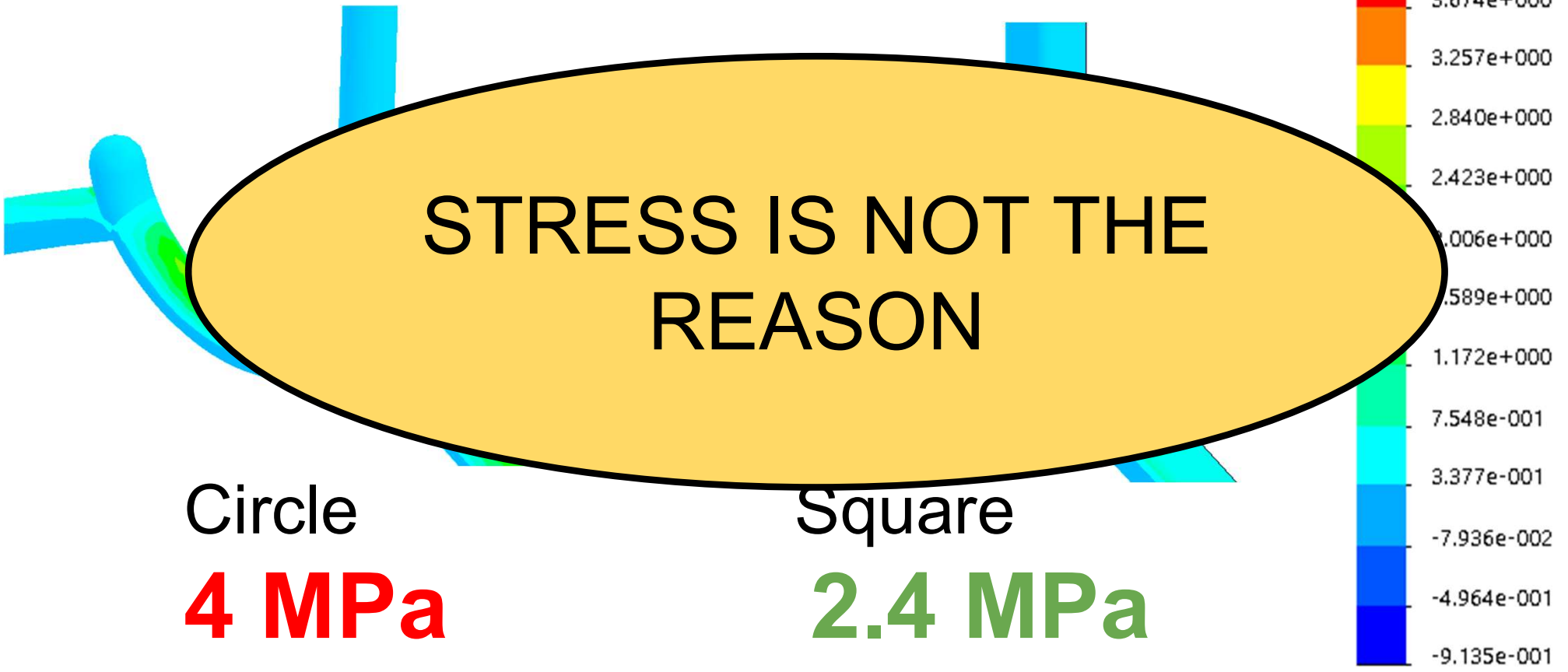


Square

2.4 MPa



FILLET, 1 MM



