Report GS6 July 2011

<u>Fatigue life analysis of RotorSport UK Rotor Blade MkII</u>

Summary of fatigue calculations performed using a stress spectrum measured from strain gauges mounted on a new design of rotor and using bolted joint ESDU data from light load transfer and lug geometries

P E Irving, J Doucet
Cranfield University

Background

This document describes further calculations on the bolted attachment joint of a rotor blade from Gyroplanes operated by RotorSport UK. Previous reports [1-5] documented 2 fatigue failures in the original design of rotor blade bolted joint and have conducted fracture mechanics analysis and calculations of the overall fatigue life [3-4] using supplied stress spectrum data measured on the rotor blade together with published data on the fatigue lives of bolted joints in aluminium with similar geometries. A further report [5] modified the fatigue lives calculated in [4] to take account of slight changes in the gauge factor used to convert from strains to stresses, and changes in the duration of manoeuvres making up the one hour flight.

This report describes the fatigue analysis performed using strain data gathered on a new design of rotor for the Gyroplane during a service load measurement exercise. The techniques used in the fatigue life prediction were the same as those used in [4] and [5], and the constant amplitude fatigue data used as input to the analysis was the same as in the previous analyses.

Stress spectra

The recordings of strain made during service of the new design of rotor were received on 30 June 2011 in an email from Rotorsport UK. No details of the data acquisition exercise were communicated. The strain gauge was stated as located outboard of the outermost bolt in the joint and was on the lower blade surface. It was stated that this gauge output could be considered as the remote stress input to the bolted joint. As in the stress history data supplied in the fatigue analysis of the current design of rotorblade [4,5] the data were in 3 groups.

(1) Strain & stress history for take off, climb, descent and land -total duration 266 seconds. In the fatigue calculation this stress history was repeated once

(2) 60° turns, two turns, duration 60 seconds, In the fatigue analysis this was repeated 5 times to represent 10 turns

(3) General flight, duration 340 seconds; In the fatigue analysis this was repeated 9 times.

With repeats, this totalled 3626 seconds- 26 seconds over the 1 hour.

This makeup was different from the previous spectrum for the Mark I rotor in that the takeoff and land section occupied 266 seconds instead of 180 seconds, and the general flight occupied 340 seconds instead of 74 seconds. Consequently the general flight was repeated only 9 times instead of 43 times to make up the 1 hour flight.

A comparison of the stress history plotted against time for the old and new designs of rotor for these 3 flight types is shown in figures 1, 2 and 3.

