

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...

NOV 9, 7:14 PM

Bajinder

My clothes hanger broke today

What say?

Where did it break?

Bajinder

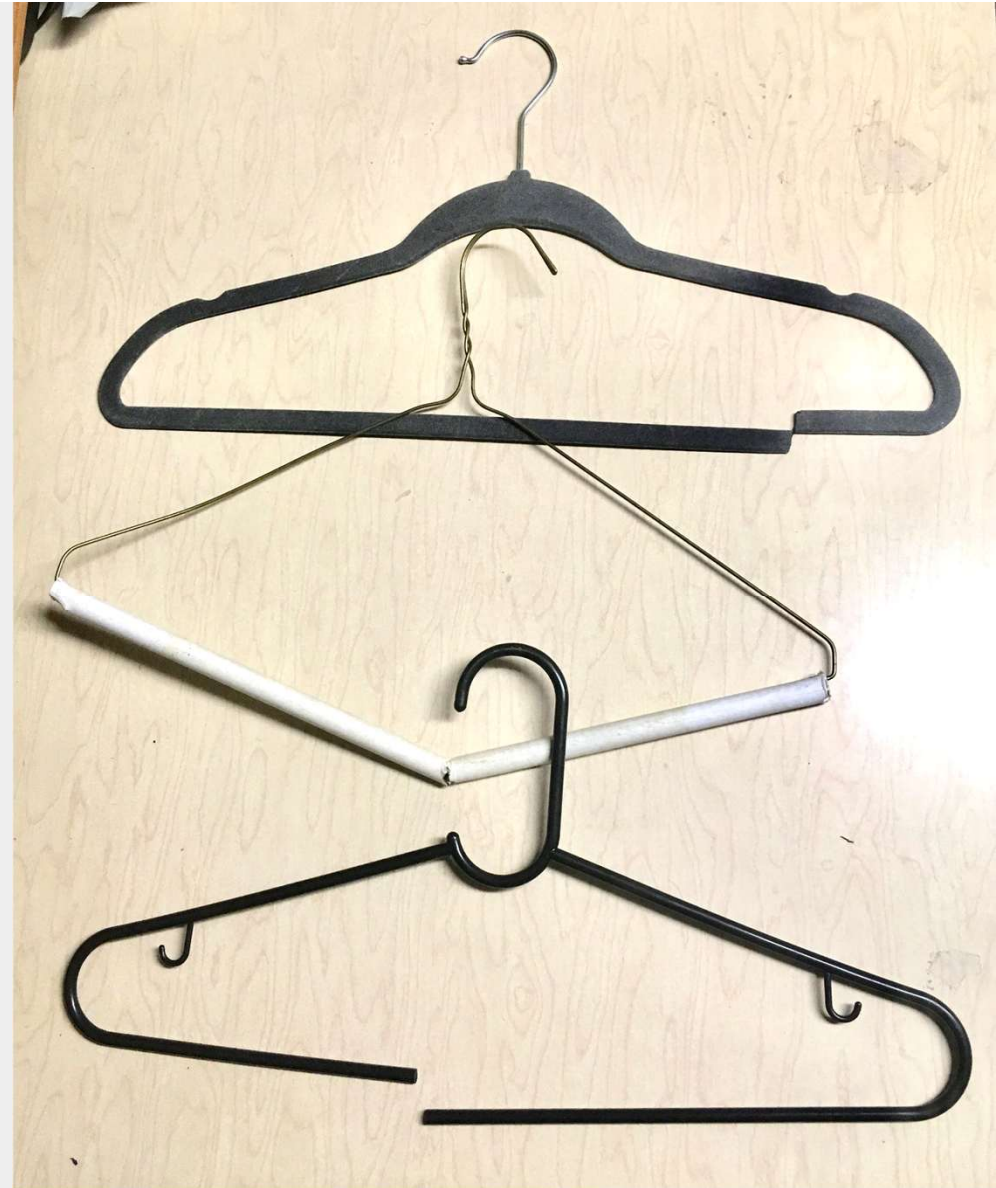
Not where you would expect lol

But yea them hangers be breaking always



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 \approx 2 kg)

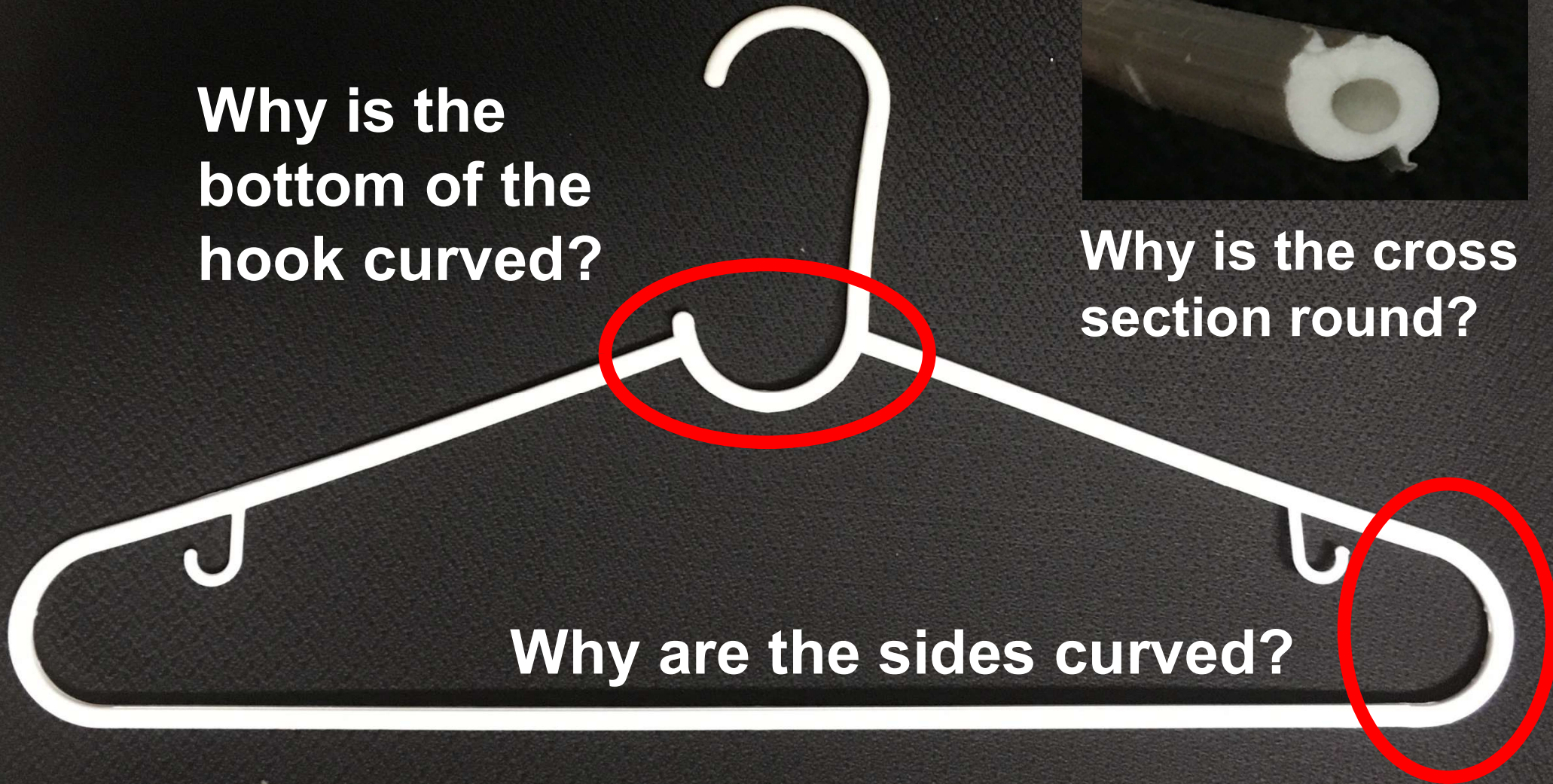


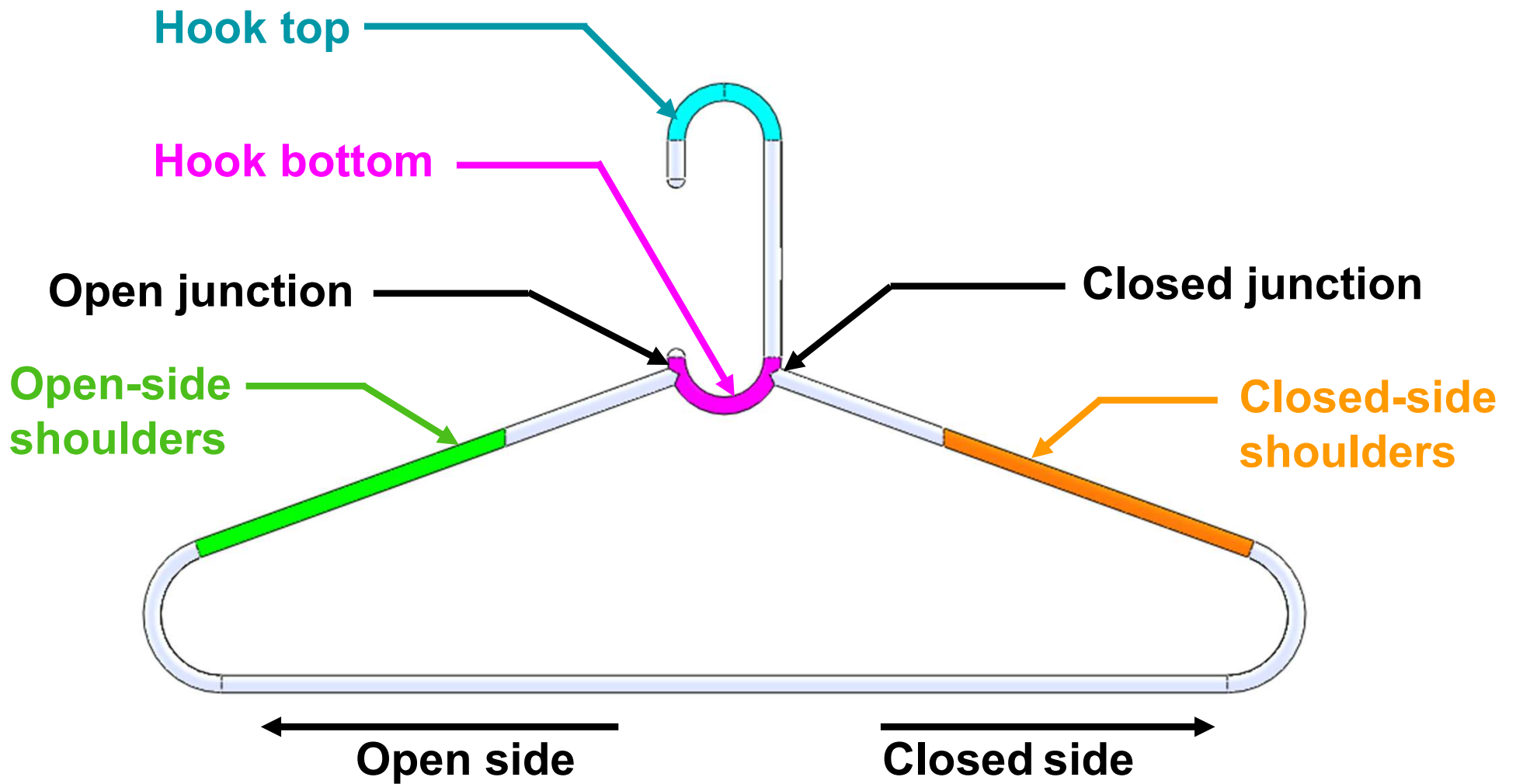
Why is the bottom of the hook curved?



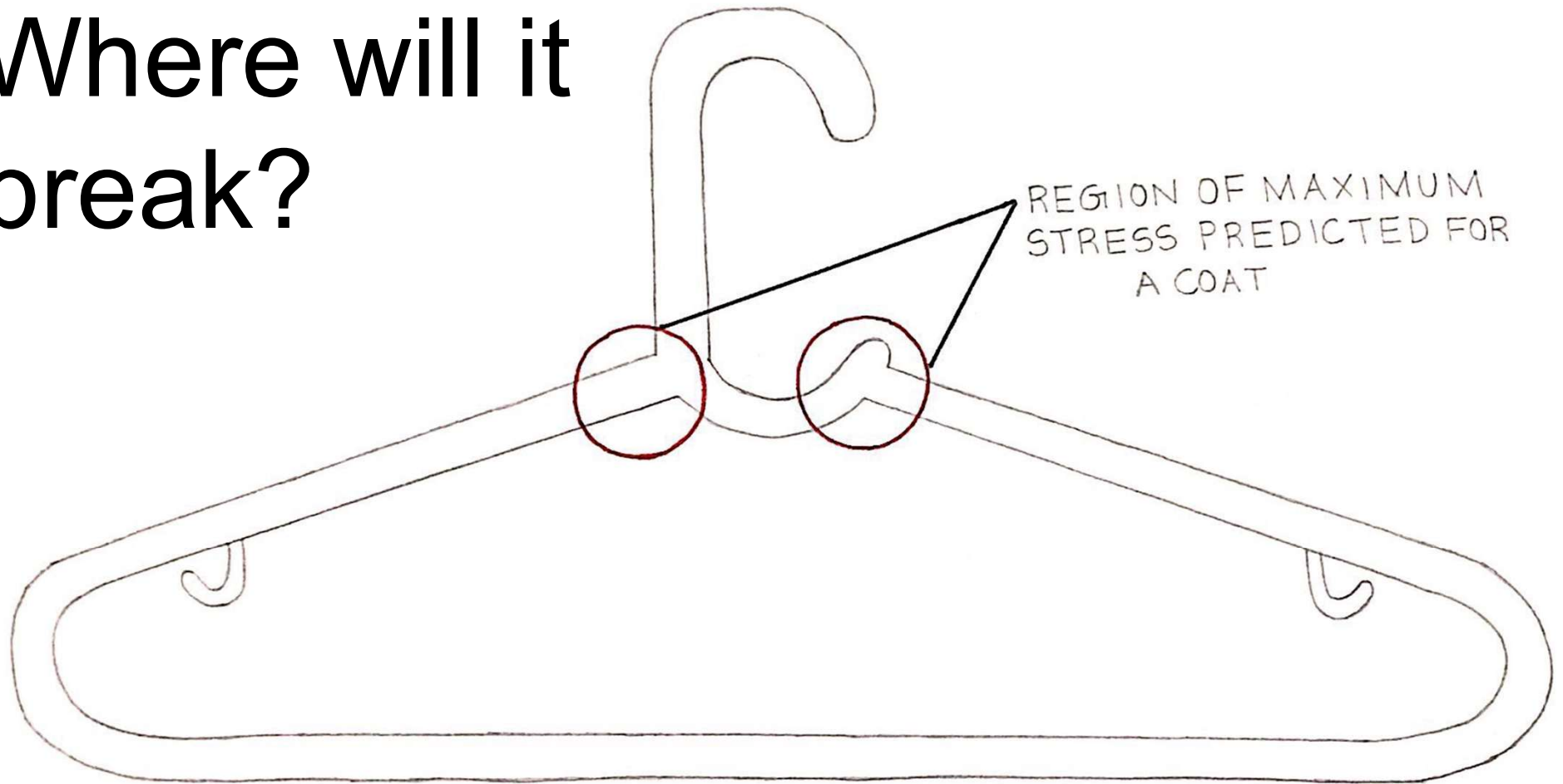
Why is the cross section round?

Why are the sides curved?





Where will it
break?



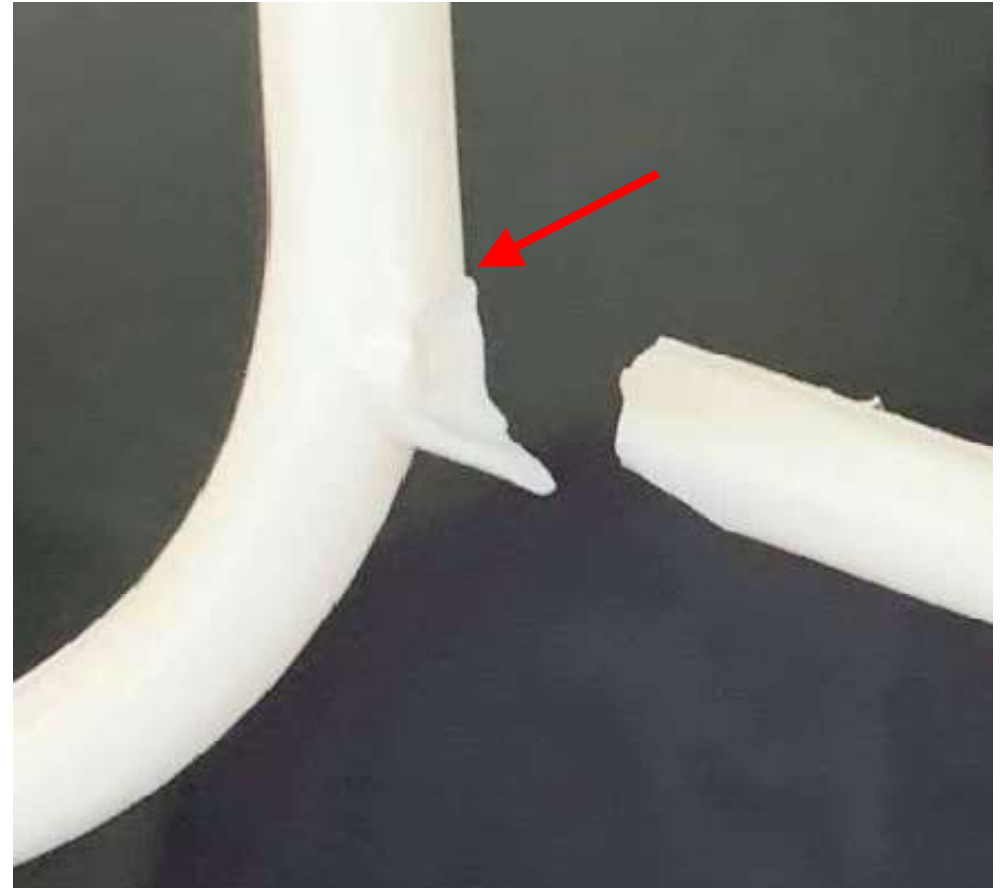
Experiments



Uneven load to balance hanger

Jacket (1.7 kg)

Jacket + weights in pocket (6.1 kg)



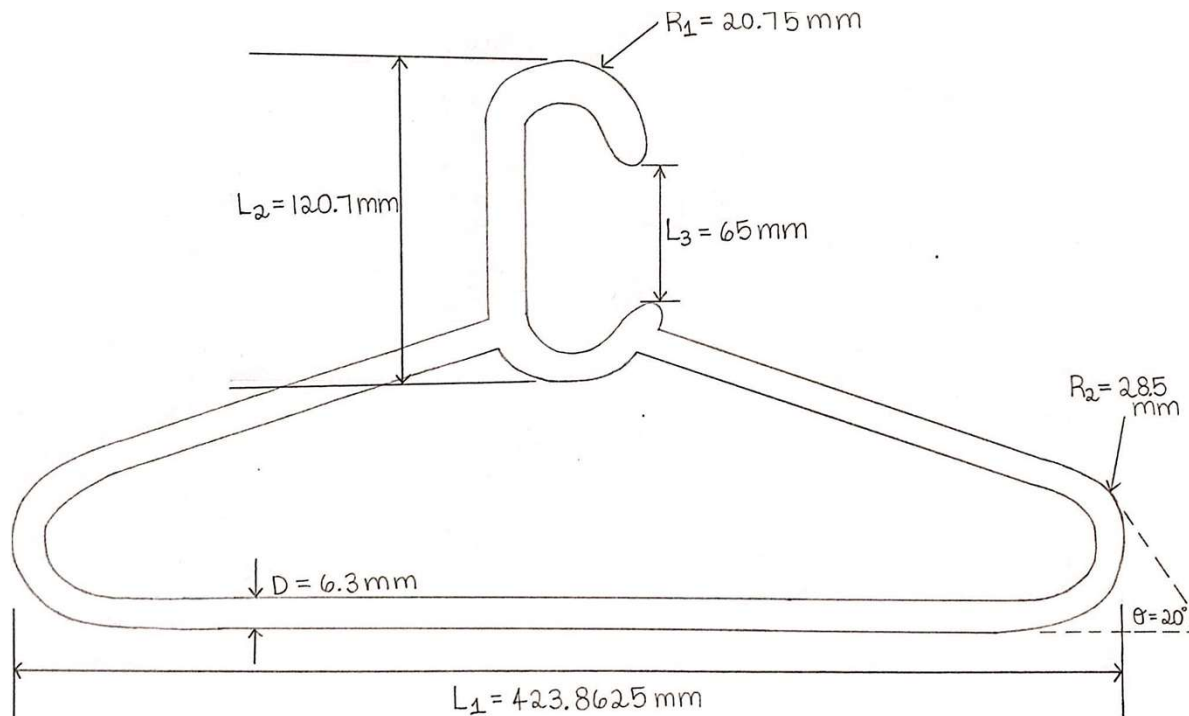
Brittle fracture by tension

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

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

Geometry

MEASUREMENTS

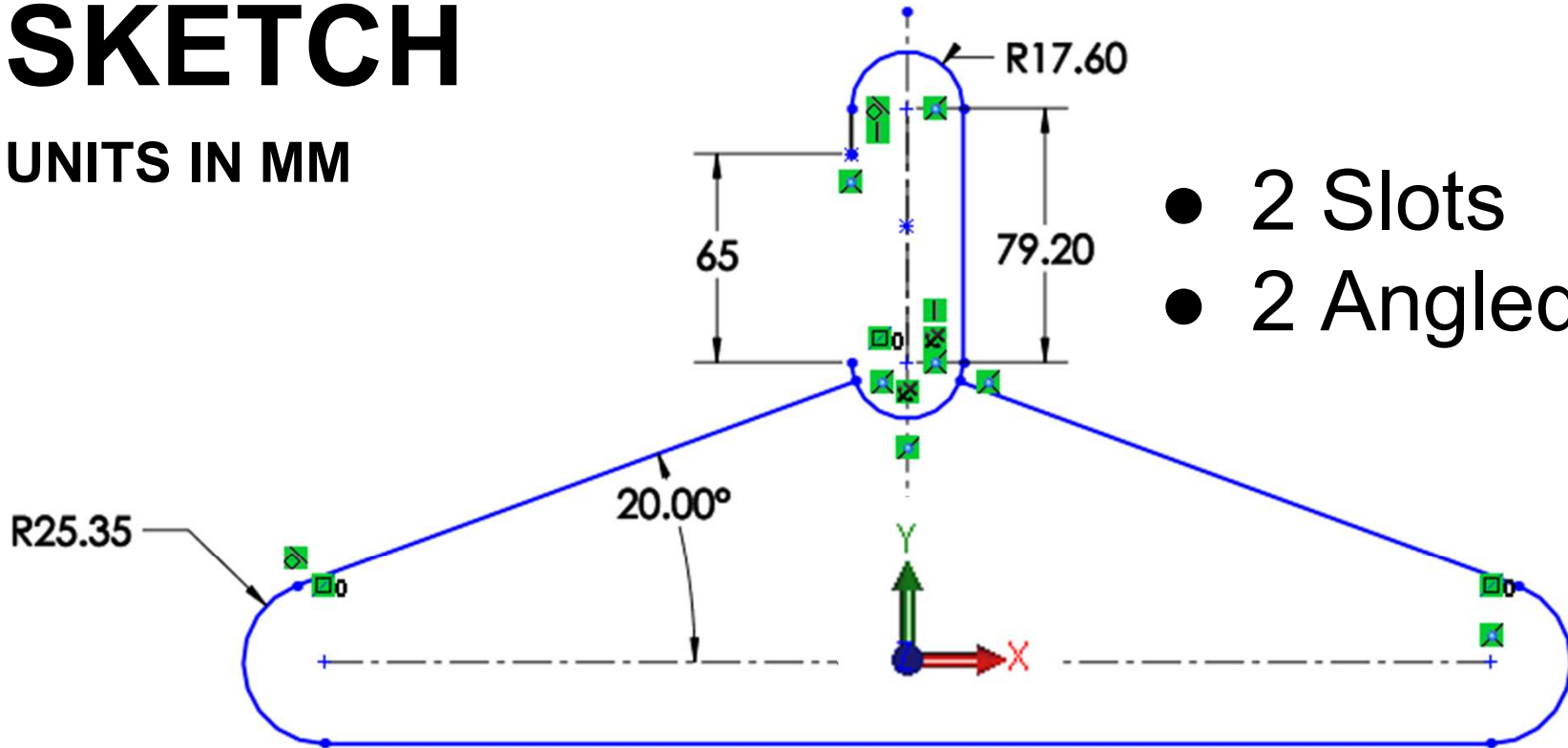


ASSUMPTION

- Vertically symmetric (except for the hook opening)