STRESS IS NOT THE REASON

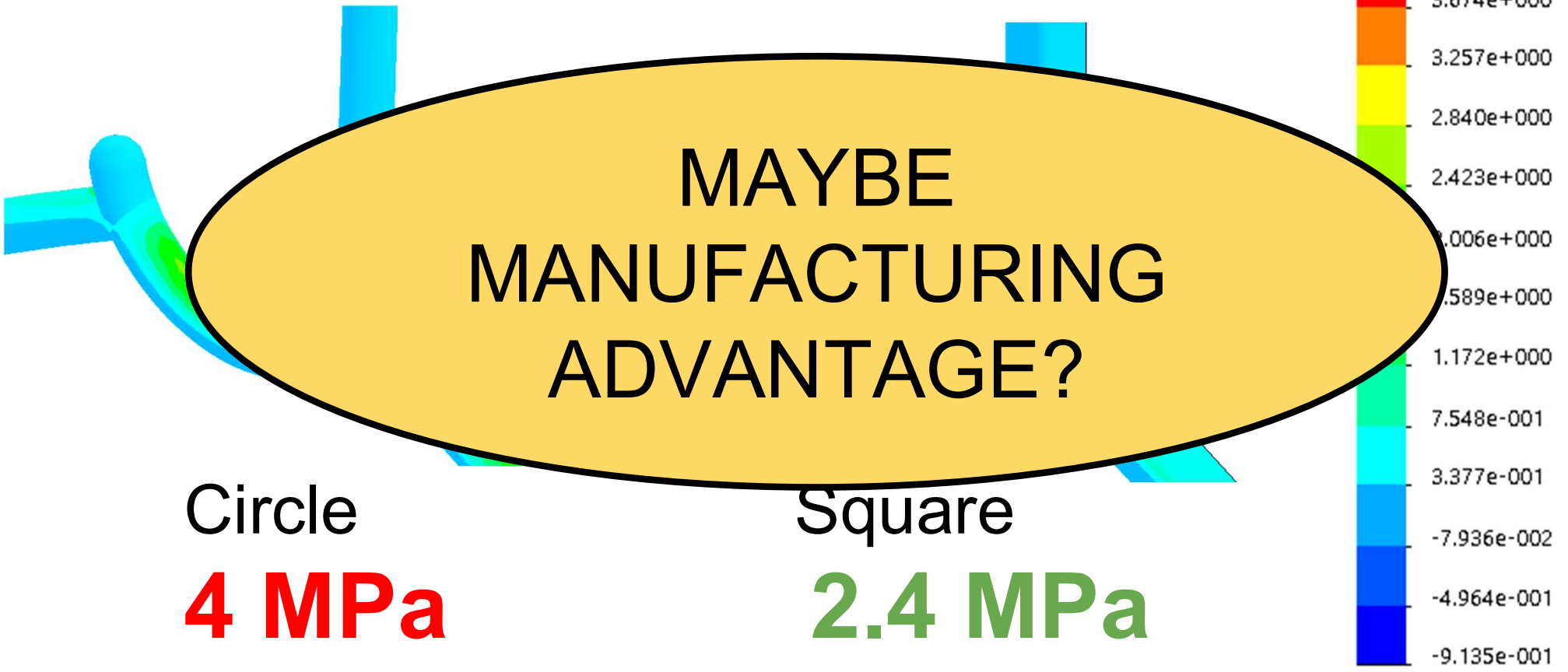
Circle

4 MPa

Square

2.4 MPa

