CLASSICAL CRYPTOGRAPHY COURSE
BY LANAKI

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LECTURE 15

STATISTICAL ATTACKS

SUMMARY

Lecture 15 considers the role and influence that statistics and probability theory exert on the cryptanalysis of unknown ciphers. We develop our subject by the following references: [FRE3], [SINK], [MAST], [ELCY], [GLEA], [KULL].

DISCUSSION

As you may know, William F. Friedman and Dr. Solomon Kullback were the first Americans to apply Probability Theory and Applied Statistics to the Science of Cryptanalysis. Their achievements were so dynamic that American Crypee's were able to read the secret messages of many of the Foreign Governments that it dealt with. [YARD]

SCOPE

We shall look at three tests: Kappa test for coincidences, Chi test or cross product test for superimposition, and Phi test for monoalphabeticity. We will briefly touch on Gleason's logarithmic weighting scheme for determination of number of letters to differentiate a transposition. The References and Resource section is substantially broadened with nearly 150 more choice plums.

BASIC THEORY OF COINCIDENCES

We have already looked at a table of Phi Values For Monoalphabetic and Digraphic Text By Kullback in Lecture 1. We have also studied various Phi values for Xenocrypts in Lecture 5. We found that the probability is related to coincidences and that it is of significance when we investigate repetitions of letters in a cipher.

We know that the probability of monographic coincidence (1) of random text employing a 26 letter alphabet is 0.0385 , (2) in English telegraphic plain text is 0.0667. We have defined these values as Kr and Kp respectively.

One of the most important techniques in cryptanalysis is that of applying the Kappa Test or Test of Coincidences. The most important purpose for this test is to ascertain whether two or more sequences are correctly superimposed. Correct means the sequences are so arranged to facilitate or make possible a solution. The Kappa test has the following theoretical basis the following circumstances:

(1) If any two rather lengthy sequences of characters are superimposed, it will be found that as successive pairs of letters are brought into vertical juxtaposition, thatin a certain number of cases the two superimposed letters will coincide,

(2) If we are dealing with random text (26 alphabet) there will be 38 or 39 cases of coincidence per 1000 pairs of letters examined because Kr = 0.0385.

(3) If we are dealing with plain text (English) there will be 66 or 67 cases of coincidence per 1000 pairs of letters examined because Kp = 0.0667.

(4) If the superimposed sequences are wholly monoalphabetic encipherments of plain text by the same cipher alphabet, there will be 66 or 67 cases of coincidence per 1000 pairs of letters examined because in monoalphabetic substitution there is a fixed or unvarying relation between plain text and cipher text, so that for statistical purposes the cipher text behaves just as if it were normal plain text.

(5) Even if the two superimposed sequences are polyalphabetic in character, there still will be 66 or 67 cases of coincidence or identity per 1000 pairs of letters examined provided the two sequences really belong to the same cryptographic system and are superimposed at the proper point with respect to the keying sequence.

(6) This last point may be seen in the two polyalphabetic messages below: They have been enciphered poly-alphabetically by the same two primary components sliding against each other. The two messages begin at the same point in the keying sequence. Consequently, they are identically enciphered, letter for letter, the only differences between them is due to differences in plain text.

No. 1

```
Alpha   16 21 13 5 6 4 17 19 21 21 2 6 3 6 13 13 1 7 12 6
Plain   W  H  E  N I N T  H  E  C  O U R S E  L  O N G M
Cipher  E  Q  N  B T F Y  R  C  X  X L Q J N  Z  O Y A W
```

No. 2

```
Alpha   16 21 13 5 6 4 17 19 21 21 2 6 3 6 13 13 1 7 12 6
Plain   T  H  E  G E N E  R  A  L  A B S O L  U  T E L Y
Cipher  P  Q  N  T U F B  W  D  J  L Q H Y Z  P  T M Q I
```

Note, that (a) in every case in which two superimposed cipher letters are the same, the plain text letters are identical and (b) in every case in which two superimposed cipher letters are the different, the plain text letters are different. In such a system, even though the cipher alphabet changes from letter to letter, the number cases of identity or coincidence in the two members of a pair of superimposed cipher letters will still be about 66 or 67 per thousand cases examined, because the two members of each pair of superimposed letters are in the same alphabet and it has been seen in (4) that in monoalphabetic cipher text K is the same as for plain text, viz, 0.667. The fact that in this case each monoalphabet contains just two letters does not affect the theoretical value of K (Kappa) and whether the actual number of coincidences agrees closely with the expected number based upon Kp = 0.0667 depends upon the lengths of the two superimposed sequences. Messages No's 1 and 2 are said to be superimposed correctly , that is brought into proper juxtaposition with respect to the keying sequences.

(7) Now change the situation by changing the juxtaposition to an incorrect superimposition with respect to the keying sequence.

No. 1

```
Alpha   16 21 13 5 6 4 17 19 21 21 2 6 3 6 13 13 1 7 12 6
Plain   W  H  E  N I N T  H  E  C  O U R S E  L  O N G M
Cipher  E  Q  N  B T F Y  R  C  X  X L Q J N  Z  O Y A W
```

No. 2

```
Alpha     16 21 13 5 6 4 17 19 21 21 2 6 3 6  13 13 1 7
Plain      T  H  E G E N E  R  A  L  A B S O   L  U  T E
Cipher     P  Q  N T U F B  W  D  J  L Q H Y   Z  P  T M
```

It is evident that the two members of every pair are not in the same cipher alphabets and any identical letters after superimposition is strictly accidental. Actually the number of repetitions will approximate Kr = 0.0385.

Note again, that in every case in which two superimposed cipher letters are the same, the plain text letters are not identical and in every case in which two superimposed cipher letters are the different, the plain text letters are no always different. Look at the superimposed T(cipher)'s representing two different plain text letters and that the S in "COURSE" gives the value J (cipher) and in the word ABSOLUTELY gives H (cipher). It should be clear that an incorrect superimposition by two different plain-text letters enciphered by two different alphabets may "by chance" produce identical cipher letters, which on superimposition yield coincidence but have no external indications as to dissimilarity in plain text equivalents. This incorrect superimposition will coincide by a value of Kr = 0.0385.

(8) Note the two Z's and they represent the plain text L. This occurred because the same cipher alphabet came into play by chance twice to encipher the same plain text letter both times. This may distort the Kr value for some systems.

(9) In general, in the case of correct superimposition the probability of identity or coincidence is Kp = 0.0667; in the case of incorrect superimposition, the probability is greater than or equal to Kr = 0.0385. The Kappa test, aka coincidence test is defined by these values.

APPLYING THE KAPPA TEST

When we say Kp = 0.0667, this means that in a 1000 cases where two letters are drawn at random from a large volume of plain text, we should expect 66 or 67 cases of two letters to coincide or be identical. Nothing is specified what these letters shall be; they can be two Z's or two E's. Another way is to consider that at random 6.67% of the comparisons made will yield coincidences. So for 2000 examinations, we expect 2000 x 6.67% = 133.4 coincidences [use integers and round down to 133]. Or 20,000 comparisons means 1,334 coincidences.

A more practical approach is to find the ratio of observed number of coincidences to the total number of cases in question that may occur, i.e. the total number of comparisons of superimposed letters. When the ratio is closer to 0.0667 than 0.0385 the correct superimposition has been found. This is true because both members of each pair of superimposed letters belong to the same monoalphabet and therefore the probability of their coinciding is 0.067; whereas, in the case of incorrect superimposition, each pair belongs to different monoalphabets and the probability of their coinciding approaches 0.0385 rather than 0.0667.

To use the Kappa test requires calculating the total number of comparisons in a given case and the actual number of coincidences in the case under consideration. When two messages are superimposed, the total number of comparisons made equals the number of superimposed letters. When more than two messages are superimposed in a superimposition diagram (Lecture 13) it is necessary to calculate the number of comparisons based on the number of letters in the column.

$$n \text{ letters} = n(n-1)/2 \text{ pairs or comparisons, in column}$$

For a column of 3 letters , there are 3(2)/2 = 3 comparisons. We compare the 1st with the 2nd, 2nd with 3rd and 1st with 3rd columns. The more general probability formula is

$$nCr = n!/r!(n-r)!$$

where we determine the number of combinations of n different things taken r at a time. For two letters, r is always 2, so n!/r!(n-r)! is the same as

$$n(n-1)(n-2)!/2(n-2)!$$

$$\text{becomes} \quad n(n-1)/2$$

with the cancellation of terms using (n-2)!.

RULE

The number of comparisons per column times the number of columns in the superimposition diagram of letters gives the total number of comparisons. The extension to this reasoning is where the superimposition diagram involves columns of various lengths, then we add together the number of comparisons for columns of different lengths to obtain a grand total. Table 15-1 shows the number of letters in a column versus the number of comparisons calculated. [FRE3]

Table 15 -1

Number of letters in column	Number of comparisons	Number of letters in column	Number of comparisons
2	1	16	120
3	3	17	136
4	6	18	153
5	10	19	171
6	15	20	190
7	21	21	210
8	28	22	231
9	36	23	253
10	45	24	276
11	55	25	300
12	66	26	325
13	78	27	351
14	91	28	378
15	105	29	406
		30	435

In ascertaining the number of coincidences in the case of a column containing several letters, we still use the n(–1)/2 formula, only in this case, n is the number of identical letters in the column. The reasoning is essentially the same as above. The total number of coincidences is the sum of the number of coincidences for each case of identity.

