Distribution A: Approved for public release (AFLCMC-2026-0203)

Fastener Load Transfer Post Ligament Failure in Continuing Damage Analysis

Presented By: Jacob Warner
Authored By: Brian Boeke

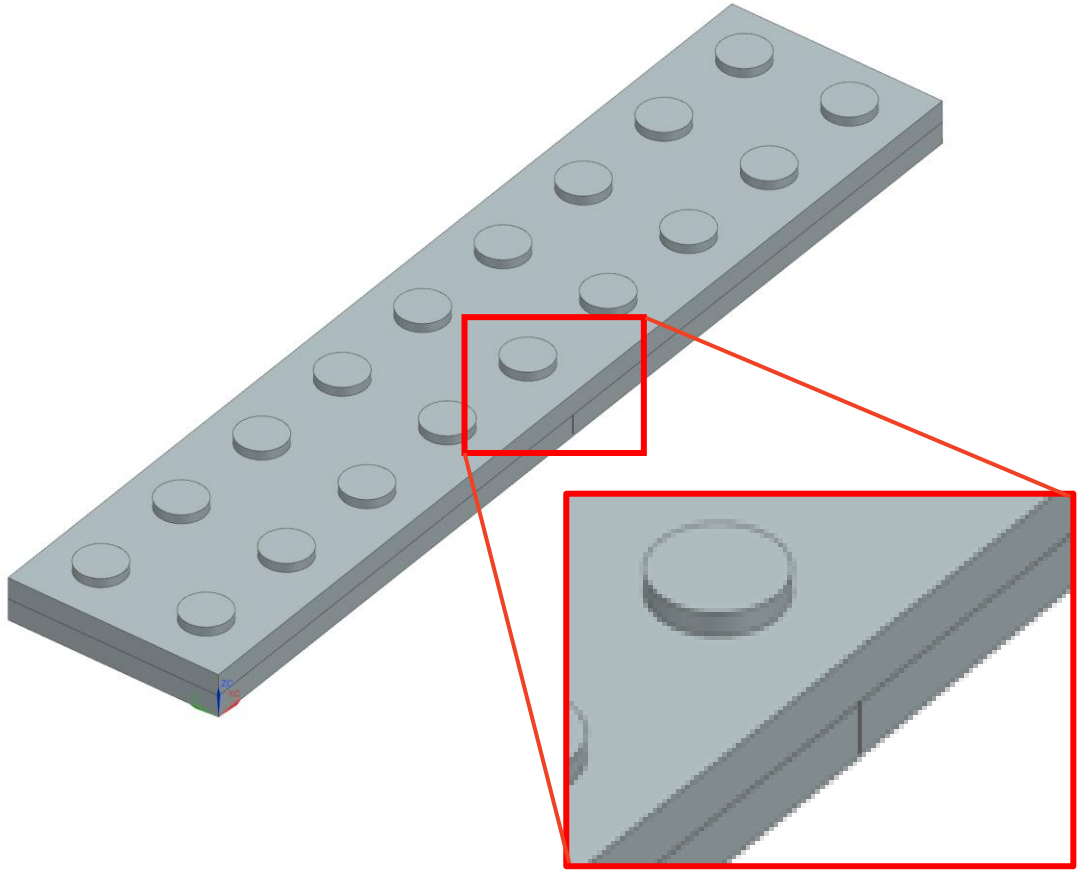
Background

- **A-10 and B-52 programs have a different approach for the bearing load post-ligament failure when performing continuing damage analysis**
  - A-10: Bearing load goes to zero after ligament failure: BSF = 0 and ASF = 1
  - B-52: Bearing load unchanged pre/post ligament failure
- **No data was found to support either approach**
- **A FEM project was started to better understand pin loads after a ligament fails for this phase of analysis**
- **The scope of this FEM project was for a quasi-infinite joint scenario such as a spar to skin attachment. Load transfer joints are point design solutions that would likely require a special case for each scenario**