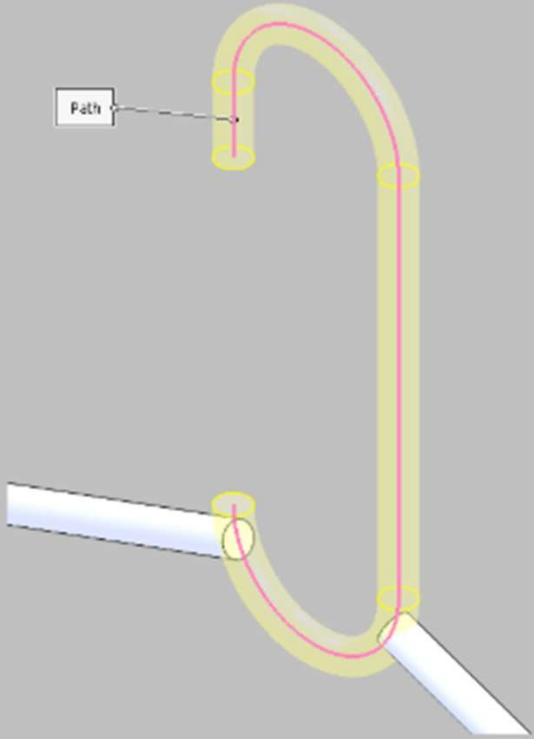
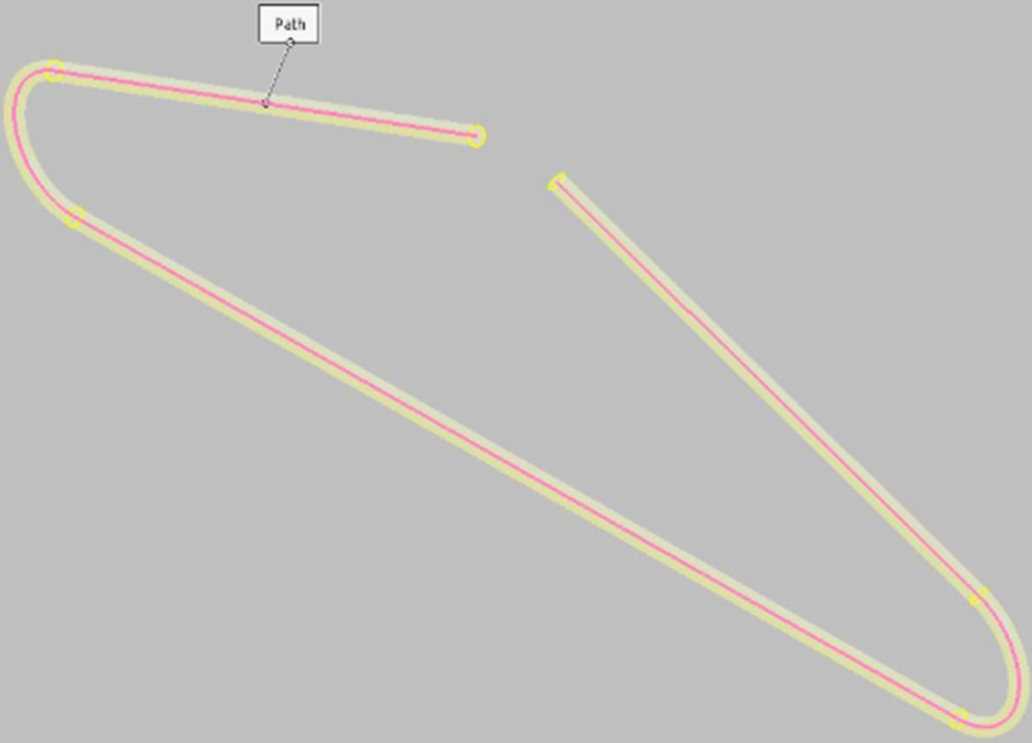
SKETCH

UNITS IN MM

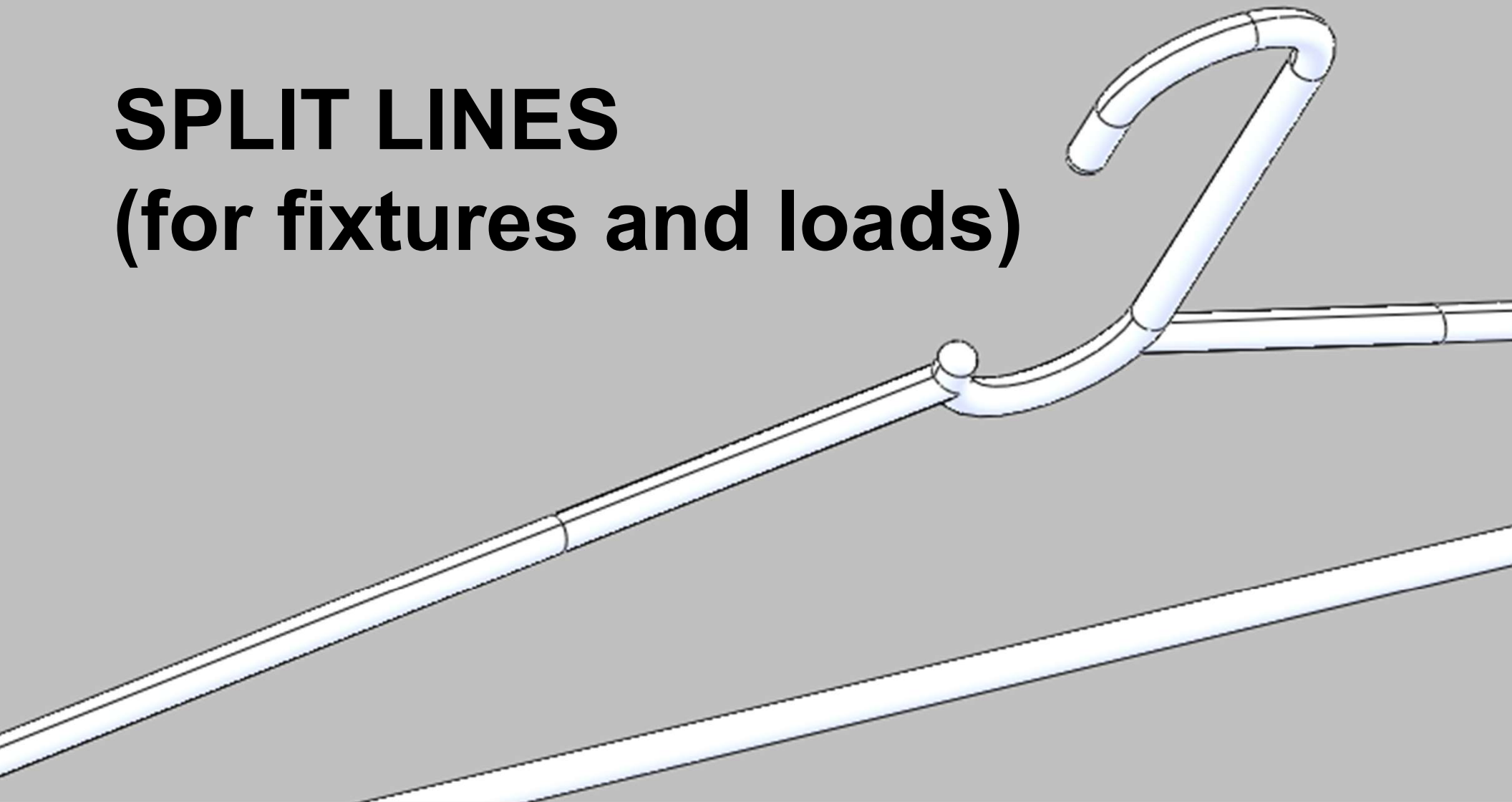


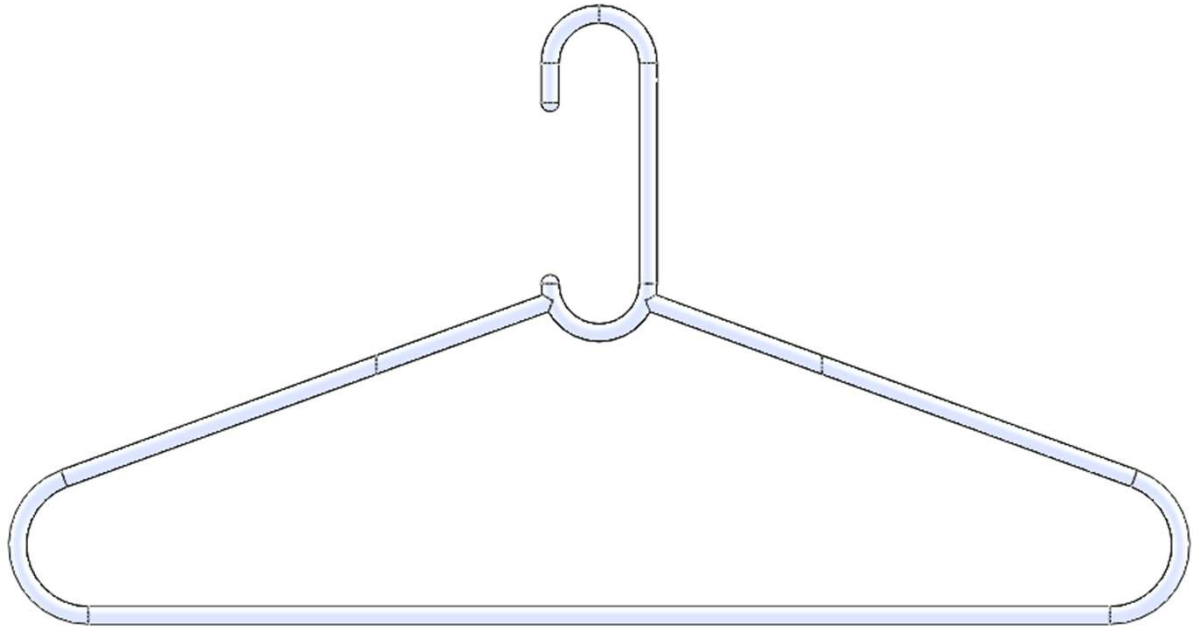
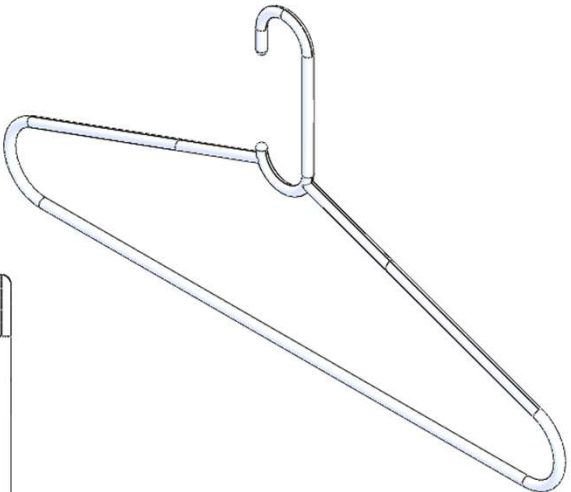
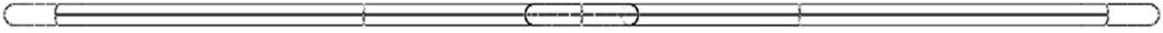
- 2 Slots
- 2 Angled lines

CIRCULAR SWEEP

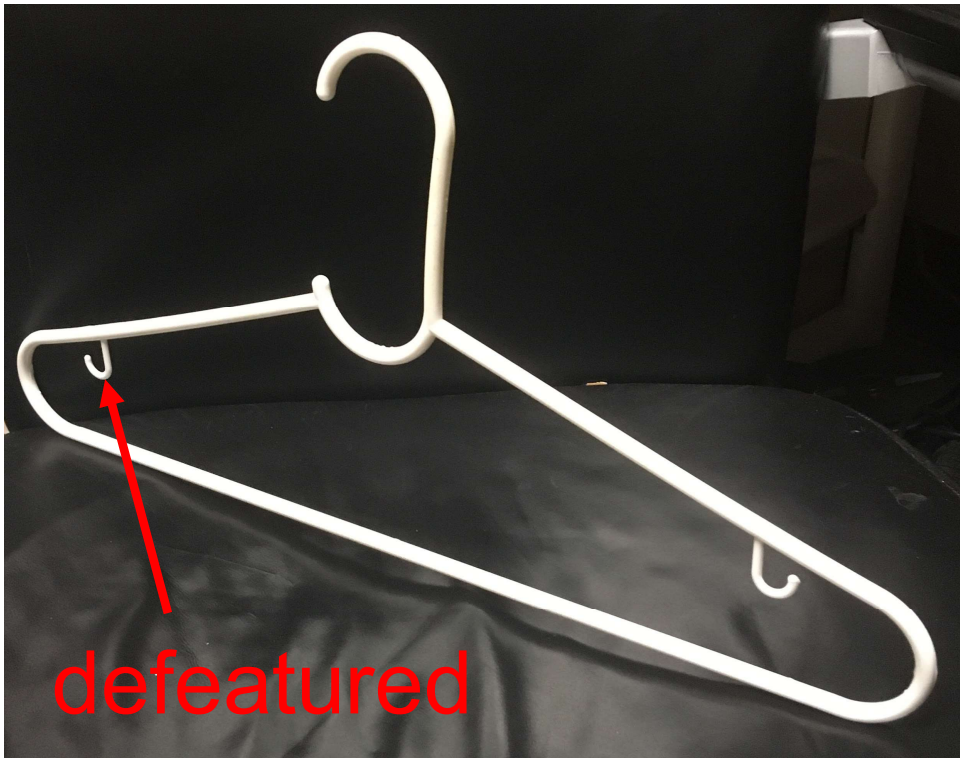


SPLIT LINES **(for fixtures and loads)**

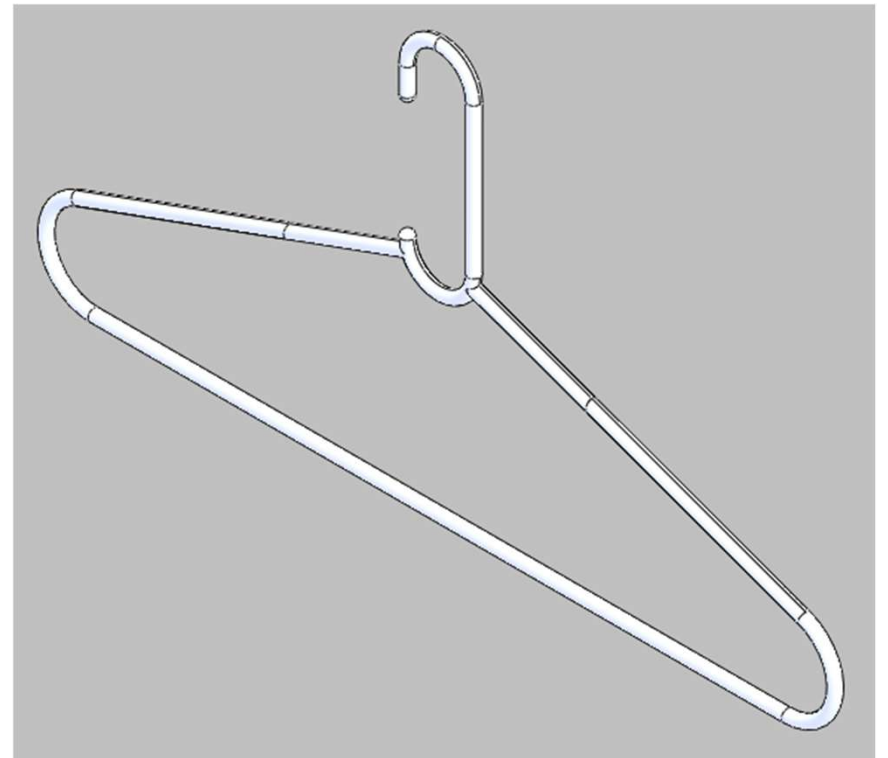




Real Object

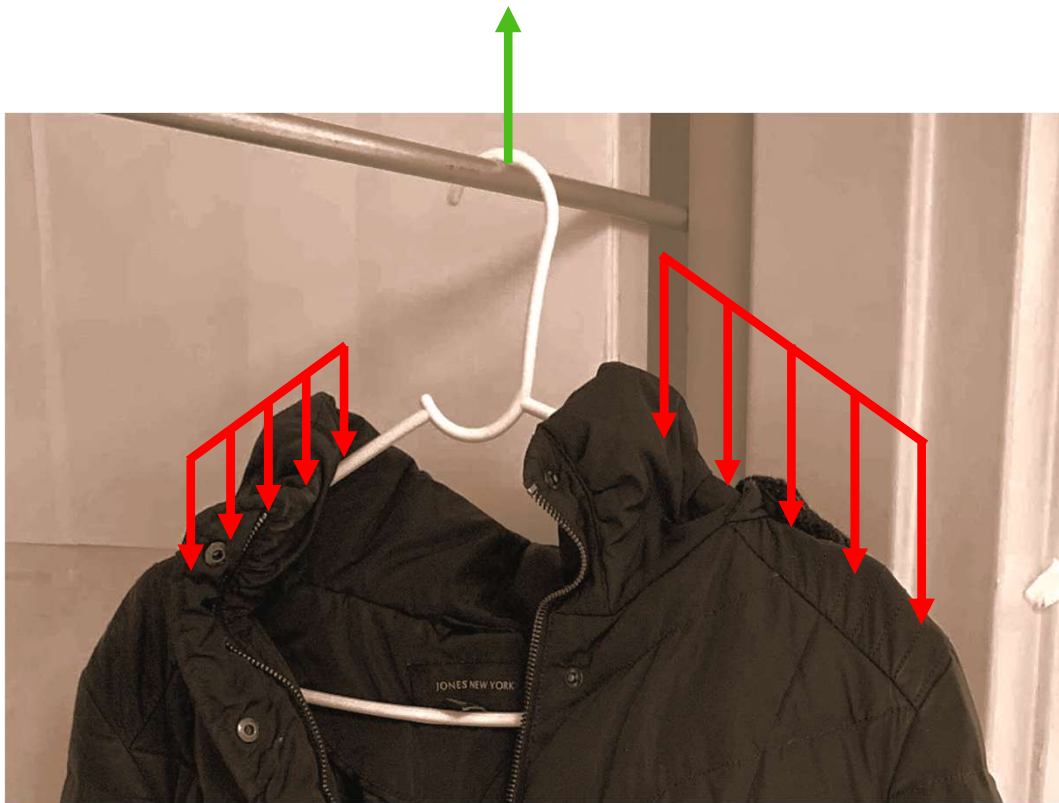


Model

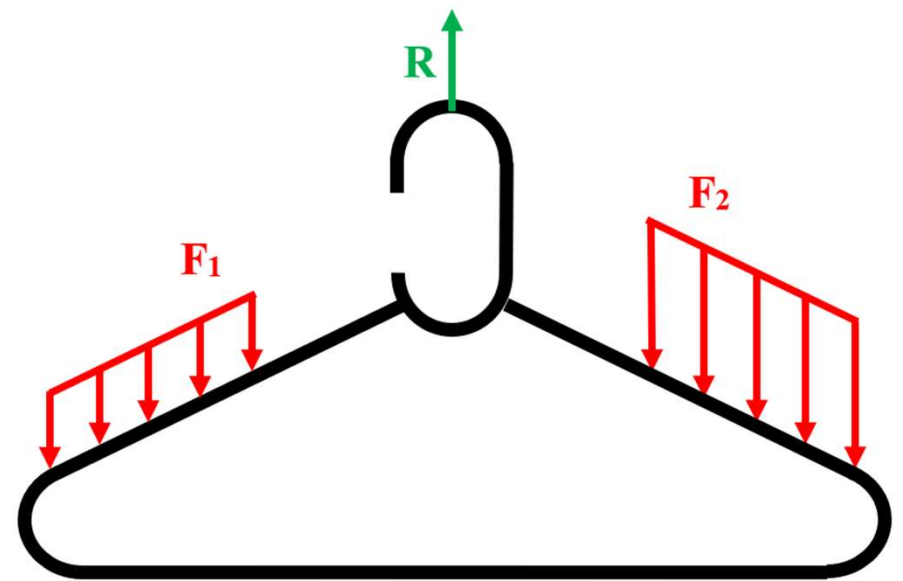


Boundary Conditions

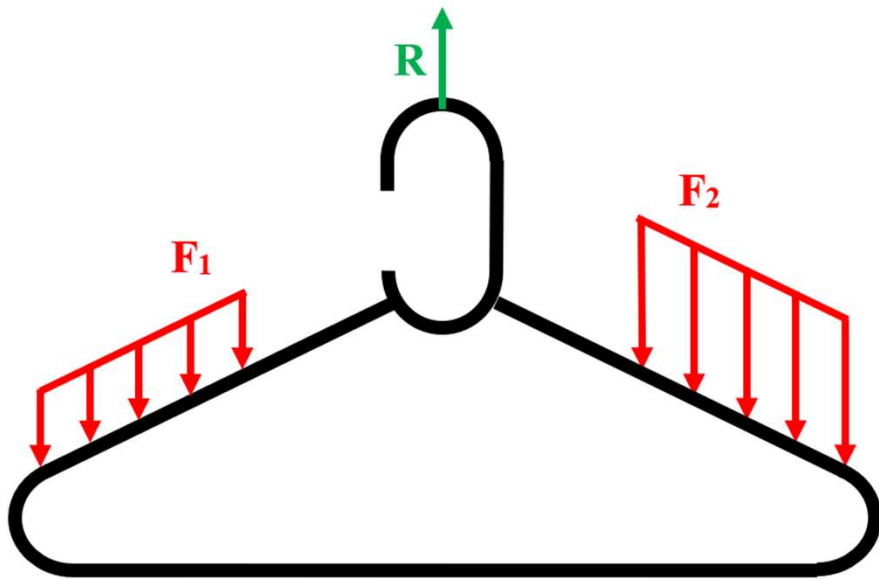
REAL-LIFE



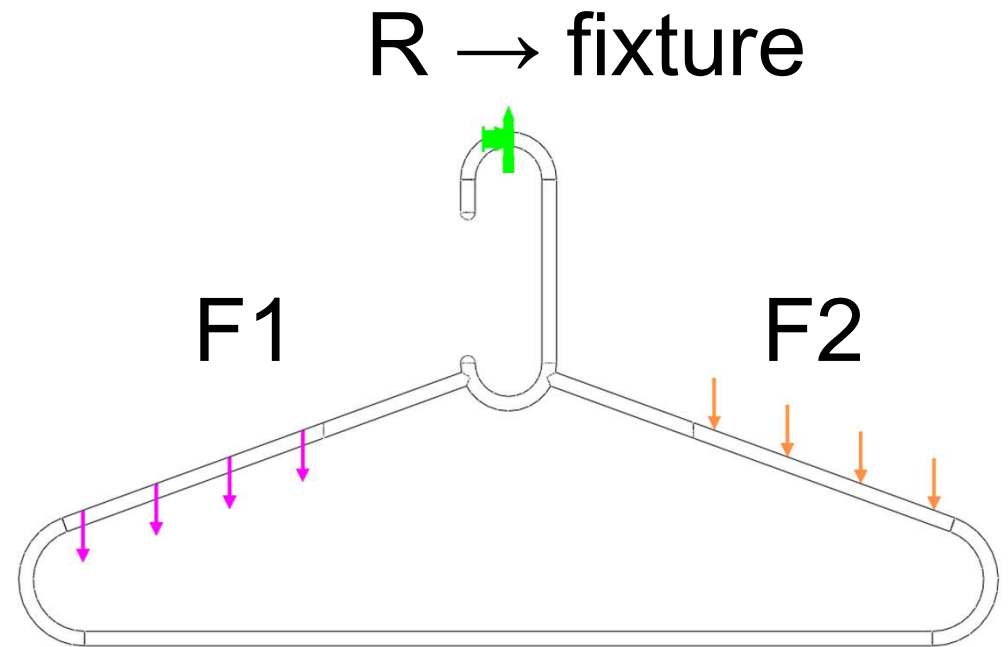
FREE-BODY DIAGRAM



FREE-BODY DIAGRAM



SOLIDWORKS SIMULATION

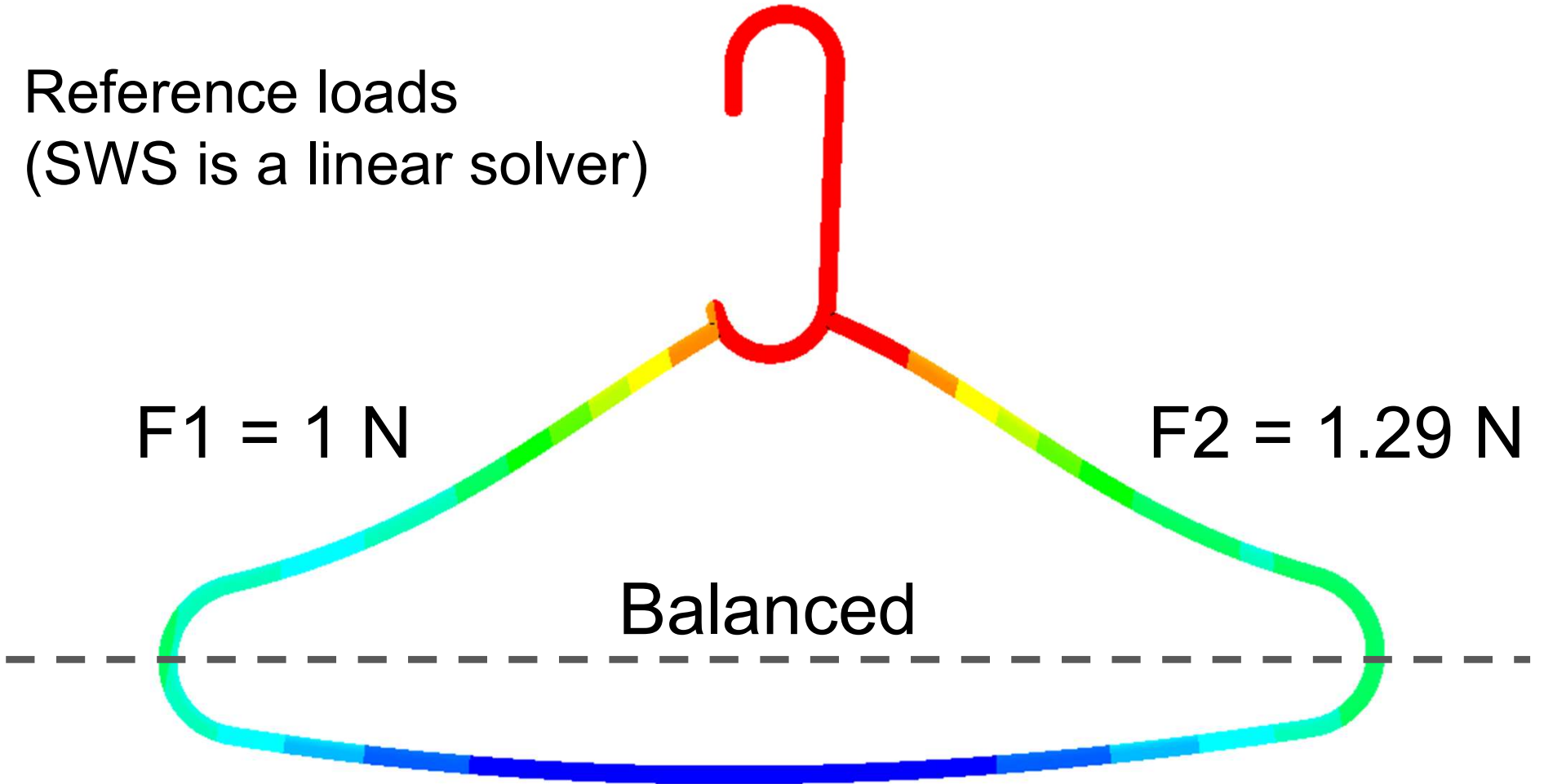


Reference loads
(SWS is a linear solver)

