A ONE-PASS METHOD FOR COUNTING RANGE MEAN PAIR CYCLES FOR FATIGUE-ETC(U)

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A ONE-PASS METHOD FOR COUNTING RANGE MEAN PAIR CYCLES FOR FATIGUE ANALYSIS

by

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SUMMARY

A one pass method for counting Range Mean Pair cycles is described. The Range Mean Pair Table which is used to represent the data generated by the method is considered with reference to its use in fatigue analysis.
**ABSTRACT**

A one pass method for counting Range Mean Pair cycles is described. The Range Mean Pair Table which is used to represent the data generated by the method is considered with reference to its use in fatigue analysis.
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1. INTRODUCTION

The interpretation of loading environment remains fundamental to many fields of fatigue investigation:

(1) life estimation;
(2) fatigue test load selection;
(3) comparison of load spectra and damage estimates between aircraft, mission type etc.;
(4) load spectra prediction for future aircraft design;
(5) sequence analysis;
(6) crack growth analysis.

Of all the cycle counting methods that exist for this purpose\textsuperscript{1} \textsuperscript{5} the Rainflow and Range Mean Pair methods are deemed the most generally useful from a theoretical point of view because both identify load cycles in terms of the stable cyclic stress-strain behaviour of the material concerned (i.e. turning points are paired that define closed hysteresis loops).\textsuperscript{5} \textsuperscript{9} However, although simpler by definition, the multipass characteristic of existing range mean pair methods has meant that they are less efficient than the one pass rainflow method for use on other than short load records.

The present paper describes a one pass method for counting range mean pair cycles that can be applied to complex load histories of unspecified lengths. The storage of range mean pair data is also discussed with particular attention to the benefits afforded by recording such information in a table. It should be noted that where load is referred to in this paper, strain, normal load factor, stress, bending moment etc., are equally applicable.

2. CYCLE DEFINITION

The basic method for the extraction of range mean pairs from a given load history is given in Reference 2 and is summarized below:

The method is to select and remove from a time ordered list of load maxima and minima (turning points), the adjacent pair having the smallest absolute difference. This is repeated until all possible pairs are removed. Each pair is then considered to constitute the peak and trough of one load cycle for which a mean and alternating load can be determined.

Though extremely simple, this procedure has an obvious limitation: it obtains only one range mean pair for each pass through a given record and thus cannot be efficiently applied to long complex histories in this form.

However, an immediate start to reducing the number of passes required is made when it is seen that this minimum difference definition identifies cycles which constitute perturbations of other larger cycles (i.e. turning points which relate to closed stress-strain hysteresis loops) and that a test based on this may be used to detect more than one range mean pair per pass. From Figure 1 it can be seen that a perturbation test may be expressed so:

for a sequence of four turning points (TP's) denoted $TP(k \rightarrow 3)$, $TP(k \rightarrow 2)$, $TP(k \rightarrow 1)$, $TP(k)$ if

$$
| TP(k \rightarrow 3) - TP(k \rightarrow 2) | < | TP(k \rightarrow 1) - TP(k \rightarrow 2) | \leq | TP(k) - TP(k \rightarrow 1) |
$$

\text{equation (A)}

the cycle $TP(k \rightarrow 2)$, $TP(k \rightarrow 1)$ constitutes a range mean pair. This will hitherto be referred to as the 'four point test'.

By advancing through the load history and considering four turning points at a time, using (A), the number of range mean pairs obtained per pass is increased although several passes are still required to process the entire load history. The refinement necessary to obtain complete processing in a single pass is realized when (A) is used repetitively as follows:

As each turning point is passed it is loaded into a turning point stack and equation (A) used to test if it identifies the previous two turning points in the stack as a range mean pair.
If a range mean pair is not detected the next turning point in the load history is loaded into the stack and the process repeated until a range mean pair is found. When this occurs the range mean pair turning points are removed from the stack, the gap closed and equation (A) used again to detect as many range mean pairs as possible e.g. if the turning point TP(A) identifies the turning points [TP(k - 1), TP(k - 2)] as a range mean pair it may similarly detect the turning points [TP(k - 3), TP(k - 4)] as a range mean pair and so on. The sequence of points for which this repetitive pairing occurs is shown in Figure 2.