Given the column:

C
K
B
K
Z
K
C
B
B
K

There are 10 letters with 3B's, 2C's 4K's and 1 Z. The 3B's yield 3 coincidences, the 2 C's yield 1 coincidence, the 4 K's yield 6 coincidences. The sum is 3 + 1 + 6 = 10 coincidences in 45 comparisons = 0.2222

ENCIPHERMENT WITH SAME KEY BUT DIFFERENT INITIATION POINTS

In Lecture 13, I ended with the note that several messages enciphered by the same keying sequence but each beginning at a different point presented a challenge. The best attack is that by superimposition and the Kappa test is used to correctly line up the messages with respect to each other.

It is understood that the messages may be shifted relative to each other at many points of superimposition but there is only one point of superimposition for each message which corresponds to monoalphabetic columnar superimposition of the cipher text.

The method:

(1) Number the message according to their lengths.

(2) Fix message 1, message 2 is placed under it so that the first pair of letters coincide.

(3) Examine, calculate total number of cases in which superimposed letters are identical, thus the observed number of coincidences. The total number of superimposed pairs is calculated and multiplied by 0.0667 to find the expected number of coincidences.

(4) If the observed number is considerably below the expected number, or if the ratio of the observed number of coincidences to the total is closer to 0.0385 than 0.0667, then the superimposition is wrong and we shift message 2 one letter to the left.

(5) Repeat steps (3) - (4) until the correct superimposition is found.

(6) Test message 3 against message 1 and then against message 2.

(7) Continue the process until all the messages are lined up correctly.

Computers are a big help in this process.

EXAMINE OF KAPPA TEST

Given 4 messages of 30 intercepted using a long enciphered keying sequence:

Message 1

```
PGLPN  HUFRK  SAUQQ  AQYUO  ZAKGA  EOQCN
PRKOV  HYEIU  YNBON  NFDMW  ZLUKQ  AQAHZ
MGCDS  LEAGC  JPIVJ  WVAUD  BAHMI  HKORM
LTFYZ  LGSOG  K.                   [101]
```

Message 2

```
CWHPK  KXFLU  MKURY  XCOPH  WNJUW  KWIHL
OKZTL  AWRDF  GDDEZ  DLBOT  FUZNA  SRHHJ
NGUZK  PRCDK  YOOBV  DDXCD  OGRGI  RMICN
HSGGO  PYAOY  X.                   [101]
```

Message 3

```
WFWTD  NHTGM  RAAZG  PJDSQ  AUPFR  OXJRO
HRZWC  ZSRTE  EEVPX  OATDQ  LDOQZ  HAWNX
THDXL  HYIGK  VYZWX  BKOQO  AZQND  TNALT
CNYEH  TSCT.                       [99]
```

Message 4

```
TULDH  NQEZZ  UTYGD  UEDUP  SDLIO  LNNBO
NYLQQ  VQGCD  UTUBQ  XSOSK  NOXUV  KCYJX
CNJKS  ANGUI  FTOWO  MSNBQ  DBAIV  IKNWG
VSHIE  P                           [96]
```

Superimpose messages 1 and 2.

```
              *     *      *
No. 1      PGLPN  HUFRK  SAUQQ  AQYUO  ZAKGA  EOQCN
No. 2      CWHPK  KXFLU  MKURY  XCOPH  WNJUW  KWIHL

                                                 *
No. 1      PRKOV  HYEIU  YNBON  NFDMW  ZLUKQ  AQAHZ
No. 2      OKZTL  AWRDF  GDDEZ  DLBOT  FUZNA  SRHHJ

            *                        *      *
No. 1      MGCDS  LEAGC  JPIVJ  WVAUD  BAHMI  HKORM
No. 2      NGUZK  PRCDK  YOOBV  DDXCD  OGRGI  RMICN

                     *
No. 1      LTFYZ  LGSOG  K.                   [101]
No. 2      HSGGO  PYAOY  X.                   [101]
```

The number of comparisons is 101 x 0.0667 = 7 coincidences which is less than the observed 8. Nice start but suspicious. Shifting one letter to right the number of coincidences is 4. One more shift = 3. Then:

```
                 *      *    *
No. 1      PGLPNHUFRKSAUQQAQYUOZAKGAEOQCN
No. 2         CWHPKKXFLUMKURYXCOPHWNJUWKW

               *                        *
No. 1      PRKOVHYEIUYNBONNFDMWZLUKQAQAHZ
No. 2      IHLOKZTLAWRDFGDDEZDLBOTFUZNASR

                              *        **
No. 1      MGCDSLEAGCJPIVJWVAUDBAHMIHKORM
No. 2      HHJNGUZKPRCDKYOOBVDDXCDOGRGIRM

                 *
No. 1      LTFYZLGSOGK.
No. 2      ICNHSGGOPYAOYX.          [98]
```

Now 98 x 0.0667 = 6.5366 versus 9 coincidences or 30% more than the first comparison. The first test was accidental. The jump is normal from incorrect to correct. The correct superimposition is either 100% correct or incorrect.

Friedman suggests that tests be made first to the right and then to the left, one letter at a time for best efficiency. [FRE3]

It is possible to systematize our investigation by testing three or four messages at a time.

We make a diagram where the number of coincidences are tallied with all three messages:

```
          1     2     3
        ----------------
      1|  x     9     3
       |
      2|  x     x     3
       |
      3|  x     x     x
```

The number of tallies in cell 1-2 is 9 as examined. A column which shows identical letters in messages 1 and 3 yields a tally in 1-3, between 2 and 3 goes to 2-3 and so forth. Only when a superimposition yields three identical letters in a column is a tally to be recorded in 1-3 or 1-2 (3 coincidences.

So adding message 3 to the investigation:

```
                    *
No. 1      PGLPNHUFRKSAUQQAQYUOZAKGAEOQCN
No. 2         CWHPKKXFLUMKURYXCOPHWNJUWKW
No. 3      WFWTDNHTGMRAAZGPJDSQAUPFROXJRO

            *   *            *
No. 1      PRKOVHYEIUYNBONNFDMWZLUKQAQAHZ
No. 2      IHLOKZTLAWRDFGDDEZDLBOTFUZNASR
No. 3      HRZWCZSRTEEEVPXOATDQLDOQZHAWNX

            *      *
No. 1      MGCDSLEAGCJPIVJWVAUDBAHMIHKORM
No. 2      HHJNGUZKPRCDKYOOBVDDXCDOGRGIRM
No. 3      THDXLHYIGKVYZWXBKOQOAZQNDTNALT


No. 1      LTFYZLGSOGK.
No. 2      ICNHSGGOPYAOYX.
No. 3      CNYEHTSCT.
```

so:

```
          1     2     3
       -----------------
     1|   x     9     3
      |
     2|   x     x     3
      |
     3|   x     x     x
```

Successive number of columns are examined and coincidences (of messages 1 and 3 and 2 and 3) are tabulated. We find:

Combination	Total Number of Comparisons	Number of Coincidences Expected	Observed	Delta %
1 - 3	99	~ 7	3	-57
2 - 3	96	~ 6	3	-50
1- 2- 3	293	~ 20	15	-21

A correct superimposition for one of the three combinations may yield such good results as to mask the bad results for the other two combinations.

We shift message 3 one space to the right with the following results:

```
                                 *
No. 1       PGLPNHUFRKSAUQQAQYUOZAKGAEOQCN
No. 2          CWHPKKXFLUMKURYXCOPHWNJUWKW
No. 3        WFWTDNHTGMRAAZGPJDSQAUPFROXJR

             *   *               *   *
No. 1       PRKOVHYEIUYNBONNFDMWZLUKQAQAHZ
No. 2       IHLOKZTLAWRDFGDDEZDLBOTFUZNASR
No. 3       OHRZWCZSRTEEEVPXOATDQLDOQZHAWN

                           *    *
No. 1       MGCDSLEAGCJPIVJWVAUDBAHMIHKORM
No. 2       HHJNGUZKPRCDKYOOBVDDXCDOGRGIRM
No. 3       XTHDXLHYIGKVYZWXBKOQOAZQNDTNAL

              *    *
No. 1       LTFYZLGSOGK.
No. 2       ICNHSGGOPYAOYX.
No. 3       TCNYEHTSCT.
```

	1	2	3
1	x	9	10
2	x	x	7
3	x	x	x

Combination	Total Number of Comparisons	Number of Coincidences Expected	Observed	Delta %
1 - 3	99	~ 7	10	+43
2 - 3	97	~ 6	6	0
1- 2- 3	294	~ 20	25	+25

The results are very good. We add the fourth message.

```
No. 1       PGLPNHUFRKSAUQQAQYUOZAKGAEOQCN
No. 2          CWHPKKXFLUMKURYXCOPHWNJUWKW
No. 3        WFWTDNHTGMRAAZGPJDSQAUPFROXJR
No. 4         TULDHNQEZZUTYGDUEDUPSDLIOLNN

No. 1       PRKOVHYEIUYNBONNFDMWZLUKQAQAHZ
No. 2       IHLOKZTLAWRDFGDDEZDLBOTFUZNASR
No. 3       OHRZWCZSRTEEEVPXOATDQLDOQZHAWN
No. 4       BONYLQQVQGCDUTUBQXSOSKNOXUVKCY
```

```
No. 1      MGCDSLEAGCJPIVJWVAUDBAHMIHKORM

No. 2      HHJNGUZKPRCDKYOOBVDDXCDOGRGIRM
No. 3      XTHDXLHYIGKVYZWXBKOQOAZQNDTNAL
No. 4      JXCNJKSANGUIFTOWOMSNBQDBAIVIKN

No. 1      LTFYZLGSOGK.
No. 2      ICNHSGGOPYAOYX.
No. 3      TCNYEHTSCT.
No. 4      WGVSHIEP.
```

	1	2	3	4
1	x	9	10	7
2	x	x	7	7
3	x	x	x	5
4	x	x	x	x

Combination	Total Number of Comparisons	Number of Coincidences Expected	Observed	Delta %
1 - 3	96	~ 6	7	+16
2 - 3	95	~ 6	7	+16
3 - 4	96	~ 6	5	-16
1,2,3,4	581	~39	44	+10