$F1 = 1 \text{ N}$

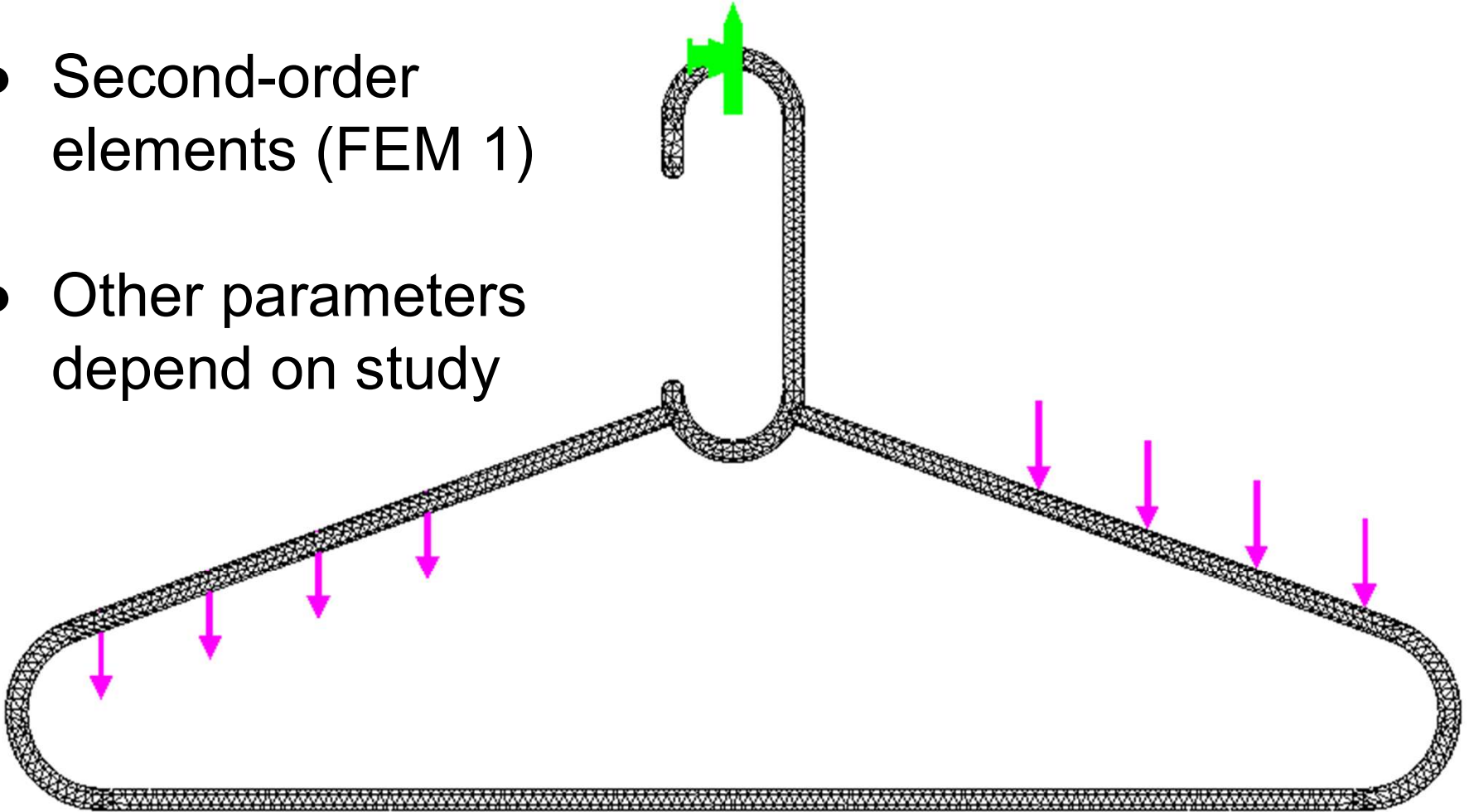
$F2 = 1.29 \text{ N}$

Balanced



Mesh

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



Results

Is our results valid?

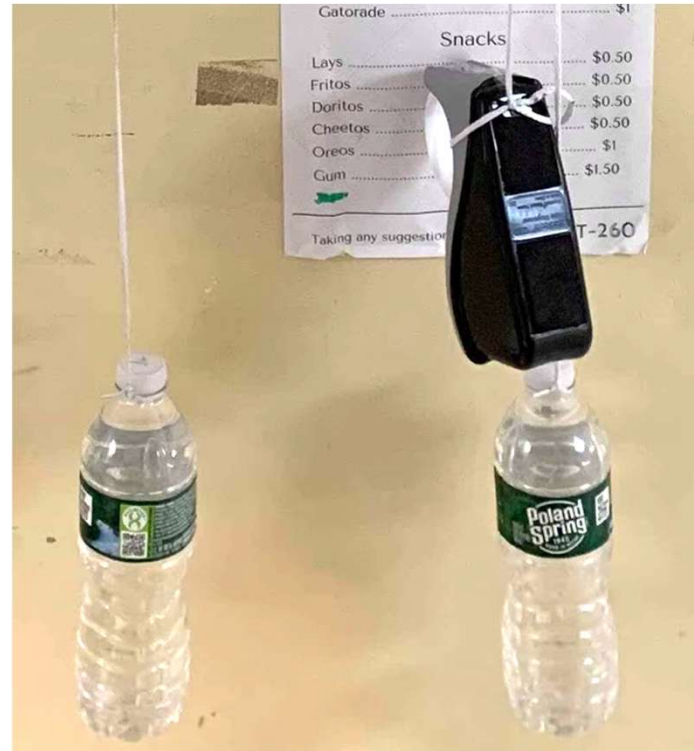
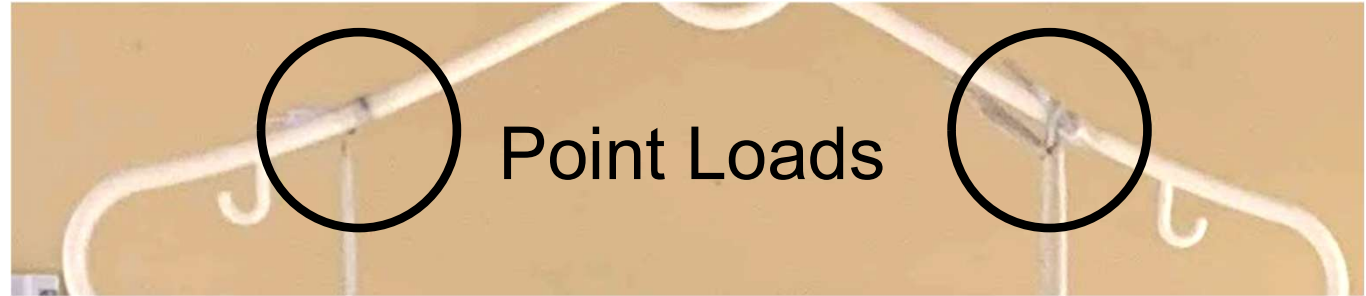
| Evaluation of | Method | Remedy | Valid? |
|----------------------|--|---------------------------------|---------------|
| Model | Displacement | Boundary Condition | |
| Solution | Convergence Analytical Sensitivity | Geometry | |
| Design | Failure Theory Factor of Safety | Geometry Loading Material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

Is our results valid?

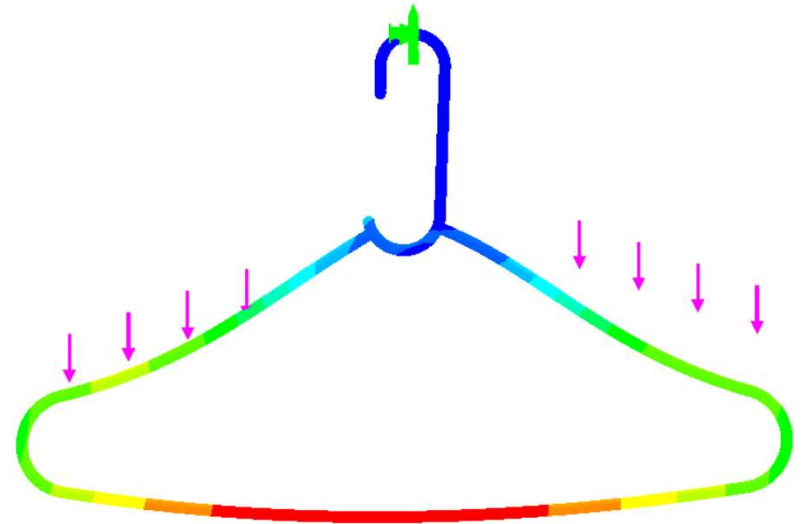
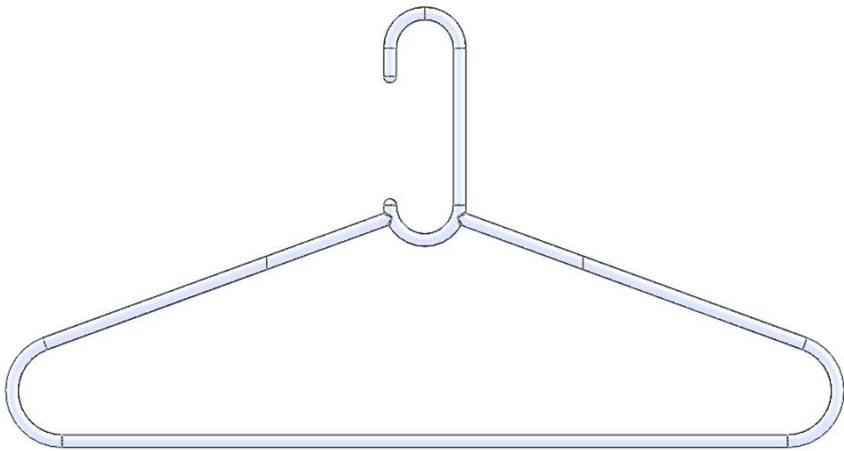
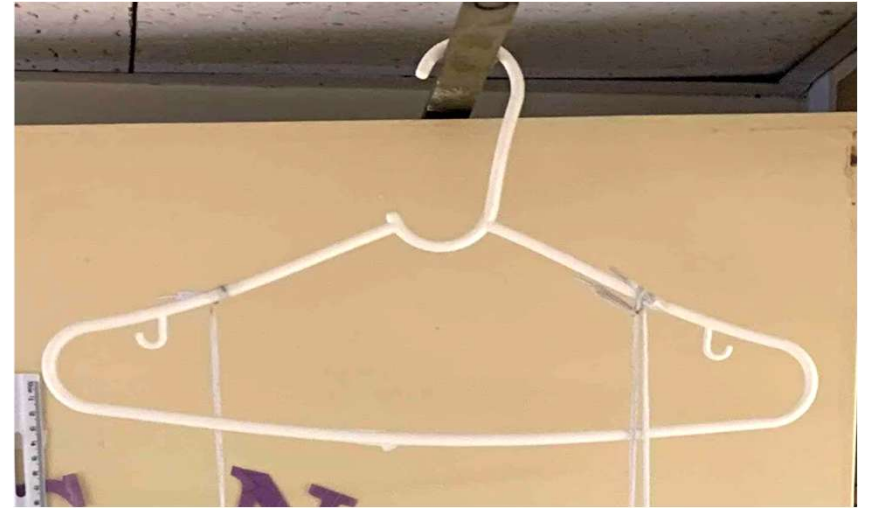
| Evaluation of | Method | Remedy | Valid? |
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Water Bottle
(0.5 kg)



Water Bottle +
Tape Dispenser
(0.85 kg)



Is our MODEL valid?

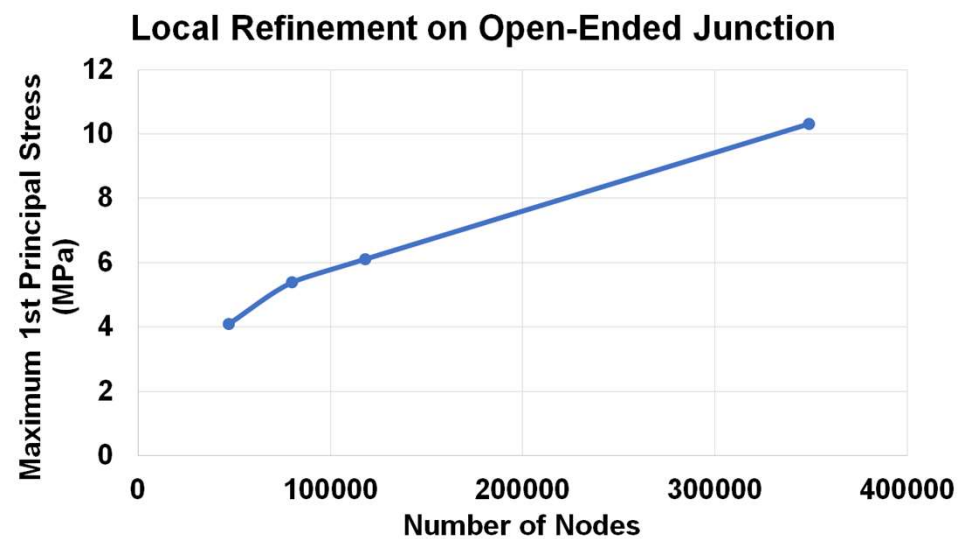
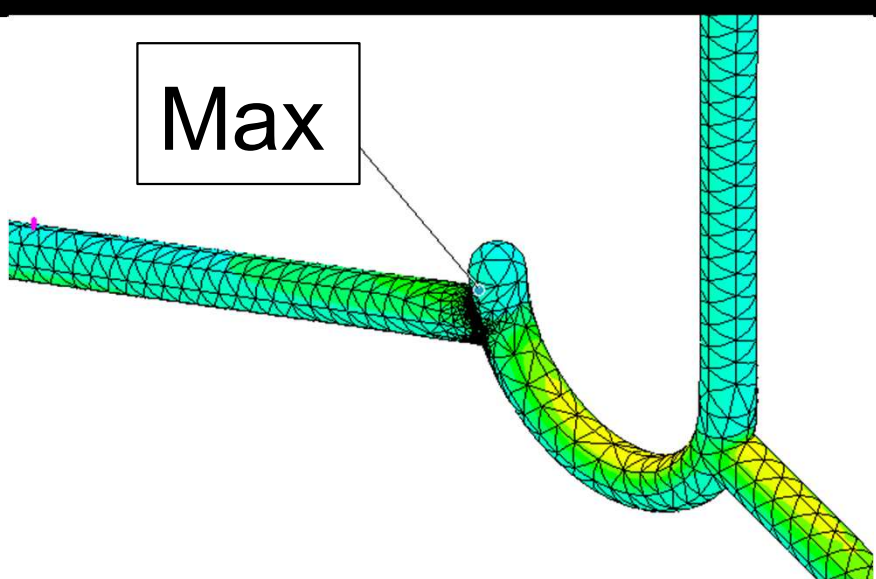
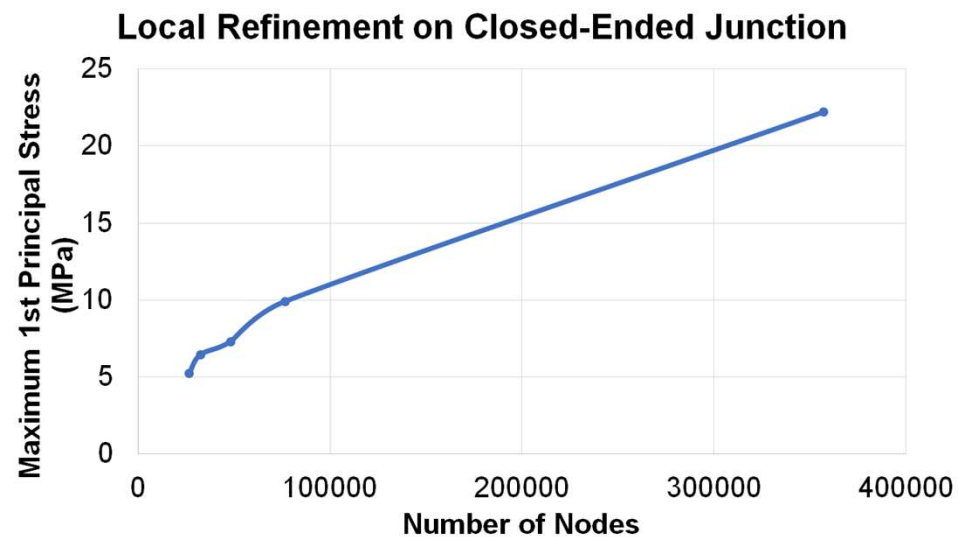
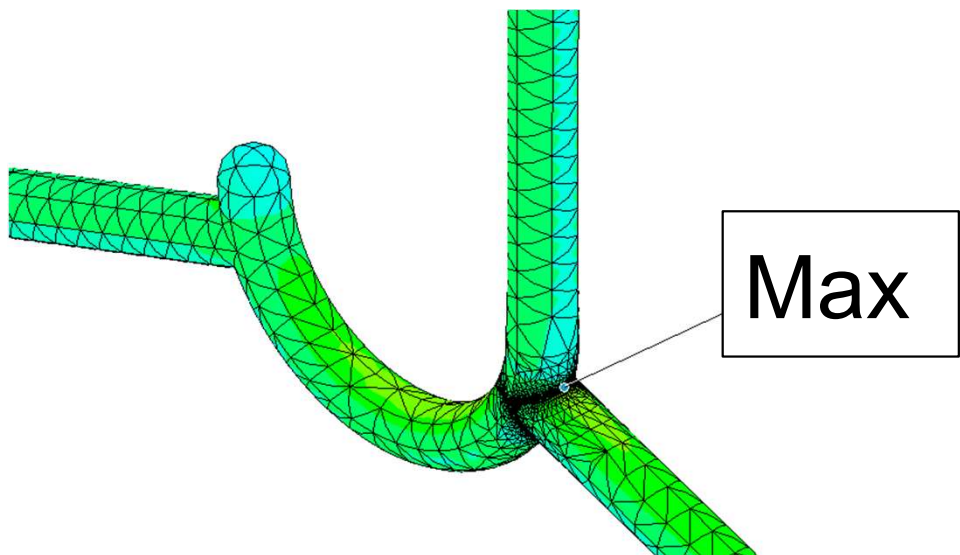
| Evaluation of | Method | Remedy | Valid? |
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| Model | Displacement | Boundary Condition | |
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Is our MODEL valid?

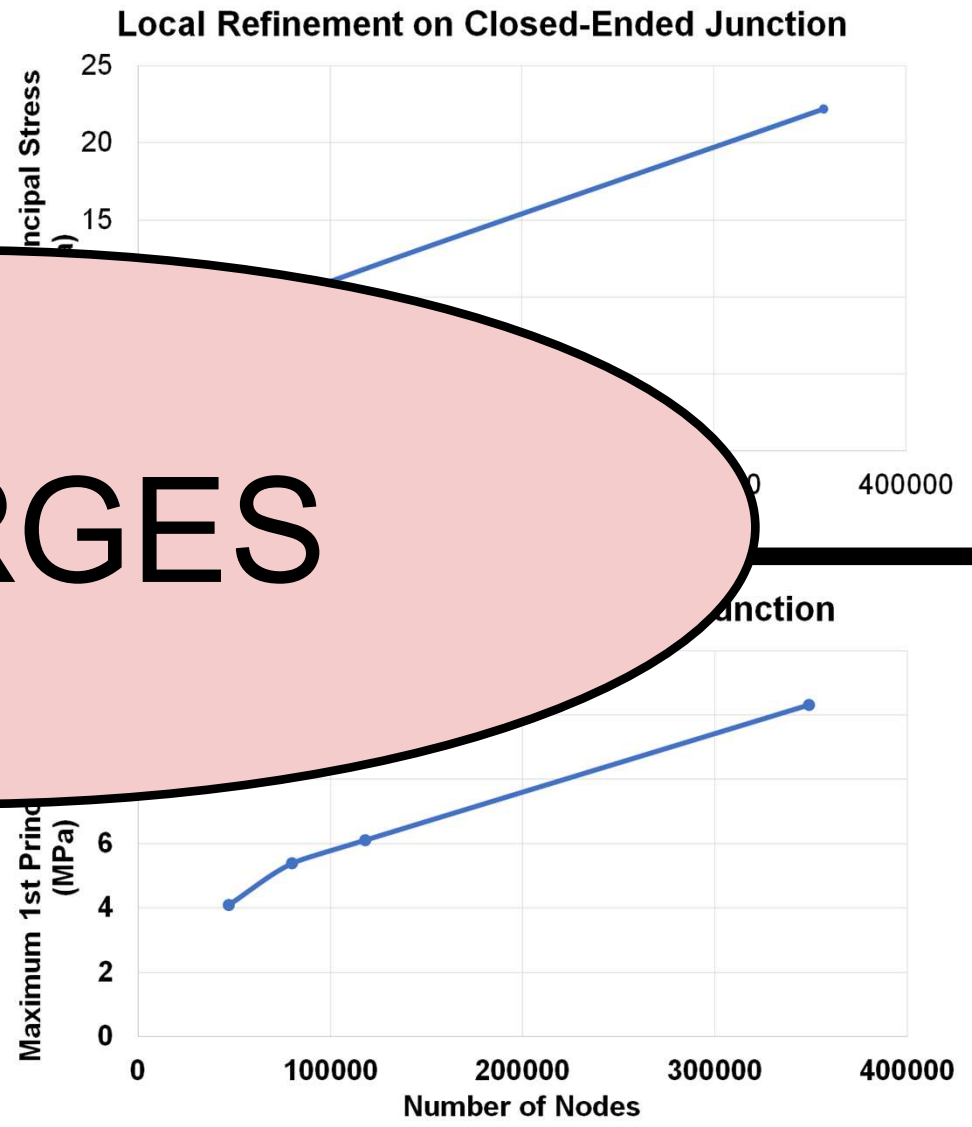
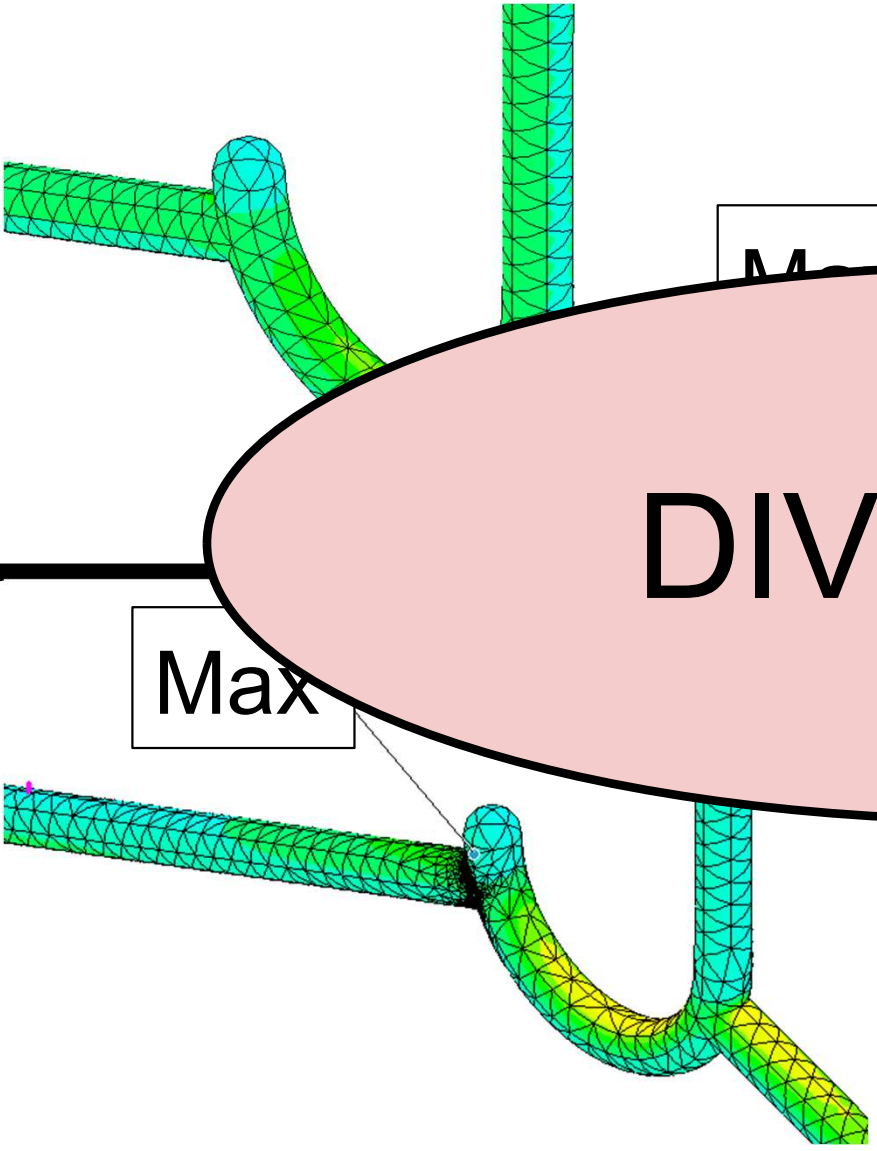
| Evaluation of | Method | Remedy | Valid? |
|---------------|--|---------------------------------|--------|
| Model | Displacement | Boundary Condition | ✓ |
| Solution | Convergence Analytical Sensitivity | Geometry | |
| Design | Failure Theory Factor of Safety | Geometry Loading Material | |

Is our SOLUTION valid?

| Evaluation of | Method | Remedy | Valid? |
|---------------|--|---------------------------------|--------|
| Model | Displacement | Boundary Condition | ✓ |
| Solution | Convergence Analytical Sensitivity | Geometry | |
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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?

