Air Force Life Cycle Management Center

U.S. AIR FORCE

Fastener Load Sensitivity Study for Repair Doubler Geometries:

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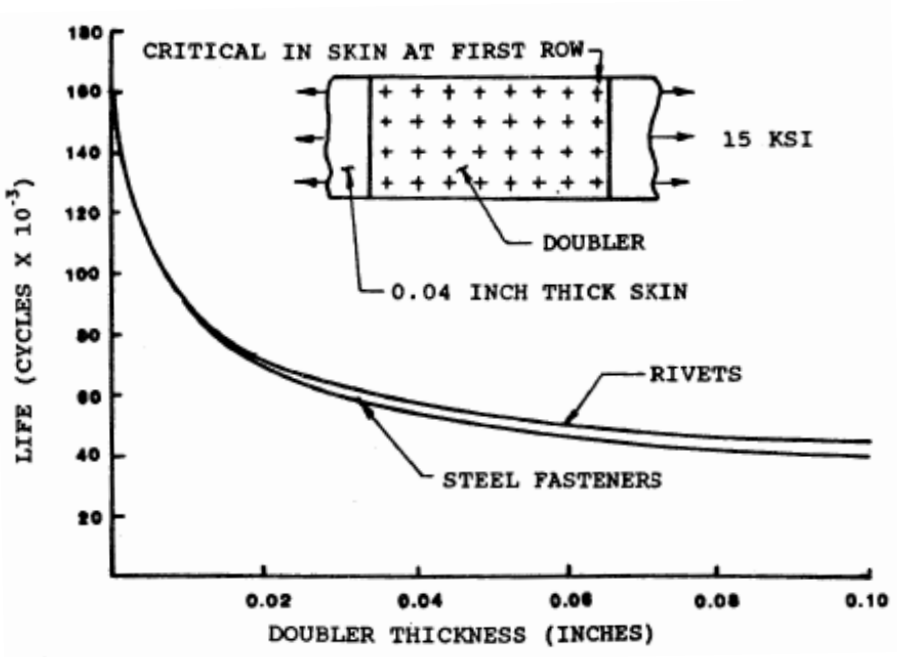
Outline

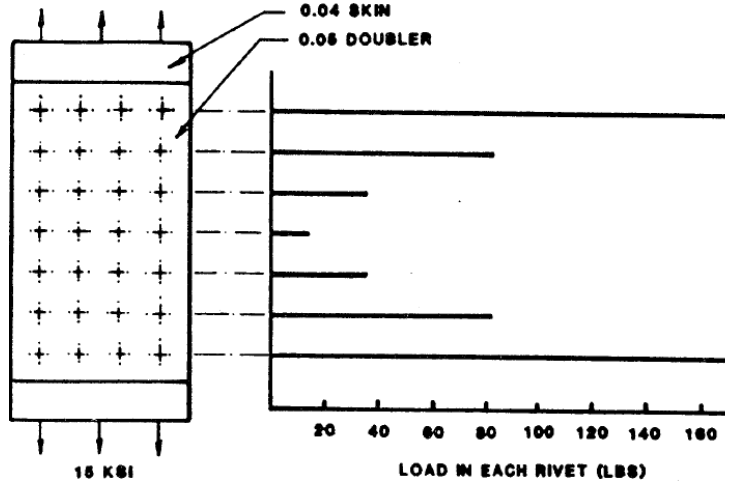
- **Background**
  - **FAA-AIR-90-01, Repairs to Damage Tolerant Aircraft**
  - **Fastener Loads**
  - **AFGROW inputs**
  - **Miscellaneous**
- **Results**
  - **Load Reduction Doubler**
  - **Splice Repair**
- **Summary/Conclusion**
  - **Future work?**

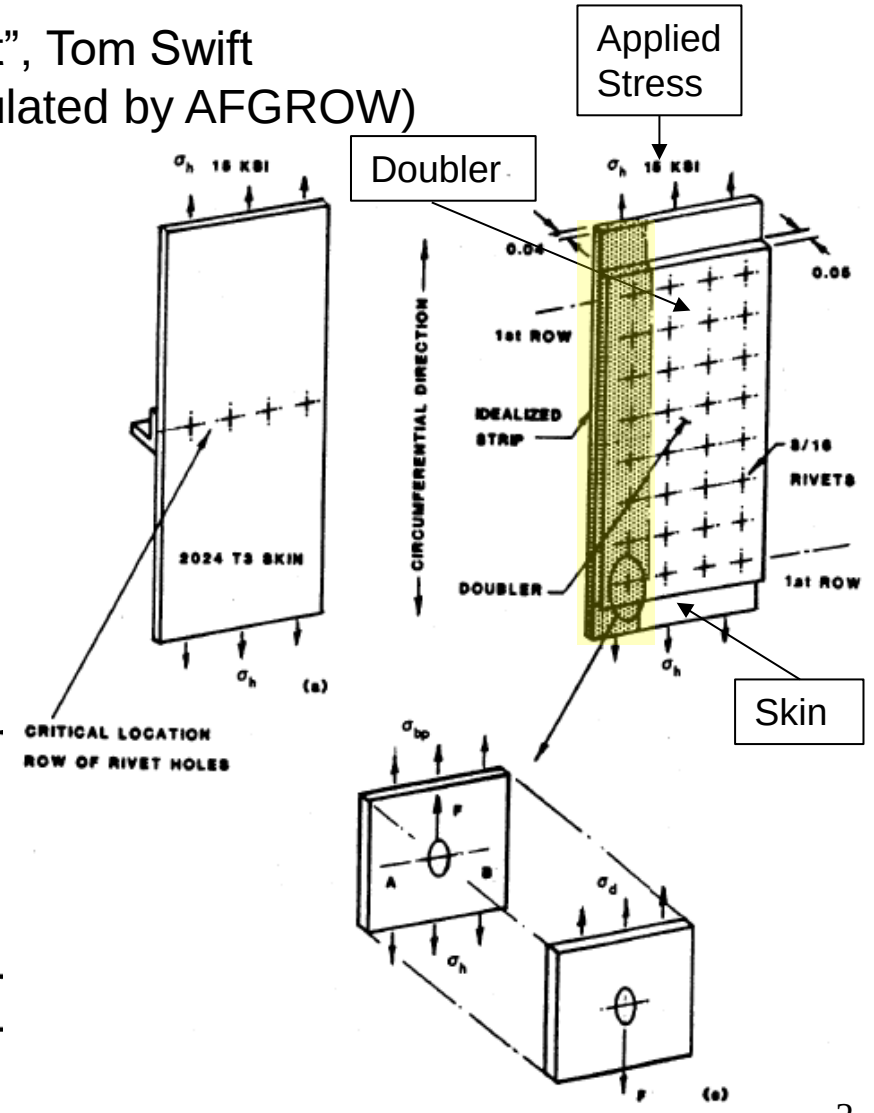
Background

Basic Assumptions/Approach:

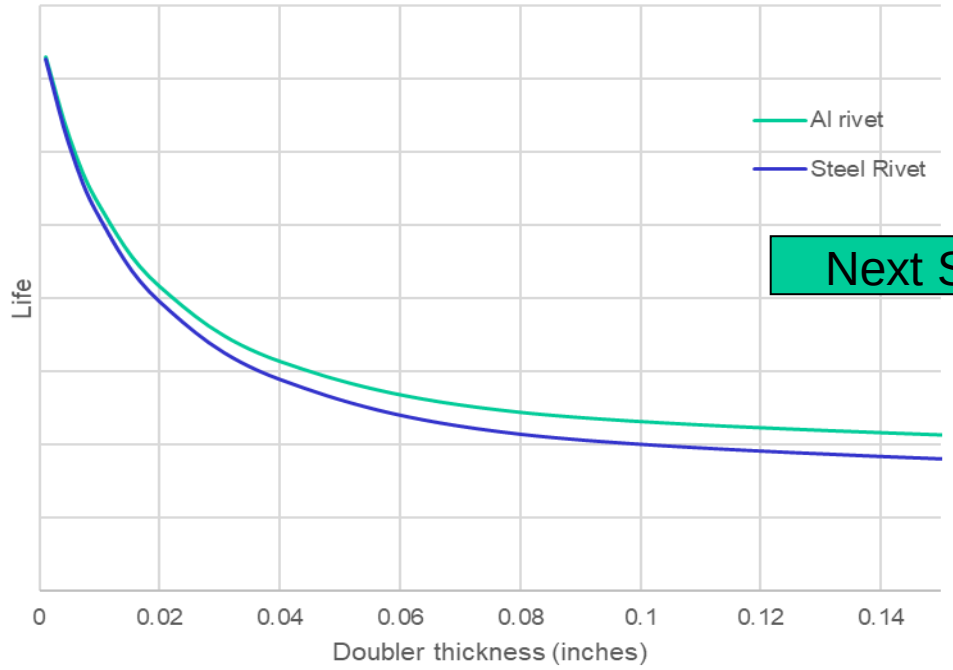
- Replicate trends from “FAA-AIR-90-01, Repairs to Damage Tolerant Aircraft”, Tom Swift
  - Magnitudes will differ but basic premise is established (life will be calculated by AFGROW)
- 1st fastener load increases with increasing doubler thickness
  - Load follows (or increases) with stiffness
- Life of joint decreases at the first fastener
- 15 ksi tensile stress applied (R = 0)
- Is there a general rule that can be applied for repair doubler thickness?







Background



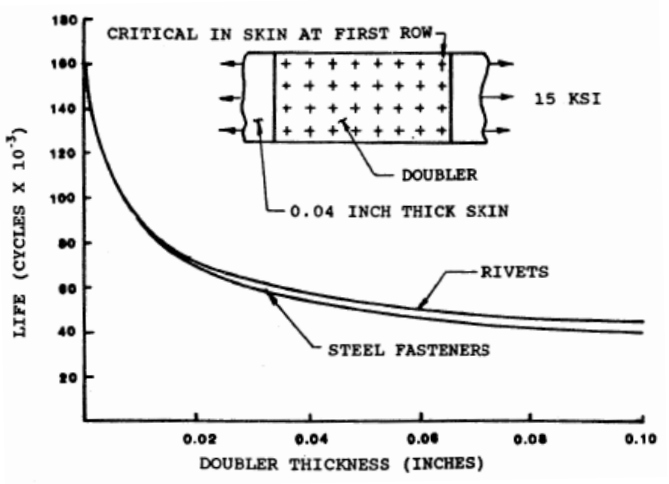
Next Steps

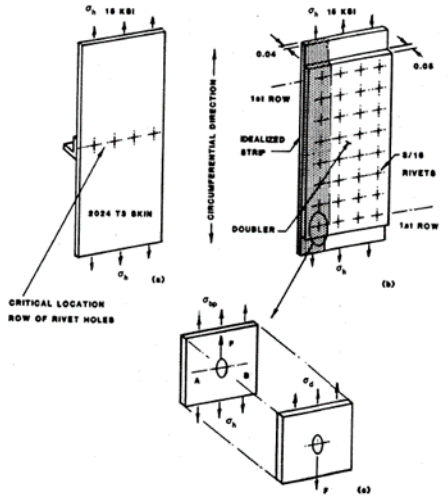
Added Repair:

- Easy to determine the max thickness as it needs to handle 125% of the original material capability
  - 0.050” doubler thickness will be used as it is 125% of the 0.040” base material

Details for the added repair:

- Load on first fastener determined from in-house Excel Spreadsheets (used in the **TSF** and **BSF** calculations)
- Because life decreases with stiffness, how do we step the load in?
  - **What thickness steps should be implemented?**
  - **What should be the 1st layer?**
  - **How does the decrease in life affect inspection?**
  - **How does a Load Reduction Repair compare to a Splice Repair?**





Background –Fastener Loads

Fastener Load Distribution

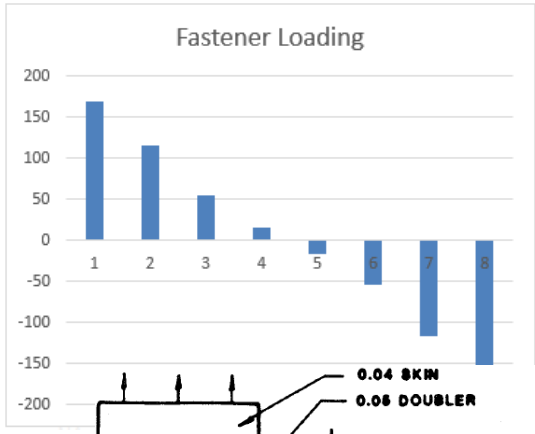
Key: User Entry

Part Stress	15.0	ksi
Part Load	780	lbs
Fastener Flexibility	2	1 = Huth Bolt 2 = Huth Rivet 3 = Niu