This is actually the correct group of superimpositions. Testing another message 4 movement to right shows us the picture.

```
No. 1      PGLPNHUFRKSAUQQAQYUOZAKGAEOQCN
No. 2         CWHPKKXFLUMKURYXCOPHWNJUWKW
No. 3       WFWTDNHTGMRAAZGPJDSQAUPFROXJR
No. 4         TULDHNQEZZUTYGDUEDUPSDLIOLN

No. 1      PRKOVHYEIUYNBONNFDMWZLUKQAQAHZ
No. 2      IHLOKZTLAWRDFGDDEZDLBOTFUZNASR
No. 3      OHRZWCZSRTEEEVPXOATDQLDOQZHAWN
No. 4      NBONYLQQVQGCDUTUBQXSOSKNOXUVKC

No. 1      MGCDSLEAGCJPIVJWVAUDBAHMIHKORM
No. 2      HHJNGUZKPRCDKYOOBVDDXCDOGRGIRM
No. 3      XTHDXLHYIGKVYZWXBKOQOAZQNDTNAL
No. 4      YJXCNJKSANGUIFTOWOMSNBQDBAIVIK

No. 1      LTFYZLGSOGK.
No. 2      ICNHSGGOPYAOYX.
No. 3      TCNYEHTSCT.
No. 4      NWGVSHIEP.
```

```
          1     2     3     4
        ----------------------
      1|   x     9     10    3
       |
      2|   x     x     7     3
       |
      3|   x     x     x     2
       |
      4|   x     x     x     x
```

Combination	Total Number of Comparisons	Number of Coincidences Expected	Observed	Delta %
1 - 3	96	~ 6	3	-50
2 - 3	96	~ 6	3	-50
3 - 4	96	~ 6	2	-83
1,2,3,4	582	~39	33	-18

SUBSEQUENT SOLUTION STEPS

These four messages were enciphered by a long keying sequence. We now have found the correct superimposition of the four messages. Therefore, the text has been reduced to monoalphabetic columnar form and can be solved. What was not given on this example was that the enciphering device was a U. S. Army Cipher Disk and that the key was intelligent as well as the alphabets are reversed standard.

It doesn't matter to the Kappa test what kind of cipher alphabets were used or whether or not the key is random or intelligent. We try our favorite technique - the probable word on message 1 of DIVISION.

```
Ciphertext      P G L P N H U F R K S A U Q Q
Assumed Plain   D I V I S I O N
Resultant Key   S O G X F
```

nope, shift one letter right.

```
Ciphertext      P G L P N H U F R K S A U Q Q
Assumed Plain   . D I V I S I O N
Resultant Key   . J T K
```

nope, shift one more, and one and finally to the end with no resultant intelligent key.

```
Ciphertext      P G L P N H U F R K S A U Q Q
Assumed Plain           R E G I M E N T N O
Resultant Key           E L A N D O F T H E
```

which suggests LAND of T(HE) which yields REGIMENT NO. More assumptions yield an E before LAND and the cipher text yielding IS for the plain. The process continues one letter at a time and checking the cipher versus the plain for reconstructive clues.

We can use all four messages to gives us clues by multiple superimposition.

```
     Key                    E L A N D O F T
No 1 Ciphertext      P G L P N H U F R K S A U Q Q
     Plain                  R E G I M E N T

No 2 Ciphertext           C W H P K K X F L U M K
     Plain                  I E L D T R A I

No 3 Ciphertext        W F W T D N H T G M R A A Z
     Plain                  L I N G K I T C

No 4 Ciphertext          T U L D H N Q E Z Z U T Y
     Plain                  T I T A N K G U
```

We see No. 2 gives us FIELD TRAIN, No 3 has ROLLING KITCHEN, and No 4 with ANTITANK GUN. These words yield additional letters. If the key is unintelligent text we use the messages against each rather than against the key.

UNKNOWN SEQUENCES

The previous example assumed a known cipher alphabet. When it is not known, Data for solution by indirect symmetry by detection of isomorphs cannot be expected, for isomorphs may not be produced by the system. Solution can be reached only if there is sufficient text to permit analysis of columns for superimposition diagram. Large amount of text yields repetitions and the basis for probable word assumption. After establishment of a few values for cipher text letters does indirect symmetry come into play. Each column requires 15 -20 letters minimum. These can be studied statistically and if two columns have similar characteristics, they may be combined using the cross product test.

RUNNING KEY PRINCIPLE

The running - key principle may be interesting in principle but difficult in practice. Mistakes in encipherment or transmission, essentially decrease the likely hood of the correct decipherment. The running Key does improve cryptographic security but the mechanical details involved in the production, reproduction, and distribution of such keys represents a formidable challenge - enough to destroy the effectiveness of the system for practical purposes (voluminous communication).

Suppose a basic unintelligible, random sequence of keying characters which is not derived from the interaction of two or more shorter keys and which NEVER repeats is employed only ONCE as a key for encipherment. Can such a cryptogram be solved. No. No method of attack will solve this because the system is not uniquely solvable.

Two things are required for solution: the logical answer must be offered and it must be unique. The Bacon-Shakespeare "cryptographers tend to overlook the latter issue. To attempt to solve a cryptogram enciphered as previously described is like solving an equation in two unknowns with absolutely no data available for solution but the solution itself. The key is one unknown and the plain text is the other. Any one quantity may be chosen and yield a viable result without the required uniqueness constraint being observed. There are an infinite number of solutions possible.

The problem is better defined when the running key constitutes intelligent test, or if it is used to encipher more than one message, or if it is the secondary result of the interaction of two or more short primary keys which go thru cycles themselves. The additional information in these cases are enough to meet the uniqueness constraint.

CROSS-PRODUCT TEST OR CHI [X]

The KAPPA test is used to prepare data for analysis. It circumvents the polyalphabetic obstacle. It moves the solution from polyalphabetic to monoalphabetic terms. The solution can be reached if their is some cryptographic relationship between the columns, or the letters can be combined into a single frequency distribution.

The amount of data has to be sufficient for comparison purposes and this depends on the type of cipher alphabets involved. Although the superimposition diagram may be composed of many columns, often only a relatively small number of different cipher alphabets are put into play. The number of times that a secondary alphabet is employed is directly related to the key text or number of keying elements in the sequence.

In the running-key cipher using a long phrase or book as a key, the key is intelligible text and it follows that the secondary alphabets will be employed with frequencies directly related to the respective frequencies of occurrence of letters of plain text. The key letter 'E' alphabet should be most frequent, 'T' next and so forth. J, K, Q, X, Z are improbable, so the cryptanalyst usually handles no more than 19-20 secondary alphabets.

It is possible to study the various distributions for the columns of the superimposition diagram with the view of assembling those distributions which belong to the same cipher alphabet, say 'E', thus making the determination of values easier in a combined distribution.

If the key is random text, and assuming sufficient text within the columns, the columnar frequency distributions may afford the opportunity to amalgamate a large number of small distributions into a smaller number of larger distributions. This is known as matching and we use the Cross-Product or Chi Test, aka X test.

The Chi test is used to identify distributions which belong to the same cipher alphabet. It is used when the amount of data is not very large.

DERIVATION OF CHI TEST [KULL]

The theory of monographic coincidence in plain text was originally developed by Friedman and applied in his technical paper written in 1925 dealing with his solution of messages enciphered by a cryptographic machine known as the "Herbern Electric Super-Code." The paper is among the Riverbank Publications in 1934.

The probability of coincidence of two A's in plain text is the square of the probability of occurrence of the single letter A in such text. Samething with B's through Z's. The sum of these squares for all letters of the alphabet as shown in Table 15-2, is found to be 0.0667. This is almost double the combined probability of random text for hitting two random text letters coincidentally or:

26 letters x 1/26 x 1/26 = 1/26 = 0.0385 = Kr

Table 15-2

Letter	Frequency in 1000 Letters	Probability of Occurrence Separately	Square of Probability of Separate Occurrence
A	73.66	0.0737	0.0054
B	9.74	.0097	.0001
C	30.68	.0307	.0009
D	42.44	.0424	.0018
E	129.96	.1300	.0169
F	28.32	.0283	.0008
G	16.38	.0164	.0003
H	33.88	.0339	.0012
I	73.52	.0735	.0054
J	1.64	.0016	.0000
K	2.96	.0030	.0000
L	36.42	.0364	.0013
M	24.74	.0247	.0006
N	79.50	.0795	.0063
O	75.28	.0753	.0057
P	26.70	.0267	.0007
Q	3.50	.0035	.0000
R	75.76	.0758	.0057
S	61.16	.0612	.0037
T	91.90	.0919	.0084
U	26.00	.0260	.0007
V	15.32	.0153	.0002
W	15.60	.0156	.0002
X	4.62	.0046	.0000
Y	19.34	.0193	.0004
Z	.98	.0010	.0000
Total	1,000.00	1.0000	0.0667

We have seen this value before as Kp. It is the probability that any two letters selected at random in a large volume of normal English plain text will coincide.

