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Countersunk Hole Bearing Solutions Investigation

AFGROW User Workshop 2019

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Countersunk Hole Bearing Solutions

- Work in progress…
- This is intended to be a thought-provoking presentation to facilitate discussions and determine path forward for AFGROW implementation
- The problem is quite complex with many factors influencing the solutions
- We cannot solve everyone's problems with new canned solutions in AFGROW
- What is the best approach given the existing solutions in AFGROW?

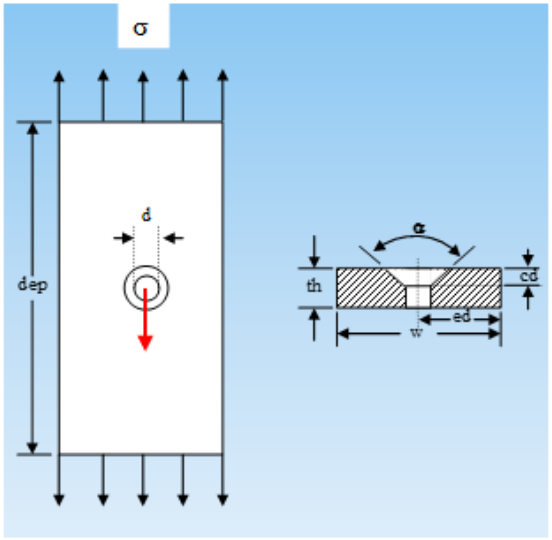
How do we get everyone on the same page?

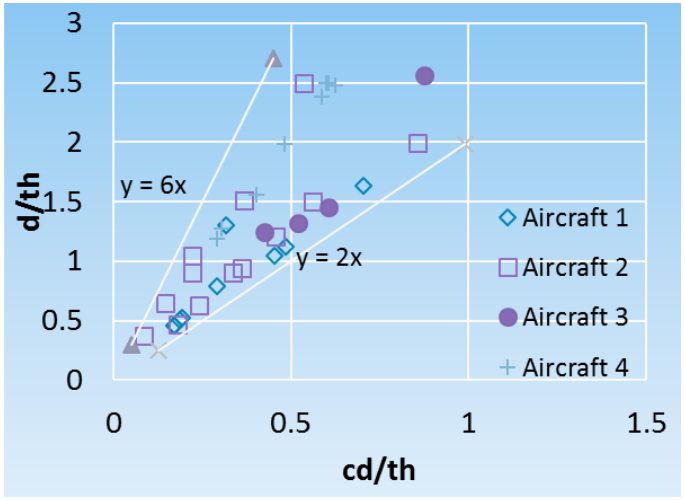
Countersunk Hole Bearing Solutions

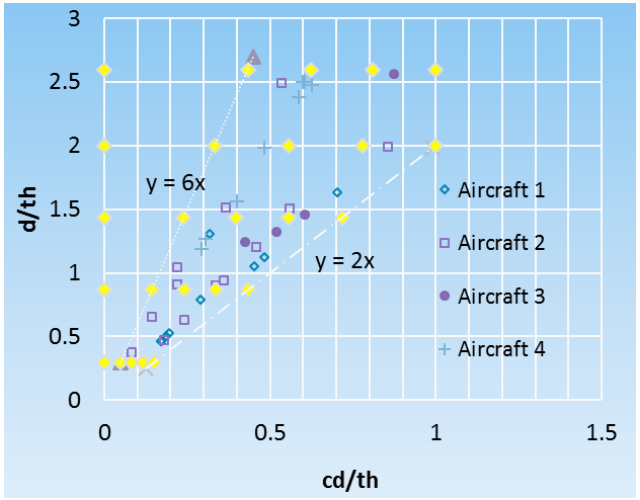
- **Background**
  - Stress intensity solutions for countersunk holes under tension loading was previously developed by Jody Cronenberger
  - Stress intensity solutions for straight shank holes under bearing loading was previously developed by Fawaz-Andersson
  - Stress intensity solutions for countersunk holes under bearing loading do not exist in AFGROW
- **Objective**
  - Complete an initial investigation to compare/contrast various approaches to model bearing loads at countersunk holes
  - Develop the necessary data to support the determination of modeling approach for new AFGROW solutions
- **Approach**
  - Review typical solution space
  - Review key factors
  - Identify comparison conditions
  - Identify analysis methods
  - Compare/contrast results

Solution Space Investigation

- Aircraft survey (four aircraft) used to investigate hole diameter (d), plate thickness (th), and countersink depth (cd)
- Results show a very organized distribution that has an engineering explanation
- 25 d/th vs. cd/th points
- cd/th ranges from 0.001 to 0.95



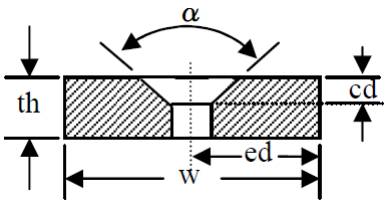


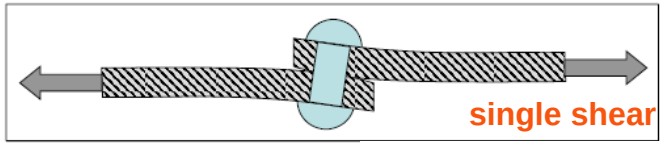


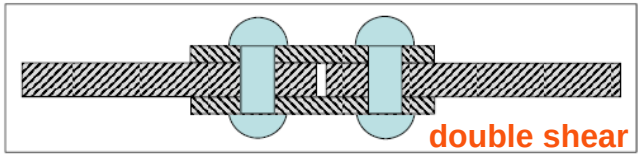
Courtesy: SwRI and Dallen Andrew

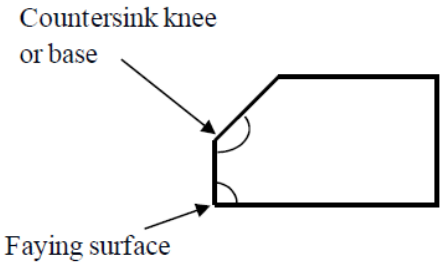
Key Factors

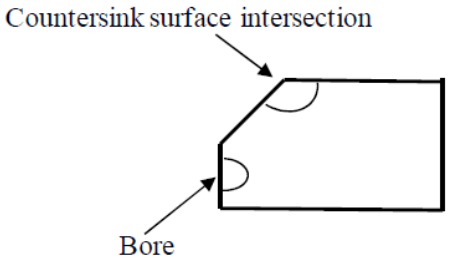
- **Geometric**
  - Countersink depth ‘cd’ (as % of thickness)
    - Knife-edge conditions
  - Hole shank diameter ‘D’ (as ratio of D/th)
  - Countersink angle ‘α’
- **Joint Design**
  - Single vs. double shear
  - Fastener racking
  - Bolt preload
  - Fastener fit (clearance, neat, interference)
- **Load Application**
  - Bore only vs. bore and countersink
  - Method
    - COS^2 distribution
    - Full contact
    - Springs/other
- **Material**
  - Plate material
  - Fastener material
- **Crack Definition**
  - Location
    - Countersink knee
    - Faying surface
    - Bore
    - Countersink surface intersect
  - Aspect ratio
  - Crack shape
  - Corner vs. thru crack
  - Crack size







