Accounting for Post Buckled Effects in Spectra Development

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Post Buckled Spectra Effects

Focus of this presentation is to demonstrate a potential approach to more accurately representing the effects of post buckled structure in the development of fatigue spectra.

- Review of Buckling in Airframe Structures
- Examples of Various Buckled Structures
- Front Spar Web Analytical Example
- Fuselage Lap Joint Example

Post Buckled Spectra Effects

For semi-monocoque airframe design and construction, it is common to permit structures to buckle in order to meet weight requirements. The common misconception assumes this is only permitted between limit and ultimate loads and does not impact fatigue and damage tolerance analysis.

In most semi-monocoque airframes, thin sheet structure is permitted to buckle below limit load. Typical structural components which are permitted to buckle are as follows:

- Fuselage skins
- Wing Skins and Spar Caps and Webs
- Vertical Tail Skins and Spars
- Horizontal Tail Skins and Spars

Post Buckled Spectra Effects

Two primary types of buckling occurring in airframe built up stiffened flat and curved panels are:

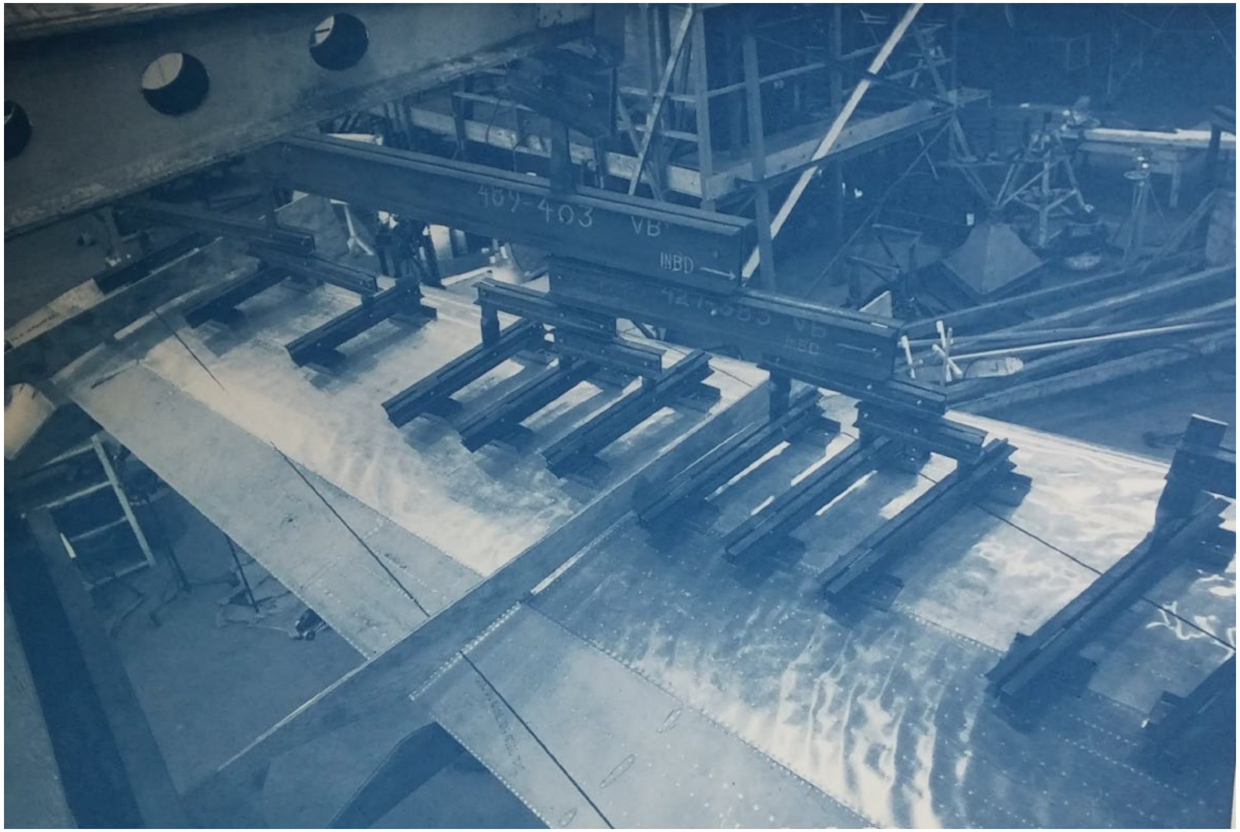
- Compression Buckling
- Shear Web Buckling

The methods for determining the effects of each type of buckling on the surrounding structure has long been established in industry standard methods:

- NACA-TN-2661 Summary of Diagonal Tension Part I
- NACA-TN-2662 Summary of Diagonal Tension Part II
- Stresses in Aircraft and Shell Structures by Paul Kuhn
- Aircraft Structures by Peery
- Airplane Structural Analysis & Design by Sechler and Dunn
- Analysis & Design of Flight Vehicle Structures by E.F. Bruhn

Post Buckled Spectra Effects

For most modern day transports but not all, wing skins are typically maintained shear resistant up to limit load so as not to alarm the passengers. In the past however, it was commonplace to allow the wing skins to buckle below limit load.



US Navy R4D (DC-3) Wing Proof Test – Extent of Buckling at 80% of Limit Load

Ref. National Archives Public Data – SM107340

Post Buckled Spectra Effects

However, there is still current evidence that several aircraft depending on the components and aircraft model still permit in flight buckling.

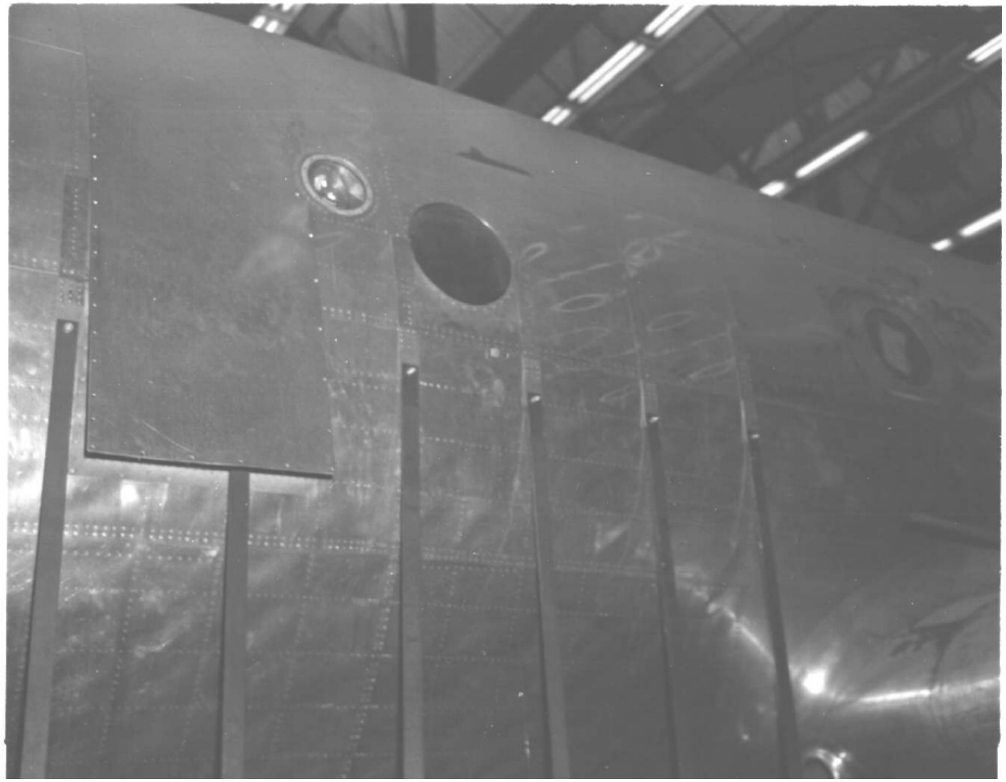
Large Transport Category

Small Aircraft General Aviation

Ref. Airliners.net

Post Buckled Spectra Effects

Most modern day transports, still permit the lower fuselage skins to buckle. This generally can occur anywhere between 50% to 100% of limit load depending on the manufacturer and aircraft model.



Model 1049 Fuselage Proof Test – Extent of Buckling from 50% to 75% of Limit Load

Ref. National Archives Public Data – LR 8603

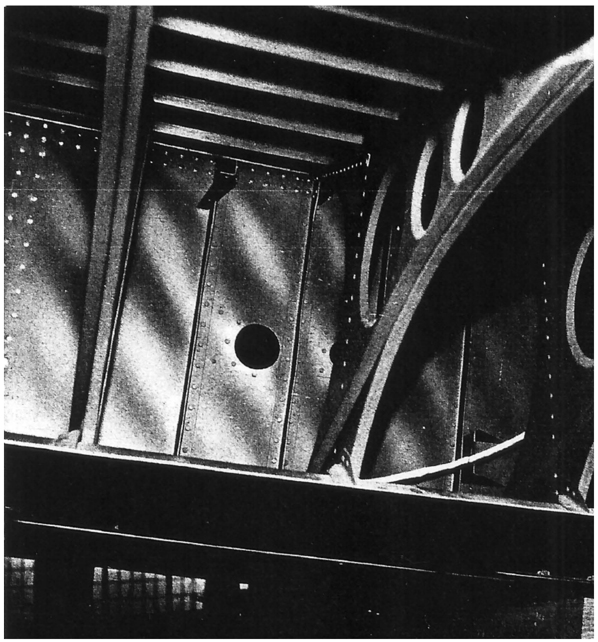
Post Buckled Spectra Effects

There are many examples of commercial transport fuselage buckling during normal flight particularly on approach when balancing tail loads are highest.

Ref. Altair.com

Post Buckled Spectra Effects

For wings and stabilizers, depending on the aircraft model, it is common even today to permit the spar webs to buckle to a certain degree. Buckling below limit load can induce fatigue cracking which is often not accounted for or in unexpected areas.



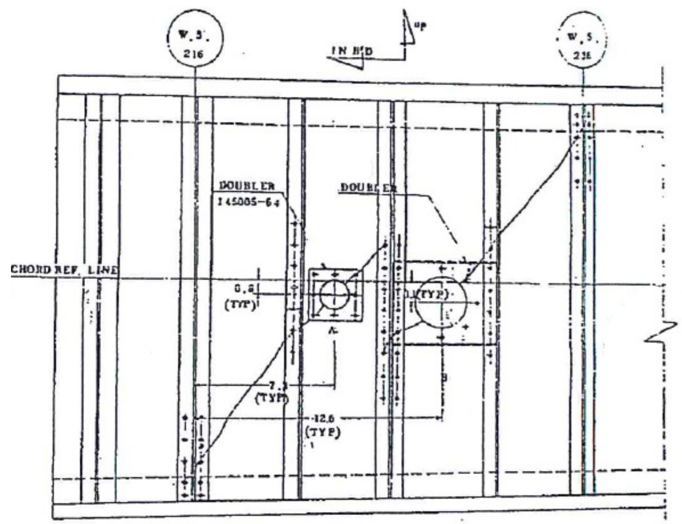
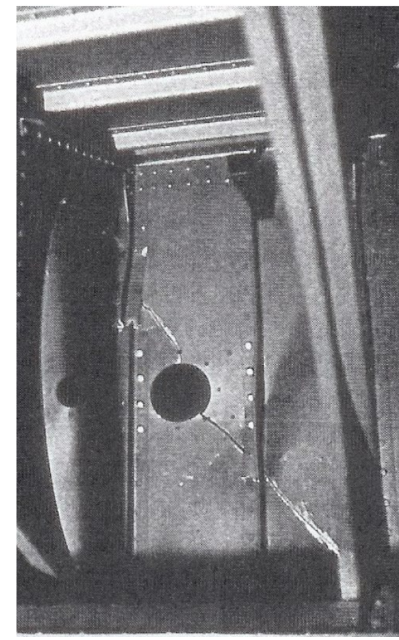


FIGURE 1. FATIGUE FAILURE OF REAR SPAR WEB



USN P2V-4 Static Test Rear Spar Buckling

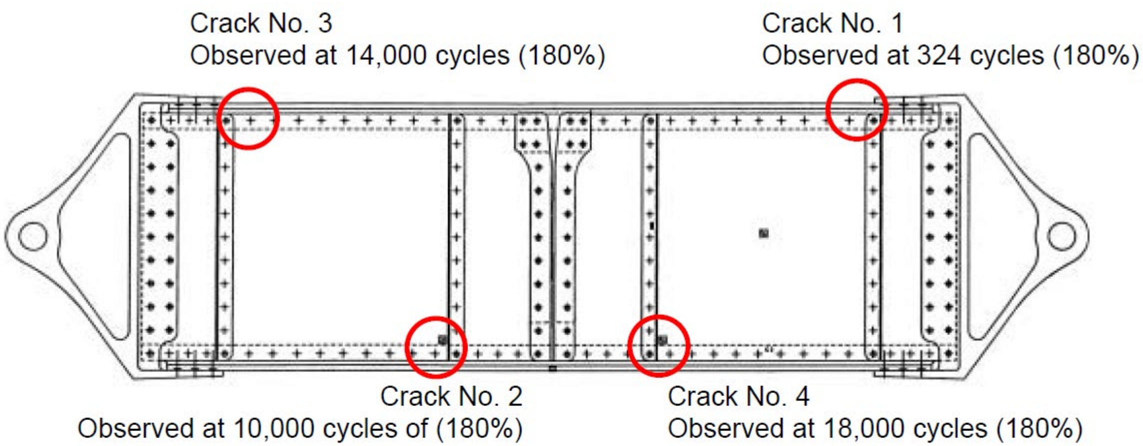
P2V-7 Japanese JDF Full Scale Fatigue Test Cracking

Ref. National Archives Public Data – LR 7217

Ref. USFS via Japanese Embassy

Post Buckled Spectra Effects

Crack initiation locations due to the buckling of the web are different than what would normally be expected in a built up structure such as this.



Failed at 18,862 cycles (total 78,862 cycles)

- Test Load Sequences

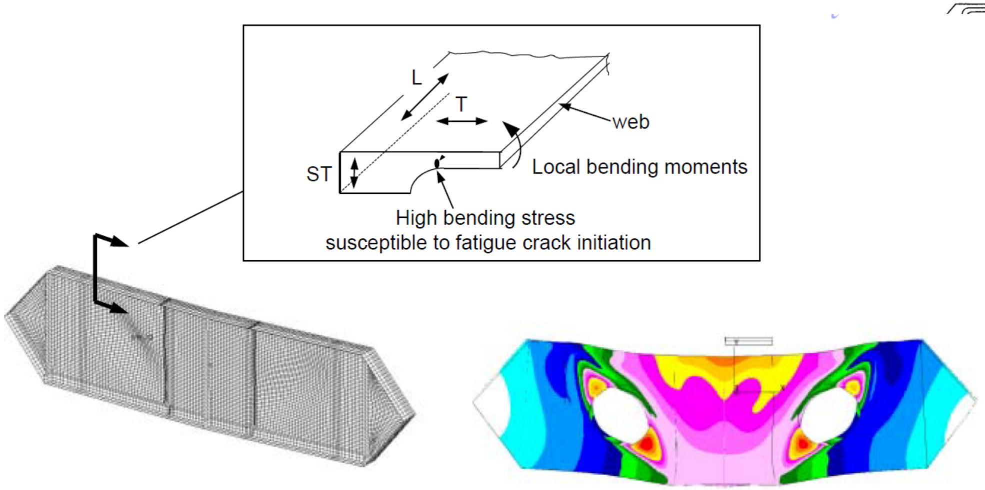
No. Of Cycles	Load Level	Loads (lbs)
30,000	100%	8820
10,000	120%	10584
10,000	140%	12701
10,000	160%	14112
As required	180%	15876

- Stress Survey up to 100% load
- Stress ratio .10 for fatigue cycles

Ref: Investigations of Post-Buckled Behaviors of Monolithic Bulkhead by Test & Analysis, by Hsu, Tzong, Chan
The Boeing Company, 6th Joint FAA/DoD/NASA Conference on Aging Aircraft, 2002

Post Buckled Spectra Effects

With the need for increasing performance and thus the need to reduce weight, additional structure is being designed to buckle below limit load in integrally machined parts such as floor beams and bulkheads.

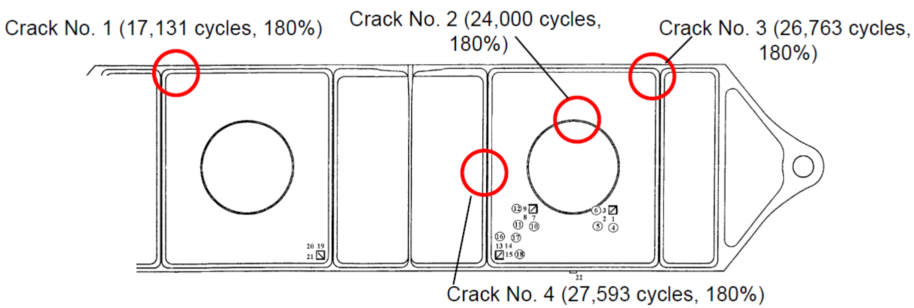


Buckled at 25~30% of Test Load

Specimen No. 1 and 2

Buckled at 65% of Test Load

Specimen No. 3

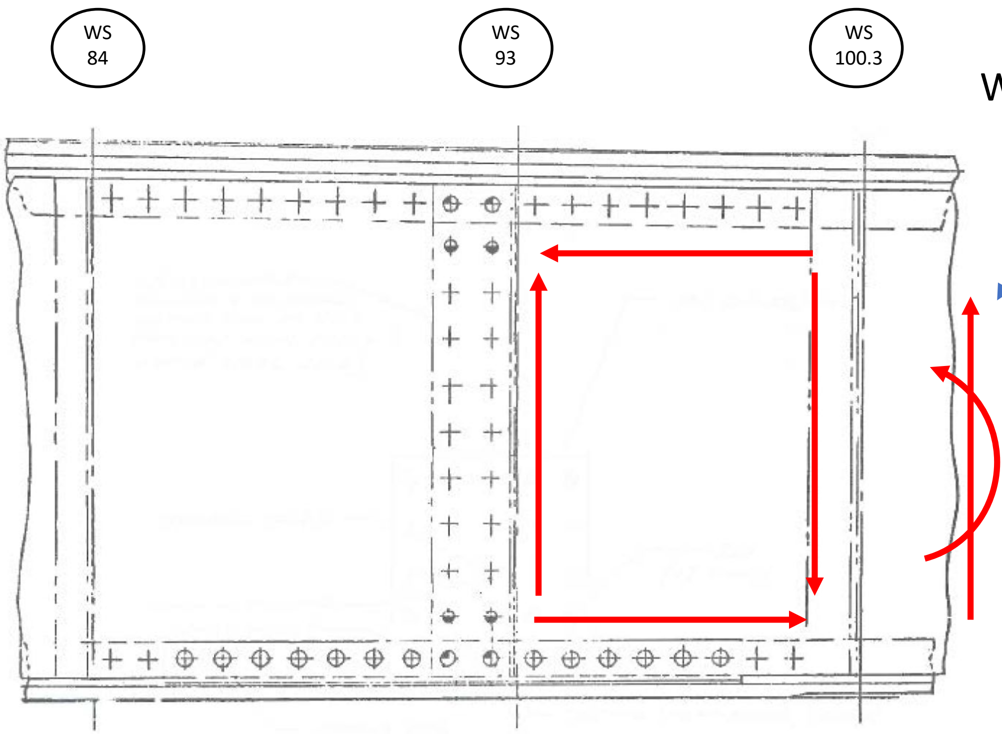


Failed at 27,731 cycles (total 87,731 cycles)