© 2026 Reliant Aero

Finite Element Model

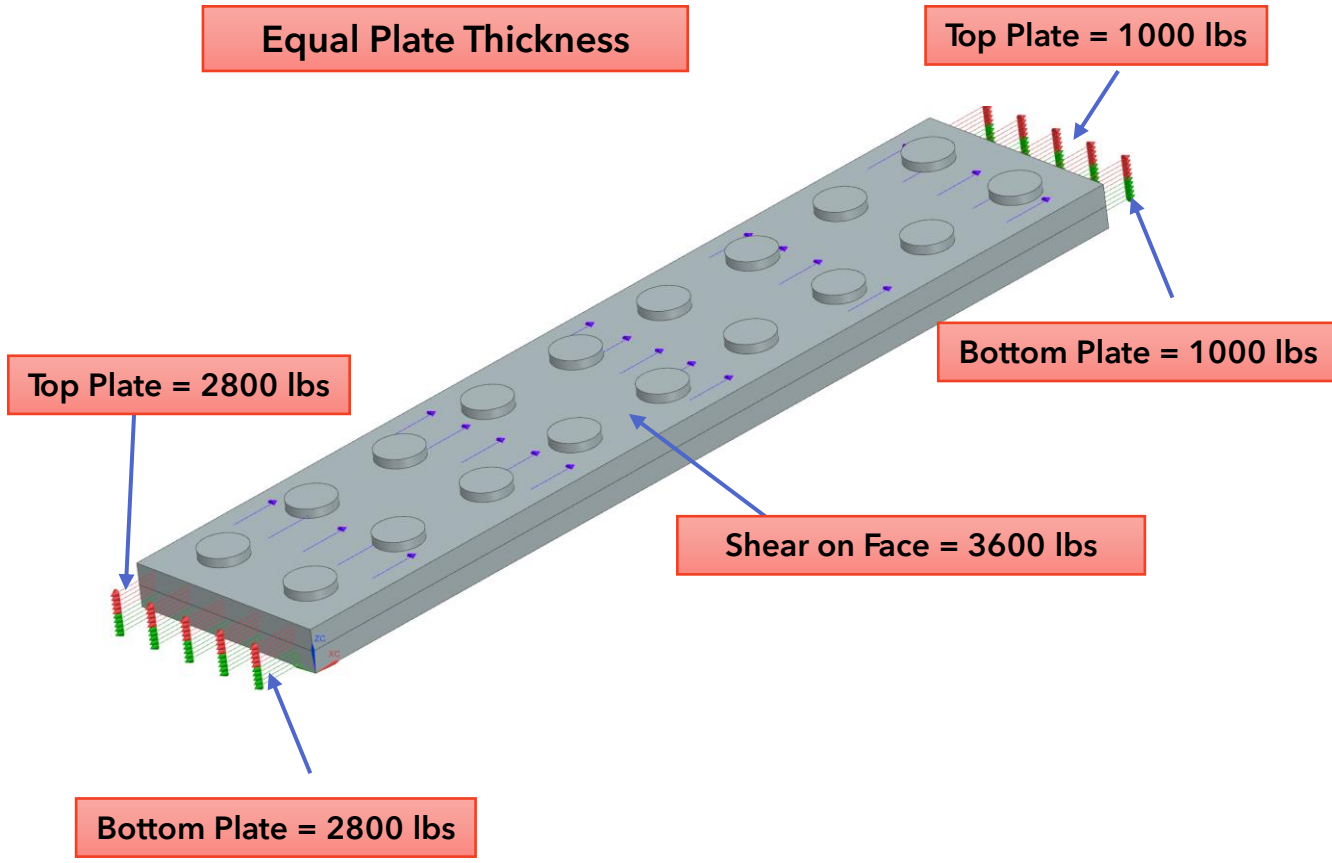
- **Two plates connected with 9 rows of fasteners**
  - 9 rows were required to allow impact of failed ligament on load transfer with minimal (~5%) impact from loading/constraints.
- **Each row had 2 fasteners, all modeled in 3D with contact**
  - Fasteners were simplified to cylinders for the head/shank/nut. Diameters based on Hi-Loks
- **Other model info:**
  - Diameter: 0.25”
  - Width: 8*Diameter
  - Length: 36*Diameter
  - Top and bottom plate thickness: varied
  - Material: Aluminum
- **Failed ligament at 5th (middle) row. Always in bottom plate**



© 2026 Reliant Aero

Loading and Constraints

- **Balanced loading was applied to the model to target 100 lbs of load transfer at each fastener**
  - Mostly achieved. The first and last rows were a little further off this target
  - End load applied to each plate
  - Shear applied to plate top face
    - Shear applied to side face also investigated and gave similar results
  - Balancing end load applied to opposite end of plate
  - Loading based on thickness ratio
  - Thanks to Kaylon Anderson for helping with this.



© 2026 Reliant Aero

Loads and Constraints

Top plate 4x thicker than bottom plate (0.2" and 0.05")