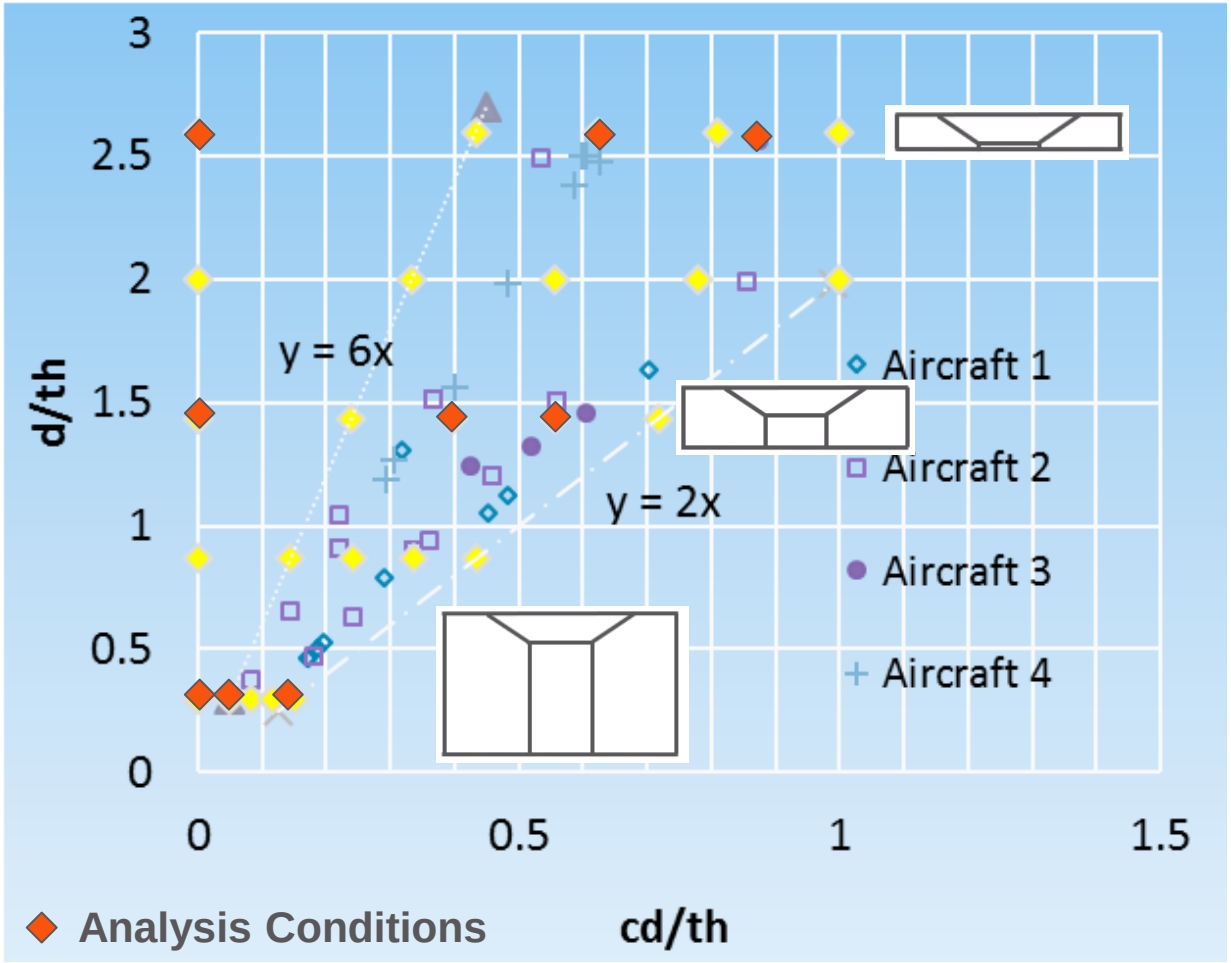




Images Courtesy SwRI, Jody Cronenberger and Zachary Whitman

Comparison Conditions

- Exercise bounds and "typical" conditions within solution space
- Establish fixed inputs/assumptions
  - Controls
- Vary key factors
  - Variables



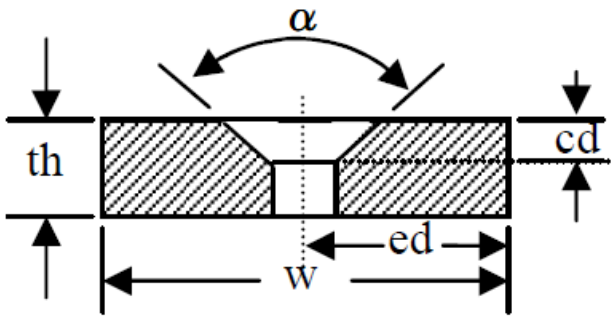
Analysis Assumptions

- **Geometric**
  - Fixed: 100o countersink angle
  - Countersink depth (as % of thickness)
  - Hole shank diameter (as ratio of D/th)
  - Thickness
- **Joint Design**
  - Single and double shear
  - No fastener restraint
  - Fixed: No bolt preload
  - Fixed: Neat fastener fit
- **Load Application**
  - Bore only vs. bore and countersink
  - Method
    - $COS^2\Theta$ distribution
    - Springs
    - Full contact
- **Material**
  - Fixed: Plate material (Aluminum), Fastener material (Steel)
- **Crack Definition**
  - Fixed: Crack size
  - Fixed: Aspect ratio (a/c = 1)
  - Fixed: Crack shape (Elliptical)
  - Fixed: Corner cracks only
  - Location: Countersink knee, faying surface