FILLET, 1 MM



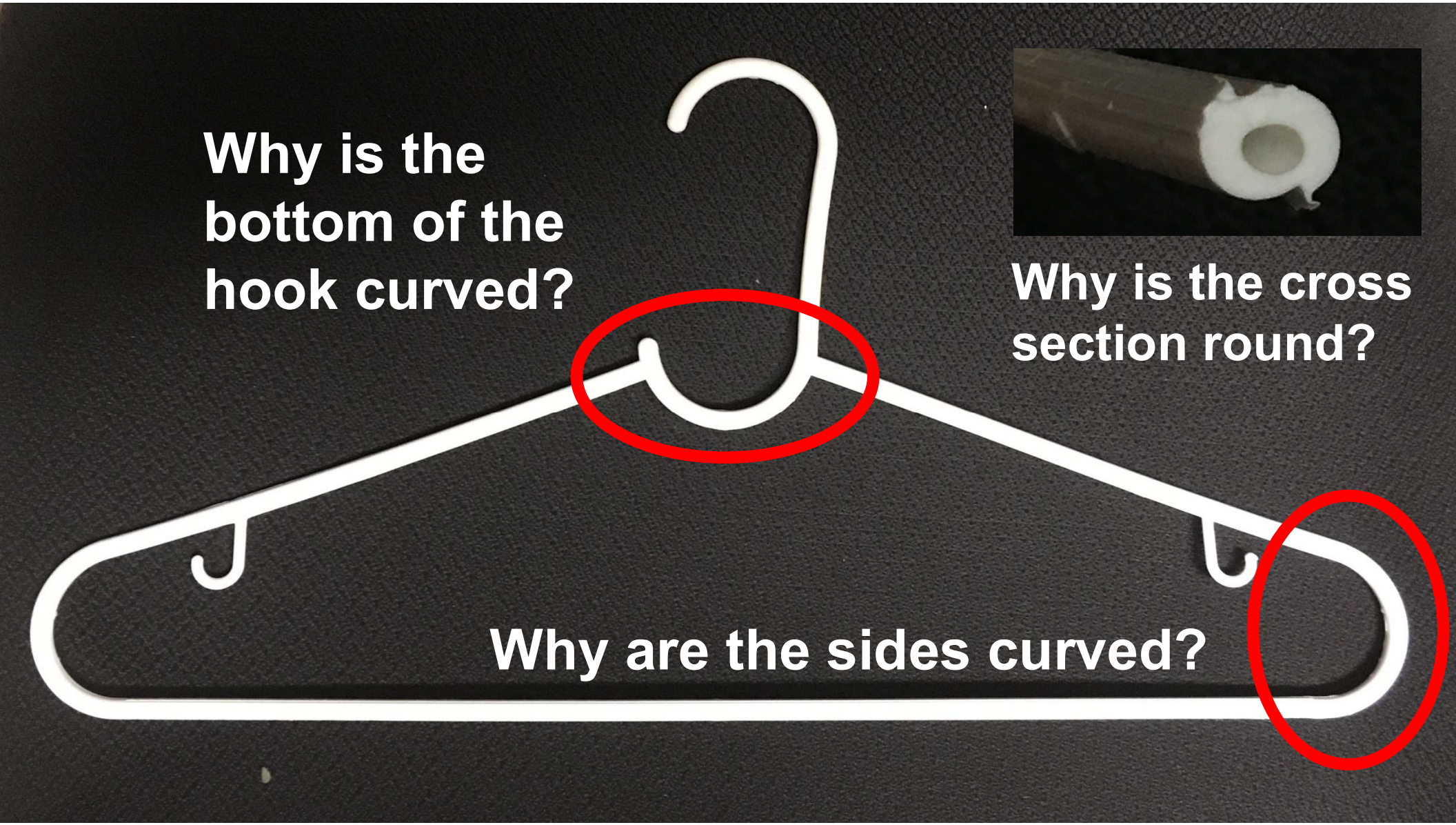
MAYBE MANUFACTURING ADVANTAGE?