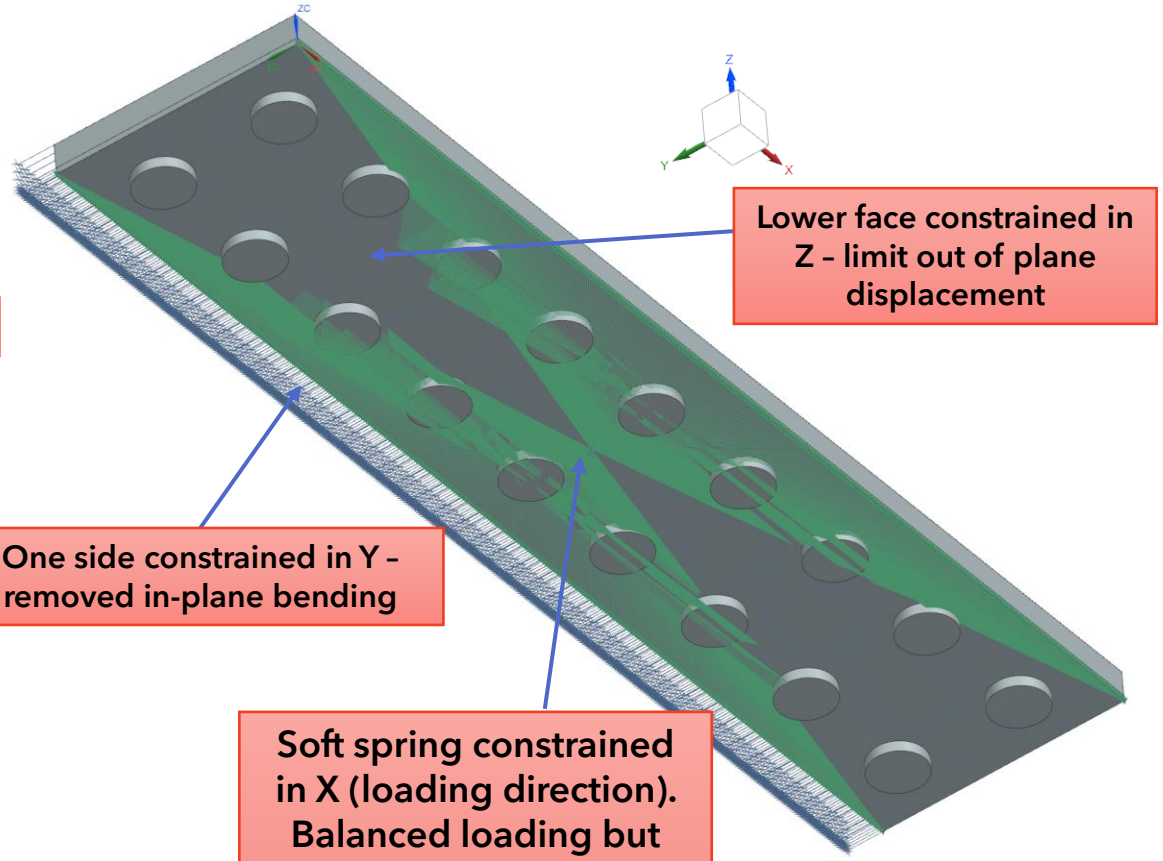
Top Plate = 1000 lbs

Bottom Plate = 250 lbs

Top Plate = 8200 lbs

Shear on Face = 9000 lbs (5 x 1800 lb load transfer to get required load in top and bottom plate)

Bottom Plate = 2050 lbs



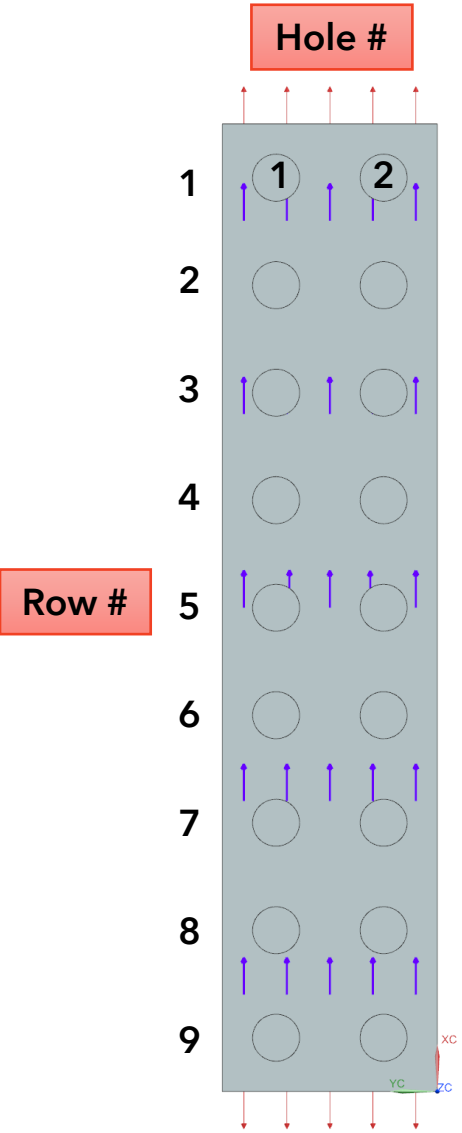
Lower face constrained in Z – limit out of plane displacement

One side constrained in Y – removed in-plane bending

Soft spring constrained in X (loading direction). Balanced loading but prohibits rigid body motion

© 2026 Reliant Aero

Results: 0.05" Plates



Top Plate t = 0.05"
Bottom Plate t = 0.05"
Fastener dia = 0.25"