In this way cycle counting proceeds through the load history with the turning point stack being progressively loaded and emptied.

In the preceding it has been shown that a four point test can be used to process a load history in a single pass. However, it can be demonstrated that the single pass characteristic itself is conducive to a further improvement in the actual test for a range mean pair.

Consider Figure 3 where the second sequence of Figure 1 has been reproduced. The four point test (equation A) would pair TP(k -1), TP(k - 2) as before. Now suppose that the same situation exists except that the TP(k - 3) is in a different position such as in Figure 3b. In this instance the one pass four point procedure would not reach TP(k) with the given sequence undisturbed since it should have removed the pair TP(k - 3), TP(k - 2) when it reached TP(k - 1). Thus the turning point TP(k - 3) can only lie where it is depicted in Figure 3a (i.e. below the load values of TP(k - 2) and TP(k - 1)) if it is to remain in the history unpaired when the four point one pass method reaches TP(k). Hence the use of the fourth point, TP(k - 3) is unnecessary in this situation and only the right hand portion of equation (A) need be used as the range pair test (hereafter called the three point test). The same argument applies to the mirror image of Figure 3 if “below” is replaced by “above” so that the three point test suffices for all cases. The decision to use either the four point or three point test in the one pass method is considered below.

3. END EFFECTS

The end effect problem is basically due to the fact that every practical load history is of a finite length and thus there must exist in every load history turning points which cannot be identified as perturbations of larger cycles simply because the turning points of those larger cycles do not occur in the given record. Hence, every range mean pair method must leave at the end of processing some unpaired “residual” turning points.

Consider Figure 6a where load histories (a) to (h) are depicted. Because the prior and subsequent load sequences for each history are unknown no range mean pair can be found in any of them (i.e. no corresponding closed stress strain hysteresis loop can be firmly identified without more information at the ends of the given sequences) and thus the conservative strategy of pairing maximum peak to minimum trough is usually adopted.

After the last turning point of the load history has been loaded into the TP stack and either the three or four point test used to check if it defines any range mean pairs, it and possibly other TP’s representing those discussed above, will remain unpaired in the TP stack. (It should be noted that the number of TP’s involved is usually very small, often only two or three, and that sequences (a) to (d) represent the residuals possible after a three point test has been used while for the four point test, (e) to (h) are also possible.)

When a four point test is used in the one pass procedure the turning point stack is emptied using the minimum trough to maximum peak method as already outlined, however when a three point test is in use, it is possible to unload the residual TP’s in the stack without changing to a different pairing process. If one considers sequences (a) to (e) of Figure 6a again, it can be seen that pairing of the turning points in the stack at the end of the load history can be accomplished by loading a large “dummy” turning point into the end of stack and using the three point test as before to pair right to left as shown in Figure 2. When the last TP is a peak the “dummy” TP is a large negative number and vice versa for a trough (e.g. – 10^30). This may necessitate further adjustments as described below.

The advantages in using the three point test for both the main processing and the end effect correction are that the computer program written to implement the method is short and simple and the execution time is similarly short even on long load histories. The disadvantage is that
in some instances the pairing of the end effect sequence is unconservative i.e. minimum trough
to maximum peak pairing does not occur.

When a load history contains an odd number of turning points one TP will obviously remain
after pairing. When the four point test is used this TP will be the peak or trough closest to
the mean of the 'residual' sequence, (e.g. one of the turning points at either end of sequences (e)
to (h) in Figure 6a) and when the three point test is used it will be the largest peak or smallest
trough in the load history. In the former instance the damage contribution is slight and can
usually be ignored, however in the latter case the damage contribution may be significant
enough to warrant adding a mean load TP to the TP stack to ensure its pairing (this is sometimes called
closing the sequence). When this nominal TP is used it is added to the stack before the dummy
to obtain conservative pairing.

