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F&DT Analysis of an Aircraft Wing

Tejaswini Borra, Ganesh Kumar Pamarthi

Abstract— This paper focuses on estimation of fatigue life of a fastener and crack growth analysis of an aircraft wing of GARUDA - 101. There is no much literature and tools to avoid fatigue damage and failures. Life of the joints, components, and whole aircraft should be estimated to reduce the structural failures due to fatigue. Life after crack initiation should also be estimated.

To start the analysis we should have the stress histories. As I"m a student and company"s original data will not be given to publish, I had to generate displacement and stress data manually. I used normal distribution function to generate stress histories. This way GAG cycles are generated for 15 load cases for 33.3 minutes of flight of Garuda 101 aircraft. As an aircraft experiences a variable amplitude load history, this should to be converted into constant amplitude load history for the ease of calculation. For this, an algorithm is developed. Based on the algorithm a template in excel using VBA is developed to automate the conversion. According to the theory, the aircraft is designed in such a way that the fasteners fail first. So, fatigue life of the fastener is estimated. This process of estimation of life for lap and but joints is automized using VBA excel. Crack initiation process starts once the fatigue life is completed. A template is developed to estimate the crack propagation for 15 different cases of loading.

The template was tested with Garuda"s official template to calculate life. The results were more accurate. The time taken by this template to estimate life was 1/10th of the time taken by the Garuda"s template.

Index Terms— Fatigue and Damage tolerance, Crack initiation, Crack growth, Fastener life, S-N curves, load histories, Rain flow method.

1 1 Introduction

THIS Document focuses on mechanical failure modes of an aircraft structure and F&DT analysis and also to automate process of estimation of Fatigue life using Excel 2007 and VBA 5.0 macros.

There is no much literature and tools to avoid fatigue damage and accidents. Life of the joints, components, and whole aircraft should be estimated to reduce the structural failures due to fatigue. Life after crack initiation should also be estimated. So, aim of the thesis is to estimate the fatigue life of an aircraft wing and calculate stress intensity factor after crack initiation.

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2 Design Methodology

2.1 Process

To estimate the fatigue life the followings steps are to be followed

i. Generation of Ground-Air-Ground cycles (GAG) cycles
ii. Estimation of life of the Fasteners
iii. Crack growth analysis i.e., life after crack initiation
iv. Verification of the results

2.2 Geometry

Spars

Number of spars = 2

Table 1 Front Spar geometry

Length	1669.07"
Thickness	1"

Ribs

Number of ribs = 15

Thickness = 0.600393"

Skin

Thickness = 0.7874"

2.3 Generation of GAG Cycles

To start the analysis we should have stress histories. Hence GAG cycles are to be generated for 15 different load cases for 33.3 minutes of flight of Garuda 101 aircraft.

2.3.1 Stress Histories for 15 different load cases

As I"m a student and companies original load history data will not be given to publish I had to generate displacement and stress histories manually. I used normal distribution function in excel to generate random displacement and stress data.

1		2		3	
Time(sec)	Stress(ksi)	Stress(ksi)		Stress(ksi)	
20	45.77262	20	41.77262	20	39.77262
40	44.71428	40	45.71428	40	40.71428
60	41.66156	60	42.66156	60	45.66156
80	49.61383	80	44.61383	80	45.61383
100	49.57044	100	44.57044	100	49.57044
120	43.5307	120	43.5307	120	45.5307
140	48.49393	140	41.49393	140	52.49393
160	48.4594	160	52.4594	160	44.4594