https://www.123rf.com/stock-photo/assumptions.html

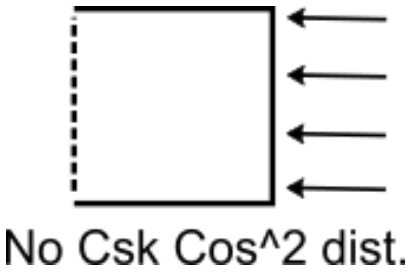
Analysis Matrix

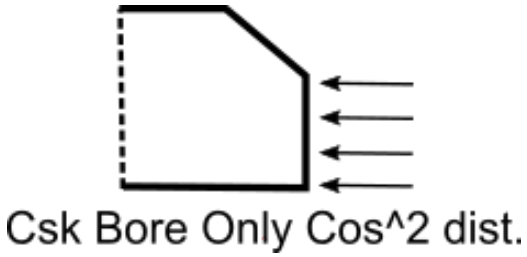
Geometry						Load Application		Crack Definition		# of Models		
cd (inch)	th (inch)	D (inch)	cd/th	D/th	Bore Thickness (inch)	Location	Method	Location	Size (% of bore thickness)	Adv Model	Cos²	Contact
0.000	0.630	0.189	0.000	0.300	0.630	Bore	Adv. Model, COS²	Faying	10, 25, 50%	3	3	0
0.000	0.175	0.250	0.000	1.429	0.175	Bore	Adv. Model, COS²	Faying	25, 50%	2	2	0
0.000	0.120	0.313	0.000	2.604	0.120	Bore	Adv. Model, COS²	Faying	50%	1	1	0
0.032	0.630	0.189	0.050	0.300	0.599	Bore, Full	Contact, COS²	Faying, Knee	10, 25, 50%	0	12	6
0.070	0.175	0.250	0.400	1.429	0.105	Bore, Full	Contact, COS²	Faying, Knee	50, 75%	0	8	4
0.072	0.120	0.313	0.600	2.604	0.048	Bore, Full	Contact, COS²	Faying, Knee	50, 75%	0	8	4
0.095	0.630	0.189	0.150	0.300	0.536	Bore, Full	Contact, COS²	Faying, Knee	10, 25, 50%	0	12	6
0.098	0.175	0.250	0.560	1.429	0.077	Bore, Full	Contact, COS²	Faying, Knee	25, 50%	0	8	4
0.094	0.120	0.313	0.780	2.604	0.026	Bore, Full	Contact, COS²	Faying, Knee	75%	0	4	2
									Total:	6	58	26

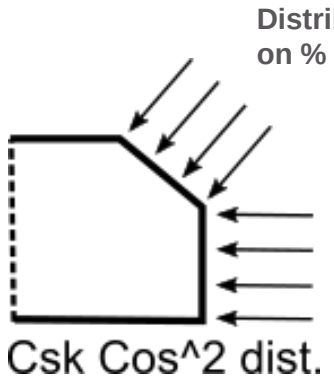


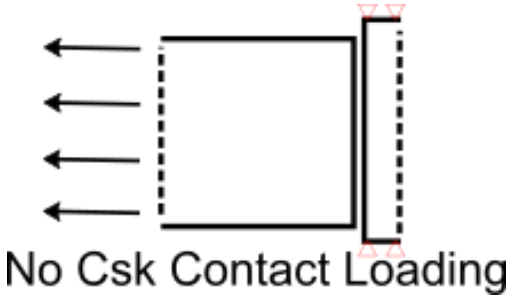
Boundary Conditions

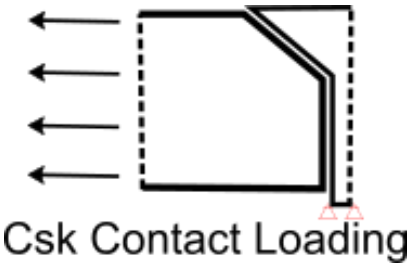
- Five different scenarios









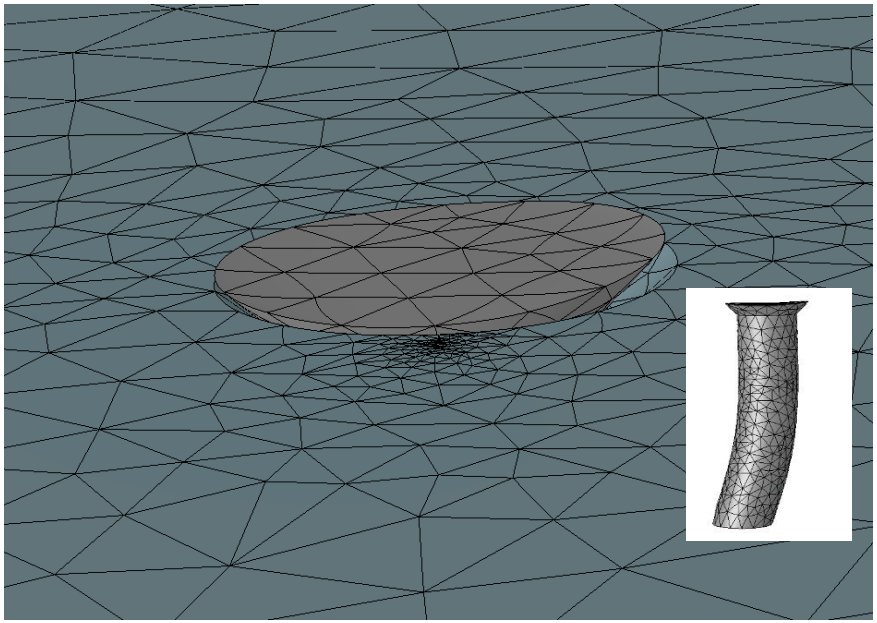


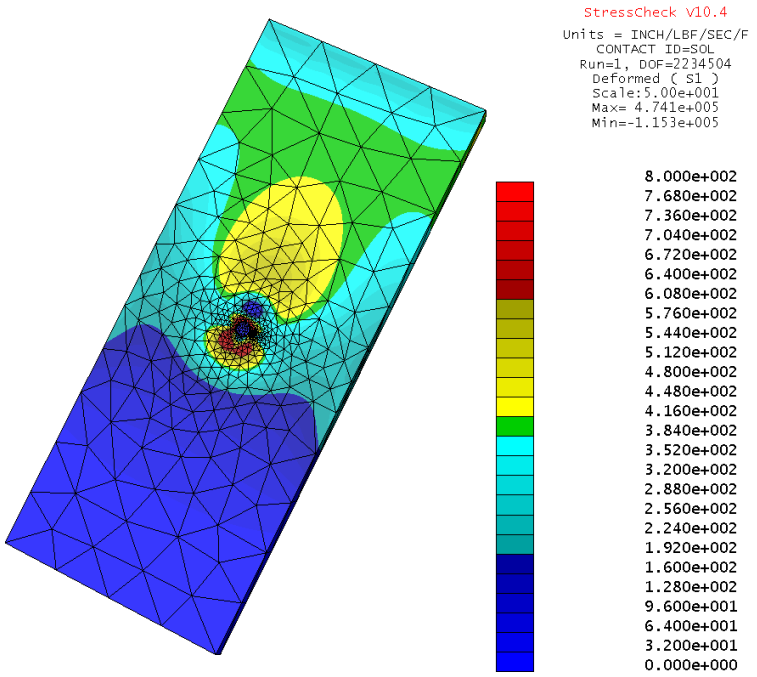
Boundary Conditions

- **Bearing Distribution Models**
  - $Cos^2\Theta$ distribution acting on the faces of the bore and countersink in the lengthwise direction
    - Distribution on countersink a normal force (adjusted to give equivalent lengthwise load)
    - For “full” bearing solution distribution of load based on % of total thickness
  - Fixed constrain on one end of model
  - Fixed constrain on faying surface to react out of plane load from Csk (??)
- **Contact Models**
  - Remote load applied at one end of the model acting in the lengthwise direction
  - Constraints at opposite end of the model to restrict rotation
  - A fixed constraint was placed on the shear plane of the fastener
  - Fixed constrain on faying surface to react out of plane load from Csk (??)
  - Contact boundary conditions and default parameters utilized in StressCheck

