# PREDETERMINED MOTION TIMES

A comparison of four recognised systems, a discussion of the basic arm motion times and the presentation of a new theory for $\frac{1}{2}$ to $3\frac{1}{2}$ inch hand motions

by

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(PRECIS REPORT)

## OBJECT

The object of the studies conducted under this project was to investigate, examine and explain the use of some of the predetermined motion time systems that have evolved during the past fifteen years. Particular attention was to be paid to two systems, Work-Factor and Methods-Time Measurement, which have achieved considerable industrial application. The time values assigned to the basic arm motions in the two systems were to be compared in a search for the true basic times for human motions. If the values were different, practical research was to be made into the short motion times of Methods-Time Measurement, some of which were known to be extrapolated and tentative.

## SUMMARY

Four systems of predetermined basic motion times are considered, Holmes', Engstrom's, Work-Factor and Methods-Time Measurement (MTM). The basic and application principles of each system are briefly discussed, and a number of small operations analyzed in detail. The analyses are compared and discussed for accuracy and reproducibility.

The Work-Factor and MTM times for basic arm motions are analyzed in detail, to see if the base time is common to both. Curves are plotted for different groups of arm motions, depending on the initial and final conditions of the motion. The arm motions are reanalyzed, taking into

account the true measurement of the motion path; the effect of weight is also considered.

In order to check some short motion times in the MTM system, and also to establish firm values for others, a series of films on industrial operations were taken. These were analyzed frame by frame until a large quantity of data was established, giving levelled times at various distances for some of the basic hand motions. These values are examined statistically and graphically, and the Logarithmic Theory of short motions is developed.

SUMMARY OF CONCLUSIONS

1. Holmes' system, evolved in the laboratory, is complex to apply, often requiring micromotion study. His treatment of "Eye and Sense" motions is of considerable interest but the basic movement theory is incorrect.
2. Engstrom's system permits rapid setting of standards on certain types of work. It is highly limited in its application and is standard data rather than basic data.
3. Both Work-Factor and MTM have achieved considerable industrial use and were established on industrial operations. They give a simple language for discussion, a precise definition of the method and closely comparing standards. Analysts must be properly trained.

4. The activity level of a Work-Factor standard is about 25% higher than the corresponding MTM value.

5. The Work-Factor arm times, using linear distance, include body assistance and are incorrect where this does not occur. The MTM measurement of actual arc is considered superior.

6. There are definite differences in the effect of weight on basic arm movement times between Work-Factor and MTM systems.

7. The basic arm movement times allowed by Work-Factor and MTM agree very closely for distances over four inches, excluding conditions covered by conclusions 5 and 6.

8. Certain revisions are required in the MTM system on the levelled times for short Reaches and Moves. For distances between $\frac{1}{2}$" and $3\frac{1}{2}$", the time is given by the Logarithmic Theory equation

$$T = a \cdot D^b \qquad \text{where } T = \text{Time, TMU}$$

$$D = \text{Distance, inches}$$

$$a,b = \text{Constants.}$$

9. For basic motions without full control, the constant 'a' has a value of 2.6 TMU/in.; this value becomes 2.3 TMU/in. if the hand is in motion at beginning or end of the movement. The constant 'b' has values between 0.6 and 0.8, and decreases as the required control becomes less.

10. The minimum motion time is 1.8 TMU, becoming 1.5 TMU if the hand is in motion at beginning or end of the movement.

11. Evidence suggests a further basic MTM motion "Move with Control", the control being applied over the full path of the motion.

## (DETAILED REPORT)

### INTRODUCTION

The industrial use of predetermined motion times is growing daily. Many claims, both for and against, have been made by all concerned from top management to union leaders and shop stewards; some of them have been wild mis-statements, others have produced sound, critical analyses. The moving forces which have engendered and nurtured the various systems can be briefly summarized under two headings:

(a) The Search for Better Methods

- (i) Methods in advance of production.
- (ii) Methods correction and improvement.
- (iii) Methods comparison and evaluation.
- (iv) Methods definition and control.

(b) The Search for Better Standards

- (i) Standards in advance of production.
- (ii) Standards for plant, company, or even industry-wide use.
- (iii) Precise standard data and formulae.
- (iv) Standards set without stop watch or rating.
- (v) Standards permitting more objective discussion.

Each of these aspects has played its part in bringing about the development of some predetermined motion time system; and the final scope of that system has depended on its versatility, simplicity and accuracy, as well as how closely it has helped in the search for better methods and standards.

# PART I

## GENERAL COMPARISON OF SYSTEMS

### HISTORICAL BACKGROUND

#### General

The need for standard data, and of the most refined form known as predetermined motion times, was first expressed by Frederick Taylor himself. The industrial engineer was endeavouring to eliminate wasted time and inefficient methods on the plant scale; and yet, when considered on a national scale, the same element was being studied and timed over and over again in plants throughout the country. The engineer was thus practising the precise antithesis of his purpose. Taylor thought that a time value could be given to each industrial operation, and that each value, with its methods description, should be centrally filed. The final result was to be a dictionary of standard times for all operations which any qualified person could apply without using a stop watch. The idea was fundamentally sound, but would have involved a library rather than a dictionary due to the macroscopic time elements.

Gilbreth gave part of the answer to the problem by proposing the use of therbligs, which he considered to be basic elements of motion. Some attempt was made to establish corresponding time values but it met with little success, for the elements were not truly basic. Within themselves, they contained a number of even more basic motions and the range of each element, though greatly reduced from Taylor's original concept, was still unwieldly for practical use.

The first fundamental system in this field was developed by A.B. Segur who made the initial installation as far back as 1912. The system achieved considerable popularity during the 1920's and 1930's, especially in the tyre and rubber industries where it was used to set standards and compare methods. It was during this time, in 1927, that the fundamental principle of predetermined basic motion times was first detailed. Segur, in an article (11) entitled "Labour Costs at the Lowest Figures", said: "Within practical limits, the time required for all experts to perform true fundamental motions is a constant."

Segur's system, though still used in a number of plants, has never been published, so no information or detail is available and further comment is impossible. However, a number of major companies and several firms of industrial consultants have developed their own systems of predetermined motion times since then. Men like Holmes, Engstrom and Olsen, (19,20), groups like Work-Factor, Methods-Time Measurement and Basic-Motion-Times, have each contributed to the knowledge in the field; and it is proposed to consider some of these systems for which sufficient information has been made available.

Holmes System

The first constructive table of basic motion times was published in "Applied Time and Motion Study" by W.G. Holmes in 1938 (1). In the preface, he stated "For a considerable period of time, perhaps some 10 to 15 years, time study engineers have discussed the possibility of determining time values for body member movements and nerve reactions. So far as the author is aware, such values, although they may have been found and used, hitherto have never been put into any organized form and published. In this book, the author's determinations appear and are the first published values of these fundamentals. Each value in this table was determined from a thousand or more creditable observations made by the author, and had been used in practice to a sufficient extent to establish its creditability."

Some interest was aroused following publication of the book, and the table was reprinted in a number of handbooks (8). However, the system was cumbersome and difficult to apply, even though its analysis was extremely detailed and refined, with the result that few people, then or now, have used the system to any advantage. The original work was done at the Timken-Detroit Axle Company, where Holmes was Time Study Engineer.

Engstrom System

The system was developed by Harold Engstrom and his associates while he was Motion Study Supervisor at the Bridgeport Plant of the General Electric Company. It was first used for the estimation of labour costs on new products, but was later used to establish time standards, both in the original plants and in others. The first reference to the work appeared as a reprint in a book by Ralph Barnes (33); reference was also made in an article by H.C. Geppinger (15). During the following years the data was expanded to cover such work as turret lathes, sensitive drills, soldering and general light machine assembly work (34). However, its use is still limited as it depends on certain special characteristics of the work, and it has not created very great interest.

## Work Factor

Work-Factor had its origin at the Watsontown, Pa., plant of the Philco Radio Corporation in 1934. A group of time study engineers, headed by J.H. Quick, initiated the development of a system which would eliminate the necessity for human judgment in rating operators when taking studies and establishing standards.

Films, stroboscopic cameras and even a special photo-electric timing device were used to establish the basic time values, and over three years were spent in accumulating data from both the shop floor and the laboratory. A further two years were spent in checking and simplifying the data before the system was first put into general use in 1938, when it was applied at the R.C.A. Victor Division of Radio Corporation of America in Camden, New Jersey.

The system was first brought to the notice of the general industrial public in May, 1945, when an article entitled "Motion-Time Standards" appeared in "Factory Management and Maintenance" (18), and aroused sufficient interest to result in the system being applied in other factories. In order to make the system available to all industries, and to concentrate on its development and application, three of the original Work-Factor investigators formed the Work-Factor Company in 1946 (6).

Since then, installations of the system have been made in a wide variety of plants. In-plant training has been given to selected personnel, who have then continued and maintained the system. In addition, appreciation training in the Work-Factor system has been offered at several universities.

Methods-Time Measurement

In contrast to Work-Factor, MTM originated as a methods analysis tool to develop the correct method before installation. Both systems resulted in a complete set of predetermined motion times, but their prime purposes were very different. The original research on MTM was carried out at the Westinghouse Plant, Pittsburgh, Pa., under the auspices of a consulting company, the Methods Engineering Council (MEC). The purpose was to set up formulae and standard data on drillpress work which could be used to compare the output of different methods. After considerable checking of the results, it was realized on December 8th, 1941, that a set of data had been obtained which not only applied to drillpress work but which appeared to be a basic standard time system. By 1943, the formulae were being tried out in a number of plants around Pittsburgh with excellent results. Some of the data had been further broken down and it was found that it applied not only to drillpress work, but to any operation involving basic human motions.

In 1948, the accumulated and refined data was made public through the book "Methods-Time Measurement" (5). The original work had been expanded to include most of the basic motions, and had reached a point far ahead of its original scope and concept. Articles in the technical press (22,26,27), evaluating and commenting on the system, gave it wider publicity and demands for training came from many widely differing industries, including such companies as duPont, Remington and the Celanese Corporation of America. In June, 1949, MEC started regular programmes of instruction in Pittsburgh, though J. Schwab had been teaching MTM at Bridgeport Engineering Institute as early as 1945 (26).

With the continuing increase in interest, MEC decided to license other industrial consultant firms so that they also could sell and use MTM as a service. In addition, the system began to spread abroad, Sweden and Australia receiving it first, and later Denmark, Canada, Norway, Holland, and Great Britain by the end of 1951.

By the middle of 1951 over half a dozen different consulting firms were using MTM as a customer service, and the system had been installed in several hundred plants, covering almost every aspect of industry. In order to maintain the standard of instruction and also to extend the basic research work even further, a number of companies formed the MTM Association for Standards and Research (31). This was a non-profit organisation with wide representation, and MTM was no longer the private property of the originators but open and available to all interested.

DETAIL OF SYSTEMS

Holmes

Holmes did not trust films for his analysis, for he considered that no two cycles were exactly alike either in movement or in time value. He considered that it was impossible to say from a film analysis if an operator's nervousness or inability caused the additional time, or even whether one element overlapped another; in addition, it was almost impossible to obtain a work cycle without defective movements or sequences.

This argument has a certain validity when considered in the light of the rating system. Regardless of the way in which the data is obtained, it has to be levelled before it can be used. Under the pace rating system that was in use at the time, the time study man made a flat rating on the operator. This rating is in terms of effects: the speed of the motions is compared with a mental concept of normal and, at the same time, an assessment is made of the effectiveness of the method used. The rating factor thus combines a judgment of both speed of motion and effectiveness of method, and a downrating may be due to either low effort or fumbling and ineffective work resulting from poor method. In the latter case, the problem of obtaining basic motion times by film analysis is quite acute. The rating factor, lowered due to, and to compensate for, ineffective working, affects all the motions and will give a false result unless the ineffective working time is prorated through all the elements in the study - which would be almost impossible. In other words, to get a true result the rating system must be such that fumbling is neither included in the rating nor in the film analysis.

This problem was quite simply avoided by Holmes. His basic motion times were obtained by the regular repetition of the movement one thousand or more times. The timing was done with a stop watch and, after the necessary rating and fatigue corrections, the average time per basic motion distance was calculated. Additional data of a more approximate nature were obtained for eye motions, and the speed of the nerve reaction was set at a flat rate of 30 ft. per second, as determined by physiological studies on car drivers prorated over the various distances in the human body.

The Holmes system "Time of Movements Chart" is shown in Table 1.(p. 68). This chart gives the times for body member movements and also includes nerve reaction and mind decision times. Each motion is subdivided according to the type of movement, namely the joint and the direction about which the motion occurs. The analysis has some similarity to the original Work-Factor system; for example, Grasp is analyzed as a series of Finger motions. However, it is more complex than any other system and includes many movements which are grouped together under broader headings in the others.

The analysis is based, in general, upon therbligs, and the original purpose of the analysis was to give a check rating. To each therblig, obtained by micromotion study, a corresponding motion or set of motions could be ascribed, the total giving the normal time for the operation. By the judicious use and understanding of the eye, nerve and decision times, it was also possible to account for the slower time required by less experienced operators. The complete analysis is extremely cumbersome, as each activity requires the information, in separate columns, of: therblig, body member moved, type of movement, distance, occurrence, and hence the movement time. This has to be done not only for the left and right hands, but also for the eye and sense cycle, even though the latter is limited out by the former for normal, trained operators unless there is a specific inspection element.

The times for the body motions are basic, and do not include any control factors of any type, neither has the effect of weight been considered. In order to get the complete time for a motion, it is necessary to add in the terminal controlling factors which stop the body member at the correct place. For example:

| Operation | Therblig | Body Member Movement |
|---|---|---|
| Pick up part | TE | 14" Angular Arm |
| | PP | 2" Hinge Finger |
| | G | 2" Hinge Finger |

Thus, as each basic motion becomes more complex, the end conditions increase further, and may even require mind decision and nerve reaction before being complete.

Engstrom

In contrast to the other three systems considered in this work, the Engstrom system did not establish times for "basic" motions. Instead, the results were expressed in terms of the larger elements "Get" and "Place", with variables depending on the original and final states of the object and the method of holding it.

Extensive use was made of films on industrial operations during the analysis, together with comparison by stop watch studies. The film cycles were broken down into "gets", "places", "uses" and "disposes" from which the final charts were built up. These are shown briefly in Tables 2 and 3 (p. 69,70). Further detail, with illustrations, can be found in Barnes' "Motion and Time Study" (2). The times are for use on a standard workplace layout, with parts being supplied from well-designed bins or hoppers, with a maximum working distance of 24" from the operator. Instead of giving times for each distance, a few representative distances are taken, usually 8", 12" and 24"; a small correction factor is given, but is not recommended by the originators of the system.

In addition to the basic element times, Engstrom also developed values for such "process" operations as soldering, cementing, spinning, power drivers and many others. Some of these values were also further divided into small, medium and large. The first values for all motions are included on the "Standard Times Computation Sheet", from which the standard for any operation which fits the rather narrow limits of the system can be computed. The process time values must be used with considerable care as they are necessarily only average times and large variations may be encountered on different jobs.

Work-Factor

This, the first really practical fundamental system of predetermined time data, took nearly ten years to appear in public. Part of this time was spent on the original research, but more than half was spent in checking and refining the data until it was as correct as the accuracy of the checking procedure. At the same time, however, it had to be made into a usable system; one of the main dangers in all forms of analysis of this type is to make it so fundamentally accurate that it loses any value for practical application.

The original concept in the Work-Factor system was of a series of factors which would influence the times for the basic motions in identical fashion. The major variables of Body Member, Linear Distance between points, and Weight presented no problem; it was the fourth variable, that of Purpose or Difficulty of the motion, which complicated the problem. This variable could influence the motion at various stages - at the start, at the end, at some specific point or even over the whole path of the motion. Considerable research was pursued to isolate the various controlling factors, with especial attention to their influence on the basic motions by the Finger, Arm, Forearm Swivel, Leg, Foot and Trunk. From this work, four controlling factors on the time per motion distance were isolated, in addition to the original one of weight. These four factors were each considered to be equal to one degree of motion difficulty, and this degree was known as "One Work-Factor". An illustration of each is given below:

1. Definite Stop - D : Reach to part lying on bench so as to grasp it.

2. Directional Control - S : Also known as Steer, as in bringing a plug up to a hole before inserting it.

3. Care - P : Care, or Precaution, for either the operator or the part, as in putting down a fragile part.

4. Change Direction - U : Abrupt, requiring muscular and mental control to get around an obstruction.

The fifth influencing factor is Weight, and the influence increases with each increase in weight, in definite steps which vary according to the body member used and the sex of the operator. The complete data are shown on the "Work-Factor" Moving Time Table in Tables 4 and 5 (pp. 71,72).

To find the time for any one basic motion, the body member and distance are first determined; then the various influencing factors - Work-Factors - are picked out and added together. From the data table, the corresponding time according to member, distance and total factors is determined. Special tables have also been developed up to 8 Work-Factors for use with heavy weights, but these have not been made available for general use as yet. However, extrapolation from the existing figures has been found to give satisfactory results.

Considerable attention was given later to the motions of Grasp and Align (Position). The motions are not basic in nature, since they consist of a series of very short finger and arm motions, plus the appropriate control factors. In the initial application on short cycle work, the Grasps and Aligns were broken down as required, and the time obtained; but, as the use of Work-Factor grew, this method was found to be cumbersome and slow, as well as difficult in many cases.

Howard Flicker, Production Superintendent of the Ideal Clamp Company found this difficulty an important factor in determining fair standards by Work-Factor. The company carried out a series of experiments and concluded that, instead of looking for a formula connecting Grasp times and Finger Motions, it would be better to break down Grasp in various groups, with the appropriate time for each. The initial theory was based on the degree to which the part is confined - i.e. depending on the number of planes by which the part could be moved away, with a maximum of three for an object on a flat surface. The results were published in "Factory Management and Maintenance" (25). Further work was done by the Work-Factor Company and the ultimate result was the long, but simple to apply, table for "Complex Grasps from Random Piles".

Alignment, with or without engagement of one object with another, is one of the most complex motions encountered industrially. One of the best answers to the problem lies in the "Work-Factor" Assembly Tables.

A series of motion frequencies have been reduced to time values for various conditions. The target diameter, and the ratio of plug diameter to target diameter for open and closed targets, have been taken as the datum lines. To these values appropriate percentages are added for the special conditions of distance between targets if motions are simultaneous, blind targets, and the distance between the gripping point on the part and the point of alignment. The resulting tables are long, and the conditions are not easily expressed by symbols, but understanding and application are relatively simple.