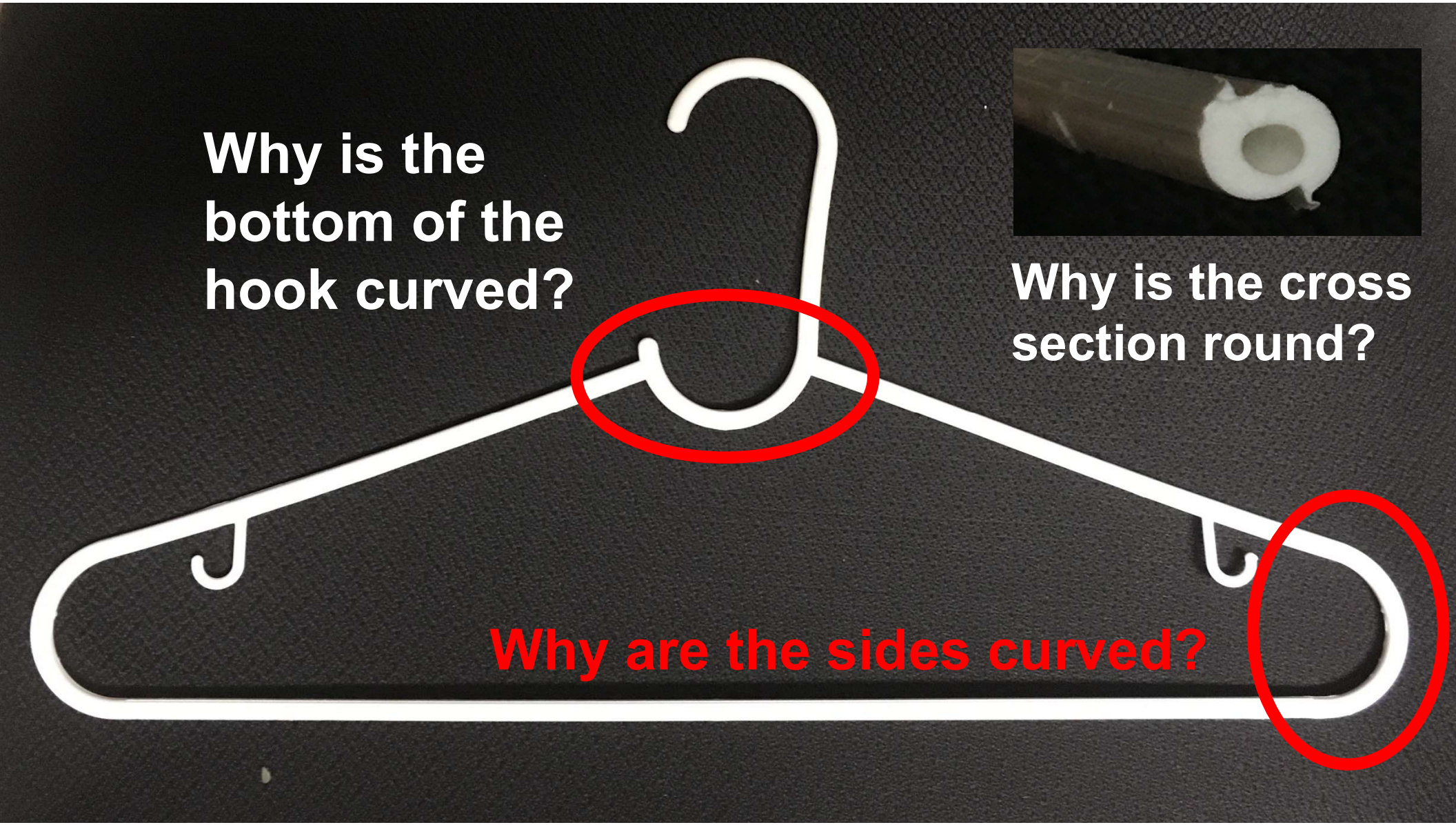
Circle

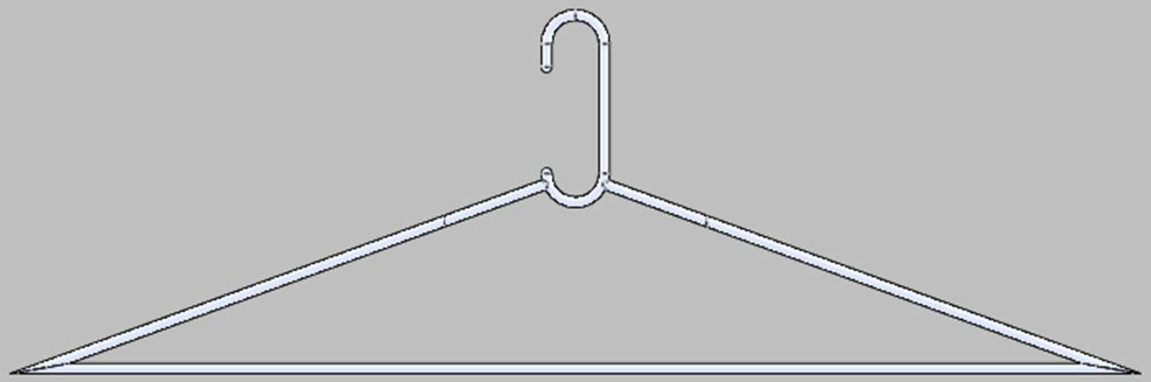
4 MPa

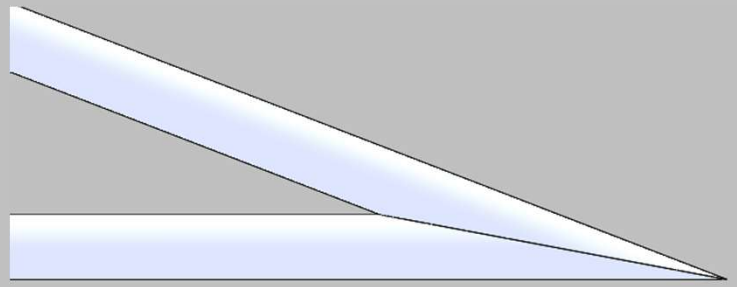
Square

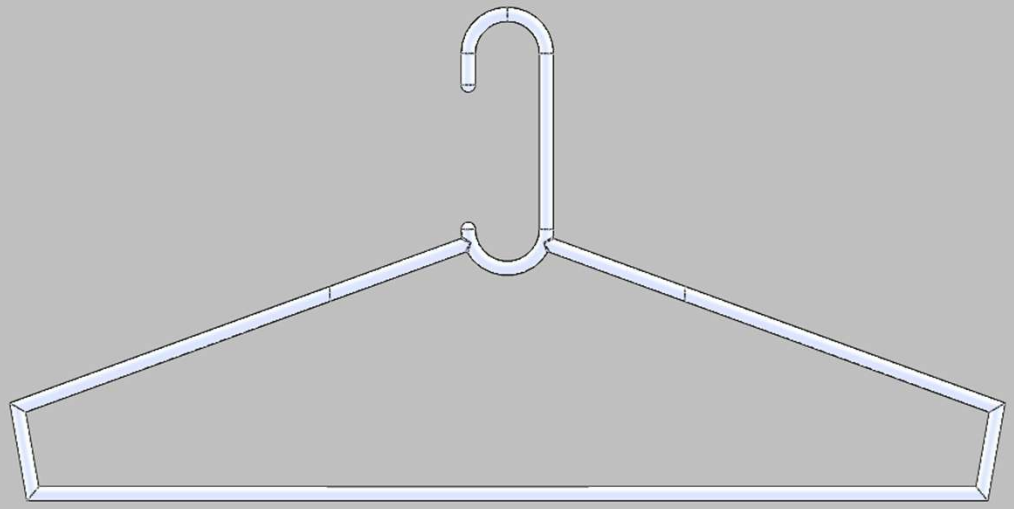
2.4 MPa

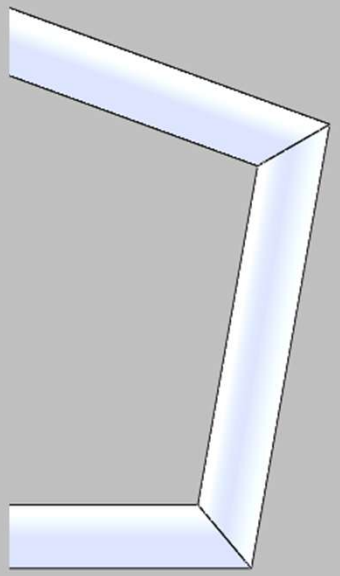