Fastener Row Number	Diameter	Number of Fasteners	Part thickness tp	Strap thickness ts	tav	Part Modulus Ep	Strap Modulus Es	Fastener Modulus	Faste Flex
1	0.188	1	0.04	0.025	0.0325	1.08E+07	1.08E+07	1.08E+07	
2	0.188	1	0.04	0.05	0.045	1.08E+07	1.08E+07	1.08E+07	
3	0.188	1	0.04	0.05	0.0				
4	0.188	1	0.04	0.05	0.0				
5	0.188	1	0.04	0.05	0.045	1.08E+07	1.08E+07	1.08E+07	
6	0.188	1	0.04	0.05	0.045	1.08E+07	1.08E+07	1.08E+07	
7	0.188	1	0.04	0.05	0.045	1.08E+07	1.08E+07	1.08E+07	
8	0.188	1	0.04	0.025	0.0325	1.08E+07	1.08E+07	1.08E+07	

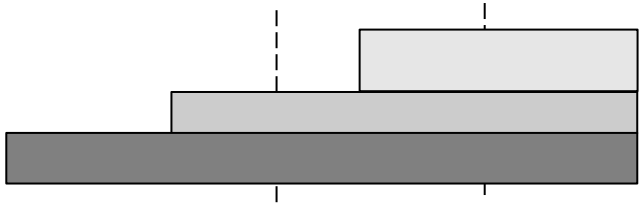
Solution

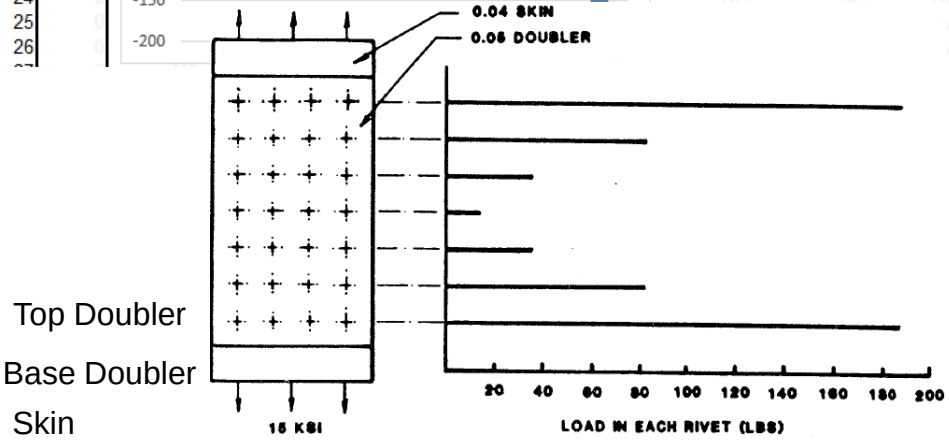
Fastener Row	Fastener Load Per Row	Part Load Before Fas	% Load Re	Part Stress Before Fastener	Part TSF	Part BSF	Load in Strap After Fastene	Strap Stress After Fastene	Strap TSF	Strap BSF
1	169	780	21.7%	15.0	0.783	1.50	169	5.2	0.00	6.91
2	116	611	36.6%	11.7	0.810	1.31	285	4.4	0.59	2.81
3	55	495	43.6%	9.5	0.890	0.76	340	5.2	0.84	1.11
4	16	440	45.6%	8.5	0.964	0.25	356	5.5	0.95	0.31
5	-16	424	45.6%	8.2	0.964	0.25	340	5.2	0.95	0.31
6	-55	440	43.6%	8.5	0.890	0.76	285	4.4	0.84	1.11
7	-116	495	36.6%	9.5	0.810	1.31	169	5.2	0.59	2.81
8	-169	611	21.7%	11.7	0.783	1.50	0	0.0	0.00	6.91
9	0	780	NA	15.0						



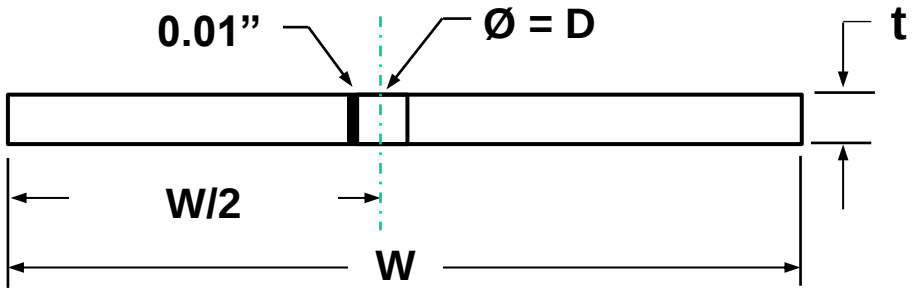
Fastener Loads:

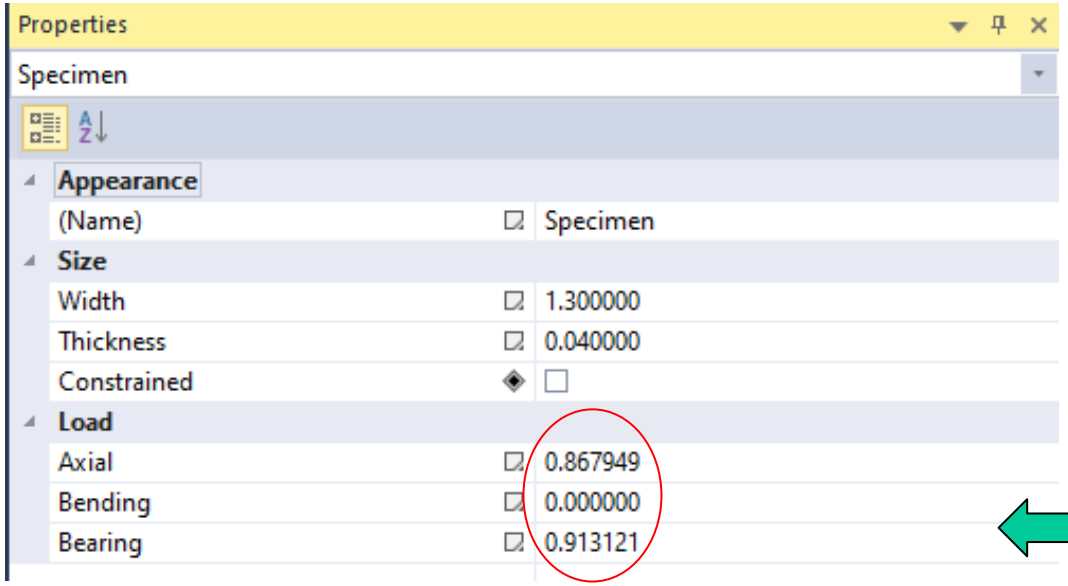
- Huth equations used to find distribution and load magnitudes
- Load Reduction and Splice calculations are different