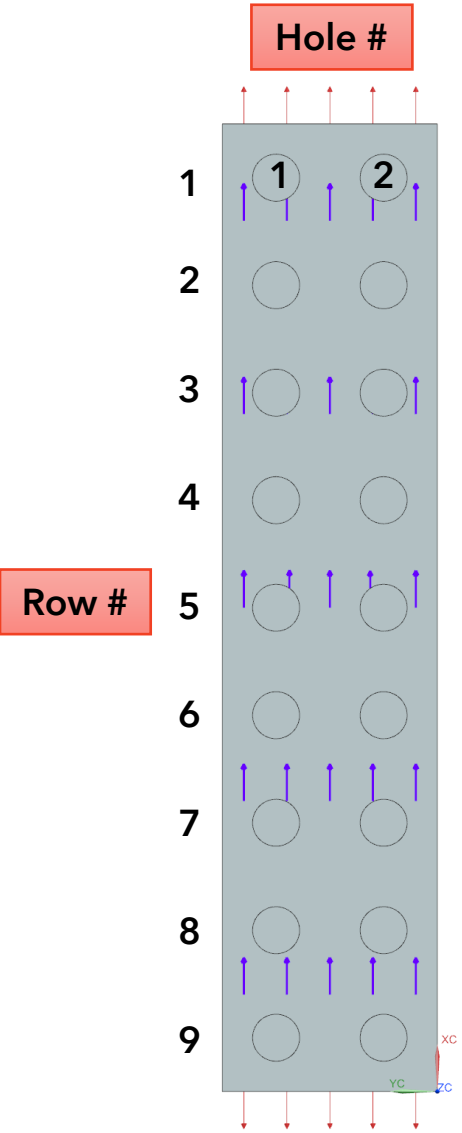
Nominal Pin Loads		
Row #	Hole 1	Hole 2
1	114.6	115.4
2	107.4	108.6
3	102.3	101.9
4	99.9	99.1
5	98.7	98
6	97.9	97.3
7	96.6	96.2
8	94.4	94.5
9	88	89.9

Cracked Pin Loads		
Row #	Hole 1	Hole 2
1	111	110.2
2	99.8	96.3
3	90.4	70.7
4	92	35.8
5	91.2	43
6	99.1	232.8
7	105.6	132.2
8	100.3	105
9	91.1	94.3

% of Nominal Load		
Row #	Hole 1	Hole 2
1	97%	95%
2	93%	89%
3	88%	69%
4	92%	36%
5	92%	44%
6	101%	239%
7	109%	137%
8	106%	111%
9	104%	105%

© 2026 Reliant Aero

Results: 0.2" Plates



Top Plate t = 0.20"
Bottom Plate t = 0.20"
Fastener dia = 0.25"

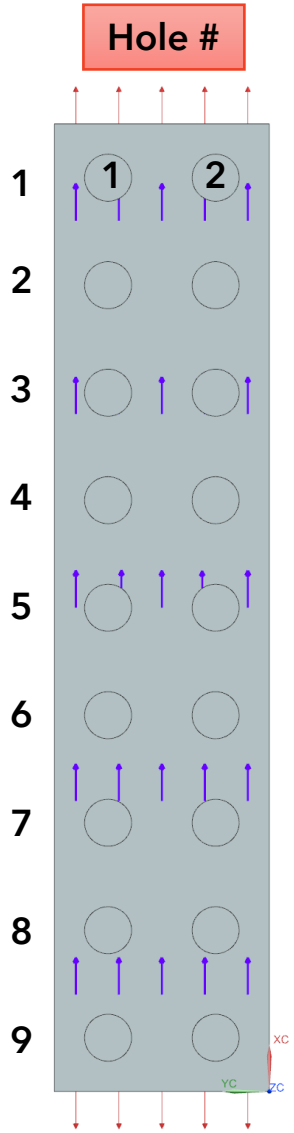
Nominal Pin Loads		
Row #	Hole 1	Hole 2
1	110.9	111.8
2	105.8	106.9
3	102.7	102.7
4	101	100.5
5	99.9	99.4
6	99.1	98.5
7	97.7	97.3
8	97.7	95.2
9	85.8	87.5

Cracked Pin Loads		
Row #	Hole 1	Hole 2
1	105.7	105.3
2	98.4	96.1
3	93.3	78
4	96.8	45.2
5	97.4	42.1
6	100.8	193.4
7	108.5	135
8	106.4	110.3
9	92.2	95.3

% of Nominal Load		
Row #	Hole 1	Hole 2
1	95%	94%
2	93%	90%
3	91%	76%
4	96%	45%
5	97%	42%
6	102%	196%
7	111%	139%
8	109%	116%
9	107%	109%

© 2026 Reliant Aero

Results: 0.2" Top Plate, 0.1" Bottom Plate



Top Plate t = 0.20"
Bottom Plate t = 0.10"
Fastener dia = 0.25"