Why is the bottom of the hook curved?
Why is the cross section round?
Why are the sides curved?

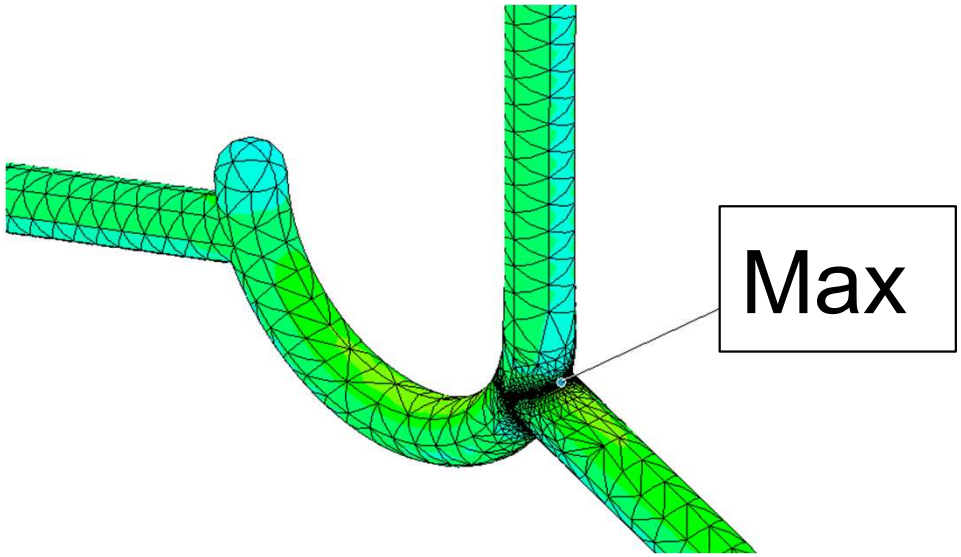

Why is the bottom of the hook curved?
Why is the cross section round?
Why are the sides curved?