For a data sequence consisting of more than one block (flight) two alternatives exist for the
application of the end effect correction. It may be used at the end of each block or at the end
of the entire sequence. The choice of either alternative is basically a philosophical one, and
may depend on many factors such as the accuracy of the data record in representing local loading
conditions e.g. for a sequence of many flights of data over which there was little change in struc-
tural condition (no crack initiation or crack growth etc.) the latter alternative may be chosen.
When the opposite is true it may be considered that applying the end effect correction at the
end of each block results in some consistency in the results (i.e. turning points are paired which
occur under similar conditions). The treatment of the 'odd' number turning point as discussed
in the previous paragraph is also relevant here as is obvious that applying the end effect correction
at the end of the entire sequence of blocks will result in only one possible 'odd' number turning
point.

One other end effect requires some consideration. Should the first and last points in the
record be considered as turning points? e.g. if Figure 7 represents an in-service load sequence
it may be argued that points A and B constitute turning points though the influence of points
A and B on the pairing is small in all cases except where the data record is very short. One
convenient method of 'closing' a sequence uses point B as follows: if the turning point stack
contains an odd number of turning points after the last true turning point has been loaded and
used to detect as many range mean pairs as possible, then point B is considered a turning point
and is loaded into the stack and used to test for range mean pairs. The pairing of the residual
history proceeds as before for the specific test used. When the reverse is true and the stack con-
tains an even number of turning points after the last true turning point has been considered
then point B is not used and end correction proceeds.

Now consider the pairs obtained when the three point one pass procedure is used to cycle
count each of the turning point sequences shown in Figure 6a using the 'nominal' and 'dummy'
TP's as relevant. The results are shown in Figure 6b and for all sequences baring c, g, f max-
peak to min-trough type pairing occurs. The influence of the less conservative pairing demon-
strated in sequences c, g, f on fatigue damage estimates is small for all but short load records.
In the latter case a four point test is substituted for a three point test and a max-peak to min-
trough pairing method used to pair off the g, e, f, h type sequences that will remain when all
range mean pairs have been removed.

The complete one pass counting method obtained by correcting the basic procedure for end
effects as above is shown schematically in Figure 8.

4. RANGE MEAN PAIR TABLE

Because of the large amount of RMP data that can be generated from long data records
a means of recording such data efficiently is desirable. The range mean pair table fulfills this
requirement and also provides a form which, as is shown in the next section, proves useful in
many areas of fatigue analysis.

The table is simply a half array with axes of peak and trough load obtained by grouping
the range mean pairs obtained from the load history into a number of cells.

Suppose that the maximum possible load existing in a given record will not exceed the
value $L_{max}$ and the minimum possible load will not be less than $L_{min}$. Then dividing this load
range into $n$ levels to give the level size $LS$, provides a basis for grouping the range mean pairs.
Consider Figure 9 where the range mean pair of load $x_1$ to load $x_2$ is shown to be represented
on the basis of levels by the range mean pair of level \((i \cdot 1)\) to level \((i \cdot 5)\). Hence the cell in the range mean pair table corresponding to this range mean pair would record a count of one. At the end of processing of a load history all range mean pairs whose trough and peak were similarly in levels \((i \cdot 1)\) and \((i \cdot 5)\) respectively would be represented in the table as a corresponding count in the same cell (Fig. 10). Similarly all other range mean pairs generated by the counting method would be grouped into their respective cells in the range mean pair table.