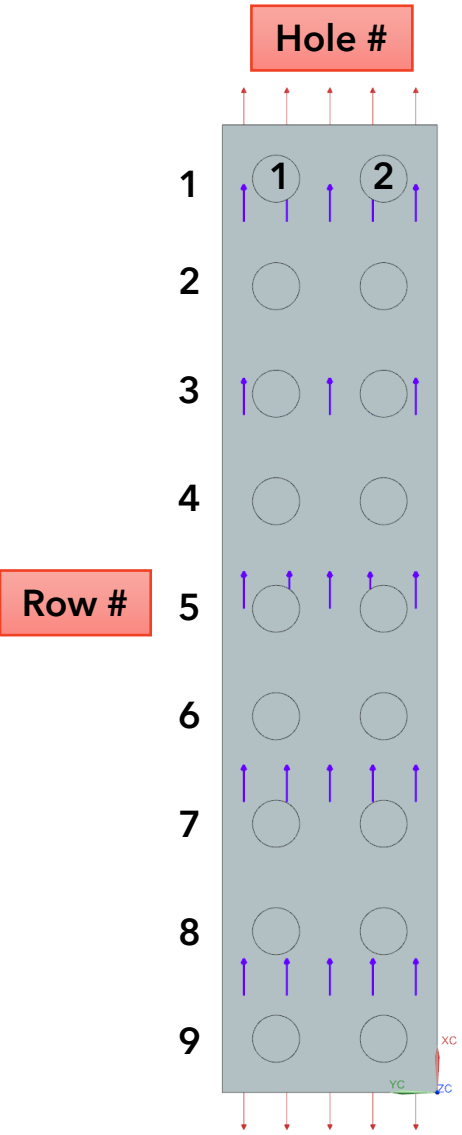
Nominal Pin Loads		
Row #	Hole 1	Hole 2
1	101.5	102.2
2	101.8	102.8
3	100.6	100.2
4	99.7	99
5	99.3	98.7
6	99.1	98.6
7	99.2	99
8	101.4	100
9	97.6	99.6

Cracked Pin Loads		
Row #	Hole 1	Hole 2
1	97.4	96.7
2	95	92.2
3	90.4	73.8
4	93.4	41.2
5	96.2	44.4
6	100.2	206.2
7	106.3	135.2
8	108	112.8
9	102.7	106.1

% of Nominal Load		
Row #	Hole 1	Hole 2
1	96%	95%
2	93%	90%
3	90%	74%
4	94%	42%
5	97%	45%
6	101%	209%
7	107%	137%
8	107%	113%
9	105%	107%

© 2026 Reliant Aero

Results: 0.2" Top Plate, 0.05" Bottom Plate



Nominal Pin Loads		
Row #	Hole 1	Hole 2
1	110.7	112.1
2	104.2	105.9
3	100.7	100.7
4	99.3	98.8
5	98.2	98
6	97.4	97.6
7	97	97.1
8	95.7	96.5
9	94.5	95.9

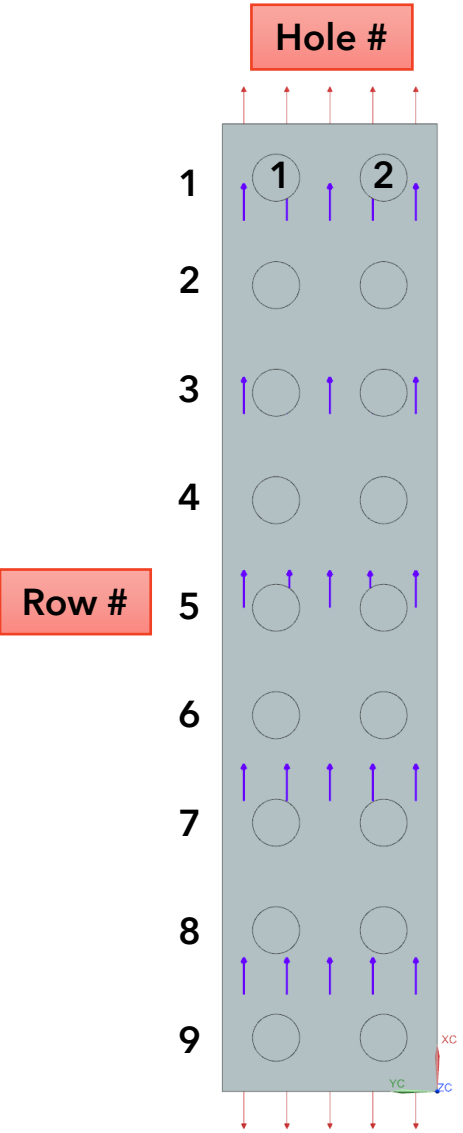
Cracked Pin Loads		
Row #	Hole 1	Hole 2
1	106.3	106.5
2	97.6	95.4
3	90.6	75
4	91.9	43.3
5	95.2	45.5
6	99.3	199.4
7	105.8	129.2
8	104.1	109.4
9	101	104.8

% of Nominal Load		
Row #	Hole 1	Hole 2
1	96%	95%
2	94%	90%
3	90%	74%
4	93%	44%
5	97%	46%
6	102%	204%
7	109%	133%
8	109%	113%
9	107%	109%