Condition 1: Contact Model

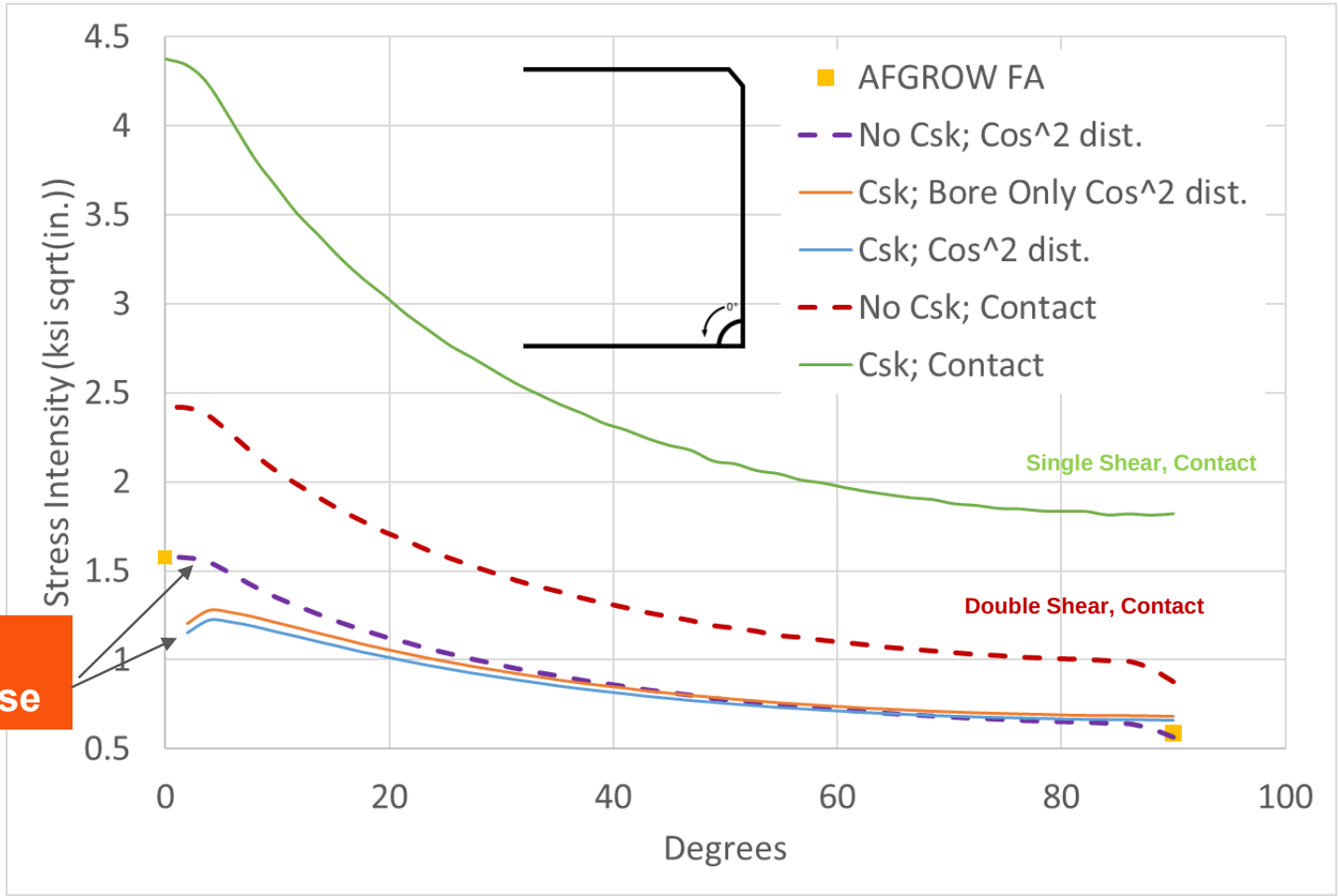
- Deformations and Stress Profiles





Condition 1: Results

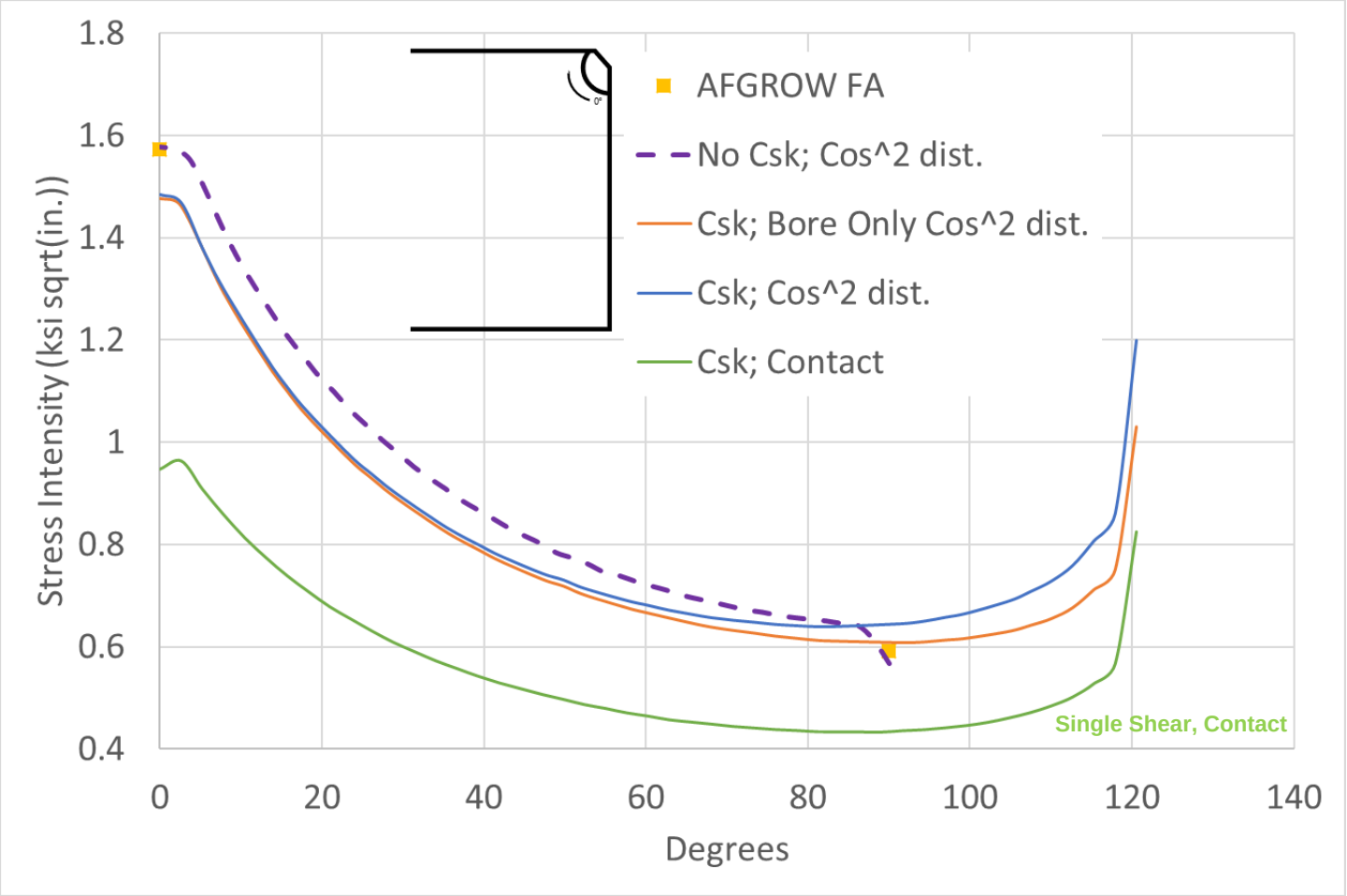
- Faying Surface Flaw



This difference doesn't make sense

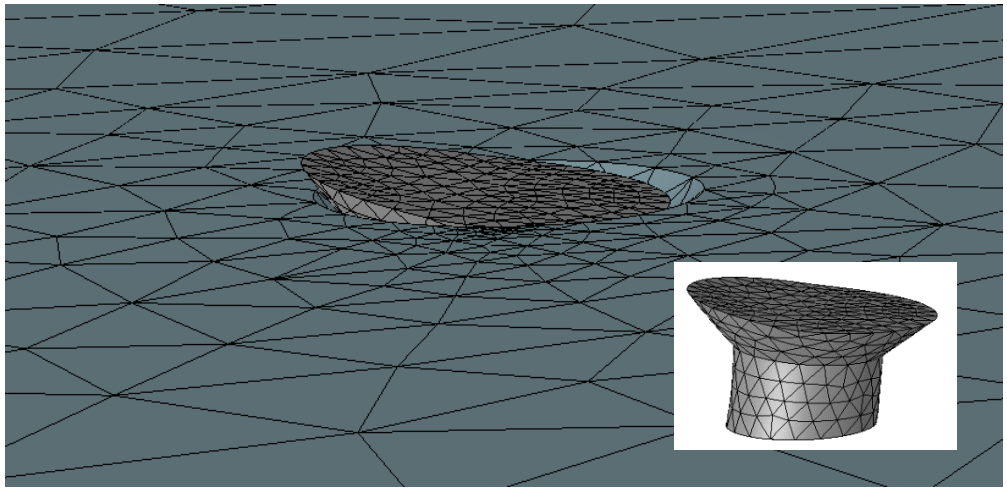
Condition 1: Results

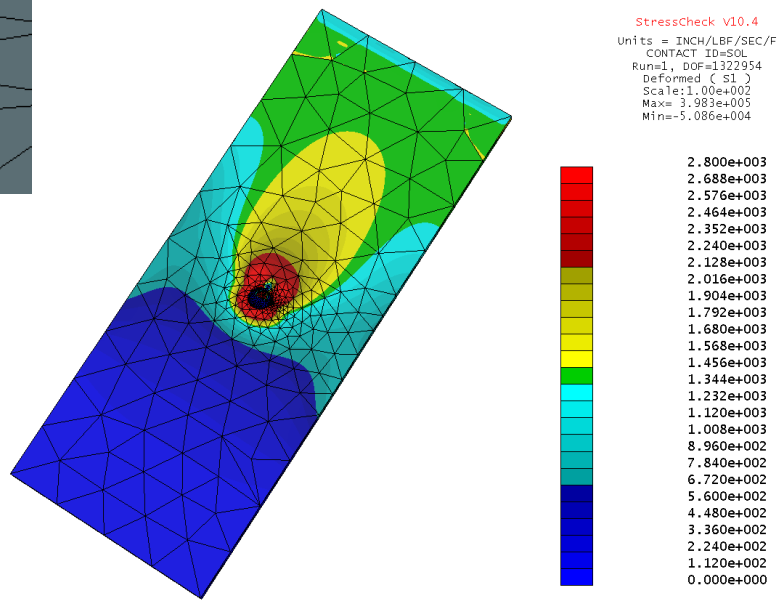
- Knee Flaw



Condition 5: Contact Model