Given a 50 letter plain-text distribution:

```
3   1 1 7 1   2 3     1 2 5 6     2 5 6 2   2
A B C D E F G H I J K L M N O P Q R S T U V W X Y Z
```

The number of pairings that can be made are n (n-1)/2 = (50 x 49)/2 = 1,225 comparisons. According to the theory of coincidences, there should be 1,225 x 0.0667 = 81.7065 or approximately 82 coincidences of single letters. We look at the distribution and finds there are 83 for a very close agreement. [N(N-1)/2]

```
3   1 1 7 1   2 3     1 2 5  6     2 5  6  2   2
A B C D E  F G H I J K L M N  O  P Q R S  T  U V W X Y Z
3+0+0+1+21+0+0+1+3+0+0+0+1+10+15+0+0+1+10+15+1+0+1+0+0+0=83
```

If N is the total number of letters in the distribution, then the number of comparisons is N(N-1)/2 and the expected number of coincidences may be written:

.0067N(N-1)/2

or (.0067N**2 - 0.0667N)/2 eq. I

If we let Fa = number of occurrences of A in the foregoing distribution, the number of coincidences for letter A is Fa(Fa-1)/2. Similarly for B, we have Fb(Fb-1)/2. The total number of coincidences for the distribution is:

Fa(Fa-1)/2 +Fb(Fb-1)/2+...+Fz(Fz-1)/2.

Let Fa = any letter A..Z and d = the sum of all terms that follow it. The distribution d(Fa**2-Fa)/2 represents the actual coincidences.

Although derived from different sources we equate the terms.

d(Fa**2-Fa)/2 = (.0067N**2 - 0.0667N)/2

and dFa = N

d(Fa**2-Fa) = (.0067N**2 - 0.0667N)

dFa**2 - N = (.0067N**2 - 0.0667N)

dFa**2 = .0067N**2 + 0.9333N eg. II

Equation II tells us the sum of the squares of the absolute frequencies of a distribution is equal to 0.0667 times the square of the total number of letters in the distribution, plus 0.933 times the total number of letters in the distribution. We let S2 replace dFa**2.

Suppose two monoalphabetic distributions pertain to the same cipher alphabet. If they are to be correctly combined into a single distribution, the latter must still be monoalphabetic. We use subscripts 1 and 2 to indicate the distributions in question. So:

d(Fa1+Fa2)**2 = .0067(N1+N2)**2 + 0.9333(N1+N2)

expanding terms:

dFa1**2 +2dFa1Fa2 +dFa2**2 =0.0667(N1**2 +2N1N2 + N2**2) +.9333N1 +.9333N2 eq. III

dFa1**2 = .0067N1**2 + 0.9333N1

dFa2**2 = .0067N2**2 + 0.9333N2

and rearranging:

.0667N1**2 +.9333N1 +2dFa1Fa2 + .0667 N2**2 + .9333N2 =

.0667(N1**2 +2N1N2 +N2**2) + .9333N1 +.9333N2

further reducing:

2dFa1Fa2 = 0.667 (2N1N2)

finally:

$$dFa1Fa2 = \frac{0.667}{N1N2} \qquad \text{eq. IV}$$

This equation permits the establishment of an expectant value for the sum of products of the corresponding frequencies of the two distributions being considered for amalgamation. The Chi test or Cross-product test is based on Equation IV.

Given two distributions to be matched:

```
     1 4   3   1     1     1     1     3 2 2 1   1 3   2
F1 - A B C D E F G H I J K L M N O P Q R S T U V W X Y Z

       2       3     1   1     1 1     3 1 1         1 2
F2 - A B C D E F G H I J K L M N O P Q R S T U V W X Y Z
```

We juxtapose the frequencies for convenience.

```
                                                N1 = 26
Fa1    1 4   3   1     1     1     1     3 2 2 1   1 3   2
       A B C D E F G H I J K L M N O P Q R S T U V W X Y Z
Fa2      2       3     1   1     1 1     3 1 1         1 2
                                                N2 = 17
Fa1Fa2 0 8 0 0 0 3 0 0 1 0 0 0 0 0 1 0 0 9 2 2 0 0 0 0 0 4
             d=30
```

N1N2 = 26 x 17 = 442

$$\frac{dFa1Fa2}{N1N2} = \frac{30}{442} = 0.0711$$

or 442 x 0.0667 = 28.15 expected value versus 30. The two distributions very probably belong together.

To point out the effectiveness of the correct Chi test placement, we look at the example but juxtaposed one interval to the left.

```
                                                  N1=26
     1 4   3   1     1     1     1     3 2 2 1   1 3   2
F1 - A B C D E F G H I J K L M N O P Q R S T U V W X Y Z
F2 - B C D E F G H I J K L M N O P Q R S T U V W X Y Z A
     2       3     1   1     1 1     3 1 1         1 2
                                                  N2=17
Fa1Fa2 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 3 2 0 0 0 0 3 0 0
          dFa1Fa2=2+3+2+3= 10
```

```
dFa1Fa2      10
--------  = ---- =  0.226
 N1N2        442
```

Thus, if the two distribution pertain to the same primary components then they are not properly superimposed. The Chi test may be applied also to cases where two or more frequency distributions must be shifted relatively in order to find the correct superimposition. The problem determines whether we use direct superimposition or shifted superimposition of the second distribution in question.

APPLYING THE CHI TEST TO PROGRESSIVE-ALPHABET SYSTEM

We assume for this example that the secondary alphabets were derived from the interaction of two identical mixed primary components. The cipher alphabet is based on HYDRAYLIC...Z sequence shifted one letter to the right for each encipherment. Based on Figure 15-1, the horizontal sequences are all identical and shifted relatively. The letters inside the square are plain-text letters.

Instead of letters in the cells of the square we tally the normal frequencies of the letters occupying the respective cells. For the first 3 rows we have:

```
  1 . . . 5 . . . . 10 . . . . 15 . . . . 20 . . . . . 26

A 7 3 4 8 3 1 12 3 2     3 8 7  3   6 9 1 1      3 2 4  8
B 112 3 2     3 8 7  3   6 9 1 1      3 2 4  8 7 3 8 3  1
C 3 112 3 2     3 8 7  3   6 9  1 1     3 2 4  8 7 3 4  8
```

The shift required in this case is 5 to the right to match up A and B. Note that amount of displacement, or number of intervals, the B sequence must be shifted to make it match A sequence corresponds exactly to the distance between the letters A and B in the primary cipher component.

```
                  ..... A U L I C B ......
                        0 1 2 3 4 5
```

The fact that the primary plain component is identical with the primary cipher component is coincidental. The displacement interval is being measured on the cipher component.

The Given Cipher message is written into a 26 column (26 alphabets) square rather than the standard 5 letter groups.

FIGURE 15-1

ALPHABET NO

```
        1   5    10   15   20    26
   A | AULICBEFGJKMNOPQSTVWXZHYDR
   B | BEFGJKMNOPQSTVWXZHYDRAULIC
   C | CBEFGJKMNOPQSTVWXZHYDRAULI
   D | DRAULICBEFGJKMNOPQSTVWXZHY
   E | EFGJKMNOPQSTVWXZHYDRAULICB
   F | FGJKMNOPQSTVWXZHYDRAULICBE
C  H | HYDRAULICBEFGJKMNOPQSTVWXZ
I  I | ICBEFGJKMNOPQSTVWXZHYDRAUL
P  J | JKMNOPQSTVWXZHYDRAULICBEFG
H  K | KMNOPQSTVWXZHYDRAULICBEFGJ
E  L | LICBEFGJKMNOPQSTVWXZHYDRAU
R  M | MNOPQSTVWXZHYDRAULICBEFGJK
   N | NOPQSTVWXZHYDRAULICBEFGJKM
   O | OPQSTVWXZHYDRAULICBEFGJKMN
L  P | PQSTVWXZHYDRAULICBEFGJKMNO
E  Q | QSTVWXZHYDRAULICBEFGJKMNOP
T  R | RAULICBEFGJKMNOPQSTVWXZHYD
T  S | STVWXZHYDRAULICBEFGJKMNOPQ
E  T | TVWXZHYDRAULICBEFGJKMNOPQS
R  U | ULICBEFGJKMNOPQSTVWXZHYDRA
   V | VWXZHYDRAULICBEFGJKMNOPQST
   W | WXZHYDRAULICBEFGJKMNOPQSTV
   X | XZHYDRAULICBEFGJKMNOPQSTVW
   Y | YDRAULICBEFGJKMNOPQSTVWXZH
   Z | ZHYDRAULICBEFGJKMNOPQSTVWX
```

```
   1 . . . 5 . . . .10 . . . .15 . . . .20 . . . . . 26
1  W G J J M M M J X E D G C O C F T R P B M I I I K Z
2  R Y N N B U F R W W W W Y O I H F J K O K H T T A Z
3  C L J E P P F R W C K O O F F F G E P Q R Y Y I W X
4  M X U D I P F E X M L L W F K G Y P B B X C H B F Y
5  I E T X H F B I V D I P N X I V R P W T M G I M P T
6  E C J B O K V B U Q G V G F F F K L Y Y C K B I W X
7  M X U D I P F F U Y N V S S I H R M H Y Z H A U Q W
8  G K T I U X Y J J A O W Z O C F T R P P O Q U S G Y
9  C X V C X U C J L M L L Y E K F F Z V Q J Q S I Y S
10 P D S B B J U A H Y N W L O C X S D Q V C Y V S I L
11 I W N J O O M A Q S L W Y J G T V P Q K P K T L H S
12 R O O N I C F E V M N V W N B N E H A M R C R O V S
13 T X E N H P V B T W K U Q I O C A V W B R Q N F J V
14 N R V D O P U Q R L K Q N F F F Z P H U R V W L X G
15 S H Q W H P J B C N N J Q S O Q O R C B M R R A O N
16 R K W U H Y Y C I W D G S J C T G P G R M I Q M P S
17 G C T N M F G J X E D G C O P T G P W Q Q V Q I W X
18 T T T C O J V A A A B W M X I H O W H D E Q U A I N
19 F K F W H P J A H Z I T W Z K F E X S R U Y Q I O V
20 R E R D J V D K H I R Q W E D G E B Y B M L A B J V
21 T G F F G X Y I V G R J Y E K F B E P B J O U A H C
22 U G Z L X I A J K W D V T Y B F R U C C C U Z Z I N
23 N D F R J F M B H Q L X H M H Q Y Y Y M W Q V C L I
24 P T W T J Y Q B Y R L I T U O U S R C D C V W D G I
25 G G U B H J V V P W A B U J K N F P F Y W V Q Z Q F
26 L H T W J P D R X Z O W U S S G A M H N C W H S W W
27 L Y R Q Q U S Z V D N X A N V N K H F U C V V S S S
28 P L Q U P C V V V W D G S J O G T C H D E V Q S I J
29 P H Q J A W F R I Z D W X X H C X Y C T M G U S E S
30 N D S B B K R L V W R V Z E E P P P A T O I A N E E
31 E E J N R C Z B T B L X P J J K A P P M J E G I K R
32 T G F F H P V V V Y K J E F H Q S X J Q D Y V Z G R
33 R H Z Q L Y X K X A Z O W R R X Y K Y G M G Z B Y N
34 V H Q B R V F E F Q L L W Z E Y L J E R O Q S O Q K
35 O M W I O G M B K F F L X D X T L W I L P Q S E D Y
36 I O E M O I B J M L N N S Y K X J Z J M L C Z B M S
37 D J W Q X T J V L F I R N R X H Y B D B J U F I R J
38 I C T U U U S K K W D V M F W T T J K C K C G C V S
39 A G Q B C J M E B Y N V S S J K S D C B D Y F P P V
40 F D W Z M T B P V T T C G B V T Z K H Q D D R M E Z
41 O O
```