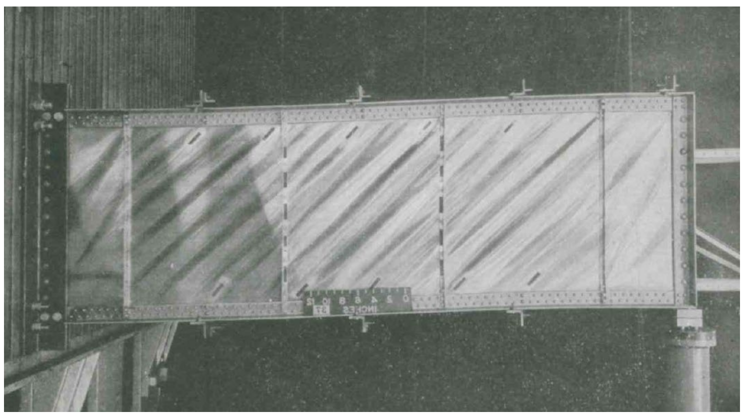
Ref: Investigations of Post-Buckled Behaviors of Monolithic Bulkhead by Test & Analysis, by Hsu, Tzong, Chan
The Boeing Company, 6th Joint FAA/DoD/NASA Conference on Aging Aircraft

Example 1 – Front Spar Cap & Web

USAF T-28 Trainer Front Spar Cap and Web



Wing Up and Down Bending Shear and Moment

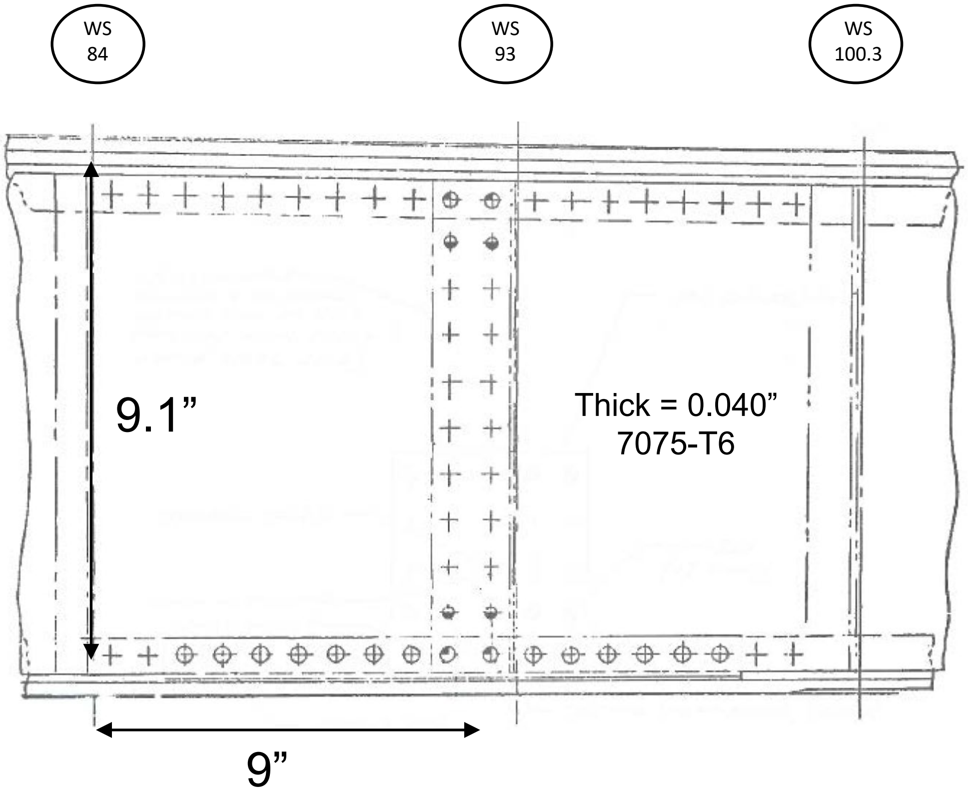


- Example Problem 1A – Shear Resistant Spar Web
- Example Problem 1B – Web Buckles at 50% of Fatigue Loads

Ref. Advanced Spectrum and DTA Applications Course, Burd and Dr. Fawaz, 2025
Ref. National Archives, NA-48-1007, Wing Analysis for an Airplane, Model T-28, 1956
Ref. Stresses in Aircraft and Shell Structures, by Paul Kuhn, 1956.

Example 1 – Front Spar Cap & Web

T-28 Trainer Front Spar Cap and Web



Front Spar properties:

Web thickness = 0.040” 7075-76
Spar Cap = 2014-T6
Spar Cap flange thickness = 0.125”
Spar Cap Area = 0.870 in^2
(Cap area includes skin and web)
Stiffener = 7075-T6
Stiffener thickness = 0.094”
Stiffener Area = 0.155 in^2

Limit Load Condition – Max Wing Up-bending

Spar cap ult stress = 30.431 ksi
Spar cap limit stress = 20.287 ksi
Web ult shear flow = 570 lbs/inch
Web ult shear stress = 570/.04 = 14.25 ksi
Web limit shear flow = 380 lbs/inch
Web limit shear stress = 9.5 ksi

Ref. National Archives, NA-48-1007, Wing Analysis for an Airplane, Model T-28, 1956
Ref. NACA-TN-1364 Strength Analysis of Stiffened Web Beams

Example 1 – Front Spar Cap & Web

The original analysis of the T-28 spar web used NACA-TN-1364. The same method is presented in several references. For ease of illustration, Bruhn is cited for the example. Primarily, the main focus is to determine when the spar web buckles and what are the increase in loads as a result. For this analysis section, ultimate stresses are used.

The elastic critical shear stress is calculated using Equation 53 from Section C11.17.

$$F_{s_{cr}} = k_{ss} E \left(\frac{t}{d_c}\right)^2 \left[R_h + \frac{1}{2}(R_d - R_h)\left(\frac{d_c}{h_c}\right)^3\right] \quad (53)$$

Following thru the calculation and using Figures C11.16a and C11.16b, the following elastic critical shear stress is obtained:

Fscr = 2000 psi

fs/Fscr = 14250/2000 = 7.125 from Fig. C11.19 Diagonal factor k = 0.42

So, this means that the spar web will buckle for any applied load that is above the following shear flow:

q = 2000*0.040 = 80 lbs/inch Note: Example assumption this occurs 50% of time

Ref. NACA-TN-1364 Strength Analysis of Stiffened Web Beams
Ref. Analysis and Design of Flight Vehicle Structures, by Bruhn.

Example 1 – Front Spar Cap & Web

To calculate the increase in spar cap stress, the method in Bruhn on Page C11.22 is utilized.

Ultimate bending moment on front spar Mx = -255,720 inch-lbs
I_{xx} all intact = 51.47 in^4
I_{xx} web buckled = 49.01 in^4

Moment for shear resistant web = (1-k)Mx = (1-0.42)*(-255720) = -148,300 inch-lbs
Moment for diagonal tension = k*Mx = (0.42)*(-255720) =-107,420 inch-lbs

Stress = 17649 + 13728 = 31377 psi
Spar cap stress increase factor = 31377/30431 = 1.03

Additionally, the effective web area must be removed since it is no longer effective.

Spar cap revised area = 0.870 – (1 inch width)*(0.040 web) = 0.83 in^2

Spar cap stress with web failed = 31377*0.87/0.83 = 32.889 ksi ultimate
Limit spar cap stress with web buckled = 21.926 ksi

Ref. National Archives, NA-48-1007, Wing Analysis for an Airplane, Model T-28, 1956
Ref. Analysis and Design of Flight Vehicle Structures, by Bruhn.

Example 1 – Front Spar Cap & Web

To calculate the increase in fastener load in the web to flange, Equation 53 on Page C11.18 of Bruhn is used along with the k value previously determined:

Fastener load per inch = q*(1+0.414*k) = 570*(1+0.414*0.42) = 670 lbs/inch
Fastener load increase factor = 670/570 = 1.18

Effective fasteners per bay for shear flow = 11
Bay width at web to spar cap attachment = 9 inches

Shear resistant fastener load = 570*9/11 = 466 lbs per fastener
Ultimate Bearing stress for shear resistant web = 466/(0.1875*0.04) = 62.133 ksi
Ultimate Bearing stress for shear resistant web = 62.133/1.5 = 41.422 ksi

Ultimate Bearing stress for buckled web = 41.422*1.18 = 48.671 ksi

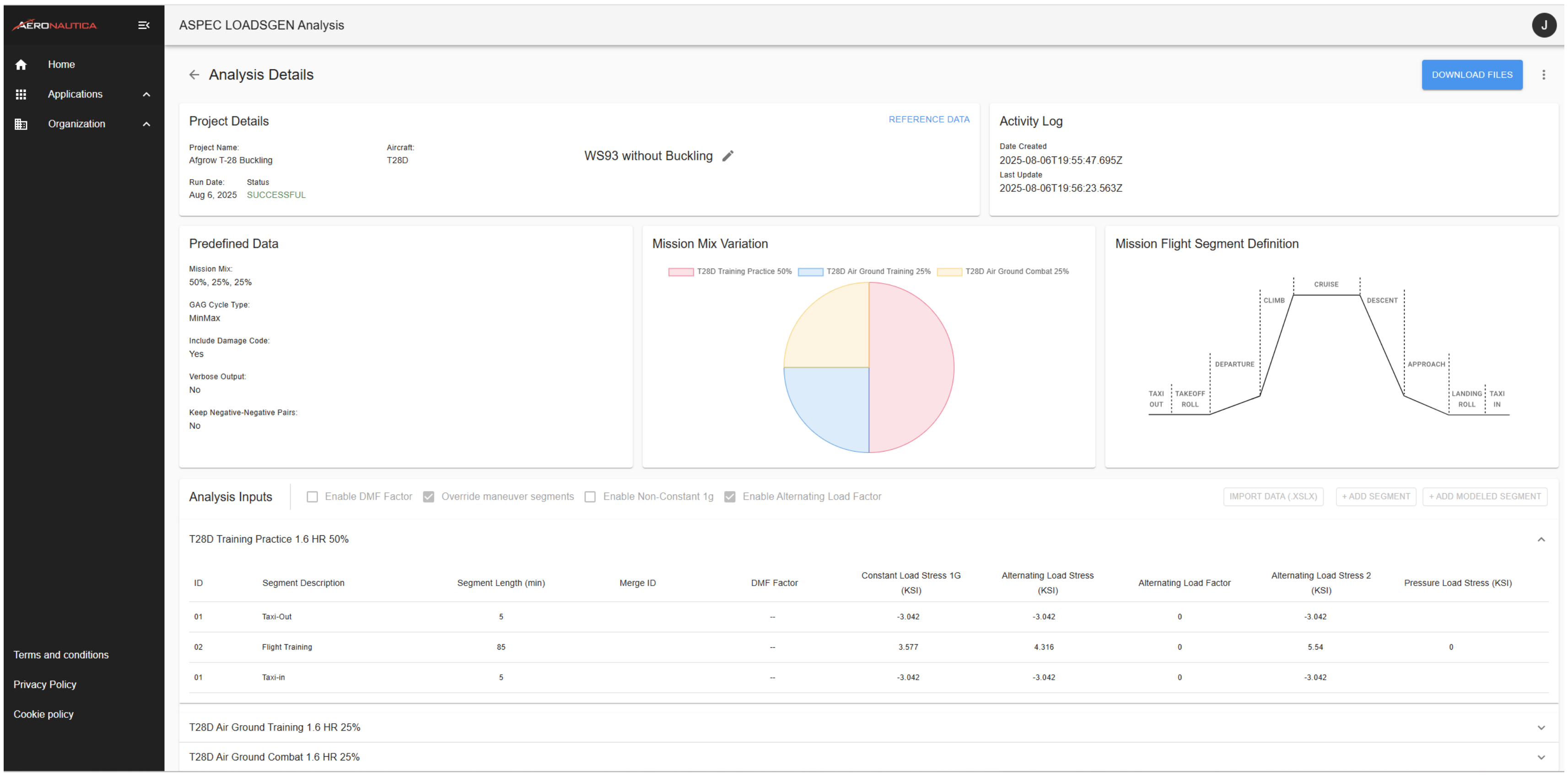
Impact of buckling:
Axial stress increase = 8%
Bearing stress increase = 18%

Ref. National Archives, NA-48-1007, Wing Analysis for an Airplane, Model T-28, 1956
Ref. Analysis and Design of Flight Vehicle Structures, by Bruhn.

Example 1 – Front Spar Cap & Web

Example 1A - Analysis of Spar Cap at Web Attach Flange – Shear Resistant Web:

Spectrum is developed using the Aspec tool for a simple Mission mix of 3 flights (see Ref)



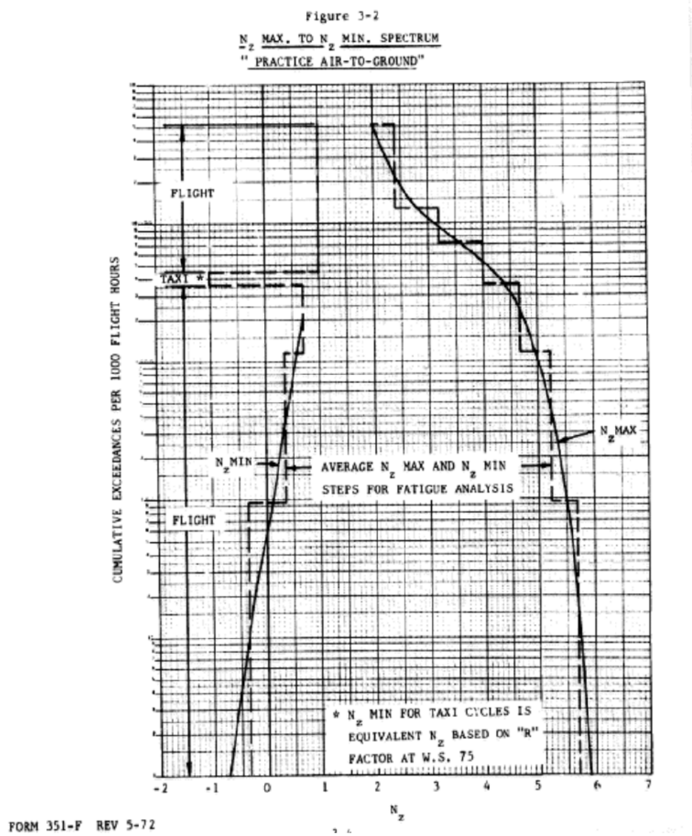
ID	Segment Description	Segment Length (min)	Merge ID	DMF Factor	Constant Load Stress 1G (KSI)	Alternating Load Stress (KSI)	Alternating Load Factor	Alternating Load Stress 2 (KSI)	Pressure Load Stress (KSI)
01	Taxi-Out	5		--	-3.042	-3.042	0	-3.042	
02	Flight Training	85		--	3.577	4.316	0	5.54	0
01	Taxi-in	5		--	-3.042	-3.042	0	-3.042	

Ref: Fatigue Loads and Damage Tolerance Methods for Airworthiness, by Burd, 2024 ASIP Conference, Austin, Tx.
Ref. Advanced Spectrum and DTA Applications Course, Burd and Fawaz, 2025

Example 1 – Front Spar Cap & Web

Example 1A - Analysis of Spar Cap at Web Attach Flange – Shear Resistant Web:

Spectrum uses T-28 USAF load histories: Sample Load History for Mission 3



Notes:

1. Spectrum includes load histories which slightly exceed limit load.

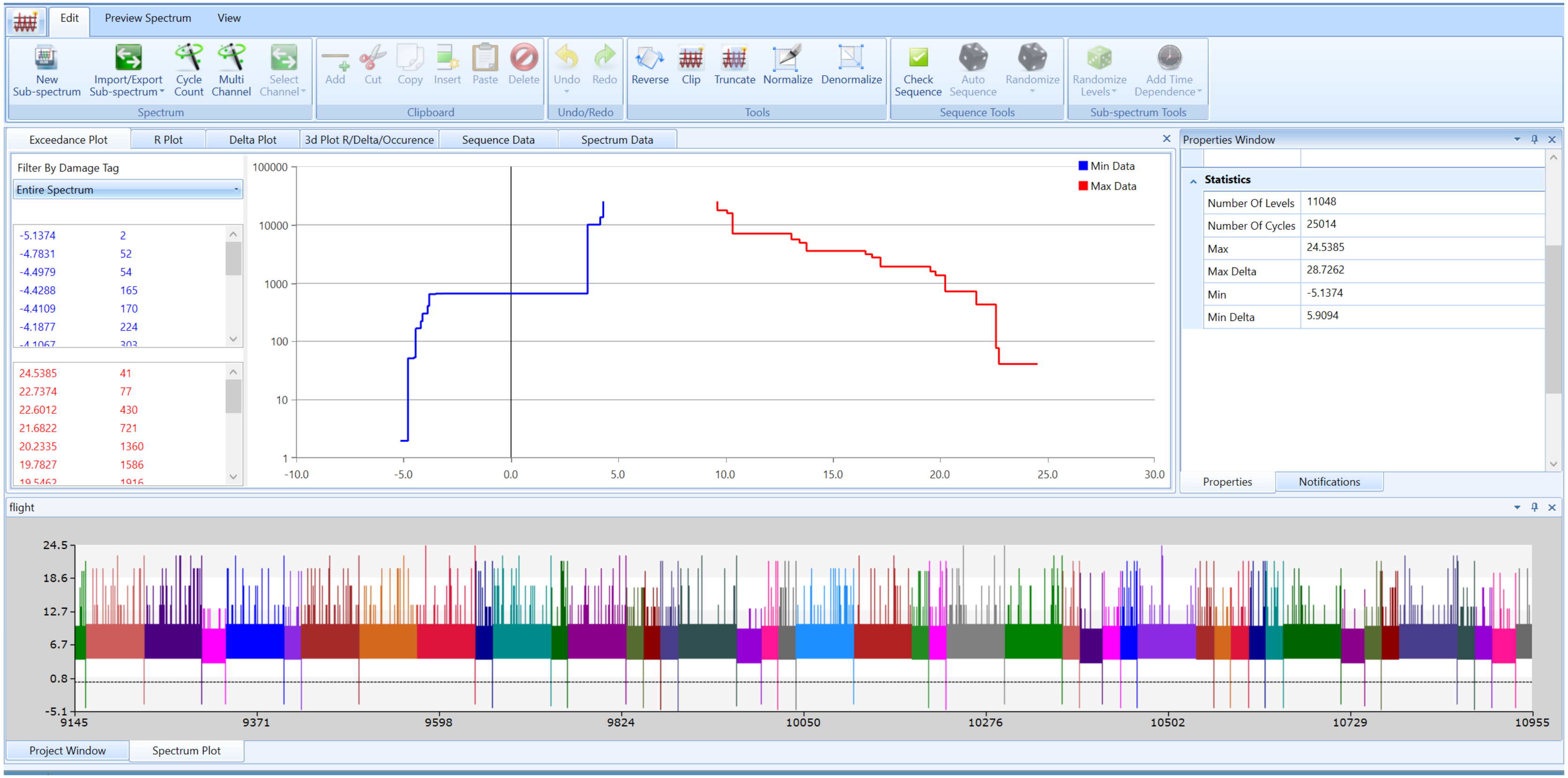
2. Spectrum is limited since load history is not separated into individual flight segments such as takeoff, climb, approach, landing, etc. and use of flight controls. Spar Webs are heavily driven by conditions which induce torsion. If load histories are not detailed enough, this imposes very conservative assumptions to be used throughout spectrum.

Ref: USAF FOIA NR73H-9 Model T-28A/D/D-5/D-10 Airplane Fatigue Life Evaluation, Burd.
Ref. Advanced Spectrum and DTA Applications Course, Burd and Fawaz, 2025

Example 1 – Front Spar Cap & Web

Example 1A - Analysis of Spar Cap at Web Attach Flange – Shear Resistant Web:

Maximum spar cap spectrum stress for the shear resistant web configuration is 24.54 ksi. Note this is above limit because spectrum includes loads above it and buckling effects.