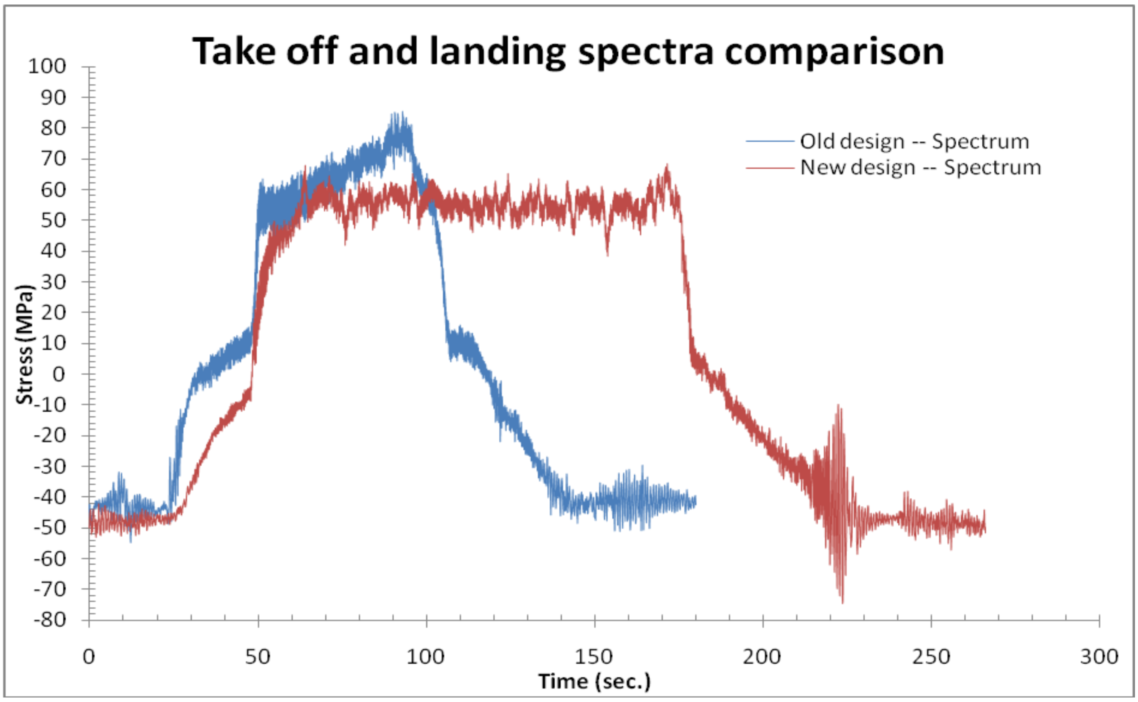


Figure (1) Plot of stress Vs flight time for take off climb, descent and land for old and new blade designs

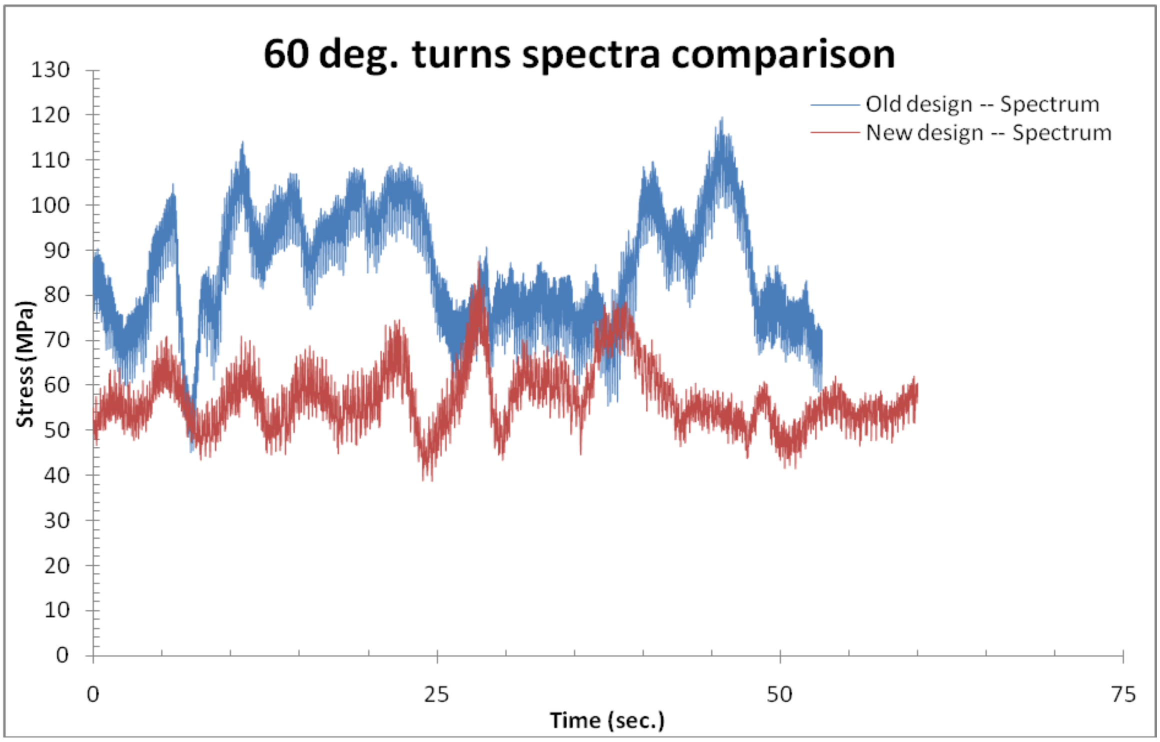


Figure (2) plot of stress Vs flight time for 2 60 ° banked turns for the old and dew blade designs