Background – AFGROW Inputs





Basic Assumptions/Approach:

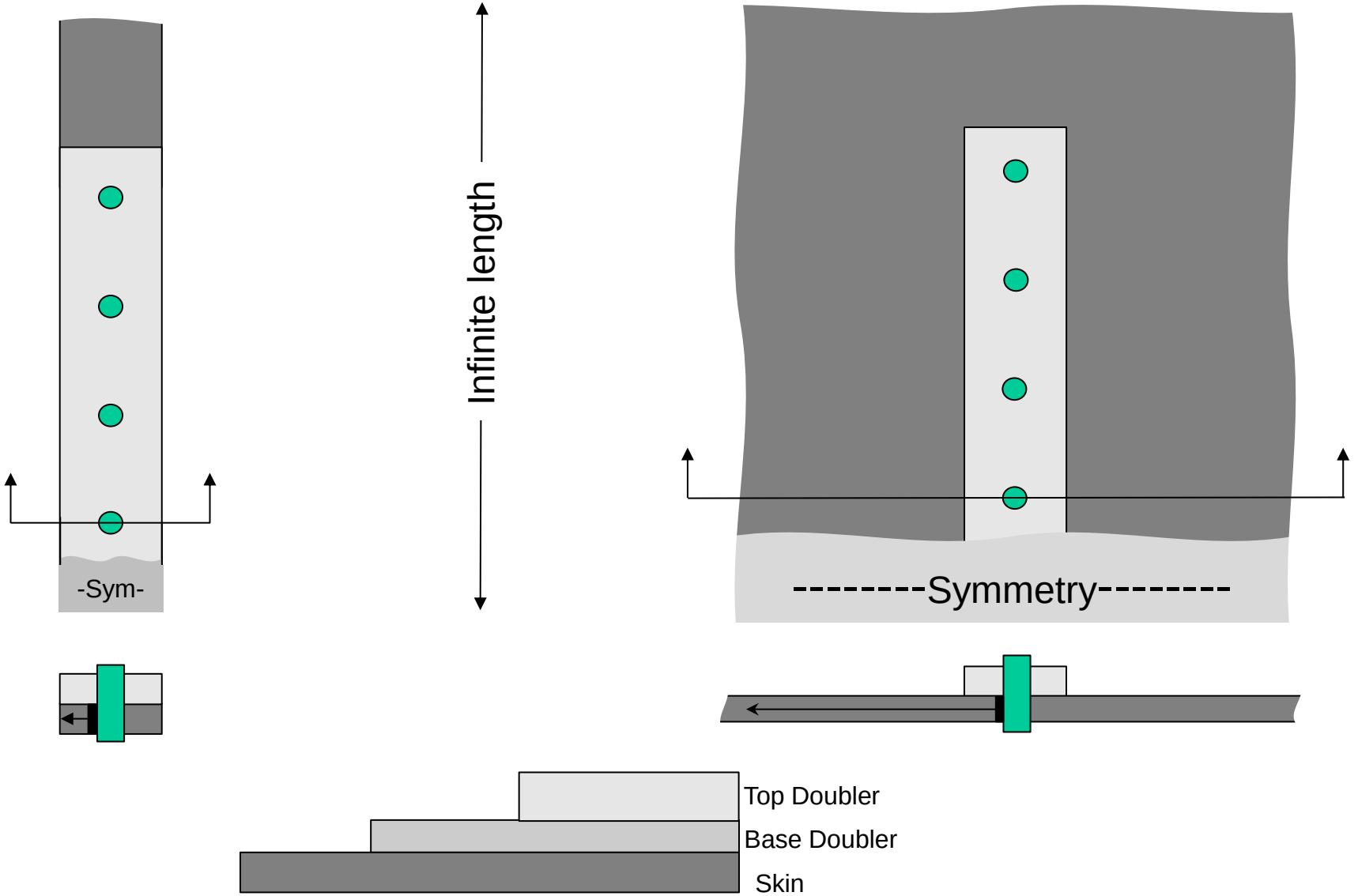
- Advanced model (center hole, through crack)
- **TSF** and **BSF** are calculated for each case
- 1.3” & 25” wide samples (**W**)
- IFS of 0.01”
- Diameter of rivet (**D**) – 3/16
- Skin thickness is 0.040” (**t**)
- Load spectrum from modern Fighter Jet
  - 24 ksi tensile stress applied and life in hours
- Load Reduction Doubler and Splice use same geometry inputs

$$\sigma_{Bearing} = \frac{Force}{D * t} \qquad BSF = \frac{\sigma_{Bearing}}{\sigma_{Far\ Field}}$$

$$\sigma_{Far\ Field} = \frac{Force}{t\ * Weq} \qquad TSF = \frac{\sigma_{Bypass}}{\sigma_{Far\ Field}} = 1 - (BSF * \frac{D}{W_{eq}})$$