A frequency distribution square is compiled, each column of the text forming a separate distribution in columnar form in the square. See Figure 15-2. Note the size of each distribution on the right side of the square under N.

The Chi test is applied to the horizontal rows in the square. Since the test is statistical, it is more reliable as the size of the distribution increases. We choose the V and W distributions because they have the greatest total number of tallies at 53 and 52 occurrences, respectively.

Figure 15-2

```
   1 . . . 5 . . . .10 . . . .15 . . . .20 . . . . . 26 N
A  1       1   1 4 1 3 1   1       3   2       3 3 1    25
B        6 3   3 7 1 1   1   1 2   1 2 1 8     1 4      43
C  2 3   2 1 3 1 1 1 1   1 2   4 2   1 5 2 6 4   2   1  45
D  1 4   4     2     2 7       1 1  2   1 3 3 1   1 1    34
E  2 3 2 1       4   2     1 4 2   3 2 1   2 1   1 3 1  35
F  2   4 2   3 7 1 1 2 1     6 3 9 3   2       2 1 1 1  51
G  3 6     1 1 1     1 1 4 2   1 4 3   1 1   3 2   3 2  39
H    5     7       4       1   3 4   2 6     2 2   2 1  38
I  4     2 3 2   2 2 1 3 1   1 4       1     3 2 8 4 2  45
J    1 4 3 4 4 3 6 1     3   4 2   1 3 2   4       2 2  50
K    3       2   3 3   4       6 2 2 2 2 1 2 2     2 1  37
L  2 2   1 1     1 2 2 7 4 1       2 1   1 1 1   3 1 1  33
M  2 1   1 3 1 5   1 3     2 1       2   4 7     3 1    37
N  3   2 5           1 7 1 3 2   3       1     1 1   4  34
O  2 3 1   6 1         2 2 1 5 4   2     1 3 1   2 2    38
P  4       2 9   1 1     1 1   1 1 1 9 5 1 2     1 3    43
Q      5 3 1   1 1 1 3   2 2     3     2 5 1 7 5   3    45
R  5 2 1 1 2   1 4 1 1 3 1   2 1   3 4   3 4 1 3   1 2  46
S  1   2       2     1     5 4 1   4   1       3 6 1 8  39
T  3 2 6 1   2     2 1 1 1 2     6 4     3     2 1   1  39
U  1   3 3 2 4 2   2     1 2 1   1   1   2 1 2 4 1      33
V  1   2     2 6 4 8     7     2 1 1 1 1 1   6 4    2 4 53
W  1 1 5 3   1     2 8 1 7 6   1     2 3   2 1 2    4 2 52
X    4   1 3 2 1   5     3 2 3 2 3 1 2     1       1 3 37
Y    1 1     3 3   1 4     4 2   1 4 2 4 3   5 1    2 3 44
Z      2 1     1 1   3 1   2 2     2 2     1   3 3    3 27
   1 . . . 5 . . . .10 . . . .15 . . . .20 . . . . . 26
```

The results of three relative displacements are given.

Test 1

```
  FV  1   2     2 6 4 8     7     2 1 1 1 1 1   6 4   2 4
      1 . . . 5 . . . .10 . . . .15 . . . .20 . . . . . 26
  FW    4 2 1 1 5 3   1     2 8 1 7 6   1     2 3   2 1 2
      24. . 1 . . . 5 . . . .10 . . . .15 . . . .20 . . .
FVFW      4     1018  8    14    14 6   1      18     2 8

                NV = 53, NW =52
                dFVFW = 103

                dFVFW = 103
                -----   ---  = 0.037      nok.
                NVNW    2756
```

```
                          Test 2

  FV  1   2     2 6 4 8     7     2 1 1 1 1 1   6 4   2 4
      1 . . . 5 . . . .10 . . . .15 . . . .20 . . . . . 26
  FW  2 3   2 1 2   4 2 1 1 5 3   1     2 8 1 7 6   1
      . .20 . . . 24. . 1 . . . 5 . . . .10 . . . .15 . .
FVFW  2         4  16 16   35     2     2 8 1  36

               NV = 53, NW =52
               dFVFW = 122

               dFVFW = 122
               -----   ---  = 0.044      nok.
               NVNW    2756

                          Test 3

  FV  1   2     2 6 4 8     7     2 1 1 1 1 1   6 4   2 4
      1 . . . 5 . . . .10 . . . .15 . . . .20 . . . . . 26
  FW  3   1     2 8 1 7 6   1     2 3   2 1 2   4 2 1 1 5
      . 5 . . . .10 . . . .15 . . . .20 . . . . .26 1 . .
FVFW  3   2     4 48 4 56   7     4 3   2 1 2   24 8 2 20

               NV = 53, NW =52
               dFVFW = 190

               dFVFW = 190
               -----   ---  = 0.069      OK!
               NVNW    2756
```

More tests would indicate that we have found the best correlation for these two cipher alphabets. Therefore, the primary cipher component has the letters V and W in these positions. The 4th cell of the W distribution must be placed under the 1 st cell of the V distribution per Test 3.

```
                   1 2 3 4
               . . . V . . W . . .
```

The next best row is F with 51 occurrences. We must test this row against V, W, and V+W. Test 4,5 and 6 show the correct superimpositions for the F row. Note that the computer can be a big time help in this evaluation.

```
                          Test 4

  FV  1   2     2 6 4 8     7     2 1 1 1 1 1   6 4   2 4
      1 . . . 5 . . . .10 . . . .15 . . . .20 . . . . . 26
  FF  1 1 2 1     6 3 9 3   2       2 1 1 1 2   4 2   3 7
      . .10 . . . .15 . . . .20 . . . . .26 1 . . . 5 . .
FVFF  1   4      36 12 72   14      2 1 1 1 2  24 8   6 28

               NV = 53, NF =51
               dFVFF = 212

               dFVFW = 212
               -----   ---  = 0.078
               NVNF    2703

                          Test 5

  FW  1 1 5 3   1     2 8 1 7 6   1     2 3   2 1 2   4 2
      1 . . . 5 . . . .10 . . . .15 . . . .20 . . . . . 26
  FF    3 7 1 1 2 1     6 3 9 3   2       2 1 1 1 2   4 2
      5 . . . .10 . . . .15 . . . .20 . . . . .26 1 . . .
FVFF    3 35    2      48 3 63 18 2       6   2 1 4  16 4

               NW = 52, NF =51
               dFWFF = 210

               dFWFF = 210
               -----   ---  = 0.078
               NWNF    2703

                          Test 6

FV+W  4   3     414 515 6   8    4  4 1 3 2  3 10 6 1 3  9
      1 . . . 5 . . . .10 . . . .15 . . . .20 . . . . . 26
  FF  1 1 2 1     6 3 9 3   2       2 1 1 1  2  4 2   3  7
      . .10 . . . .15 . . . .20 . . . . . 26 1 . . . 5 . .
FV+W  4   6      84 15 35 18 16     8 1 3 21 6  40 12 9 63
*FF
               N(V+W) = 105, NF = 51
               dF(W+V)FF = 422

               dF(W+V)FF = 422
               --------    ---  = 0.079
               N(W+V)NF    5355
```

This test yield the sequence:

```
     1 2 3 4 5 6 7 8 9

     V . . W . . . F .
```

As the work progresses, we use smaller and smaller distributions. This decrease in information is counterbalanced by the number of superimpositions being reduced as the primary cipher alphabet comes to the surface.

The completely reconstructed primary cipher component (both plain and cipher were specified as identical) is:

```
1 . . . 5 . . . .10 . . . .15 . . . .20 . . . . . 26
V A L W N O X F B P Y R C Q Z I G S E H T D J U M K
```

In practice, the matching process would be interrupted after a few letters of the primary component were retrieved and the skeleton of a few words became apparent.

We ascertain the initial position for the primary cipher component and decipher the cryptogram.

```
   1 . . . 5 . . . .10 . . . .15 . . . .20 . . . . . 26
1  W G J J M M M J X E D G C O C F T R P B M I I I K Z
   W I T H T H E I M P R O V E M E N T S I N T H E A I

2  R Y N N B U F R W W W W Y O I H F J K O K H T T A Z
   R P L A I N A N D T H E M E A N S O F C O M M U N I

3  C L J E P P F R W C K O O F F F G E P Q R Y Y I W X
   C A T I O N A N D W I T H T H E V A S T S I Z E O F
```

..... and so forth.