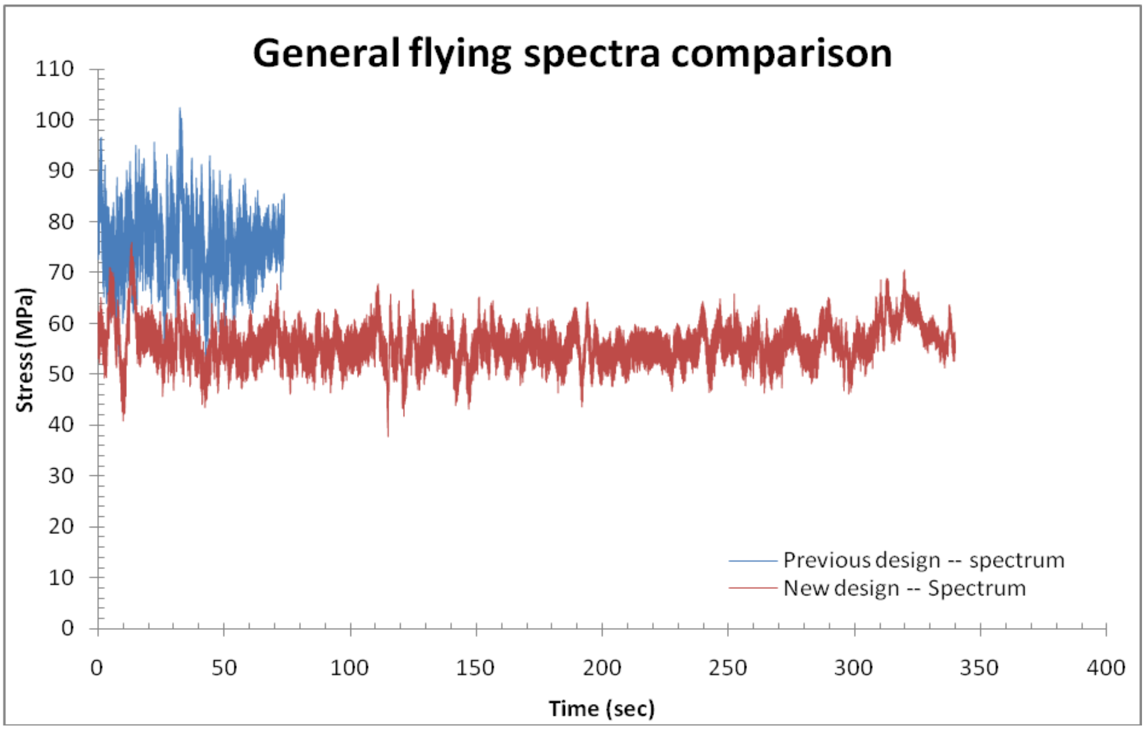
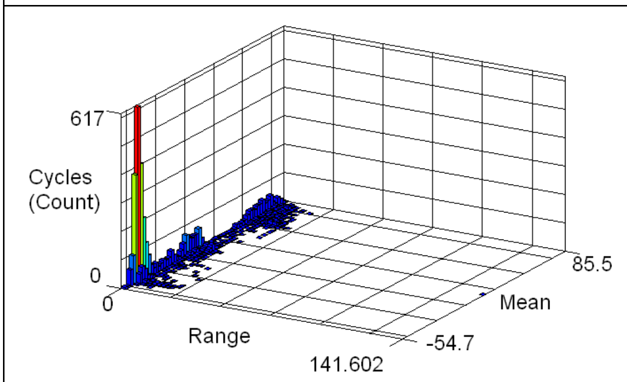


Figure 3 Plot of stress history Vs flight time for general flight for old and new designs of rotor