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180	54.42639	180	45.42639	180	40.42639	1080	81.21604	1080	74.21604	1080	81.21604
200	52.39414	200	53.39414	200	42.39414	1100	78.39051	1100	77.39051	1100	72.39051
220	53.3619	220	45.3619	220	47.3619	1120	82.53354	1120	81.53354	1120	78.53354
240	54.32887	240	57.32887	240	49.32887	1140	77.64497	1140	84.64497	1140	80.64497
260	53.29426	260	51.29426	260	54.29426	1160	73.72465	1160	72.72465	1160	80.72465
280	46.25726	280	57.25726	280	58.25726	1180	86.7725	1180	74.7725	1180	78.7725
300	47.21705	300	50.21705	300	50.21705	1200	76.78846	1200	73.78846	1200	80.78846
320	49.17279	320	61.17279	320	61.17279	1220	78.7725	1220	83.7725	1220	84.7725
340	60.12365	340	55.12365	340	54.12365	1240	83.72465	1240	80.72465	1240	79.72465
360	56.06876	360	52.06876	360	50.06876	1260	84.64497	1260	85.64497	1260	77.64497
380	63.00727	380	52.00727	380	61.00727	1280	83.53354	1280	73.53354	1280	82.53354
400	61.93831	400	62.93831	400	58.93831	1300	83.39051	1300	75.39051	1300	78.39051
420	52.86101	420	55.86101	420	65.86101	1320	78.21604	1320	85.21604	1320	82.21604
440	62.77448	440	58.77448	440	52.77448	1340	74.01035	1340	84.01035	1340	83.01035
460	67.67786	460	57.67786	460	67.67786	1360	83.77367	1360	79.77367	1360	83.77367
480	63.57025	480	63.57025	480	63.57025	1380	80.5063	1380	77.5063	1380	75.5063
500	65.45079	500	59.45079	500	61.45079	1400	79.20854	1400	81.20854	1400	76.20854
520	63.31858	520	56.31858	520	63.31858	1420	81.88075	1420	84.88075	1420	70.88075
540	62.17276	540	61.17276	540	71.17276	1440	72.52332	1440	71.52332	1440	74.52332
560	69.01245	560	58.01245	560	71.01245	1460	78.13667	1460	76.13667	1460	70.13667
580	61.83679	580	64.83679	580	62.83679	1480	80.72126	1480	83.72126	1480	78.72126
600	64.64492	600	62.64492	600	65.64492	1500	73.27756	1500	81.27756	1500	69.27756
620	71.43599	620	66.43599	620	67.43599	1520	74.80611	1520	69.80611	1520	69.80611
640	67.20916	640	72.20916	640	70.20916	1540	80.30743	1540	82.30743	1540	77.30743
660	61.9636	660	70.9636	660	65.9636	1560	73.78212	1560	76.78212	1560	74.78212
680	62.6985	680	74.6985	680	69.6985	1580	70.23078	1580	69.23078	1580	73.23078
700	65.41307	700	63.41307	700	70.41307	1600	67.65403	1600	69.65403	1600	80.65403
720	72.10651	720	72.10651	720	64.10651	1620	73.05253	1620	67.05253	1620	70.05253
740	64.77806	740	69.77806	740	75.77806	1640	74.42698	1640	79.42698	1640	71.42698
760	67.42698	760	67.42698	760	66.42698	1660	71.77806	1660	72.77806	1660	68.77806
780	72.05253	780	73.05253	780	75.05253	1680	71.10651	1680	69.10651	1680	76.10651
800	66.65403	800	77.65403	800	71.65403	1700	67.41307	1700	73.41307	1700	72.41307
820	76.23078	820	72.23078	820	70.23078	1720	71.6985	1720	62.6985	1720	63.6985
840	80.78212	840	80.78212	840	71.78212	1740	70.9636	1740	61.9636	1740	75.9636
860	78.30743	860	73.30743	860	78.30743	1760	71.20916	1760	74.20916	1760	72.20916
880	77.80611	880	80.80611	880	71.80611	1780	68.43599	1780	62.43599	1780	61.43599
900	76.27756	900	74.27756	900	82.27756	1800	73.64492	1800	68.64492	1800	63.64492
920	72.72126	920	83.72126	920	71.72126	1820	66.83679	1820	71.83679	1820	59.83679
940	84.13667	940	82.13667	940	80.13667	1840	72.01245	1840	64.01245	1840	68.01245
960	77.52332	960	84.52332	960	73.52332	1860	66.17276	1860	67.17276	1860	67.17276
980	79.88075	980	82.88075	980	82.88075	1880	60.31858	1880	62.31858	1880	62.31858
1000	85.20854	1000	73.20854	1000	78.20854	1900	66.45079	1900	66.45079	1900	67.45079
1020	75.5063	1020	74.5063	1020	81.5063	1920	58.57025	1920	60.57025	1920	66.57025
1040	73.77367	1040	73.77367	1040	80.77367	1940	56.67786	1940	64.67786	1940	57.67786
1060	81.01035	1060	83.01035	1060	75.01035	1960	52.77448	1960	58.77448	1960	52.77448

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1980	57.86101	1980	60.86101	1980	56.86101
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820	74.23078	820	69.23078
840	75.78212	840	67.78212
860	68.30743	860	73.30743
880	75.80611	880	82.80611
900	76.27756	900	69.27756
920	70.72126	920	75.72126
940	76.13667	940	81.13667
960	80.52332	960	79.52332
980	75.88075	980	71.88075
1000	80.20854	1000	85.20854
1020	72.5063	1020	80.5063
1040	71.77367	1040	76.77367
1060	85.01035	1060	72.01035
1080	74.21604	1080	79.21604
1100	79.39051	1100	79.39051
1120	79.53354	1120	72.53354
1140	86.64497	1140	80.64497
1160	83.72465	1160	82.72465
1180	75.7725	1180	73.7725
1200	78.78846	1200	82.78846
1220	74.7725	1220	82.7725
1240	86.72465	1240	74.72465
1260	79.64497	1260	73.64497
1280	82.53354	1280	79.53354
1300	82.39051	1300	80.39051
1320	76.21604	1320	76.21604
1340	84.01035	1340	76.01035
1360	82.77367	1360	82.77367
1380	75.5063	1380	79.5063
1400	73.20854	1400	73.20854
1420	79.88075	1420	70.88075
1440	83.52332	1440	72.52332
1460	76.13667	1460	73.13667
1480	74.72126	1480	70.72126
1500	79.27756	1500	78.27756
1520	71.80611	1520	78.80611
1540	79.30743	1540	74.30743
1560	71.78212	1560	77.78212
1580	79.23078	1580	77.23078
1600	72.65403	1600	67.65403
1620	76.05253	1620	79.05253
1640	79.42698	1640	79.42698
1660	67.77806	1660	77.77806
1680	72.10651	1680	69.10651
1700	76.41307	1700	73.41307

4

Time(sec)	Stress(ksi)
20	34.77262
40	41.71428
60	40.66156
80	48.61383
100	49.57044
120	42.5307
140	43.49393
160	51.4594
180	51.42639
200	48.39414
220	54.3619
240	57.32887
260	49.29426
280	53.25726
300	56.21705
320	60.17279
340	50.12365
360	55.06876
380	52.00727
400	58.93831
420	63.86101
440	53.77448
460	66.67786
480	67.57025
500	62.45079
520	70.31858
540	70.17276
560	70.01245
580	68.83679
600	63.64492
620	67.43599
640	74.20916
660	66.9636
680	76.6985
700	73.41307
720	71.10651
740	70.77806
760	69.42698
780	75.05253
800	77.65403

5

Time(sec)	Stress(ksi)
20	45.77262
40	43.71428
60	46.66156
80	39.61383
100	39.57044
120	43.5307
140	50.49393
160	44.4594
180	52.42639
200	44.39414
220	44.3619
240	52.32887
260	54.29426
280	55.25726
300	60.21705
320	54.17279
340	52.12365
360	58.06876
380	59.00727
400	50.93831
420	52.86101
440	65.77448
460	56.67786
480	64.57025
500	58.45079
520	57.31858
540	71.17276
560	71.01245
580	70.83679
600	70.64492
620	67.43599
640	67.20916
660	62.9636
680	65.6985
700	64.41307
720	73.10651
740	75.77806
760	66.42698
780	76.05253
800	76.65403