Top Plate t = 0.20"
Bottom Plate t = 0.05"
Fastener dia = 0.25"

© 2026 Reliant Aero

Results: 0.1" Top Plate, 0.2" Bottom Plate



Top Plate t = 0.10"
Bottom Plate t = 0.20"
Fastener dia = 0.25"

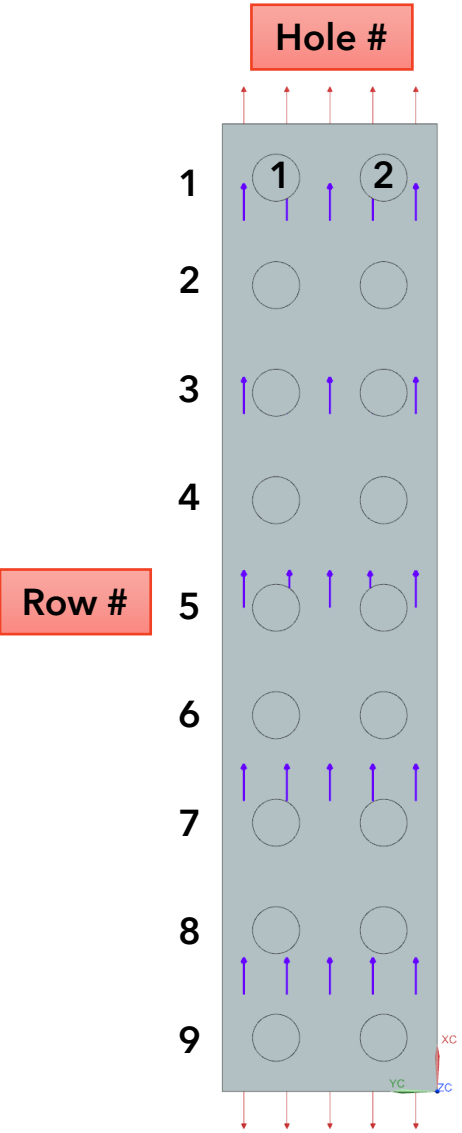
Nominal Pin Loads		
Row #	Hole 1	Hole 2
1	103.6	104.2
2	102.3	103.1
3	101.1	101
4	100.5	100.1
5	100.2	99.7
6	100	99.6
7	99.7	99.7
8	101.5	100
9	90.6	93.1

Cracked Pin Loads		
Row #	Hole 1	Hole 2
1	101.2	100.9
2	98.3	97
3	95.4	84.5
4	98.6	51.7
5	99.8	38.8
6	102.4	184.9
7	107.6	129.9
8	106.5	110.2
9	94.6	97.8

% of Nominal Load		
Row #	Hole 1	Hole 2
1	98%	97%
2	96%	94%
3	94%	84%
4	98%	52%
5	100%	39%
6	102%	186%
7	108%	130%
8	105%	110%
9	104%	105%

© 2026 Reliant Aero

Results: 0.05" Top Plate, 0.2" Bottom Plate



Nominal Pin Loads		
Row #	Hole 1	Hole 2
1	102.8	103.2
2	101.5	102.2
3	100.7	100.7
4	100.3	100.1
5	100.1	100
6	100	99.9
7	99.8	100.1
8	101.2	101
9	91.8	94.5

Cracked Pin Loads		
Row #	Hole 1	Hole 2
1	101.6	101.6
2	99.5	99.2
3	97.7	91.7
4	100	68.7
5	101.6	40.2
6	103.7	164.7
7	105.7	121.3
8	104.3	107.5
9	94	97.2