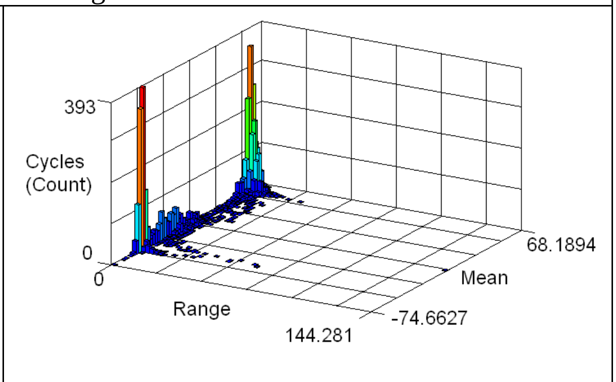
It can be seen that in all 3 flight types the strains in the new design are reduced compared with the strains in the old design of blade. This is true for both the mean stresses, and the range of the stress cycles

Figures 4, 5 and 6 show histograms of the rainflow cycle count for each of the 3 types of flight. The X and Y axes on each chart represent the range and the mean of individual cycles, the z axis shows the number of cycles of each range and mean.

Rainflow counting



Old design



New design

Figure 4 Histograms of the stress spectrum produced by the rainflow cycle count of the stress time histories from new and old designs of blade. Take off and land sequence; the range and mean stress values are in MPa.

Old spectrum max = 85.5 MPa and min = -54.7 MPa
New spectrum max = 68.2 MPa and min = -74.7 MPa

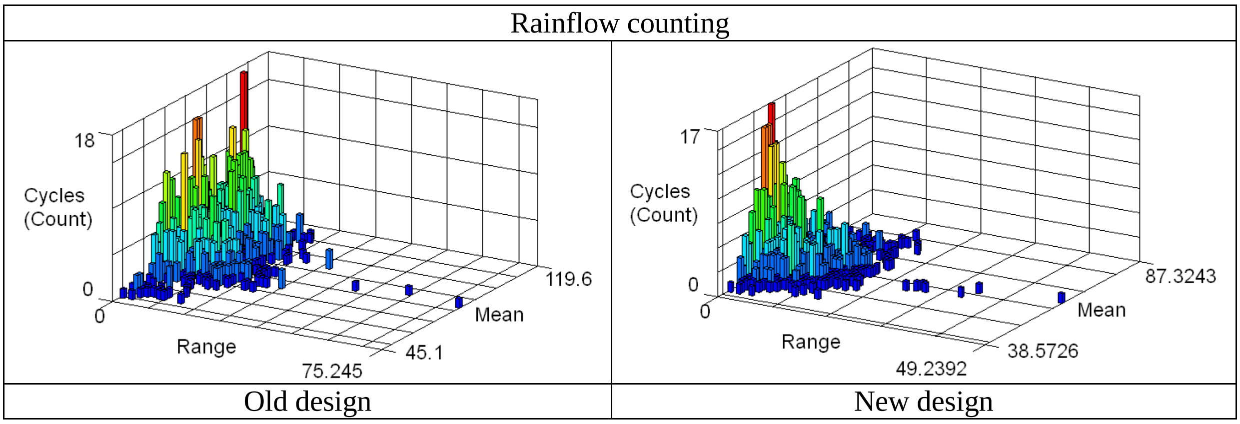


Figure 5 Histograms of the stress spectrum produced by the rainflow cycle count of the stress time histories from new and old designs of blade. 60 ° banked turn sequence; the range and mean stress values are in MPa.
Old spectrum max = 119.6 MPa and min = 45.1 MPa
New spectrum max = 87.3 MPa and min = 38.6 MPa