Work-Factor units (1 unit = .006 sec.) do not contain any allowances for fatigue, personal or unavoidable delays. The final cumulative time obtained by a Work-Factor analysis must be multipled by the appropriate allowance to give a standard, to meet which "the employees are working at a premium level with better than average skill and effort". According to Mr. Quick, one of the originators, the time values are for base rates in incentive programmes which have a starting normal at 75%. In day rate shops, it is necessary to include 25% additional time to compare with average, normal 100% or whatever normal is employed.

Thus, the level of activity as expressed by a Work-Factor standard is about the top of the normal industrial incentive range, which is near 25%. At a meeting with Mr. Duncan, Work-Factor Company, he agreed that a Work-Factor standard probably represented a 125% level of output when compared with MTM 100%, which is based on the Westinghouse system of rating. Information on the rating system used in the original Work-Factor analysis is not available.

## Methods-Time Measurement

Methods-Time Measurement (MTM) is a comparative newcomer in the field of predetermined motion times and yet, in the space of a few years, it has aroused more interest and is being used more than any system previously available. It combines accuracy with ease of application, instruction and explanation and appears to have given a simple language to the field of Work Study. The complete system and its simplified form are shown in Tables 6 and 7 (pp. 73,74).

In contrast to Work-Factor times for Arm Motion, which use similar time increments for widely different influencing factors, MTM developed times for separate groups of overall motions. Five classes of the Gilbreth element "Transport Empty", rechristened "Reach", were isolated, with variable times depending on the end conditions. Another five classes of "Transport Loaded", known as "Move", were also analyzed, but these were later reduced to three after it was found that some could be combined with others. In all cases, the distance recorded was the actual motion path, not the linear distance between points.

Eight groups of basic motions were isolated in the original work:- Reach, Move, Turn, Apply Pressure, Grasp, Position, Release, Disengage and Body Motions. Later research work has also produced time values for such motions as Eye Travel and Eye Focus, and Cranking. Some of these groups were truly fundamental motions - namely Reach, Move, Turn and Apply Pressure; but others were combinations of very small fundamental motions, usually so small as to make separate analysis extremely difficult. Such a motion is found in Position, which actually can be broken into Aligns, Finger and Hand Moves and Reaches, Turns and Apply Pressures.

In order to make the final data easy to apply - whilst maintaining the required accuracy - some motions were broken down into broader groupings which included a range of possible values. There are only eighteen types of Position to cover an actual infinity of variations, but innumerable experimental applications have shown excellent results.

While the original analysis films were being taken, the operations were rated by a number of experienced time study engineers using the Westinghouse rating system, which is also known as the "Skill and Effort" system. The levelled time developed from this, after addition of the appropriate allowances, represents the time required "by an operator of average skill, working with average effort and under average conditions (3)". This system of rating is widely used throughout the United States; an indication of its meaning can be judged from the fact that, based on 100% standards, the average output in many plants lies between 118% and 120%. This 100% represents the Westinghouse average rating, and also is the standard obtained by cumulating the MTM times for the basic motions of the operation.

Following the great public interest in the system, Professor Kendall C. White, Cornell University, undertook a research project into the validity of the MTM values (32). Starting completely anew in June 1949, he took films of industrial operations, having them rated at the same time, and then reanalyzing them for the basic motion times. The final results in September, 1950, showed that the time values could be reproduced for the great majority of the basic motions within reasonable limits, and the agreement was much closer where considerable data were available. Generally, values were within 1½% and only in isolated instances did this go as high as 10%. Differences were distributed very nearly uniformly between positive and negative, with a total check time of 2452.6 as against 2459.2 from the existing MTM data.

Similar checks have been carried out by the Singer Manufacturing Company, and their results are within 3-5% of the MTM figures. However, it is to be noted that neither of these experiments questioned the validity of the basic motion breakdown used by MTM. They only confirmed that the specific time values assigned to the motions as defined by MTM were correct.

## APPLICATION EXAMPLES OF SYSTEMS

Each of the four systems of methods analysis treats the motions from different aspects. In spite of this, however, the ultimate results are usually very similar as long as the system is capable of application along the lines of the original analysis. No one system can claim to be the absolute answer to the problems of basic human motions. At the best, the result is a statistical average; at the worst, the system does not apply to the class of work under consideration.

To give a brief picture of each of the four systems under consideration, the breakdown of a very short operation has been made. The operation consists of reaching to a pile of flat-ended steel pins, 2" long x $\frac{1}{4}$" dia., picking up one pin and inserting into an unchamfered hole in a board so that the pin stands upright. The operation is considered to be on a continuous basis.

The analysis of the method is shown in Table 8 (p.75). The time units used are those relevant to the system concerned. A condensed form of the results is shown in Table 9, in which all time units have been reduced to units of .0001 minutes. In addition to this, the Work-Factor units have been multiplied by 1.25 to give a comparable level of activity with the other three systems.

Table 9

Pin insertion results

| Element description | Total levelled time (.0001 min.) per element | | | |
|---|---|---|---|---|
| | M.T.M. | W.F. | Holmes | Engstrom |
| 1. Reach to pin | 69 | 67 | 63 | 110 |
| 2. Select and grasp one pin | 54 | 45 | 51 | |
| 3. Move pin to board | 71 | 87 | 63 | |
| 4. Align pin and insert | 97 | 90 | 108 | 190 |
| 5. Release pin | 10 | 10 | 17 | |
| Total | 301 | 299 | 302 | 300 |

This example, short as it is, shows the close similarity in final results, as well as the variations between short elements. This variation is due to differences in the concept of each basic motion by each system, and a series of compensating factors are built up between elements.

The complete analysis of a normal industrial short-cycle operation is shown in Appendix I (pp.92-96). The operation is "Assemble bolt and washers, two-handed method" and has been analyzed by each system. The operator is seated in front of chute bins containing rubber, steel and lock washers. He in turn selects and slides two of each kind of washer along the bench and into a small fixture which is flush with the benchtop. Finally, the operator picks up two bolts from an open bin, pushes each one through an assembled stack of three washers, and disposes of the complete part through drop delivery while reaching for the next rubber washers.

The results from this analysis are shown in Table 10.

Table 10

Bolt and washer assembly results

| System | Actual time | Normal minutes | No. of time elements |
|---|---|---|---|
| Holmes | 0.1109 min. | 0.111 | 36 |
| Engstrom | 0.1209 min | 0.121 | 9 |
| Work-Factor | 0.910 WFTU | 0.114 | 18 |
| MTM | 179.1 TMU | 0.107 | 23 |

COMPARISON OF RESULTS BY NORMALISED TIME

Comparison between the systems is not an easy matter, for each will have its own definition of normal performance, and differences in method may account for variations. In the ideal experiment to make this comparison, six trained analysts from each system would all study six actual plant operations, after which the results could be examined, both for consistency of application by each system and consistent comparison between the systems themselves. Until something of this nature can be done, comparison work has been limited to studying and analyzing films of the operation, which is a very unsatisfactory means of determining the exact method.

Three operations were studied in this manner; the method was analyzed by each of the four systems and, in addition, the film was rated on the Westinghouse system by four trained time study observers. The results from the studies are shown in Table 11, the second operation is from Appendix I.

Table 11

Film analysis results

Time in normal minutes

| System | Bolt and washer assembly. One hand | | Bolt and washer assembly. Two hands | | Fold and flatten sheets of paper | |
|---|---|---|---|---|---|---|
| | Time | % diff. | Time | % diff. | Time | % diff. |
| Time study | 0.0973 | - | 0.1097 | - | 0.0500 | - |
| Holmes | 0.1025 | +5% | 0.1109 | +1% | 0.0531 | +6% |
| Engstrom | 0.1006 | +2% | 0.1208 | +10% | - | - |
| WF | 0.1048 | +7% | 0.1138 | +4% | 0.0513 | +3% |
| MTM | 0.0956 | -2% | 0.1063 | -3% | 0.0516 | +3% |

No special significance can be given to these results, though they are indicative of the accuracy of each system when used on a class of work to which it is applicable. The Engstrom system could not be used for the third operation under any conditions known to the analyst.

Of considerably greater interest are the results of the number of motions to which a specific time was assigned.

Table 12

Film analysis results

Number of basic motions with an assigned time value

| System | Operation 1 | Operation 2 | Operation 3 |
| --- | --- | --- | --- |
| Holmes | 33 | 36 | 18 |
| Engstrom | 8 | 9 | - |
| WF | 16 | 18 | 10 |
| MTM | 23 | 23 | 11 |

It is these figures that give a reasonable assessment of the complexity of the systems. Holmes' analysis is extremely refined and detailed, but it requires considerable time to establish a standard by this method. In contrast, the Engstrom system uses broad groupings, each containing several basic motions; this allows rapid analysis, but also severely limits the analyst to certain specific conditions and to certain types of work. In other words, it is not truly basic time data.

Both Methods-Time Measurement and Work-Factor have similar numbers of basic motions assigned a specific time. There is a difference of five for Operations 1 and 2 in Table 12, but this comes from five Contact Grasps and Releases, to which a zero time is given under the

MTM system. They are included in the analysis so as to define the method exactly, but have no equivalent symbol in the Work-Factor system.

Prof. Ralph Barnes (23) obtained some interesting results when he asked the head of the Standard Department of a large radio plant to undertake a special experiment. Five experienced analysts, using an unspecified system of predetermined motion time data, independently established standards on seven different jobs. Each job was on regular production, and the standards were set simultaneously. The results are considered to be of sufficient value to include here in tabular form.

Table 13

Percentage variation from average

| Operation | Analyst No. | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 |
| Assemble capacitor over coil form | 0 | +2 | -1 | +2 | -3 |
| Assemble and solder leads to coil | -2 | -3 | -1 | +3 | +1 |
| Test oscillator coil | -2 | -3 | -2 | +3 | +2 |
| Rivet capacitor to antenna loop back | +2 | +6 | -3 | -4 | -3 |
| Rivet three capacitors to bracket | -3 | +3 | +2 | 0 | -3 |
| Drill two holes in coil form | -1 | +2 | -2 | -2 | +4 |
| Press spindle to shaft | +2 | -4 | +2 | 0 | 0 |

Although no general conclusions can be drawn from this one case, the results are as good as, if not better than, the results which would be obtained by a similar set of stop watch studies.

## CONCLUSIONS

Having considered each of the systems separately and together, certain facts and conclusions emerge. It is proposed to summarize these before attempting a more detailed analysis of the Work-Factor and MTM basic motion time values.

### Holmes System

1. The system was developed under highly specialized laboratory conditions, not on the shop floor.
2. Each basic motion was analyzed separately, under repetitive conditions, without considering the effect of preceding or succeeding motions.
3. The methods analysis is by basic movements, plus the addition of further motions at the end to account for control (Holmes (1) recognized this inaccuracy in commenting on the slowing of "transport empty" by "select").
4. The "Eye and Sense" section in the analysis is of considerable interest. If the actual values could be checked and refined, they might well fill in gaps in the more widely used systems. This is especially true in considering learning times and untrained operator standards.

5. The system requires great detail to be used properly, often with prior application of micromotion study. It is complex beyond the errors in analysis due to personal limitations of an analyst.

Engstrom System

1. For establishing standards, this system is probably the fastest within its range of application.
2. There is a good breakdown of the various types of "Grasp" and "Position", although their basic times are included in those for "Get" and "Place".
3. Broad groupings are used to cover ranges of distances but, in many cases, the stationary times are greater than those involved in moving the parts concerned, and errors in time of travel may not be important.
4. The system is limited to specific types of workplace layouts, and operations in a narrow range. It is not basic data, but standard data.

MTM and Work-Factor

The following observations apply to either system and detailed comparison will be left until further data has been presented.

1. A number of plants, covering a wide range of industries, use the systems for methods analysis and for establishing standards.

2. The systems give the methods engineer a language in which to discuss and evaluate his work.
3. The systems give a precise description of the average method.
4. The original films were taken on industrial operations under normal operating conditions.
5. Analysts in either system must be properly trained and experienced before their results are trustworthy.
6. With proper training different analysts can set standards which will be within a close range of each other.
7. For ease of application, certain complex combinations of motions have been grouped together into classes which cover a specific range. The definitions of these combinations vary in range, making individual comparison doubtful.
8. The activity level of a Work-Factor normal time is about 25% higher than the corresponding value established by MTM.

# PART II

## DETAILED COMPARISON OF MTM AND WORK-FACTOR BASIC ARM MOTIONS

### INTRODUCTION

Until the publication of the Work-Factor and MTM systems of predetermined time standards, the knowledge on this subject in industry was very limited. A number of people had obtained times for certain motions from micromotion analysis, suitably rated, but with little attention to such precise conditions as destination and distance. Holmes' published work in the field gave considerable information, in spite of the synthetic method of establishing the values but, again, little attention was paid to the effect of the "Purpose" of the motion on the time value. The work of Engstrom did not take basic motions as the datum line; instead, both Grasp and Move were included in the same total. Early work by Barnes and Mundel was only of indicative value as there were no rating assessments of the values.

By the end of 1949, two systems had been established which could replace the stop watch on manual operations. MTM and Work-Factor had both been applied in many widely differing industries, and repeated tests and successful applications showed that there was a fair guarantee of accuracy in the results. However, when the two systems were compared with each other, basic motion by basic motion, a considerable amount of difference was observed, even when the summations were identical.

This fact has disturbed a number of people who feel that if both systems have really discovered the times for basic human motions - and assuming that a basic time actually does exist - then the two sets of data should correlate.

BASIC ARM MOVEMENT TIMES

In order to illustrate the differences between the values given by Work-Factor and MTM a series of curves has been plotted for various combinations of motions. The basic definitions of each system are not the same, for a Work-Factor basic arm motion can be either reaching to an object or carrying it to some location, whereas the MTM system divides the motion into two specific types - Reach and Move - with subdivisions depending on the required control. Reach occurs when the predominant purpose is to move the hand to an object or location, Move occurs when the predominant purpose is to move an object with the hand to a destination.

For the purpose of comparison, all Work-Factor times have been multiplied by 125% so that they represent the same level of activity as MTM. The levelled results are plotted directly on Figures 1-8

Figure 1 (Page 77) Time against distance travelled for basic arm motions with minimum control during the motion.

(a) Move, Case B, Type 2; moving an object to an approximate or indefinite location, hand in motion at the beginning or end - MTM.

(b) Reach, Case E; moving the hand to an indefinite location, no particular attention as to where it stops - MTM.

(c) Move, Case A; moving an object against a stop, the object stopping the hand rather than the hand stopping the object. No particular control or care - MTM.

(d) Basic angular arm time - Holmes.

(e) Arm time with zero control factors - Work-Factor.

<u>Figure 2</u> (Page 78) Time against distance travelled for basic arm motions with some control or weight during the motion.

(a) Reach, Case B; reaching the hand to an object in an approximate location - MTM.

(b) Move, Case A, 6 lb. wt.; moving an object weighing six pounds against a stop, the object stopping the hand - MTM.

(c) Arm Time with one control factor - Work Factor. This factor may be either a Definite Stop A-D to correspond with (a) or Weight A-W, corresponding with (b).

<u>Figure 3</u> (Page 79) Time against distance travelled for basic arm motions with definite control during the motion.

(a) Reach, Case D; reaching to a very small object or where an accurate grasp is required - MTM.

(b) Move, Case C; moving an object to an exact location with the hand - MTM.

(c) Arm Time with two control factors - Work-Factor. In both (a) and (b), the hand must be steered to the object and come to a definite stop, giving the equivalent of A-D.S.

<u>Figure 4</u> (Page 80) Time against distance travelled for basic arm motions with definite control and some weight, or some control and increased weight during the motion.

(a) Move, Case C, 6 lb. wt.; moving an object weighing six pounds to an exact location with the hand - MTM.

(b) Move, Case B, 11 lb. wt.; moving an object weighing eleven pounds to an approximate location - MTM.

(c) Arm Time with three control factors - Work-Factor. In case (a), the Weight only requires one factor, but the Definite Stop and Steer impose two more to give A-D.W.S. In case (b), only a Definite Stop is needed, but the Weight factor is increased to two, A-D.W.W.

In each of these sets of diagrams, it is significant to note that the Work-Factor times start at a higher value than MTM, but then bend over and usually end up at a lower value as the distance gets greater. In addition, a straight line function is rarely reached until the linear distance between points exceeds twenty inches. The MTM curves, on the other hand, are usually straight line functions after four to six inches, and rapidly exceed Work-Factor values at longer distances. This is true in all cases except in Figure 4, for the Move, Case B, 11 lb.wt. All the basic MTM times start lower than and end higher than the Work-Factor times; it is only when weight is introduced that this rule breaks down. As a result, it is proposed to examine these two phenomena separately, under the question of distance and weight.

MEASURED DISTANCE EFFECT ON ARM TIMES

In the previous section, a direct comparison was made on the basis of time per unit distance. Each system recognizes that, in moving the hand from one point to another, the arm rarely makes an absolutely straight-line motion. Instead, it follows a natural arc, a slightly curved path of a ballistic type which is less fatiguing than forcing the hand along a straight line. When the latter condition exists, a definite state of control appears and results in a higher time value under either system.

When the original data were set up two different methods of measurement were employed:

(a) The Work-Factor system assumed that the body member would always follow a natural arc, unless muscularly restrained, and that it would automatically choose the quickest path between two points. Thus, the time to perform an Arm motion, apart from end control factors, would vary according to the linear distance between the points, without considering the actual distance travelled along the curved path.

(b) The MTM system recognized that this would happen in most cases, but that different conditions would exist depending on the direction, weight and other physical factors. In some cases, the natural arc distance would be longer than in others for the same linear distance travelled, and a longer time should be allowed. Furthermore, movement of the hand about the wrist could either decrease or increase the distance moved by the arm. If the fingers moved from right to left while the arm performed a similar motion, the arm would not have to go as far to move an object between two fixed points as in the case where the hand moved in the reverse direction about the wrist. Taking these various arguments into consideration, MTM distance was measured as the actual arc distance, measured at 1st knuckle for arm motions, and discounting any assistance from other body members.

The result of these two different ideas was two totally different approaches, both in the setting up of the original data and in using them to establish output standards. MTM takes the total motion, splits it into component parts, measures each one along its natural arc and takes the longest time. Work-Factor measures the total time for each motion, with the assistance of the others included, and measures distance linearly between the two points concerned. The full implications of this can be brought out after considering Tables 14, 15 and 16 and corresponding curves, (Figures 5, 6 and 7).