6

Time(sec)	Stress(ksi)
20	37.77262
40	42.71428
60	41.66156
80	37.61383
100	41.57044
120	46.5307
140	38.49393
160	41.4594
180	40.42639
200	46.39414
220	55.3619
240	49.32887
260	57.29426
280	51.25726
300	53.21705
320	48.17279
340	50.12365
360	49.06876
380	55.00727
400	61.93831
420	58.86101
440	59.77448
460	65.67786
480	68.57025
500	63.45079
520	59.31858
540	58.17276
560	60.01245
580	69.83679
600	66.64492
620	73.43599
640	64.20916
660	63.9636
680	72.6985
700	76.41307
720	69.10651
740	74.77806
760	66.42698
780	71.05253
800	69.65403

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1720	70.6985	1720	65.6985	1720	73.6985
1740	64.9636	1740	62.9636	1740	72.9636
1760	74.20916	1760	64.20916	1760	75.20916
1780	67.43599	1780	68.43599	1780	61.43599
1800	72.64492	1800	68.64492	1800	71.64492
1820	71.83679	1820	61.83679	1820	61.83679
1840	69.01245	1840	60.01245	1840	70.01245
1860	69.17276	1860	60.17276	1860	60.17276
1880	62.31858	1880	61.31858	1880	61.31858
1900	63.45079	1900	60.45079	1900	60.45079
1920	58.57025	1920	63.57025	1920	64.57025
1940	60.67786	1940	63.67786	1940	65.67786
1960	52.77448	1960	65.77448	1960	65.77448
1980	65.86101	1980	54.86101	1980	63.86101
2000	58.93831	2000	57.93831	2000	64.93831

560	64.01245	560	59.01245
580	68.83679	580	69.83679
600	62.64492	600	71.64492
620	62.43599	620	71.43599
640	66.20916	640	70.20916
660	64.9636	660	73.9636
680	65.6985	680	71.6985
700	74.41307	700	77.41307
720	70.10651	720	66.10651
740	66.77806	740	71.77806
760	67.42698	760	67.42698
780	79.05253	780	80.05253
800	75.65403	800	77.65403
820	72.23078	820	81.23078
840	68.78212	840	77.78212
860	77.30743	860	71.30743
880	76.80611	880	77.80611
900	75.27756	900	82.27756
920	71.72126	920	82.72126
940	70.13667	940	74.13667
960	75.52332	960	71.52332
980	82.88075	980	84.88075
1000	73.20854	1000	79.20854
1020	80.5063	1020	80.5063
1040	80.77367	1040	77.77367
1060	73.01035	1060	86.01035
1080	81.21604	1080	73.21604
1100	84.39051	1100	85.39051
1120	77.53354	1120	76.53354
1140	85.64497	1140	86.64497
1160	79.72465	1160	78.72465
1180	76.7725	1180	84.7725
1200	75.78846	1200	86.78846
1220	76.7725	1220	74.7725
1240	83.72465	1240	73.72465
1260	79.64497	1260	84.64497
1280	83.53354	1280	73.53354
1300	81.39051	1300	75.39051
1320	84.21604	1320	73.21604
1340	72.01035	1340	75.01035
1360	85.77367	1360	81.77367
1380	78.5063	1380	78.5063
1400	83.20854	1400	77.20854
1420	81.88075	1420	74.88075
1440	84.52332	1440	83.52332

7		8		9	
Time(sec)	Stress(ksi)	Time(sec)	Stress(ksi)	Time(sec)	Stress(ksi)
20	41.77262	20	43.77262	20	33.77262
40	45.71428	40	42.71428	40	37.71428
60	36.66156	60	41.66156	60	46.66156
80	41.61383	80	40.61383	80	48.61383
100	41.57044	100	43.57044	100	41.57044
120	44.5307	120	42.5307	120	37.5307
140	45.49393	140	42.49393	140	51.49393
160	50.4594	160	43.4594	160	45.4594
180	47.42639	180	52.42639	180	47.42639
200	48.39414	200	54.39414	200	41.39414
220	43.3619	220	49.3619	220	49.3619
240	49.32887	240	54.32887	240	44.32887
260	51.29426	260	51.29426	260	50.29426
280	49.25726	280	56.25726	280	48.25726
300	46.21705	300	47.21705	300	50.21705
320	48.17279	320	49.17279	320	52.17279
340	48.12365	340	51.12365	340	53.12365
360	59.06876	360	59.06876	360	54.06876
380	57.00727	380	53.00727	380	52.00727
400	60.93831	400	58.93831	400	59.93831
420	63.86101	420	58.86101	420	57.86101
440	59.77448	440	64.77448	440	64.77448
460	59.67786	460	55.67786	460	67.67786
480	64.57025	480	63.57025	480	56.57025
500	62.45079	500	67.45079	500	58.45079
520	69.31858	520	56.31858	520	64.31858
540	57.17276	540	70.17276	540	63.17276