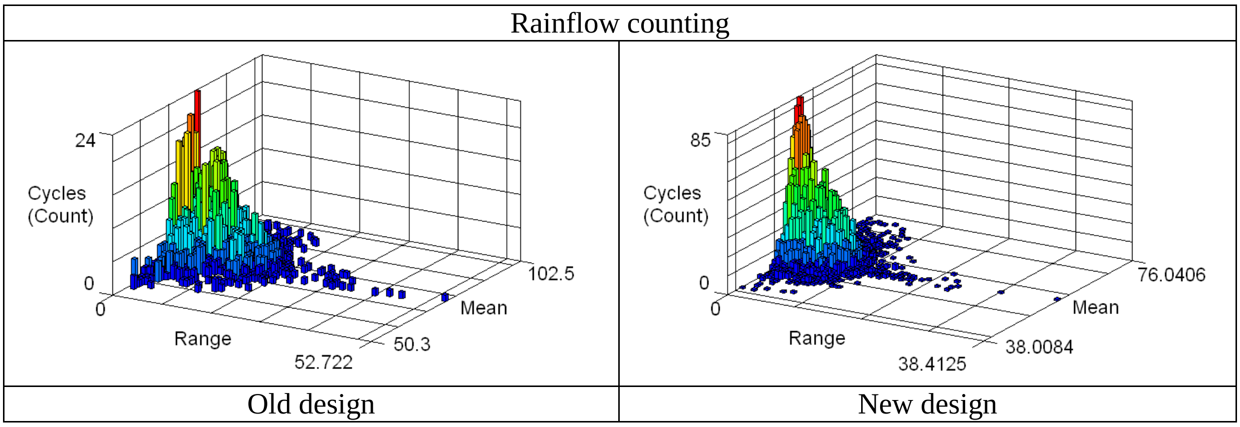


Figure 6 Histograms of the stress spectrum produced by the rainflow cycle count of the stress time histories from new and old designs of blade. General flight sequence; the range and mean stress values are in MPa.

Old spectrum max = 102.5 MPa and min = 50.3 MPa
New spectrum max = 76.04 MPa and min = 38.01 MPa

The histogram cycles counts confirm the impressions of the stress -time histories; that the stresses and stress ranges measured on the new design of rotor blade are significantly less than those measured on the old design of blade.

Constant amplitude S-N fatigue data

The same constant amplitude S- N data was used as input to the fatigue analysis as was used in the previous analyses in [4] and [5] . Data sources were ESDU data items numbers 89046 for light load transfer aluminium bolted joints[6] and number 80007 for aluminium lugs [7]. It will be recalled that the ESDU S-N mean data line for lugs is almost identical to the mean data lines for other published fatigue data [8,9] for aluminium bolted joints of similar geometries, once the lines have all been corrected to the same common R ratio. This strongly suggests that the constant amplitude fatigue properties of the bolted blade joint is similar to those of lugs and other medium and heavy load transfer joints rather than the light load transfer fatigue properties which are very different.

The constant amplitude fatigue lines used are shown in figure 7.