In each case, two simple motions have been taken. For MTM, Reach, Case B, to a single object in a slightly variable location; for Work-Factor, Arm motion with one control factor A-D, the operator deliberately exercising manual control to terminate the motion of the hand.

Distances have been measured linearly for Work-Factor and over the natural arc between the points for MTM, thus giving the time which each system would allow for motions with identical results. Body motion, a natural assistance, has also been measured and included. Under Work-Factor, it is evaluated separately; under MTM, body motion, which is grosser and slower than arm motions, is considered only to assist the arm for as long as there is time available. It is not limiting until certain muscular conditions exist, after which the complete time for a Bend is allowed.

1. <u>Seated Bend, forward arc</u> (Table 14)

The operator is seated in a chair in front of a table of normal height. He reaches forward without body twist, to pick up an object from the table. The normal times allowed over various distances are shown as follows:

Table 14

Seated, forward reach

| Linear distance (in.) | Trunk motion (in.) | Actual arm motion (in.) | W.F. limiting time x 1.25 | | MTM Reach time TMU |
|---|---|---|---|---|---|
| | | | Arm TMU | Trunk TMU | |
| 2 | - | 2¼ | 6.0 | - | 4.7 |
| 4 | - | 4½ | 7.9 | - | 7.5 |
| 6 | - | 7 | 9.8 | - | 9.3 |
| 8 | - | 9 | 11.2 | - | 10.8 |
| 10 | - | 11 | 12.7 | - | 12.2 |
| 12 | - | 13 | 13.5 | - | 13.7 |
| 14 | 2¼ | 14 | 14.4 | - | 14.4 |
| 16 | 3¼ | 15 | 15.2 | - | 15.1 |
| 18 | 5½ | 16 | 15.8 | - | 15.8 |
| 20 | 6½ | 17 | 16.6 | - | 16.5 |
| 22 | 8½ | 18 | 17.3 | (16.8) | 17.2 |
| 24 | 10¼ | 18 | (17.9) | 18.5 | 17.2 |
| 28 | 12½ | 18 | - | 19.8 | 17.2 |

These values have been plotted in Figure 5, (p. 81). The two curves are almost identical between 4" and 22", which is over the main range of distances commonly encountered in industry. There is a break away at the high values, and another one at the very low ones. The former may be due to differences of analysis of body motions, but the latter has no other explanation than that the two systems have different times for the same motion.

2. Standing Bend, forward arc (Table 15)

The conditions are similar to Case 1, except that the operator is standing in front of the table, not seated. Normal times allowed are shown as follows:

Table 15

Standing, forward reach

| Linear distance (in.) | Trunk motion (in.) | Actual arm motion (in.) | Limiting time - W.F. x 1.25 | | MTM Reach time TMU |
|---|---|---|---|---|---|
| | | | Arm TMU | Trunk TMU | |
| 0 - 10 | - | As above | As above | - | As above |
| 12 | $2\frac{1}{2}$ | 12 | 13.8 | - | 12.9 |
| 16 | $6\frac{1}{2}$ | 16 | 15.2 | (13.5) | 15.8 |
| 20 | $8\frac{3}{4}$ | 20 | (16.6) | 17.2 | 18.6 |
| 24 | $15\frac{1}{2}$ | 21 | - | 21.2 | 19.4 |
| 28 | 20 | 21 + bend | - | 24.1 | 29.0 |

These values have been plotted in Figure 6, (p. 82). Again, the curves almost mated between 4" and 22", with discrepancies at either end. At high values, body motions come into the picture; at low values, the breakaway is still evident.

3. Standing, body swivel (Table 16)

The operator is standing at right angles to the same table so that, in reaching for an object on the table, the trunk is turned about the hips in order to assist the moving hand and arm. Normal times allowed at each linear distance are shown as follows:-

Table 16

Standing, body swivel reach

| Linear distance (in.) | Trunk motion (in.) | MTM distances (in.) a. Knuckle travel | b. Trunk 6" from spine | Actual (a - 5.b) | W.F. arm x 1.25 TMU | MTM Reach TMU |
|---|---|---|---|---|---|---|
| 12 | - | 13 | - | 13 | 13.5 | 13.7 |
| 15 | 1 | 17 | ½ | 14½ | 14.8 | 14.8 |
| 19 | 3½ | 22 | 1 | 17 | 16.2 | 16.5 |
| 25 | 5 | 28 | 2 | 18 | 18.3 | 17.2 |
| 26 | 5½ | 29 | 2 | 19 | 18.7 | 17.8 |
| 28 | 6 | 31 | 2 | 21 | 19.3 | 19.3 |
| 32 | 6½ | 36 | 2½ | 23½ | 20.4 | 21.1 |

These values have been plotted in Figure 7, (p. 81). Even better agreement than in the previous cases has been obtained, and the maximum variation over the range between 4" and 22" is less than 6%. The difference below 4" remains unchanged as the body motions are insignificant at short hand distances.

In the three conditions analysed, there is body assistance with the arm motion, the body is either leaning or twisting at the same time; and the time values under each system check closely. The MTM system has "limited out" the assistance before measuring the distance and hence the time; the Work-Factor system has taken the two in combination and the slope of the curves decreases as the body assistance increases.

However, these conditions assume that body assistance is present, and that it occurs in its most favourable form. Very often these conditions are not fully met; motion about the wrist may retard rather than assist, more or less trunk motion may be required for balance prior to the next motion, and simultaneous, two-handed motions in opposite directions almost elimate body assistance. The easiest example to consider is the motion of the hand from above the head, dropped down to waist level. Linear distances up to 50" are quite possible without any body assistance except a small amount from hand motion about the wrist. These types of motions are not unusual, and the chargeable arc distances give wide variations in the final times.

If these motions were plotted, the curve would actually resemble Figure 2 (p. 78), equivalent time for equivalent distance. For the longer motions, the time allowed by Work-Factor would be low - and incorrectly low since the motion does not include body assistance - and, hence, should be allowed a longer time than the motion which does have body assistance to reduce the time to complete the motion.

WEIGHT EFFECT ON ARM TIMES

The moving of weight, with its consequent effects, has caused discussion and dissension for many decades. Not only do the motions become slower, but they become more tiring if repeated, and the operator has to be allowed a higher time for the weight-carrying motion, as well as a high allowance for fatigue. The latter is outside the range of predetermined time analysis, and is dependent on plant policy and other regional factors. However, the retarding effect of weight on the basic motion time has to be included in any system that is to have a reasonable breadth of application.

Figure 8 (p. 83) shows the weight curves according to the definition of each system. A Move, Case B has been chosen for the MTM system, but the actual one selected is of no great significance since it is percentage variation with weight that is important. For this reason, the curves have not been corrected to equivalent distance but have been plotted directly from the tables.

There is a very definite difference in the two sets of data as to the effect of weight. Over the range from zero weight to 25 lb., there is an increase in time by 25% for the Work-Factor values, compared with 11% for MTM. The effect of weights between 45 lb. and 50 lb. on the Work-Factor system is not known, but the additional time by MTM is only 25%.

These differences are highly significant, and cannot be easily explained. Both have been successfuly applied in practice and either there is an error in one of the systems or there is a difference in the motion analysis. The latter explanation becomes more probable when it is realized that the Work-Factor system has no value for the MTM basic motion Apply Pressure. With heavy weights, wide changes in motion pattern occur; more and more body motions are used in place of arm motions and pressure, followed by jerking, may be needed to overcome initial inertia. If part of this is included within the Work-Factor time, then direct comparison is difficult and only overall study comparison can be used. So far, no particular difficulty in using weights has been encountered by practitioners of either system.

## CONCLUSIONS

1. There are appreciable differences in time allowed by each system for the same accomplishment at distances under 4".
2. The Work-Factor Arm times include body assistance, and, hence, will be incorrect at longer distances in the cases where there is no body assistance.
3. The MTM system of measurement, using actual arc distance, is superior to the Work-Factor linear distance as it allows all motions to be considered separately. In addition, due allowance can be made for any increase in arc distance not sufficient to be covered by a Change of Direction (U) Work-Factor.

4. There are wide differences in the weight factors for the two systems which require investigation. Differences in motion concept, especially with respect to Apply Pressure in MTM, may be the explanation. If this is correct, then truly basic human motions have not been reached.

5. Excluding weight conditions, the arm movement times allowed by Work-Factor and MTM agree very closely for distances over 4" within the normal accuracy limits of measurement.

# PART III

## MTM SHORT MOTION TIMES - LOGARITHMIC THEORY

### INTRODUCTION

The comparison curves in Part II between Work-Factor and MTM indicated definite differences in times for basic movements below 4" in linear distance. Not only did the time values differ, but the shapes of the curves joining the points were completely different: the MTM curve dropped straight to the origin while the Work-Factor curve had a definite point of inflexion. Furthermore, general experience on the part of MTM practitioners indicated that the time for a one inch motion was definitely low, and that it was necessary to use the two inch value if there was any possibility of the motion being slightly over one inch long. This situation was frequently encountered in screwing motions, using the fingers to run a nut up or down, or a screwdriver on a light screw. In such cases the fingers perform very short motions, but at normal speeds of working the ballistic nature of the movement and the actual inertia of the fingers themselves usually results in a motion path something over one inch long, distances being measured at the finger-tips about the knuckle. In this class of work, various time study and production checks had indicated the need to use the two inch time values.

Further evidence was provided by a consideration of the initial research itself. This work was done with films taken at 16 frames/second, whence one frame is equal to 1.7 TMU. This represents between 80% and 100% of the total time for a 1" motion, and even if an operator took 50% longer than the observed time of one frame, it would not show up as two frames of film. There was a definite potential error here which was recognized by the originators of the system. Where the values were definitely in doubt, or obtained by extrapolation, the data card (Tables 6 and 7, pp. 73 and 74) gave them in light type. The validity of the extrapolation for time values - especially those close to the origin - was suspect.

## PROCEDURE

In order to investigate the times required to perform short motions, as classified by the MTM analysis, a series of films was taken with a 16 mm. cine-camera. Most of the films were of actual industrial operations and were taken under normal operating conditions on the shop floor. In each case, the prior consent of management, union and employee was obtained, and representatives of each were present at all times. The exceptions to this occurred during the filming of clerical operations with typewriters and comptometers, normal office conditions prevailing during these sequences. Operation, layout, equipment, operator and rating details are given in Appendix II (pp. 97-100 ).

A 16 mm. Bell and Howell camera was used to film all operations. The camera drive was electric and periodic check films of a stop watch were taken to ensure that it remained correctly calibrated. All films used were taken at a shutter speed of 4000 frames per minute, so that one frame of film was equivalent to 0.417 multiplied by the overall levelling factor for that study, in TMU. In all cases, the TMU is the basic unit of measurement and is 0.00001 hours.

Some supplementary lighting was used while the films were being made, but it was always directed onto the operator's hands and carefully shielded to prevent interference with vision. The need for the precise analysis of the distance made a distinct record essential; and the paucity of operations with a high ratio of short motions gave little scope to find perfectly lit conditions. Nothing else changed on the layout and the method was similarly untouched. While the film was being made, at least three and usually four qualified observers rated the operator, using the Westinghouse (3) system. Average values were taken. Each operation was filmed for either 50 or 100 ft. of film, depending on the useful cycle time, and at least 10 cycles were obtained in each case.

## FILM ANALYSIS

The films were analyzed frame by frame, in accordance with standard MTM nomenclature. A specially converted (2) electrically driven projector was used, equipped with a reversible speed control as well as a reversible frame counter. This was an essential to the analysis as the breakpoints between one motion and the next were not always easy to determine. The best procedure was to take a reading as soon as the first motion was known to have stopped, and another one frame back from the visible start of the subsequent motion. If these coincided, this was the reading used; but where there was a difference, it was averaged between the two motions.

Distances were measured as accurately as possible, and usual accuracy was within $^1/8$" for distances up to 1", and $\frac{1}{4}$" for distances up to 4". After each film was taken, all possible information about lengths of reference objects was recorded; this included the lengths of each joint on each of the operator's fingers as well as every dimension of the materials. When the film was later projected, the position of the projector was altered until the image of the operator's fingers was life size, after which direct measurement of distance could be made on the screen. Values were adjusted, if necessary, for motion perpendicular to the screen, usually by imitating and measuring them in practice.

After the number of frames corresponding to each motion had been determined, it was multiplied by the factor 0.417 and the levelling factors (see Appendix II), to give the levelled TMU over the distance. The completed figures were tabulated by motion class and distance, and show the mean levelled time obtained from each study. The results are shown in Tables 17 to 25 inclusive (see Appendix III, pp. 101-105).

EFFECT OF INDIVIDUAL FINGERS

General research into typewriting and the work loading of individual fingers had revealed that some fingers are stronger than others and, hence, that they should carry a heavier load (35). However, no known work had been done on the relative speed of each digit. It was considered possible that the load capacities might have a significant effect on the time values at short distances.

During the analysis of the films on typewriting, the key depression motion was very frequently encountered. This motion was usually an mM½A, a half-inch move of the key against a stop with the fingers in motion. The results are shown in Table 17 (p. 76), giving the levelled time values and the digit used.

For Finger No. 1: $\Sigma X^2 = 61.59 \quad \therefore \sigma_x = 0.28$

Hence, 95% confidence limits of $\bar{X}_1 = 1.94 \pm 0.15$

(Sample, $n = 16$, $t_a = 2.13$ for 95% confidence limits)

This means that the average levelled time for an mM½A, as performed by the second and fourth fingers, is just significantly different from that of the first finger. This is only in the second decimal place.

Calculation of the 95% confidence limits of the time for Finger No. 2 shows it to have a value of 2.14 ± 0.17. This gives a 25% overlap between the limits of probability for the two means.

Further results were considered for other short motions during the analysis of the first three films. In each case, the values indicated that a small difference in average speed between the various digits was possible, but there was never less than a 25% overlap between the limits of probability at the 95% confidence limits. In addition, the maximum observed difference between the averages for any two digits was only 0.2 TMU for $\frac{1}{2}$" motions, with no one finger consistently faster than another.

In view of these figures, it was concluded that no particular value was to be found in separating the various digits during the analysis of the results. The difference in average speeds was smaller than the inherent experimental errors in measurement of time and distance, as well as the cycle-to-cycle variations of any one operator. However, it is possible that further work would reveal a statistically significant difference in average speeds between the digits. The size of the difference will not be great and will certainly not be as great as the difference in capacity for work (35).

## ANALYSIS OF RESULTS

When all the results had been completed and tabulated, statistically significant data had been found for four of the MTM basic motions. In addition, there was sufficient data for some of the other motions to demonstrate significant trends. The four motions investigated in considerable detail were:

| | | |
|---|---|---|
| R-Am | - | Reach to an object in a fixed location, hand in motion at the end. |
| R-A | - | Reach to an object in a fixed location. |
| R-E | - | Reach to an indefinite location. |
| M-B | - | Move object to an approximate location. |

The mean of all levelled data at each distance was plotted, together with the arithmetic mean of these mean values. The results for each of the four motions are shown in Figures 9, 10, 11 and 12 (pp. 84, 85, 86 and 87). From these, it was immediately evident that the curves departed radically from the original MTM data, having a point of inflexion similar to that found in Work-Factor, though at lower values.

## LOGARITHMIC THEORY OF SHORT MOTIONS

The shape of the curves suggested that a mathematical equation could be fitted over part of the range and, after several experiments, the general form chosen was:

$$T = aD^b \qquad \text{where } T = \text{Time in TMU}$$

$$D = \text{Distance in inches}$$

$$a \text{ and } b = \text{Constants for each motion}$$

The means of the individual distances were plotted on log-log paper and showed that the points lay very close to a straight line (see Figures 13, 14, 15 and 16, pp. 88 and 89 ). Accordingly, the separate values from each study were taken, not the mean values, and analyzed completely to obtain the equations of the curves.

The form of analysis is shown in Appendix IV (pp. 106-109). The logarithms of distance and corresponding time are tabulated for Reach, Case A in Table 34 (pp. 106-107 ); following it are the complete calculations for the line equation and the 90% confidence limits.

The results from the four sets of significant data are given in Table 18 as follows:-

Table 18

Statistical analysis of Logarithmic Theory

| Motion | Equation | $\bar{T}$ TMU | $\bar{D}$ in. | Correlation Coefficient | $\pm 3\,\sigma_r$ | $\pm 3\,s_E$ | 90% Con. Lts. of index |
|---|---|---|---|---|---|---|---|
| R-Am | $T = 2.38\,D^{.61}$ | 2.96 | 1.44 | 0.909 | ±0.09 | ±0.17 | ±0.08 |
| R-A | $T = 2.57\,D^{.64}$ | 2.87 | 1.21 | 0.931 | ±0.08 | ±0.19 | ±0.09 |
| R-E | $T = 2.58\,D^{.64}$ | 2.85 | 1.19 | 0.822 | ±0.18 | ±0.31 | ±0.14 |
| M-B | $T = 2.61\,D^{.73}$ | 3.21 | 1.33 | 0.955 | ±0.06 | ±0.18 | ±0.10 |

Where $\bar{T}$ = Mean time value

$\bar{D}$ = Mean distance value

$\sigma_r$ = Standard deviation of the correlation coefficient

$s_E$ = Standard error of estimate

Thus, for the first curve, R-Am, the time is given by the expression $T = 2.38\ D^{.61}$. The mean points have a correlation coefficient of .909 with respect to the ideal, or straight line, of 1.0 when plotted on log-log axes. The three standard deviations limit of accuracy on .909 is $\pm$ 0.09, and the three standard deviations limit on the actual regression line is $\pm$ 0.17 i.e. 97% of all the values will lie within $\pm$ 0.17 of the value given by the curve. The final 90% confidence limits of $\pm$ 0.08 refer to the index value 0.61 in the equation for T.

The compiled results show a very high degree of correlation for M-B and R-A, a trustworthy degree for R-Am and a slightly doubtful value for R-E. The latter doubt is substantiated by the larger limits for the regression coefficient, regression line and D index. However, the variations, though significant statistically, have very little effect on the first decimal place, and a basic motion time for one inch of 2.6 TMU appears to have a strong probability. The corresponding figure for "hand in motion" motions is 2.3 TMU.

At very short distances, certainly at values of ½" and below, the theory will break down. The extremely short motions values from Tables 26, 28, 29 and 32 in Appendix III (pp. 101-105) all point to a minimum time value of 1.8-1.9 TMU for basic motions, with a similar minimum of 1.4-1.5 for "hand in motion" values from Tables 25, 30 and 31.

These two facts - the constant values at very short distances and also at one inch - suggest that for distances of one inch or less the motion classification is not important and has no effect on the time value. It is a true basic motion. This certainly applies to all motions, except Reach Case C and D, and Move Case C, for which no data have been obtained, and it also applies to Type II motions, known as "hand in motion" movements.