The interesting point is that all the tallies in the frequency square were made of cipher letters occuring in the cryptogram, and the tallies represented their actual occurences. We compared cipher alphabet to cipher alphabet. The plain text letters were held as unknown through out the process.

CRACKING THE PROGRESSIVE CIPHER USING INDIRECT SYMMETRY

What happens when we do not have enough data to foster the statistical attack? We can use indirect symmetry because of certain phenomena arising from the mechanics of the progressive cipher encipherment method itself.

Take:

```
Plain    HYDRAULICBEFGJKMNOPQSTVWXZ
Cipher   FBPYRCQZIGSEHTDJUMKVALWNOX
```

Encipher FIRST BATTALION by the progressive method sliding the cipher component to the left one interval after each encipherment.:

```
         1 2 3 4 5 6 7 8 91011121314
Plain    F I R S T B A T T A L I O N
Cipher   E I C N X D S P Y T U K Y Y
Index    F E B C I L U A R D Y H Z X
shift(-)   1 2 3 4 5 6 7 8 910111213
```

Repeated letters in the text are two I's, three T's and two A's. Lets look at them:

```
         F I R S T B A T T A L I O N
         1 2 3 4 5 6 7 8 91011121314
Plain    . I . . . . . . . . . I . .
Cipher   . I . . . . . . . . . K . .
Plain    . . . . T . . T T . . . . .
Cipher   . . . . X . . P Y . . . . .
Plain    . . . . . . A . . A . . . .
Cipher   . . . . . . S . . T . . . .
```

The two I's are 10 letters apart in both the plain and cipher components. Since the cipher component is displaced one step after each encipherment, two identical letters n intervals apart in the plain text must yield cipher equivalents which are n intervals apart in the cipher component. This leads to the probable word and indirect symmetry attack on the progressive cipher.

A second flaw concerns the repeated cipher letters. Look at the three Y's.

```
         1 2 3 4 5 6 7 8 91011121314
Plain    . . . . . . . . T . . . O N
Cipher   . . . . . . . . Y . . . Y Y
```

Reference to the plain component shows that the N O . . . T is reversed in order with respect to the plain text. The intervals are correct. Since the cipher component is shifted one to the left each encipherment, two identical letters n intervals apart in the cipher text must yield plain text equivalents which are n intervals apart in the cipher component. If the cipher is displaced to the left than the order of the plain is logically reversed.

Given the following message, which is assumed to start with the military greeting COMMANDING GENERAL FIRST ARMY (probable words) the data yielded by this assumption is:

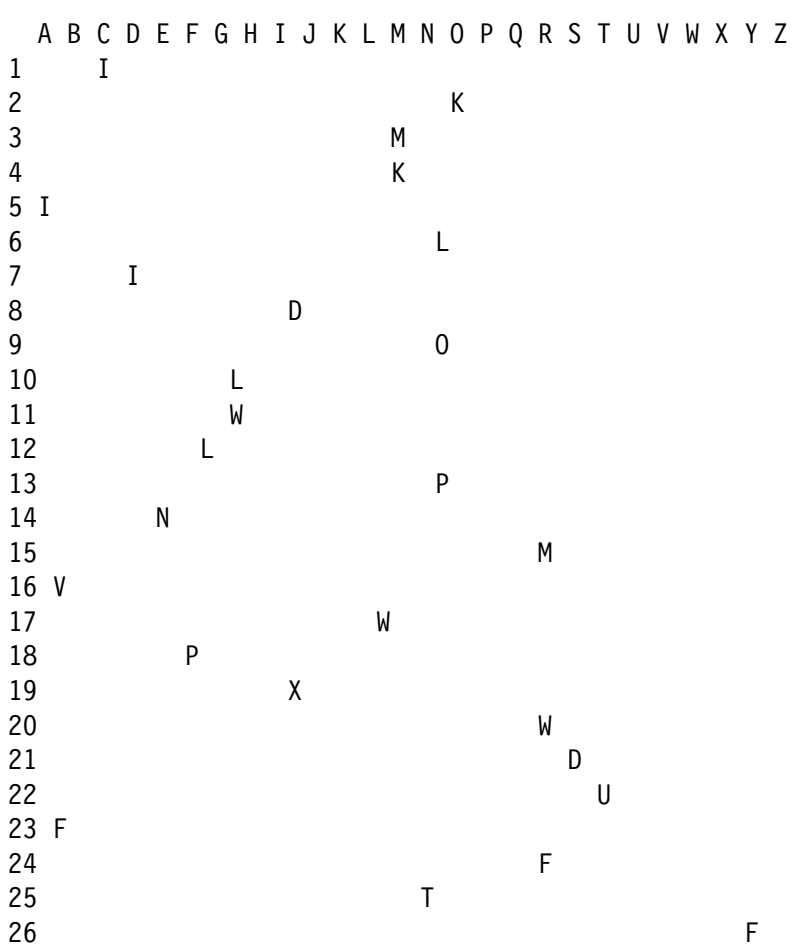
```
IKMKI  LIDOL  WLPNM  VWPXW  DUFFT
FNIIG  XGAMX  CADUV  AZVIS  YNUNL ...

               1.....................26

Plain (assumed) COMMANDINGGENERALFIRSTARMY
Cipher          IKMKILIDOLWLPNMVWPXWDUFFTF
```

Set up the decryption square in Figure 15-3.

Figure 15-3



Applying indirect symmetry to the above square gives:

```
       1 . . . 5 . . . .10 . . . .15 . . . .20 . . . . . 26
Plain  A     L I C   E F G   M N O     S             Y D R
Cipher     M K V . L W N O . F . P . . . . . I . . . . T
       D . . . . . . . . . . M
```

Setting C (plain) = I (cipher) for the first encipherment, the 8th value, I (plain) = D (cipher) which yields D and eventually X. We use the partial sequences to unlock other letters. Using the word ARMY we open the gaps some more.

```
           1 2 3 4 5 6 7 8 9 10 11 12
Plain      N I I G X G A M X  C  A  D
Cipher     . I L . . . . E O  .  .  R
```

The next word after ARMY might be WILL. We then insert the W in the plain and G in the Cipher.

The presence of MMM, WWW, FFF in the cipher might be a short word used several time.. hmm how about THE?? replacing any one of the triplets with THE, applying indirect symmetry, we may have a wedge.

MACHINE CRYPTOGRAPHY

The principles discussed in the previous paragraph may be used with progressive systems in which the interval is > 1 and with modifications to those intervals which are irregular but follow a pattern such as 1-2-3, 1-2-3, ... or 2-5-7-3-1, 2-5-7-3-1- and so on. The latter type of progression is encountered in certain mechanical cryptographs. [FRE3]

THE PHI TEST h FOR MONOALPHABETICITY

The Chi test is based on the general theory of coincidences and the probability constants Kp and Kr. Now two monoalphabetic distributions when correctly combined will yield a single distribution which still will be monoalphabetic in character. The Phi (h) test is used to confirm that a distribution is in fact alphabetic.

DERIVATION Of PHI h TEST

Start with a uniliteral frequency distribution, the total number of pairs of letters for comparison purposes is:

N(N-1)/2 for N letters

from the discussion on the Chi (a) test we found that the expected value of Fa(Fa-1)/2 +..+Fz(Fz-1) for A...Z is equal to the theoretical number of coincidences of two letters to be expected in N(N-1)/2 for N letters, which for normal English plaintext is Kp x N(N-1)/2 and for random text is Kr x N(N-1)/2.

d Fi (Fi-1) = E(hp) = Kp x N(N-1)

for i= A to Z for plain text

d Fi (Fi-1) = E(hr) = Kr x N(N-1)

for i= A to Z for random text

E(a) means the average or expected value of the expression in parenthesis, Kp = 0.0667 for normal English plain text, Kr = 0.0385 for random English text (26 letters).

Example 1:

Is the following enciphered monoalphabetically:

```
1     1 2 3 4 2     1       4 2   1           1   3  N=25
A B C D E F G H I J K L M N O P Q R S T U V W X Y Z
```

E(ao) = 1x0+1x0+2x1+3x2+4x3+2x1+1x0+4x3+2x1+1x0+1x0+3x2= 2+6+12+2+12+2+6 = 42 o = observed

E(ap) = Kp x N(N-1) = 0.0667 x 25 x 24 = 40 plain

E(ar) = Kr x N(N-1) = 0.0385 x 25 x 24 = 23.1 random

Since the E(ao) =42 is closer to E(ap) = 40, the distribution is most likely monoalphabetic.

Example 2:

```
Y O U I J   Z M M Z Z  M R N Q C   X I Y T W   R G K L H
```

The distribution is

```
    1       1 1 2 1 1 1 3 1 0 2 1 2   1 1   1 1 2 3 N=25
A B C D E F G H I J K L M N O P Q R S T U V W X Y Z
```

d Fi(Fi-1) = 18

Since E(ar) is closer to E(ao) the enciphement is probabably polyalphabetic to suppress the frequency distribution. The message was enciphered actually by 25 alphabets used in sequence.

LOGARITHMIC WEIGHT: CHI SQUARED TEST

Gleason discusses an important application of the theory of testing hypothesis. Given a number of messages, some of which are transposed English text and some are flat text. We want to develop a test for picking out the transpositions, and to accomplish this is possible to frame a statistical hypothesis concerning each message. Gleason discusses a 5 step procedure to 1) obtain probability information, 2) calculate its critical region, 3) differentiate by weighted logs 4) calculate the values of alpha and beta statistical inference 5) examine the normal distribution for given values of alpha and beta. The answer tells us how many letters to examine at some level of certainty to determine if we are dealing with a transposition. Chapter 13 Problem 1 gives a reasonable look at the process. [GLEA] Problems 2 and 3 look at the concept of Bayesian probability applied to transposition problems and should be of interest.