When the information stored in the range mean pair table is required, the load data is calculated using the minimum load \((L_{\text{min}})\) and level size (LS) values e.g. the counts shown in Figure 10 represent range mean pairs from a trough of load \(L_{\text{min}} \cdot (i \cdot 1 - 0.5)\)LS to a peak of load \(L_{\text{min}} \cdot (i \cdot 5 - 0.5)\)LS. The mean and alternating loads can then be calculated from these values accordingly. It should be noted that:

(i) The leading diagonal of the range mean pair table represents "degenerate" range mean pairs i.e. range mean pairs for which both the peak and trough lie within the one level. As the alternating load for these grouped range mean pairs is zero when determined by assigning load values to their peaks and troughs as above, they are not usually used in a fatigue damage calculation based on the range mean pair table (the S-N data used will determine if the range mean pair data contained in this diagonal should be included in the damage calculation in which case a conservative estimate of alternating load such as LS/4 could be used.)

(ii) Diagonals parallel to the leading diagonal (down left to right) represent range mean pairs with the same alternating load.

(iii) Conversely, diagonals in the opposite sense (up left to right) represent range mean pairs with the same mean load value. (Fig. 11).

(iv) The range mean pair table shown in Figure 10 as a half array can also be configured as a vector to save computer storage space.

(v) The number of levels into which the load range is divided determines the accuracy of the table in recording the range mean pairs discussed below.

In Figure 10 range mean pairs with troughs in level \(i \cdot 1\) and peaks in level \(i \cdot 5\) are shown recorded in the range mean pair table by the respective number of counts \(K\). These range mean pairs are assumed to be distributed within the given levels such that their mean value in load terms can be taken to be the mean value of those levels. Thus the smaller the level size used (i.e. the larger the number of levels) the smaller the error inherent in this assumption. A typical example of the effect of the number of levels chosen for the table on its accuracy is illustrated in Figure 12 where fatigue damage estimated for a structural component has been calculated from the individual range mean pairs of an in service record and compared with that obtained from range mean pair tables of the same data. The 'zig-zagging' effect within the envelope shown in Figure 12 is a result of the range mean pairs suddenly crossing level boundaries as the number of levels within the tables is changed. Figure 12 also indicates the rapid convergence of damage estimates obtained from the tables to the correct value as the number of levels is increased. Experience has shown thirty or more levels to be preferable for range mean pair table damage estimates though sufficient accuracy is often obtained with as few as ten levels. The table's accuracy can be checked by comparing damage calculated at processing time with that obtained from the completed table.

5. RANGE MEAN PAIR TABLE USE

The range mean pair table is used primarily for fatigue life estimation although it is useful in some of the other areas of fatigue interest given in the introduction.

Fatigue damage estimates can be obtained from the data contained in the table by calculating the damage attributable to each cell on the basis of its mean and alternating load and on the counts recorded therein. (degenerate diagonal cells are ignored) and summing in accordance with Miner's rule.

The range mean pair table also facilitates damage density calculations because of the way in which it presents ordered sets of mean and alternating load. (Fig. 11).

Fatigue meter counts of normal load factor form the basis of many in-service fatigue damage estimates. These counts can be simulated from range mean pair tables of vertical acceleration or related parameters. For a fatigue meter of \(x\) thresholds (where \(x\) is typically 8) the counts
recorded for each threshold can be found by summing all range mean pair counts within the area of the table bounded by those levels which encompass the corresponding 'cocking' and 'firing' levels, denoted respectively $L_r$ and $L_f$. This is demonstrated in Figure 13 where the smallest range mean pairs capable of registering a count for the two types of thresholds ($L_f > L_r$ and $L_f < L_r$ respectively) are shown. Thus for either threshold type a range mean pair having a peak in a higher level and a trough in a lower level than the minimum required would also register a count for that threshold. Hence the total number of counts registered for the given fatigue meter threshold is the sum of all such range mean pairs in the table, i.e. the sum of all range mean pairs in the table bounded by the respective 'cocking' and 'firing' levels.

For a fatigue meter that 'fires' all thresholds at the same value (typically 1 g) the summation can be performed cumulatively. This is illustrated in Figure 14 for positive 'cocking' values. The same procedure is used to sum vertically for negative values.