Ref: USAF FOIA NR73H-9 Model T-28A/D/D-5/D-10 Airplane Fatigue Life Evaluation, Burd.
Ref. Advanced Spectrum and DTA Applications Course, Burd and Fawaz, 2025

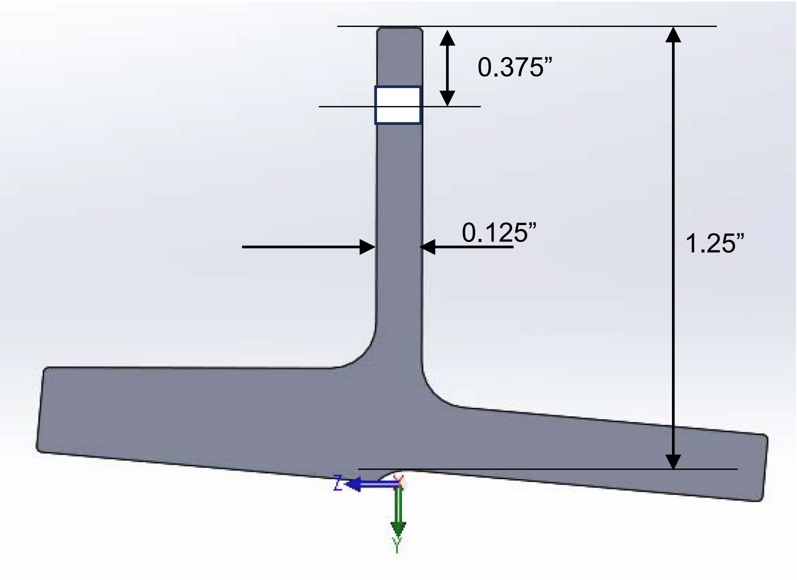
Example 1 – Front Spar Cap & Web

Example 1A - Analysis of Spar Cap at Web Attach Flange – Shear Resistant Web:

Afgrow analysis is performed on vertical flange of spar cap at web attachment. AFMAT tabular data is used for 2014-T6.

Limit stress = 20.287 ksi
Shear resistant fastener load = 466 lbs/1.5 = 311 lbs/inch
Spar cap vertical flange thickness = 0.125 inches
Fastener hole diameter 0.1875 inches
Bearing stress = 13.269 ksi
Bearing/Ref = 13.269/20.287 = 0.65

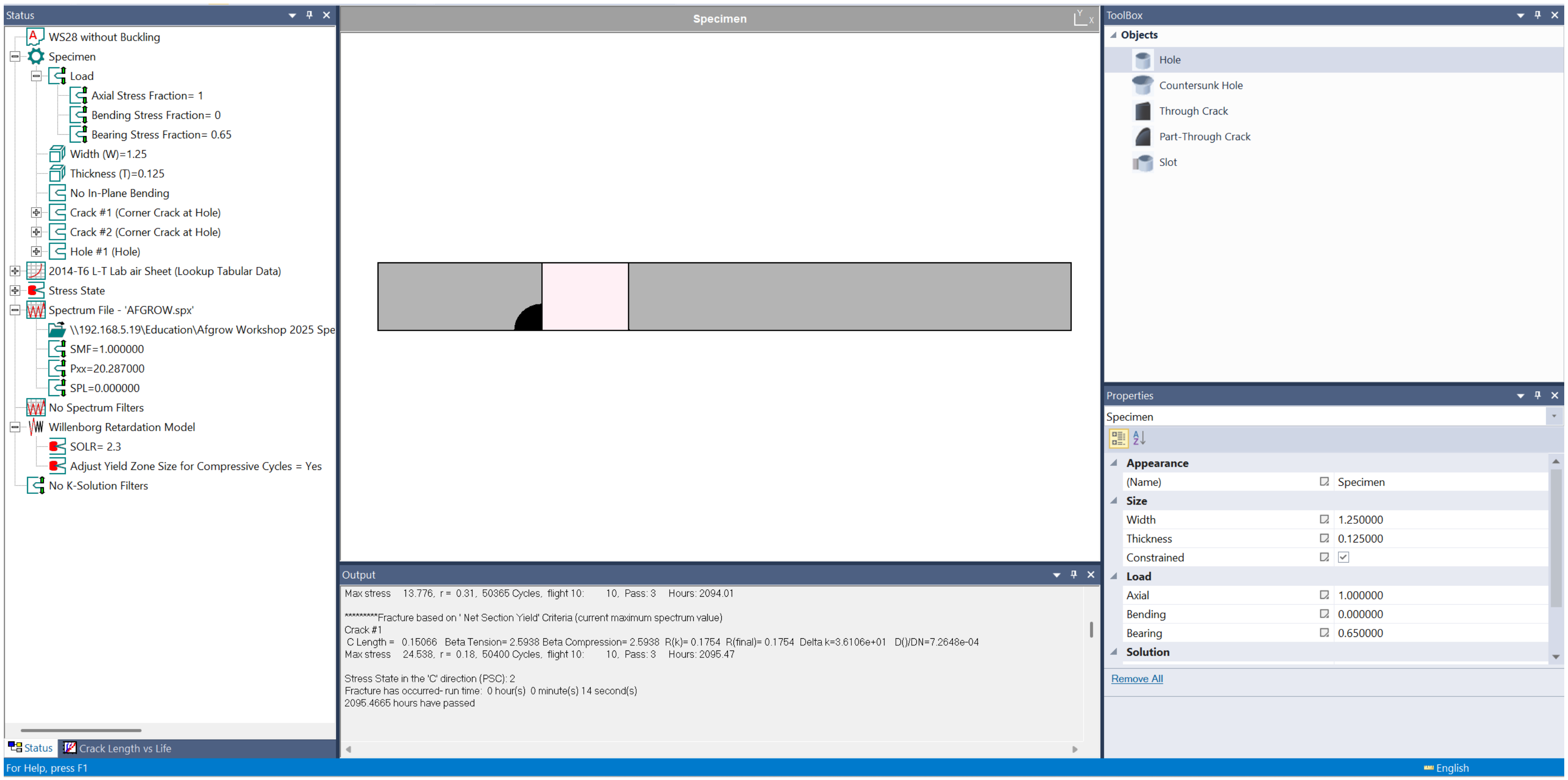
Effective vertical flange length = 1.25 inches
Thickness of flange = 0.125 inches



Ref: USAF FOIA NR73H-9 Model T-28A/D/D-5/D-10 Airplane Fatigue Life Evaluation, Burd.
Ref. Advanced Spectrum and DTA Applications Course, Burd and Fawaz, 2025

Example 1 – Front Spar Cap & Web

Example 1A - Analysis of Spar Cap at Web Attach Flange – Shear Resistant Web Phase 1:

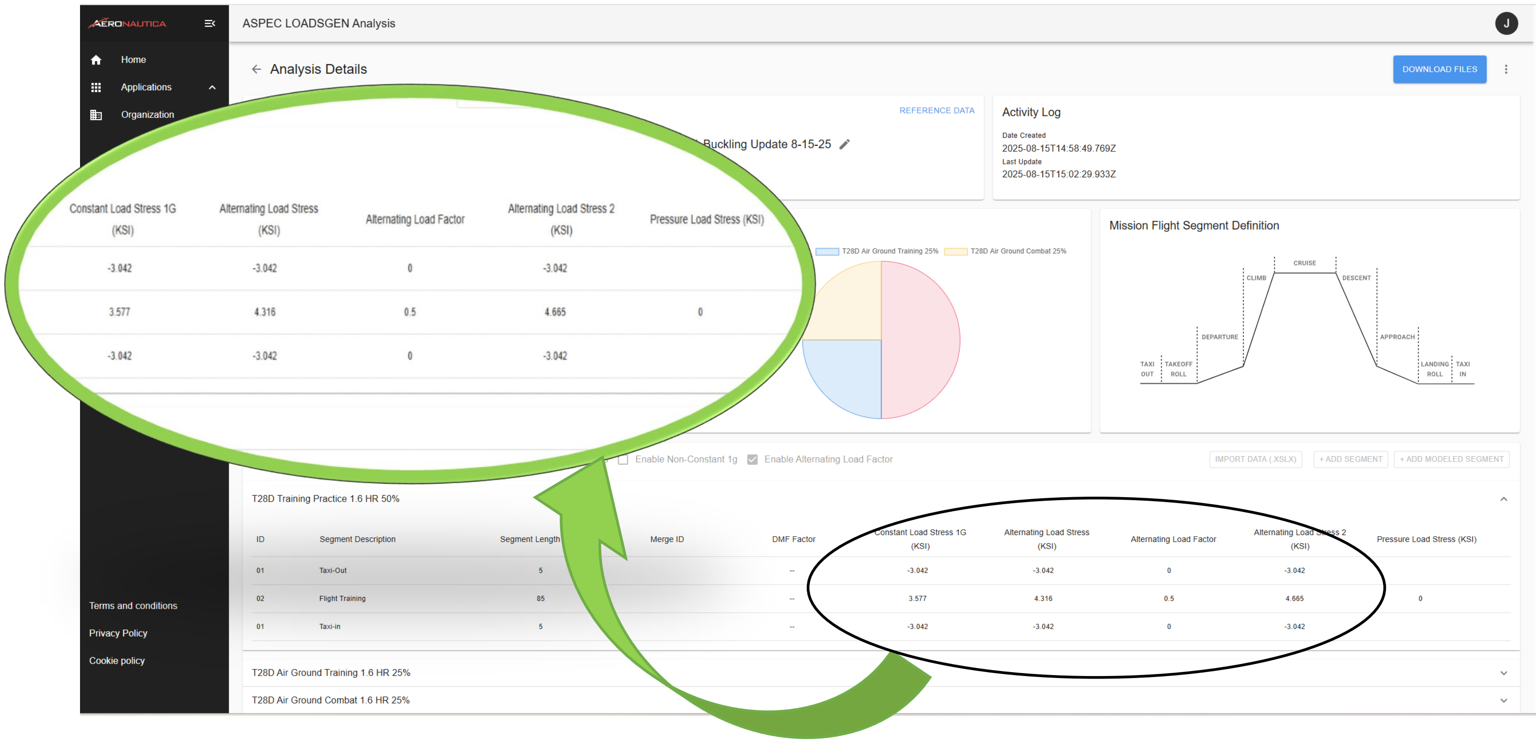


Ref: USAF FOIA NR73H-9 Model T-28A/D/D-5/D-10 Airplane Fatigue Life Evaluation, Burd.
Ref. Advanced Spectrum and DTA Applications Course, Burd and Fawaz, 2025

Example 1 – Front Spar Cap & Web

Example 1B - Analysis of Spar Cap at Web Attach Flange – Buckled Web Mode:

Spectrum is developed using the Aspec tool for a simple Mission mix of 3 flights (see Ref) using a factor 0.5 for the alternating load. Any load greater than this percentage will use post buckled stresses while those below this will use the shear resistant stresses.



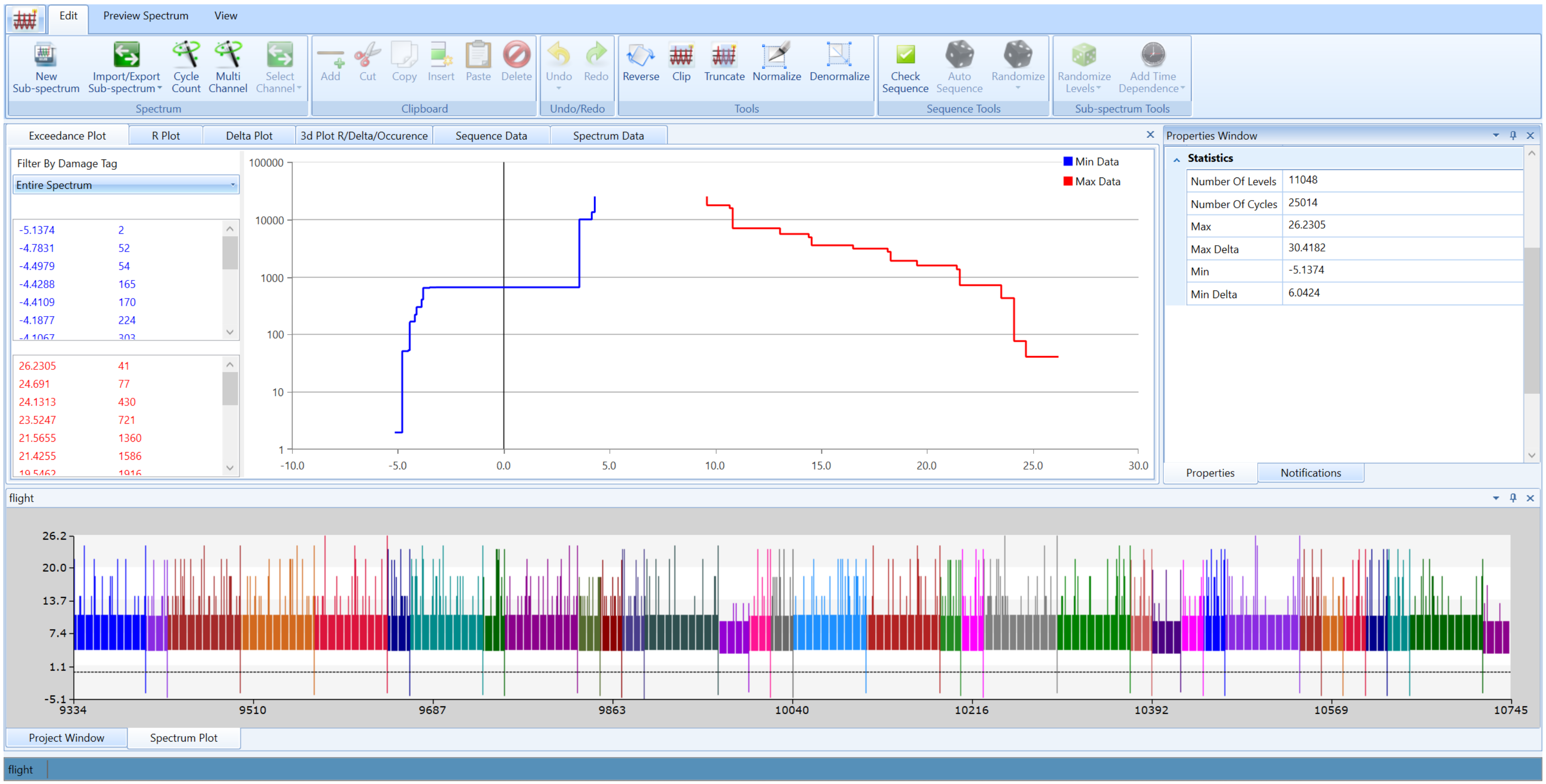
**New: Aspec capable of using different alternating loads based on assigned load factor for all segments.

Ref: Fatigue Loads and Damage Tolerance Methods for Airworthiness, by Burd, 2024 ASIP Conference, Austin, Tx.
Ref. Advanced Spectrum and DTA Applications Course, Burd and Fawaz, 2025

Example 1 – Front Spar Cap & Web

Example 1B - Analysis of Spar Cap at Web Attach Flange – Buckled Web Mode:

Maximum spar cap spectrum stress for the buckled web configuration is 26.23 ksi



Ref: Fatigue Loads and Damage Tolerance Methods for Airworthiness, by Burd, 2024 ASIP Conference, Austin, Tx.
Ref. Advanced Spectrum and DTA Applications Course, Burd and Fawaz, 2025

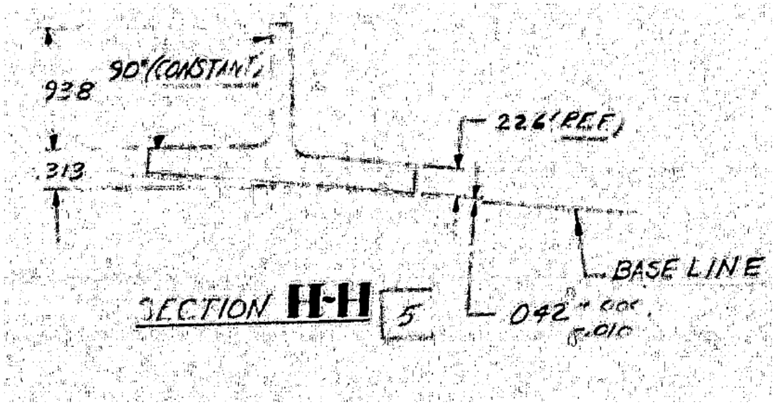
Example 1 – Front Spar Cap & Web

Example 1B - Analysis of Spar Cap at Web Attach Flange – Buckled Web Mode:

Afgrow analysis is performed on vertical flange of spar cap at web attachment. AFMAT tabular data is used for 2014-T6.

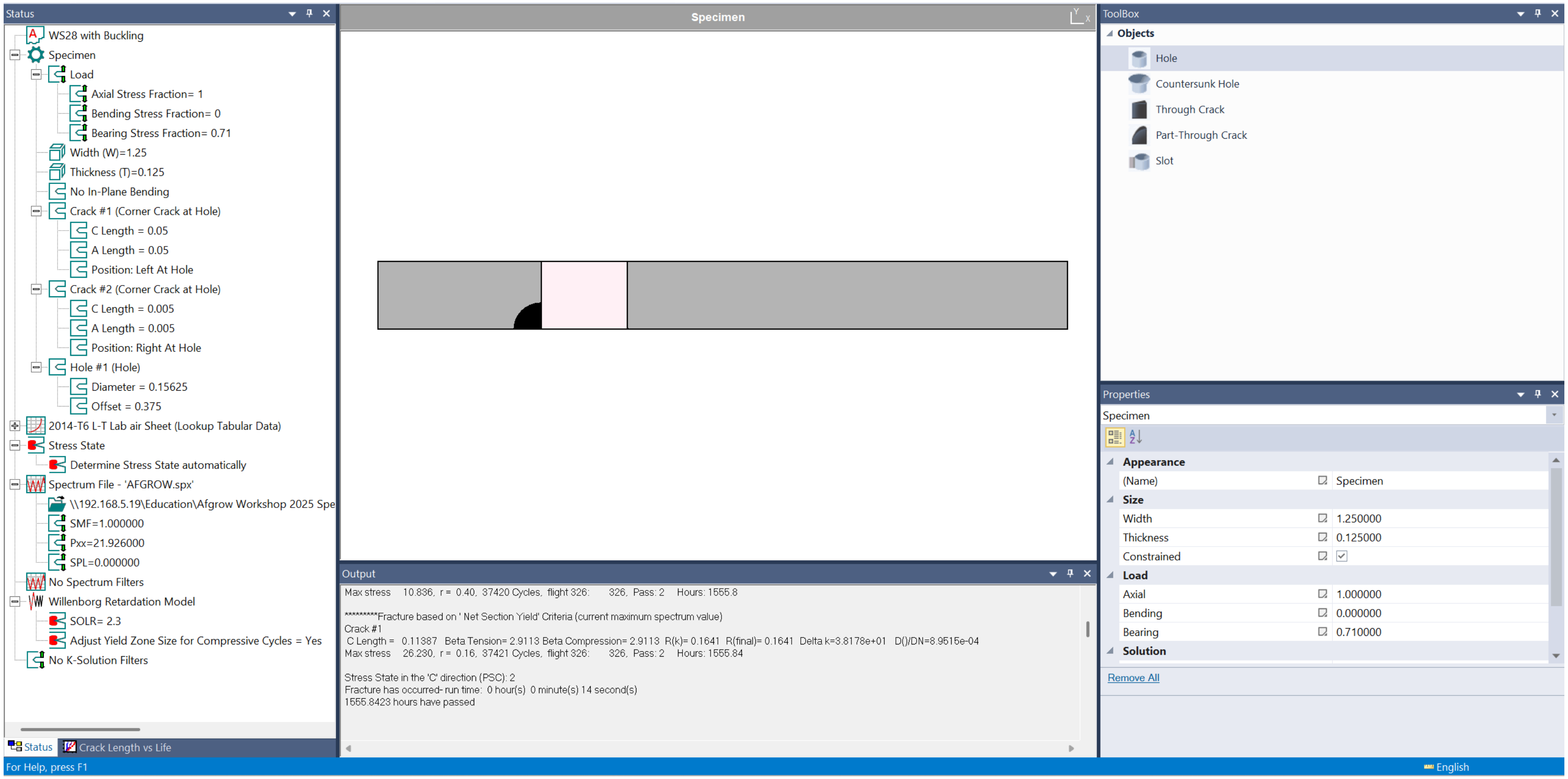
Limit stress cap with web buckled = 21.926 ksi
Diagonal tension fastener load = 311*1.175 = 365 lbs
Spar cap vertical flange thickness = 0.125 inches
Fastener hole diameter 0.1875 inches
Bearing stress = 15.573 ksi
Bearing/Ref = 15.573/21.926 = 0.71