PROPOSED BASIC MOTION TIMES

From the results obtained by film analysis, two sources of proposed values are obtained. The first is by drawing a smooth curve through the mean of the means at each distance, the other is the Logarithmic Theory. Observed data gives constant values at ½" of 1.8 TMU, and both Theory and observation give 2.6 TMU at 1" distance for basic motion times. After that, the index derived from the Logarithmic Theory gives the required value from 1" to 3½", following which the accepted values continue in the normal straight line relationship as given in the original MTM data (5).

For Type II motions, the Logarithmic Thoery holds from ½" to 3", with a 1" value of 2.3 TMU and a minimum value of about 1.5 TMU. The range and the curves are similar to those for Type I, but are shifted towards the origin due to the "hand in motion" effect.

The following tables compare curve and Logarithmic Theory results and include the proposed new values. An asterisk denotes an extrapolated value in the present MTM data.

Table 19

Reach, Case A, Type II

Short motion line equation $T = 2.38 \times D^{.61}$

| Distance (in.) | Time - TMU | | | |
|---|---|---|---|---|
| | Present data | Curve Fig. 9 | Line equation | Proposed value |
| ½ | 1.3 * | 1.5 | 1.5 | 1.5 |
| 1 | 1.3 * | 2.3 | 2.3 | 2.3 |
| 1½ | 2.1 * | 2.9 | 3.0 | 3.0 |
| 2 | 2.8 * | 3.6 | 3.5 | 3.5 |
| 2½ | 3.3 * | 4.1 | 4.1 | 4.1 |
| 3 | 3.8 * | 4.5 | 4.5 | 4.5 |
| 3½ | 4.4 * | 4.7 | 5.0 | 4.7 |
| 4 | 4.9 | 4.9 | - | 4.9 |

Table 20

Reach, Case A

Short motion line equation $T = 2.57 \times D^{.64}$

| Distance (in.) | Time - TMU | | | |
|---|---|---|---|---|
| | Present data | Curve Fig. 10 | Line equation | Proposed value |
| ½ | 1.8 * | 2.0 | 1.6 | 1.8 |
| 1 | 1.8 * | 2.6 | 2.6 | 2.6 |
| 1½ | 2.8 * | 3.3 | 3.3 | 3.3 |
| 2 | 3.7 * | 4.0 | 4.0 | 4.0 |
| 2½ | 4.4 * | 4.7 | 4.6 | 4.6 |
| 3 | 5.0 * | 5.2 | 5.2 | 5.2 |
| 3½ | 5.6 * | 5.8 | 5.7 | 5.7 |
| 4 | 6.1 | 6.1 | 6.2 | 6.1 |

Table 21

Reach, Case E

Short motion line equation $T = 2.58 \times D^{.64}$

| Distance (in.) | Time - TMU | | | |
|---|---|---|---|---|
| | Present data | Curve Fig. 11 | Line equation | Proposed value |
| ½ | 1.7 * | 1.8 | 1.6 | 1.8 |
| 1 | 1.7 * | 2.3 | 2.6 | 2.6 |
| 1½ | 2.8 * | 3.1 | 3.3 | 3.3 |
| 2 | 3.8 * | 4.2 | 4.0 | 4.1 |
| 2½ | 4.6 * | 5.2 | 4.6 | 5.2 |
| 3 | 5.3 * | 5.9 | 5.2 | 5.9 |
| 3½ | 6.1 * | 6.4 | 5.7 | 6.4 |
| 4 | 6.8 * | 6.8 | 6.2 | 6.8 |

Table 22

Move, Case B

Short motion line equation $T = 2.61 \times D^{.73}$

| Distance (in.) | Time - TMU | | | |
|---|---|---|---|---|
| | Present data | Curve Fig. 12 | Line equation | Proposed value |
| ½ | 1.7 | 1.8 | 1.6 | 1.8 |
| 1 | 1.7 | 2.4 | 2.6 | 2.6 |
| 1½ | 2.9 | 3.6 | 3.5 | 3.5 |
| 2 | 4.2 | 4.6 | 4.3 | 4.3 |
| 2½ | 4.9 | 5.3 | 5.1 | 5.1 |
| 3 | 5.7 | 5.8 | 5.8 | 5.7 |
| 3½ | 6.3 | 6.4 | 6.5 | 6.4 |
| 4 | 6.9 | 6.9 | 7.1 | 6.9 |

LOGARITHMIC THEORY APPLIED TO REACH, CASE B

If the Logarithmic Theory on short motions is correct, then it should be possible to obtain the complete equation if only two correct values are known. In the research work, a series of values for Reach Case B, as given in Table 27 (Appendix III, p.102) were obtained but the shortest distance encountered was $1\frac{3}{4}$ inches. Below this, the motion tends to become either Case A, by knowing instinctively where to reach, or else Case D, having to reach with care or exactitude so as to stop at the right place.

The values obtained in the range $1\frac{3}{4}$" to 4" show close agreement with those already given on the MTM data card in heavy type. These values are plotted on Figure 17 (p. 90). The time values for 2" and 3" are both actual MTM data, and also appear to lie on the line developed by the experimental data. If the actual TMU values for 2" and 3" are substituted in the general logarithmic expression, $T = aD^b$, the equation becomes

$$T = 2.51 \times D^{.78}$$

This gives a unit distance of 2.5, which is extremely close to the proposed value of 2.6 and indicates the probable validity of the expression. Within the single decimal place limits of T as given on the data card, this value gives the closest agreement.

CONTROLLED MOTIONS

Litte data could be obtained from the films for motion of the type Reach Cases C and D, and Move Case C, and it is not known if the Logarithmic Theory is applicable in these cases. It is highly probable that the one inch times will not be 2.6 TMU but somewhat higher.

Several instances were encountered of "Controlled" Moves, when the control was exerted throughout the motion to guide the object. One case was steering a small nut along a narrow ledge to a hole, another involved painting a small object with lubricant. The levelled times for "Controlled" Moves have been plotted on Figure 18 (p. 91). There is a definite curve above the present MTM times for Moves Case C which corresponds more closely to the Work-Factor definition of "Care or Precaution" control throughout the motion.

From these results, it can be concluded that a further motion classification is required in the MTM data, that of a "Move with Control". However, it is not known if this condition will continue in a similar way at the longer distance values. It may be difficult to obtain and define such data into a usable grouping since control can have very variable effects. It may double or even quadruple the usual time for the motion in the case where the operator's speed becomes completely controlled and limited by the physical process. For cases where the operator has full control over the motion, but has to exercise continuous control throughout its duration, it should be possible to establish a specific motion time.

## LIMITATIONS OF THE MEASURING PROCEDURES

Three limitations and one basic assumption must be taken into account when discussing any system of predetermined time data. When establishing this data from films, the camera speed itself imposes one limitation, the errors in measurement of distance impose the second, and the rating system the third.

Before discussing the basic assumption, the limitations should be considered first as they only result in mathematical error. All the films were taken at 4000 frames per minute, so that any reading is liable to an error of ± half a frame. The distance error has already been discussed under Film Analysis (p. 49 ), and may give an error up to $\frac{1}{4}$" at short distances. The rating of each study is a blanket or overall rating, not one on individual elements or cycles, and may lead to large errors in any one time measurement. The Westinghouse rating system allows an increase of 28% due to skill and effort on the part of the operator over normal, and there is no bottom limit on how slow the operator may perform one particular motion.

All these three limitations can and have been overcome by the accumulation of large quantities of data, followed by a statistical analysis to show if the figures are significant. This was done in the four main basic motion analyses, and it indicated that the values for Reach Case E were open to suspicion. The values for motions other than the four analyzed can only be used to indicate trends, and further work must be done before they can be considered statistically significant.

The analysis and use of predetermined motion times involves one basic assumption, and one that is common to all systems: namely, that a fundamental normal time does exist for the elements of human motion. If this is not true, then the psychological and physiological differences between each operator, depending on environment, heredity and education, make the results, at best, only an average from the group studied; an average from a set of unconnected data that should not be averaged. This means that the data has been drawn, not from a random sample, but from an indefinitely large number of separate units, each of which has an infinite number of variables. It is recognized that the differences may be small - and small enough to give the illusion of connection with only one variable, namely the rating factor - but very small increments of time are involved in these analyses and the experimental error may be as great as the actual difference from one worker to another.

It is impossible to resolve this paradox since it can only be done by measurement and comparison of the very factors that are in doubt. Working standards are essential to management, not only for incentive payments or employee control, but for such things as costing, estimating and scheduling. The vast store of knowledge that has been accumulated on all aspects of Work Study indicates without any doubt that time standards, however set, and even if not based on a correct theoretical assumption, are both practical and applicable. The increasing knowledge on predetermined time standards is demonstrating the same conclusion and it would appear, at least in industry, that a fundamental normal time exists for the average employee.

## CONCLUSIONS

1. Not all the MTM data card times for short motions are correct, particularly the values known to be doubtful and derived by extrapolation.

2. For short motions, distances between ½" and 3½", the equation of the motion time curve is given by

$$T = aD^b$$

3. The basic normal time for a one inch motion without full control is 2.6 TMU; and 2.3 TMU if "hand in motion".

4. The basic minimum normal time for any motion, however short, is 1.8 TMU; and 1.5 TMU if "hand in motion".

5. MTM data card values should be revised as follows (blanks indicate no further information available, brackets indicate present data not statistically conclusive):-

Table 23

Revised values for Reach

| Distance (in.) | Basic motion - TMU | | | | Hand in motion | |
|---|---|---|---|---|---|---|
| | Case A | Case B | Case C.D. | Case E | Case A | Case B |
| 1 | 2.6 | 2.6 | - | 2.6 | 2.3 | (2.3) |
| 2 | 4.0 | 4.3 | - | 4.1 | 3.5 | - |
| 3 | 5.2 | 5.9 | - | 5.9 | 4.5 | - |
| 4 | 6.1 | 7.1 | - | 6.8 | 4.9 | 4.3 |

Table 24

Revised values for Move

| Distance (in.) | Basic motion - TMU | | | Hand in motion | |
|---|---|---|---|---|---|
| | Case A | Case B | Case C | Case A | Case B |
| 1 | 2.6 | 2.6 | - | (2.3) | (2.3) |
| 2 | (3.8) | 4.3 | - | - | - |
| 3 | 4.9 | 5.7 | - | - | - |
| 4 | 6.1 | 6.9 | - | 7.3 | 4.3 |

6. Further research work is required on motions with control, and there appears to be a further basic motion: "Move with Control exerted throughout the Distance".

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| ADDED TOTALS ARE EQUAL TO THE WORK CYCLE TIME | TIME OF MOVEMENTS CHART | | | | | | | | | | | TIME IN DEC. MIN. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| BODY MEMBER MOVED | TYPE OF MOVEMENT | MOVED AT | MEASURE MOVEMENT OF | IMPULSE PRESS NERVE MIND | DISTANCE MOVED 0" TO 2" 5° | 4" 10° | 6" 15° | 8" 20° | 1' 30° | 1½' 45° | 2' 60° | 2½' 90° |
| FINGER | HINGE | KNUCKLE | FINGER TIP | .0015 | .0017 | .0021 | | | | | | |
| FINGER | SIDE | KNUCKLE | FINGER TIP | .0021 | .0032 | | | | | | | |
| HAND | HINGE | WRIST | FINGER TIP | .0020 | .0022 | .0025 | | | | | | |
| HAND | ANGULAR | WRIST | FINGER TIP | .0022 | .0032 | .0038 | | | | | | |
| FOREARM | ANGULAR | ELBOW | KNUCKLE | .0023 | .0027 | .0030 | .0033 | .0036 | .0041 | | | |
| FOREARM | HINGE | ELBOW | KNUCKLE | .0018 | .0020 | .0022 | .0024 | .0027 | .0031 | | | |
| FOREARM | ROTATE | ELBOW | KNUCKLE | .0020 | .0022 | .0024 | .0026 | .0028 | .0032 | .0038 | .0045 | .0053 |
| FOREARM | TWIST | ELBOW | KNUCKLE | .0018 | .0018 | .0019 | .0020 | .0021 | .0023 | .0025 | .0028 | .0032 |
| ARM | ANGULAR | SHOULDER | KNUCKLE | .0029 | .0030 | .0035 | .0040 | .0048 | .0060 | .0080 | .0095 | .0105 |
| ARM | ROTATE | SHOULDER | KNUCKLE | .0032 | .0034 | .0039 | .0045 | .0054 | .0067 | .0090 | .0107 | .0118 |
| ARM | TWIST | SHOULDER | KNUCKLE | .0020 | .0022 | .0025 | .0027 | .0028 | .0029 | .0030 | .0032 | |
| HEAD | HINGE | NECK | NOSE | ✓ | .0059 | .0061 | .0063 | .0065 | .0069 | .0075 | .0087 | .0100 |
| HEAD | TURN | NECK | NOSE | ✓ | .0051 | .0053 | .0055 | .0057 | .0063 | .0070 | .0078 | .0090 |
| FOOT | HINGE | ANKLE | TOE | .0024 | .0027 | .0032 | | | | | | |
| FOOT | ANGULAR | ANKLE | TOE | .0028 | .0031 | .0036 | | | | | | |
| FORELEG | HINGE | KNEE | TOE | .0036 | .0040 | .0043 | .0047 | .0052 | | | | |
| FORELEG | SIDE | KNEE | TOE | .0040 | .0045 | .0050 | .0056 | .0064 | | | | |
| FORELEG | ANGULAR | KNEE | TOE | .0045 | .0051 | .0057 | .0064 | .0072 | | | | |
| THIGH | HINGE | HIP | KNEE | .0036 | .0038 | .0040 | .0042 | .0050 | | | | |
| THIGH | SIDE | HIP | KNEE | .0040 | .0045 | .0050 | .0056 | .0064 | | | | |
| THIGH | ANGULAR | HIP | KNEE | .0046 | .0052 | .0058 | .0068 | .0080 | | | | |
| LEG | HINGE | HIP | TOE | .0030 | .0032 | .0034 | .0036 | .0038 | .0043 | .0050 | .0058 | .0065 |
| LEG | SIDE | HIP | TOE | .0045 | .0048 | .0052 | .0056 | .0060 | .0068 | .0080 | | |
| LEG | ANGULAR | HIP | TOE | .0050 | .0052 | .0056 | .0060 | .0065 | .0072 | .0084 | .0096 | .0108 |
| OPERATOR | TURN | HIP OR ANKLE | SHOULDER | ✓ | .0062 | .0076 | .0088 | .0095 | .0106 | .0120 | .0136 | .0160 |
| OPERATOR | TURN | MOVE FEET | SHOULDER | ✓ | ✓ | ✓ | ✓ | .0200 | .0210 | .0220 | .0226 | .0230 |
| OPERATOR | BEND | HIP OR ANKLE | SHOULDER | ✓ | .0077 | .0087 | .0095 | .0102 | .0111 | .0125 | .0142 | .0168 |
| OPERATOR | SIT | HIP | SHOULDER | ✓ | .0180 TO .0210 | | | | | | | |
| OPERATOR | STAND | HIP | SHOULDER | ✓ | .0220 TO .0280 | | | | | | | |
| EYE | MOVE SIGHT | SOCKET | PATH ANGLE | ✓ | .0050 | .0055 | .0059 | .0062 | .0066 | .0073 | | |
| EYE | FOCUS | GET IMAGE CLEAR | | ✓ | .0020 TO .0040 | | | | | | | |
| EYE | INSPECT | READ | | ✓ | .0035 TO .0045 | | | | | | | |
| EYE | INSPECT | SEE PART | | ✓ | .0025 TO .0035 | | | | | | | |
| EYE | INSPECT | OBSERVE (GLANCE) | | ✓ | .0015 TO .0025 | | | | | | | |
| NERVE REACTION | | EYE TO BRAIN : OR REVERSE | | .0003 | | | | | | | | |
| NERVE REACTION | | HAND TO BRAIN : OR REVERSE | | .0024 | | | | | | | | |
| NERVE REACTION | | KNEE TO BRAIN . OR REVERSE | | .0026 | | | | | | | | |
| NERVE REACTION | | FOOT TO BRAIN : OR REVERSE | | .0030 | | | | | | | | |
| NERVE REACTION | | REALIZE CONTACT | | .0010 TO .0040 | | | | | | | | |
| NERVE REACTION | | HEAR OR SMELL | | .0025 TO .0040 | | | | | | | | |
| MIND DECISION | | MENTAL PROCESS | | .0010 TO .0100 | | | NOT OVER .0100 | | | | | |
| OPERATOR | WALK | | | PER STEP AFTER 5 STEPS | | 1 STEPS | 2 STEPS | 3 STEPS | 4 STEPS | 5 STEPS | 8 STEPS | 10 STEPS |
| OPERATOR | WALK | HIP | 6" STEP | | | .0160 | .0260 | .0350 | | | | |
| OPERATOR | WALK | HIP | 12" STEP | | | .0210 | .0330 | .0440 | .0530 | .0610 | | |
| OPERATOR | WALK | HIP | 18" STEP | .0070 | | .0240 | .0370 | .0490 | .0580 | .0640 | .0850 | .0990 |
| OPERATOR | WALK | HIP | 24" STEP | .0075 | | .0260 | .0400 | .0530 | .0630 | .0720 | .0945 | .1150 |
| OPERATOR | WALK | HIP | 30" STEP | .0080 | | .0270 | .0420 | .0560 | .0670 | .0770 | .1010 | .1170 |

NOTE :–
USE CIRCULAR MEASURE
FOR UNDERLINED VALUES.

Table 1

Table 2

Engstrom system - Get

Distances up to 8", time in normal minutes

| Condition of grasp | Medium (3F) 3 fingers and thumb | Large (H) Extended hand | Small (2F) 2 fingers and thumb | Very large (2H) Two hands |
|---|---|---|---|---|
| A. Very best grasp facility possible. The object is prepositioned for grasp or the grasp is not hindered by other objects in contact with the object grasped | .006<br>Get screw-driver from bench | .006<br>Get suspended power driver | .006<br>Get small bolt from other hand | .006<br>Get large open box |
| B. Good grasp facility but parts may be in quantities requiring some selection of a single part. No untangling or difficult separation | .006<br>Get 3" disc from pile | .011<br>Get book from pile | .011<br>Get small washer from bin | .011<br>Get large flat plate from bench |
| C. The design of parts or kind of finish prevents ready grasping. Parts may tangle, or be packed with separators or require special handling | .011<br>Get wired terminal plug from box. Some tangling | .017<br>Get large parts from box; paper separators | .019<br>Get small lockwashers from bin | .024<br>Get heavy parts from constricted area |

Corrections for data

1. More than one Grasp per Get, multiply base time by 1.50

2. Simultaneous Gets in both hands, multiply base time by 1.30

3. Reach distance over 8", under 20", add .0004 minutes per extra inch. For additional distance over 20", add .0006 minutes per inch.