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1460	76.13667	1460	81.13667	1460	[illegible].13667
1480	73.72126	1480	81.72126	1480	[illegible].72126
1500	78.27756	1500	69.27756	1500	[illegible].27756
1520	77.80611	1520	74.80611	1520	[illegible].80611
1540	73.30743	1540	81.30743	1540	[illegible].30743
1560	73.78212	1560	67.78212	1560	[illegible].78212
1580	78.23078	1580	77.23078	1580	[illegible].23078
1600	71.65403	1600	67.65403	1600	[illegible].65403
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1640	72.42698	1640	79.42698	1640	[illegible].42698
1660	67.77806	1660	67.77806	1660	[illegible].77806
1680	64.10651	1680	76.10651	1680	[illegible].10651
1700	69.41307	1700	70.41307	1700	[illegible].41307
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1740	64.9636	1740	69.9636	1740	[illegible].9636
1760	64.20916	1760	70.20916	1760	[illegible].20916
1780	60.43599	1780	72.43599	1780	[illegible].43599
1800	71.64492	1800	59.64492	1800	[illegible].64492
1820	66.83679	1820	66.83679	1820	[illegible].83679
1840	60.01245	1840	63.01245	1840	[illegible].01245
1860	60.17276	1860	66.17276	1860	[illegible].17276
1880	66.31858	1880	68.31858	1880	[illegible].31858
1900	58.45079	1900	64.45079	1900	[illegible].45079
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1940	56.67786	1940	66.67786	1940	[illegible].67786
1960	52.77448	1960	63.77448	1960	[illegible].77448
1980	56.86101	1980	55.86101	1980	[illegible].86101
2000	64.93831	2000	56.93831	2000	[illegible].93831

300	60.21705	300	58.21705
320	47.17279	320	61.17279
340	56.12365	340	49.12365
360	61.06876	360	61.06876
380	59.00727	380	60.00727
400	52.93831	400	58.93831
420	53.86101	420	52.86101
440	53.77448	440	63.77448
460	66.67786	460	59.67786
480	60.57025	480	55.57025
500	68.45079	500	64.45079
520	64.31858	520	69.31858
540	62.17276	540	61.17276
560	58.01245	560	70.01245
580	61.83679	580	64.83679
600	71.64492	600	72.64492
620	61.43599	620	62.43599
640	74.20916	640	65.20916
660	70.9636	660	68.9636
680	71.6985	680	74.6985
700	76.41307	700	72.41307
720	71.10651	720	64.10651
740	69.77806	740	69.77806
760	75.42698	760	78.42698
780	69.05253	780	71.05253
800	73.65403	800	79.65403
820	68.23078	820	71.23078
840	68.78212	840	67.78212
860	76.30743	860	71.30743
880	70.80611	880	78.80611
900	76.27756	900	75.27756
920	72.72126	920	79.72126
940	76.13667	940	76.13667
960	78.52332	960	76.52332
980	81.88075	980	75.88075
1000	78.20854	1000	74.20854
1020	72.5063	1020	81.5063
1040	85.77367	1040	71.77367
1060	78.01035	1060	77.01035
1080	76.21604	1080	84.21604
1100	85.39051	1100	75.39051
1120	72.53354	1120	81.53354
1140	82.64497	1140	79.64497
1160	79.72465	1160	84.72465
1180	72.7725	1180	83.7725

10

Time(sec)	Stress(ksi)
20	36.77262
40	34.71428
60	39.66156
80	37.61383
100	48.57044
120	47.5307
140	45.49393
160	53.4594
180	52.42639
200	42.39414
220	52.3619
240	52.32887
260	50.29426
280	55.25726

11

Time(sec)	Stress(ksi)
20	42.77262
40	41.71428
60	34.66156
80	49.61383
100	44.57044
120	44.5307
140	46.49393
160	50.4594
180	44.42639
200	45.39414
220	53.3619
240	53.32887
260	56.29426
280	54.25726

12

Time(sec)	Stress(ksi)
20	44.77262
40	34.71428
60	46.66156
80	42.61383
100	50.57044
120	46.5307
140	43.49393
160	43.4594
180	40.42639
200	55.39414
220	49.3619
240	53.32887
260	58.29426
280	56.25726

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1200	80.78846	1200	86.78846	401200	42.714288.78846	40	45.71428
1220	82.7725	1220	85.7725	601220	40.661580.7725	60	45.66156
1240	79.72465	1240	83.72465	801240	41.613837.72465	80	42.61383
1260	84.64497	1260	74.64497	1001260	46.570474.64497	100	37.57044
1280	73.53354	1280	84.53354	1201280	49.580753354	120	46.5307
1300	85.39051	1300	73.39051	1401300	39.493973.39051	140	39.49393
1320	78.21604	1320	74.21604	1601320	53.459421604	160	44.4594
1340	85.01035	1340	78.01035	1801340	43.426329.01035	180	43.42639
1360	74.77367	1360	84.77367	2001360	50.394147.77367	200	48.39414
1380	80.5063	1380	73.5063	2201380	49.361977.5063	220	50.3619
1400	75.20854	1400	79.20854	2401400	57.328787.20854	240	54.32887
1420	72.88075	1420	79.88075	2601420	48.294262.88075	260	57.29426
1440	79.52332	1440	83.52332	2801440	59.257362.52332	280	57.25726
1460	70.13667	1460	82.13667	3001460	49.217051.13667	300	48.21705
1480	81.72126	1480	70.72126	3201480	47.172797.72126	320	51.17279
1500	73.27756	1500	69.27756	3401500	56.123652.27756	340	49.12365
1520	71.80611	1520	79.80611	3601520	54.068760.80611	360	63.06876
1540	81.30743	1540	72.30743	3801540	54.007273.30743	380	63.00727
1560	77.78212	1560	76.78212	4001560	62.938317.78212	400	52.93831
1580	67.23078	1580	74.23078	4201580	55.861012.23078	420	61.86101
1600	76.65403	1600	78.65403	4401600	59.774486.65403	440	60.77448
1620	67.05253	1620	80.05253	4601620	65.677860.05253	460	66.67786
1640	79.42698	1640	75.42698	4801640	64.570252.42698	480	59.57025
1660	70.77806	1660	74.77806	5001660	63.450797.77806	500	65.45079
1680	76.10651	1680	77.10651	5201680	63.318580.10651	520	66.31858
1700	73.41307	1700	63.41307	5401700	65.172764.41307	540	62.17276
1720	70.6985	1720	70.6985	5601720	60.012451.6985	560	70.01245
1740	62.9636	1740	65.9636	5801740	63.836795.9636	580	66.83679
1760	62.20916	1760	65.20916	6001760	61.644922.20916	600	73.64492
1780	72.43599	1780	70.43599	6201780	69.435994.43599	620	70.43599
1800	66.64492	1800	68.64492	6401800	74.209164.64492	640	71.20916
1820	71.83679	1820	68.83679	6601820	69.963663.83679	660	63.9636
1840	70.01245	1840	60.01245	6801840	66.698501245	680	71.6985
1860	66.17276	1860	69.17276	7001860	65.413079.17276	700	64.41307
1880	65.31858	1880	60.31858	7201880	78.106531858	720	78.10651
1900	63.45079	1900	67.45079	7401900	76.778067.45079	740	69.77806
1920	56.57025	1920	58.57025	7601920	76.426988.57025	760	66.42698
1940	62.67786	1940	59.67786	7801940	76.052539.67786	780	72.05253
1960	63.77448	1960	58.77448	8001960	70.654038.77448	800	67.65403
1980	63.86101	1980	62.86101	8201980	72.230782.86101	820	75.23078
2000	52.93831	2000	61.93831	8402000	77.782121.93831	840	76.78212
				860	77.30743	860	75.30743
				880	73.80611	880	75.80611
				900	79.27756	900	71.27756
				920	69.72126	920	83.72126