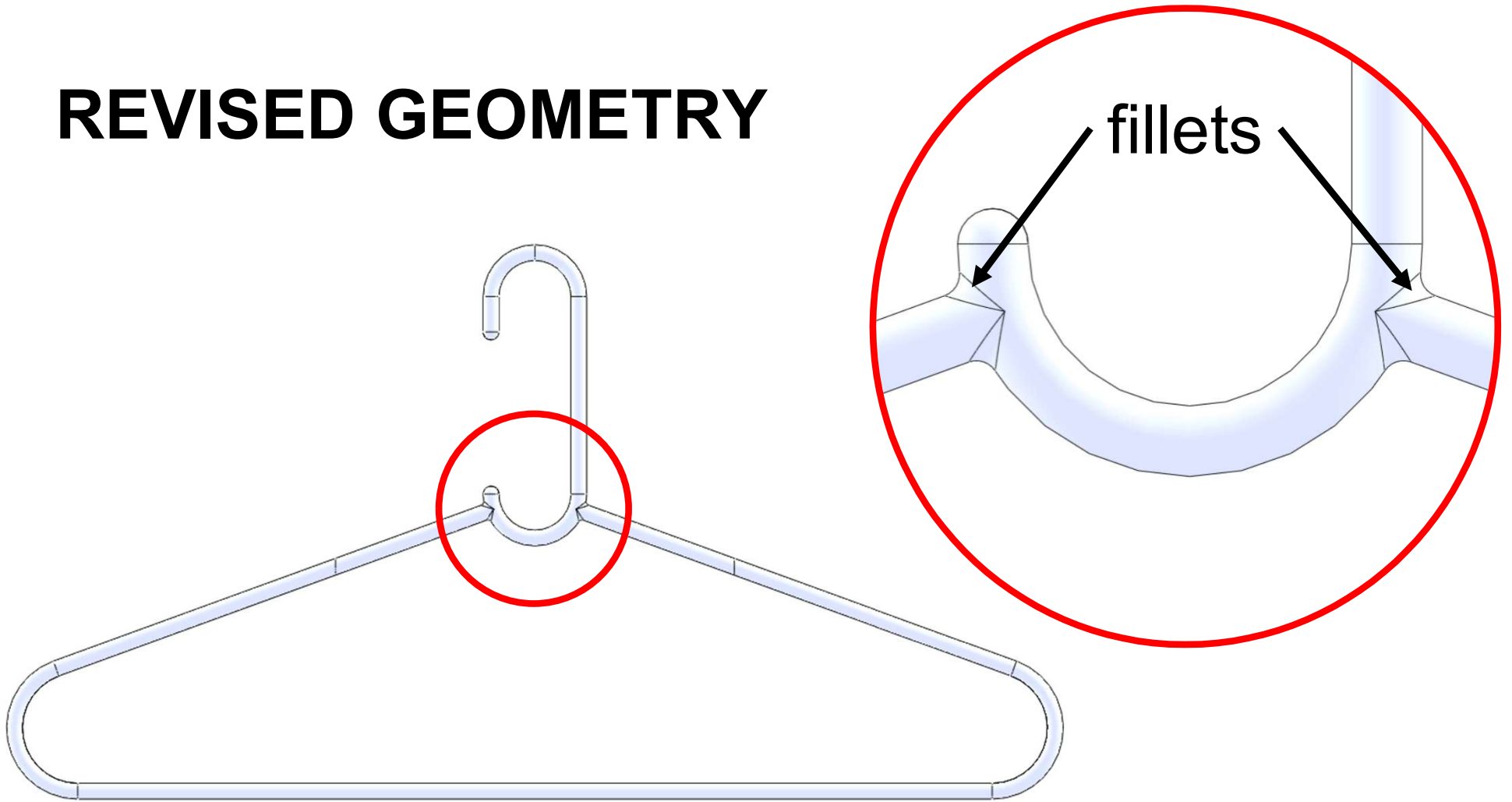
| Evaluation of | Method | Remedy | Valid? |
|---------------|--|---------------------------------|--------|
| Model | Displacement | Boundary Condition | ✓ |
| Solution | Convergence Analytical Sensitivity | Geometry | X |
| Design | Failure Theory Factor of Safety | Geometry Loading Material | |

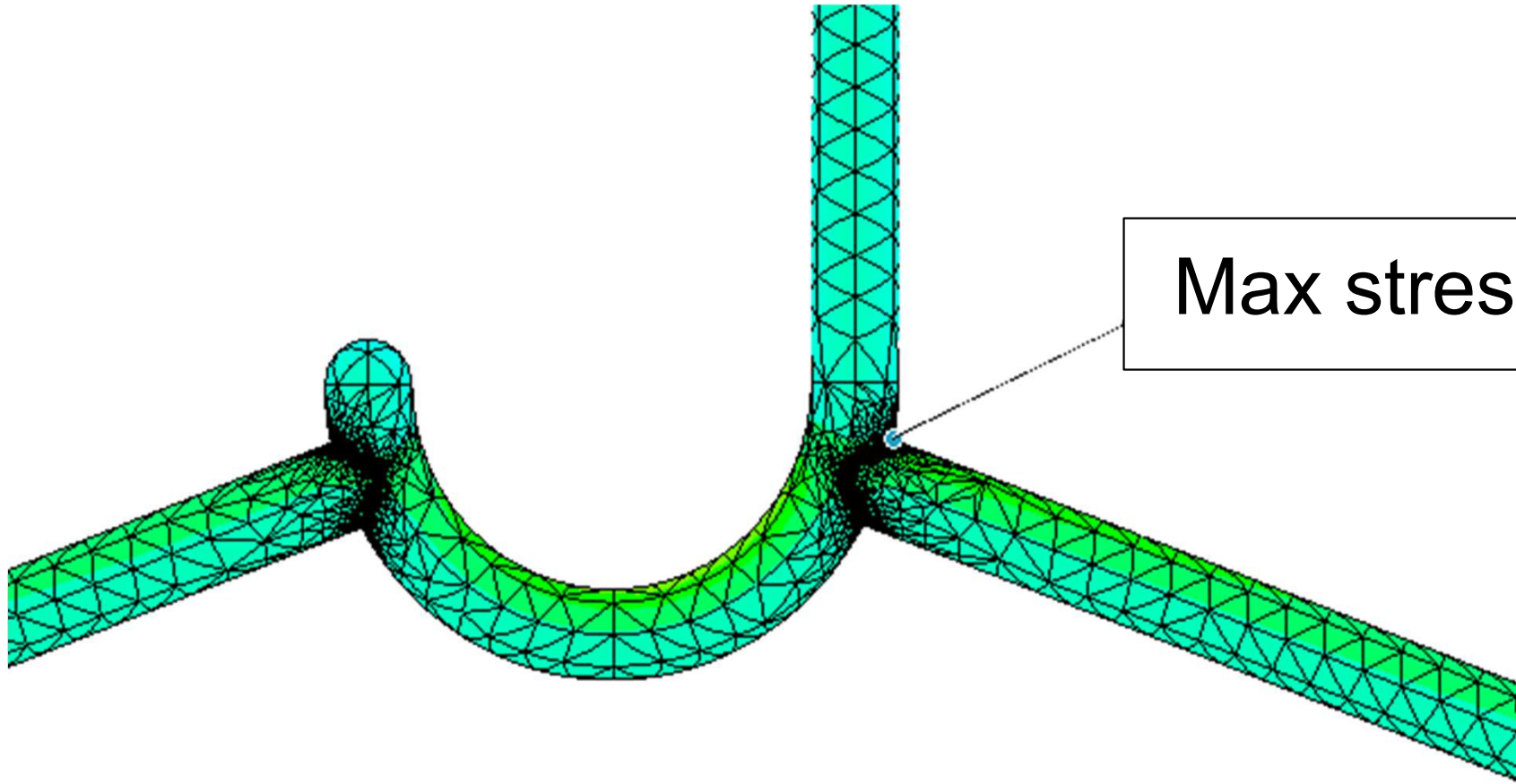
Is our SOLUTION valid?

| 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

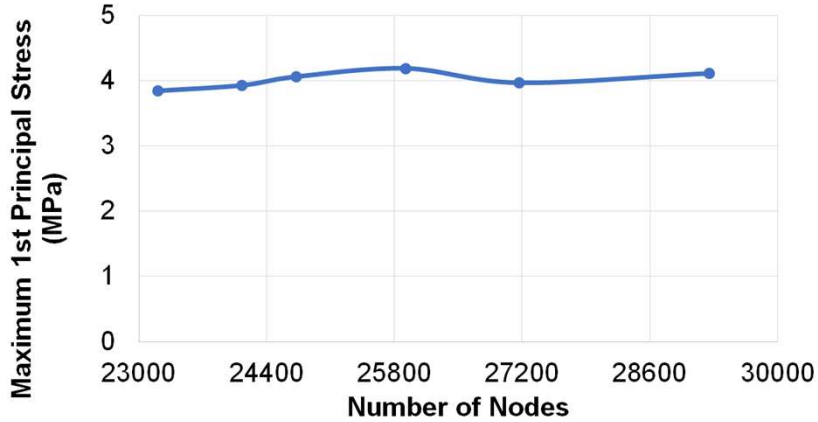
REVISED GEOMETRY



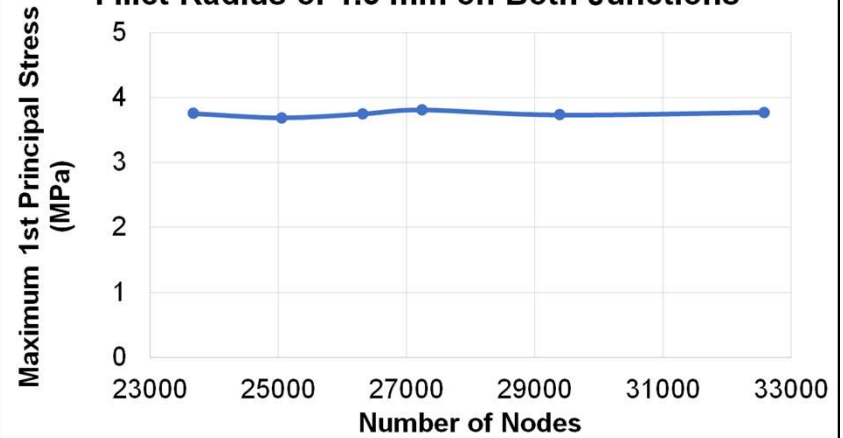


Max stress

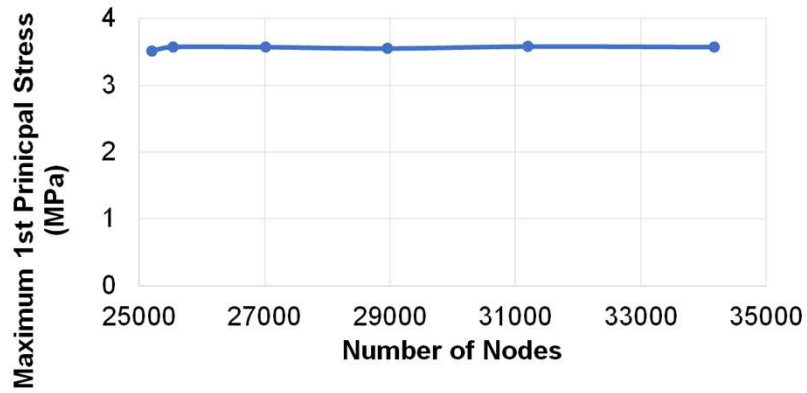
**Local Refinement with
Fillet Radius of 1.0 mm on Both Junctions**



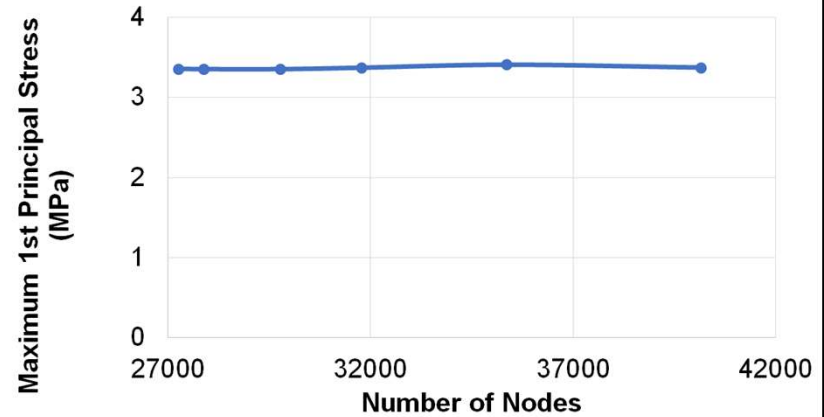
**Local Refinement with
Fillet Radius of 1.5 mm on Both Junctions**



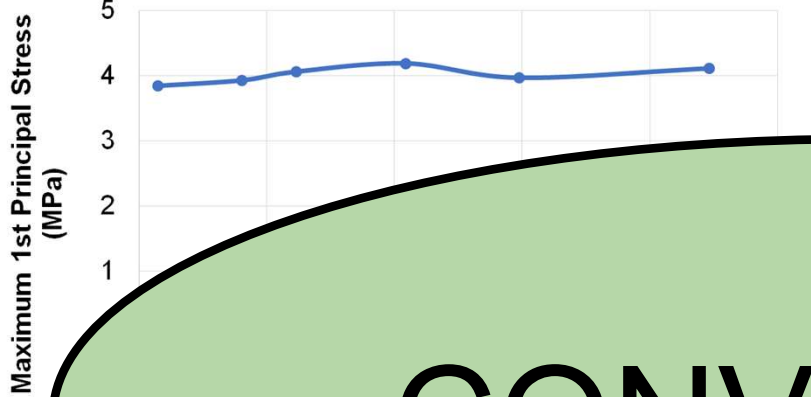
**Local Refinement with
Fillet Radius of 2 mm on Both Junctions**



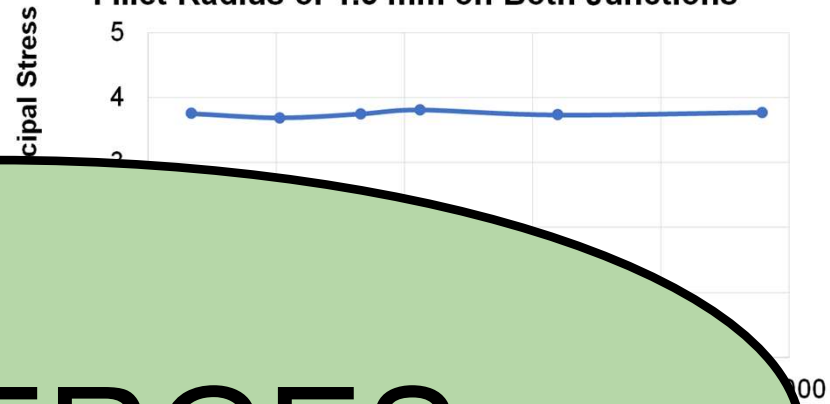
**Local Refinement with
Fillet Radius of 3 mm on Both Junctions**



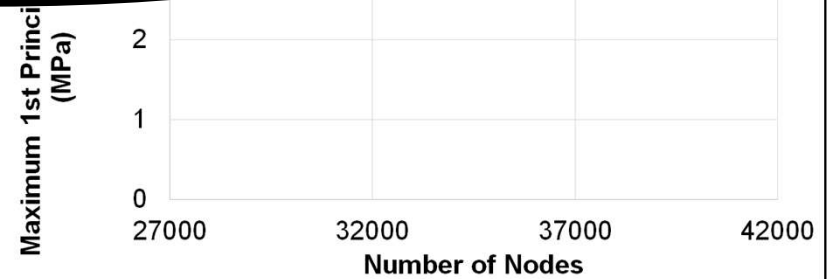
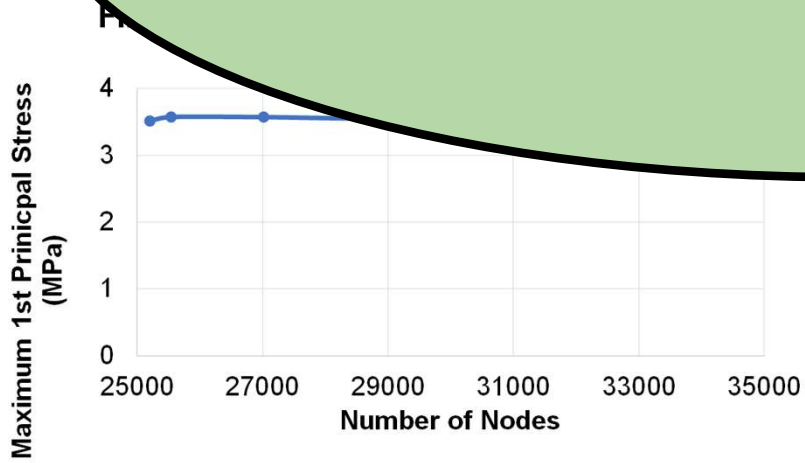
Local Refinement with
Fillet Radius of 1.0 mm on Both Junctions



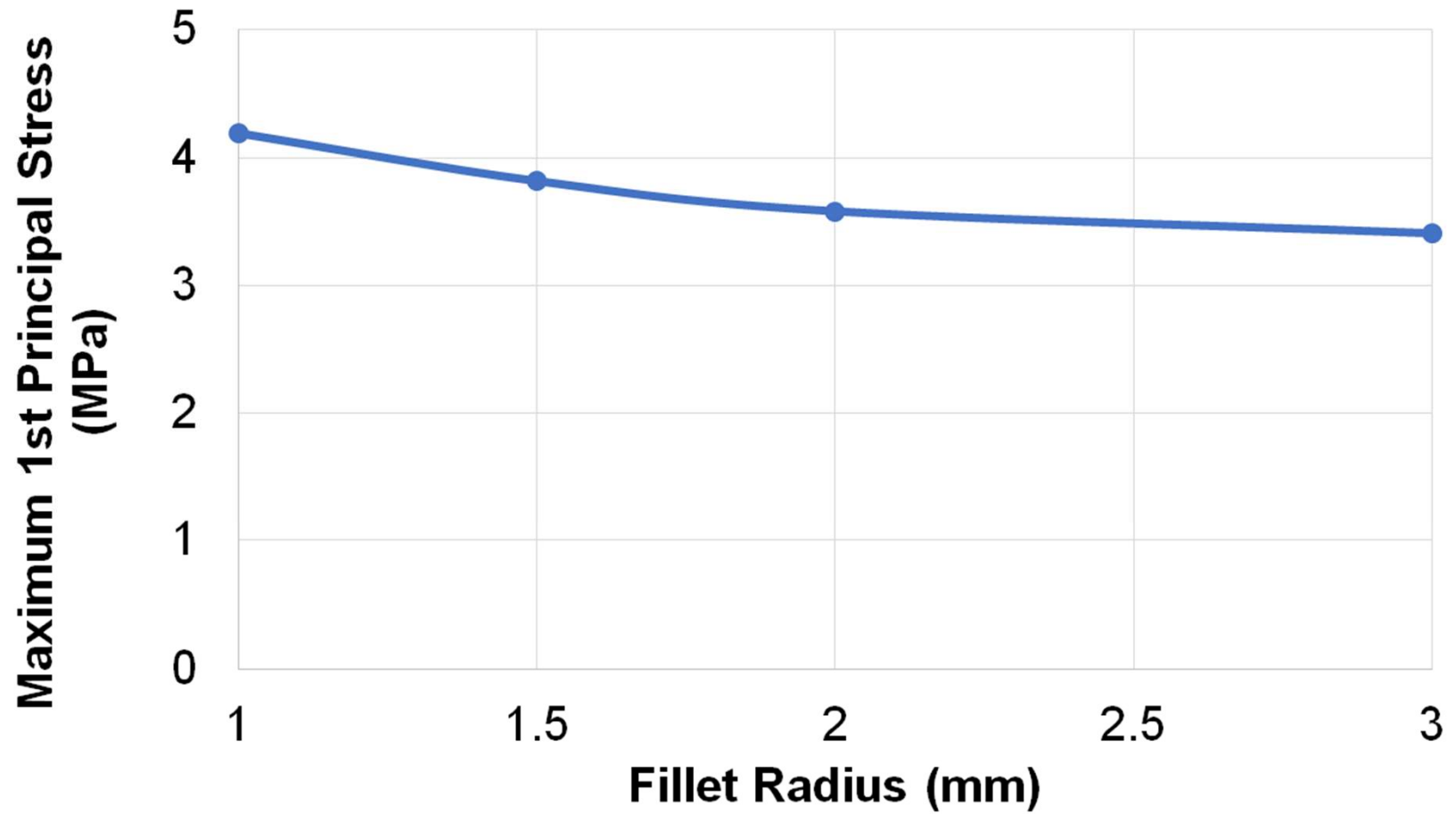
Local Refinement with
Fillet Radius of 1.5 mm on Both Junctions