Table 3

Engstrom System - Place

Distances up to 8", time in normal minutes

| Condition of place | Medium (3F) 3 fingers and thumb | Large (H) Extended hand | Small (2F) 2 fingers and thumb | Very large (2H) Two hands |
|---|---|---|---|---|
| A. Positioning is normally little more than releasing the object on the work place | .006<br>Put part into other hand | .006<br>Put medium sized box on table | .006<br>Put small screw into other hand | .011<br>Slide large part to rough position |
| B. On or into definite locations with ample tolerances, simple open nests or fixtures, or assemblies with one point of location | .006<br>Put screw-driver into funnel-type holder | .011<br>Put medium sized box on pile | .011<br>Place steel washer over stud, large tolerances | .019<br>Large part to line or simple fixture |
| C. On or into difficult or complicated locations Assemblies or fixtures requiring positioning of parts with respect to two definite points, or location in two directions | .011<br>Place socket wrench over nut | .019<br>Place power driver on self-tapping screw | .019<br>Place screw in tapped hole | .030<br>Place large part on locating pin |
| D. Much the same as in C, but in addition may involve close tolerances greater care of finishes, three or more points or directions of location, or application of force to assemble | .019<br>Place screw-driver on screw | Not used | .024<br>Nut on terminal in limited or cramped space | .042<br>Place cover plate over studded hole |

Corrections for data

1. Simultaneous placing of identical parts, multiply base time by 1.40
2. Simultaneous placing of unlike parts, multiply base time by 1.50
3. Large parts obtained with one hand, placed with two, use 2H times and add .005 min.
4. Two or more parts assembled in the hands and then placed in a fixture require the sum of the times for the simultaneous places and the 2H place.
5. Reach distance over 8", under 20", add .0004 minutes per extra inch. For additional distance over 20", add .0006 minutes per inch.
6. If one hand "gets" and the other "places" simultaneously, use the higher value only.

# Work-Factor* MOVING TIME TABLE for DETAILED ANALYSIS

## TIME IN Work-Factor* UNITS

### (A) ARM – *Measured at Knuckles*

| DISTANCE MOVED | BASIC | WORK FACTORS 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|
| 1" | 18 | 26 | 34 | 40 | 46 |
| 2" | 20 | 29 | 37 | 44 | 50 |
| 3" | 22 | 32 | 41 | 50 | 57 |
| 4" | 26 | 38 | 48 | 58 | 66 |
| 5" | 29 | 43 | 55 | 65 | 75 |
| 6" | 32 | 47 | 60 | 72 | 83 |
| 7" | 35 | 51 | 65 | 78 | 90 |
| 8" | 38 | 54 | 70 | 84 | 96 |
| 9" | 40 | 58 | 74 | 89 | 102 |
| 10" | 42 | 61 | 78 | 93 | 107 |
| 11" | 44 | 63 | 81 | 98 | 112 |
| 12" | 46 | 65 | 85 | 102 | 117 |
| 13" | 47 | 67 | 88 | 105 | 121 |
| 14" | 49 | 69 | 90 | 109 | 125 |
| 15" | 51 | 71 | 92 | 113 | 129 |
| 16" | 52 | 73 | 94 | 115 | 133 |
| 17" | 54 | 75 | 96 | 118 | 137 |
| 18" | 55 | 76 | 98 | 120 | 140 |
| 19" | 56 | 78 | 100 | 122 | 142 |
| 20" | 58 | 80 | 102 | 124 | 144 |
| 22" | 61 | 83 | 106 | 128 | 148 |
| 24" | 63 | 86 | 109 | 131 | 152 |
| 26" | 66 | 90 | 113 | 135 | 156 |
| 28" | 68 | 93 | 116 | 139 | 159 |
| 30" | 70 | 96 | 119 | 142 | 163 |
| 35" | 76 | 103 | 128 | 151 | 171 |
| 40" | 81 | 109 | 135 | 159 | 179 |
| *Weight in Lbs. – Male* | 2 | 7 | 13 | 20 | UP |
| *Fem.* | 1 | 3-1/2 | 6-1/2 | 10 | UP |

### (L) LEG – *Measured at Ankle*

| DISTANCE MOVED | BASIC | WORK FACTORS 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|
| 1" | 21 | 30 | 39 | 46 | 53 |
| 2" | 23 | 33 | 42 | 51 | 58 |
| 3" | 26 | 37 | 48 | 57 | 65 |
| 4" | 30 | 43 | 55 | 66 | 76 |
| 5" | 34 | 49 | 63 | 75 | 86 |
| 6" | 37 | 54 | 69 | 83 | 95 |
| 7" | 40 | 59 | 75 | 90 | 102 |
| 8" | 43 | 63 | 80 | 96 | 110 |
| 9" | 46 | 66 | 85 | 102 | 117 |
| 10" | 48 | 70 | 89 | 107 | 123 |
| 11" | 50 | 72 | 94 | 112 | 129 |
| 12" | 52 | 75 | 97 | 117 | 134 |
| 13" | 54 | 77 | 101 | 121 | 139 |
| 14" | 56 | 80 | 103 | 125 | 144 |
| 15" | 58 | 82 | 106 | 130 | 149 |
| 16" | 60 | 84 | 108 | 133 | 153 |
| 17" | 62 | 86 | 111 | 135 | 158 |
| 18" | 63 | 88 | 113 | 137 | 161 |
| 19" | 65 | 90 | 115 | 140 | 164 |
| 20" | 67 | 92 | 117 | 142 | 166 |
| 22" | 70 | 96 | 121 | 147 | 171 |
| 24" | 73 | 99 | 126 | 151 | 175 |
| 26" | 75 | 103 | 130 | 155 | 179 |
| 28" | 78 | 107 | 134 | 159 | 183 |
| 30" | 81 | 110 | 137 | 163 | 187 |
| 35" | 87 | 118 | 147 | 173 | 197 |
| 40" | 93 | 126 | 155 | 182 | 206 |
| *Weight in Lbs. – Male* | 8 | 42 | UP | - | - |
| *Fem.* | 4 | 21 | UP | - | - |

### (T) TRUNK – *Measured at Shoulder*

| DISTANCE MOVED | BASIC | WORK FACTORS 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|
| 1" | 26 | 38 | 49 | 58 | 67 |
| 2" | 29 | 42 | 53 | 64 | 73 |
| 3" | 32 | 47 | 60 | 72 | 82 |
| 4" | 38 | 55 | 70 | 84 | 96 |
| 5" | 43 | 62 | 79 | 95 | 109 |
| 6" | 47 | 68 | 87 | 105 | 120 |
| 7" | 51 | 74 | 95 | 114 | 130 |
| 8" | 54 | 79 | 101 | 121 | 139 |
| 9" | 58 | 84 | 107 | 128 | 147 |
| 10" | 61 | 88 | 113 | 135 | 155 |
| 11" | 63 | 91 | 118 | 141 | 162 |
| 12" | 66 | 94 | 123 | 147 | 169 |
| 13" | 68 | 97 | 127 | 153 | 175 |
| 14" | 71 | 100 | 130 | 158 | 182 |
| 15" | 73 | 103 | 133 | 163 | 188 |
| 16" | 75 | 105 | 136 | 167 | 193 |
| 17" | 78 | 108 | 139 | 170 | 199 |
| 18" | 80 | 111 | 142 | 173 | 203 |
| 19" | 82 | 113 | 145 | 176 | 206 |
| 20" | 84 | 116 | 148 | 179 | 209 |
| *Weight in Lbs – Male* | 11 | 58 | UP | - | - |
| *Fem.* | 5-1/2 | 29 | UP | - | - |

### (F,H) FINGER-HAND – *Measured at Finger Tip*

| DISTANCE MOVED | BASIC | WORK FACTORS 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|
| 1" | 16 | 23 | 29 | 35 | 40 |
| 2" | 17 | 25 | 32 | 38 | 44 |
| 3" | 19 | 28 | 36 | 43 | 49 |
| 4" | 23 | 33 | 42 | 50 | 58 |
| *Weight in Lbs – Male* | 2/3 | 2-1/2 | 4 | UP | - |
| *Fem.* | 1/3 | 1-1/4 | 2 | UP | - |

### (FT) FOOT – *Measured at Toe*

| DISTANCE MOVED | BASIC | WORK FACTORS 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|
| 1" | 20 | 29 | 37 | 44 | 51 |
| 2" | 22 | 32 | 40 | 48 | 55 |
| 3" | 24 | 35 | 45 | 55 | 63 |
| 4" | 29 | 41 | 53 | 64 | 73 |
| *Weight in Lbs – Male* | 5 | 22 | UP | - | - |
| *Fem.* | 2-1/2 | 11 | UP | - | - |

### (FS) FOREARM SWIVEL – *Measured at Knuckles*

| DISTANCE MOVED | BASIC | WORK FACTORS 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|
| 45° | 17 | 22 | 28 | 32 | 37 |
| 90° | 23 | 30 | 37 | [illegible] | 49 |
| 135° | 28 | 36 | 44 | 52 | 58 |
| 180° | 31 | 40 | 49 | 57 | 65 |
| *Torque in " Lbs – Male* | 3 | 13 | UP | - | - |
| *Fem.* | 1-1/2 | 6-1/2 | UP | - | - |

### Work-Factor* SYMBOLS

- W WEIGHT OR RESISTANCE
- S DIRECTIONAL CONTROL (STEER)
- P CARE (PRECAUTION)
- U CHANGE DIRECTION
- D DEFINITE STOP



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### WALKING TIME

| TYPE | 30" PACES 1 | 2 | OVER 2 |
|---|---|---|---|
| GENERAL | 150 | 260 | 120 + 80/PACE |
| RESTRICTED | 180 | 300 | 120 + 100/PACE |

ADD 100 FOR 120° - 180° TURN AT START

| | |
|---|---|
| UP STEPS (8" RISE - 10" FLAT) | 126 |
| DOWN STEPS | 100 |

### VISUAL INSPECTION

| | |
|---|---|
| FOCUS | 20 |
| INSPECT | 30[illegible] |
| REACT | [illegible] |

HEAD TURN 45° 40, 90° 60

1 TIME UNIT = .006 SECONDS
= .0001 MINUTES
= .0000167 HOURS

* TRADE MARK

Table 4.

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# Work-Factor® GRASP TABLE

## COMPLEX GRASPS FROM RANDOM PILES

| SIZE (Major dimension or length) | | SOLIDS & BRACKETS THICKNESS (over 3/64 .0469") Blind - Simo | SOLIDS & BRACKETS Visual - Simo | THIN FLAT OBJECTS THICKNESS (less then 1/64) 0 - .0156" Blind - Simo | (less then 1/64) Visual - Simo | (1/64" to 3/64") .0156" - .0469" Blind - Simo | (1/64" to 3/64") Visual - Simo | CYLINDERS AND SQ. CROSS SECTIONED SOLIDS DIAMETER 0 - .0625" (1/16) Blind - Simo | .0626"- .125" (1/8) Blind - Simo | .1251"- .1875" (3/16) Blind - Simo | .1876"- .5000" (1/2) Blind - Simo | .1876"- .5000" (1/2) Visual - Simo | .5001" & up (over 1/2) Blind - Simo | .5001" & up (over 1/2) Visual - Simo | Add for Entangled, Nested or Slippery objects. * - Simo |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 000" - .0625" | 1/16" & less | 120 172 | B B | - - | - - | 131 189 | B B | S S | S S | S S | S S | S S | S S | S S | 17 26 |
| 0626" - .1250" | over 1/16" to 1/8" | 79 111 | B B | 108 154 | B B | 85 120 | B B | 85 120 | S S | S S | S S | S S | S S | S S | 12 18 |
| 1251" - .1875" | over 1/8" to 3/16" | 64 88 | B B | 102 145 | B B | 74 103 | B B | 79 111 | 74 103 | S S | S S | S S | S S | S S | 12 18 |
| 1876" - .2500" | over 3/16" to 1/4" | 48 64 | B B | 72 100 | B B | 56 76 | B B | 79 111 | 68 94 | 64 88 | S S | S S | S S | S S | 8 12 |
| 2501" - .5000" | over 1/4" to 1/2" | 40 52 | B B | 64 88 | B B | 48 64 | B B | 62 85 | 56 76 | 56 76 | 44 58 | B B | S S | S S | 8 12 |
| 5001" - 1.0000" | over 1/2" to 1" | 40 52 | 32 40 | 64 88 | 60 82 | 48 64 | 44 58 | 62 85 | 56 76 | 48 64 | 48 64 | 44 58 | 40 52 | 32 40 | 8 12 |
| 0001" - 4.0000" | over 1" to 4" | 37 48 | 20 22 | 53 72 | 36 46 | 45 60 | 28 34 | 56 76 | 48 64 | 40 52 | 40 52 | 36 46 | 37 48 | 20 22 | 8 12 |
| 0001" & up | over 4" | 46 61 | 20 22 | 70 97 | 44 58 | 62 85 | 36 46 | 56 76 | 48 64 | 40 52 | 40 52 | 36 46 | 37 48 | 20 22 | 9 14 |

B = Use Blind column since visual grasp offers no advantage. S = Use Solid Table.

* Add the indicated allowances when objects: (a) are entangled (not requiring two hands to separate); (b) are nested together because of shape or film; (c) are slippery (as from oil or polished surface.) Note: When objects both entangle and are slippery, or both nest and are slippery, use double the value in the table.

Note: Special grasp conditions should be analyzed in detail.

# Work-Factor® ASSEMBLY TABLES

## AVERAGE NO. OF ALIGNMENTS (A1S Motions)

| TARGET DIAMETER | CLOSED TARGETS — Ratio of Plug Dia. ÷ Target Dia. To .224 | .225 to .289 | .290 to .414 | .415 to .899 | .900 to .934 | .935 to 1.000 | OPEN TARGETS — Ratio of Plug Dia. ÷ Target Dia. To .224 | .225 to .289 | .290 to .414 | .415 to .899 | .900 to .934 | .935 to 1.000 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 75" & up | D* (18) | D* (18) | D* (18) | 1/4 (25) | 1/4** (51) | 1/4*** (59) | D* (18) | D* (18) | D* (18) | D* (18) | 1/4** (51) | 1/4*** (59) |
| 25" to .874" | D* (18) | D* (18) | SD* (18) | 1/4 (25) | 1/4** (51) | 1/4*** (59) | D* (18) | D* (18) | D* (18) | SD* (18) | 1/4** (51) | 1/4*** (59) |
| 75" to .624" | SD* (18) | SD* (18) | 1/4 (25) | 1/2 (31) | 1/2** (57) | 1/2*** (65) | SD* (18) | SD* (18) | SD* (18) | 1/2 (31) | 1/2** (57 | 1/2*** (65) |
| 25" to .374" | 1/2 (31) | 1 (44) | 1 (44) | 1-1/2 (57) | 1-1/2** (83) | 1-1/2*** (91) | 1/4 (25) | 1/2 (31) | 1/2 (31) | 3/4 (38) | 3/4** (64) | 3/4*** (72) |
| 75" to .224" | 1 (44) | 1 (44) | 1 (44) | 1-1/2 (57) | 1-1/2** (83) | 1-1/2*** (91) | 1/2 (31) | 1/2 (31) | 1/2 (31) | 3/4 (38) | 3/4** (64) | 3/4*** (72) |
| 25" to .174" | 1 (44) | 1-1/4 (51) | 1-1/2 (57) | 1-1/2 (57) | 1-1/2** (83) | 1-1/2*** (91) | 3/4 (38) | 1 (44) | 1 (44) | 1 (44) | 1** (70) | 1*** (78) |
| 75" to .124" | 2-1/2 (83) | 2-1/2 (83) | 2-1/2 (83) | 2-1/2 (83) | 2-1/2** (109) | 2-1/2***(117) | 1-1/4 (51) | 1-1/4 (51) | 1-1/4 (51) | 1-1/4 (51) | 1-1/4** (77) | 1-1/4*** (85) |
| 25" to .074" | 3 (96) | 3 (96) | 3 (96) | 3 (96) | 3** (122) | 3*** (130) | 1-1/2 (57) | 1-1/2 (57) | 1-1/2 (57) | 1-1/2 (57) | 1-1/2** (83) | 1-1/2*** (91) |

Units shown in parentheses [illegible] total assembly time when the assembly does not involve more than: a) Alignment with S Work-Factors, b) A1S Upright, and c) A1 or A1P insert.

* Indicates Work-Factors required to move immediately preceding assembly. All assemblies [illegible] Alignments [illegible] preceded by a move with SD Work-Factors.

** Add upright to all .900 [illegible] ratio    *** Upright and insert with P Work-Factor required

## DISTANCE BETWEEN TARGETS

| Distance Between Targets | % Addition to Alignments | Method of Alignment |
|---|---|---|
| 0 - .99" | Neg. | Simo |
| 1 - 1.99" | 10% | Simo |
| 2 - 2.99" | 30% | Simo |
| 3 - 4.99" | 50% | Simo |
| 5 - 6.99" | 70% | Simo |
| 7 - 14.99" | Align 1st, insert 1st, Align 2nd (1) Insert 2nd. | |
| 15" & up | Align 1st, Insert 1st, Focus and Inspect, Align 2nd (1), Insert 2nd. | |

(1) If connected, treat 2nd Assembly as open target with no upright.

## BLIND TARGETS

| Distance from Target to Visible Area | % Addition to Alignments — Permanent (Blind at all times) | Temporary (Blind during assembly) |
|---|---|---|
| 0 - .49" | 20% | 0% |
| .5 - .99" | 30% | 10% |
| 1.0 - 1.99" | 40% | 20% |
| 2.0 - 2.99" | 70% | 30% |
| 3.0 - 4.99" | 130% | 50% |
| 5.0 - 6.99" | 250% | 70% |
| 7.0 - 10.00" | 380% | 120% |

## GRIPPING DISTANCE

| Distance from Gripping Point to Align. Point | % Addition to Alignments | Length of Upright Motion |
|---|---|---|
| 0 - 1.99" | Neg. | 1" |
| 2 - 2.99" | 10% | 1" |
| 3 - 4.99" | 20% | 2" |
| 5 - 6.99" | 30% | 2" |
| 7 - 9.99" | 40% | 3" |
| 10 - 14.99" | 60% | 5" |
| 15 - 19.99" | 80% | 6" |
| 20 & up | 100% | 7" & up |

## GENERAL RULES

1. Add Work-Factors to Alignments for weight, etc. as required.
2. When Alignment is performed by fingers use 50% of above Alignments.
3. Where Gripping Distance, Two Targets, and Blind Targets are involved, add each percentage to Original Alignment. Don't pyramid percentages.