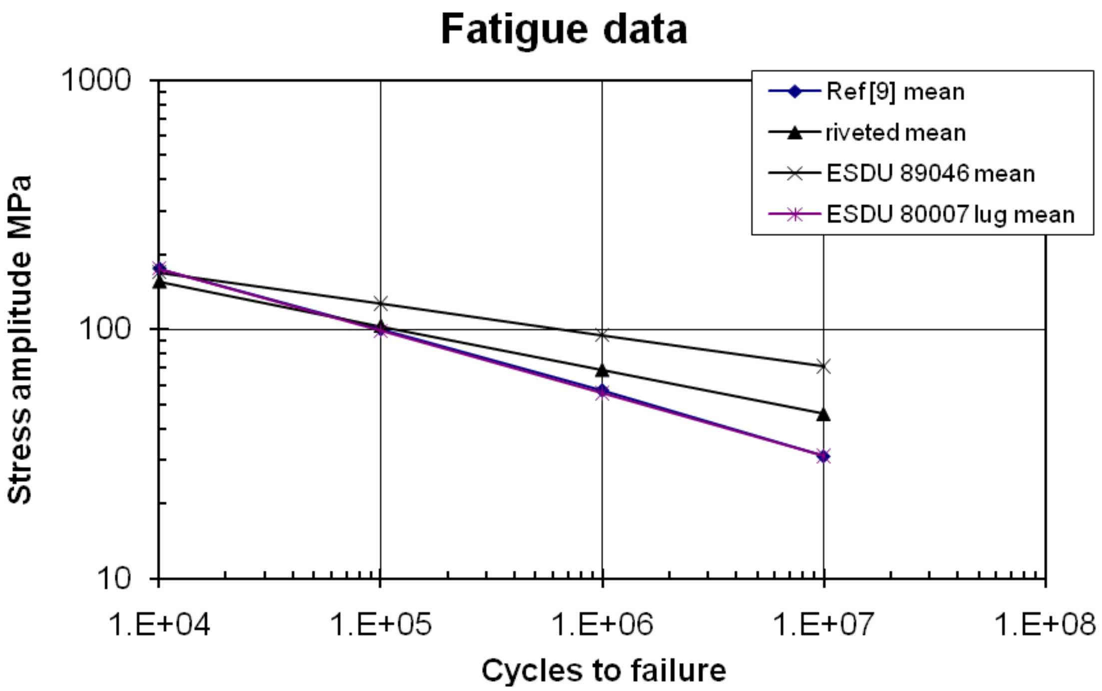


Figure (1) Plot of stress amplitude Vs fatigue life for constant amplitude data from ESDU items 89046 (light load transfer) and 80007 (pin loaded lugs), Cranfield riveted data set and data from references [8] and [9] are also shown . Mean lines representing 50% probability of failure are shown.

Fatigue life calculations using the new spectrum and constant amplitude S-N data

Fatigue life calculations were performed as described in [4] using the supplied spectrum together with ESDU constant amplitude data for aluminium lugs [6] and for light load transfer lugs [7]. The life calculations were performed as before using Miners proportional damage summation with failure assumed to occur at a damage sum of unity, with mean stress corrections applied using the Goodman rule. The predicted lives for the new spectrum are shown in table I below.

TABLE I

S-N data type	**Old spectrum mean (hours)**	**Old spectrum mean /5 (hours)**	**New design spectrum**	
			Mean life (hours)	Mean life /5 hours
S-N rivet	2727	545	16,738	3348
ESDU light load	9497	1899	190921	38184
ESDU lug	593	118	8,970	1794

It can be seen from table I that the new blade design has a fatigue life increased by a factor of between 15 and 20, resulting in mean fatigue lives for the light loaded bolts of 190,921 flight hours and for the lug data 8,970. Following the same procedure as before to calculate a safe life of factoring the mean numbers by 5 and taking a geometric mean of the factored life for light load transfer and lug data produces a recommended safe life of 8277 flight hours.

Conclusions

(1) The new design of rotorblade has service stress spectra which are significantly reduced in both range and mean from the values found in the original design of rotorblade.
(2) The reduced stresses result in increased predicted fatigue lives by a factor of 15-20 times. The recommended safe life on the new blade design is 8000 flight hours.

References

[1] N Smyth , P E Irving, “Report on investigation of crack in Gyroplane rotor” Cranfield University report GS1 to RotorSport UK September 2010
[2] N Smyth , P E Irving, “Report on investigation of crack in Gyroplane rotor” Cranfield University report GS2 to RotorSport UK December 2010
[3] N Smyth, P E Irving J Doucet, “Fatigue life analysis of a RotorSport UK Rotorblade” Cranfield University Report GS3 to RotorSport UK April 2011.
[4] P E Irving “Fatigue life analysis of Rotorsport UK rotor blade” Cranfield University report GS4 to Rotorsport UK April 2011.
[5] P E Irving, J Doucet “Fatigue life analysis of Rotorsport UK rotor blade” Cranfield University report GS5 June 2011.
[6] ESDU data item 80007 “ Endurance of aluminium alloy lugs with nominally push fit pins (tensile mean stress) “ ESDU May 1980.
[7] ESDU data item 89046 “Fatigue life of aluminium alloy joints with various fastener systems low load transfer” ESDU November 1989
[8] B Atzori P Lazzerin M Quaresimin “A re analysis on Fatigue data of aluminium alloy bolted joints” Int J Fat vol 19 pp 679-588 (1997).
[9] R B Heywood “Designing against fatigue” Chapman & Hall 1962 p 204 figure 10.5