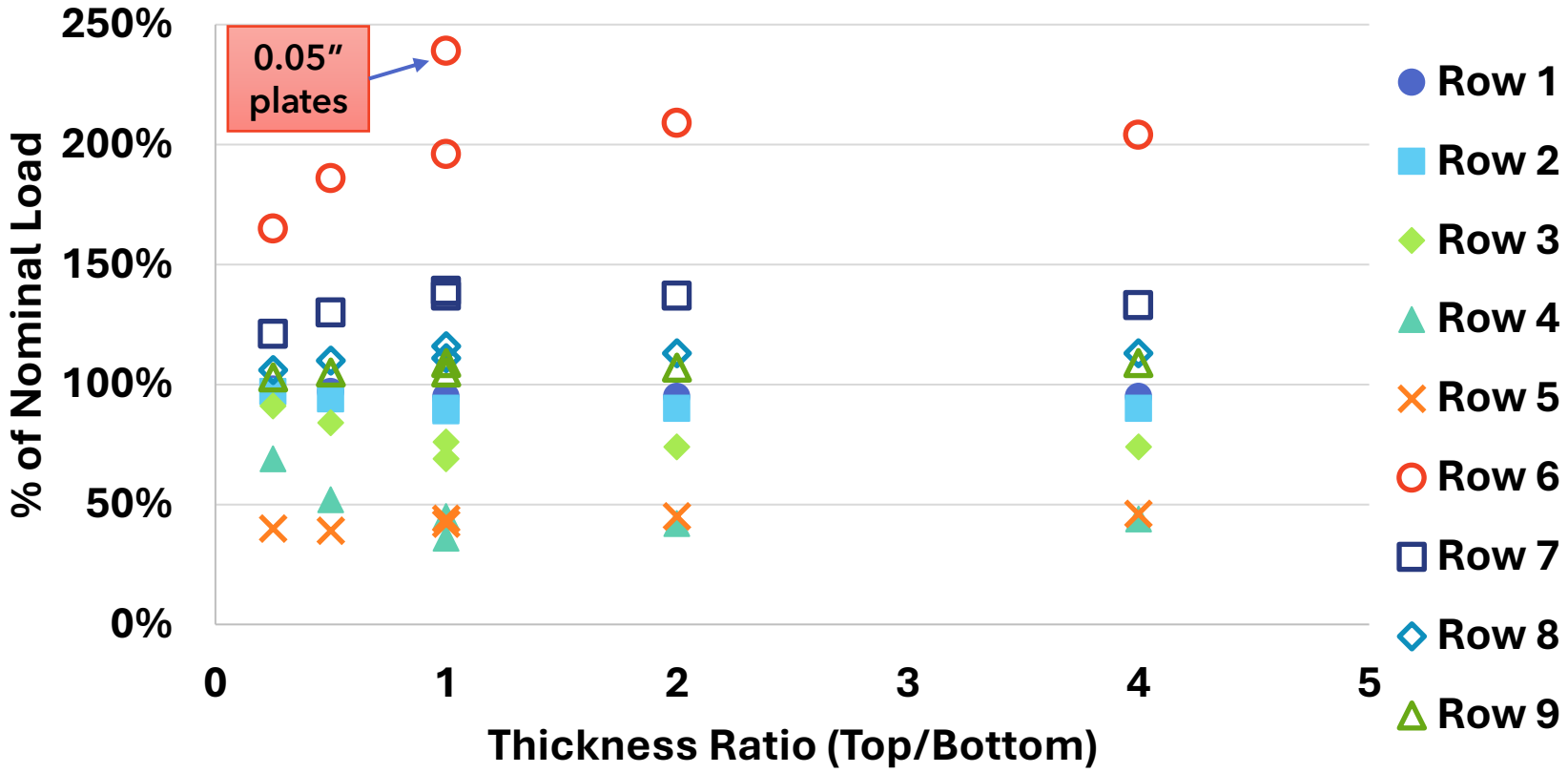
% of nominal load		
Row #	Hole 1	Hole 2
1	99%	98%
2	98%	97%
3	97%	91%
4	100%	69%
5	101%	40%
6	104%	165%
7	106%	121%
8	103%	106%
9	102%	103%

Top Plate t = 0.05"
Bottom Plate t = 0.20"
Fastener dia = 0.25"

© 2026 Reliant Aero

Load Transfer as a Function of Thickness Ratio

- Cracked pin loads reduce by half
- Row after crack roughly doubles for thickness ratios >1
- Minimal changes in 1st and last rows suggest sufficient model length



© 2026 Reliant Aero

Discussion

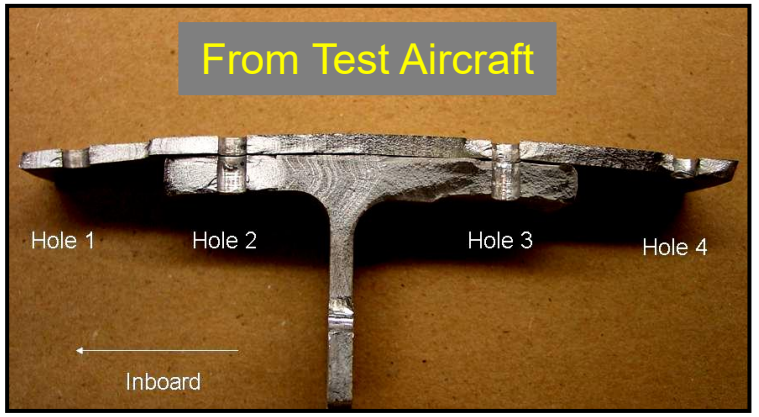
- **The load transfer at the hole with the failed ligament was consistently between 40% and 50% of the nominal load**
  - Maybe this is partially due to the loading method? Other approaches did show a similar trend
- **Load transfer at hole aft (with reference to loading direction) of failed hole showed large increase in bearing load.**
  - Probably not an issue with crack growth, because the failed hole will still grow much faster than hole aft, but maybe a strength concern?
- **It is recognized this is a limited data set. Future work includes looking at fastener diameter variation, material variation, and some different geometry.**
- **Initial impression:**
  - 50% of nominal load may be a good estimation of load transfer in the final phase of continuing damage analysis
  - It could be worth creating a FEM of the actual joint under consideration if the life from post-ligament failure is important.