13

Time(sec)	Stress(ksi)
20	42.77262

14

Time(sec)	Stress(ksi)
20	38.77262

15

Time(sec)	Stress(ksi)
20	32.77262

940	76.13667	940	78.13667	940	[illegible]
960	70.52332	960	82.52332	960	[illegible]
980	74.88075	980	83.88075	980	[illegible]
1000	81.20854	1000	76.20854	1000	[illegible]
1020	85.5063	1020	81.5063	1020	[illegible]
1040	79.77367	1040	84.77367	1040	[illegible]
1060	83.01035	1060	73.01035	1060	[illegible]
1080	72.21604	1080	84.21604	1080	[illegible]
1100	78.39051	1100	80.39051	1100	[illegible]
1120	76.53354	1120	85.53354	1120	86.53354
1140	77.64497	1140	81.64497	1140	75.64497
1160	82.72465	1160	80.72465	1160	74.72465
1180	76.7725	1180	86.7725	1180	81.7725
1200	73.78846	1200	82.78846	1200	75.78846
1220	86.7725	1220	84.7725	1220	86.7725
1240	86.72465	1240	84.72465	1240	82.72465
1260	79.64497	1260	82.64497	1260	86.64497
1280	79.53354	1280	75.53354	1280	77.53354
1300	82.39051	1300	81.39051	1300	73.39051
1320	86.21604	1320	79.21604	1320	82.21604
1340	79.01035	1340	82.01035	1340	84.01035
1360	79.77367	1360	76.77367	1360	85.77367
1380	77.5063	1380	77.5063	1380	71.5063
1400	82.20854	1400	80.20854	1400	85.20854
1420	77.88075	1420	74.88075	1420	77.88075
1440	79.52332	1440	82.52332	1440	78.52332
1460	70.13667	1460	73.13667	1460	70.13667
1480	82.72126	1480	78.72126	1480	76.72126
1500	82.27756	1500	82.27756	1500	76.27756
1520	78.80611	1520	69.80611	1520	77.80611
1540	68.30743	1540	76.30743	1540	72.30743
1560	80.78212	1560	79.78212	1560	70.78212
1580	76.23078	1580	81.23078	1580	78.23078
1600	69.65403	1600	71.65403	1600	72.65403
1620	75.05253	1620	69.05253	1620	74.05253
1640	75.42698	1640	74.42698	1640	76.42698
1660	74.77806	1660	67.77806	1660	75.77806
1680	78.10651	1680	68.10651	1680	77.10651
1700	77.41307	1700	73.41307	1700	68.41307
1720	64.6985	1720	76.6985	1720	67.6985
1740	66.9636	1740	68.9636	1740	67.9636
1760	62.20916	1760	65.20916	1760	69.20916
1780	68.43599	1780	74.43599	1780	70.43599
1800	68.64492	1800	60.64492	1800	64.64492
1820	59.83679	1820	68.83679	1820	69.83679

1840	65.01245	1840	66.01245
1860	61.17276	1860	71.17276
1880	62.31858	1880	59.31858
1900	65.45079	1900	61.45079
1920	55.57025	1920	63.57025
1940	60.67786	1940	64.67786
1960	59.77448	1960	56.77448
1980	57.86101	1980	60.86101
2000	60.93831	2000	53.93831

2.3.2 Conversation of Variable amplitude load histories to Constant amplitude load histories.

These are variable amplitude stress histories. For the purpose of calculation these are to be converted into constant amplitude stress histories. An algorithm is developed to for this. This will give a single number that represents number of equivalent constant amplitude cycles of given stress range experienced by the structure.

The number of constant amplitude xksi cycles is determined in two steps. The first step is to find the equivalent constant amplitude stress range (S_{Re}) from the variable amplitude stress ranges (S_{Ri}). This equation is developed using **Error! Reference source not found.**, is show below

$$S_{Re} = \left(\sum \gamma_i S_{Ri}^3\right)^{1/3}$$

Equation 2-1

The terms γ_i and S_{Re} are defined as follows:

$$\gamma_i = n_i/N$$
$$N = \sum n_i$$
$$S_{Ri} = S_{max} - S_{min}$$

Equation 2-2

where n_i is the number of cycles at the stress range S_{Ri}, N is total number of cycles and S_{ri} is the stress range. Therefore, γ_i represents the percentage of stress cycles at the stress range S_{Ri}.

After the effective constant amplitude stress range, S_{Re}, is found, the next step is to determine the cumulative fatigue damage in terms of equivalent 10ksi constant amplitude stress cycles, $N_{10\ ksi}$. The constant amplitude stress range S_{Re} and the total number of cycles, N, can be used to find $N_{10\ ksi}$ as follows:

$$N_{(10\ ksi)} = N(S_{Re}/xksi)^3$$

Template

Using the above algorithm a template is developed in Excel (VBA-Excel) to automate this process.