Effective vertical flange length = 1.25 inches
Thickness of flange = 0.125 inches



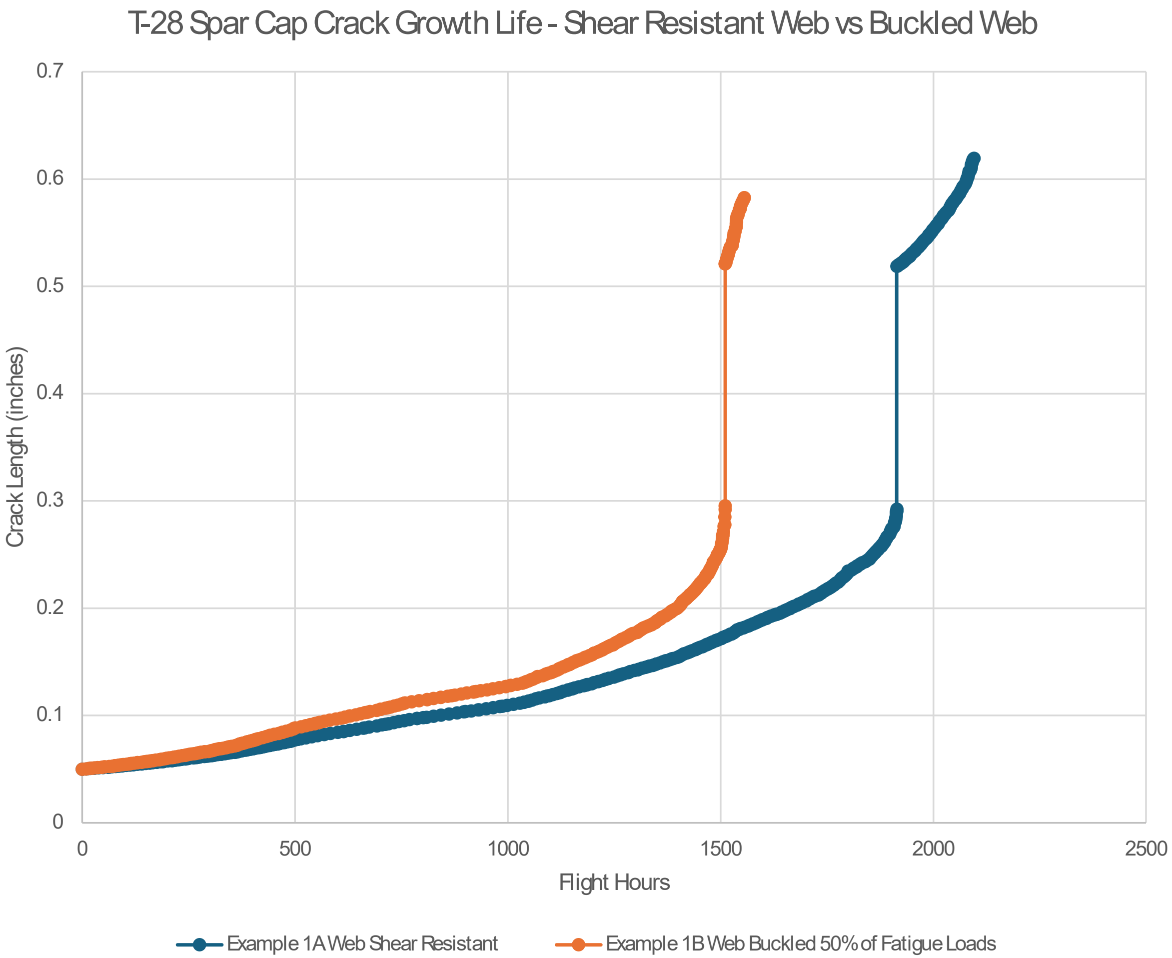
Example 1 – Front Spar Cap & Web

Example 1B - Analysis of Spar Cap at Web Attach Flange – Buckled Web Mode:



Example 1 – Front Spar Cap & Web

Example 1A and Example 1B – Crack growth Life Comparison



Life is reduced 26% as a result of the spar web buckling.

Potential impacts:

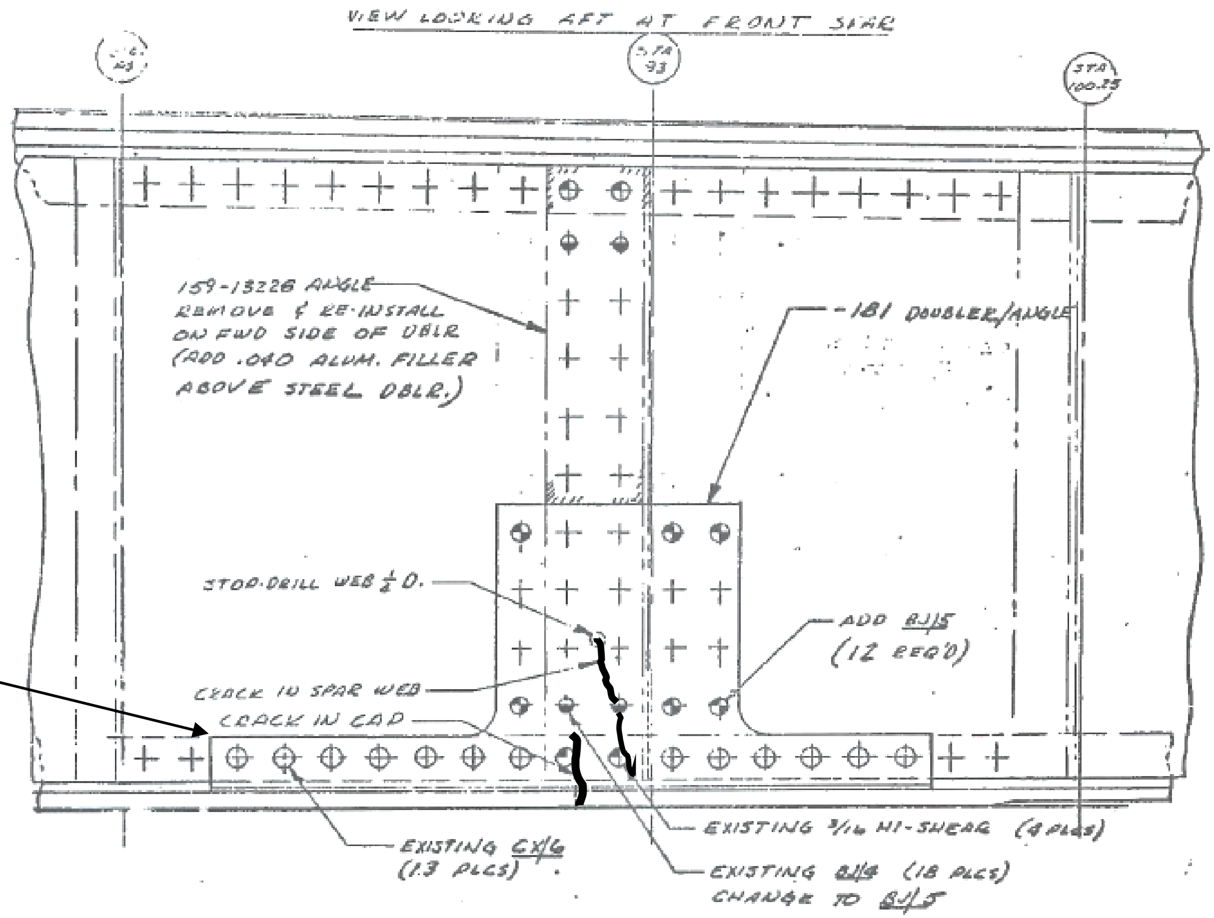
1. Need revised load history per flight segment to determine for which conditions panel buckles
2. Revise spectrum with actual percentage of buckling in missions.
3. Use a multi channel spectrum to account for bearing and axial out of phase.
4. Determine additional effects of buckling such as fastener loads in corners of spar web, bending stresses in web at flange attachment, etc.

Example 1 – Front Spar Cap & Web

T-28 Trainer Front Spar Cap and Web

Front Spar at WS93 cracked during the USAF T-28 Full Scale Fatigue Test at 12,900 hours.

Repair doubler applied to continue testing.



Ref. ADA018907, NR73H-35 T-28 Service Life Evaluation

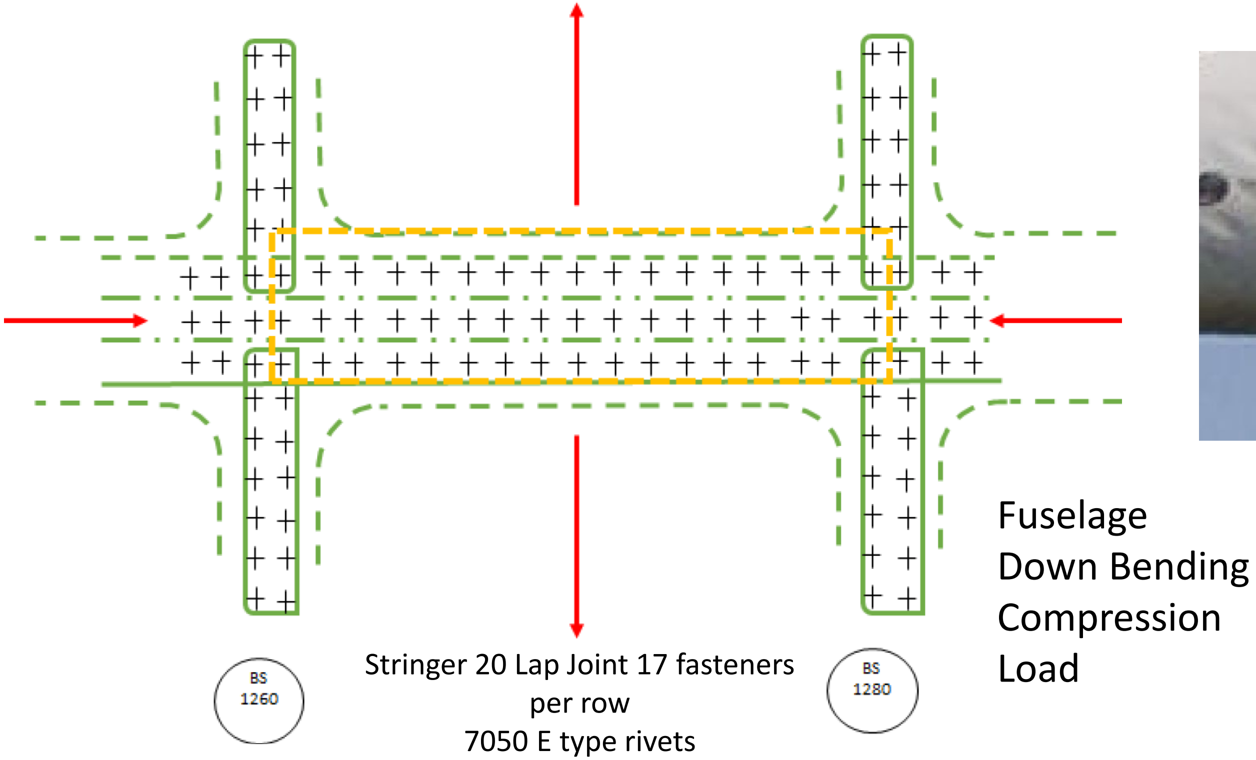
Example 1 – Front Spar Cap & Web

SUMMARY CONCLUSIONS:

1. Fully understand loading of structure --- Free Body Diagram
2. Does complex loading apply? Axial and Shear?
3. Determine if structure is impacted by buckling during spectra
4. Impact of buckling on load in other components, caps, fasteners, etc.
5. Determine other effects of buckling, ie secondary bending stress in webs, etc.
6. Does spectrum need to account for pre and post buckling?
7. At what percent of applied fatigue loads does structure buckle?
8. Is load history detailed enough to capture when buckling occurs?
9. Are loads out of phase? Axial due to wing bending, shear due to torsion?
10. Is a multi-channel spectrum needed?

Example 2 – Fuselage Lap Joint

Large Transport Aft Lower Fuselage Lap Joint

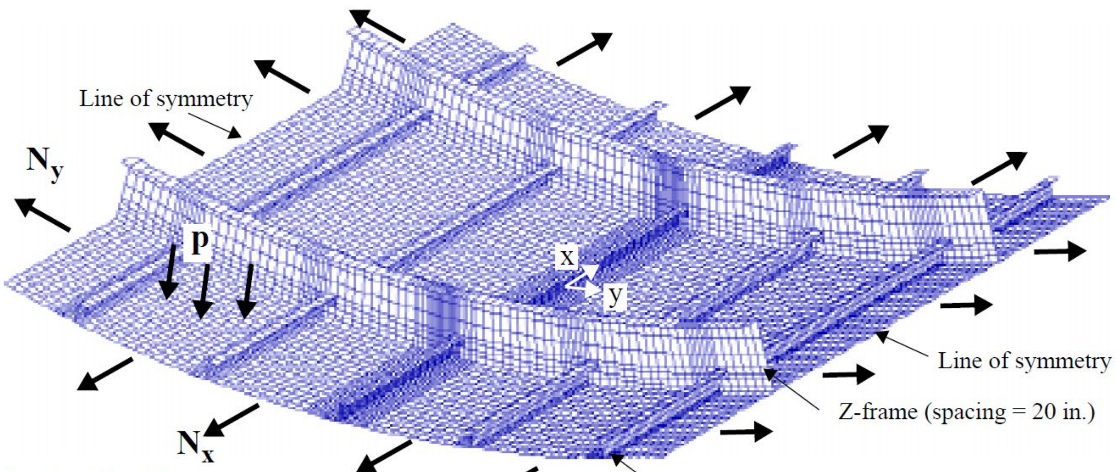


Aircraft Usage is around 1000 flight cycles / 2500 flight hours per year

- Example Problem 2A – Const Amplitude Press
- Example Problem 2B – Const Amplitude Press + Shear Flow
- Example Problem 2C – Const Amplitude Press + Shear Flow + Buckled Skin above 0.2g
- Example Problem 2D – Flight by Flight Multi Channel Spectra Buckled above 0.2g

Example 2 – Fuselage Lap Joint

Buckling can occur during both unpressurized and pressurized conditions:



Loading Condition
Internal pressure: p = 8 psi
Axial load: $N_x = \chi N_y$ (χ = -1.2 to +2)

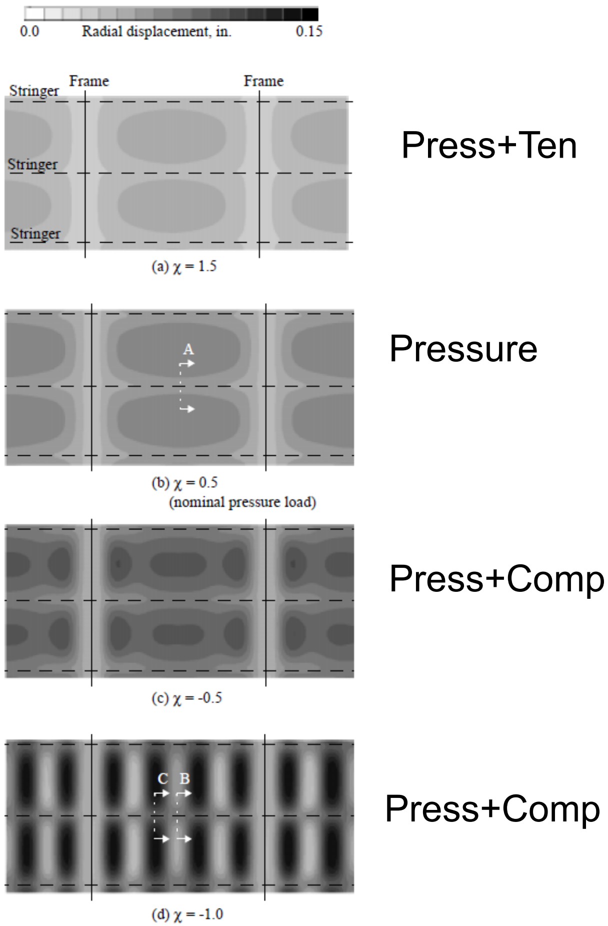


Figure 5. Fuselage-skin radial displacement for biaxial loading ratio values of χ = 1.5, 0.5, -0.5, and -1.0.

Ref: Skin, Stringer and Fastener Loads in Buckled Fuselage Panels by Young, Rose and Starnes, NASA Langley, AIAA-2001-1326

Example 2 – Fuselage Lap Joint

Assumptions for Example 2:

1. Example 2A: Assume skins are fully effective throughout all fatigue load cases and primary loading is only hoop pressure
    1. Fully effective bay width
    2. Fastener Load Transfer Only due to Hoop Pressure
2. Example 2B: Assume skins are fully effective throughout all fatigue load cases but include loading from hoop and shear flow fastener loads
    1. Fully effective bay width
    2. Biaxial fastener loads due to both hoop and shear flow
3. Example 2C: Assume skins are buckled and assume hoop pressure and shear flow loading
    1. Reduced effective skin width for loads due to buckling
    2. Biaxial fastener loads due to both hoop and shear flow
    3. Increased fastener shear loads due to buckling
4. Example 2D: Develop a flight by flight complex spectrum where hoop axial load and bearing due to shear are included with buckling assumed to occur for any fatigue loads above a delta Nz of 0.2g.