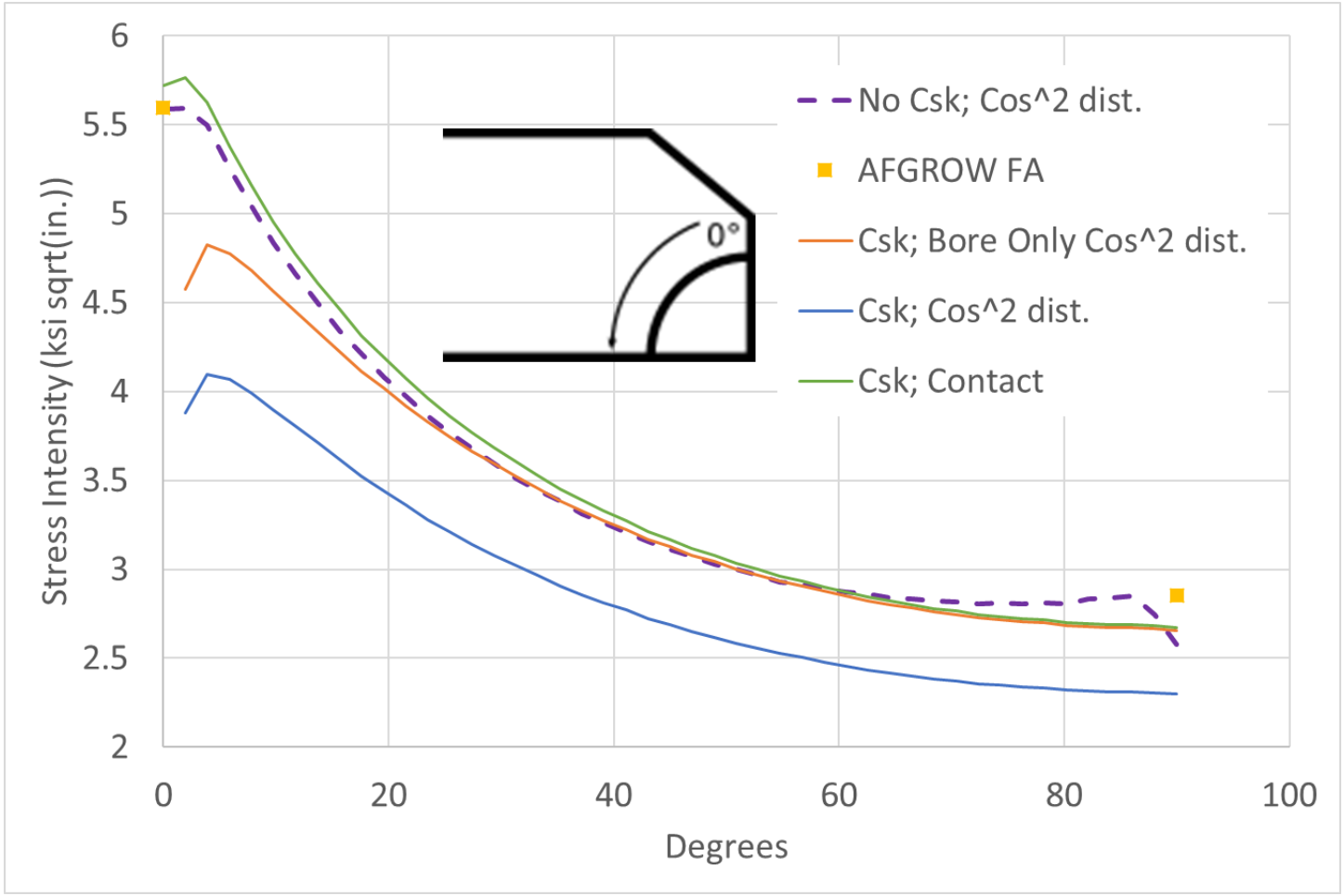
- Deformations and Stress Profiles





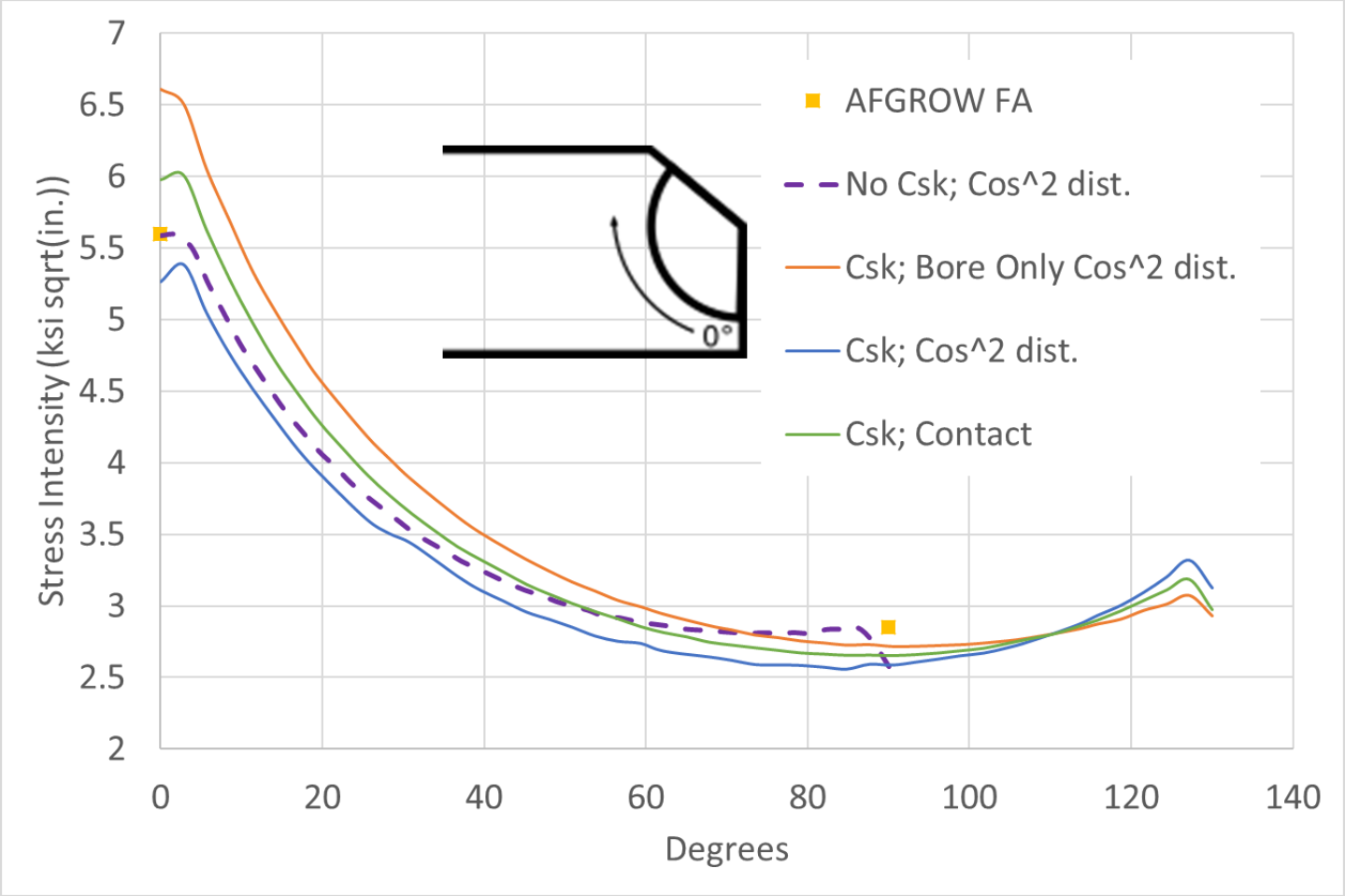
Condition 5: Results

- Faying Surface Flaw



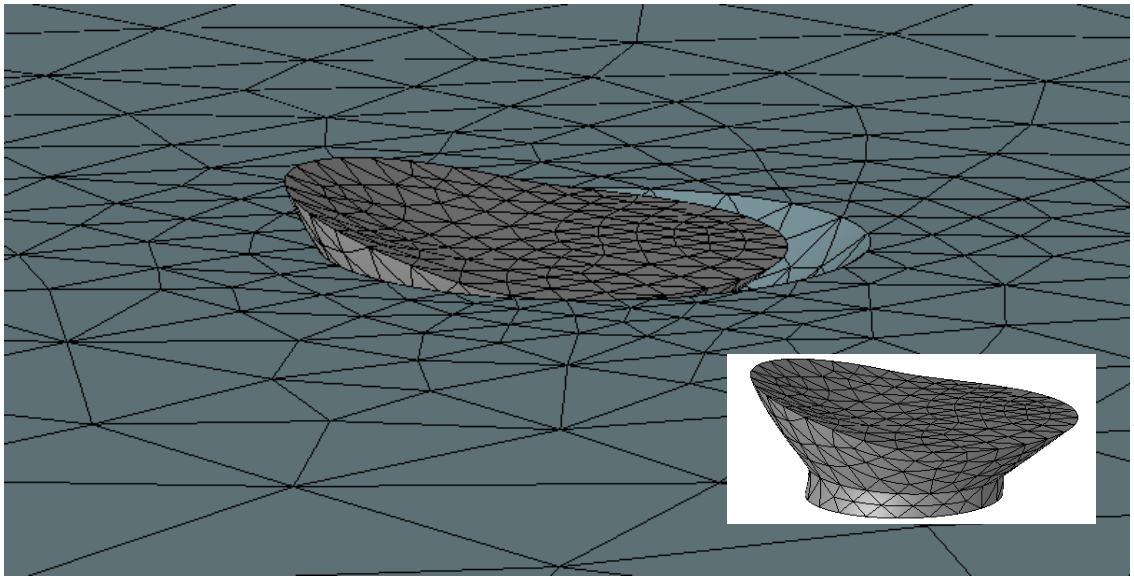
Condition 5: Results

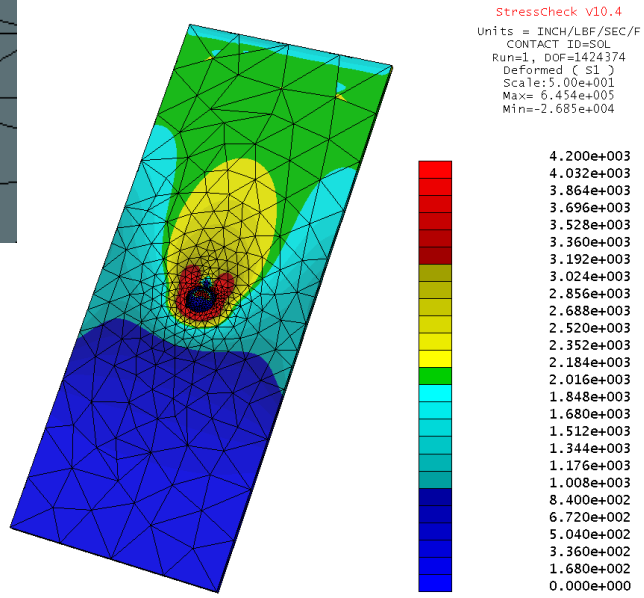
- Knee Flaw



Condition 13: Contact Model

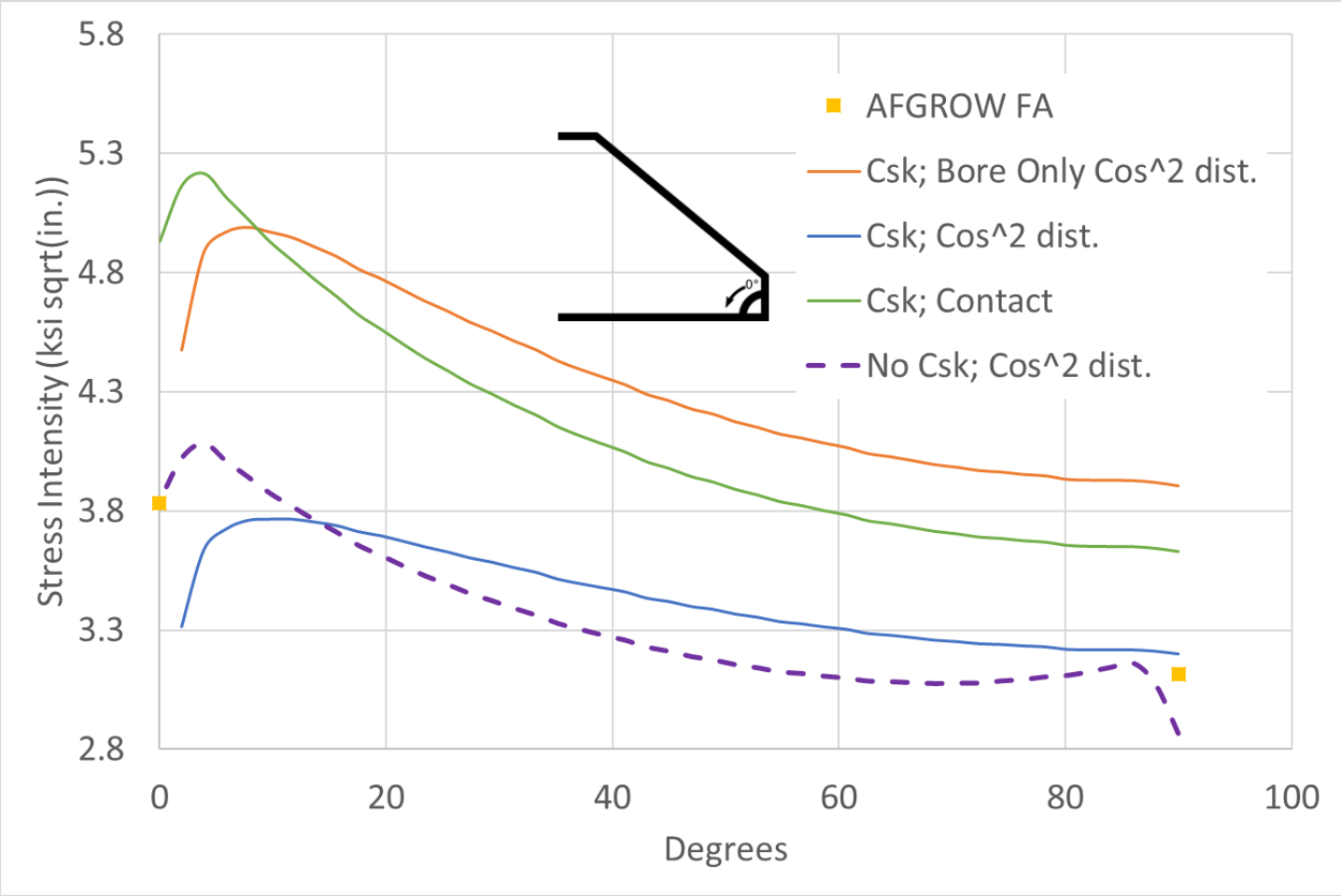
- Deformations and Stress Profiles