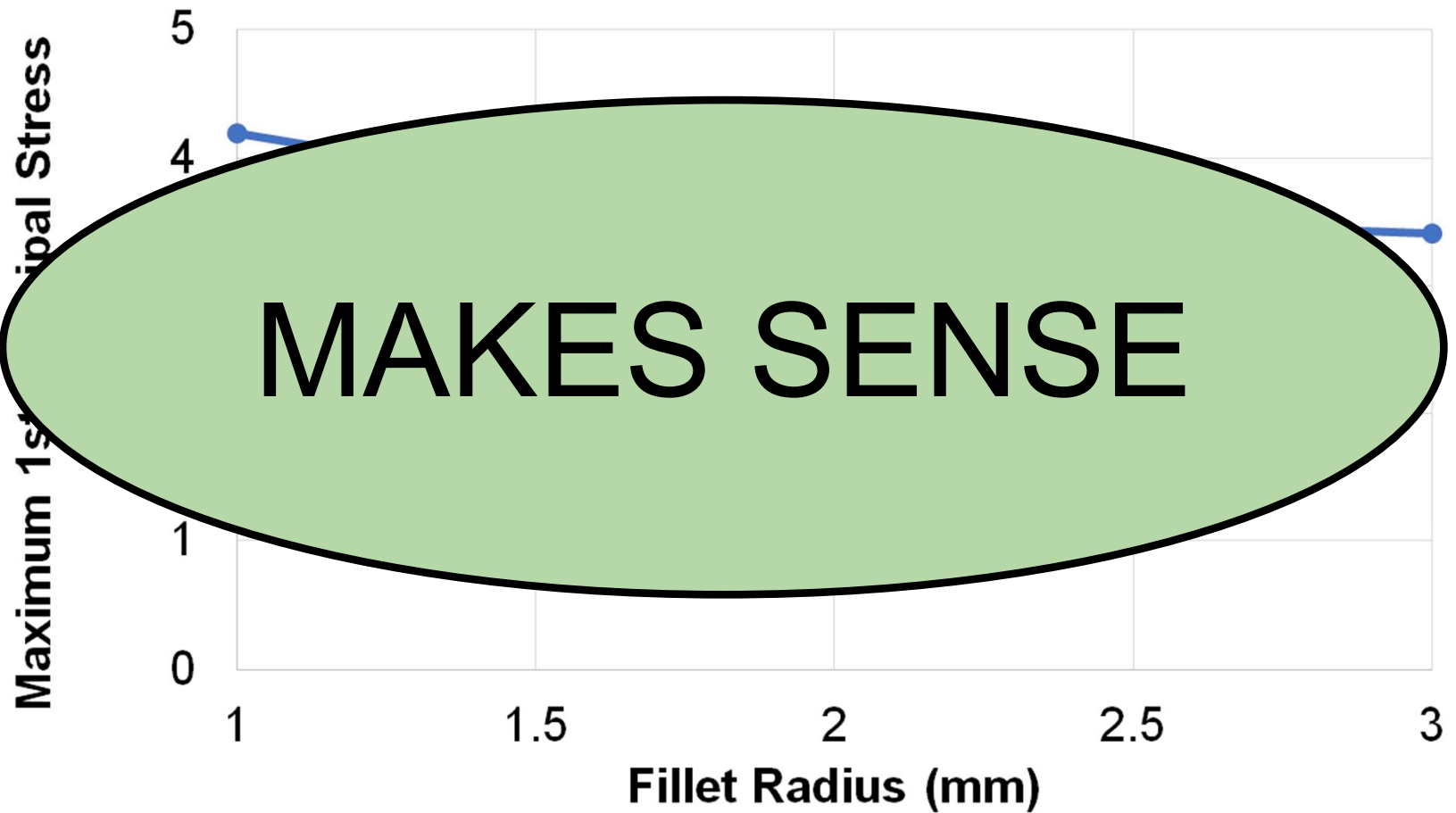
CONVERGES



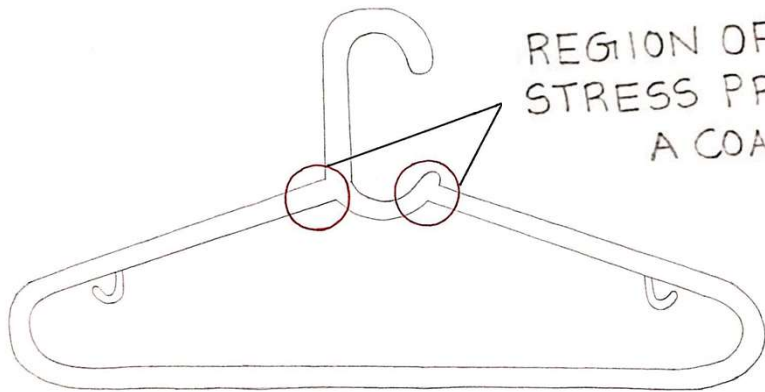
Sensitivity Test Results



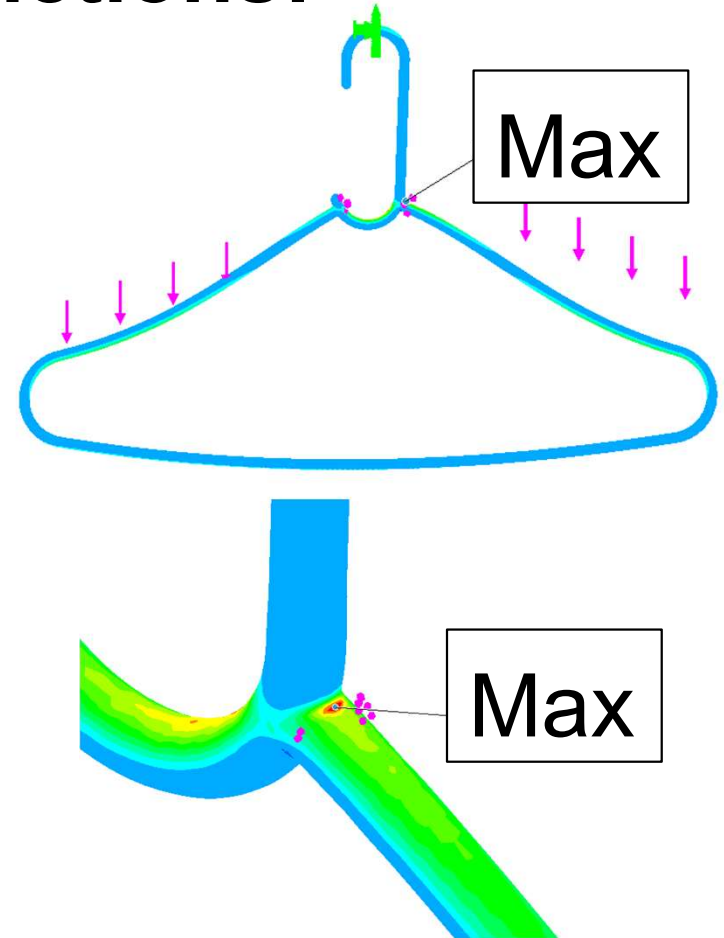
Sensitivity Test Results



And it did match our predictions!



REGION OF MAXIMUM
STRESS PREDICTED FOR
A COAT



Is our SOLUTION valid? (With fillets)

| Evaluation of | Method | Remedy | Valid? |
|---------------|--|---------------------------------|--------|
| Model | Displacement | Boundary Condition | ✓ |
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MAXIMUM STRESS FRACTURE THEORY:

Fracture occurs if...

$$\text{First Principal Stress} > \text{Tensile Strength}$$

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 | |

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

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

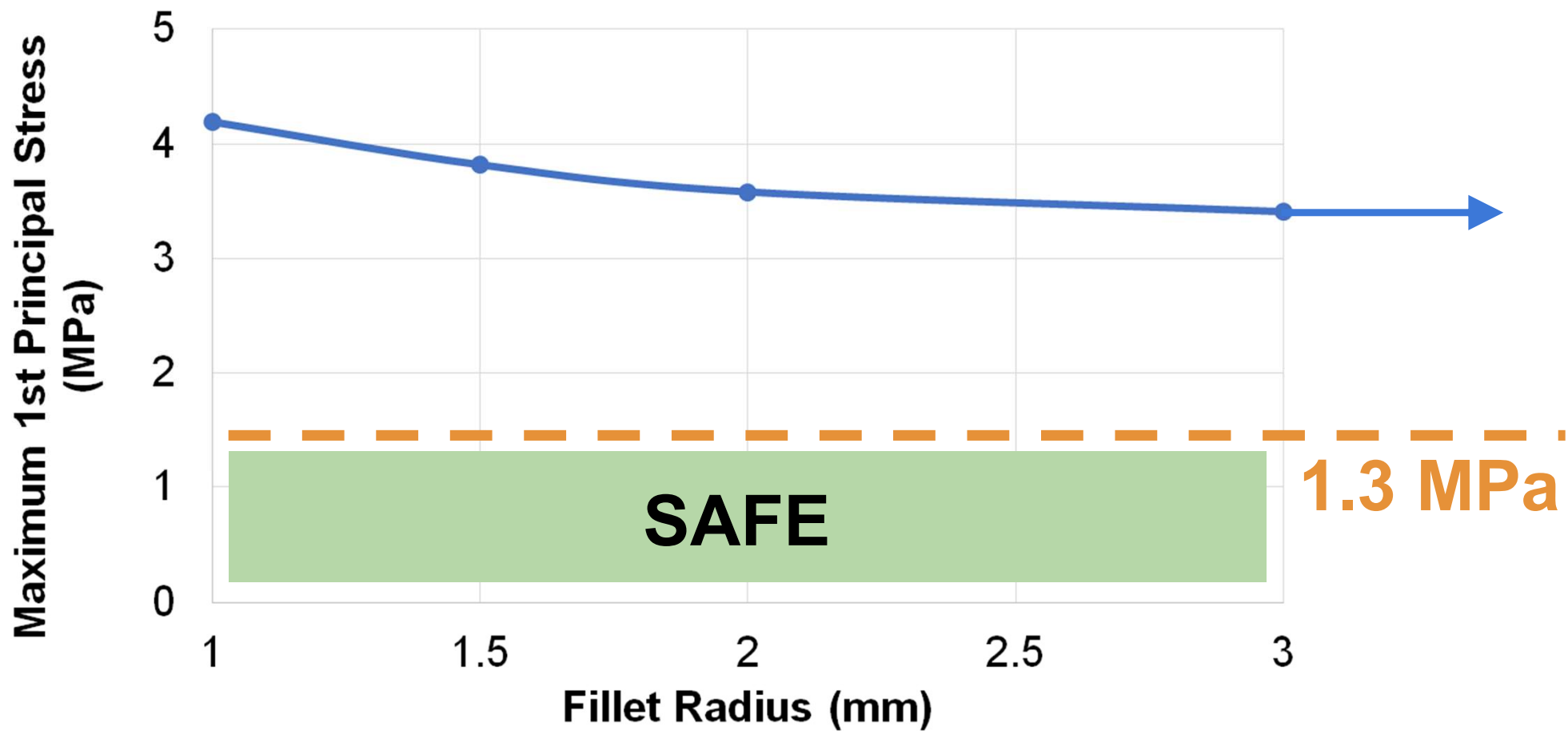
JACKET AND WEIGHTS (FRACTURES)

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

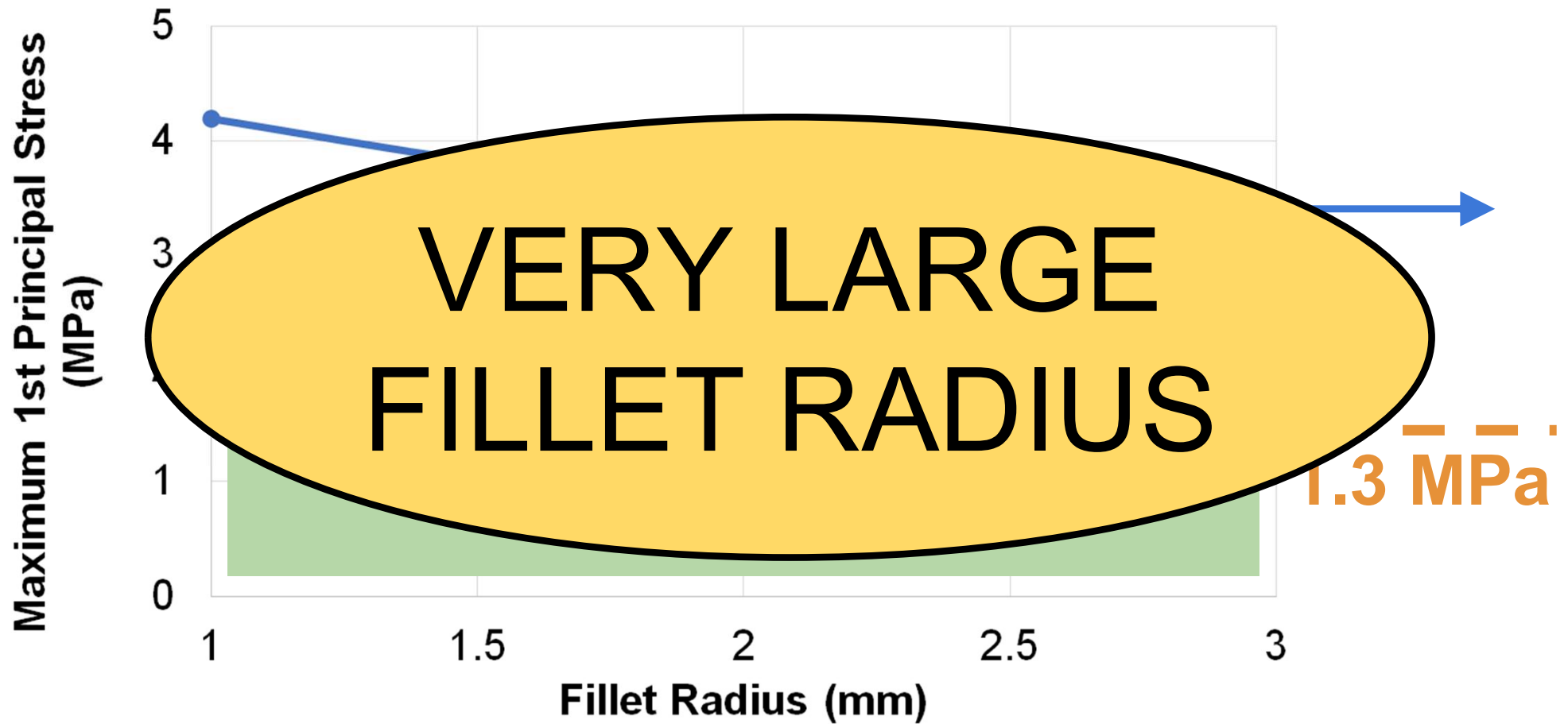
$$\frac{61}{2.29} = 27$$

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

Sensitivity Test Results



Sensitivity Test Results



| 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 | ✓ |
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Doesn't really make sense! (With fillets)

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Doesn't really make sense! (With fillets)

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| 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? |
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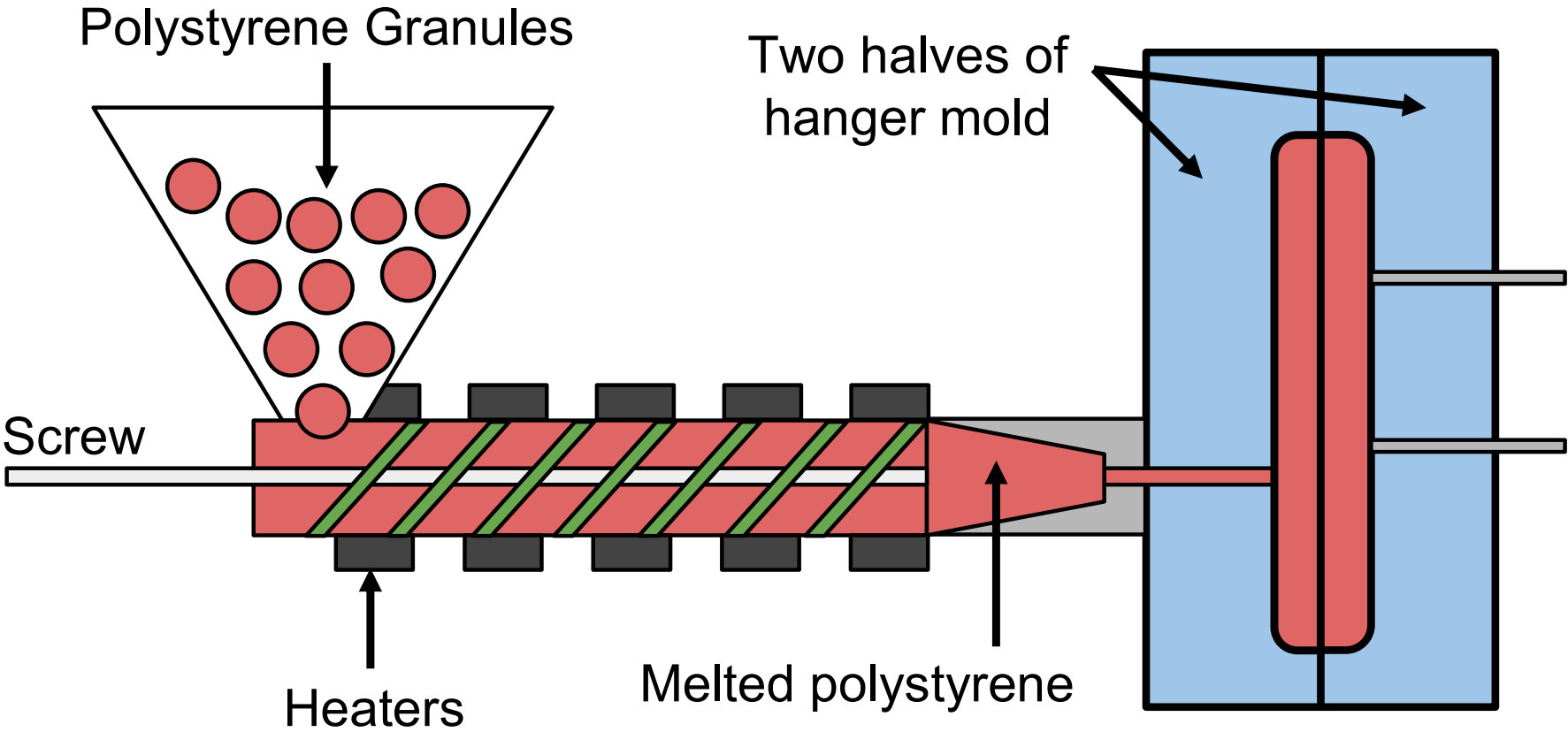
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| Model | | | ✓ |
| S | | | |
| Design | Failure theory Factor of Safety (N/A) | Geometry Loading Material | X |

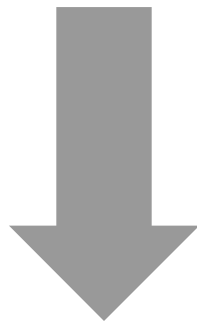
DIFFICULT TO VALIDATE

Sources of Problems

INJECTION MOLDING



Simulation does not work out



Rely on **experiments!**



6.1 kg

Jacket + weights

6.1 kg \approx 3 Heavy Jackets



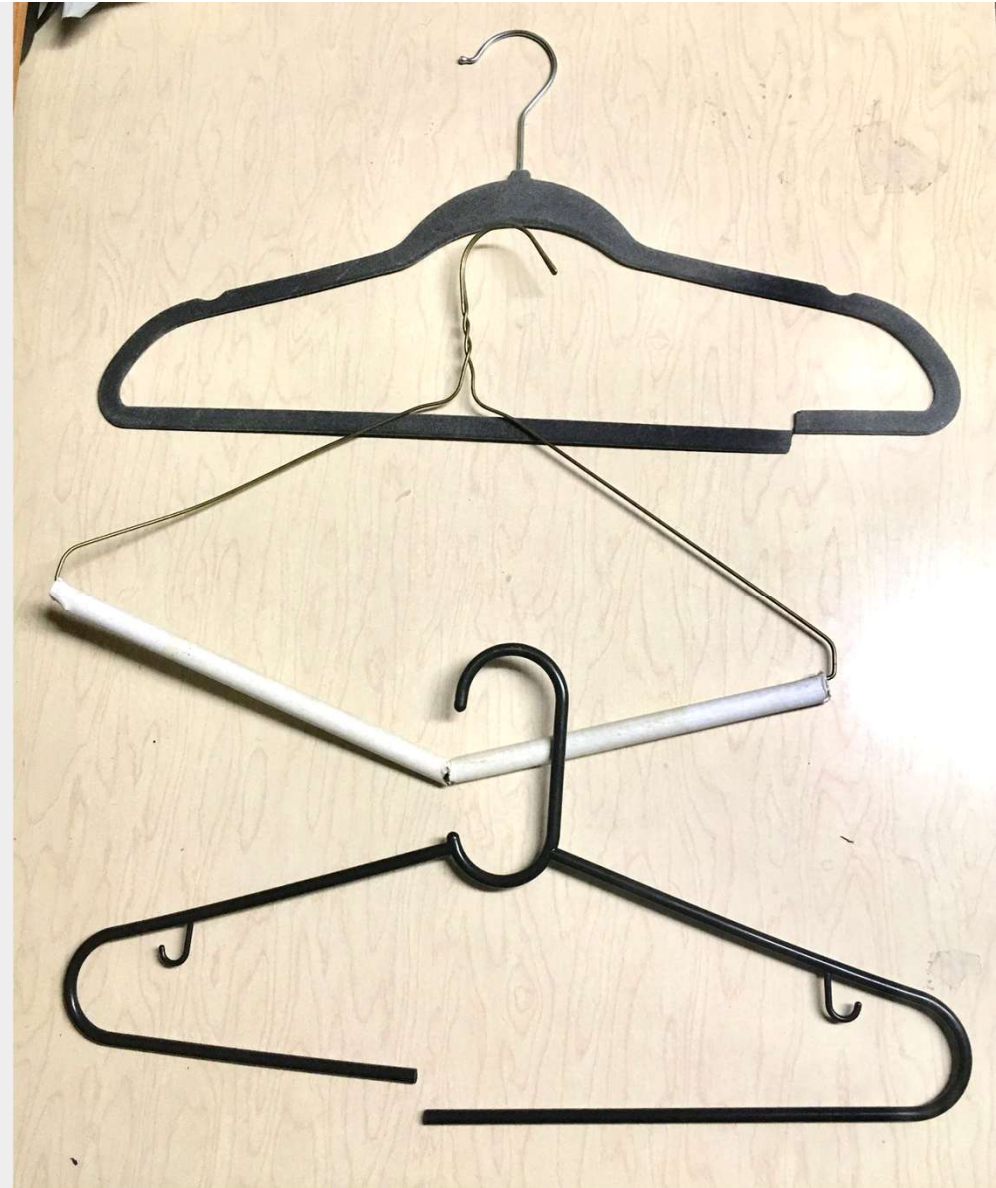
6.1 kg \approx 3 Heavy Jackets

GOOD DESIGN!



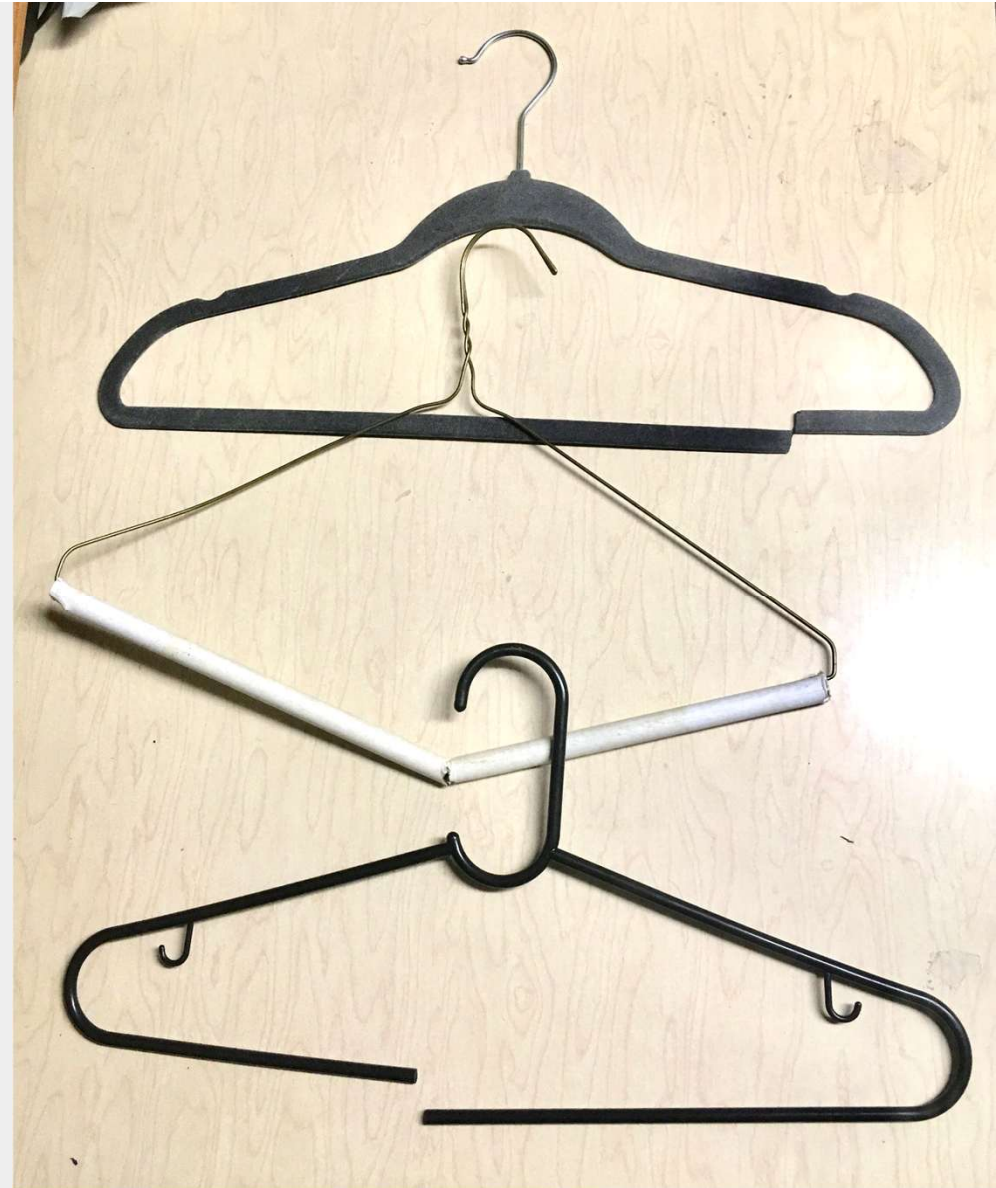
PROBLEM STATEMENT

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



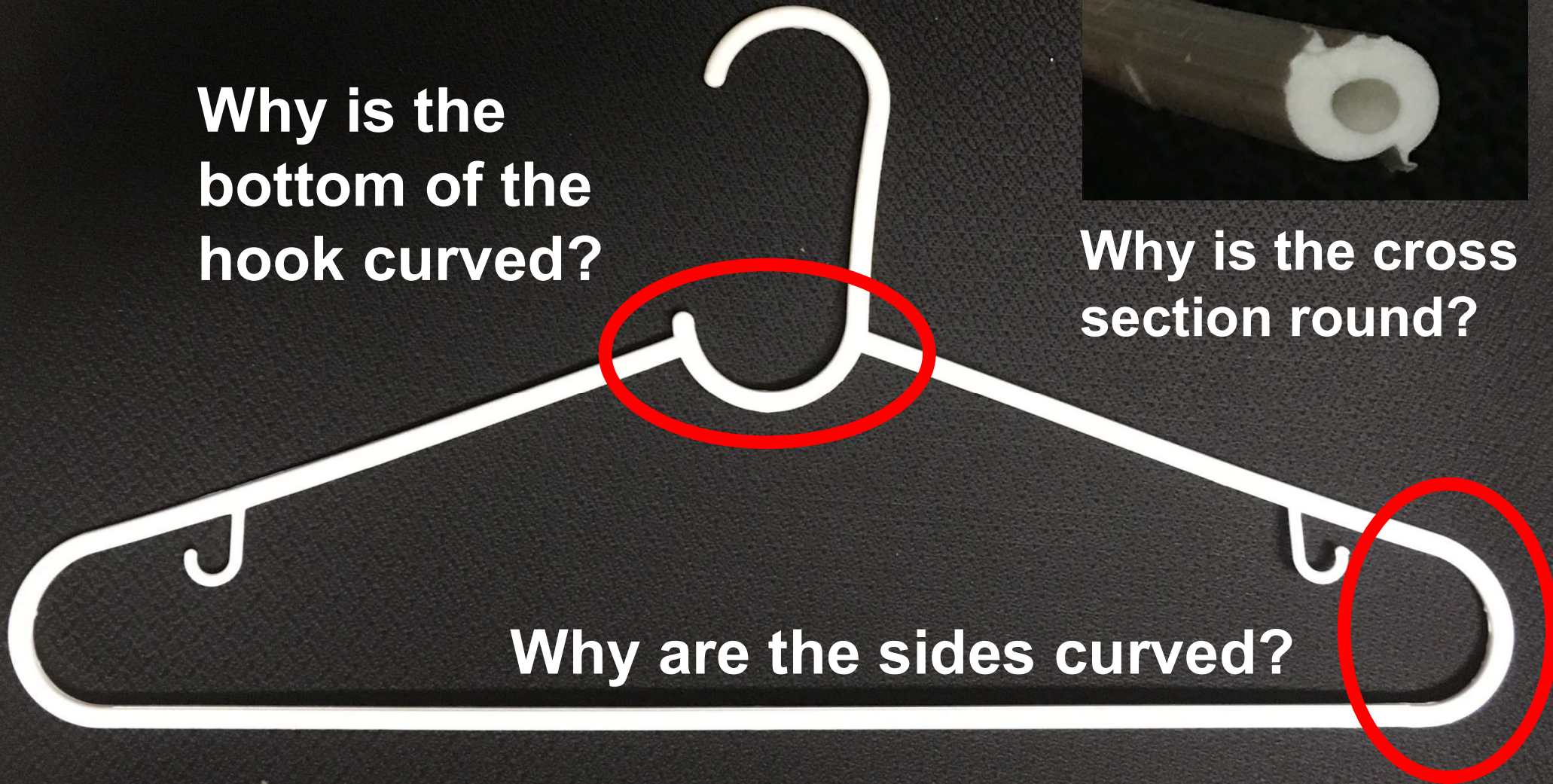
Design Implications

Why is the bottom of the hook curved?