Example 2 – Fuselage Lap Joint

General Geometry Assumptions:

Frame Bay Width = 20 inches

Stringer Bay Pitch = 8 inches (7 degree spacing)

Skin Material = 2024-T3

Skin Thickness = 0.050 inches in chem milled pockets

Skin Thickness = 0.056 inches at pad ups

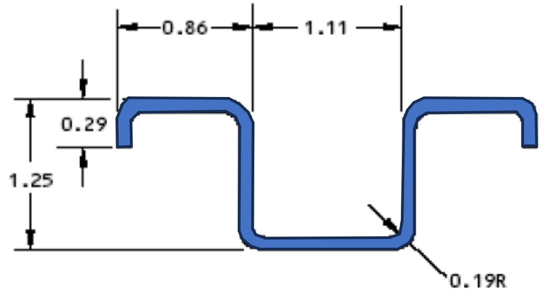
Frame Material = 7075-T6

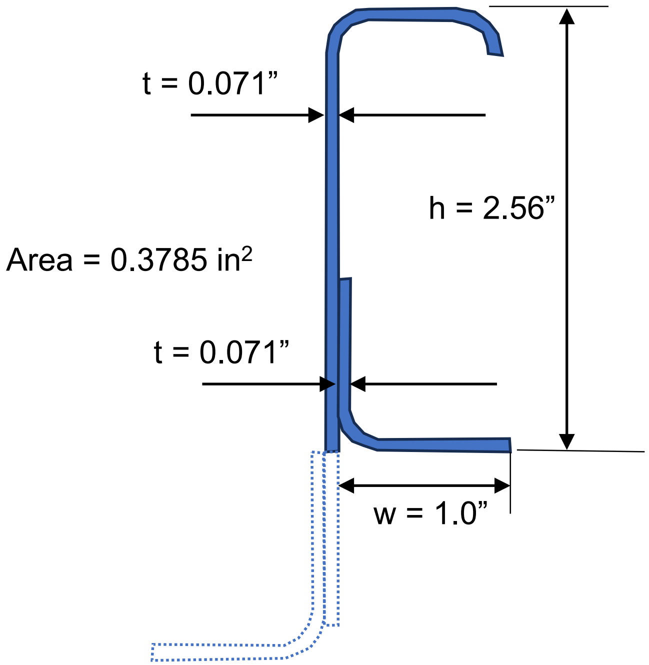
Frame Area = 0.392 inches^2 (plus skin pad up)

Stringer Material = 7075-T6

Stringer Thickness = 0.16 inches

Stringer Area = 0.543 inches^2





Example 2 – Fuselage Lap Joint

Stringer 20 Lap Joint Details:

Fastener Rows in Lap Joint = 3

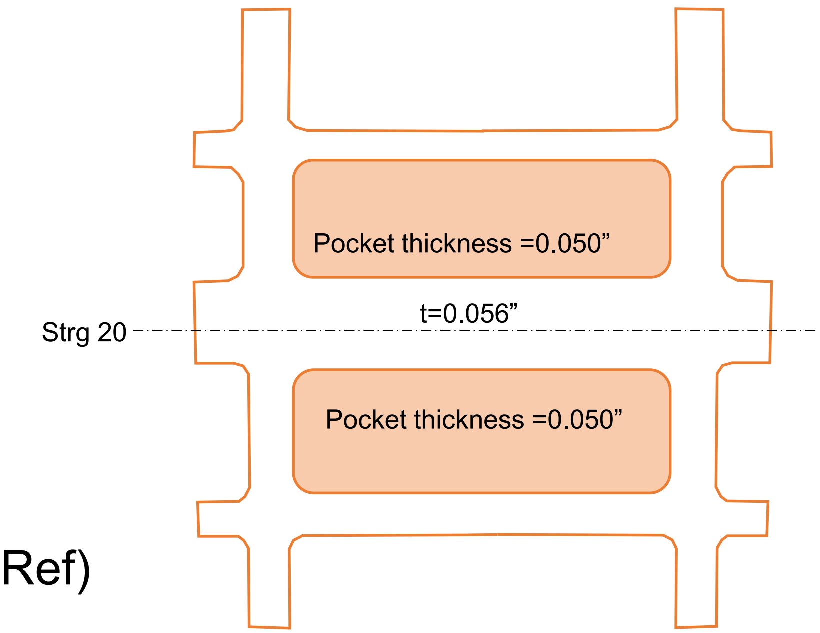
Fastener Types = 3/16” diameter rivet

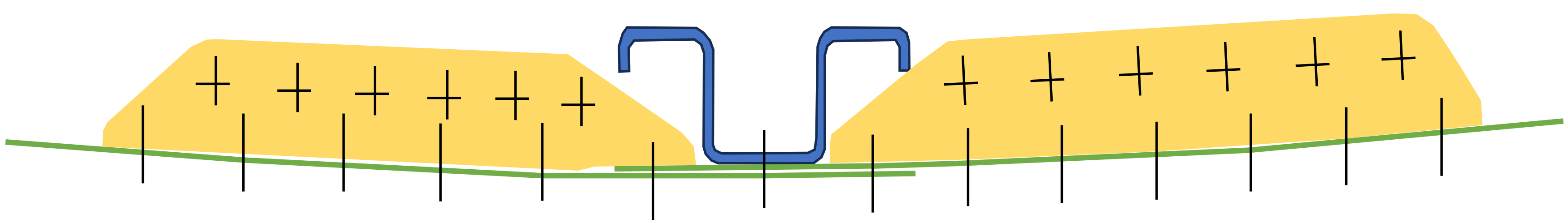
Fastener pitch = 1.25 inches

Lap joint width = 3.5 inches

Fuselage Internal Pressure = 8.6 psi

Hoop Fastener Load Transfer = 33.8% (see Ref)





Ref: Fawaz, S. A. (2000). Equivalent Initial Flaw Size Testing and Analysis, Air Force Research Laboratory.

Example 2 – Fuselage Lap Joint

Pressure stresses determined using Flugge NACA-TN-2612:

Pressurized Cabin Stress Analysis

NACA TN 2612 Stress Problems in Pressurized Cabins
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Input Values

Fuselage radius,	a = 74 in.
Cabin pressure,	p = 8.6 psi
Stringer area,	A_L = 0.543 in²
Stringer angular spacing,	δ = 7°
Frame area,	A_R = 0.392 in²
Frame spacing,	λ = 20 in.
Skin thickness,	t = 0.05 in.
Poisson Ratio,	ν = 0.33

Calculated Values

Longitudinal load per inch in shell: $N_x = \frac{1}{2}pa =$ 318.2 lb/in

Hoop load per inch in shell: $N_\phi = pa =$ 636.4 lb/in

Effective longitudinal thickness: $t_x = t + \frac{A_L}{a\delta} =$ 0.110 in.

Effective hoop thickness: $t_\phi = t + \frac{A_R}{\lambda} =$ 0.070 in.

Results

Hoop Stress: $\sigma_\phi = \frac{t_x N_\phi + \nu(t_\phi - t)N_x}{(1-\nu^2)t_\phi t_x + \nu^2 t(t_\phi + t_x - t)} =$ 9573 psi

Frame Stress: $\sigma_R = \frac{[(1-\nu^2)t_x + \nu^2 t]N_\phi - \nu t N_x}{(1-\nu^2)t_\phi t_x + \nu^2 t(t_\phi + t_x - t)} =$ 8050 psi

Longitudinal Stress: $\sigma_x = \frac{t_\phi N_x + \nu(t_x - t)N_\phi}{(1-\nu^2)t_\phi t_x + \nu^2 t(t_\phi + t_x - t)} =$ 4615 psi

Stringer Stress: $\sigma_L = \frac{[(1-\nu^2)t_\phi + \nu^2 t]N_x - \nu t N_\phi}{(1-\nu^2)t_\phi t_x + \nu^2 t(t_\phi + t_x - t)} =$ 1456 psi

Per FAA FAR 25.571 for pressure only, the residual strength hoop stress is as follows:

Residual Strength Pxx = 1.15*9.573 = 11 ksi

Example 2 – Fuselage Lap Joint

Do determine if panel buckles, a fuselage bending analysis is performed:

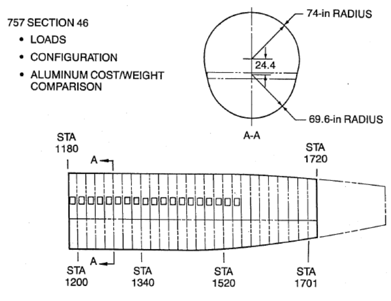


Figure 2.4-2. Commercial Transport Baseline Study Section

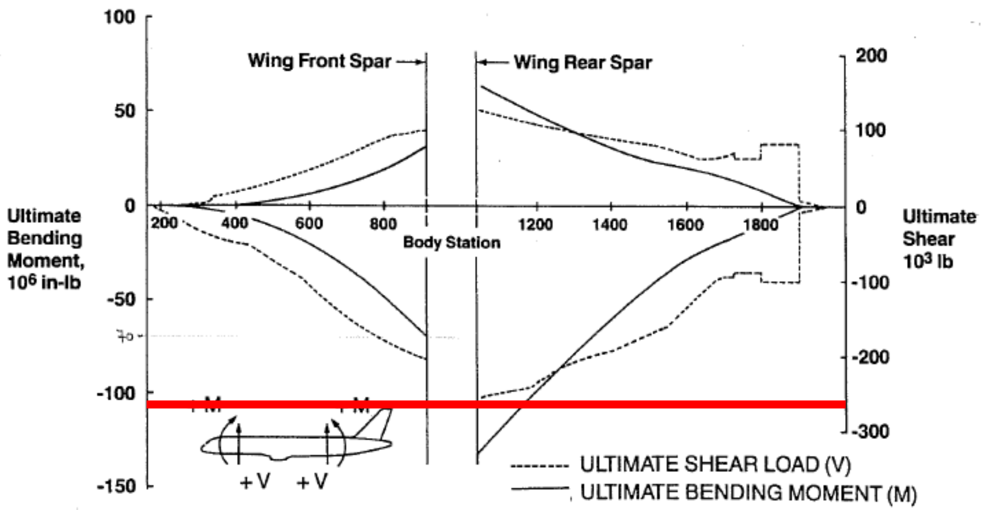


Figure 2.5-1. Ultimate Bending Moment and Shear Load Envelopes for Fuselage During Flight

Ultimate loads at station:

Vz = -285000 lbs

My = -118000000 inch-lbs

Limit loads at station:

Vz = -190,000 lbs

My = -78,667,000 inch-lbs

Ref: NASA-CR-172406 Study on Advanced Composite Fuselage Structure (757).

Example 2 – Fuselage Lap Joint

Limit load is applied to a classical internal loads model (see Ref):

100% OF LIMIT LOAD

V Z	M Y	V Y	M Z	TORSION	TOTAL EFF. A	TOTAL TEN. A	FACTOR PRESS.
LB.	IN.-KIP	LB.	IN.-KIP		SQ.IN.	SQ.IN.	
-190000.	-78667.	0.	0.	0.	52.084	61.011	1.000

K P	BAR Z	BAR Y	I Y	I Z	I ZY	DELTA V Z	DELTA V Y
PPI	IN.	IN.	IN.4TH	IN.4TH	IN.4TH	LB.	LB.
338.41	223.08	-0.00	199919.	134163.	-0.	0.	0.

STRINGERS ON THE RIGHT SIDE

STIFF. NO.	SKIN GAGE IN.	STIFF. AREA SQ.IN.	DELTA AREA SQ.IN.	EFF. AREA SQ.IN.	BAR DZ IN.	BAR DY IN.	F B PSI	P B LB.	Q TOTAL PPI	DELTA FC PSI	P PRESS LB.	DELTA FT PSI	F TOTAL PSI
100.00	0.050	0.603	0.150	1.232	83.42	0.00	32825.	40441.	49.	0.	3242.	2631.	35457.
200.00	0.050	0.603	0.000	1.083	82.80	9.56	32581.	35271.	134.	-130.	3246.	2998.	35579.
300.00	0.050	0.603	0.000	1.083	80.94	18.98	31849.	34485.	217.	-629.	3247.	2999.	34848.
400.00	0.050	0.603	0.000	1.083	77.89	28.07	30649.	33185.	297.	-1354.	3247.	2999.	33648.
500.00	0.045	0.603	0.000	1.059	73.68	36.70	28992.	30698.	372.	-2198.	3248.	3067.	32060.
600.00	0.045	0.603	0.000	1.034	68.39	44.70	26911.	27838.	439.	-3022.	3245.	3137.	30047.
700.00	0.045	0.603	0.000	1.025	62.12	51.95	24444.	25055.	499.	-3540.	3174.	3096.	27540.
800.00	0.045	0.603	0.000	1.016	55.29	58.07	21756.	22111.	553.	-3996.	3108.	3058.	24814.
900.00	0.045	0.603	0.000	1.017	47.73	63.31	18781.	19095.	599.	-4450.	3111.	3060.	21841.
1000.00	0.045	0.603	0.135	1.151	39.59	67.57	15578.	17931.	642.	-4279.	3106.	2699.	18277.
1100.00	0.080	0.311	0.000	0.881	31.00	70.78	12198.	10751.	668.	-3464.	3088.	3504.	15702.
1200.00	0.000	0.000	0.000	0.333	21.92	71.00	8625.	2874.	675.	-9159.	2819.	8460.	17085.
1300.00	0.080	0.311	0.000	0.616	14.88	73.80	5855.	3606.	684.	-4152.	2580.	4189.	10044.
1400.00	0.080	0.543	0.000	1.151	7.21	73.97	2837.	3266.	692.	-451.	2573.	2235.	5072.
1500.00	0.040	0.561	0.000	0.905	-0.30	73.36	-118.	-107.	691.	-3150.	2556.	2520.	-3269.
1600.00	0.040	0.543	0.000	0.629	-7.77	72.11	-3058.	-1922.	687.	-7319.	2530.	3005.	-10377.
1700.00	0.040	0.800	0.000	0.873	-14.98	70.53	-5895.	-5148.	674.	-8288.	3835.	3060.	-14183.
1800.00	0.040	0.677	0.000	0.736	-30.10	68.31	-11844.	-8721.	653.	-984[illegible].	3915.	3435.	-21689.
1900.00	0.040	0.543	0.000	0.602	-37.65	66.14	-14815.	-8912.	632.	-7416.	2659.	3102.	-22231.
2000.00	0.050	0.543	0.150	0.766	-44.91	63.13	-17672.	-13538.	599.	-5197.	2660.	2541.	-22869.
2100.00	0.050	0.543	0.000	0.628	-51.79	59.33	-20379.	-12792.	568.	-5544.	2660.	2842.	-25923.
2200.00	0.050	0.543	0.000	0.624	-58.20	54.78	-22902.	-14300.	534.	-5159.	2659.	2841.	-28061.
2300.00	0.050	0.543	0.000	0.622	-64.06	49.55	-25207.	-15675.	496.	-4718.	2658.	2841.	-29926.
2400.00	0.050	0.543	0.000	0.620	-69.29	43.69	-27265.	-16900.	455.	-4237.	2659.	2841.	-31503.
2500.00	0.050	0.677	0.000	0.753	-73.84	37.28	-29056.	-21884.	402.	-3002.	2660.	2486.	-32058.
2600.00	0.050	0.677	0.150	0.903	-77.64	30.40	-30551.	-27576.	336.	-1984.	2660.	2180.	-32535.
2700.00	0.040	0.677	0.000	0.737	-80.65	23.14	-31736.	-23391.	279.	-2114.	2659.	2580.	-33850.
2800.00	0.040	0.677	0.000	0.724	-82.82	15.59	-32589.	-23595.	222.	-1883.	2658.	2681.	-34472.
2900.00	0.040	2.000	0.000	2.048	-84.14	7.85	-33109.	-67800.	58.	-279.	2574.	1117.	-33387.
3000.00	0.040	0.677	0.000	0.725	-84.58	0.50	-33282.	-24124.	0.	0.	1415.	1676.	-33282.

Internal loads indicate that at 100% limit load there is considerable buckling. This is evidenced by the Delta Fc which is the additional compression the stringer must carry due to the reduced effective width of the skin.

Axial load at Stringer 20 is -13538 lbs and as a result the panel buckles. This adds additional compression in the stringers, -5.2 ksi worth.

Note that there is also skin shear flow of 599 lbs/inch present.

Ref: Fatigue Loads and Damage Tolerance Methods for Airworthiness, by Burd, 2024 ASIP Conference, Austin, Tx.
Ref. Advanced Spectrum and DTA Applications Course, Burd and Fawaz, 2025
Ref. Analysis & Design of Flight Vehicle Structures", by E.F. Bruhn, 1973
Ref. Progress Report on Methods of Analysis Applicable to Monocoque Aircraft Structures, by J.S. Newell and J.H. Harrington, Air Corps Information Circular No. 713, May 15, 1939.

Example 2 – Fuselage Lap Joint

60% of Limit load is also applied to determine if buckling under fatigue loading:

60% OF LIMIT LOAD

V Z LB.	M Y IN.-KIP	V Y LB.	M Z IN.-KIP	TORSION	TOTAL EFF. A SQ.IN.	TOTAL TEN. A SQ.IN.	FACTOR PRESS.
-114000.	-47200.	0.	0.	0.	52.983	61.011	1.000

K P PPI	BAR Z IN.	BAR Y IN.	I Y IN.4TH	I Z IN.4TH	I ZY IN.4TH	DELTA V Z LB.	DELTA V Y LB.
338.41	222.38	0.00	202330.	137197.	0.	0.	0.

STRINGERS ON THE RIGHT SIDE

STIFF. NO.	SKIN GAGE IN.	STIFF. AREA SQ.IN.	DELTA AREA SQ.IN.	EFF. AREA SQ.IN.	BAR DZ IN.	BAR DY IN.	F B PSI	P B LB.	Q TOTAL PPI	DELTA FC PSI	P PRESS LB.	DELTA FT PSI	F TOTAL PSI
100.00	0.050	0.603	0.150	1.232	84.12	-0.00	19624.	24176.	29.	0.	3242.	2631.	22255.
200.00	0.050	0.603	0.000	1.083	83.50	9.56	19479.	21087.	80.	0.	3246.	2998.	22477.
300.00	0.050	0.603	0.000	1.083	81.64	18.98	19045.	20621.	130.	-112.	3247.	2999.	22044.
400.00	0.050	0.603	0.000	1.083	78.59	28.07	18334.	19851.	178.	-437.	3247.	2999.	21332.
500.00	0.045	0.603	0.000	1.059	74.38	36.70	17351.	18372.	222.	-979.	3248.	3067.	20418.
600.00	0.045	0.603	0.000	1.034	69.09	44.70	16117.	16673.	263.	-1512.	3245.	3137.	19254.
700.00	0.045	0.603	0.000	1.025	62.82	51.95	14655.	15021.	299.	-1818.	3174.	3096.	17751.
800.00	0.045	0.603	0.000	1.016	55.99	58.07	13061.	13274.	331.	-2087.	3108.	3058.	16120.
900.00	0.045	0.603	0.000	1.017	48.43	63.31	11298.	11486.	359.	-2360.	3111.	3060.	14358.
1000.00	0.045	0.603	0.135	1.151	40.29	67.57	9399.	10818.	385.	-2295.	3106.	2699.	12097.
1100.00	0.080	0.311	0.000	0.881	31.70	70.78	7395.	6518.	400.	-1564.	3088.	3504.	10899.
1200.00	0.000	0.000	0.000	0.333	22.62	71.00	5277.	1758.	405.	-4602.	2819.	8460.	13737.
1300.00	0.080	0.311	0.000	0.616	15.58	73.80	3634.	2239.	410.	-2489.	2580.	4189.	7823.
1400.00	0.080	0.543	0.000	1.151	7.91	73.97	1845.	2124.	415.	0.	2573.	2235.	4080.
1500.00	0.040	0.561	0.000	1.014	0.40	73.36	93.	95.	415.	-1268.	2556.	2520.	2614.
1600.00	0.040	0.543	0.000	0.661	-7.07	72.11	-1649.	-1090.	413.	-3853.	2530.	3005.	-5502.
1700.00	0.040	0.800	0.000	0.898	-14.28	70.53	-3331.	-2991.	406.	-4649.	3835.	3060.	-7981.
1800.00	0.040	0.677	0.000	0.755	-29.40	68.31	-6859.	-5181.	393.	-5524.	3915.	3435.	-12383.
1900.00	0.040	0.543	0.000	0.621	-36.95	66.14	-8620.	-5352.	380.	-3947.	2659.	3102.	-12567.
2000.00	0.050	0.543	0.150	0.790	-44.21	63.13	-10314.	-8150.	361.	-2600.	2660.	2541.	-12914.
2100.00	0.050	0.543	0.000	0.657	-51.09	59.33	-11918.	-7825.	342.	-2516.	2660.	2842.	-14434.
2200.00	0.050	0.543	0.000	0.652	-57.50	54.78	-13414.	-8744.	320.	-2292.	2659.	2841.	-15705.
2300.00	0.050	0.543	0.000	0.648	-63.36	49.55	-14781.	-9581.	297.	-2033.	2658.	2841.	-16813.
2400.00	0.050	0.543	0.000	0.645	-68.59	43.69	-16001.	-10327.	272.	-1751.	2659.	2841.	-17751.
2500.00	0.050	0.677	0.000	0.778	-73.14	37.28	-17062.	-13275.	240.	-1167.	2660.	2486.	-18229.
2600.00	0.050	0.677	0.150	0.927	-76.94	30.40	-17949.	-16638.	200.	-673.	2660.	2180.	-18621.
2700.00	0.040	0.677	0.000	0.756	-79.95	23.14	-18651.	-14105.	166.	-771.	2659.	2580.	-19422.
2800.00	0.040	0.677	0.000	0.739	-82.12	15.59	-19157.	-14154.	132.	-766.	2658.	2681.	-19923.
2900.00	0.040	2.000	0.000	2.062	-83.44	7.85	-19465.	-40145.	35.	-105.	2574.	1117.	-19570.
3000.00	0.040	0.677	0.000	0.739	-83.88	0.50	-19568.	-14469.	0.	0.	1415.	1676.	-19568.

