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REFERENCE TABLE FOR AIRCRAFT DURABILITY LOSSES CAUSED BY DIFFERENT DEGREES OF RUNWAY ROUGHNESS

INTRODUCTION

In the previous bulletin (Vol.20, Bulletin 3) the topic of Aircraft Fatigue Life versus Runway Roughness was discussed in an elementary fashion by introducing the basic concepts of runway bump heights and their cumulative effects on the fatigue life of any affected part of the aircraft.

The analysis of the problem of raised stresses due to runway roughness and the consequent reduction in service life due to fatigue involves several basic factors. These basic factors are:

I The S-N Exponent

II The Roughness Index

III The Percent of Stress Rise due to Increased Deflection Caused by the Vertical Bouncing Over Roughness Bumps Encountered on a Runway

In this bulletin we shall define and then discuss these three basic factors and then construct a mathematical procedure for combining the factors into a formula for the percent of ideal (smooth) life lost for different combinations of the factors.

BASIC FACTOR I: THE S-N EXPONENT

In the study of fatigue due to stresses in materials, mechanical engineers commonly employ what are known as S-N diagrams, which graphically show how fatigue life is reduced by increased stress levels. The most common type of mathematical relation employed for relating life (cycles) to stress is the Inverse Power Law, which states that

$$\text{LIFE} = \text{CONSTANT}/(\text{STRESS})^{P} ,$$

Where P = the S-N exponent
(S = Stress); N = Life (cycles)

Such a relation becomes a straight line on log-log paper, where it is customary to put Stress (S) on the vertical axis of the graph paper and the Life (N) on the horizontal axis of the same graph paper. Then the result is a graph of the type shown in Figure 1, i.e., an S-N Diagram.