Inputs

i. Number of load cases for which stress history has been taken.
ii. Stress Data
iii. Time interval

How does it work?

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i. Enter the number of locations in the Sheet titled "Wing Configuration"

ii. Click the button Enter Stress histories. The button Enter stress Data is assigned with the macro " Input Stress Data". Enter the stress histories for all the locations.

iii. Click on the button convert. A macro named Convert is assigned to this button. This will convert the given data into constant amplitude stress Data.

iv. Maximum stress, minimum stress and number of constant amplitude cycles the structure has experienced will be displayed in the Fmax sheet for all the locations.

```
Do While i <= (n)
    I1 = i + 1
    x2 = ActiveSheet.Rows(i).Cells(1).Value
    x3 = ActiveSheet.Rows(I1).Cells(1).Value
    'valley
    x6 = ActiveSheet.Rows(j).Cells(2).Value
    x7 = ActiveSheet.Rows(J1).Cells(2).Value
    If x2 >= x3 Or x6 >= ActiveSheet.Rows(i).Cells(1).Value Or x7 >= ActiveSheet.Rows(i)
        Do While ActiveSheet.Rows(i).Cells(1).Value >= ActiveSheet.Rows(I1).Cells(1).Val
            i = i + 1
            I1 = i + 1
        Loop
        x4 = ActiveSheet.Rows(i).Cells(1).Value
        ActiveSheet.Rows(j).Cells(2).Value = x4
        j = j + 2
    End If
    If x2 > x3 Or x4 < ActiveSheet.Rows(I1).Cells(1).Value Or x6 < ActiveSheet.Rows(i).C
        Do While ActiveSheet.Rows(i).Cells(1).Value < ActiveSheet.Rows(I1).Cells(1).Valu
            i = i + 1
            I1 = i + 1
        Loop
        x5 = ActiveSheet.Rows(i).Cells(1).Value
        ActiveSheet.Rows(J1).Cells(2).Value = x5
        J1 = J1 + 2
    End If
    i = i + 1
Loop
i = 1
If ActiveSheet.Range("A1").Value > x5 Or ActiveSheet.Range("A1").Value > x4 Then
    j = j + 1
    J1 = J1 + 1
```

Output

For each stress data of given load case the stress range, number of constant amplitude cycles for the given stress range, maximum stress, minimum stress are calculated.

2.3.3 Estimation of Fastener Life

2.3.3.1 Fastener Load And Bypass Load Distribution

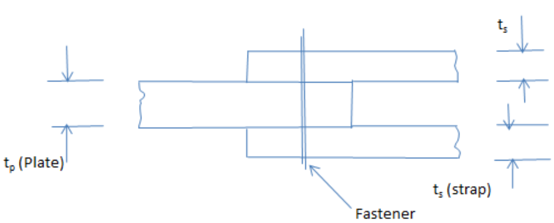
It is considered that most fatigue damage occurs under loading conditions for which the fasteners behave as linear elastic members. Even for very simple structures the treatment of the fasteners as flexible members result in rather elaborate calculations justifying the use of finite element modeling analysis. Before simulating the structural modeling, the fastener spring constant which can be converted to equivalent structural beam member is obtained by the following hypothetical equations

t_av=(2t_s+t_p)/2

Where C – Fastener constant (in/lb)

K_f – Fastener spring constant (K_f – 1/C)

E_{bb} – Fastener material modulus of elasticity



2.3.3.2 Development Of Analytical Expressions Used In

2.3.3.3 Determination Of Bolt Loads For Elastic Behavior Of Symmetrical Butt Joints – General Bolt-Load Relationship

2.3.3.3.1 Analysis of symmetrical butt joint fastened by bolts in a single line in line of applied load

After load is applied , a part of the joint between bolts i and i+1 within the joint is considered (Figure 2-1) , and the length p+Δ_p along the main plate between the two bolts is added to the deflection of bolt i+1 and equated to the length p+Δ_s along the butt straps between the two bolts plus defection of bolt i. the deformations are expressed as functions of the bolt i. the deformations are expressed as functions of the load and deformations are expressed as functions of load and deformation characteristics of the plates and bolts. The resulting equation is solved for the joint load P, and the elastic constants of the plates and bolts.

<u>List of symbols used 2.3.3.3.1</u>

C – Bolt constant
D – Bolt diameter
E – Young's modulus tension or compression ksi
L – Length, inches
P – External load applied, kips
R – Bolt load, kips
b – Pitch, inches
t – Thickness, inches
Δ - Deformation
Δ – Deflection of bolt, inches
Subscripts
b – Bolt
i – Any transverse row of bolts
n - Last transverse row of bolts with reference to end of butt strap
p – any plate, or main plate
s – butt strap
$\sum_1^{i-1} R$ summation of all bolt loads from row 1 to I, excluding i

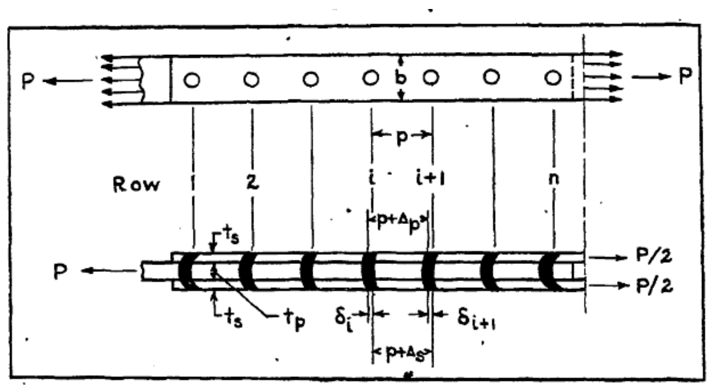


Figure 2-1 Symmetrical butt joint with bolts in a single line in the line of applied load.