60% is an approximate 1.5G condition if we consider limit load to be a 2.5G condition.

As can be seen, at 1.5G the amount of added compression is lower but this indicates the effective width of the panel is still reduced.

Note also that there is still shear flow in the panel of 361 lbs/inch.

So, the effective width of panel due to buckling needs to be considered.

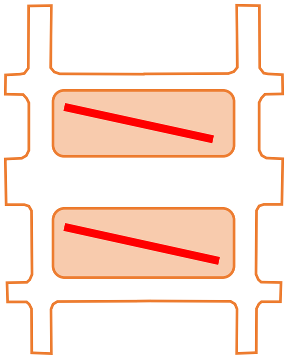
Ref: Fatigue Loads and Damage Tolerance Methods for Airworthiness, by Burd, 2024 ASIP Conference, Austin, Tx.
Ref. Advanced Spectrum and DTA Applications Course, Burd and Fawaz, 2025
Ref. Analysis & Design of Flight Vehicle Structures", by E.F. Bruhn, 1973
Ref. Progress Report on Methods of Analysis Applicable to Monocoque Aircraft Structures, by J.S. Newell and J.H. Harrington, Air Corps Information Circular No. 713, May 15, 1939.

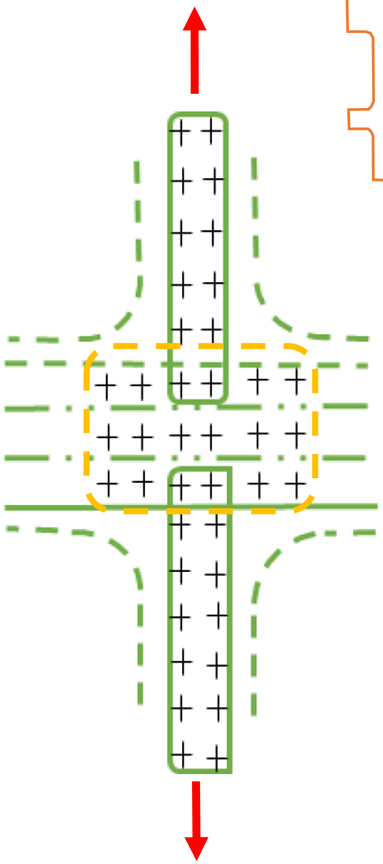
Example 2 – Fuselage Lap Joint

When the panel buckles, properties are reduced:

Assume panel buckles during fatigue loading
Assume panel becomes ineffective for tension loads

Hoop direction: only pad-up is effective in corner:





Effective Hoop Loading Width = 8.75 inches
Thickness of skin = 0.056 inches
Area = 8.75*0.056 = 0.49 in^2
Area of Frame = 0.3785 in^2
Total Area = 0.8685 in^2
Hoop running load = 636.4 lbs/inch
Bay width = 20 inches
Hoop load = 636.4*20 = 12728 lbs
Hoop stress = 12728/0.8685 = 14.655 ksi
Residual strength = 14.655*1.15 = 16.853 ksi

Example 2 – Fuselage Lap Joint

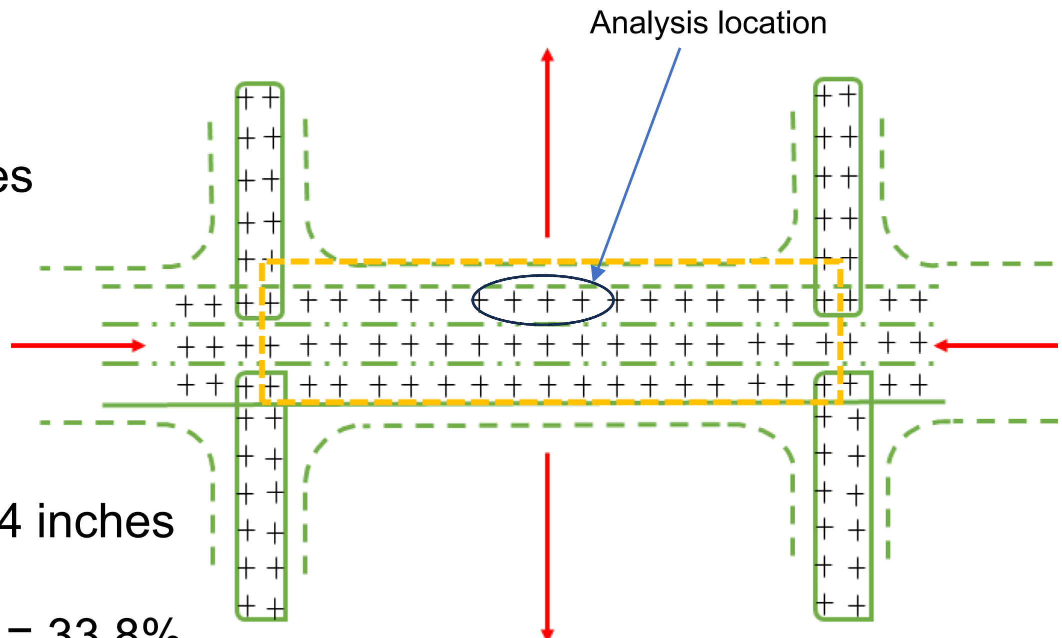
Example 2A - Pressure Only Analysis:

Assumed width = 20 inches
Thickness = 0.056 inches
Fastener diameter = 0.1875 inches
Pitch = 1.25 inches

Spectrum stress = 9.573 ksi
Residual strength = 11 ksi

8.6 psi Hoop load per inch = 636.4 inches
Bay width = 20 inches
Fastener load transfer in first row = 33.8%
Number of fasteners in first row = 17
Fastener load = (636.4*20*0.338)/17 = 253 lbs
Brg stress = 253/(0.1875*0.056) = 24.095 ksi
Bypass load = 636.4*20*(1-.338) = 8426 lbs
Bypass stress = 8426/(20*.056) = 7.523 ksi

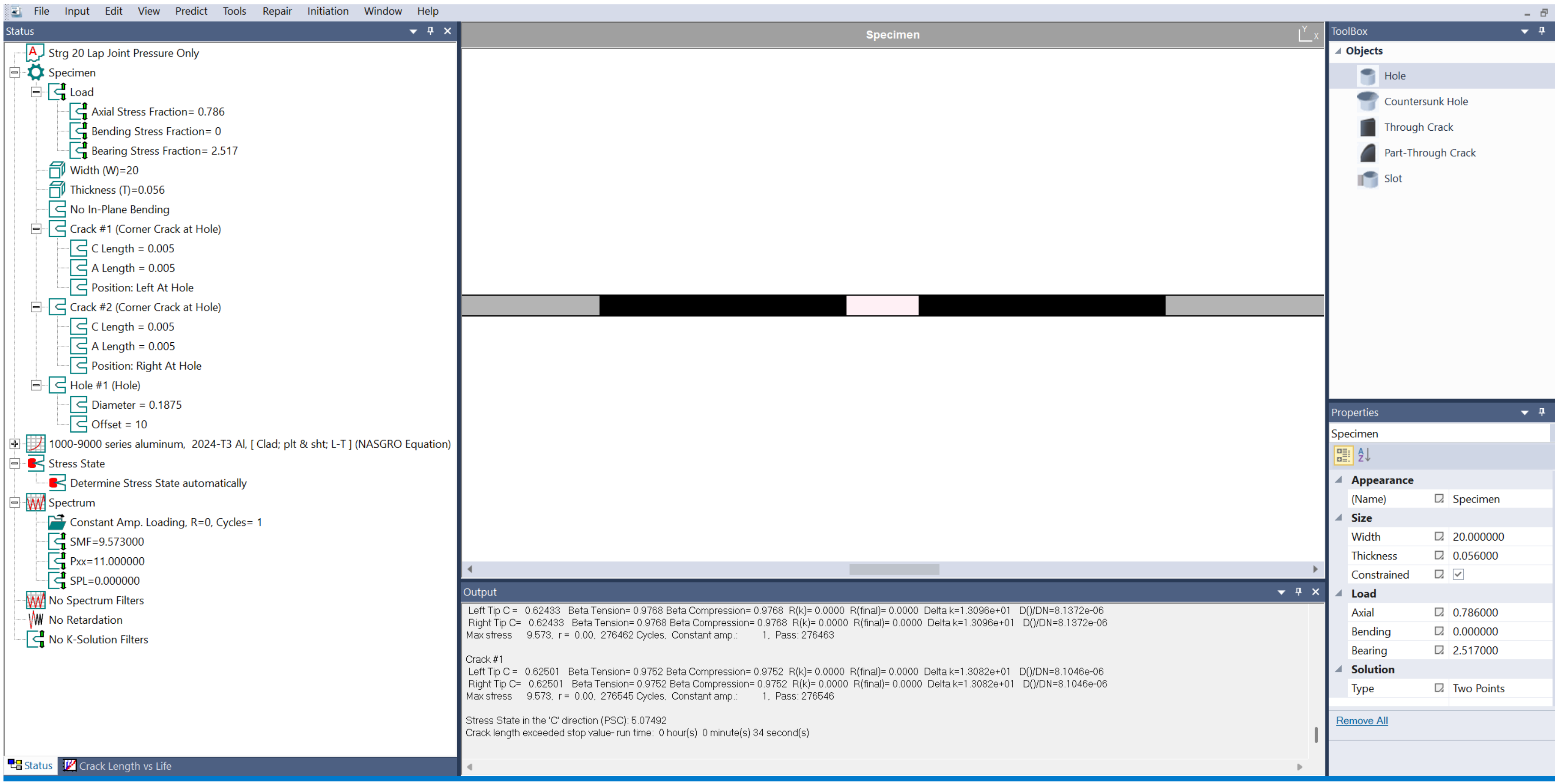
Pressure Only Spectrum



Bypass/Ref = 7.523/9.573
Bypass/Ref = 0.786
Brg/Ref = 24.095/9.573
Brg/Ref =2.517

Example 2 – Fuselage Lap Joint

Assumptions: Two 0.005” Corner Flaws, Nasgro 2024-T3 L-T, Advanced Model



Growth limited to half of fastener pitch: N = 276,546 flight cycles / 276,546 flight hours

Example 2 – Fuselage Lap Joint

Example 2B: Press + Shear Flow – No Buckling:

Geometry remains the same

Spectrum stress = 9.573 ksi
Residual strength = 11 ksi

8.6 psi Hoop load per inch = 636.4 inches
Bay width = 20 inches
Fastener load transfer in first row = 33.8%
Number of fasteners in first row = 17
Hoop Fastener load = (636.4*20*0.338)/17 = 253 lbs
Limit Load Shear Flow = 599 lbs/inch
Effective rows in shear = 3
Fastener load = 599*20/(17*3) = 235 lbs
Brg stress = $\sqrt{(253^2+235^2)}/(0.1875*0.056)$ = 32.886 ksi

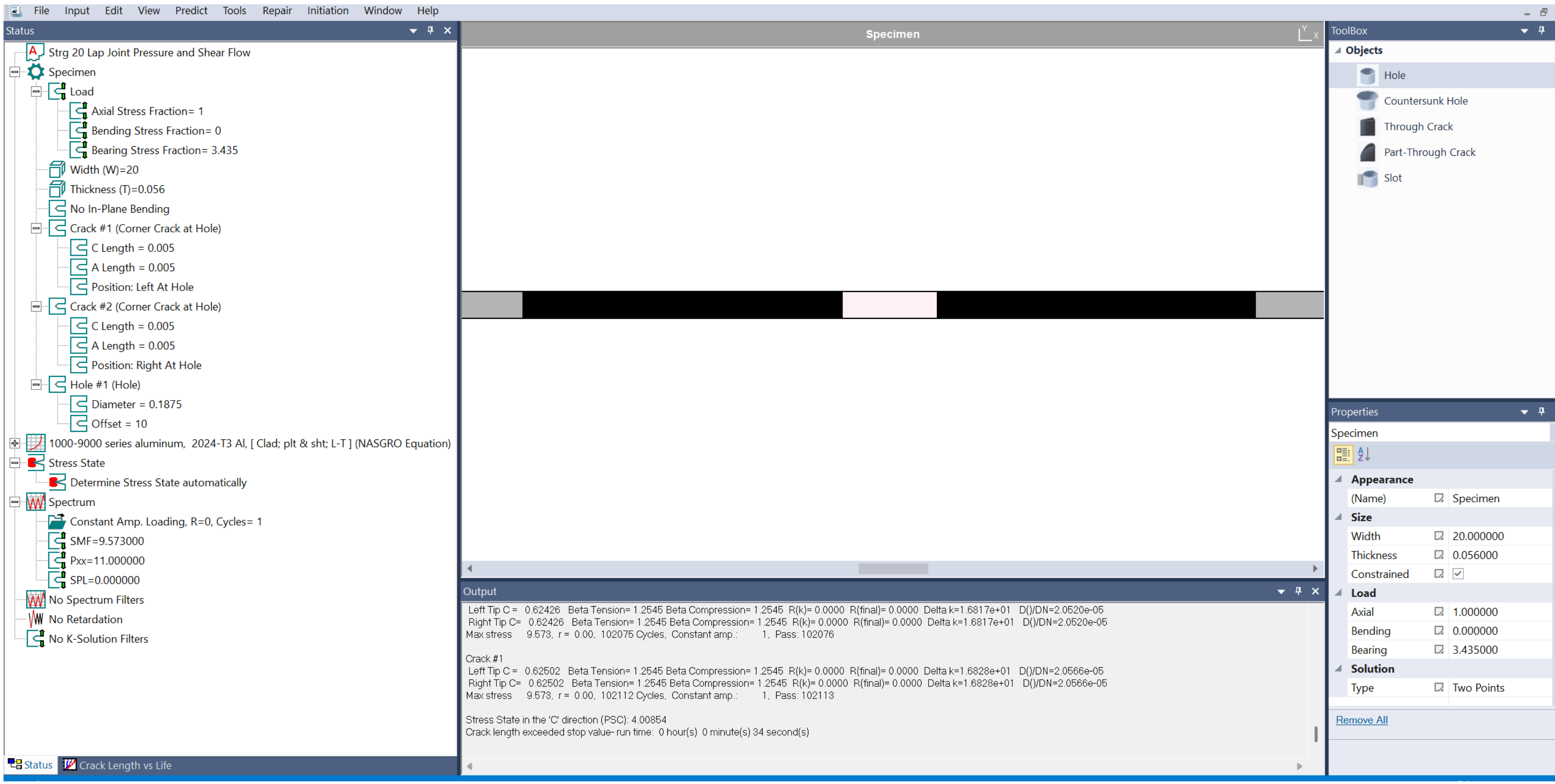
Note: Bypass stress is set to 1 since fastener load includes shear flow now

Pressure + Shear Flow Spectrum

Bypass/Ref = 1.0
Brg/Ref =3.435

Example 2 – Fuselage Lap Joint

Assumptions: Two 0.005" Corner Flaws, Nasgro 2024-T3 L-T, Advanced Model



Life limited to half of pitch to adj fastener: N = 102,113 flight cycles / 102,113 flight hours

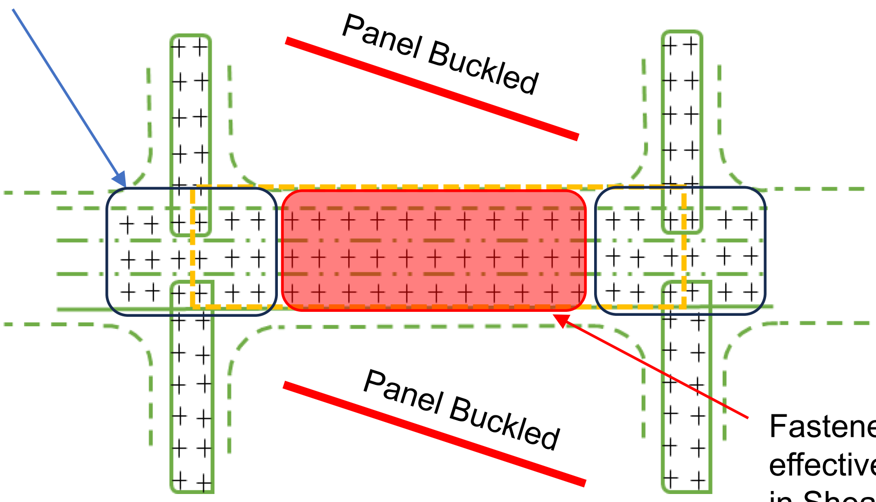
Example 2 – Fuselage Lap Joint

Example 2C: Press + Shear Flow with Buckled Skin:

Constant Pressure +
Shear Flow
Buckled Panel

Panel buckling occurs in the thin pocketed section of skin
Only remaining effective skin is at frame locations at corners with a loading width limited to 8.75”

Analysis location



Fasteners effective only in Shear

Stress = 14.655 ksi
Residual Strength = 16.853 ksi

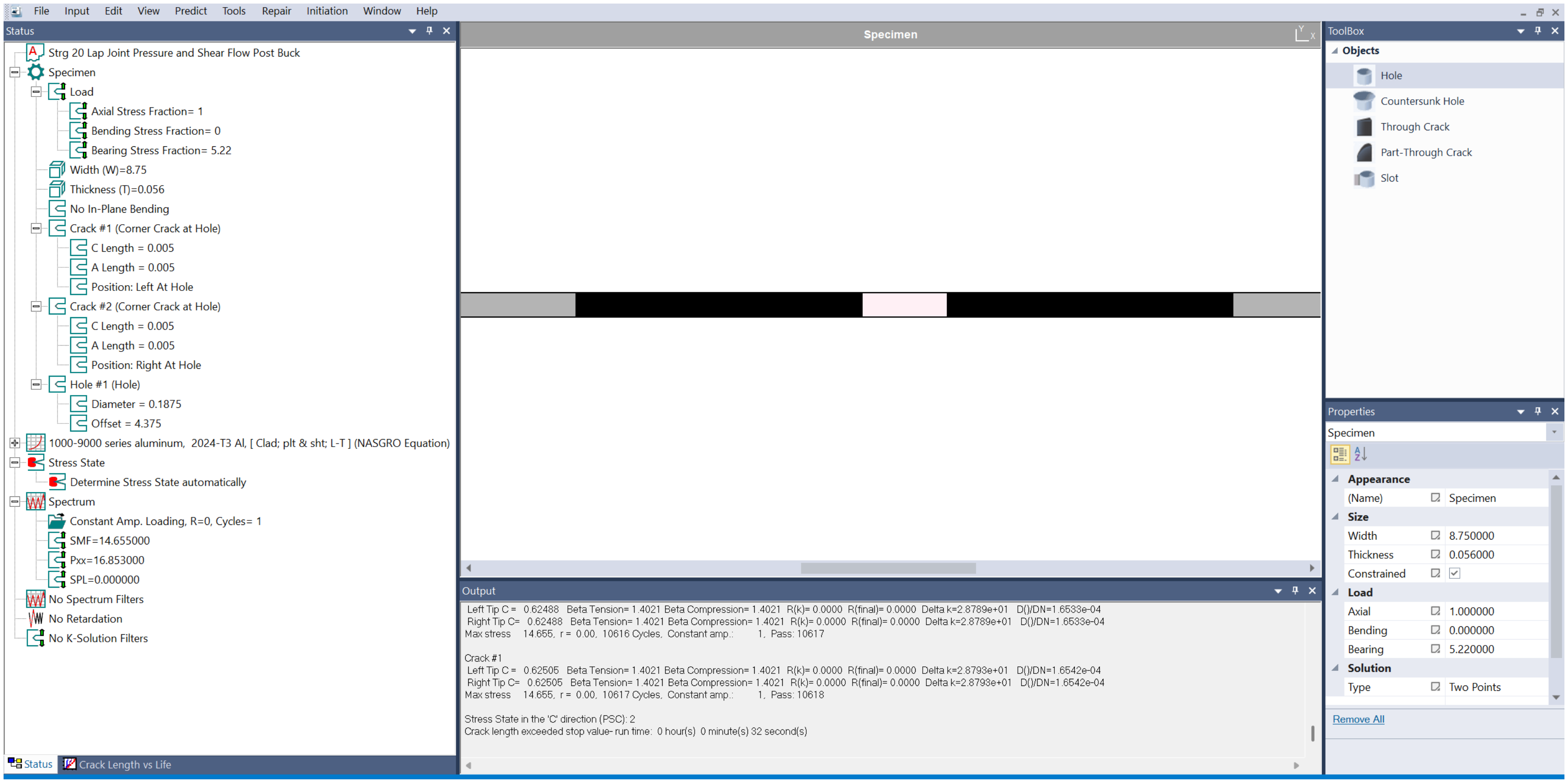
8.6 psi Hoop loading:
Fasteners per row = 6
Rows effective = 3
Total fasteners = 18
Fastener load = (636.4*20*.338)/6
Fastener load = 717 lbs