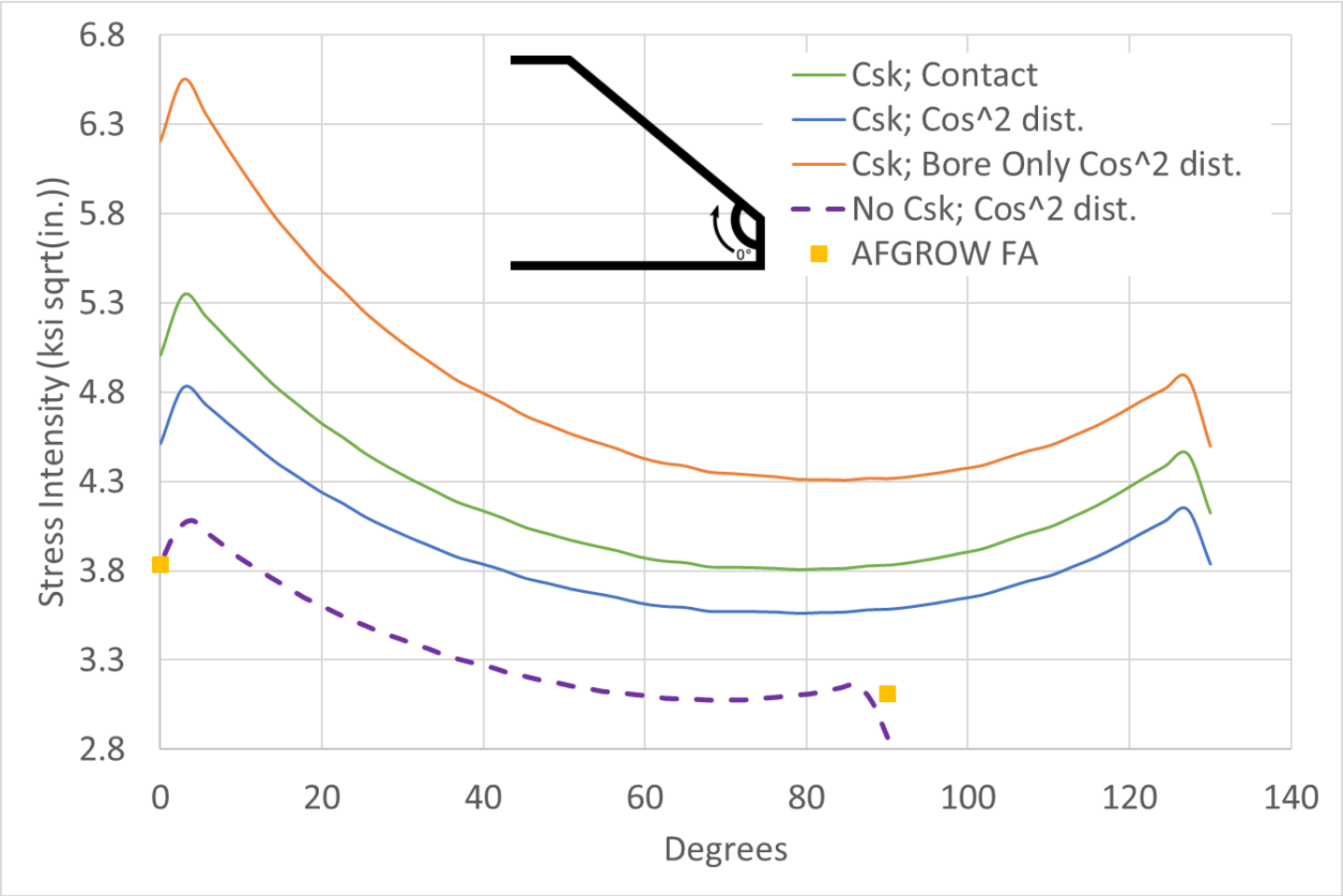
Condition 13: Results

- Faying Surface Flaw



Condition 13: Results

- Knee Flaw



Reflecting Back to Key Factors

- **Geometric**
  - Countersink depth ‘cd’ (as % of thickness)
    - Knife-edge conditions
  - Hole shank diameter ‘D’ (as ratio of D/th)
  - Countersink angle ‘α’
- **Joint Design**