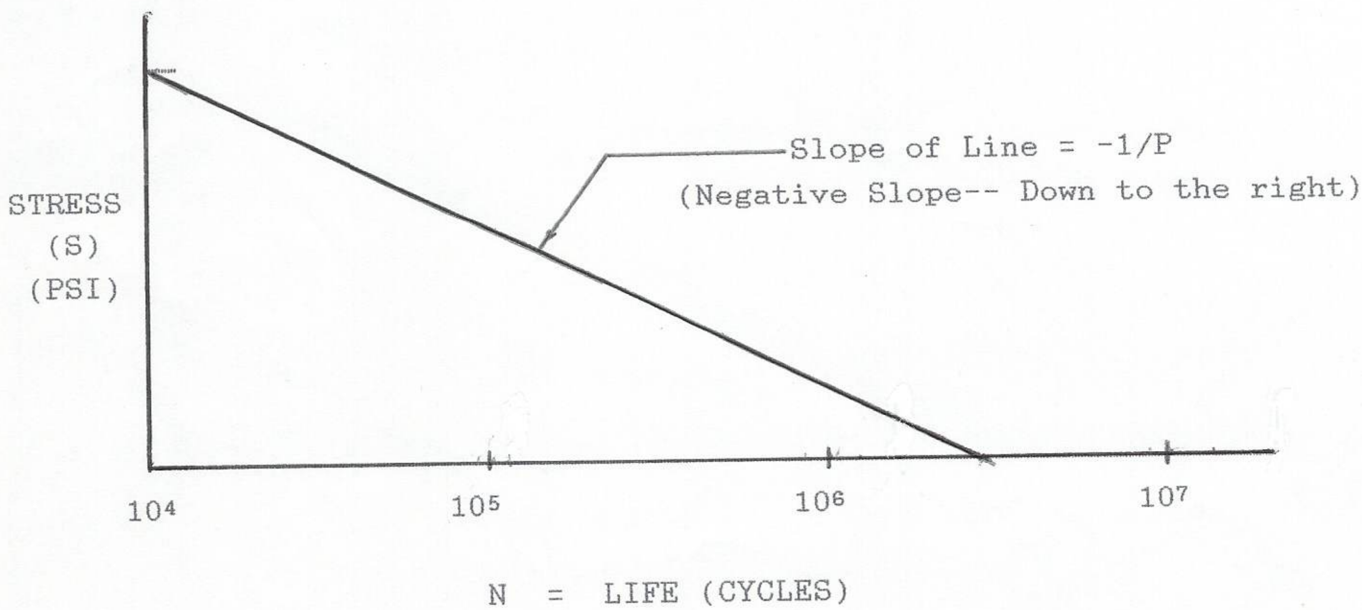
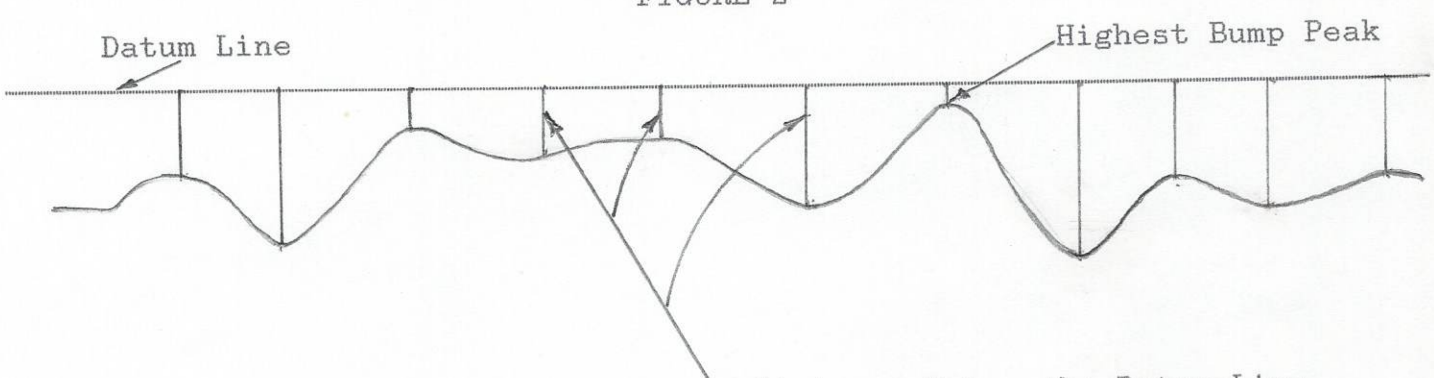


FIGURE 1

BASIC FACTOR II: THE ROUGHNESS INDEX

In order to come up with a Roughness Index for a runway we must measure bumps and depressions in the runway surface with reference to some datum line. In the previous bulletin #3 (Vol. 20) we chose a datum line above the highest peak , as sketched in Figure 2.

FIGURE 2



Each Vertical Line represents a Distance Below the Datum Line
(No. of Verical Lines = N)

The first thing to do is to calculate the average of all the indicated vertical distances of peaks and valleys below the datum line. This average then represents a smooth horizontal line for the runway if the bumps were eliminated. However, with the actual peaks and valleys present we measure how far each peak and valley is from the calculated average. We then use the S-N exponent to come up with a Roughness Index R, defined by the formula

$$R = \text{ROUGHNESS INDEX} = \left[\frac{\text{SUM OF (DEVIATION FROM AVERAGE)}^{P}}{N} \right]^{1/P}$$

This is also known as the Root Mean Pth Power of the absolute* value of deviations from the average. (P = S-N exponent)

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*A deviation is always a positive number, regarless of whether it represents a peak or a valley.

BASIC FACTOR III: PERCENT RISE IN STRESS PER 1/10 INCH OF ROUGHNESS INDEX

Every increase in Roughness Index causes a certain percentage rise in the stress on any part of the aircraft which is caused to deflect or bend more than it would on a smooth runway. In other words, if runway roughness produces bouncing actions which would induce extra deflections and, consequently, extra stresses on any affected part, such as wing, frame part, fastener, rivet, landing gear component, or a wheel assembly, it is important to know the percent of stress increase in such a part for each 1/10 inch of Roughness Index.