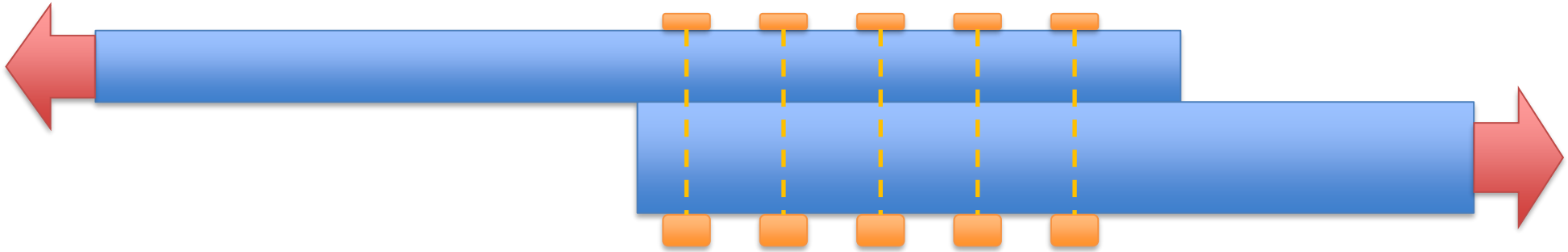
Background – Miscellaneous

Basic geometries utilized for Splice and Load Reduction samples

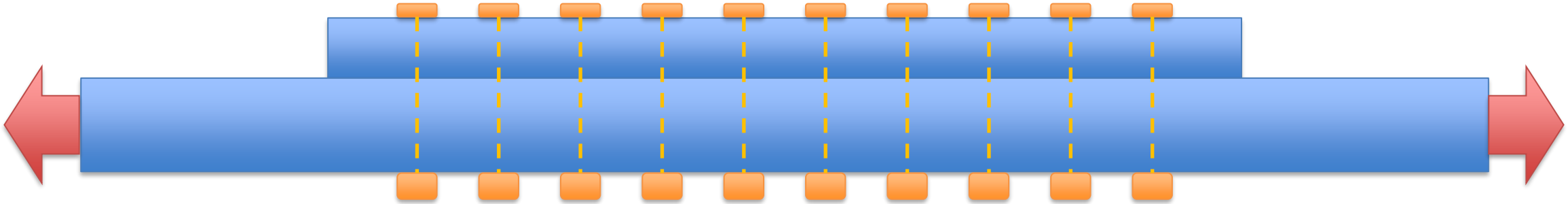


Background – Miscellaneous

- **Splice Repair**
  - All load must transfer into doubler



- **Load Reduction Repair**
  - Load is shared by doubler



Load Reduction Repair

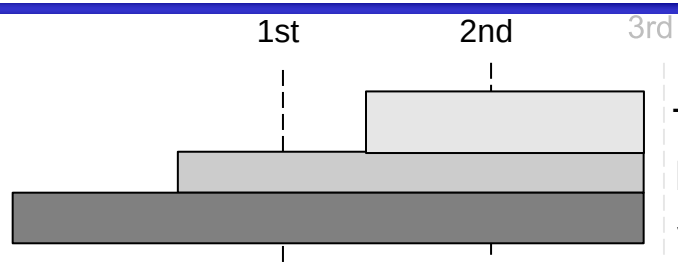
Load Reduction Loading

Fastener Row Number	Diameter	Number of Fasteners	Part thickness tp	Strap thickness ts
1	0.188	1	0.04	0.05
2	0.188	1	0.04	0.05
3	0.188	1	0.04	0.05
4	0.188	1	0.04	0.05
5	0.188	1	0.04	0.05
6	0.188	1	0.04	0.05
7	0.188	1	0.04	0.05
8	0.188	1	0.04	0.05

Fastener Row	Fastener Load Per Row
1	218
2	105
3	47
4	13
5	-13
6	-47
7	-105
8	-218

Fastener Row Number	Diameter	Number of Fasteners	Part thickness tp	Strap thickness ts
1	0.188	1	0.04	0.025
2	0.188	1	0.04	0.05
3	0.188	1	0.04	0.05
4	0.188	1	0.04	0.05
5	0.188	1	0.04	0.05
6	0.188	1	0.04	0.05
7	0.188	1	0.04	0.05
8	0.188	1	0.04	0.025

Fastener Row	Fastener Load Per Row
1	186
2	120
3	54
4	15
5	-15
6	-54
7	-120
8	-186



Base D	Top D
0.010	0.040
0.015	0.035
0.020	0.030
0.025	0.025
0.032	0.018
0.040	0.010
0.050	0.000

ALUMINUM

GAUGE*	THICKNESS
22	0.025"
20	0.032"
18	0.040"
16	0.050"
14	0.063"
12	0.080"
11	0.090
10	0.100"
	0.125"
	0.160"
	0.190"

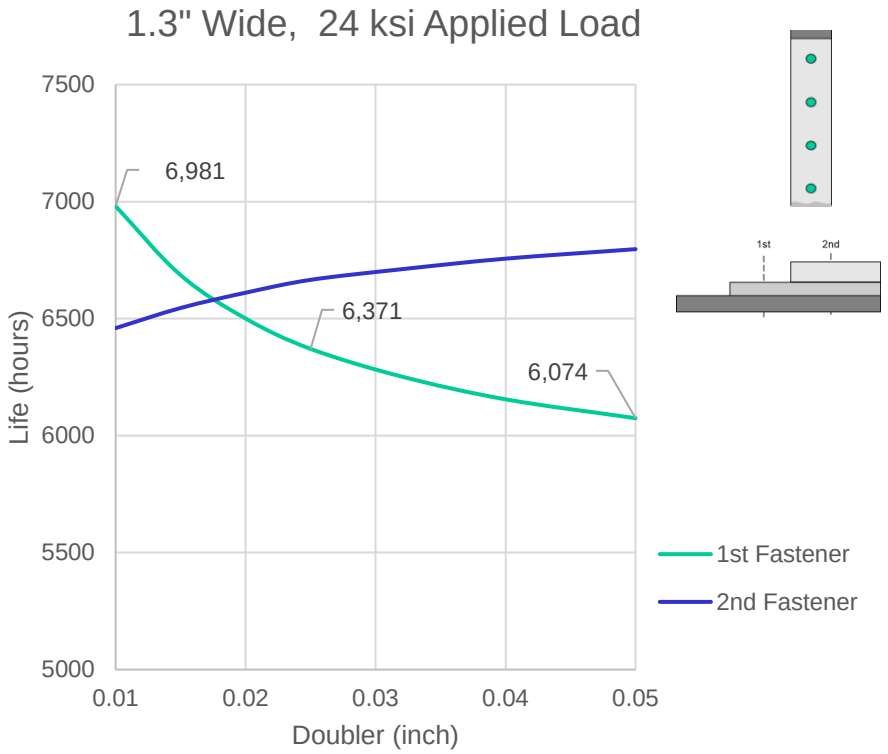
Note:
There is no official gauge standard for aluminum.