It may be seen in Figure 2-1 that

$$p + \Delta_p + \delta_{(i+1)} = p + \Delta_s + \delta_i$$

Or

$$\delta_{i+1} = \delta_i - \Delta_p + \Delta_s$$

Equation 2-3

From assumption 5,

$$\delta_{(i+1)} = C_{(i+1)}/2 \, R_{(i+1)}$$

And

$$\delta_i = C_i/2 \, R_i$$

Equation 2-4

The load on the main plate between bolts i and i+1 is equal to the joint load P minus the sum of loads on all bolts $\sum_1^i R$ preceding the part of the joint under consideration; that is,

Load in main plates between bolts i and i+1 = P - $\sum_1^i R$

The loads in the butt straps between i and i+1 are equal to the sum of loads transmitted to the butt straps by all bolts preceding the section under consideration; and since there are two butt straps,

The load in one butt strap between bolts i and i+1 = $1/2 \sum_1^i R$

With these relations and the second assumption, the plate deformations may be written as

$$\Delta_p = p/(bt_p E) \, (P - \sum_1^i R)$$

$$\Delta_s = p/(bt_s E) \, (P - \sum_1^i R)$$

Let

$$p/(bt_p E) = K_p$$

$$p/(bt_s E) = K_s$$

The plate deformations may then be written

$$\Delta_p = K_p \, (P - \sum_1^i R)$$

$$\Delta_s = K_s/2 \sum_1^i R$$

Equation 2-5

Substituting Equation 2-4 and Equation 2-5 into Equation 2-3 gives

$$C_{(i+1)}/2 \, R_{(i+1)} = C_i/2 \, R_i - K_p \, (P - \sum_1^i R) + K_s/2 \sum_1^i R$$

Solve for R_{i+1}

$$R_{(i+1)} = C_i/C_{(i+1)} \, R_i + (2K_p + K_s)/C_{(i+1)} \sum_1^i R - (2K_p)/C_{(i+1)} \, P$$

Equation 2-6

Numerical work is facilitated by letting

$$\sum_1^i R = R_i + \sum_1^{i-1} R$$

Rewrite Equation 2-6

$$R_{(i+1)} = C_i/C_{(i+1)} \, R_i + (2K_p + K_s)/C_{(i+1)} \, R_i - (2K_p)/C_{(i+1)} \, P + (2K_p + K_s)/C_{(i+1)} \sum_1^{(i-1)} R$$

Equation 2-7

A case that occurs frequently is that in which the bolts are all of same material and size and the butt straps are of the same material as the main plate with a thickness equal to one-half of the main plate. Then

$$C_i = C_{i+1} = C$$

$$2K_p = K_s$$

And

$$R_{(i+1)} = R_i + (2K_s)/C \, R_i - (2K_p)/C \, P + (2K_s)/C \sum_1^{(i-1)} R$$

Equation 2-8

Case I:

For steel plates and fasteners

$$C = 8/(t_{av} E_{bb}) \, \{0.13(t_{av}/d)^2 [2.12 + (t_{av}/d)^2] + 1.0\}$$

Equation 2-9

Case II:

For aluminum plate and straps and aluminum fasteners – same as Case I.

Case III:

For aluminum plates and steel fasteners

$$C = 8/(t_{av} E_{bb}) \, \{0.13(t_{av}/d)^2 [2.12 + (t_{av}/d)^2] + 1.87\}$$

Equation 2-10

Case IV:

For aluminum plate, steel straps and steel fasteners

$$C = 8/(t_{av} E_{bb}) \, \{0.13(t_{av}/d)^2 [2.12 + (t_{av}/d)^2] + 1.43\}$$

Equation 2-11

Case V:

For aluminum plate, steel straps and aluminum

$$C = 8/(t_{av} E_{bb}) \, \{0.13(t_{av}/d)^2 [2.12 + (t_{av}/d)^2] + 0.84\}$$

Equation 2-12

Case VI:

For aluminum plates and titanium

$$C = 8/(t_{av} E_{bb}) \, \{0.133(t_{av}/d)^2 [2.06 + (t_{av}/d)^2] + 1.242\}$$

Equation 2-13

Case VII:

For aluminum plates, titanium straps and titanium fasteners

$$C = 8/(t_{av} E_{bb}) \, \{0.1325(t_{av}/d)^2 [2.06 + (t_{av}/d)^2] + 1.1125\}$$

Equation 2-14

2.3.3.3.2 Severity Concept

1. **Concept**

The severity factor SF, which is fatigue factor that accounts for:

i. Fastener type, method of installation, interference, hole preparation, etc.
ii. Detail design
iii. Fastener load distribution to avoid "Peaking effect"
iv. Minimization of the stress concentration caused both local at a fastener and bypass load.

2. **Local Stresses**

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The maximum local stress in the considered element,

$$\sigma\_max = \sigma\_1 + \sigma\_2 = K\_tb \ \Delta P/dt\, \theta + K\_tg \ \ P/wt$$

where s_1 = Local stresses caused by load transfer ΔP

s_2 = Local stresses caused by bypass load P,

K_{tb} = Stress Concentration factor, bearing stress

K_{tg} = Stress Concentration factor, bypass

θ = Gross area stress, see Bearing distribution factor

	α
Fillet radii	1.0−1.5
Standard hole drilled	1.0
Broached or reamed	0.9
Cold worked holes	0.7−0.8

Figure 2 Hole condition factor

	β
Open holes	1.0
Lock bolt (steel)	0.75
Rivets	0.75
Threaded bolts	0.75−0.9
Taper-Lok	0.5
Hi-Lok	0.75

Figure 3 Hole Clearance Factor

A template has been developed to calculate bearing stress concentration factor, bearing stress distribution factor, bypass stress concentration factor and maximum local stress.