Shear flow fastener load = 361 lbs
Total fastener load = $\sqrt{(717^2+361^2)}$ = 803 lbs
Bearing stress = 803/(0.1875*0.056) = 76.453 ksi

Bypass/Ref = 1.0
Brg/Ref = 5.22

Example 2 – Fuselage Lap Joint

Assumptions: Two 0.005” Corner Flaws, Nasgro 2024-T3 L-T, Advanced Model

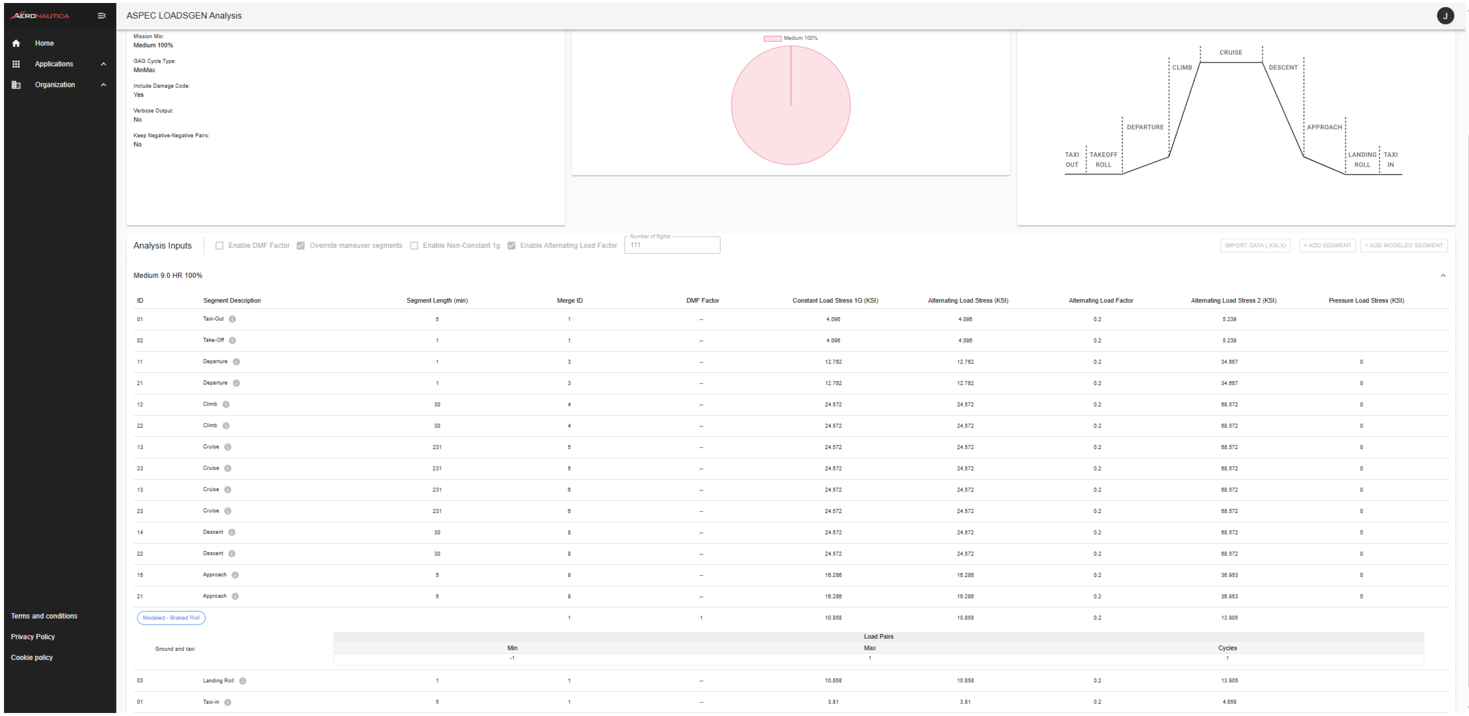


Life limited to half of pitch to adj fastener: N = 10,618 flight cycles / 10,618 flight hours

Example 2 – Fuselage Lap Joint

Example 2D: Flight by Flight Multi Channel Spectrum with Buckling:

To develop the spectrum, the fatigue loads are generated for a standard Medium Mission using Aspec for each of the flight segments using the previous cited internal loads methods. The primary flight loading is the bearing stress due to the shear flow while the axial loading is due to hoop pressure.

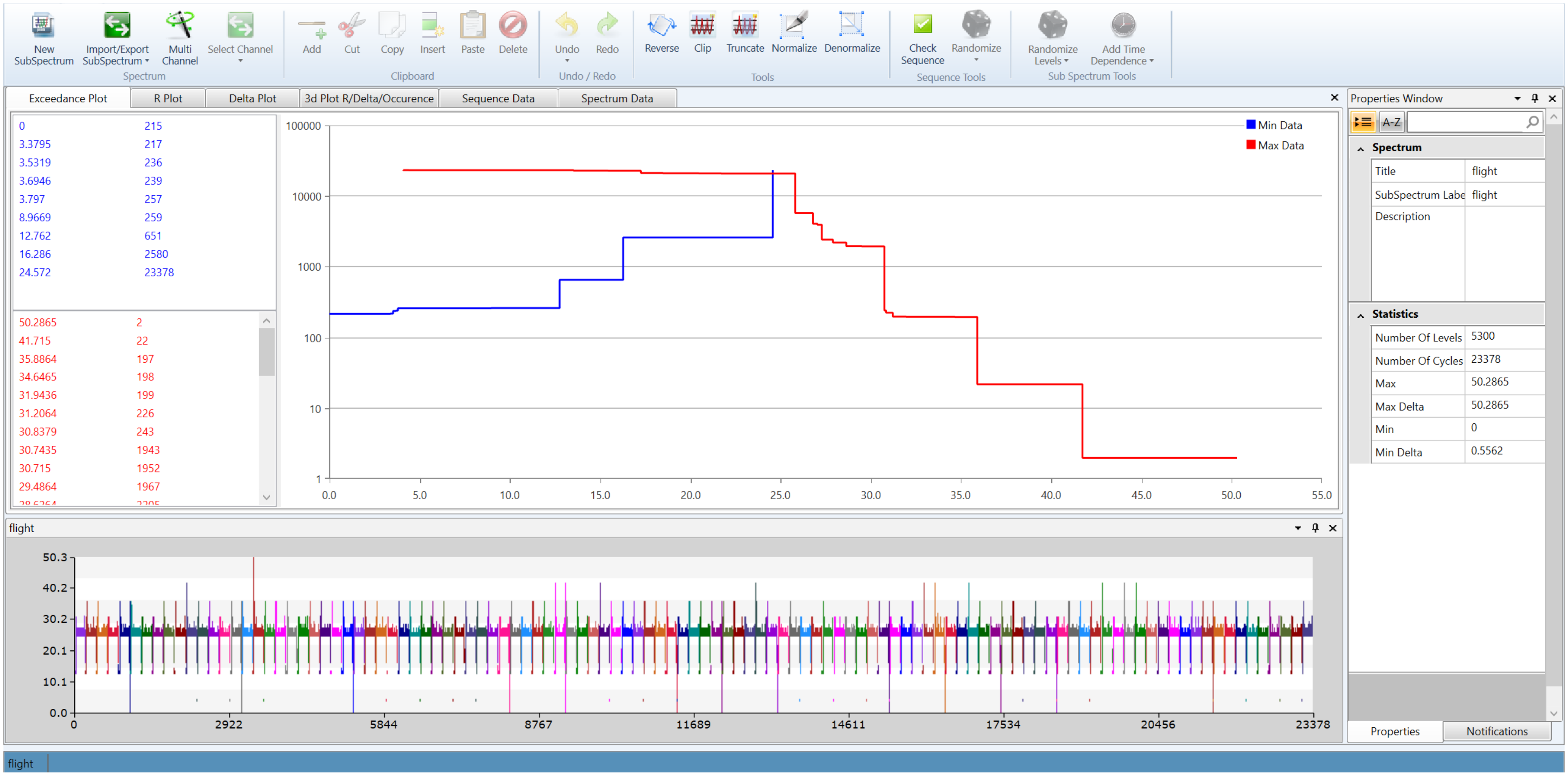


ID	Segment Description	Segment Length (min)	Merge ID	DMF Factor	Constant Load Stress 1G (KSI)	Alternating Load Stress (KSI)	Alternating Load Factor	Alternating Load Stress 2 (KSI)	Pressure Load Stress (KSI)
01	Taxi-Out	5	1	--	4.096	4.096	0.2	5.239	
02	Take-Off	1	1	--	4.096	4.096	0.2	5.239	
11	Departure	1	3	--	12.762	12.762	0.2	34.667	0
21	Departure	1	3	--	12.762	12.762	0.2	34.667	0
12	Climb	30	4	--	24.572	24.572	0.2	68.572	0
22	Climb	30	4	--	24.572	24.572	0.2	68.572	0
13	Cruise	231	5	--	24.572	24.572	0.2	68.572	0
23	Cruise	231	5	--	24.572	24.572	0.2	68.572	0
13	Cruise	231	6	--	24.572	24.572	0.2	68.572	0
23	Cruise	231	6	--	24.572	24.572	0.2	68.572	0
14	Descent	30	8	--	24.572	24.572	0.2	68.572	0
22	Descent	30	8	--	24.572	24.572	0.2	68.572	0
15	Approach	5	9	--	16.286	16.286	0.2	36.953	0
21	Approach	5	9	--	16.286	16.286	0.2	36.953	0
Modeled - Braked Roll			1	1	10.858	10.858	0.2	13.905	
03	Landing Roll	1	1	--	10.858	10.858	0.2	13.905	
01	Taxi-in	5	1	--	3.81	3.81	0.2	4.858	

Ground and taxi	Load Pairs		
	Min	Max	Cycles
	-1	1	1

Example 2 – Fuselage Lap Joint

Max spectrum bearing stress due to shear flow is 50.286 ksi. Spectrum consists of 1000 flight hours / 111 flight cycles



Example 2 – Fuselage Lap Joint

A multi channel spectrum was then generated combining axial pressure stresses for both conditions when panel is buckled and not buckled which is assumed to occur above and below a delta Nz of 0.2g in the spectrum.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W
1	delta Nz > 0.2g Buckled Results						Skin Not Buckled Results						Inertia Load Factors							Max Pressure Unbuckled	Max Pressure Buckled	Min Press	
2	13.528	12.762	3	1021	flight 1		13.528	12.762	3	1021	flight 1		1.06	1	3	1021	flight 1	LINEAR		4.787	4.787	4.787	
3	30.744	24.572	4	1022	flight 1		26.784	24.572	4	1022	flight 1		1.09	1	4	1022	flight 1	LINEAR		9.573	9.573	9.573	
4	27.889	24.572	1	1012	flight 1		27.889	24.572	1	1012	flight 1		1.135	1	1	1012	flight 1	LINEAR		9.573	9.573	9.573	
5	30.744	24.572	12	1022	flight 1		26.784	24.572	12	1022	flight 1		1.09	1	12	1022	flight 1	LINEAR		9.573	9.573	9.573	
6	25.801	24.572	14	1023	flight 1		25.801	24.572	14	1023	flight 1		1.05	1	14	1023	flight 1	LINEAR		9.573	9.573	9.573	
7	27.275	24.572	1	1023	flight 1		27.275	24.572	1	1023	flight 1		1.11	1	1	1023	flight 1	LINEAR		9.573	9.573	9.573	
8	25.801	24.572	22	1023	flight 1		25.801	24.572	22	1023	flight 1		1.05	1	22	1023	flight 1	LINEAR		9.573	9.573	9.573	
9	27.275	24.572	1	1023	flight 1		27.275	24.572	1	1023	flight 1		1.11	1	1	1023	flight 1	LINEAR		9.573	9.573	9.573	
10	25.801	24.572	9	1023	flight 1		25.801	24.572	9	1023	flight 1		1.05	1	9	1023	flight 1	LINEAR		9.573	9.573	9.573	
76	17.263	16.286	8	1021	flight 2		17.263	16.286	8	1021	flight 2		1.06	1	8	1021	flight 2	LINEAR		4.787	4.787	4.787	
77	20.462	16.286	1	1015	flight 2		18.126	16.286	1	1015	flight 2		1.113	1	1	1015	flight 2	LINEAR		4.787	4.787	4.787	
78	17.263	16.286	7	1021	flight 2		17.263	16.286	7	1021	flight 2		1.06	1	7	1021	flight 2	LINEAR		4.787	4.787	4.787	
79	35.886	0	1	1100	flight 2		30.838	0	1	1100	flight 2		1.255	0	1	1100	flight 2	BUCKLED		9.573	14.656	0	
80	13.528	12.762	1	1021	flight 3		13.528	12.762	1	1021	flight 3		1.06	1	1	1021	flight 3	LINEAR		4.787	4.787	4.787	
81	14.485	12.762	1	1021	flight 3		14.485	12.762	1	1021	flight 3		1.135	1	1	1021	flight 3	LINEAR		4.787	4.787	4.787	
82	13.528	12.762	1	1021	flight 3		13.528	12.762	1	1021	flight 3		1.06	1	1	1021	flight 3	LINEAR		4.787	4.787	4.787	
83	27.889	24.572	1	1012	flight 3		27.889	24.572	1	1012	flight 3		1.135	1	1	1012	flight 3	LINEAR		9.573	9.573	9.573	
84	30.744	24.572	8	1022	flight 3		26.784	24.572	8	1022	flight 3		1.09	1	8	1022	flight 3	LINEAR		9.573	9.573	9.573	
85	35.886	24.572	1	1022	flight 3		28.626	24.572	1	1022	flight 3		1.165	1	1	1022	flight 3	BUCKLED		9.573	14.656	14.65626	
86	30.744	24.572	7	1022	flight 3		26.784	24.572	7	1022	flight 3		1.09	1	7	1022	flight 3	LINEAR		9.573	9.573	9.573	
87	25.801	24.572	11	1023	flight 3		25.801	24.572	11	1023	flight 3		1.05	1	11	1023	flight 3	LINEAR		9.573	9.573	9.573	
88	27.275	24.572	2	1023	flight 3		27.275	24.572	2	1023	flight 3		1.11	1	2	1023	flight 3	LINEAR		9.573	9.573	9.573	
89	25.801	24.572	47	1023	flight 3		25.801	24.572	47	1023	flight 3		1.05	1	47	1023	flight 3	LINEAR		9.573	9.573	9.573	
90	27.275	24.572	1	1023	flight 3		27.275	24.572	1	1023	flight 3		1.11	1	1	1023	flight 3	LINEAR		9.573	9.573	9.573	
91	25.801	24.572	6	1023	flight 3		25.801	24.572	6	1023	flight 3		1.05	1	6	1023	flight 3	LINEAR		9.573	9.573	9.573	
92	27.275	24.572	1	1023	flight 3		27.275	24.572	1	1023	flight 3		1.11	1	1	1023	flight 3	LINEAR		9.573	9.573	9.573	
93	27.029	24.572	1	1013	flight 3		27.029	24.572	1	1013	flight 3		1.1	1	1	1013	flight 3	LINEAR		9.573	9.573	9.573	
94	25.801	24.572	16	1023	flight 3		25.801	24.572	16	1023	flight 3		1.05	1	16	1023	flight 3	LINEAR		9.573	9.573	9.573	
95	27.275	24.572	1	1023	flight 3		27.275	24.572	1	1023	flight 3		1.11	1	1	1023	flight 3	LINEAR		9.573	9.573	9.573	
96	25.801	24.572	5	1023	flight 3		25.801	24.572	5	1023	flight 3		1.05	1	5	1023	flight 3	LINEAR		9.573	9.573	9.573	
97	27.275	24.572	1	1023	flight 3		27.275	24.572	1	1023	flight 3		1.11	1	1	1023	flight 3	LINEAR		9.573	9.573	9.573	
98	25.801	24.572	2	1023	flight 3		25.801	24.572	2	1023	flight 3		1.05	1	2	1023	flight 3	LINEAR		9.573	9.573	9.573	
99	28.626	24.572	1	1023	flight 3		28.626	24.572	1	1023	flight 3		1.165	1	1	1023	flight 3	BUCKLED		9.573	14.656	14.65626	
100	25.801	24.572	25	1023	flight 3		25.801	24.572	25	1023	flight 3		1.05	1	25	1023	flight 3	LINEAR		9.573	9.573	9.573	
101	27.275	24.572	1	1023	flight 3		27.275	24.572	1	1023	flight 3		1.11	1	1	1023	flight 3	LINEAR		9.573	9.573	9.573	
102	25.801	24.572	1	1023	flight 3		25.801	24.572	1	1023	flight 3		1.05	1	1	1023	flight 3	LINEAR		9.573	9.573	9.573	
103	28.626	24.572	1	1023	flight 3		28.626	24.572	1	1023	flight 3		1.165	1	1	1023	flight 3	BUCKLED		9.573	14.656	14.65626	
104	25.801	24.572	7	1023	flight 3		25.801	24.572	7	1023	flight 3		1.05	1	7	1023	flight 3	LINEAR		9.573	9.573	9.573	
105	27.275	24.572	1	1023	flight 3		27.275	24.572	1	1023	flight 3		1.11	1	1	1023	flight 3	LINEAR		9.573	9.573	9.573	
106	25.801	24.572	21	1023	flight 3		25.801	24.572	21	1023	flight 3		1.05	1	21	1023	flight 3	LINEAR		9.573	9.573	9.573	

Example 2 – Fuselage Lap Joint

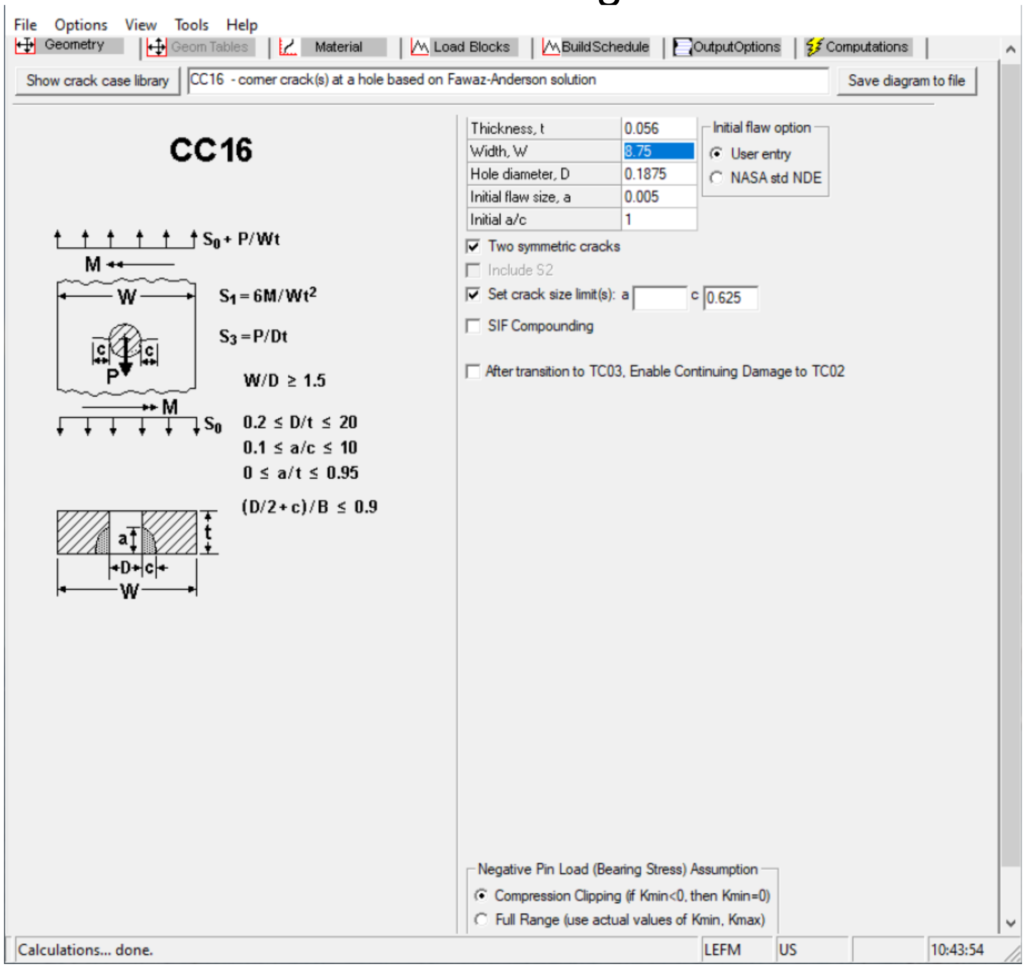
This resulted in a multi channel spectrum with axial hoop pressure stress and bearing due to shear flow for both linear and buckled panel configurations which could be used in Nasgro.