Where the objective is not to simulate the performance of a particular fatigue meter but to provide data for spectra a slight modification is utilized. From Figure 15a summing proceeds cumulatively using every level in the range mean pair table (in effect representing a fatigue meter of $n$ thresholds and variable 'cocking' and 'firing' values). This produces counts for spectra as shown in Figure 15b. Spectra for parameters other than normal load factor are produced in the same way as above from their respective range mean pair tables.

Two examples demonstrating the application of the one pass range mean pair method are given in the Appendix.

6. CONCLUSION

A method for counting range mean pair cycles has been described that can be used to process a load history of any unknown length in a single pass. The obvious benefits of this method lie in its simple implementation, speed and application to unconditioned data, (i.e. no adjustment of a load history such as setting maximum load first etc. is required).

The range mean pair table which records data two dimensionally has also been discussed with particular attention to the manner in which is can be used to enhance the capabilities of the one pass method to process and store very large amounts of data.
REFERENCES


6. Engineering Sciences Data Unit — "Fatigue life estimation under variable amplitude loading". ESDU Fatigue Sub Series, Item 77004.


When the one-pass method reaches TP(K) with the contents of the turning point stack represented as shown:
- TP(K) and TP(K−3) will detect the RMP TP(K−1), TP(K−2)
- TP(K) and TP(K−5) will detect the RMP TP(K−3), TP(K−4)
- TP(K) and TP(K−7) will detect the RMP TP(K−5), TP(K−6)

i.e.: Repetitive firing of RMPs can occur whenever a RMP test is used.

FIG. 1: THE PERTURBATION DEFINITION OF THE RANGE MEAN PAIR AND ITS CORRESPONDENCE TO STABLE CYCLIC STRESS-STRAIN HYSTERESIS LOOPS

FIG. 2: REPETITIVE PAIRING OF RANGE MEAN PAIR CYCLES BY A ONE-PASS METHOD
This type of stack cannot occur; only type (a)

FIG. 3: DERIVATION OF THE THREE-POINT TEST—SEE CYCLE DEFINITION

FIG. 4: THREE-POINT SEQUENCES
\[|TP(K-1) - TP(K-2)| \leq |TP(K) - TP(K-1)|\]

\[|TP(K-3) - TP(K-2)| \geq |TP(K-1) - TP(K-2)| \leq |TP(K) - TP(K-1)|\]

FIG. 5: THE THREE-POINT AND FOUR-POINT RANGE MEAN PAIR TESTS
FIG. 6: ILL-DEFINED RANGE MEAN PAIR SEQUENCES WITH THREE-POINT TEST PAIRING RESULTS
FIG. 7: INITIAL AND FINAL TURNING POINTS
FIG. 8: THE ONE-PASS METHOD USING THREE- AND FOUR-POINT RANGE MEAN PAIR TESTS
**FIG. 9: TABLE "GROUPING" OF RANGE MEAN PAIRS**

- **Level number**
  - \( L_{MAX} \)
  - \( n \)
  - \( n - 1 \)
  - \( n - 2 \)

- **Level boundary**
  - \( L_{MIN} \)

- **Level size**
  - \( 1 \)
  - \( 2 \)
  - \( 3 \)

- **RMP(\( x_1, x_2 \))**
  - \( i \)
  - \( i + 1 \)
  - \( i + 2 \)
  - \( i + 3 \)
  - \( i + 4 \)
  - \( i + 5 \)

- **A load value well above the maximum load expected in the load record**

- **Maximum load actually occurring**

- **Represented in range mean pair table as**
  - \( RMP(i + 1, i + 5) \)
  - See Fig. 10.