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TRADE MARK

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PRINTED IN U. S. A.

# METHODS-TIME MEASUREMENT APPLICATION DATA

## SIMPLIFIED DATA

| HAND AND ARM MOTIONS | | | BODY, LEG, AND EYE MOTIONS | |
|---|---|---|---|---|
| **REACH or MOVE** | | **TMU** | | **TMU** |
| 1″ | | 2 | Simple foot motion | 10 |
| 2″ | | 4 | Foot motion with pressure | 20 |
| 3″ to 12″ 4 + length of motion | | | Leg motion | 10 |
| over 12″ 3 + length of motion | | | Side step case 1 | 20 |
| (For TYPE 2 REACHES AND MOVES use length of motion only) | | | Side step case 2 | 40 |
| **POSITION** | | | Turn body case 1 | 20 |
| Fit | Symmetrical | Other | Turn body case 2 | 45 |
| Loose | 10 | 15 | Eye time | 10. |
| Close | 20 | 25 | Bend, stoop or kneel on one knee | 35 |
| Exact | 50 | 55 | Arise | 35 |
| **TURN—APPLY PRESSURE** | | | Kneel on both knees | 80 |
| TURN | | 6 | Arise | 90 |
| APPLY PRESSURE | | 20 | Sit | 40 |
| **GRASP** | | | Stand | 50 |
| Simple | | 2 | Walk per pace | 17 |
| Regrasp or Transfer | | 6 | (All times on this Simplified Data Table include 15% allowance) | |
| Complex | | 10 | | |
| **DISENGAGE** | | | | |
| Loose | | 5 | | |
| Close | | 10 | | |
| Exact | | 30 | | |

1 TMU = .00001 hour
= .0006 minute
= .036 second

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MEC FORM 204A 1

## TABLE I—REACH—R

| Distance Moved Inches | Leveled Time TMU A | B | C or D | E | Hand in Motion A | B |
|---|---|---|---|---|---|---|
| 1 | 1.8 | 2.1 | 3.6 | 1.7 | 1.3 | 1.5 |
| 2 | 3.7 | 4.3 | 5.9 | 3.8 | 2.8 | 2.7 |
| 3 | 5.0 | 5.9 | 7.3 | 5.3 | 3.8 | 3.6 |
| 4 | 6.1 | 7.1 | 8.4 | 6.8 | 4.9 | 4.3 |
| 5 | 6.5 | 7.8 | 9.4 | 7.4 | 5.3 | 5.0 |
| 6 | 7.0 | 8.6 | 10.1 | 8.0 | 5.7 | 5.7 |
| 7 | 7.4 | 9.3 | 10.8 | 8.7 | 6.1 | 6.5 |
| 8 | 7.9 | 10.1 | 11.5 | 9.3 | 6.5 | 7.2 |
| 9 | 8.3 | 10.8 | 12.2 | 9.9 | 6.9 | 7.9 |
| 10 | 8.7 | 11.5 | 12.9 | 10.5 | 7.3 | 8.6 |
| 12 | 9.6 | 12.9 | 14.2 | 11.8 | 8.1 | 10.1 |
| 14 | 10.5 | 14.4 | 15.6 | 13.0 | 8.9 | 11.5 |
| 16 | 11.4 | 15.8 | 17.0 | 14.2 | 9.7 | 12.9 |
| 18 | 12.3 | 17.2 | 18.4 | 15.5 | 10.5 | 14.4 |
| 20 | 13.1 | 18.6 | 19.8 | 16.7 | 11.3 | 15.8 |
| 22 | 14.0 | 20.1 | 21.2 | 18.0 | 12.1 | 17.3 |
| 24 | 14.9 | 21.5 | 22.5 | 19.2 | 12.9 | 18.8 |
| 26 | 15.8 | 22.9 | 23.9 | 20.4 | 13.7 | 20.2 |
| 28 | 16.7 | 24.4 | 25.3 | 21.7 | 14.5 | 21.7 |
| 30 | 17.5 | 25.8 | 26.7 | 22.9 | 15.3 | 23.2 |

| CASE AND DESCRIPTION |
|---|
| **A** Reach to object in fixed location, or to object in other hand or on which other hand rests. |
| **B** Reach to single object in location which may vary slightly from cycle to cycle. |
| **C** Reach to object jumbled with other objects in a group so that search and select occur. |
| **D** Reach to a very small object or where accurate grasp is required. |
| **E** Reach to indefinite location to get hand in position for body balance or next motion or out of way. |

## TABLE II—MOVE—M

| Distance Moved Inches | Leveled Time TMU A | B | C | Hand in Motion B | Multiplying Factor Wt. | Factor |
|---|---|---|---|---|---|---|
| 1 | 1.7 | 1.7 | 1.7 | 1.5 | Up to 5# | 1.00 |
| 2 | 3.6 | 4.2 | 4.2 | 2.7 | | |
| 3 | 4.9 | 5.7 | 5.7 | 3.6 | | |
| 4 | 6.1 | 6.9 | 7.3 | 4.3 | 10# | 1.03 |
| 5 | 7.3 | 8.0 | 8.7 | 5.0 | | |
| 6 | 8.1 | 8.9 | 9.7 | 5.7 | 15# | 1.05 |
| 7 | 8.9 | 9.7 | 10.8 | 6.5 | | |
| 8 | 9.7 | 10.6 | 11.8 | 7.2 | 20# | 1.08 |
| 9 | 10.5 | 11.5 | 12.7 | 7.9 | | |
| 10 | 11.3 | 12.2 | 13.5 | 8.6 | 25# | 1.11 |
| 12 | 12.9 | 13.4 | 15.2 | 10.0 | | |
| 14 | 14.4 | 14.6 | 16.9 | 11.4 | 30# | 1.14 |
| 16 | 16.0 | 15.8 | 18.7 | 12.8 | | |
| 18 | 17.6 | 17.0 | 20.4 | 14.2 | 35# | 1.16 |
| 20 | 19.2 | 18.2 | 22.1 | 15.6 | | |
| 22 | 20.8 | 19.4 | 23.8 | 17.0 | 40# | 1.19 |
| 24 | 22.4 | 20.6 | 25.5 | 18.4 | | |
| 26 | 24.0 | 21.8 | 27.3 | 19.8 | 45# | 1.22 |
| 28 | 25.5 | 23.1 | 29.0 | 21.2 | | |
| 30 | 27.1 | 24.3 | 30.7 | 22.7 | 50# | 1.25 |

| CASE AND DESCRIPTION |
|---|
| **A** Move object to other hand or against stop. |
| **B** Move object to approximate or indefinite location. |
| **C** Move object to exact location. |

## TABLE III—TURN AND APPLY PRESSURE—T AND AP

| Weight | Leveled Time TMU for Degrees Turned 30° | 45° | 60° | 75° | 90° | 105° | 120° | 135° | 150° | 165° | 180° |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Small— 0 to 2 Pounds | 2.8 | 3.5 | 4.1 | 4.8 | 5.4 | 6.1 | 6.8 | 7.4 | 8.1 | 8.7 | 9.4 |
| Medium—2.1 to 10 Pounds | 4.4 | 5.5 | 6.5 | 7.5 | 8.5 | 9.6 | 10.6 | 11.6 | 12.7 | 13.7 | 14.8 |
| Large— 10.1 to 35 Pounds | 8.4 | 10.5 | 12.3 | 14.4 | 16.2 | 18.3 | 20.4 | 22.2 | 24.3 | 26.1 | 28.2 |

APPLY PRESSURE CASE 1—16.2 TMU. APPLY PRESSURE CASE 2—10.6 TMU

Table 6.

## TABLE IV—GRASP—G

| Case | Leveled Time TMU | DESCRIPTION |
|---|---|---|
| 1A | 1.7 | **Pick Up Grasp**—Small, medium or large object by itself, easily grasped. |
| 1B | 3.5 | Very small object or object lying close against a flat surface. |
| 1C1 | 7.3 | Interference with grasp on bottom and one side of nearly cylindrical object. Diameter larger than ½". |
| 1C2 | 8.7 | Interference with grasp on bottom and one side of nearly cylindrical object. Diameter ¼" to ½". |
| 1C3 | 10.8 | Interference with grasp on bottom and one side of nearly cylindrical object. Diameter less than ¼". |
| 2 | 5.6 | **Regrasp.** |
| 3 | 5.6 | **Transfer Grasp.** |
| 4A | 7.3 | Object jumbled with other objects so search and select occur. Larger than 1" x 1" x 1". |
| 4B | 9.1 | Object jumbled with other objects so search and select occur. ¼" x ¼" x ⅛" to 1" x 1" x 1". |
| 4C | 12.9 | Object jumbled with other objects so search and select occur. Smaller than ¼" x ¼" x ⅛". |
| 5 | 0 | Contact, sliding or hook grasp. |

## TABLE V—POSITION*—P

| HANDLING | CLASS OF FIT | | SYMMETRY | | |
|---|---|---|---|---|---|
| | | | S | SS | NS |
| Easy To Handle | 1—Loose | No pressure required. | 5.6 | 9.1 | 10.4 |
| | 2—Close | Light pressure required. | 16.2 | 19.7 | 21.0 |
| | 3—Exact | Heavy pressure required. | 43.0 | 46.5 | 47.8 |
| Difficult To Handle | 1—Loose | No pressure required. | 11.2 | 14.7 | 16.0 |
| | 2—Close | Light pressure required. | 21.8 | 25.3 | 26.6 |
| | 3—Exact | Heavy pressure required. | 48.6 | 52.1 | 53.4 |

*Distance moved to engage—1" or less.

## TABLE VI—RELEASE—RL

| Case | Leveled Time TMU | DESCRIPTION |
|---|---|---|
| 1 | 1.7 | Normal release performed by opening fingers as independent motion. |
| 2 | 0 | Contact Release. |

## TABLE VII—DISENGAGE—D

| Easy to Handle | Difficult to Handle | CLASS OF FIT |
|---|---|---|
| 4.0 | 5.7 | 1—Loose—Very slight effort, blends with subsequent move. |
| 7.5 | 11.8 | 2—Close—Normal effort, slight recoil. |
| 22.9 | 34.7 | 3—Tight—Considerable effort, hand recoils markedly. |

## TABLE VIII—EYE TRAVEL TIME AND EYE FOCUS—ET AND EF

**Eye Travel Time** $= 15.2 \times \frac{T}{D}$ TMU.

where T = the distance between points from and to which the eye travels.
D = the perpendicular distance from the eye to the line of travel T, with a maximum value of 20 TMU.

**Eye Focus Time** = 7.3 TMU.

## TABLE IX—BODY, LEG, AND FOOT MOTIONS

| DESCRIPTION | SYMBOL | DISTANCE | LEVELED TIME TMU |
|---|---|---|---|
| Foot Motion—Hinged at Ankle. | FM | Up to 4" | 8.5 |
| With heavy pressure. | FMP | | 19.1 |
| Leg or Foreleg Motion. | LM | Up to 6" | 7.1 |
| | | Each add'l. inch | 1.2 |
| Sidestep—Case 1—Complete when leading leg contacts floor. | SS-C1 | Less than 12" | Use REACH or MOVE Time |
| | | 12" | 17.0 |
| | | Each add'l. inch | .6 |
| Case 2—Lagging leg must contact floor before next motion can be made. | SS-C2 | 12" | 34.1 |
| | | Each add'l. inch | 1.1 |
| Bend, Stoop, or Kneel on One Knee. | B,S,KOK | | 29.0 |
| Arise. | AB,AS,AKOK | | 31.9 |
| Kneel on Floor—Both Knees. | KBK | | 69.4 |
| Arise. | AKBK | | 76.7 |
| Sit. | SIT | | 34.7 |
| Stand from Sitting Position. | STD | | 43.4 |
| Turn Body 45 to 90 degrees— Case 1—Complete when leading leg contacts floor. | TBC1 | | 18.6 |
| Case 2—Lagging leg must contact floor before next motion can be made. | TBC2 | | 37.2 |
| Walk. | W-FT. | Per Foot | 5.3 |
| Walk. | W-P | Per Pace | 15.0 |

## TABLE X—SIMULTANEOUS MOTIONS

| REACH | | | | MOVE | | | | | | GRASP | | | | | POSITION | | | | | | DISENGAGE | | | CASE | MOTION |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A, E | B | C, D | | A, Bm | | B | | C | | G1A G2 G5 | G1B G1C | | G4 | | P1S | | P1SS P2S | | P1NS P2SS P2NS | | D1E D1D | D2 | | | |
| | | * W | O | * W | O | * W | O | * W | O | | * W | O | * W | O | ** E | D | ** E | D | ** E | D | | ** E | D | | |
| E | E | E | E | E | E | E | E | P | P | E | E | E | E | E | E | E | E | P | P | P | E | E | E | A, E | REACH |
| | E | E | P | E | E | E | P | P | D | E | E | P | P | D | P | P | P | D | D | D | E | E | P | B | |
| | | E | P | P | D | P | D | D | D | E | P | D | D | D | D | D | D | D | D | D | P | D | D | C, D | |
| | | | | E | E | E | E | E | E | E | E | E | E | E | E | E | E | P | P | P | E | E | E | A, Bm | MOVE |
| | | | | | | E | E | E | E | E | E | P | P | D | P | P | P | D | D | D | E | E | P | B | |
| | | | | | | | | P | D | E | P | D | D | D | D | D | D | D | D | D | P | D | D | C | |
| | | | | | | | | | | E | E | E | E | E | E | E | E | D | D | D | E | D | D | G1A, G2, G5 | GRASP |
| | | | | | | | | | | | D | D | P | D | D | D | D | D | D | D | D | D | D | G1B, G1C | |
| | | | | | | | | | | | | | D | D | D | D | D | D | D | D | D | D | D | G4 | |
| | | | | | | | | | | | | | | | P | D | D | D | D | D | D | D | D | P1S | POSITION |
| | | | | | | | | | | | | | | | | | D | D | D | D | D | D | D | P1SS, P2S | |
| | | | | | | | | | | | | | | | | | | | D | D | D | D | D | P1NS, P2SS, P2NS | |
| | | | | | | | | | | | | | | | | | | | | | E | E | E | D1E, D1D | DISENGAGE |
| | | | | | | | | | | | | | | | | | | | | | | E | E | D2 | |

**E** = **EASY** to perform simultaneously.

**P** = Can be performed simultaneously with **PRACTICE.**

**D** = **DIFFICULT** to perform simultaneously even after long practice. Allow both times.

**MOTIONS NOT INCLUDED IN ABOVE TABLE**

**TURN**—Normally EASY with all motions except when TURN is controlled or with DISENGAGE.

**APPLY PRESSURE**—May be EASY, PRACTICE, or DIFFICULT. Each case must be analyzed.

**POSITION**—Class 3—Always DIFFICULT.

**DISENGAGE**—Class 3—Normally DIFFICULT.

**RELEASE**—Always EASY.

**DISENGAGE**—Any class may be DIFFICULT if care must be exercised to avoid injury or damage to object.

*W = Within the area of normal vision.
O = Outside the area of normal vision.
**E = EASY to handle.
D = DIFFICULT to handle.



Table 7.

## Table 8

## Insert pin in board

## Illustration of analysis by each system

| Element description | M.T.M. | | W.F. | | Holmes | | Engstrom | |
|---|---|---|---|---|---|---|---|---|
| | Motion | Time T.M.U. | Motion | Time WFTU | Motion | Time min. | Motion | Time min |
| Reach to pile of pins | R8C | 11.5 | A8D | 54 | Forearm angular 8"<br>" " 1" | .0036<br>.0027 | Get Condition B Group 2F | .011 |
| Select and grasp one pin | G4B | 9.1 | Complex Grasp, 2" long x $\frac{1}{4}$" dia., single, visible | 36 | Finger hinge 1"<br>2 Finger hinges 1" | .0017<br>.0034 | | |
| Move pin to board | M8C | 11.8 | A8SD | 70 | Forearm angular 8"<br>" " 1" | .0036<br>.0027 | Place Condition C Grasp 2F | .019 |
| Align pin and insert | P2SE | 16.2 | Open target; $\frac{1}{4}$"dia. 0.95 plug/target ratio | 72 | 2 Forearm ang.press<br>1 Hand hinge 1"<br>2 Hand hinge press | .0046<br>.0022<br>.0040 | | |
| Release pin | RL1 | 1.7 | $\frac{1}{2}$ FI | 8 | Finger hinge 1" | .0017 | | |
| Total | | 50.3 | | 240 | | .0302 | | .030 |

Table 26

Individual finger times

| Motion | $mM\frac{1}{2}A$ and $M\frac{1}{2}Am$ | | | | |
|---|---|---|---|---|---|
| Digit | T | 1 | 2 | 3 | 4 |
| Normal time, TMU | 2.06 | 2.06 | 2.48 | 1.90 | 1.65 |
| | 2.06 | 2.06 | 2.06 | 1.42 | 2.36 |
| | 2.06 | 1.9 | 1.90 | 2.36 | 2.36 |
| | 1.9 | 1.9 | 1.83 | 1.90 | 2.29 |
| | 2.36 | 1.9 | 2.29 | 1.90 | 2.29 |
| | 1.9 | 1.42 | 2.29 | 1.83 | 2.29 |
| | 1.9 | 1.9 | 2.29 | 2.29 | 2.29 |
| | 1.29 | 1.9 | 1.83 | 1.83 | 1.83 |
| | 2.75 | 1.42 | 2.29 | 1.83 | 1.83 |
| | 2.29 | 1.83 | | 1.83 | |
| | 1.83 | 2.29 | | 2.29 | |
| | 2.29 | 2.29 | | 2.75 | |
| | 2.29 | 2.29 | | | |
| | 2.29 | 1.83 | | | |
| | 1.83 | 2.29 | | | |
| | 1.83 | 1.83 | | | |
| Total, $\Sigma X$ | 32.93 | 31.11 | 19.26 | 24.13 | 19.19 |
| Readings | 16 | 16 | 9 | 12 | 9 |
| Average, $\overline{X}$ | 2.06 | 1.94 | 2.14 | 2.01 | 2.13 |