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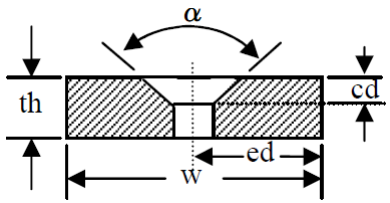

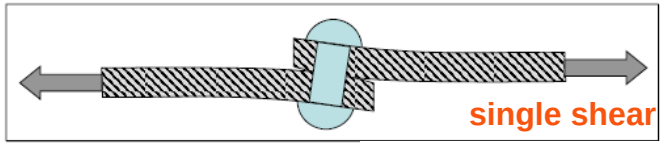

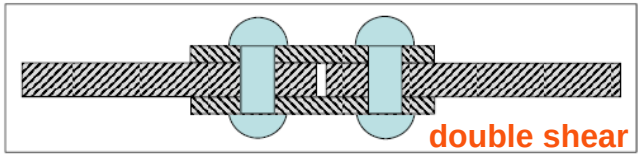

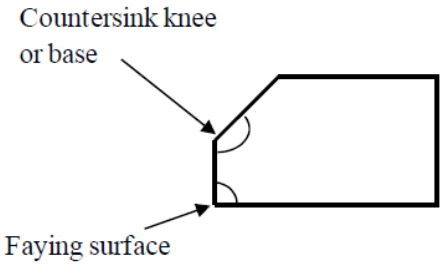

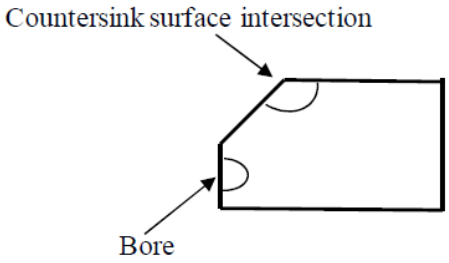

Images Courtesy SwRI, Jody Cronenberger and Zachary Whitman

Discussion

- **Takeaways**
  - Modeling assumptions have a significant impact on calculated SIFs
  - There's no one-size-fits-all conservative approach
  - Development of an AFGROW solution set utilizing contact models is not practical
- **Current AFGROW Bearing Solutions**
  - Utilizes $Cos^2\Theta$ distribution to idealize bearing loads
    - Ignores many of the confounding factors shown in the examples
- **How Do We Move Forward?**
  - We must agree on assumptions

Thoughts?