Inputs

i. Fastener Data

a. Diameter of the fastener
b. Youngs' Modulus

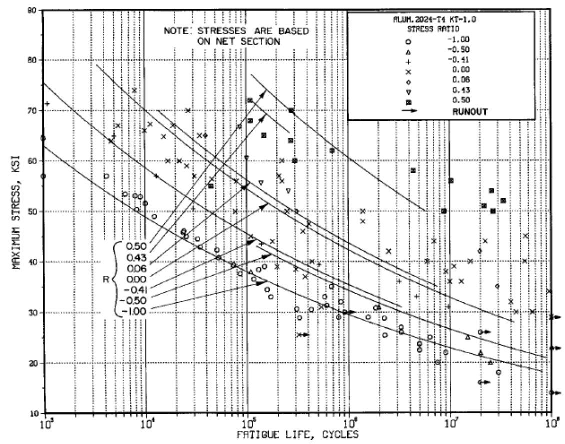
ii. Plate Data

a. Thickness of plate 1
b. Width of the plate 1
c. Youngs' modulus of Plate1
d. Thickness of plate 2
e. Youngs' modulus of plate 2
f. Type of hole
g. Number of Fasteners
h. Number of rows
i. Type of hole
j. Hole created in

Material – Aluminum T4-2024
Youngu's modulus = 10600 ksi
Fastener diameter = 0.1875"
Type of hole – Rivets
Hole created in - Non Cold worked holes

How does it work?

i. Bearing load, bypass load, hole clearance factor are calculated
ii. A matrix is developed to calculate R values i.e., R_1 to R_n
iii. After Calculation of maximum stress, stress concentration factors are calculated for all the given load cases.
iv. Life has been calculated using S-N curves from



2.3.3.4 S-N Curves of Aluminium Clad T- 2024

Figure 5 S-N curves for notched, Kt=1.0

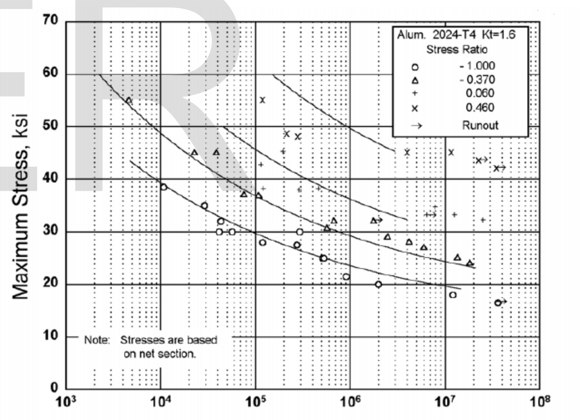
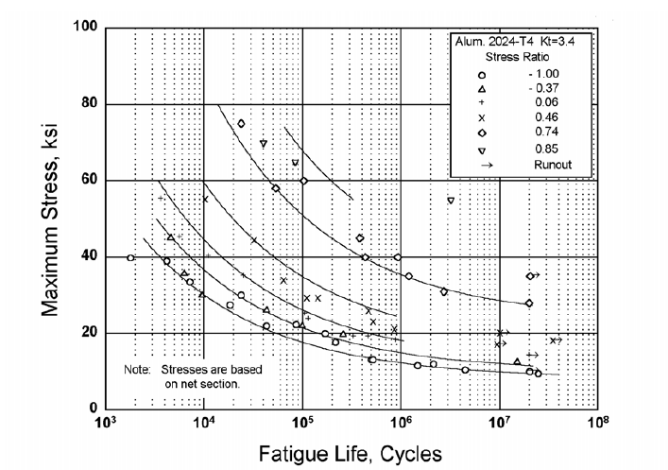


Figure 6 Figure 8 60 S-N curves for notched, Kt=3.4



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3 Results

3.1 Output

Conversion of random amplitude stress history to Constant amplitude stress history

Load case number	Stress Range	Stress Amplitude	Mean stress	Min Stress	Max Stress	No. of Cycles
1	8.33543	4.167715	65.1867	61.019	69.3544	199.889
2	7.04399	3.521997	65.5582	62.0362	69.0802	310.282
3	8.58854	4.294272	65.9986	61.7043	70.2928	193.071
4	8.79331	4.396653	65.3826	60.986	69.7793	245.821
5	10.4069	5.203468	61.7684	56.5649	66.9718	91.0483
6	8.45433	4.227165	65.3602	61.133	69.5874	239.688
7	7.48255	3.741275	64.9206	61.1794	68.6619	264.79
8	8.3064	4.153201	67.5732	63.42	71.7264	228.808
9	8.39469	4.197346	63.0053	58.808	67.2027	279.999
10	8.74683	4.373416	62.0664	57.693	66.4398	238.444
11	8.47475	4.237375	66.9207	62.6834	71.1581	283.438
12	7.92036	3.960181	65.55	61.5899	69.5102	301.702
13	8.49758	4.248788	65.033	60.7842	69.2818	205.937
14	7.58529	3.792645	65.8294	62.0368	69.6221	311.197
15	9.50481	4.752406	65.052	60.2996	69.8044	221.048

Table 4-1 Fmax Values

Life of Fastener

Load Case number	cycles for failure
1	18618.73755
2	11994.15929
3	19276.30534
4	15139.61672
5	40877.16245
6	15527.04367
7	14055.01521
8	16265.40299
9	13291.50473
10	15608.08621
11	13130.20916
12	12335.29415
13	18071.9447
14	11958.90074
15	16836.45904

4 Conclusion

The template was tested with Garuda's official template to calculate life

i. The results generate here were more accurate
ii. The time taken by this template was 1/10th of the time taken by the Garuda's template.
iii. As the input data generated is random, the cycles for failure are also random. The same load history data is given as an input to Garuda official template for the purpose of verification, results were same.

5 Acknolegments

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