WITZEND'S TABLES TO AID CRYPTARITHM SOLUTION

WITZEND has graciously produced several cryptarithmic tables to aid in solution for problems involving bases from ten to sixteen. They are given as Tables 15 - 3 through 15 - 9 and should ease the pain.

Table 15 - 3
DECIMAL - BASE 10

ADDITION

	0	1	2	3	4	5	6	7	8	9
0	0	1	2	3	4	5	6	7	8	9
1	1	2	3	4	5	6	7	8	9	10
2	2	3	4	5	6	7	8	9	10	11
3	3	4	5	6	7	8	9	10	11	12
4	4	5	6	7	8	9	10	11	12	13
5	5	6	7	8	9	10	11	12	13	14
6	6	7	8	9	10	11	12	13	14	15
7	7	8	9	10	11	12	13	14	15	16
8	8	9	10	11	12	13	14	15	16	17
9	9	10	11	12	13	14	15	16	17	18

MULTIPLICATION

	0	1	2	3	4	5	6	7	8	9
0	0	0	0	0	0	0	0	0	0	0
1	0	1	2	3	4	5	6	7	8	9
2	0	2	4	6	8	10	12	14	16	18
3	0	3	6	9	12	15	18	21	24	27
4	0	4	8	12	16	20	24	28	32	36
5	0	5	10	15	20	25	30	35	40	45
6	0	6	12	18	24	30	36	42	48	54
7	0	7	14	21	28	35	42	49	56	63
8	0	8	16	24	32	40	48	56	64	72
9	0	9	18	27	36	45	54	63	72	81

N	1	2	3	4	5	6	7	8	9
N Square	1	4	9	16	25	36	49	64	81
N Cube	1	8	27	64	125	216	343	512	729
N Fourth	1	16	81	256	625	1296	2401	4096	6561
N Fifth	1	32	243	1024	3125	7776	16807	32768	59049
N Sixth	1	64	729	4096	15625	46656	117649	262144	531441
N Sevnth	1	128	2187	16384	78125	279936	823543	2097152	4782969

X	2	4	5	5	5	5	6	8
Y	6	6	3	5	7	9	6	6
X * Y	12	24	15	25	35	45	36	48

Table 15 - 4
UNDECIMAL - BASE 11

ADDITION

	1	2	3	4	5	6	7	8	9	A
1	2	3	4	5	6	7	8	9	A	10
2	3	4	5	6	7	8	9	A	10	11
3	4	5	6	7	8	9	A	10	11	12
4	5	6	7	8	9	A	10	11	12	13
5	6	7	8	9	A	10	11	12	13	14
6	7	8	9	A	10	11	12	13	14	15
7	8	9	A	10	11	12	13	14	15	16
8	9	A	10	11	12	13	14	15	16	17
9	A	10	11	12	13	14	15	16	17	18
A	10	11	12	13	14	15	16	17	18	19

MULTIPLICATION

	1	2	3	4	5	6	7	8	9	A
1	1	2	3	4	5	6	7	8	9	A
2	2	4	6	8	A	11	13	15	17	19
3	3	6	9	11	14	17	1A	22	25	28
4	4	8	11	15	19	22	26	2A	33	37
5	5	A	14	19	23	28	32	37	41	46
6	6	11	17	22	28	33	39	44	4A	55
7	7	13	1A	26	32	39	45	51	58	64
8	8	15	22	2A	37	44	51	59	66	73
9	9	17	25	33	41	4A	58	66	74	82
A	A	19	28	37	46	55	64	73	82	91

N	1	2	3	4	5	6	7	8	9	A
N Square	1	4	9	15	23	33	45	59	74	91
N Cube	1	8	25	59	104	187	292	427	603	82A

Table 15 - 5
DUODECIMAL - BASE 12

ADDITION

	1	2	3	4	5	6	7	8	9	A	B
1	2	3	4	5	6	7	8	9	A	B	10
2	3	4	5	6	7	8	9	A	B	10	11
3	4	5	6	7	8	9	A	B	10	11	12
4	5	6	7	8	9	A	B	10	11	12	13
5	6	7	8	9	A	B	10	11	12	13	14
6	7	8	9	A	B	10	11	12	13	14	15
7	8	9	A	B	10	11	12	13	14	15	16
8	9	A	B	10	11	12	13	14	15	16	17
9	A	B	10	11	12	13	14	15	16	17	18
A	B	10	11	12	13	14	15	16	17	18	19
B	10	11	12	13	14	15	16	17	18	19	1A

MULTIPLICATION

	1	2	3	4	5	6	7	8	9	A	B
1	1	2	3	4	5	6	7	8	9	A	B
2	2	4	6	8	A	10	12	14	16	18	1A
3	3	6	9	10	13	16	19	20	23	26	29
4	4	8	10	14	18	20	24	28	30	34	38
5	5	A	13	18	21	26	2B	34	39	42	47
6	6	10	16	20	26	30	36	40	46	50	56
7	7	12	19	21	2B	36	41	48	53	5A	65
8	8	14	20	28	34	40	48	54	60	68	74
9	9	16	23	30	39	46	53	60	69	76	83
A	A	18	26	34	42	50	5A	68	76	84	92
B	B	1A	29	38	47	56	65	74	83	92	A1

N	1	2	3	4	5	6	7	8	9	A	B
N Square	1	4	9	14	21	30	41	54	69	84	A1
N Cube	1	8	23	54	A5	160	247	368	569	874	92B

X	2	3	3	4	4	6	6	6
Y	6	4	8	3	6	2	4	6
X * Y	10	10	20	10	20	10	20	30
X	6	6	8	8	8	9	9	2
Y	8	A	3	6	9	4	8	1
X * Y	40	50	20	40	60	30	60	2
X	2	3	3	3	4	4	4	4
Y	7	1	5	9	1	4	7	A
X * Y	12	3	13	23	4	14	24	34

Table 15 - 6
TERDECIMAL - BASE 13

ADDITION

	1	2	3	4	5	6	7	8	9	A	B	C
1	2	3	4	5	6	7	8	9	A	B	C	10
2	3	4	5	6	7	8	9	A	B	C	10	11
3	4	5	6	7	8	9	A	B	C	10	11	12
4	5	6	7	8	9	A	B	C	10	11	12	13
5	6	7	8	9	A	B	C	10	11	12	13	14
6	7	8	9	A	B	C	10	11	12	13	14	15
7	8	9	A	B	C	10	11	12	13	14	15	16
8	9	A	B	C	10	11	12	13	14	15	16	17
9	A	B	C	10	11	12	13	14	15	16	17	18
A	B	C	10	11	12	13	14	15	16	17	18	19
B	C	10	11	12	13	14	15	16	17	18	19	1A
C	10	11	12	13	14	15	16	17	18	19	1A	1B

MULTIPLICATION

	1	2	3	4	5	6	7	8	9	A	B	C
1	1	2	3	4	5	6	7	8	9	A	B	C
2	2	4	6	8	A	C	11	13	15	17	19	1B
3	3	6	9	C	12	15	18	1B	21	24	27	2A
4	4	8	C	13	17	1B	22	26	2A	31	35	39
5	5	A	12	17	1C	24	29	31	36	3B	43	48
6	6	B	15	1B	24	2A	33	39	42	48	51	57
7	7	11	18	22	29	33	3A	44	4B	55	5C	66
8	8	13	1B	26	31	39	44	4C	57	62	6A	75
9	9	15	21	2A	36	42	4B	57	63	6C	78	84
A	A	17	24	31	3B	48	55	62	6C	79	86	93
B	B	19	27	35	43	51	5C	84	78	86	94	A2
C	C	1B	2A	39	48	57	66	75	84	93	A2	B1

N	1	2	3	4	5	6	7	8	9	A	B	C
N Square	1	4	9	13	1C	2A	3A	4C	63	79	94	B1
N Cube	1	8	21	4C	98	138	205	365	441	5BC	785	A2C

Table 15 - 7
QUADECIMAL - BASE 14

ADDITION

	1	2	3	4	5	6	7	8	9	A	B	C	D
1	2	3	4	5	6	7	8	9	A	B	C	D	10
2	3	4	5	6	7	8	9	A	B	C	D	10	11
3	4	5	6	7	8	9	A	B	C	D	10	11	12
4	5	6	7	8	9	A	B	C	D	10	11	12	13
5	6	7	8	9	A	B	C	D	10	11	12	13	14
6	7	8	9	A	B	C	D	10	11	12	13	14	15
7	8	9	A	B	C	D	10	11	12	13	14	15	16
8	9	A	B	C	D	10	11	12	13	14	15	16	17
9	A	B	C	D	10	11	12	13	14	15	16	17	18
A	B	C	D	10	11	12	13	14	15	16	17	18	19
B	C	D	10	11	12	13	14	15	16	17	18	19	1A
C	D	10	11	12	13	14	15	16	17	18	19	1A	1B
D	10	11	12	13	14	15	16	17	18	19	1A	1B	1C

MULTIPLICATION

	1	2	3	4	5	6	7	8	9	A	B	C	D
1	1	2	3	4	5	6	7	8	9	A	B	C	D
2	2	4	6	8	A	C	10	12	14	16	18	1A	1C
3	3	6	9	C	11	14	17	1A	1D	22	25	28	2B
4	4	8	C	12	16	1A	20	24	28	2C	32	36	3A
5	5	A	11	16	1B	22	27	2C	33	38	3D	44	49
6	6	C	14	1A	22	28	30	36	3C	44	4A	52	58
7	7	10	17	20	27	30	37	40	47	50	57	60	67
8	8	12	1A	24	2C	36	40	48	52	5A	64	6C	76
9	9	14	1D	28	33	3D	47	52	5B	66	71	7A	85
A	A	16	22	2C	38	44	50	5A	66	72	7C	88	94
B	B	18	25	32	3D	4D	57	64	71	7C	89	96	A3
C	C	1A	28	36	44	52	60	6C	7A	88	96	A4	B2
D	D	1C	2B	3A	49	58	67	76	85	94	A3	B2	C1