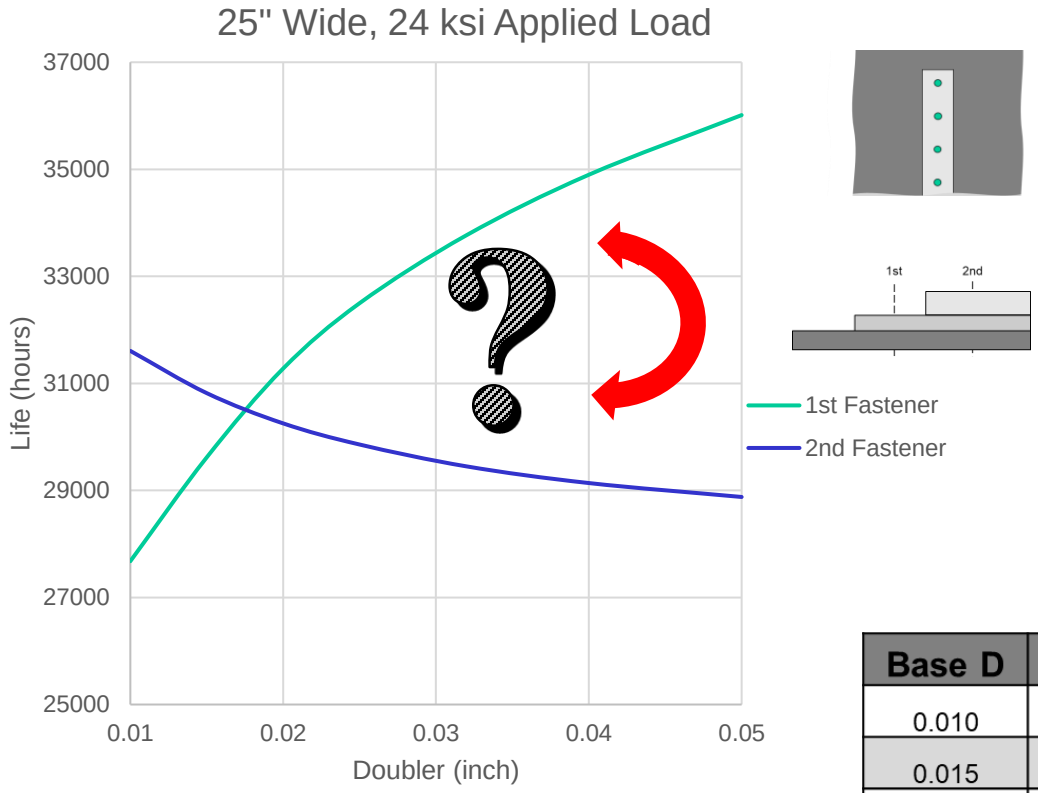
.250" & thicker is plate

*Brown & Sharpe's Gauge Standard B & S or American Gauge A.W.G.

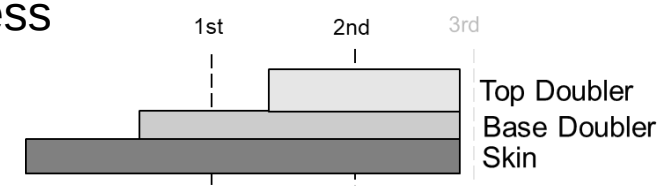
- **Developing fastener loads from Huth equations for Load Reduction configuration:**
  - Before changing the doubler thickness at 1st fastener, note its load
  - Adjust farfield load for 2nd fastener to the bypass load of 1st, rerun AFGROW
- Plot the impact to the life of the joint at the 1st and 2nd fastener
  - Plots on next slide

Results – Load Reduction Doubler





- Life at first fastener decreases with increasing doubler thickness
- Life at 2nd fastener does increase
  - Inspection window is basically the same as the 1st



Base D	Top D
0.010	0.040
0.015	0.035
0.020	0.030
0.025	0.025
0.032	0.018
0.040	0.010
0.050	0.000

Splice Repair

Splice Repair Loads

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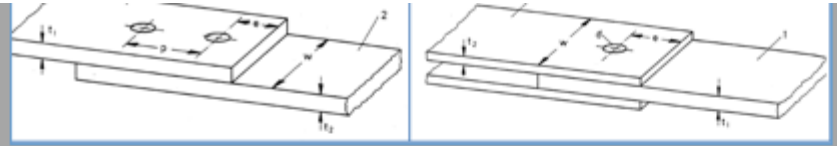
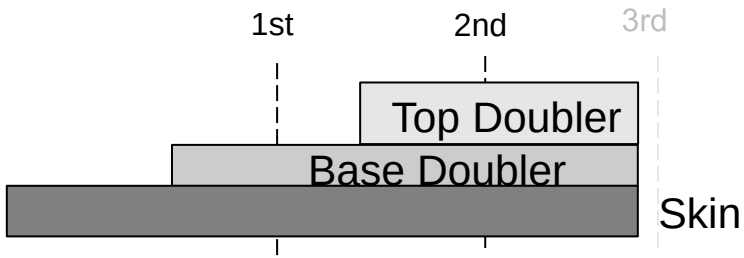
Total Fastener Row Load		
Plate Load (	1248	lbs
Plate Stress	24000	psi

Calculate Pin Loads



										Doubler she	Plate - single shear				
Fastener #	t_Repair strap (t_2)	t_plate (t_1)	Dia	Row width	Pitch	Fastener flexibility	Strap spring constant	Plate spring constant	Pin Loads (Single Shear)	Load (lbs) Before Fastener	% Load Reduction	Stress (ksi) Before Fastener	TSF	BSF
1	0.025	0.04	0.1880	1.3	1	1E-05	2.9E-06	2E-06	317	1248	25%	24.000	0.746	1.757
2	0.05	0.04	0.1880	1.3	1	8.2E-06	1.5E-06	2E-06	304	931	50%	17.903	0.673	2.261
3	0.05	0.04	0.1880	1.3	1	8.2E-06	1.5E-06	2E-06	273	627	72%	12.050	0.564	3.014
4	0.05	0.04	0.1880	1.3	1	8.2E-06	1.5E-06	2E-06	353	353	100%	6.798	0.000	6.915
5										0				