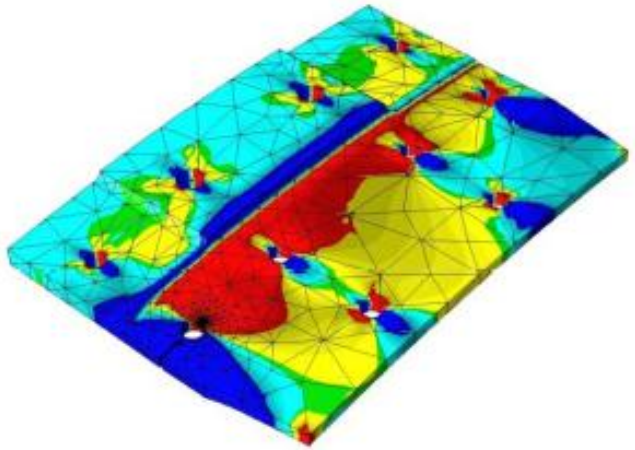
© 2026 Reliant Aero

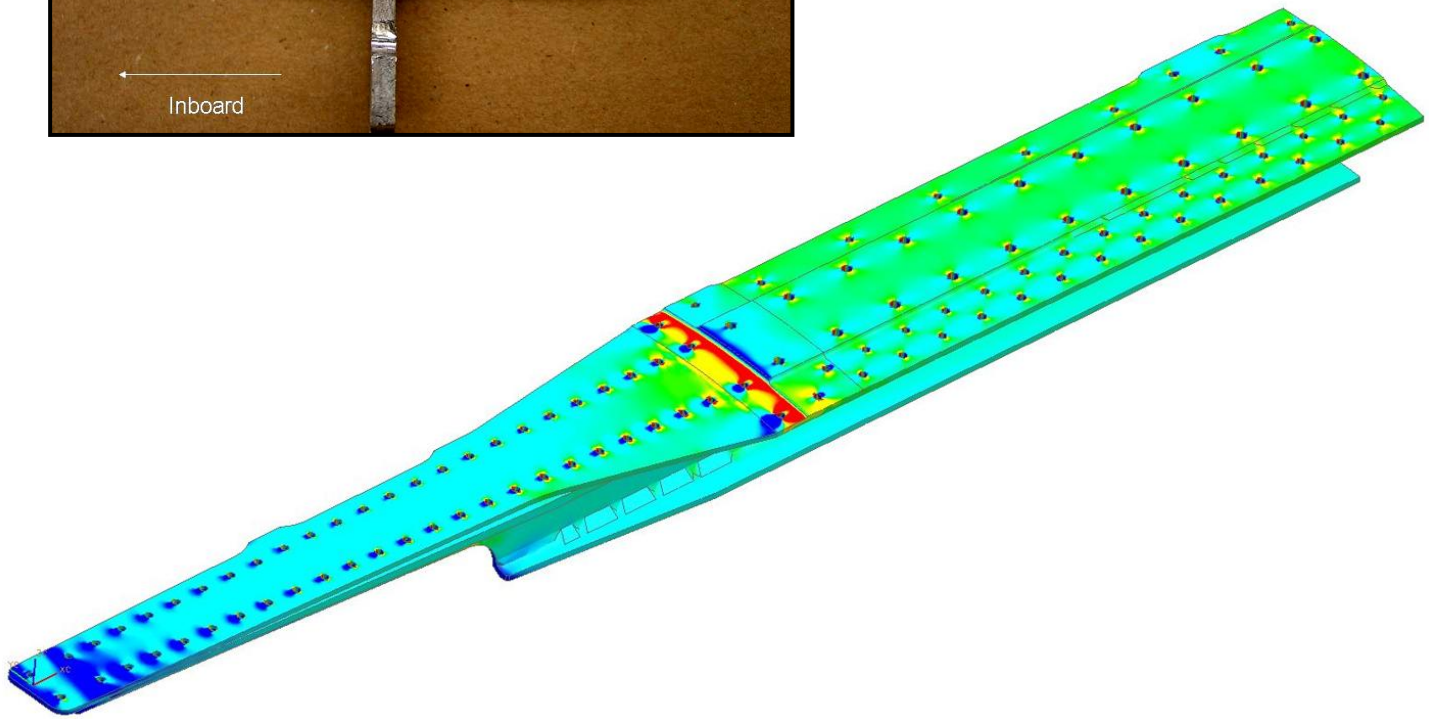
A-10 Longeron Load Redistribution

- **Forward to mid fuselage joint, not a quasi-infinite joint like what was done in this presentation's study**

Failed Segments	% Reduction in Pin Load
Hole 1 Ligament	22%
Hole 1 to Hole 2	98%
Hole 2 to Hole 3	100% (zero remaining load transfer)







© 2026 Reliant Aero