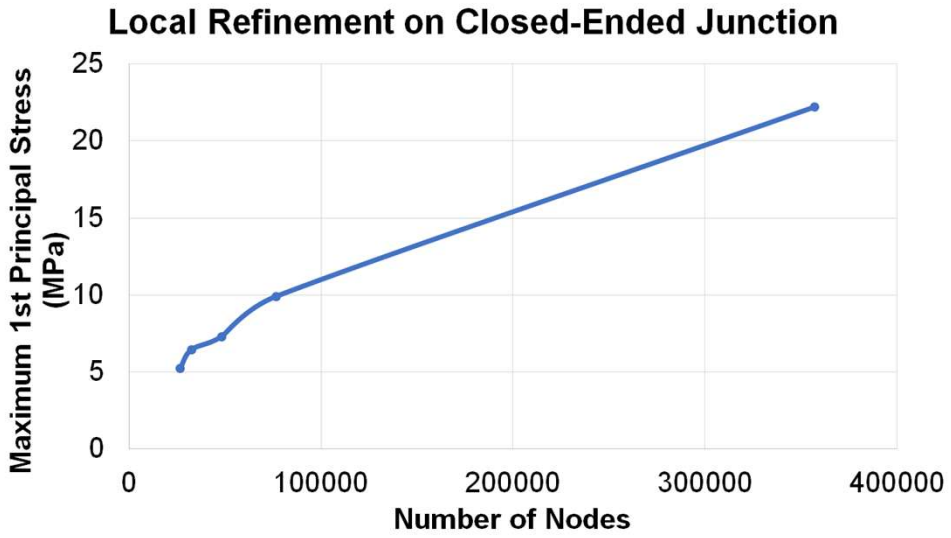


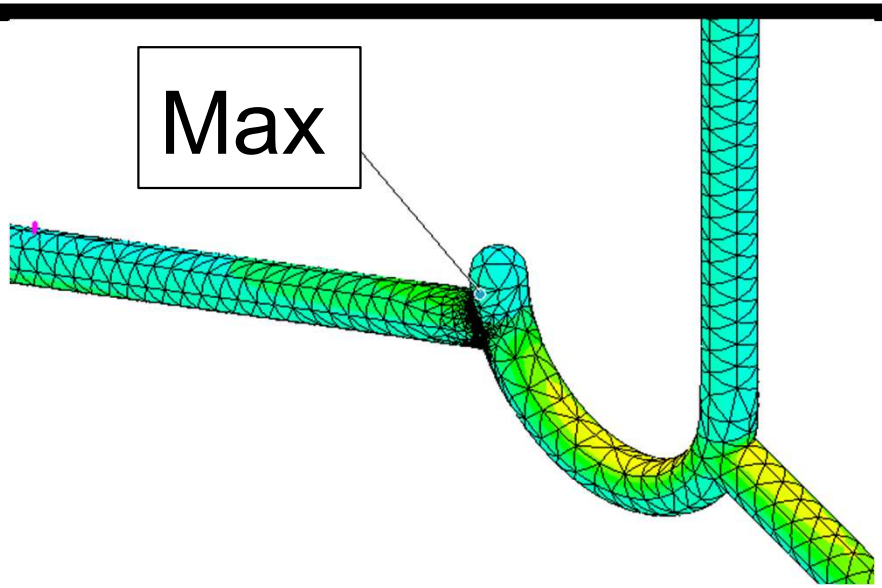


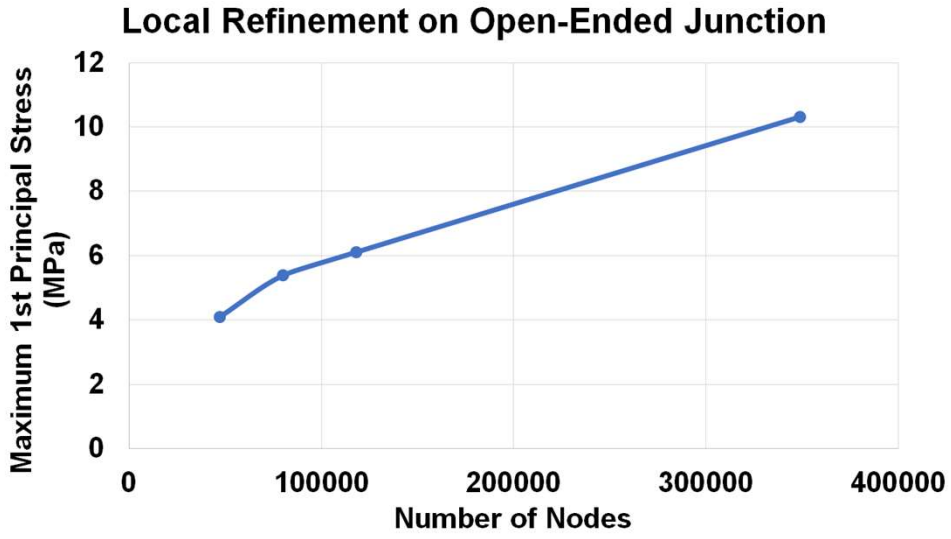


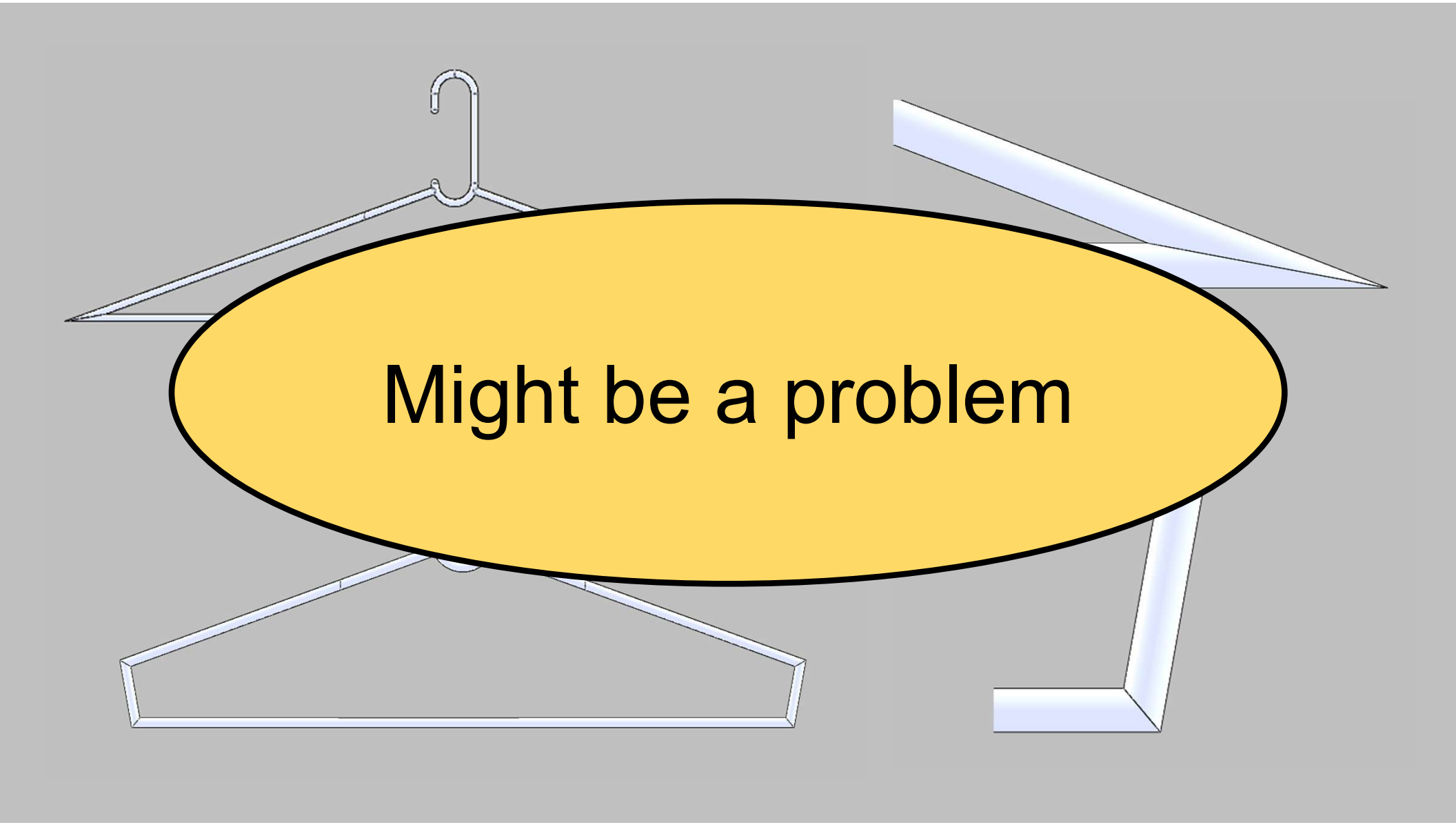


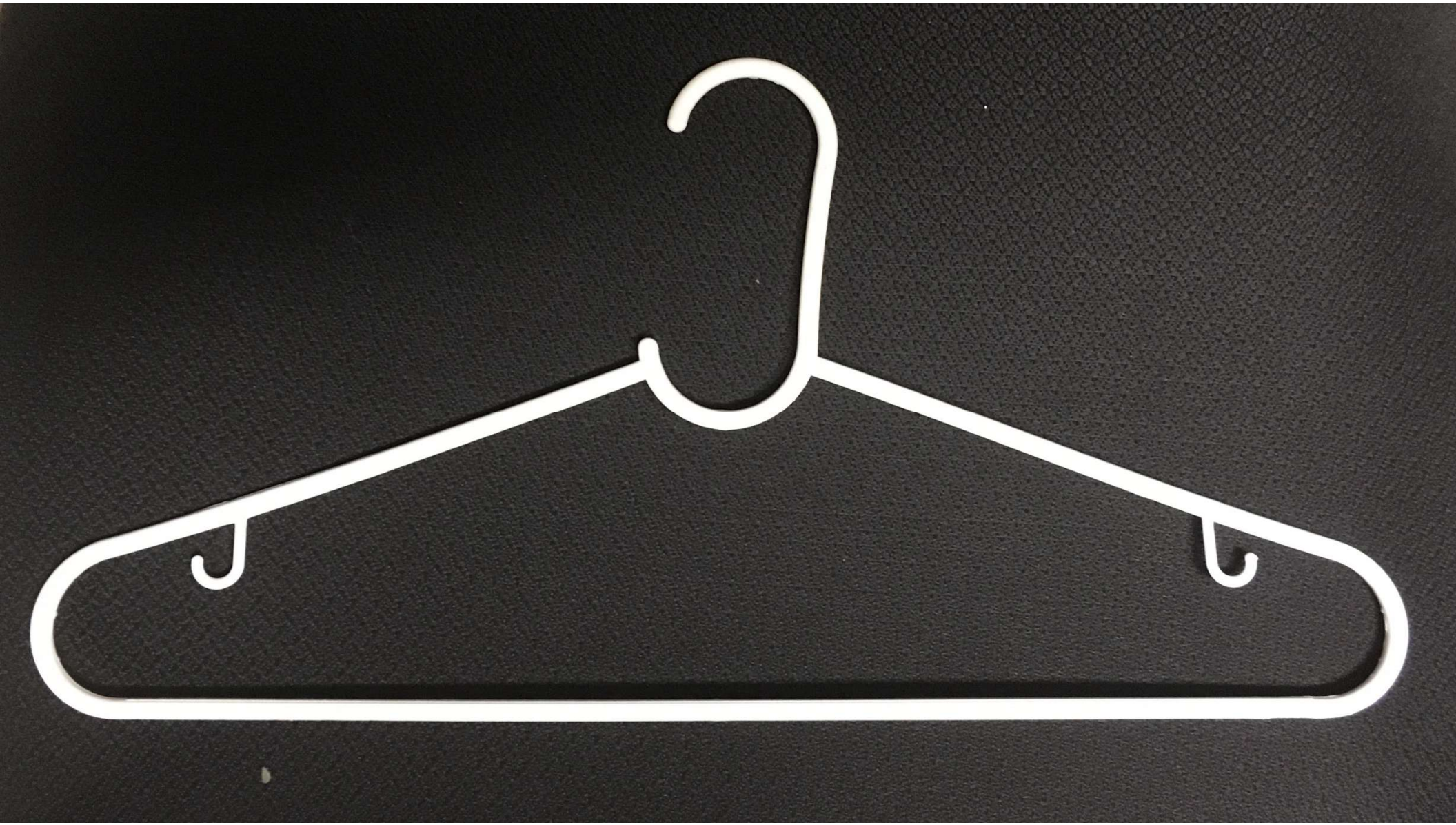

Max


Local Refinement on Closed-Ended Junction
Maximum 1st Principal Stress (MPa)
25
20
15
10
5
0
0