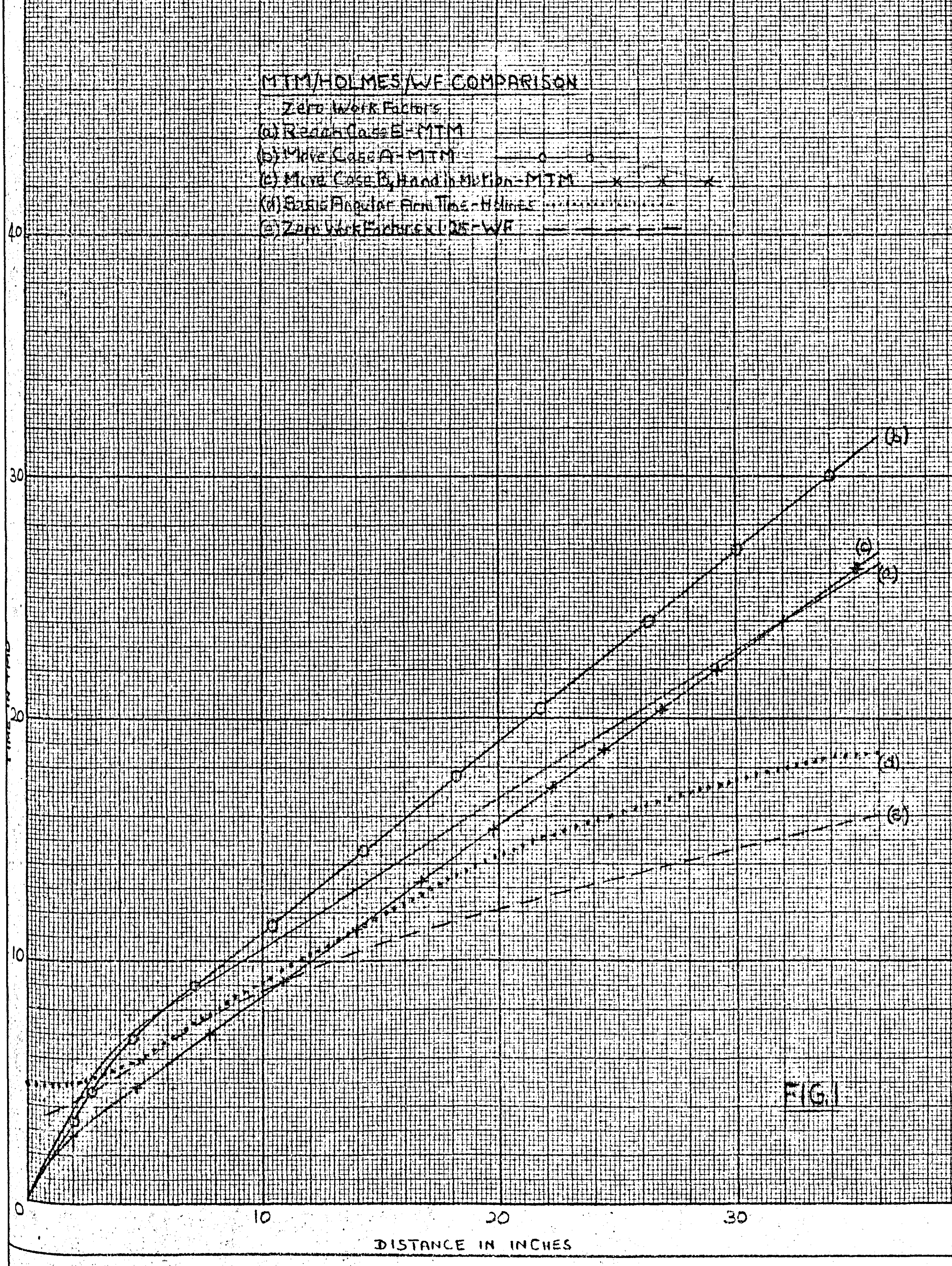

MTM/HOLMES/WF COMPARISON
Zero Work Factors
(a) Reach Case E - MTM
(b) Move Case A - MTM
(c) Move Case B, Hand in Motion - MTM
(d) Basis Angular Arm Time - Holmes
40
30
20
10
0
10
20
30
DISTANCE IN INCHES

FIG.1

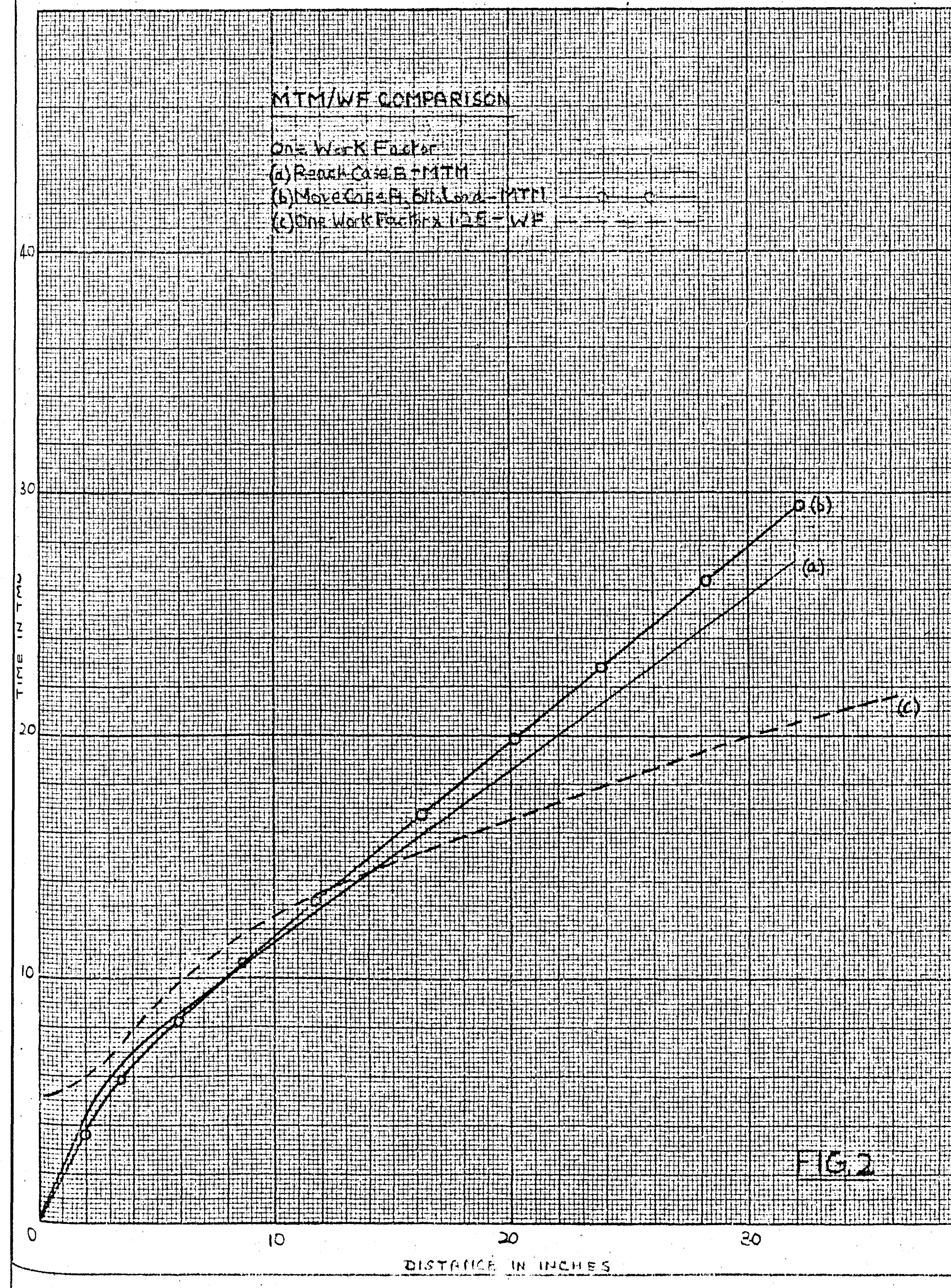

MTM/WF COMPARISON
One Work Factor
(a) Reach Case B - MTM
(b) Move Case A, 6lb Load - MTM
(c) One Work Factor x 1.25 - WF
TIME IN TMU
DISTANCE IN INCHES
0
10
20
30
40
(a)
(b)
(c)

FIG. 2

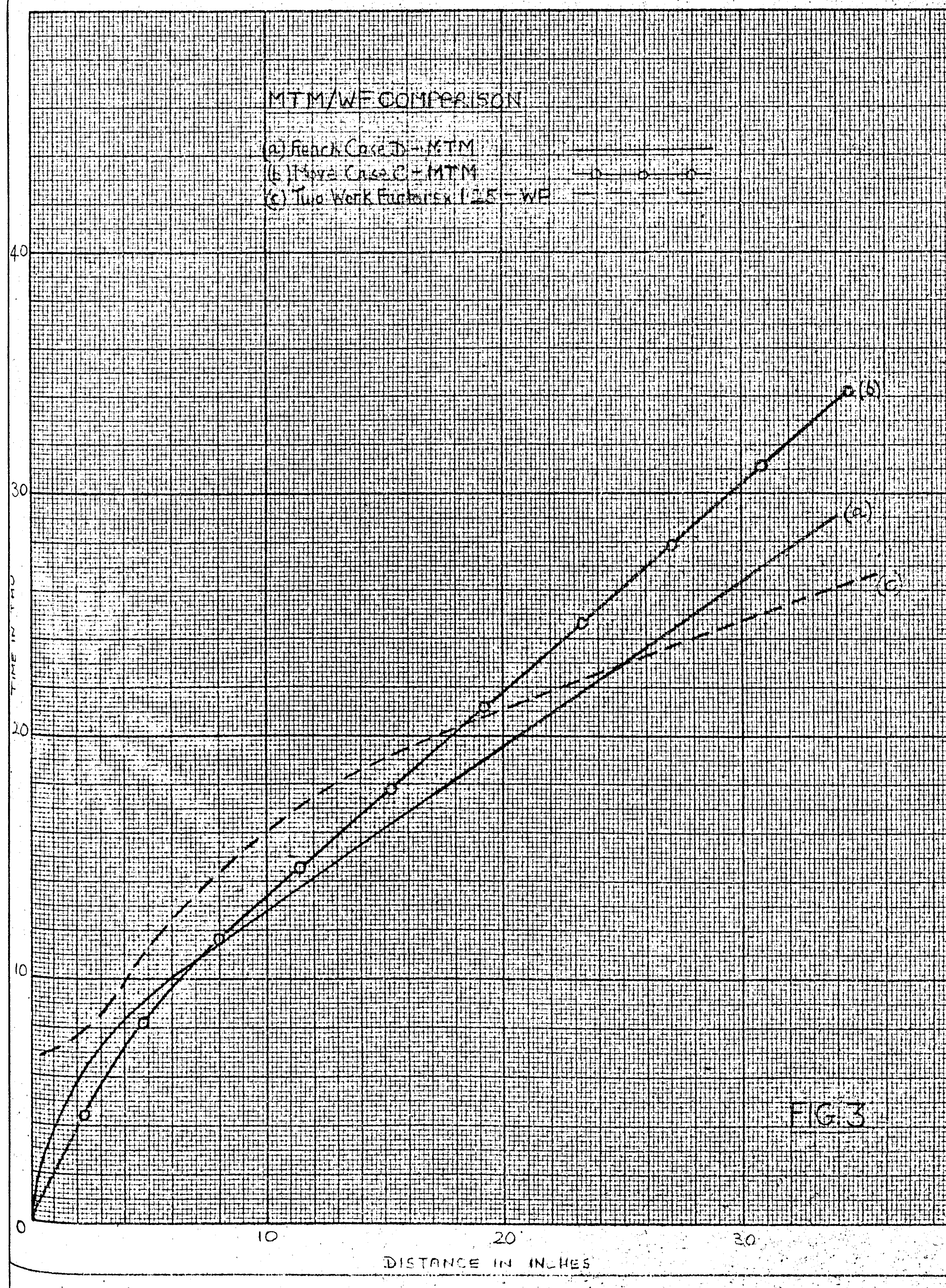
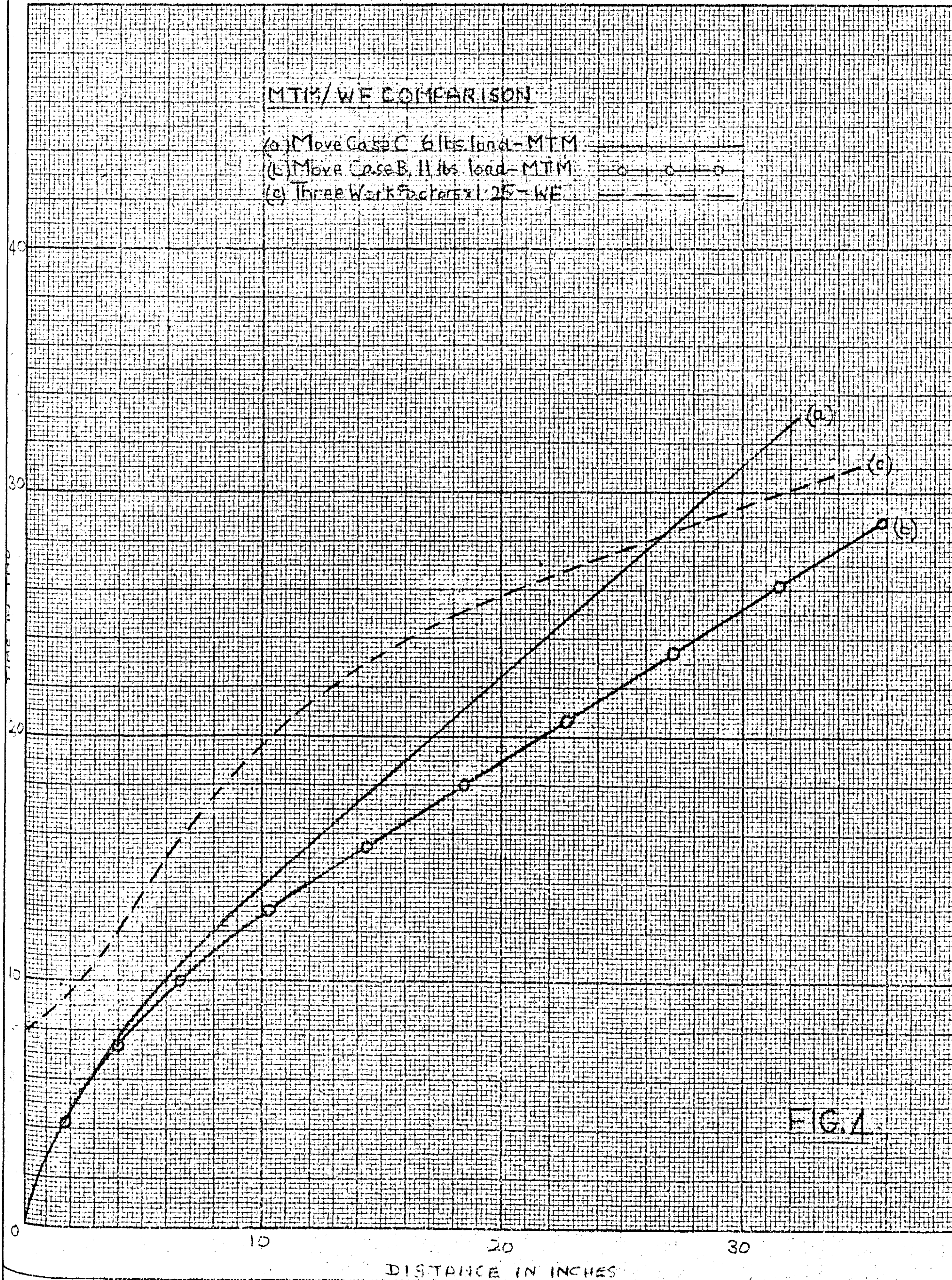

MTM/WF COMPARISON
(a) Reach Case D – MTM
(b) Move Case C – MTM
(c) Two Work Factors x 1.25 – WF
(a)
(b)
(c)
0
10
20
30
40
DISTANCE IN INCHES

FIG. 3



MTM/WE COMPARISON
(a) Move Case C 6 lbs load - MTM
(b) Move Case B, 11 lbs load - MTM
(c) Three Work Factors x 1.25 - WE
(a)
(c)
(b)
0
10
20
30
40
10
20
30
DISTANCE IN INCHES


FIG. 4

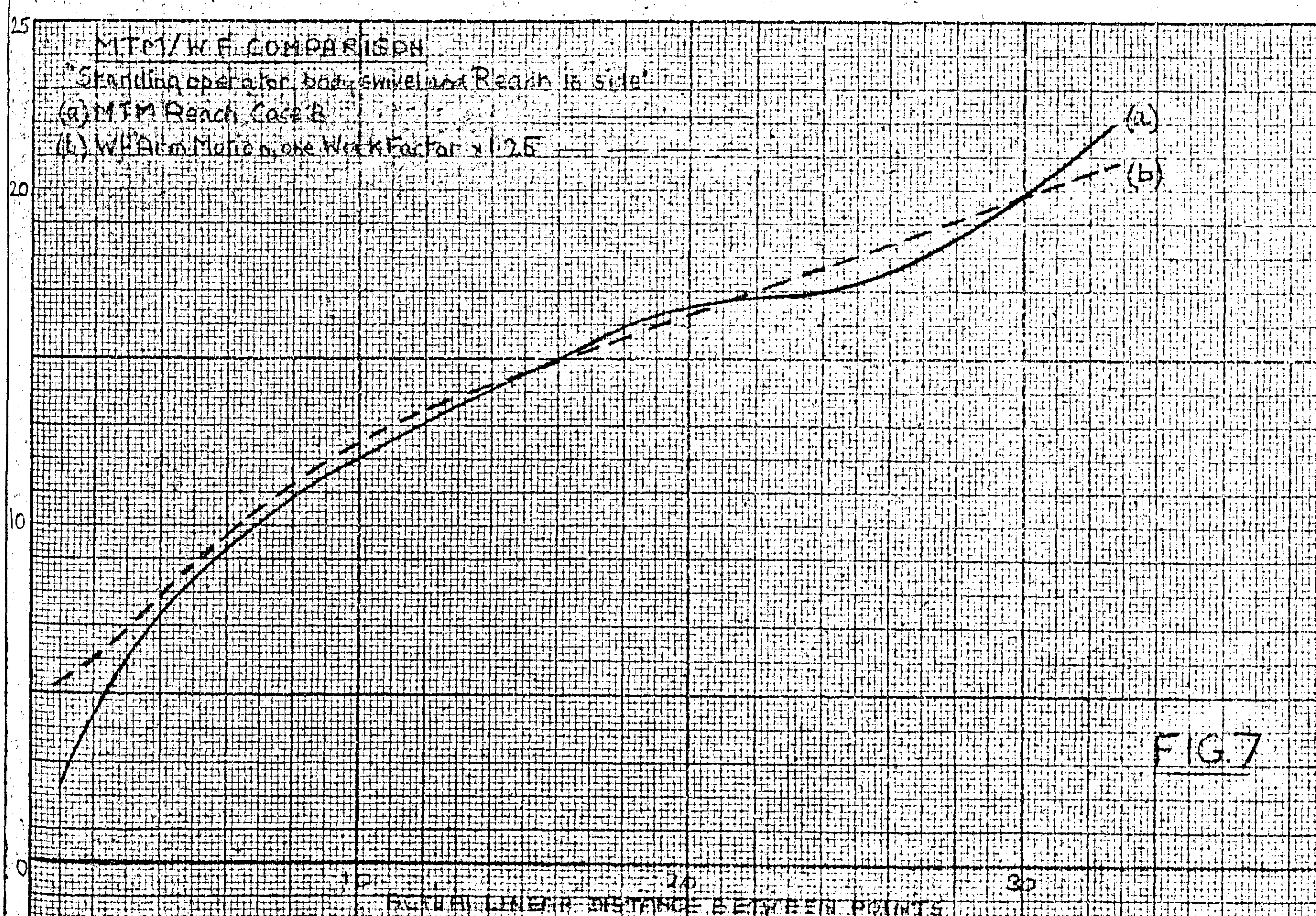

MTM/W.F. COMPARISON
"Standing operator, body swivel and Reach to side"
(a) MTM Reach Case B
(b) WF Arm Motion, one Work Factor x 1.25
(a)
(b)
25
20
10
0
10
20
30
ACTUAL LINEAR DISTANCE BETWEEN POINTS