Why is the cross section round?

Why are the sides curved?

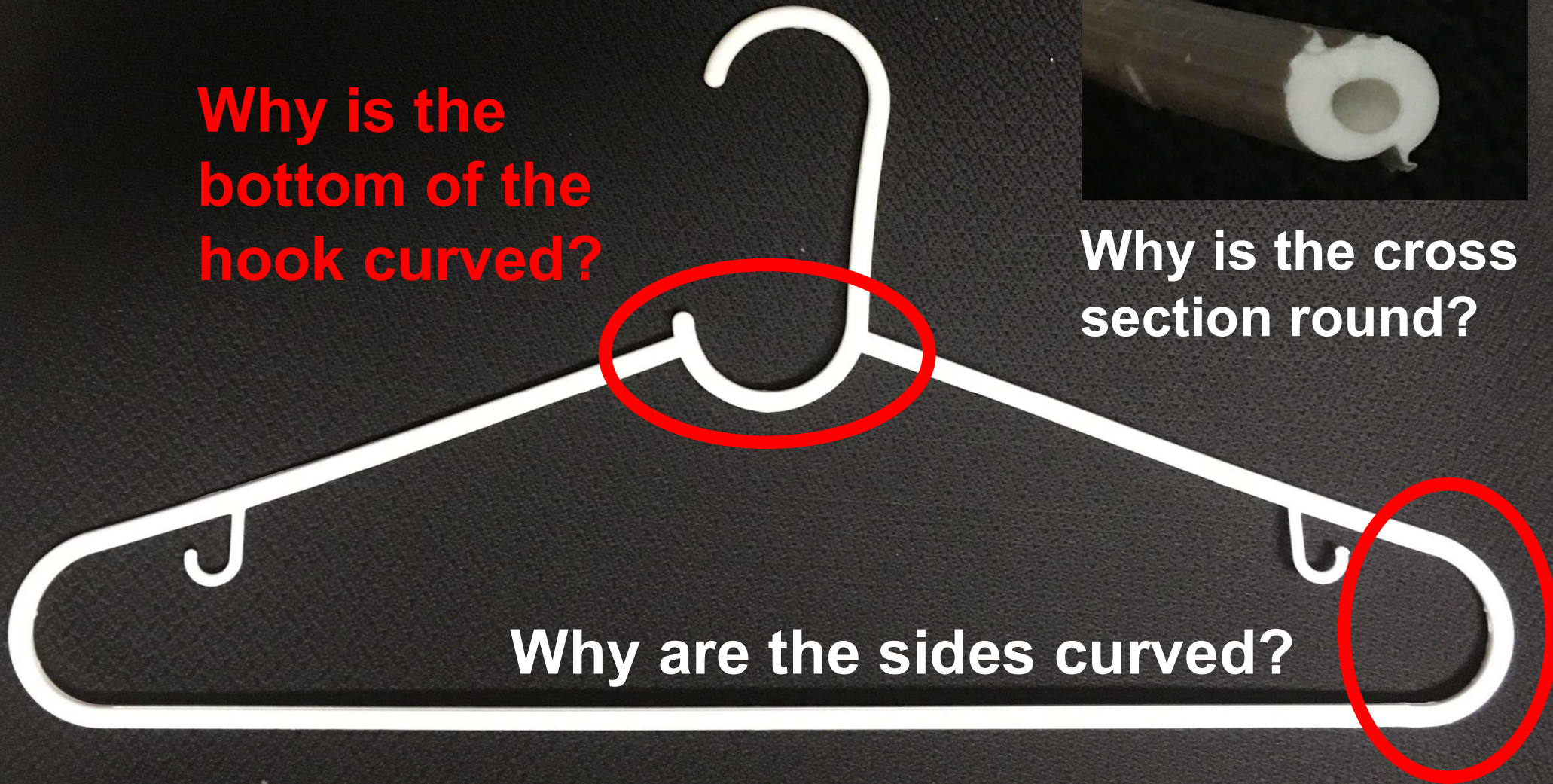


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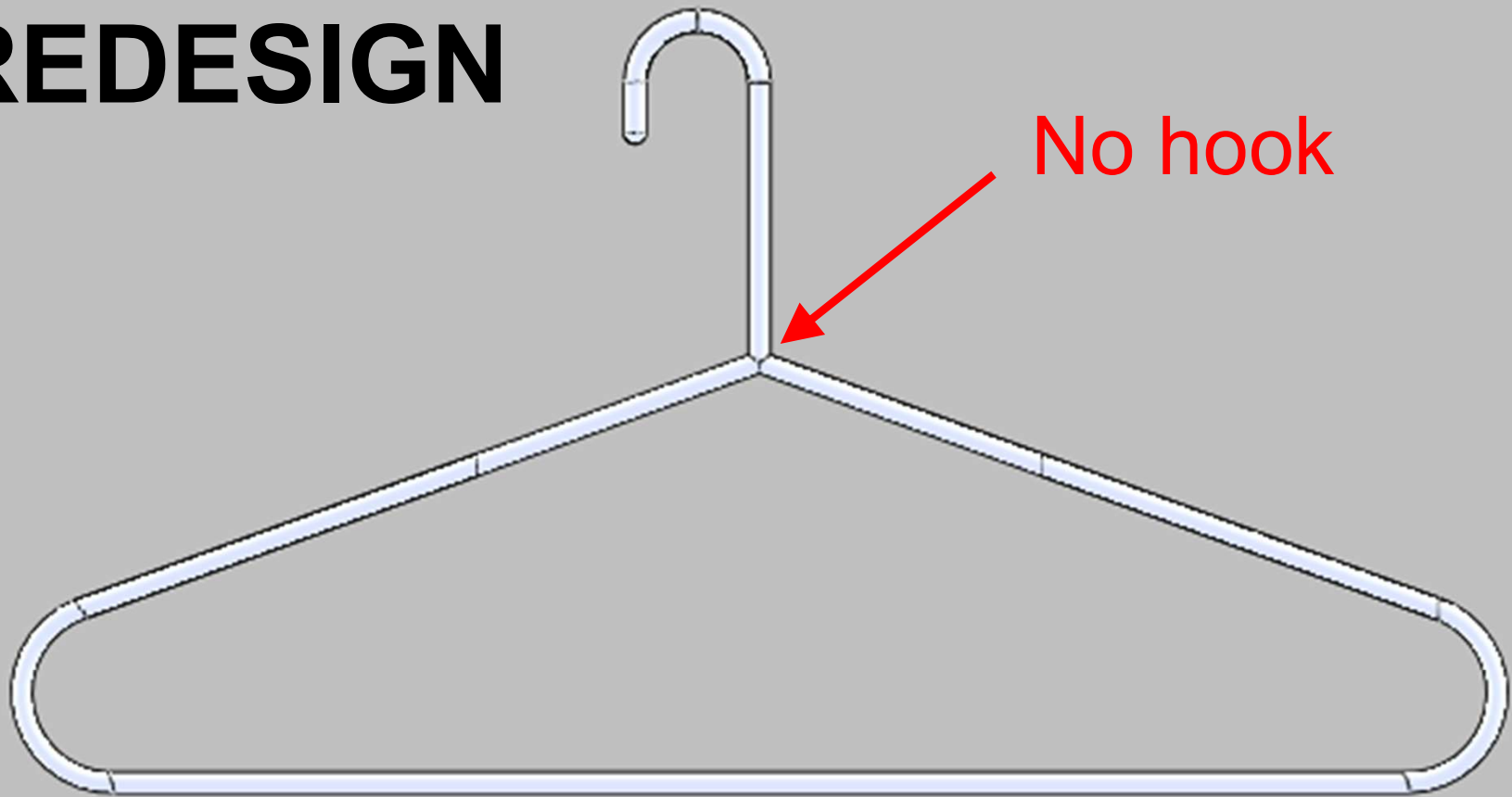


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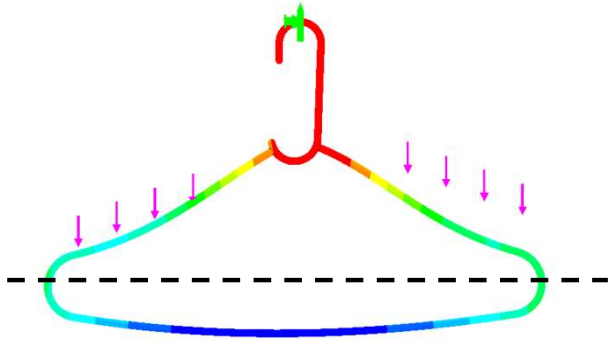
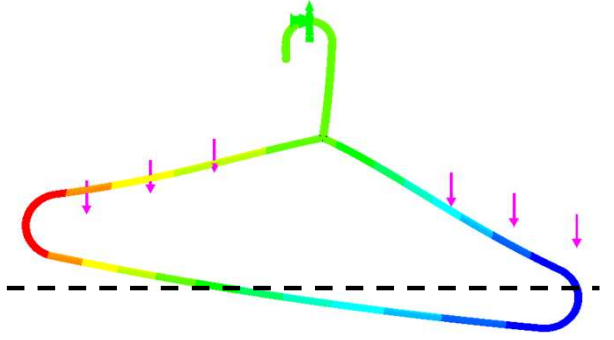
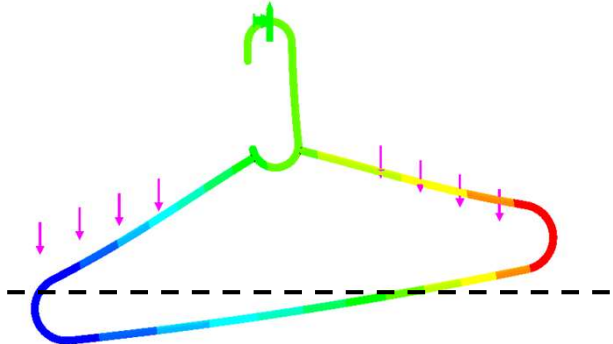
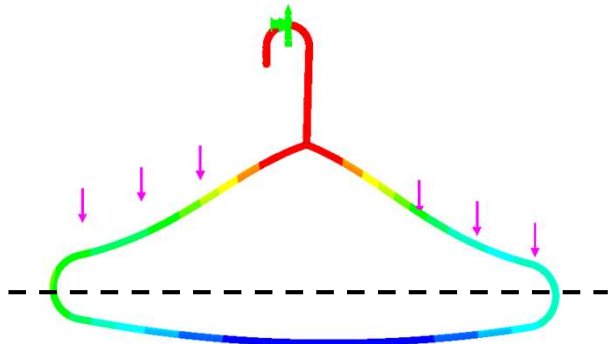
Why are the sides curved?

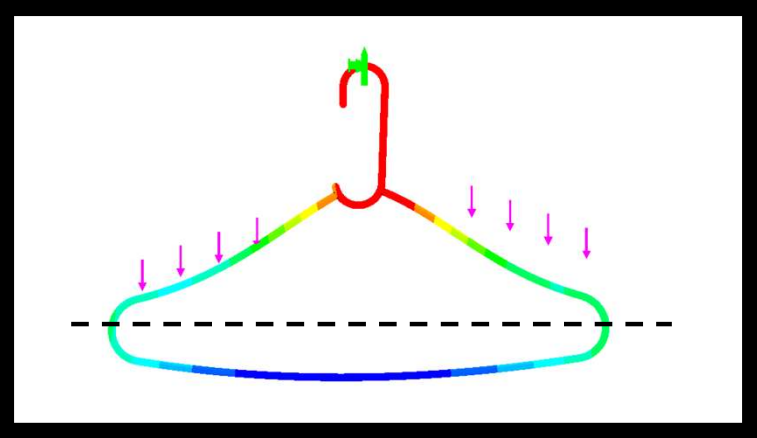
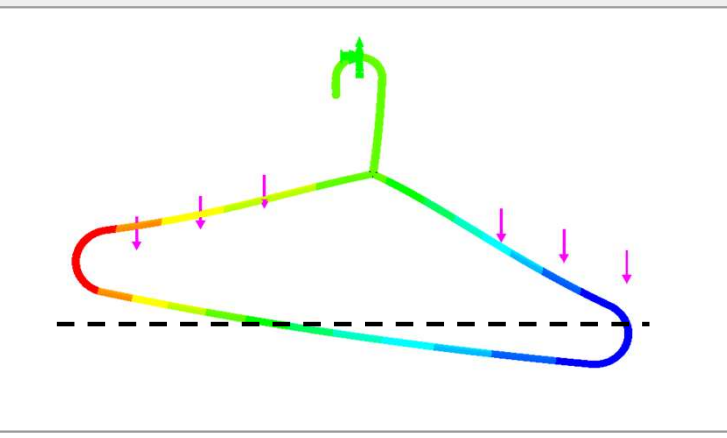
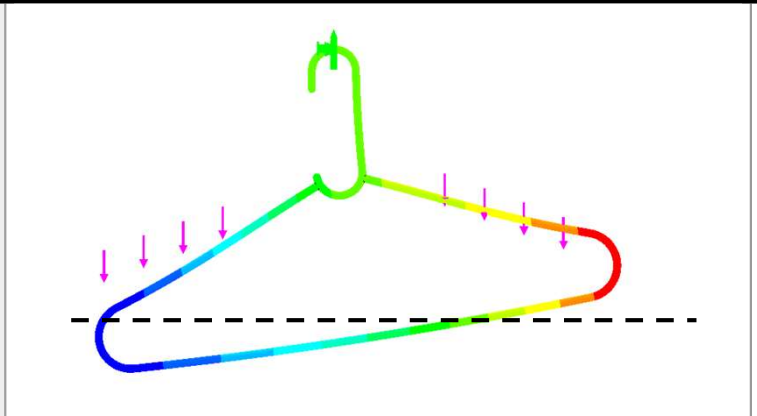
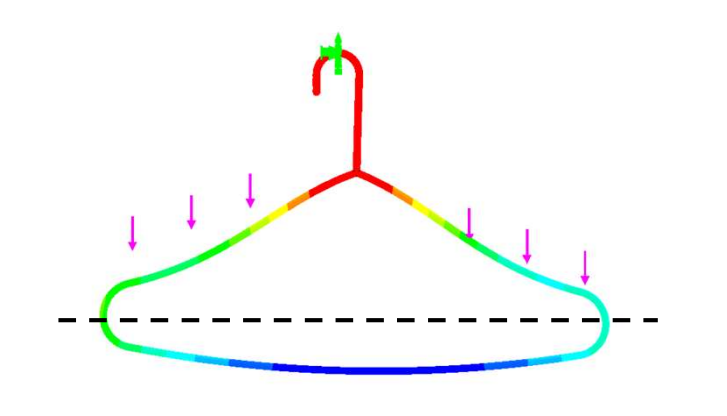


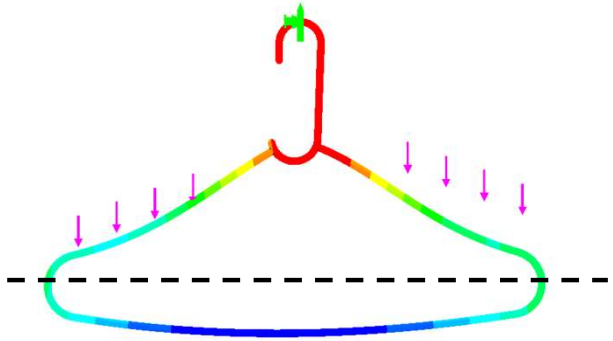
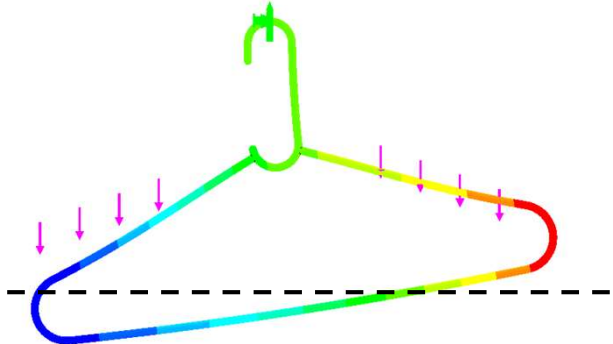
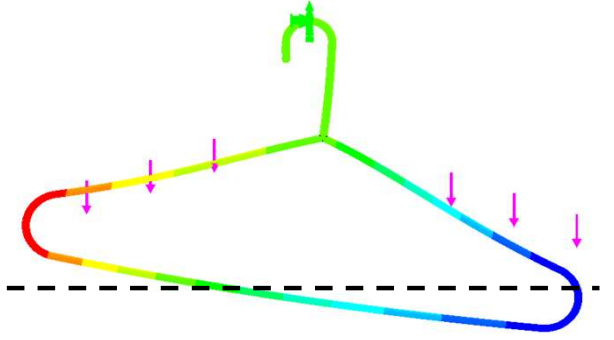
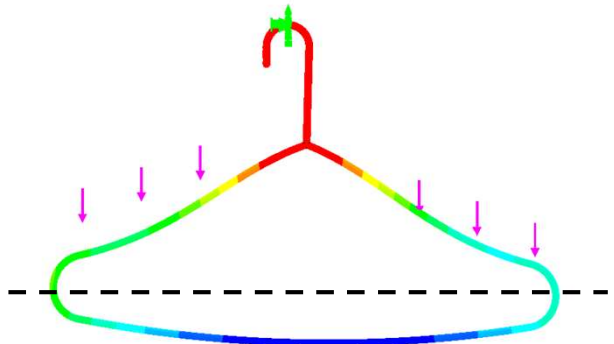
REDESIGN

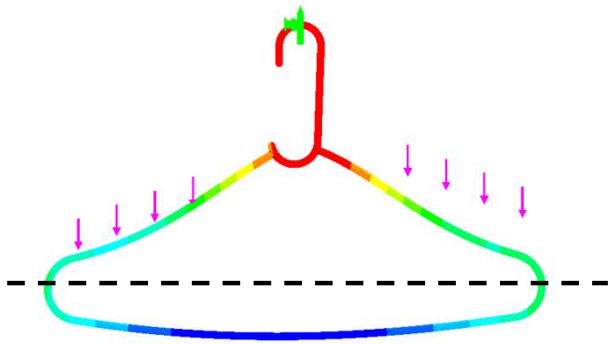
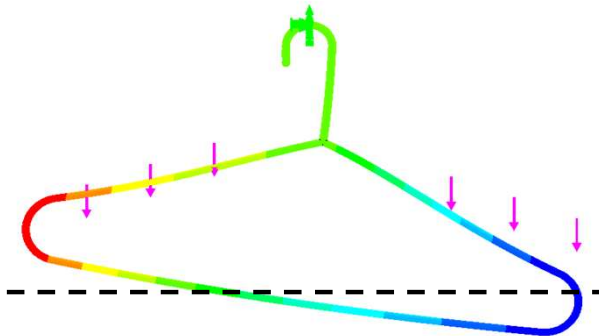
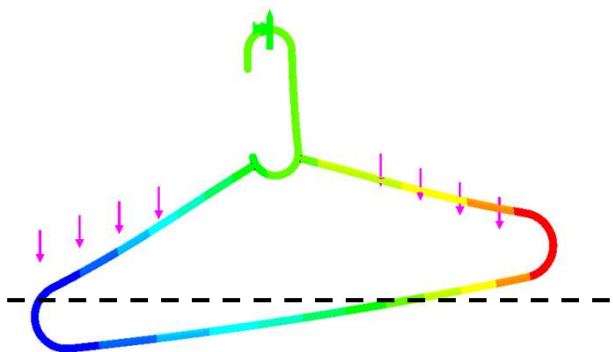
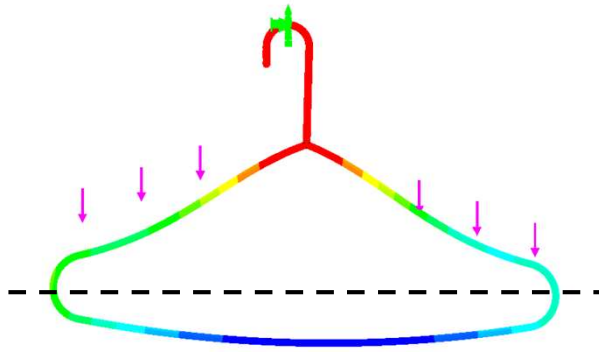


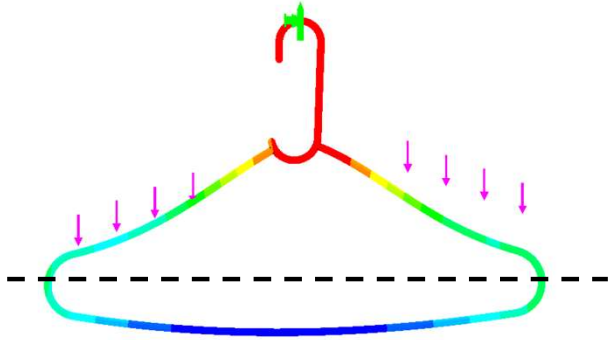
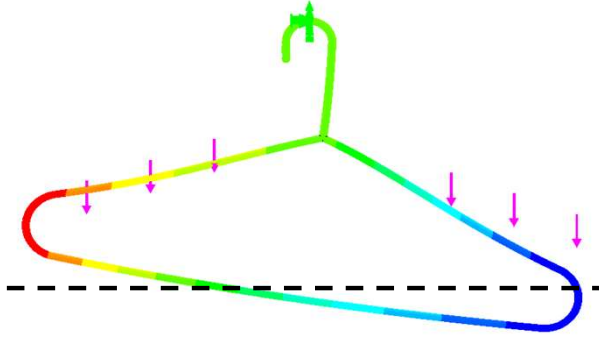
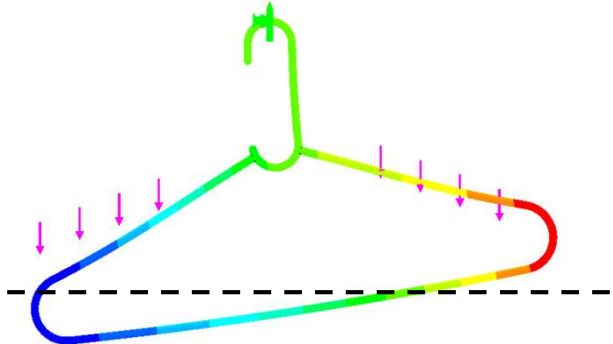
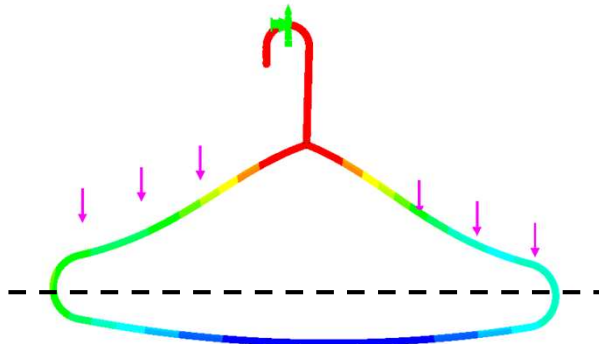
No hook