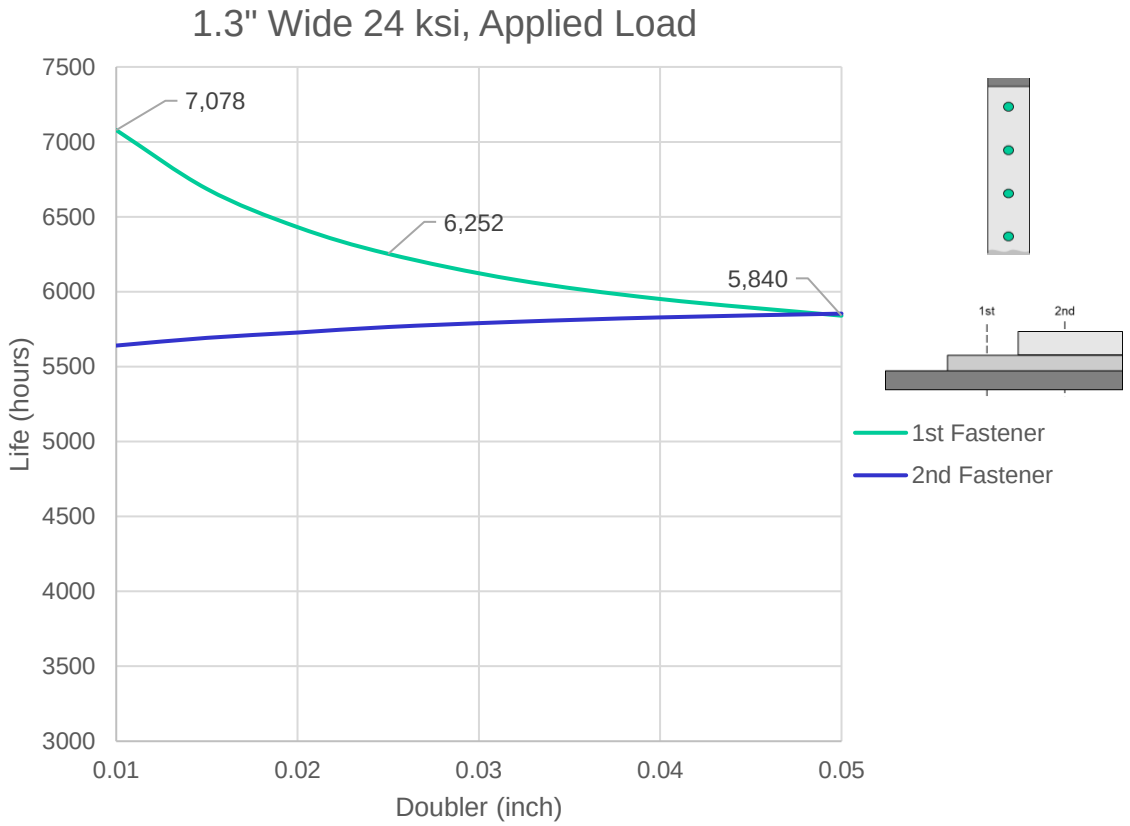
Fastener #	t_Repair strap (t_2)	t_plate (t_1)	Dia	Row width	Pitch	Fastener flexibility	Strap spring constant	Plate spring constant	Loads (Single Shear)	Load (lbs) Before Fastener	% Load Reduction	Stress (ksi) Before Fastener	TSF	BSF
1	0.05	0.04	0.1880	1.3	1	8.2E-06	1.5E-06	2E-06	392	1248	31%	24.000	0.686	2.172
2	0.05	0.04	0.1880	1.3	1	8.2E-06	1.5E-06	2E-06	267	856	53%	16.463	0.688	2.157
3	0.05	0.04	0.1880	1.3	1	8.2E-06	1.5E-06	2E-06	251	589	73%	11.328	0.574	2.948
4	0.05	0.04	0.1880	1.3	1	8.2E-06	1.5E-06	2E-06	338	338	100%	6.498	0.000	6.915



Base D	Top D
0.010	0.040
0.015	0.035
0.020	0.030
0.025	0.025
0.032	0.018
0.040	0.010
0.050	0.000

- **Developing fastener loads from Huth equations for Splice configuration:**
  - Before changing the doubler thickness at 1st fastener, note its load
  - Adjust farfield load for 2nd fastener to the bypass load of 1st, rerun AFGROW
- Plot the impact to the life of the joint at the 1st and 2nd fastener

Results – Splice Repair



- Life at first fastener decreases with increasing doubler thickness (same as before)
- Life at 2nd fastener does increase
  - Inspection window is basically the same as the 1st

Summary/Conclusion

- Basic rule-of-thumb: increased thickness, decreased life at joint
- Additional life can be achieved by using custom doublers for the first step thickness (is cost an issue?)
- So…answering the question(s) from the beginning of the study "What thickness should we set the first step?"
  - It seems that the smaller the step can aid in life for a Load Reduction repair, but negligible in terms of fleet management (inspection intervals)
- Realistic boundary conditions matter!