N	1	2	3	4	5	6	7	8	9	A	B	C	D
N **2	1	4	9	12	1B	28	37	48	5B	72	89	A4	C1
N **3	1	8	1D	48	8D	116	1A7	288	3A1	516	6B1	8B6	B2D

X	2	4	6	7	7	7	7	7
Y	7	7	7	2	4	6	8	A
X * Y	10	20	30	10	20	30	40	50

X	7	8	A	C	2	4	6	7
Y	C	7	7	7	8	8	8	3
X * Y	60	40	50	60	12	24	36	17

X	7	7	7	7	7	8	A	C
Y	5	7	9	B	D	8	8	8
X * Y	27	37	47	57	67	48	5A	6C

Table 15 - 8
QUINDECIMAL - BASE 15

ADDITION

	1	2	3	4	5	6	7	8	9	A	B	C	D	E
1	2	3	4	5	6	7	8	9	A	B	C	D	E	10
2	3	4	5	6	7	8	9	A	B	C	D	E	10	11
3	4	5	6	7	8	9	A	B	C	D	E	10	11	12
4	5	6	7	8	9	A	B	C	D	E	10	11	12	13
5	6	7	8	9	A	B	C	D	E	10	11	12	13	14
6	7	8	9	A	B	C	D	E	10	11	12	13	14	15
7	8	9	A	B	C	D	E	10	11	12	13	14	15	16
8	9	A	B	C	D	E	10	11	12	13	14	15	16	17
9	A	B	C	D	E	10	11	12	13	14	15	16	17	18
A	B	C	D	E	10	11	12	13	14	15	16	17	18	19
B	C	D	E	10	11	12	13	14	15	16	17	18	19	1A
C	D	E	10	11	12	13	14	15	16	17	18	19	1A	1B
D	E	10	11	12	13	14	15	16	17	18	19	1A	1B	1C
E	10	11	12	13	14	15	16	17	18	19	1A	1B	1C	1D

MULTIPLICATION

	1	2	3	4	5	6	7	8	9	A	B	C	D	E
1	1	2	3	4	5	6	7	8	9	A	B	C	D	E
2	2	4	6	8	A	C	E	11	13	15	17	19	1B	1D
3	3	6	9	C	10	13	16	19	1C	2A	2E	33	37	3B
4	4	8	C	11	15	19	1D	22	26	2A	2E	40	45	4A
5	5	A	10	15	1A	20	25	2A	30	35	3A	40	45	4A
6	6	C	13	19	20	26	2C	33	39	40	46	4C	53	59
7	7	E	16	1D	25	2C	34	3B	43	4A	52	5E	61	68
8	8	11	19	22	2A	33	3B	44	4C	55	5D	66	6E	77
9	9	13	1C	26	30	39	43	4C	56	60	69	73	7C	86
A	A	15	20	2A	35	40	4A	55	60	6A	75	80	8A	95
B	B	17	23	2E	3A	46	52	5D	69	75	81	8C	98	A4
C	C	19	26	33	40	4C	5E	66	73	80	8C	99	A7	B3
D	D	1B	29	37	45	53	61	6E	7C	8A	98	A7	B4	C2
E	E	1D	2C	3B	4A	59	68	77	86	95	A4	B3	C2	D1

N	1	2	3	4	5	6	7	8	9	A	B	C	D	E
N **2	1	4	9	11	1A	26	34	44	56	6A	81	99	B4	D1
N **3	1	8	1C	44	85	E6	17D	242	339	46A	5DB	7A3	9B7	C2E

X	3	3	5	5	5	5	6	6
Y	5	A	3	6	9	C	5	A
X * Y	10	20	10	20	30	40	20	40

X	9	9	A	A	A	A	C	C
Y	5	A	3	6	9	C	5	A
X * Y	30	60	20	40	60	80	80	40

X	3	3	5	5	5	5	6	9
Y	6	B	4	7	A	D	B	6
X * Y	40	80	13	23	10	25	35	45

Table 15 - 9
SEXDECIMAL - BASE 16

ADDITION

	1	2	3	4	5	6	7	8	9	A	B	C	D	E	F
1	2	3	4	5	6	7	8	9	A	B	C	D	E	F	10
2	3	4	5	6	7	8	9	A	B	C	D	E	F	10	11
3	4	5	6	7	8	9	A	B	C	D	E	F	10	11	12
4	5	6	7	8	9	A	B	C	D	E	F	10	11	12	13
5	6	7	8	9	A	B	C	D	E	F	10	11	12	13	14
6	7	8	9	A	B	C	D	E	F	10	11	12	13	14	15
7	8	9	A	B	C	D	E	F	10	11	12	13	14	15	16
8	9	A	B	C	D	E	F	10	11	12	13	14	15	16	17
9	A	B	C	D	E	F	10	11	12	13	14	15	16	17	18
A	B	C	D	E	F	10	11	12	13	14	15	16	17	18	19
B	C	D	E	F	10	11	12	13	14	15	16	17	18	19	1A
C	D	E	F	10	11	12	13	14	15	16	17	18	19	1A	1B
D	E	F	10	11	12	13	14	15	16	17	18	19	1A	1B	1C
E	F	10	11	12	13	14	15	16	17	18	19	1A	1B	1C	1D
F	10	11	12	13	14	15	16	17	18	19	1A	1B	1C	1D	1E

MULTIPLICATION

	1	2	3	4	5	6	7	8	9	A	B	C	D	E	F
1	1	2	3	4	5	6	7	8	9	A	B	C	D	E	F
2	2	4	6	8	A	C	E	10	12	14	16	18	1A	1C	1E
3	3	6	9	C	F	12	15	18	1B	1E	21	24	27	2A	2D
4	4	8	C	10	14	18	1C	20	24	28	2C	30	34	38	3C
5	5	A	F	14	19	1E	23	28	2D	32	37	3C	41	46	4B
6	6	C	12	18	1E	24	2A	30	36	3C	42	48	4E	54	5A
7	7	E	15	1C	23	2A	31	38	3F	46	4D	54	5B	62	69
8	8	10	18	20	28	30	38	40	48	50	58	60	68	70	78
9	9	12	1B	24	2D	36	3F	48	51	5A	63	6C	75	7E	87
A	A	14	1E	28	32	3C	46	50	5A	64	6E	78	82	8C	96
B	B	16	21	2C	37	42	4D	58	63	6E	79	84	8F	9A	A5
C	C	18	24	30	3C	48	54	60	6C	78	84	90	9C	A8	B4
D	D	1A	27	34	41	4E	5B	68	75	82	8F	9C	A9	B6	C3
E	E	1C	2A	38	46	54	62	70	7E	8C	9A	A8	B6	C4	D2
F	F	1E	2D	3C	4B	5A	69	78	87	96	A5	B4	C3	D2	E1

N	1	2	3	4	5	6	7	8	9	A	B	C	D	E	F
N **2	1	4	9	10	19	24	31	40	51	64	79	90	A9	C4	E1
N **3	1	8	1B	40	7D	D8	157	200	2D9	3E8	533	6C0	895	AB8	D2F

LECTURE 14 SOLUTIONS

14-1. Multiplication (Two words, 0-1) original by EDNASANDE

WOMEN X MEN = UTNNLM + TIWENO + NWTWNN = NLSMTUWM

0123456789
SLOWMINUET

14-2. Division (Two words, 0 -9) MORDASHKA

ATOM / ASK = N; - GNC = IS

0123456789
TASKCOMING

14-3. Multiplication. (No word, 0-1) FOMALHAUT

ASAP X MAB = RITMT + TMPRY + PDBYD =PAYDIRT

0123456789
DBARTMPIYS

14-4. Unidecimal multiplication. (Two words 0-X) WALRUS

TOUGH X DIG = IDIGDN + NYYDNG + UIHDOU = DDCUUILN

0123456789X
CLOUDYNIGHT

LECTURE 15 PROBLEMS - Taken from OP- 20 -G course:

15-1. Naval Text. Recover Keys.

J Z S S W B P D Z Z L F O M E K Q P D J H C K U M C

A B C O O X M Y S I I G B S G G Y V D S W A J O Q E

K U P W K N J K C C H W O Z Q Q B P Y N V J J O Q E

K U C D S L R W C F Q I A V M S R S I X Y T P O P G

D H U V N K V K C Y Y A L R Q O O Q D N Z C G L R E

K F H Q R N J B.

15-2. Naval Text.

A U V Z I S Z F B F Y E I R B I O W A O Y J L B L D

D G K U I T T Z B D B E Q I O C J R F W X D Y H G M

S P P I S W Y P F V S Y G G S H Q K L A L Z A Q F N

U T C Q H D G Y L B Z P D V C S J N W G N T P T M S

H J T W C K O C M X Z P Z R R U Y I W H H M E Z F L

O C F I S W L P D N W T Z H H T I R L Y I P N Q F N

U T C Q H D G Y L B Z P D V C S J N W G N T P T M E

O S V B W J B L V X Z P Z R R U Y I W H H P L P F T

R B P G X B U L V N W J P R H I H F Q X L N B L P S

H J T W I J T T Q W E E Q F O I I Z P M B J Q P Y M

D U Q W A T Z O W D C L Z Q M P U K.

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