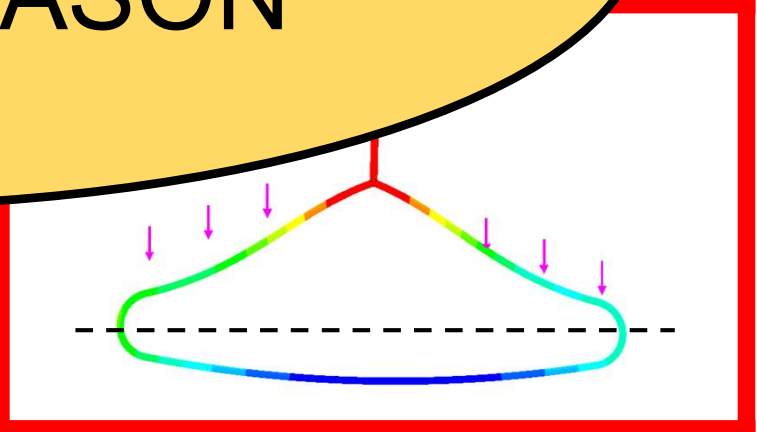
| | ORIGINAL | REDESIGN |
|--------------------------|--|--|
| UNEVEN LOAD (current) |  A diagram of a standard triangular hanger. A green arrow points upwards from the top hook. Purple arrows of varying lengths point downwards from the top bar, representing an uneven load. The hanger is color-coded with a rainbow gradient: red at the top, yellow in the middle, and blue at the bottom. A horizontal dashed line is drawn below the hanger. |  A diagram of a redesigned hanger with a curved top bar. A green arrow points upwards from the top hook. Purple arrows of varying lengths point downwards from the top bar, representing an uneven load. The hanger is color-coded with a rainbow gradient: red at the top, yellow in the middle, and blue at the bottom. A horizontal dashed line is drawn below the hanger. |
| EVEN LOAD (desired) |  A diagram of a standard triangular hanger. A green arrow points upwards from the top hook. Purple arrows of equal length point downwards from the top bar, representing an even load. The hanger is color-coded with a rainbow gradient: red at the top, yellow in the middle, and blue at the bottom. A horizontal dashed line is drawn below the hanger. |  A diagram of a redesigned hanger with a curved top bar. A green arrow points upwards from the top hook. Purple arrows of equal length point downwards from the top bar, representing an even load. The hanger is color-coded with a rainbow gradient: red at the top, yellow in the middle, and blue at the bottom. A horizontal dashed line is drawn below the hanger. |

| | ORIGINAL | REDESIGN |
|--------------------------|---|--|
| UNEVEN LOAD (current) |  A diagram of a standard triangular hanger. The neck is red, the shoulders are yellow, and the body is blue. A green arrow points up from the neck. Purple arrows point down from the shoulders and body, with a higher density on the right side. A dashed horizontal line is at the bottom. The entire diagram is enclosed in a thick black border. |  A diagram of a redesigned hanger with a curved body. The neck is green, the shoulders are yellow, and the body is blue. A green arrow points up from the neck. Purple arrows point down from the shoulders and body, with a higher density on the right side. A dashed horizontal line is at the bottom. |
| EVEN LOAD (desired) |  A diagram of the original hanger. The neck is green, the shoulders are yellow, and the body is blue. A green arrow points up from the neck. Purple arrows point down from the shoulders and body, with a higher density on the left side. A dashed horizontal line is at the bottom. |  A diagram of the redesigned hanger. The neck is red, the shoulders are yellow, and the body is blue. A green arrow points up from the neck. Purple arrows point down from the shoulders and body, with a higher density on the left side. A dashed horizontal line is at the bottom. |



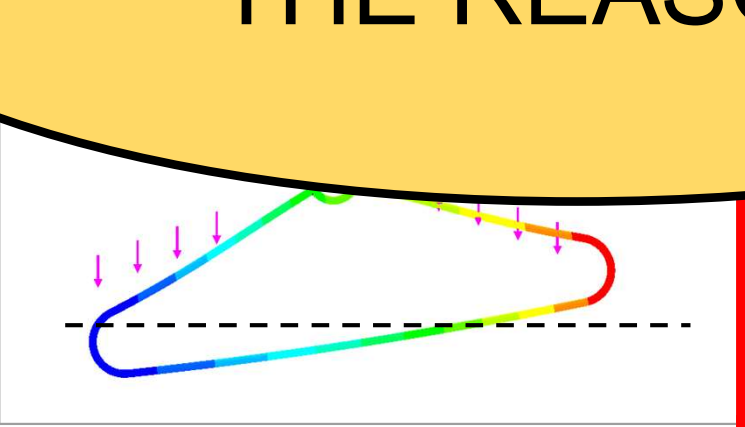
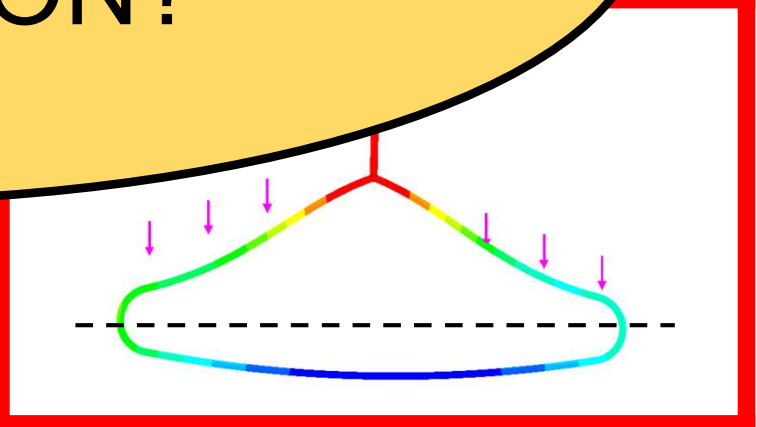
| | ORIGINAL | REDESIGN |
|--------------------------|---|----------|
| UNEVEN LOAD (current) |  A hanger with a red hook and a rainbow-colored body. Purple arrows of varying lengths point downwards from the top edge, indicating uneven load. The hanger is tilted to the right. A dashed horizontal line is at the bottom. | |
| EVEN LOAD (desired) |  A hanger with a green hook and a rainbow-colored body. Purple arrows of equal length point downwards from the top edge, indicating even load. The hanger is tilted to the left. A dashed horizontal line is at the bottom. | |
| UNEVEN LOAD (current) |  A hanger with a green hook and a rainbow-colored body. Purple arrows of varying lengths point downwards from the top edge, indicating uneven load. The hanger is tilted to the left. A dashed horizontal line is at the bottom. This cell is highlighted with a thick black border. | |
| EVEN LOAD (desired) |  A hanger with a red hook and a rainbow-colored body. Purple arrows of equal length point downwards from the top edge, indicating even load. The hanger is tilted to the right. A dashed horizontal line is at the bottom. | |

| | ORIGINAL | REDESIGN |
|--------------------------|--|---|
| UNEVEN LOAD (current) |  A diagram of a standard triangular hanger. A green arrow points upwards from the top hook. Purple arrows representing downward load are concentrated on the right side of the hanger. The hanger's shape is distorted, with the right side being significantly lower than the left side. A dashed horizontal line is drawn across the bottom of the hanger. |  A diagram of a redesigned hanger with a curved, asymmetrical shape. A green arrow points upwards from the top hook. Purple arrows representing downward load are distributed across the entire width of the hanger. The hanger's shape is distorted, with the right side being lower than the left side. A dashed horizontal line is drawn across the bottom of the hanger. |
| EVEN LOAD (desired) |  A diagram of a standard triangular hanger. A green arrow points upwards from the top hook. Purple arrows representing downward load are distributed evenly across the entire width of the hanger. The hanger's shape is distorted, with the right side being lower than the left side. A dashed horizontal line is drawn across the bottom of the hanger. |  A diagram of a redesigned hanger with a curved, asymmetrical shape. A green arrow points upwards from the top hook. Purple arrows representing downward load are distributed evenly across the entire width of the hanger. The hanger's shape is distorted, with the right side being lower than the left side. A dashed horizontal line is drawn across the bottom of the hanger. |

| | ORIGINAL | REDESIGN |
|--------------------------|--|--|
| UNEVEN LOAD (current) |  <p>A diagram of a standard triangular hanger. A green hook is at the top. The hanger body is colored with a gradient from red at the top to blue at the bottom. Purple arrows of varying lengths point downwards from the top edge, indicating an uneven load distribution. A dashed horizontal line is drawn below the hanger.</p> |  <p>A diagram of a redesigned hanger with a curved bottom edge. It has a green hook and a color gradient from red to blue. Purple arrows of varying lengths point downwards from the top edge, indicating an uneven load distribution. A dashed horizontal line is drawn below the hanger.</p> |
| EVEN LOAD (desired) |  <p>A diagram of the original triangular hanger. A green hook is at the top. The hanger body is colored with a gradient from blue at the top to red at the bottom. Purple arrows of equal length point downwards from the top edge, indicating an even load distribution. A dashed horizontal line is drawn below the hanger.</p> |  <p>A diagram of the redesigned hanger with a curved bottom edge. It has a green hook and a color gradient from blue at the top to red at the bottom. Purple arrows of equal length point downwards from the top edge, indicating an even load distribution. A dashed horizontal line is drawn below the hanger. The entire diagram is enclosed in a thick red rectangular border.</p> |

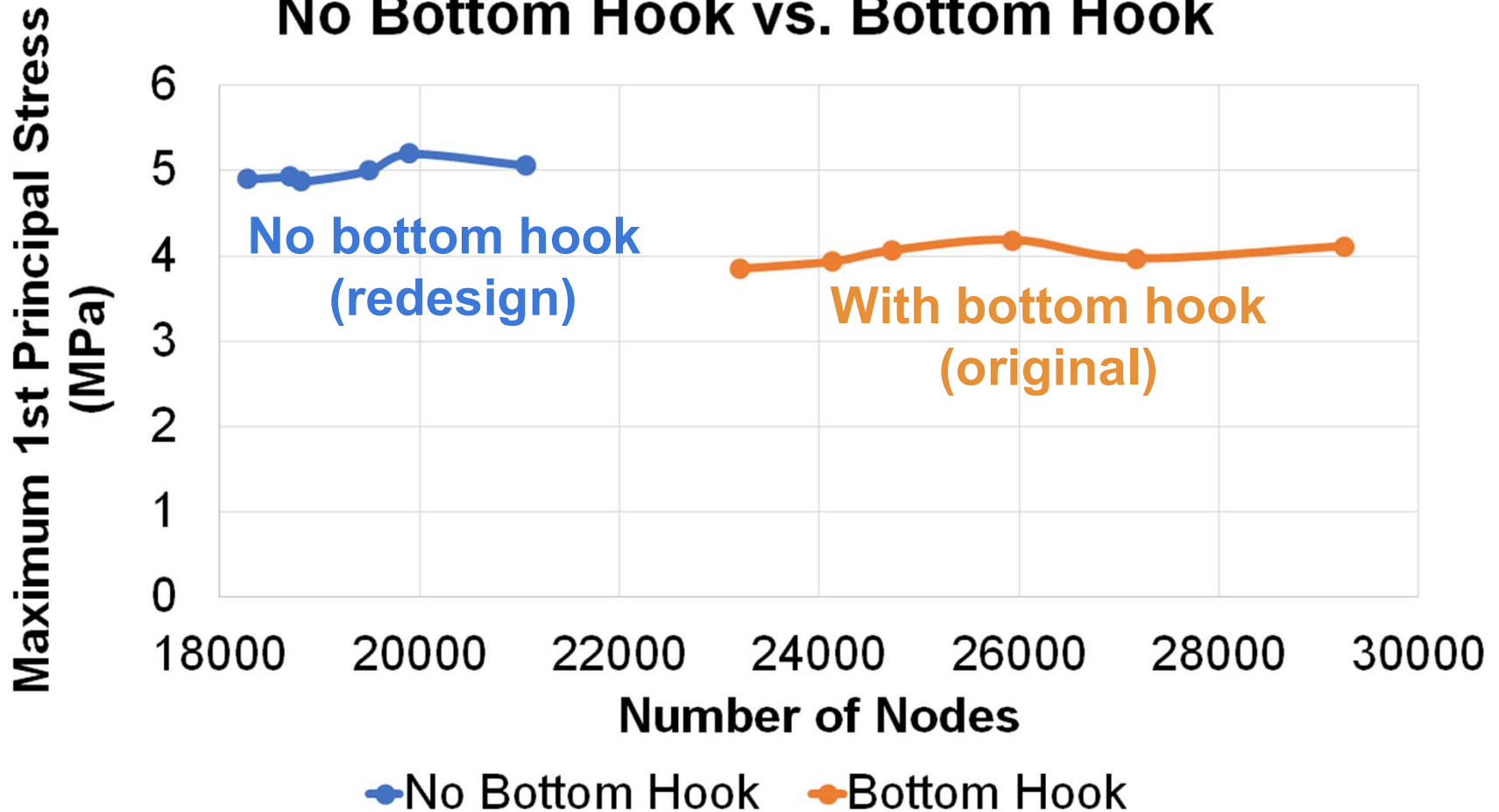
| | ORIGINAL | REDESIGN |
|---------------------------------|---|---|
| UNEVEN LOAD (current) |  <p>The original design is shown under an uneven load. A green arrow points upwards at the top center, and a red arrow points downwards at the top right. The structure is distorted, with a large yellow oval overlaid on it containing the text "DISPLACEMENT IS NOT THE REASON".</p> |  <p>The redesigned structure is shown under the same uneven load. A green arrow points upwards at the top center, and a red arrow points downwards at the top right. The structure is more symmetrical and balanced.</p> |
| EVEN LOAD (desired) |  <p>The original design is shown under an even load. Purple arrows point downwards across the top. The structure is distorted, with a large yellow oval overlaid on it containing the text "DISPLACEMENT IS NOT THE REASON".</p> |  <p>The redesigned structure is shown under an even load. Purple arrows point downwards across the top. The structure is more symmetrical and balanced. This entire row is enclosed in a red rectangular border.</p> |

DISPLACEMENT IS NOT THE REASON

| | ORIGINAL | REDESIGN |
|---------------------------------|---|---|
| UNEVEN LOAD (current) |  <p>The original design is a triangular hanger with a curved top. Under uneven load (represented by purple arrows), the top hook is distorted, shown by a green arrow pointing upwards and a red circle with a crosshair at the top vertex.</p> |  <p>The redesigned hanger has a more symmetrical, rounded top. Under the same uneven load, the top hook is straight and balanced, shown by a green arrow pointing upwards.</p> |
| EVEN LOAD (desired) |  <p>The original design under even load (purple arrows) shows significant stress concentration at the top vertex, indicated by a red-to-yellow color gradient.</p> |  <p>The redesigned hanger under even load shows a more uniform stress distribution across the top, indicated by a green-to-blue color gradient. This redesigned version is highlighted with a red rectangular border.</p> |

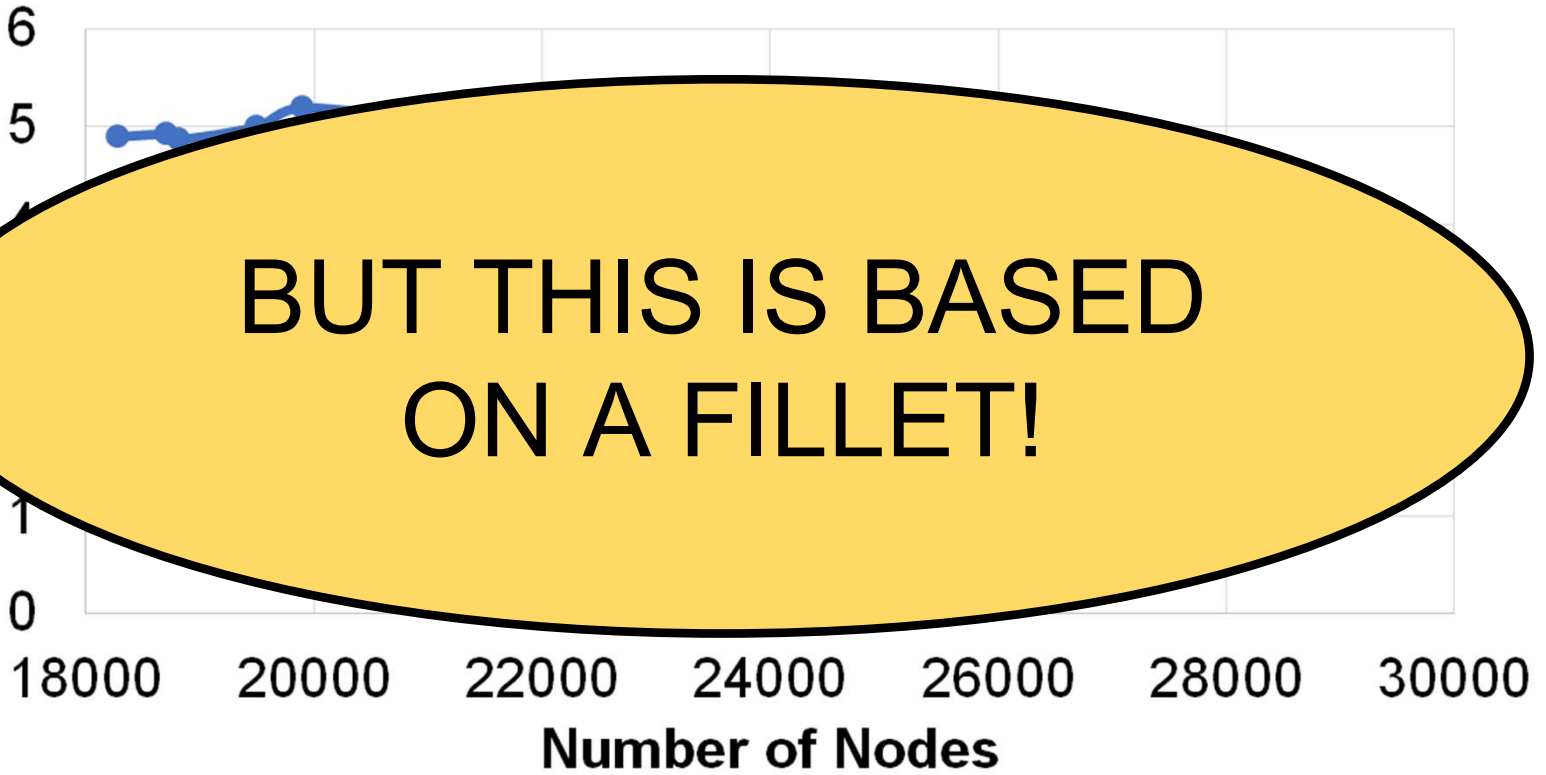
MAYBE STRESS IS THE REASON?

Convergence Test: No Bottom Hook vs. Bottom Hook



Convergence Test: No Bottom Hook vs. Bottom Hook

Maximum 1st Principal Stress



**BUT THIS IS BASED
ON A FILLET!**

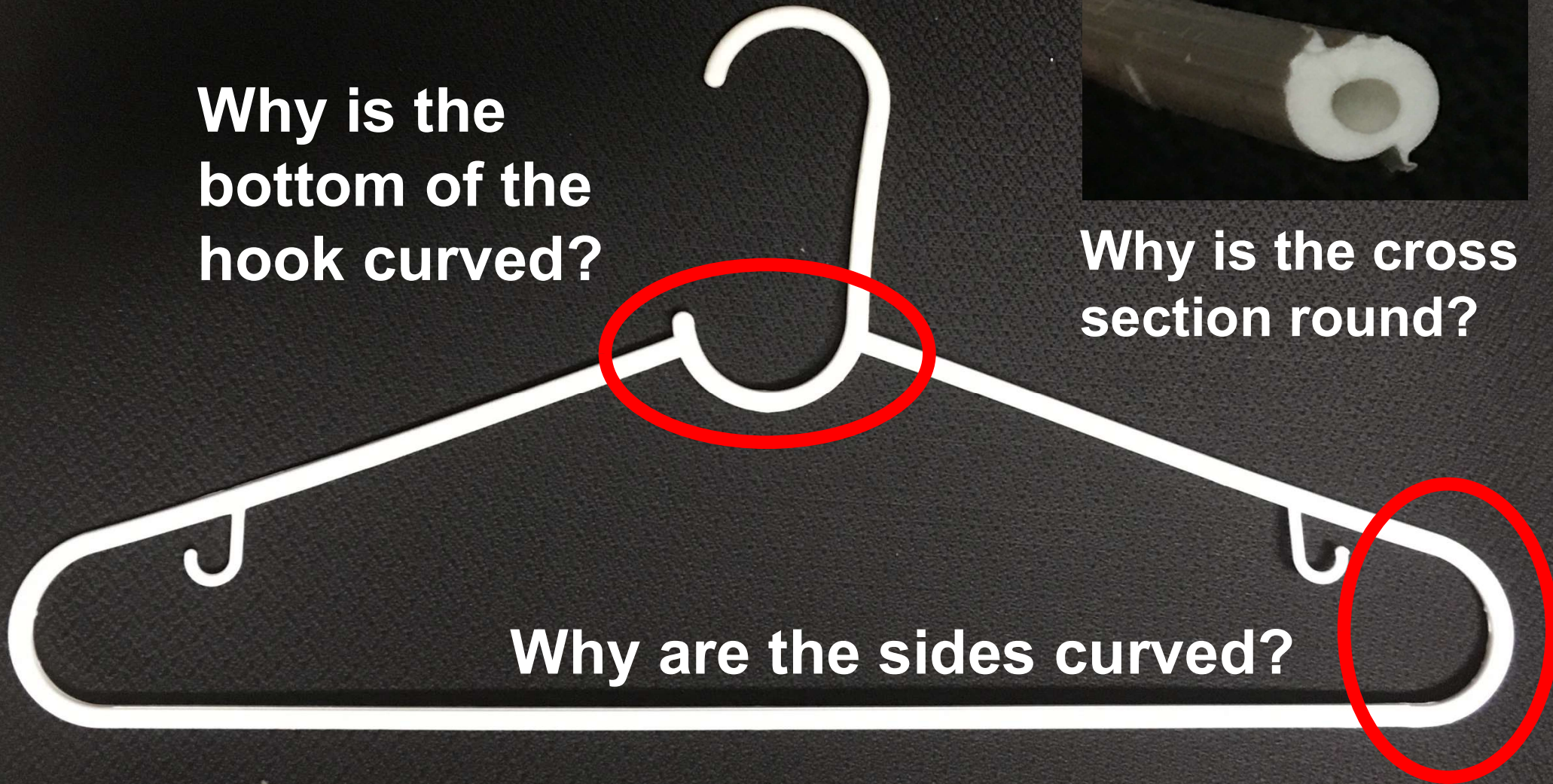
● No Bottom Hook ● Bottom Hook

Why is the bottom of the hook curved?

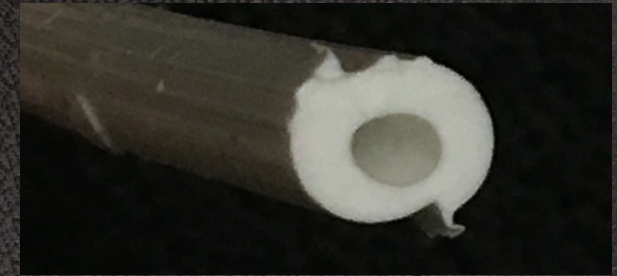


Why is the cross section round?

Why are the sides curved?

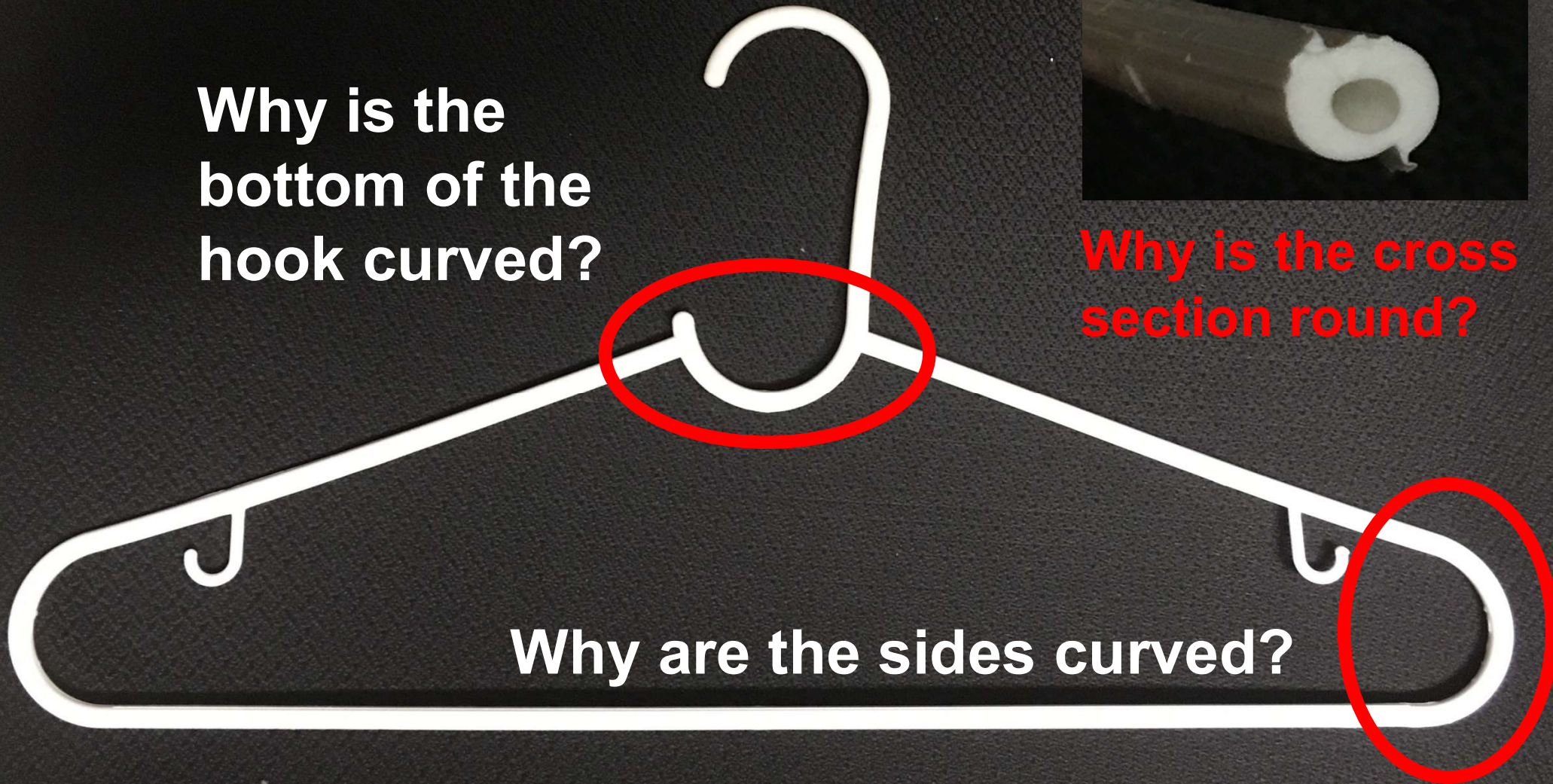


Why is the bottom of the hook curved?