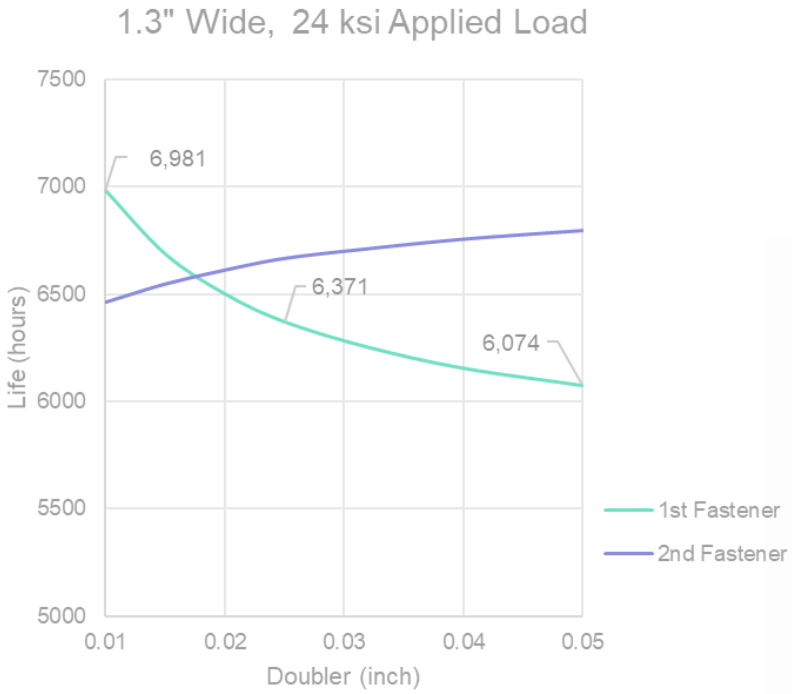
Future Work

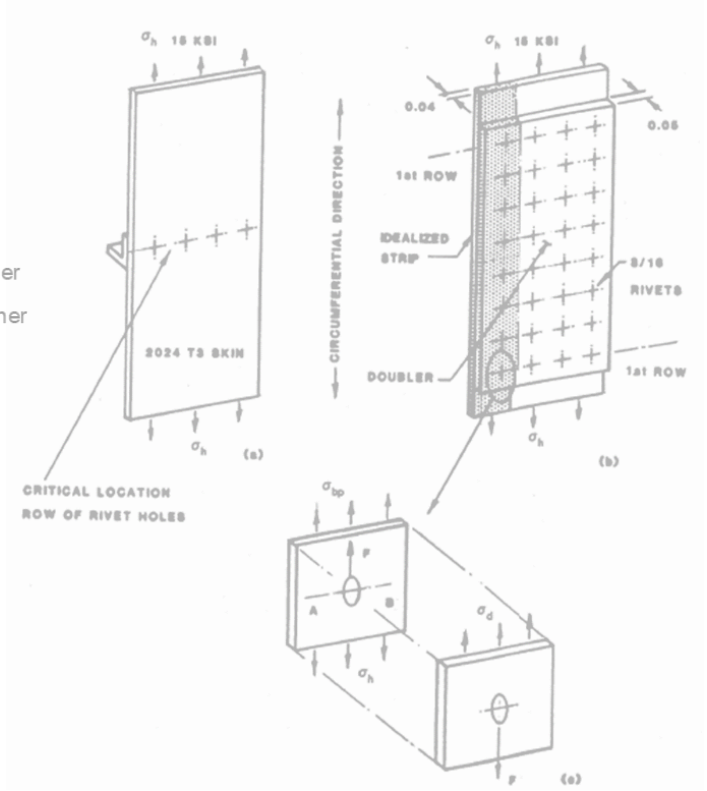
- What about thicker materials?
  - Other airframe components; i.e. longerons, spar caps
- Find a more appropriate splice repair and…
- Initial questions can be revisited

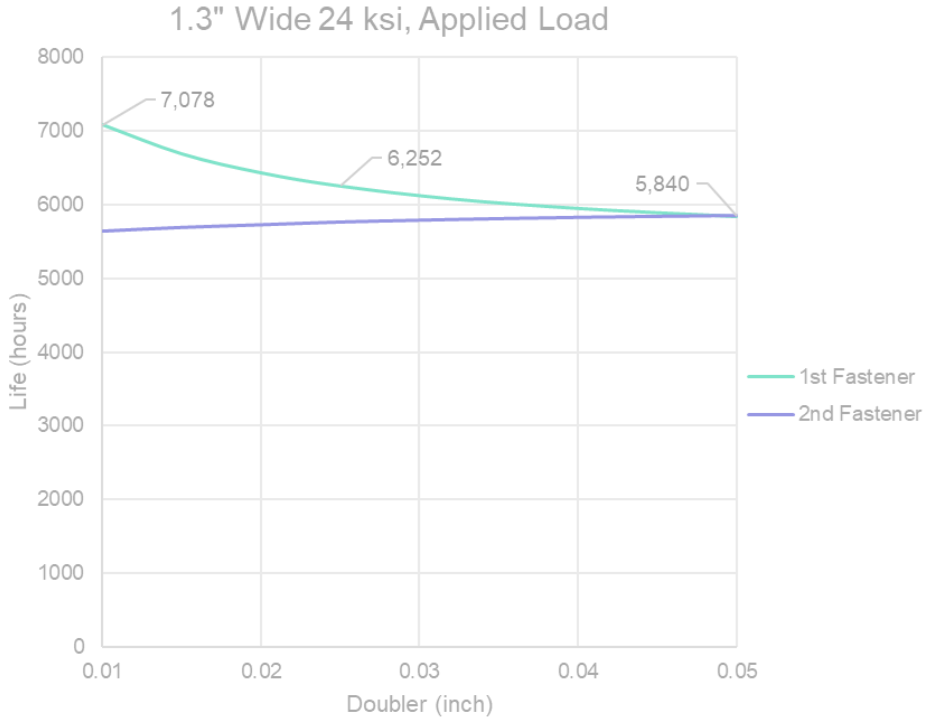
Recognition

- **Thank You!**
  - **–USAF**
  - **–Kaylon Anderson**

Questions


1.3" Wide, 24 ksi Applied Load
7500
7000
6500
6000
5500
5000
Life (hours)
6,981
6,371
6,074
0.01
0.02
0.03
0.04
0.05
Doubler (inch)
1st Fastener
2nd Fastener


σh 18 KSI
2024 T3 SKIN
CRITICAL LOCATION
ROW OF RIVET HOLES
(a)
CIRCUMFERENTIAL DIRECTION
0.04
0.05
1st ROW
IDEALIZED STRIP
DOUBLER
5/16 RIVETS
1st ROW
(b)
σbp
P
A
B
σd
(c)


1.3" Wide 24 ksi, Applied Load
8000
7000
6000
5000
4000
3000
2000
1000
0
Life (hours)
7,078
6,252
5,840
0.01
0.02
0.03
0.04
0.05
Doubler (inch)
1st Fastener
2nd Fastener