We choose 1/10 inch as a reference value, since a realistic Roughness Index would, in most cases, be an inch or less. By assuming different percentage levels of stress rise (such as 1%, 2%, 3% and 4%) for each 1/10 inch of Roughness Index we come up with a complete table of fatigue life losses as percentages of the ideal life possible on a perfectly smooth runway.

NOTE: The table applies only to a runway roughness in Category (B), as defined in Bulletin #3 of Volume 20. If the valleys are too narrow to accomodate an entire wheel then the valley depths must be reduced to represent the actual amount that the wheel drops down.

THE FORMULA FOR THE PERCENT OF LIFE LOST DUE TO DIFFERENT COMBINATIONS OF THE THREE BASIC FACTORS

Let P = S-N exponent

Let R = Roughness Index

Let Q = Percent Increase in Stress on a Part per 1/10 inch of Roughness Index

Let L = Percent of Ideal Life Lost on the Part Affected by Runway Roughness

Then, the Smooth Stress is multiplied by the factor

$$1 + (Q/100)(R/.1) = 1 + QR/10$$

Hence , the Smooth Life is divided by

$(1 + QR/10)^P$ (<u>NOTE:</u> We must use the S-N exponent P)

Thus, the life of the part in question drops from Smooth Life x down to $x/(1 + QR/10)^P$

The Loss of Life is then $x - x/(1 + QR/10)^P$

Hence, the Percentage of Lost Life is

$$L = 100\left[\frac{x - \dfrac{x}{(1 + QR/10)^P}}{x}\right] = 100\left[1 - \frac{1}{(1 + QR/10)^P}\right]$$

We program this formula for <u>L</u> into a computer and come up with the Table shown on Page 6.

HOW RUNWAY ROUGHNESS REDUCES AIRCRAFT FATIGUE LIFE

PERCENT OF IDEAL (SMOOTH) LIFE LOST

S - N EXPONENT	ROUGHNESS INDEX (INCHES)	FOR A STRESS RISE 1% PER .1 IN.	FOR A STRESS RISE 2% PER .1 IN.	FOR A STRESS RISE 3% PER .1 IN.	FOR A STRESS RISE 4% PER .1 IN
	.1	1.97%	3.88%	5.74%	7.54%
	.2	3.88%	7.54%	11.00%	14.27%
2	.3	5.74%	11.00%	15.83%	20.28%
	.4	7.54%	14.27%	20.28%	25.68%
	.5	9.30%	17.36%	24.39%	30.56%
	.1	2.94%	5.77%	8.49%	11.10%
	.2	5.77%	11.10%	16.04%	20.62%
3	.3	8.49%	16.04%	22.78%	28.82%
	.4	11.10%	20.62%	28.82%	35.93%
	.5	13.62%	24.87%	34.25%	42.13%
	.1	3.90%	7.62%	11.15%	14.52%
	.2	7.62%	14.52%	20.79%	26.50%
4	.3	11.15%	20.79%	29.16%	36.45%
	.4	14.52%	26.50%	36.45%	44.77%
	.5	17.73%	31.70%	42.82%	51.77%
	.1	4.85%	9.43%	13.74%	17.81%
	.2	9.43%	17.81%	25.27%	31.94%
5	.3	13.74%	25.27%	35.01%	43.26%
	.4	17.81%	31.94%	43.26%	52.39%
	.5	21.65%	37.91%	50.28%	59.81%
	.1	5.80%	11.20%	16.25%	20.97%
	.2	11.20%	20.97%	29.50%	36.98%
6	.3	16.25%	29.50%	40.37%	49.34%
	.4	20.97%	36.98%	49.34%	58.96%
	.5	25.38%	43.55%	56.77%	66.51%