100000
200000
300000
400000
Number of Nodes


Max


Local Refinement on Open-Ended Junction
Maximum 1st Principal Stress (MPa)
12
10
8
6
4
2
0
0
100000
200000
300000
400000
Number of Nodes


Might be a problem




Good design!

Conclusion

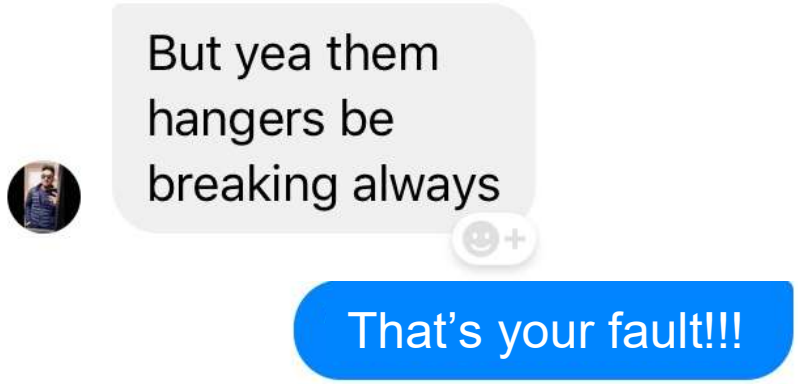
- Stress singularity is an FEA problem and we do not know enough to work our way around it

- Proper use of FEA requires the use of good engineering judgement

NO ENGINEERING PROBLEM CAN BE SOLVED, BECAUSE THERE ARE ALWAYS TOO MANY UNKNOWNS

So conclusion?

Bajinder is a bad user of hangers.



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