- **A load value well below the minimum load expected in the load record**

- **Minimum load actually occurring**

- **Level size-**
  - \( n \)
  - \( n - 1 \)
  - \( n - 2 \)

- \( LS = \frac{(L_{MAX} - L_{MIN})}{n} \)
FIG. 10: THE RANGE MEAN PAIR TABLE

FIG. 11: RANGE MEAN PAIR TABLE CHARACTERISTICS
Damage estimate calculated from individual range mean pairs

Envelope of damage estimates from range mean pair tables

FIG. 12: EFFECT OF NUMBER OF LEVELS ON ACCURACY OF THE RANGE MEAN PAIR TABLE
Fatigue meter threshold for which firing valve is greater than cocking valve i.e. $L_f > L_c$

Fatigue meter threshold for which cocking valve is greater than firing valve i.e. $L_f < L_c$

Minimum range mean pairs capable of registering a count for the given threshold type.

Fatigue meter count for respective threshold type is found by summing all counts in the table bounded by the $L_c$ & $L_f$ levels.

FIG. 13 - GENERATING FATIGUE METER COUNTS FROM THE RANGE MEAN PAIR TABLE.
FIG. 14 – CUMULATIVE COUNTING FOR FATIGUE METER WITH j 'COCKING' VALUES AND A SINGLE 'FIRING' VALUE.
FIG. 15 – PRODUCING SPECTRA FROM RANGE MEAN PAIR TABLES.
FIG. 16: TURNING POINT SEQUENCE FOR EXAMPLE 1
APPENDIX

In the following pages two sample load histories are used to demonstrate the one pass range mean pair method. In the first sequence, shown in Figure 16, the procedure is outlined step by step using a schematic turning point vector. In the second example a more realistic counting situation is proposed.
Example 1

The turning point sequence shown in Figure 16 is, in load terms:

<table>
<thead>
<tr>
<th>Turning Point</th>
<th>Cycle Sequence in Turning Point Stack</th>
<th>No. of Turning Points</th>
<th>Turning Point Stack</th>
<th>Range Mean Pairs</th>
</tr>
</thead>
<tbody>
<tr>
<td>85</td>
<td></td>
<td>1</td>
<td>85</td>
<td></td>
</tr>
<tr>
<td>-60</td>
<td></td>
<td>2</td>
<td>85 -60</td>
<td>-60 85</td>
</tr>
<tr>
<td>150</td>
<td></td>
<td>3</td>
<td>85 -60 150</td>
<td></td>
</tr>
<tr>
<td>98</td>
<td></td>
<td>2</td>
<td>150 98</td>
<td></td>
</tr>
<tr>
<td>350</td>
<td></td>
<td>3</td>
<td>150 98 350</td>
<td>98 150</td>
</tr>
<tr>
<td>-256</td>
<td></td>
<td>2</td>
<td>350 -256</td>
<td></td>
</tr>
<tr>
<td>265</td>
<td></td>
<td>3</td>
<td>350 -256 265</td>
<td></td>
</tr>
<tr>
<td>-52</td>
<td></td>
<td>4</td>
<td>350 -256 265 -52</td>
<td></td>
</tr>
<tr>
<td>120</td>
<td></td>
<td>5</td>
<td>350 -256 265 -52 120</td>
<td></td>
</tr>
<tr>
<td>80</td>
<td></td>
<td>6</td>
<td>350 -256 265 -52 120 80</td>
<td></td>
</tr>
<tr>
<td>510</td>
<td></td>
<td>7</td>
<td>350 -256 265 52 120 80 510</td>
<td>80 120 52 265 256 350</td>
</tr>
</tbody>
</table>
End Effect Correction: Odd number of TP's remaining — Add Nominal TP $\phi = 0$, say

Last TP is a trough $\therefore$ Dummy TP $= 10^{30}$

**: Range Mean Pairs obtained by Three Point Test:

<p>| | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>-60</td>
<td>85</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>98</td>
<td>150</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>80</td>
<td>120</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-52</td>
<td>265</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-256</td>
<td>350</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>295</td>
<td>303</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>260</td>
<td>320</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>80</td>
<td>268</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>78</td>
<td>150</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>210</td>
<td>290</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>110</td>
<td>155</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>320</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>420</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>95</td>
<td>510</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Using the same procedure for a Four Point Test gives:

98 150
80 120
52 265
295 303
260 320
80 268
78 150
210 290
110 155

with the Turning Point Stack containing the following at the end of the sequence:

End Effect Correction: Odd number of TP's remaining: Add Nominal TP \( \phi \) = 0 say, and pair using peak-trough counting
Comparison of Results:

<table>
<thead>
<tr>
<th>3 Point Test</th>
<th>4 Point Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>98 150</td>
<td>98 150</td>
</tr>
<tr>
<td>80 120</td>
<td>80 120</td>
</tr>
<tr>
<td>-52 265</td>
<td>-52 265</td>
</tr>
<tr>
<td>295 303</td>
<td>295 303</td>
</tr>
<tr>
<td>260 320</td>
<td>260 320</td>
</tr>
<tr>
<td>80 268</td>
<td>80 268</td>
</tr>
<tr>
<td>78 150</td>
<td>78 150</td>
</tr>
<tr>
<td>210 290</td>
<td>210 290</td>
</tr>
<tr>
<td>110 155</td>
<td>110 155</td>
</tr>
</tbody>
</table>

Cycles which can be identified as perturbations of larger cycles i.e. range mean pairs.

| -60 85       | -60 350      |
| -256 350     | -256 510     |
| 0 320        | 0 85         |
| 30 420       | 30 320       |
| -95 510      | -95 420      |

Cycles which cannot be identified as perturbations of larger cycles.
Example 2

The record shown overleaf contains two channels of data recorded during one flight of a monitored aircraft. The two channels, respectively normal acceleration by 100 and micro-strain at an important location, have been processed using the three point one-pass method.

Records of both sets of range mean pair data are listed. However, as pointed out previously, range mean pair tables present a more condensed and convenient form for the same data. The table of range mean pair data for channel one is included.
| -30 | -18 | -6  | 6   | 18  | 30  | 42  | 54  | 66  | 78  | 90  | 102 | 114 | 126 | 138 | 150 | 162 | 174 | 186 | 198 | 210 | 222 | 234 | 246 |
|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
|  0  |  0  |  0  |  0  |  0  |  0  |  0  |  0  |  0  |  0  |  0  |  0  |  0  |  0  |  0  |  0  |  0  |  0  |  0  |  0  |  0  |  0  |  0  |  0  |
|  0  |  0  |  0  |  0  |  0  |  0  |  0  |  0  |  0  |  0  |  0  |  0  |  0  |  0  |  0  |  0  |  0  |  0  |  0  |  0  |  0  |  0  |  0  |  0  |
|  0  |  0  |  0  |  0  |  0  |  0  |  0  |  0  |  0  |  0  |  0  |  0  |  0  |  0  |  0  |  0  |  0  |  0  |  0  |  0  |  0  |  0  |  0  |  0  |
|  0  |  0  |  0  |  0  |  0  |  0  |  0  |  0  |  0  |  0  |  0  |  0  |  0  |  0  |  0  |  0  |  0  |  0  |  0  |  0  |  0  |  0  |  0  |  0  |
|  0  |  0  |  0  |  0  |  0  |  0  |  0  |  0  |  0  |  0  |  0  |  0  |  0  |  0  |  0  |  0  |  0  |  0  |  0  |  0  |  0  |  0  |  0  |  0  |
|  0  |  0  |  0  |  0  |  0  |  0  |  0  |  0  |  0  |  0  |  0  |  0  |  0  |  0  |  0  |  0  |  0  |  0  |  0  |  0  |  0  |  0  |  0  |  0  |

**Total Number of Range Pairs = 36**

*RANGE PAIR TABLE FOR DATA FROM CHANNEL 1. ie. $N_Z \times 100.$*
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