	A	B	C	D	E	F	G	H	I	J	K
1	Hoop Press and Fast Brg 20% Buckles Multi Channel										
2	3	4.787	4.787	0	0	0	0	13.528	12.762		
3	4	9.573	9.573	0	0	0	0	30.744	24.572		
4	1	9.573	9.573	0	0	0	0	27.889	24.572		
5	12	9.573	9.573	0	0	0	0	30.744	24.572		
6	14	9.573	9.573	0	0	0	0	25.801	24.572		
7	1	9.573	9.573	0	0	0	0	27.275	24.572		
8	22	9.573	9.573	0	0	0	0	25.801	24.572		
9	1	9.573	9.573	0	0	0	0	27.275	24.572		
10	9	9.573	9.573	0	0	0	0	25.801	24.572		
11	1	9.573	9.573	0	0	0	0	27.275	24.572		
12	2	9.573	9.573	0	0	0	0	25.801	24.572		
13	2	9.573	9.573	0	0	0	0	27.275	24.572		
14	4	9.573	9.573	0	0	0	0	25.801	24.572		
15	1	9.573	9.573	0	0	0	0	27.275	24.572		
16	2	9.573	9.573	0	0	0	0	25.801	24.572		
17	2	9.573	9.573	0	0	0	0	27.275	24.572		
18	7	9.573	9.573	0	0	0	0	25.801	24.572		
19	1	9.573	9.573	0	0	0	0	27.275	24.572		
20	2	9.573	9.573	0	0	0	0	25.801	24.572		
21	1	9.573	9.573	0	0	0	0	27.275	24.572		
22	16	9.573	9.573	0	0	0	0	25.801	24.572		
23	1	9.573	9.573	0	0	0	0	27.275	24.572		
24	20	9.573	9.573	0	0	0	0	25.801	24.572		
25	2	9.573	9.573	0	0	0	0	27.275	24.572		
26	26	9.573	9.573	0	0	0	0	25.801	24.572		
27	2	9.573	9.573	0	0	0	0	27.275	24.572		
28	3	9.573	9.573	0	0	0	0	25.801	24.572		
29	1	9.573	9.573	0	0	0	0	27.029	24.572		
30	1	9.573	9.573	0	0	0	0	27.275	24.572		
31	5	9.573	9.573	0	0	0	0	25.801	24.572		
32	1	9.573	9.573	0	0	0	0	27.275	24.572		
33	2	9.573	9.573	0	0	0	0	25.801	24.572		
34	8	9.573	9.573	0	0	0	0	26.784	24.572		
35	1	14.656	14.656	0	0	0	0	31.206	24.572		
36	8	9.573	9.573	0	0	0	0	26.784	24.572		
37	16	4.787	4.787	0	0	0	0	17.263	16.286		
38	1	14.656	0.000	0	0	0	0	31.206	0		
39	3	4.787	4.787	0	0	0	0	13.528	12.762		
40	11	9.573	9.573	0	0	0	0	30.744	24.572		
41	1	9.573	9.573	0	0	0	0	27.889	24.572		
42	1	14.656	14.656	0	0	0	0	35.886	24.572		
43	4	9.573	9.573	0	0	0	0	30.744	24.572		
44	20	9.573	9.573	0	0	0	0	25.801	24.572		
45	1	14.656	14.656	0	0	0	0	28.626	24.572		
46	11	9.573	9.573	0	0	0	0	25.801	24.572		
47	1	9.573	9.573	0	0	0	0	27.275	24.572		

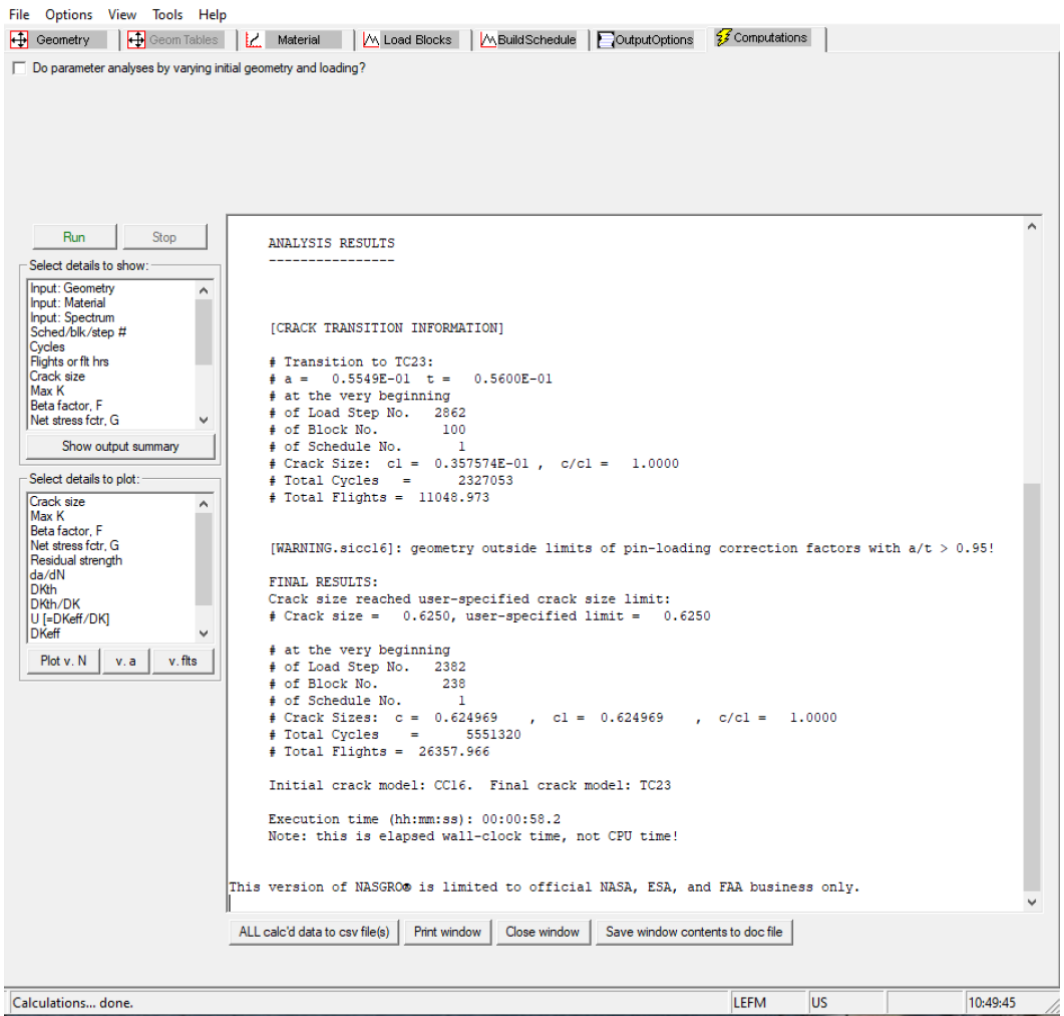
Sheet1 Sheet2

Example 2 – Fuselage Lap Joint

Assumptions: Two 0.005” Corner Flaws, Nasgro 2024-T3 L-T, Same Example 2C Geometry using Same SIF Solution as with Afgrow

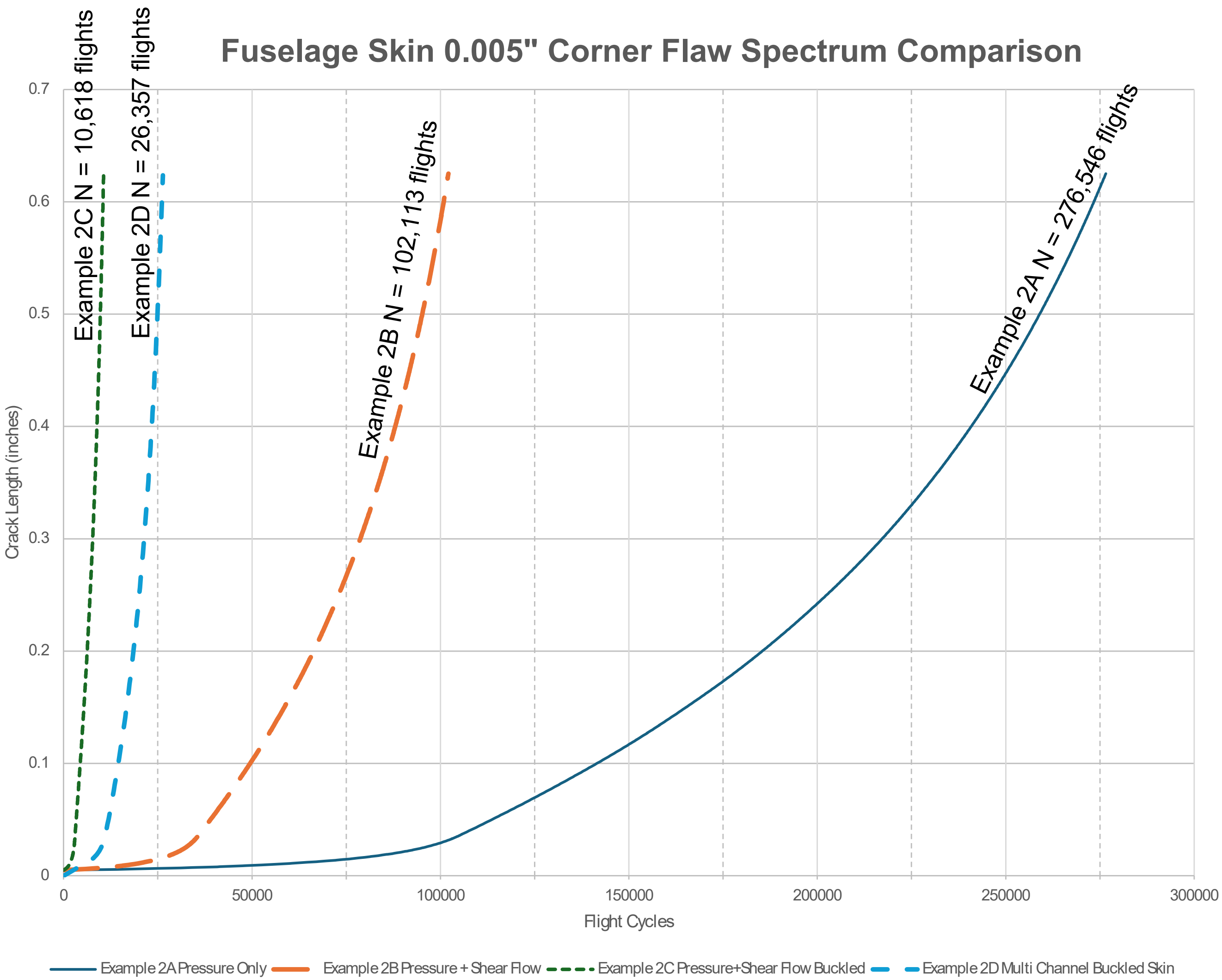


Example 2 – Fuselage Lap Joint



Life limited to half of pitch to adj fastener: N = 26,357 flight cycles / 237,459 flight hours

Example 2 – Fuselage Lap Joint



Impacts of load source and buckling on lap joint life:

>60% Reduction in life by including effect of shear flow in panels

Potential Impacts to Investigate:

1. Are panel shear and hoop in phase or not?
2. At what delta Nz does the panel buckle for each flight condition?
3. What is actual spectrum loading in terms of when panel buckles
4. Are hoop loads and shear flows out of phase? Is a multi channel spectrum needed?
5. Constant amplitude spectra does not capture effects of load histories.
6. Multi channel spectrum provides life in terms of both flight cycles and flight hours.

Example 2 – Fuselage Lap Joint

SUMMARY CONCLUSION:

1. Fully understand loading of joint --- Free Body Diagram
2. Does complex loading apply? Is a Multi-Channel Spectrum Apply?
3. Accurately represent fastener loads from all sources
4. Determine if structure is impacted by buckling during spectra
5. At what percent of applied fatigue loads does structure buckle?
6. If conservative assumptions for buckling are too severe than account for buckling in the spectra development and residual strength
7. Buckling can also have a direct impact on the stress intensity (see next slide)

Example 2 – Fuselage Lap Joint

From Starnes and Young (Ref. 1) referring to GöKGöl of MBB (see Ref. 2) on the Airbus A300:

Ref. 1: *"In addition, results of a fatigue test of an A300B fuselage indicated that compressive stress directioned parallel to a crack may increase the stress intensity factor by 40%."*

Ref. 2: "In the latter case the crack propagation determined by test could only then be simulated by calculation if the stress intensity factor in the calculation was increased by 40%. The negligence of the compressive stress directioned parallel to the crack in connection to the tensile stress acting vertically to the crack would cause a substantial under-rating of crack propagation."

Ref. 1: Skin, Stringer and Fastener Loads in Buckled Fuselage Panels by Young, Rose and Starnes, NASA Langley, AIAA-2001-1326

Ref. 2: Crack free and cracked life of the pressurized cabin of the A300B— calculation, tests and design measurements to improve damage tolerance by O. GöKGöl, Messerschmitt-Bolkow-Blohm, Aeronautical Journal, 1979

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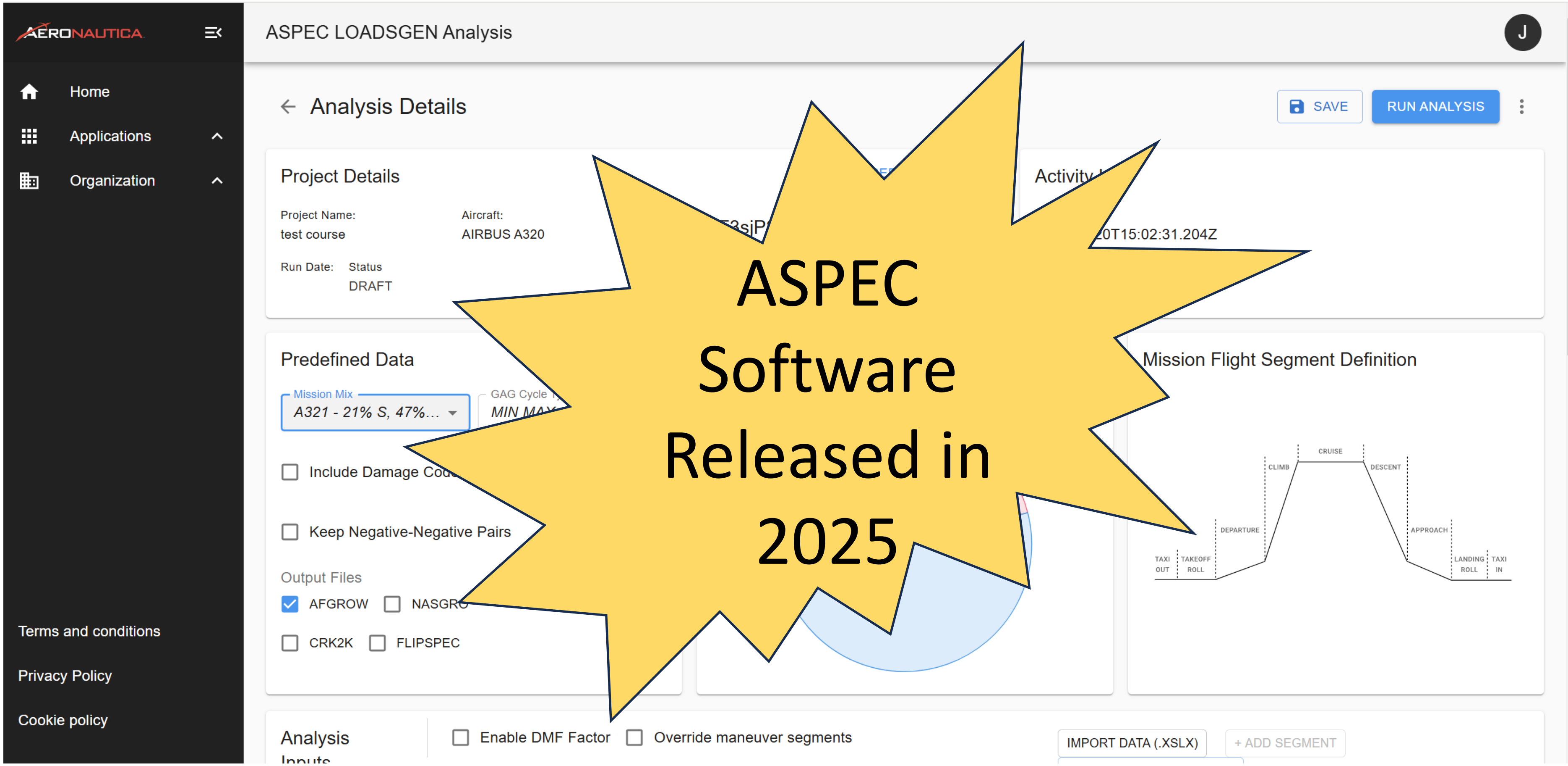

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TAKEOFF ROLL
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+ ADD SEGMENT
ASPEC
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Released in
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