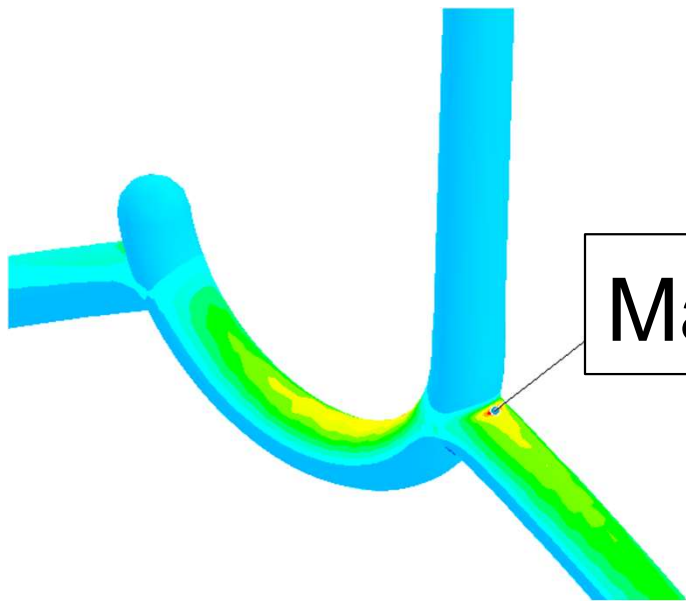


Why is the cross section round?

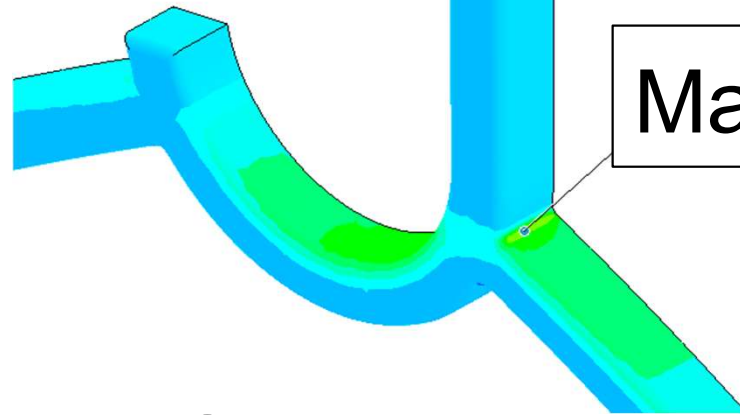
Why are the sides curved?



FILLET, 1 MM

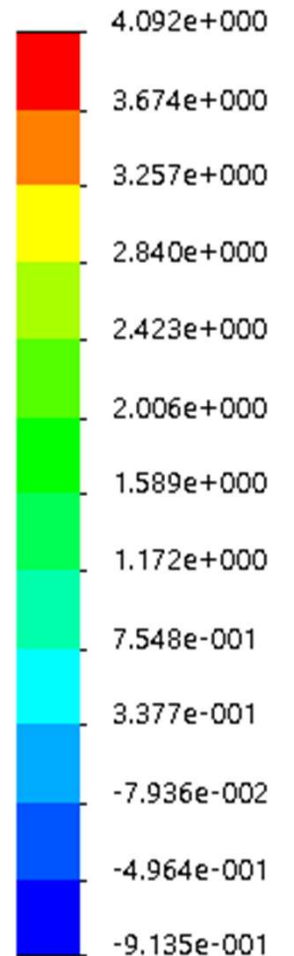


Circle
4 MPa



Square
2.4 MPa

P1 (N/mm² (MPa))



FILLET, 1 MM

STRESS IS NOT THE
REASON

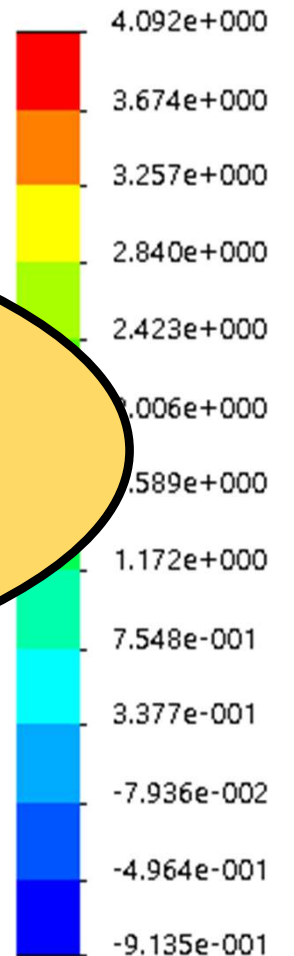
Circle

4 MPa

Square

2.4 MPa

P1 (N/mm² (MPa))



FILLET, 1 MM

MAYBE
MANUFACTURING
ADVANTAGE?

Circle

4 MPa

Square

2.4 MPa

P1 (N/mm² (MPa))

4.092e+000

3.674e+000

3.257e+000

2.840e+000

2.423e+000

2.006e+000

1.589e+000

1.172e+000

7.548e-001

3.377e-001

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-4.964e-001

-9.135e-001

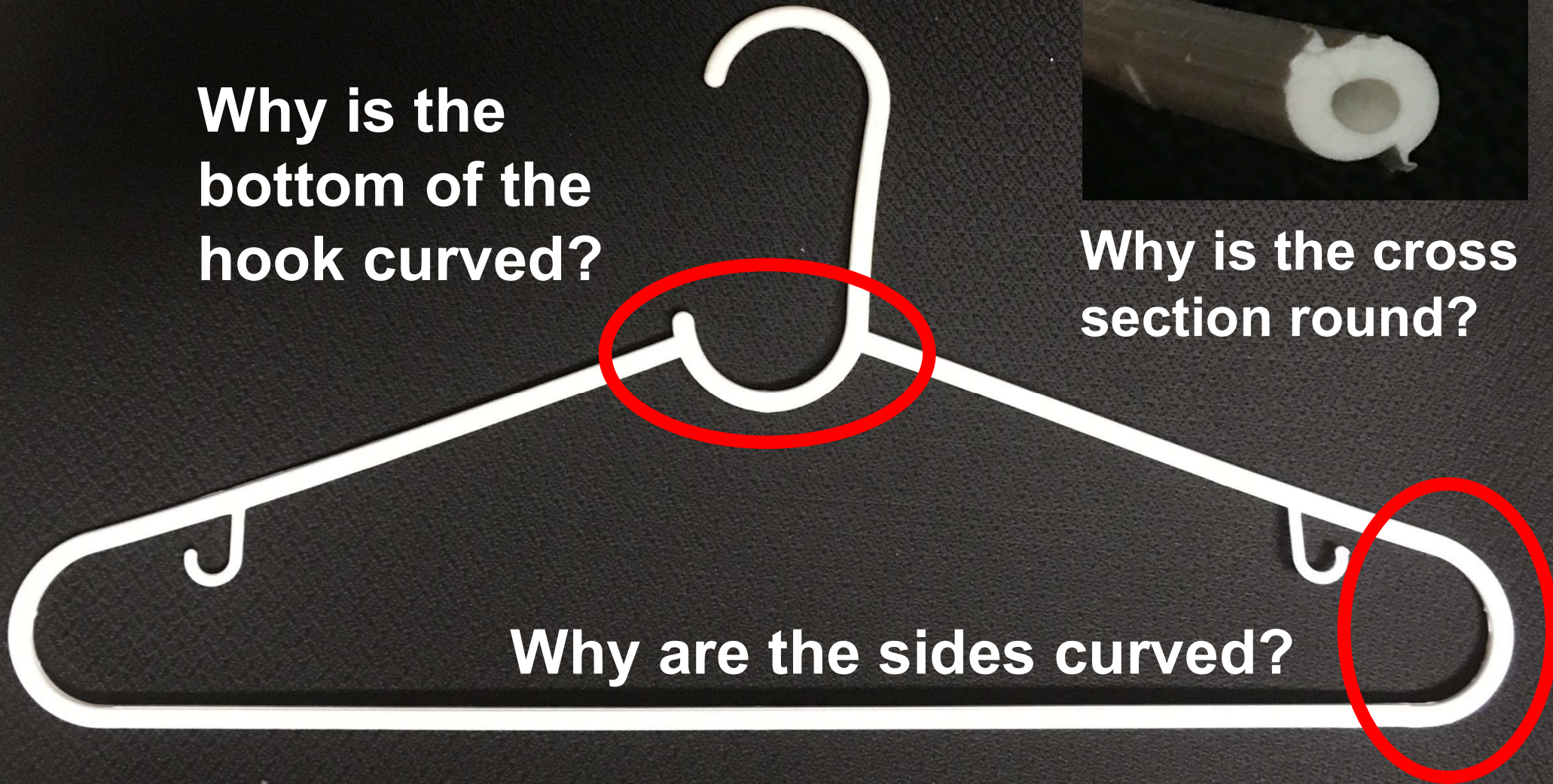


Why is the bottom of the hook curved?



Why is the cross section round?

Why are the sides curved?

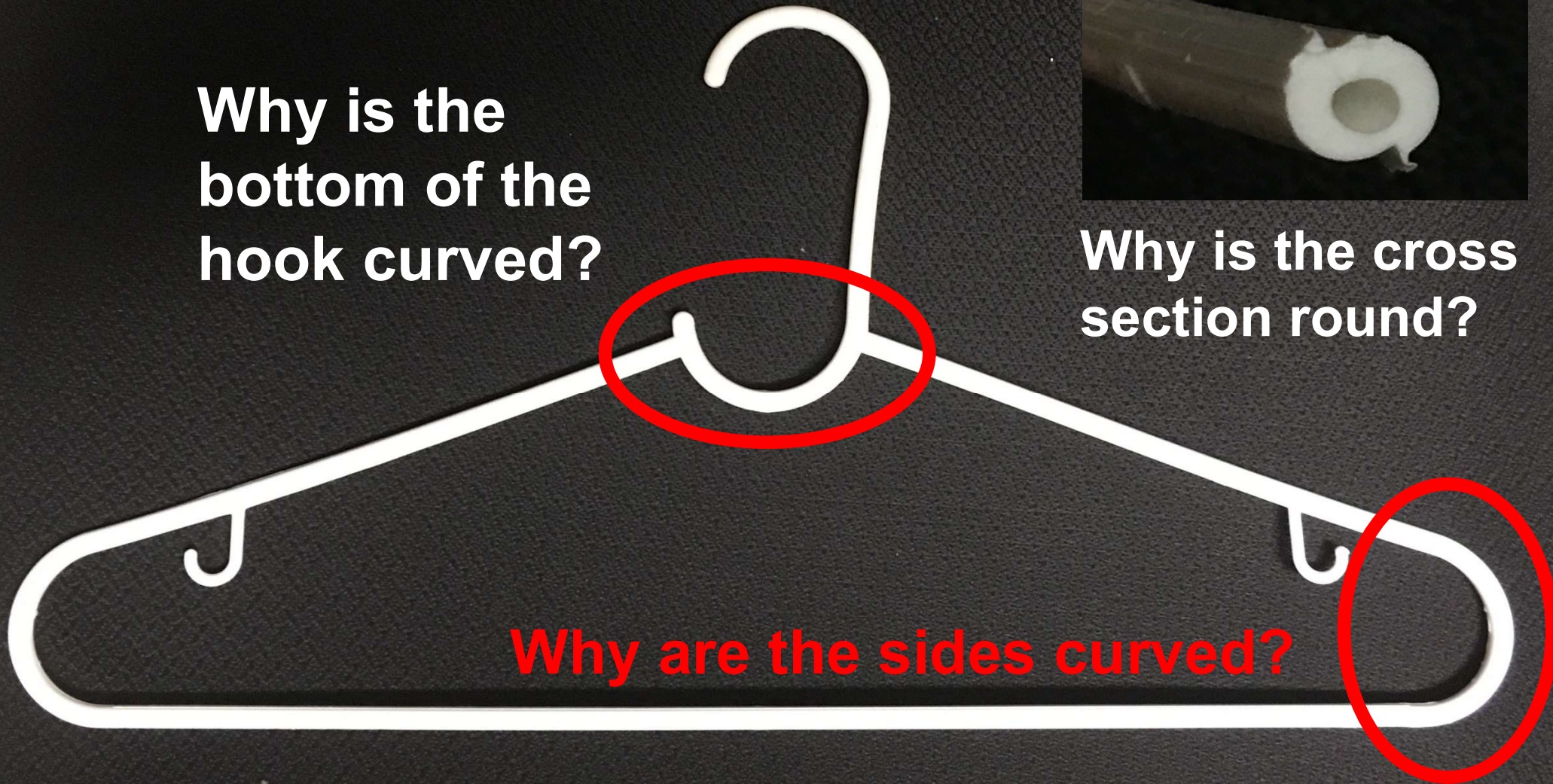


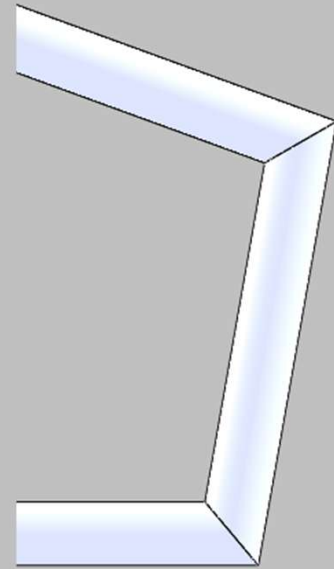
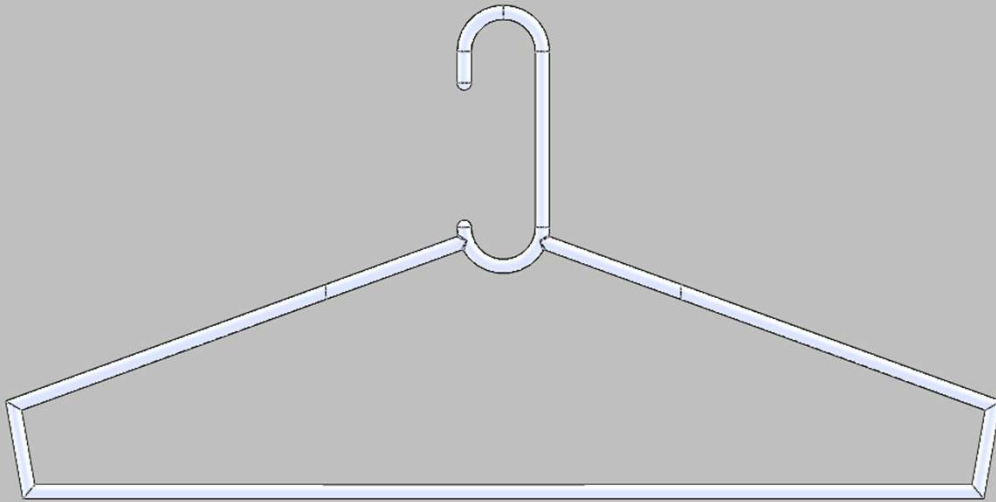
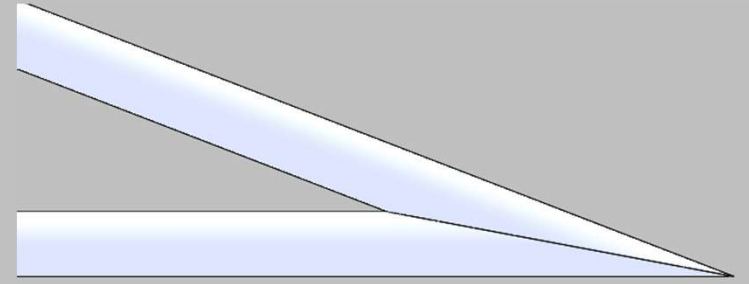
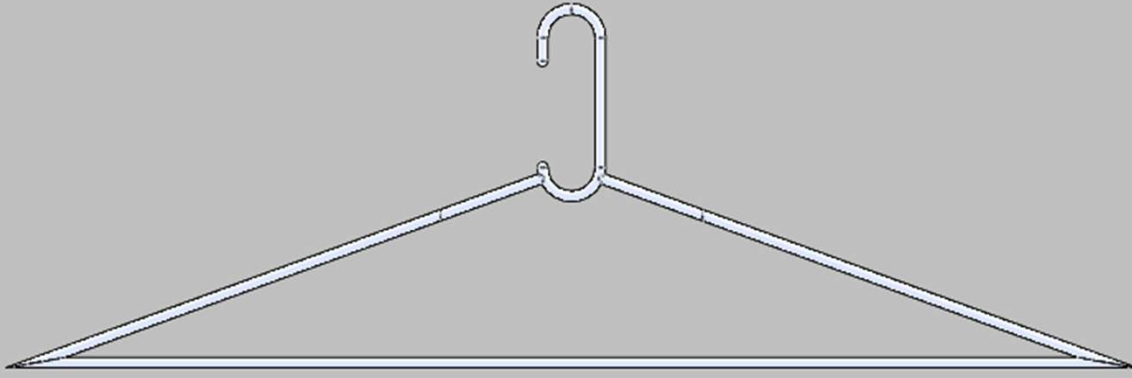
Why is the bottom of the hook curved?

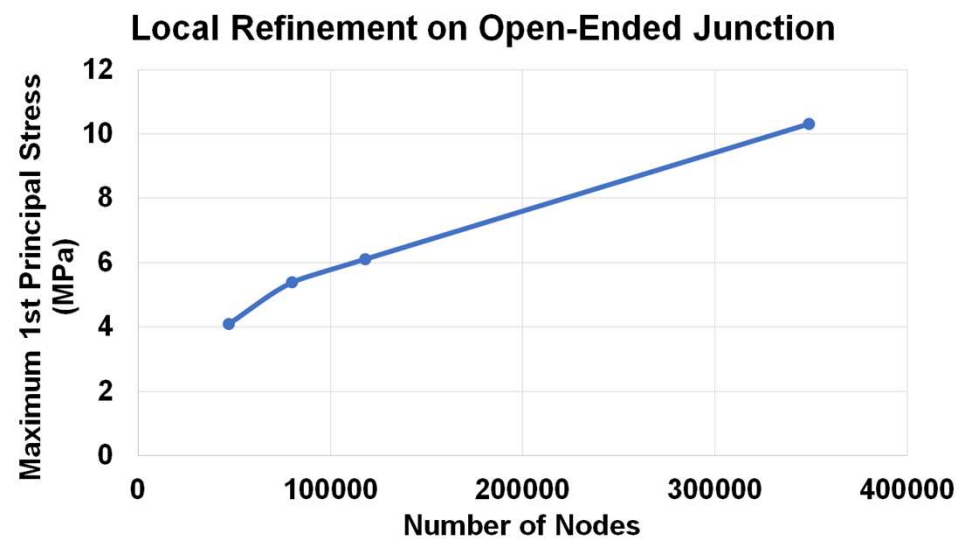
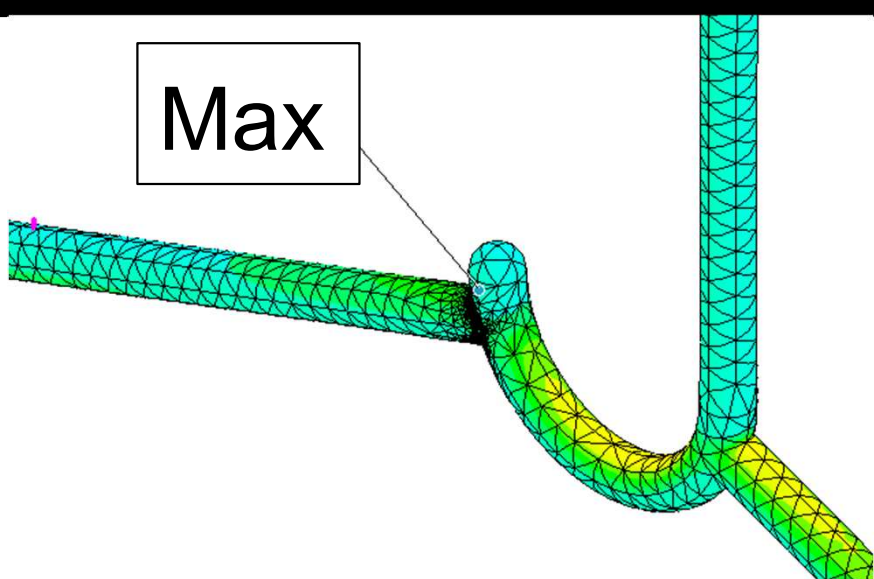
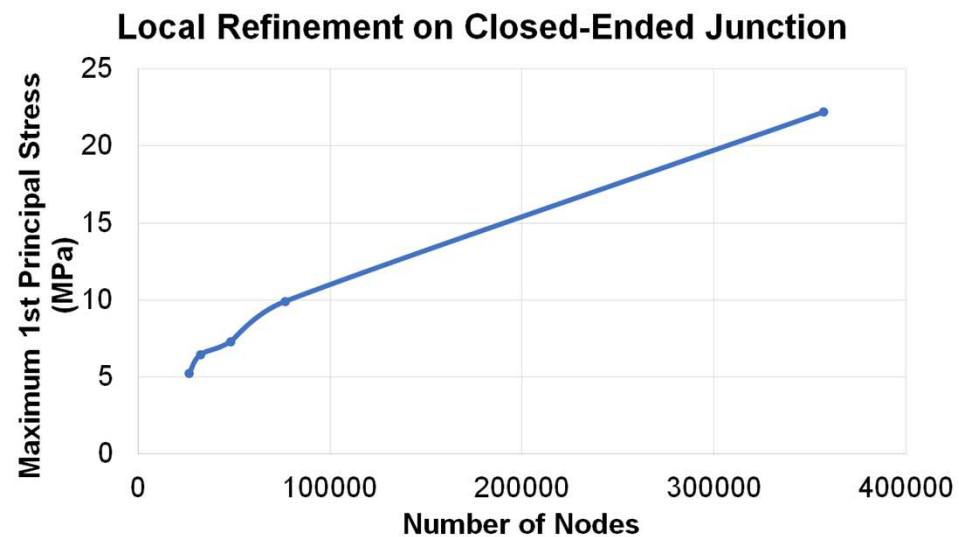
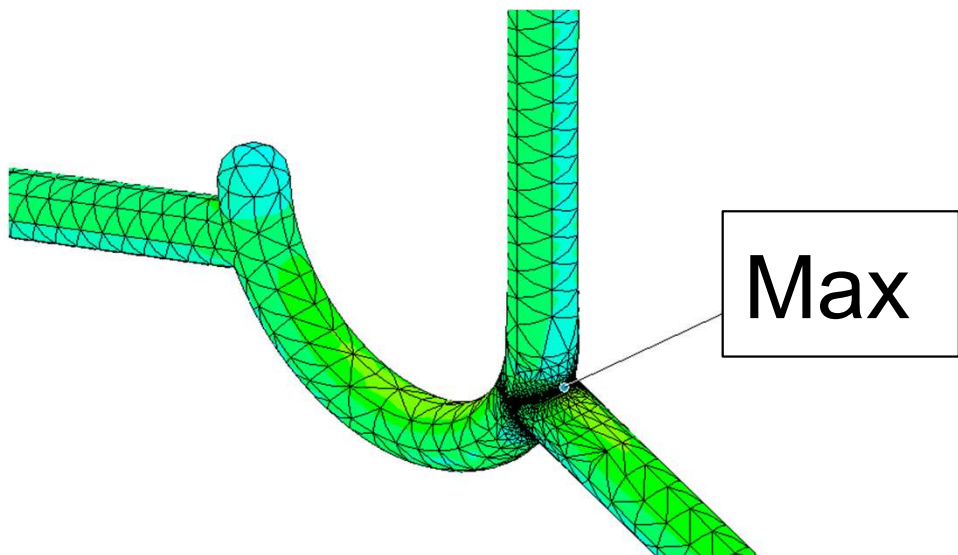


Why is the cross section round?

Why are the sides curved?









Might be a problem



A white wire clothes hanger is centered against a dark, textured background. A light green oval with a black border is superimposed over the middle of the hanger. Inside the oval, the text "Good design!" is written in a bold, black, sans-serif font.

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 UNKNOWN'S

So conclusion?

Bajinder is a bad user of hangers.



But yea them
hangers be
breaking always



That's your fault!!!

Thank you to:

Professor Benenson

Alan Faitelewicz

Kerim Ikikardaslar

Salih Yildiz

Shuaijun Li

Professor Yu

Professor Sadegh

Professor Mansoor

Gym receptionists

**Thanks for
hanging around!**