FIG.7

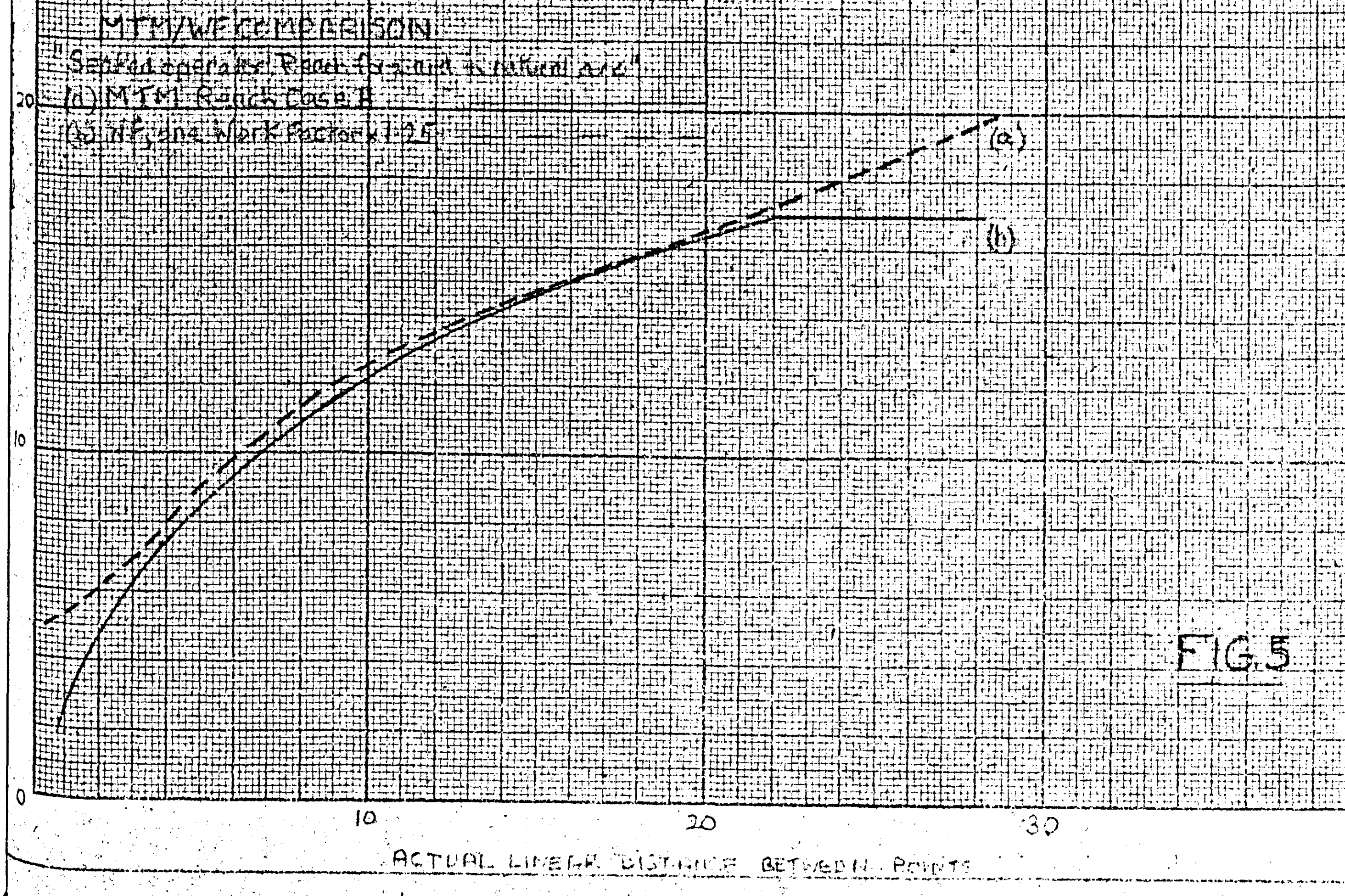

MTM/WF COMPARISON
"Seated operator. Reach forward in natural arc"
(a) MTM Reach Case B
(b) WF, one Work Factor x 1.25
(a)
(b)
20
10
0
10
20
30
ACTUAL LINEAR DISTANCE BETWEEN POINTS

FIG.5

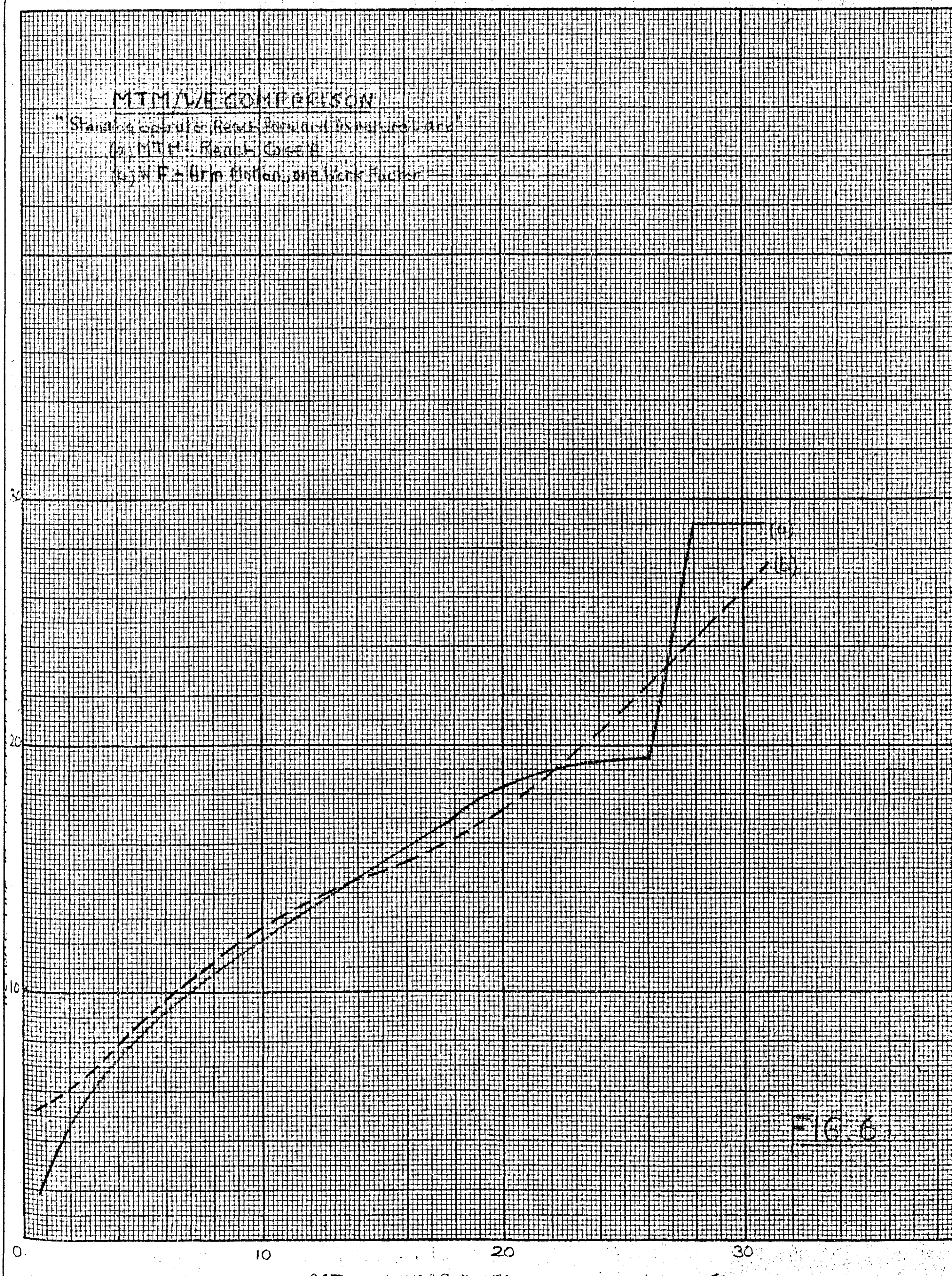
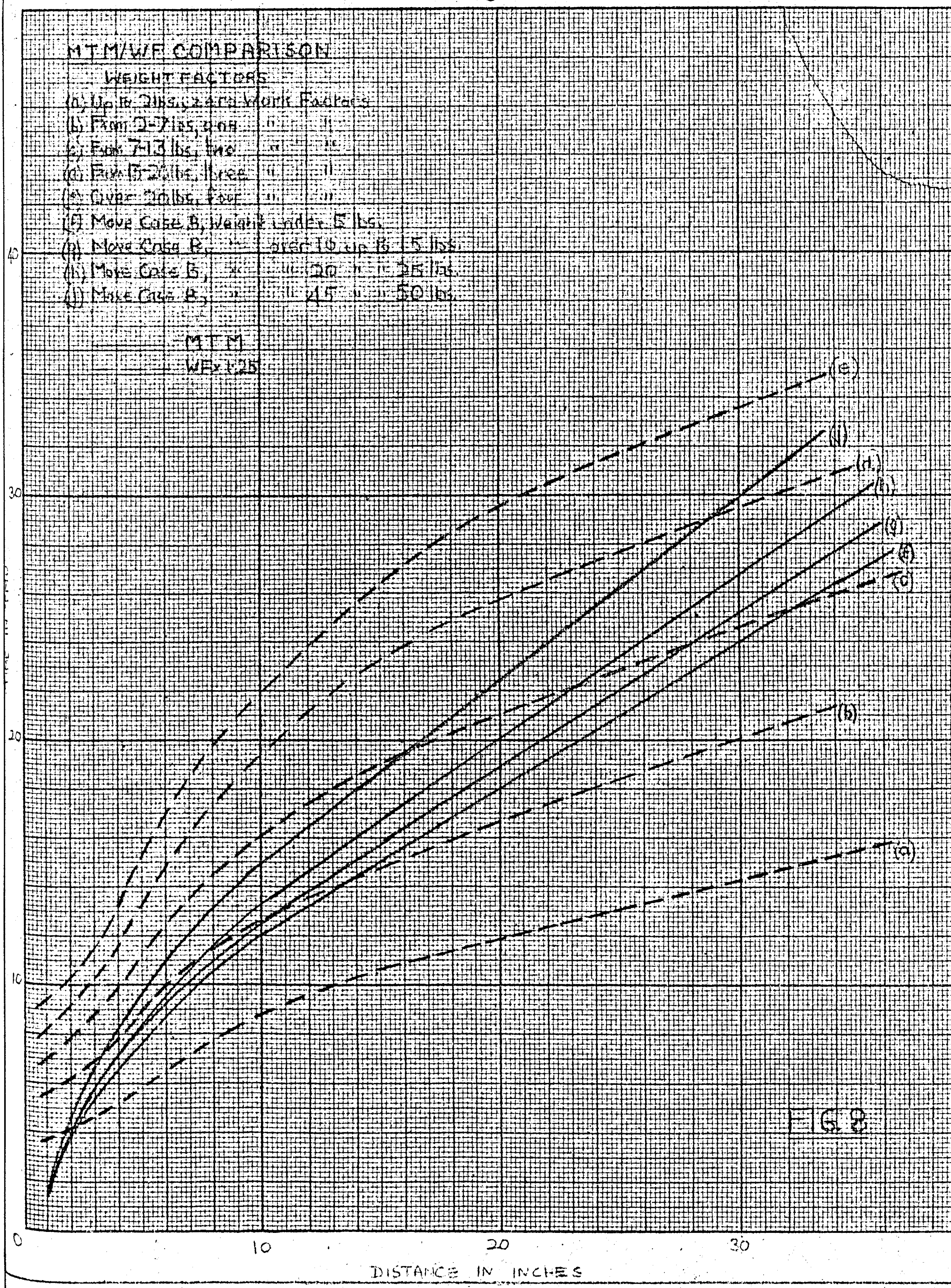

MTM/WF COMPARISON
(a)
(b)
10
20
30
0
10
20
30
ACTUAL LINEAR DISTANCE BETWEEN POINTS

FIG. 6



MTM/WF COMPARISON
WEIGHT FACTORS
(a) Up to 2 lbs, zero Work Factors
(b) From 2-7 lbs, one
(c) From 7-13 lbs, two
(d) From 13-20 lbs, three
(e) Over 20 lbs, four
(f) Move Case B, Weight under 5 lbs.
(g) Move Case B, over 10 up to 15 lbs.
(h) Move Case B, 20 25 lbs.
(i) Move Case B, 45 50 lbs.
MTM
WF x 1.25
(a)
(b)
(c)
(d)
(e)
(f)
(g)
(h)
(i)
0
10
20
30
40
DISTANCE IN INCHES
FIG 8

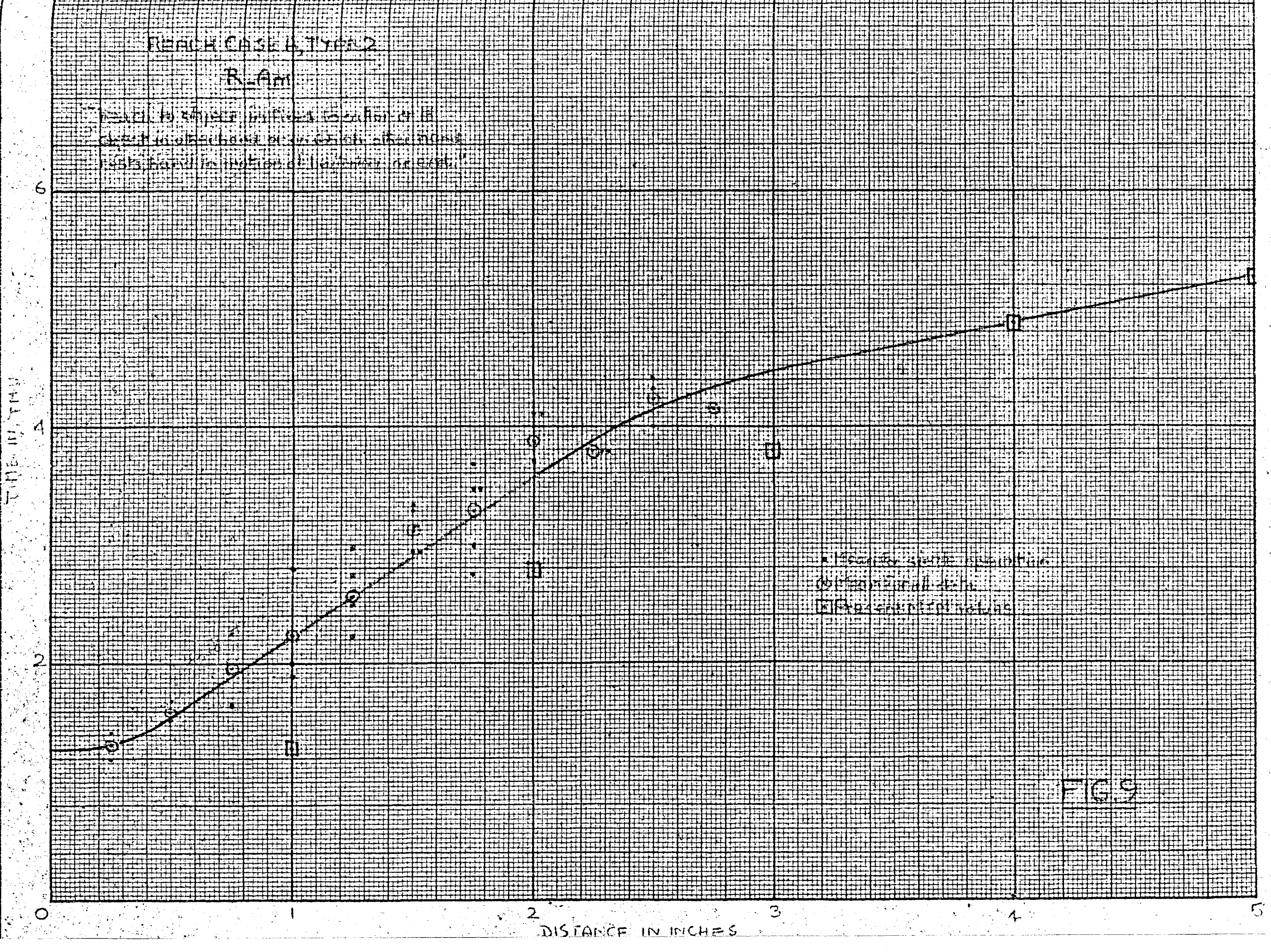

REACH CASE A, TYPE 2
R-Am
TIME IN TMU
DISTANCE IN INCHES
0
1
2
3
4
5
2
4
6

FIG. 9

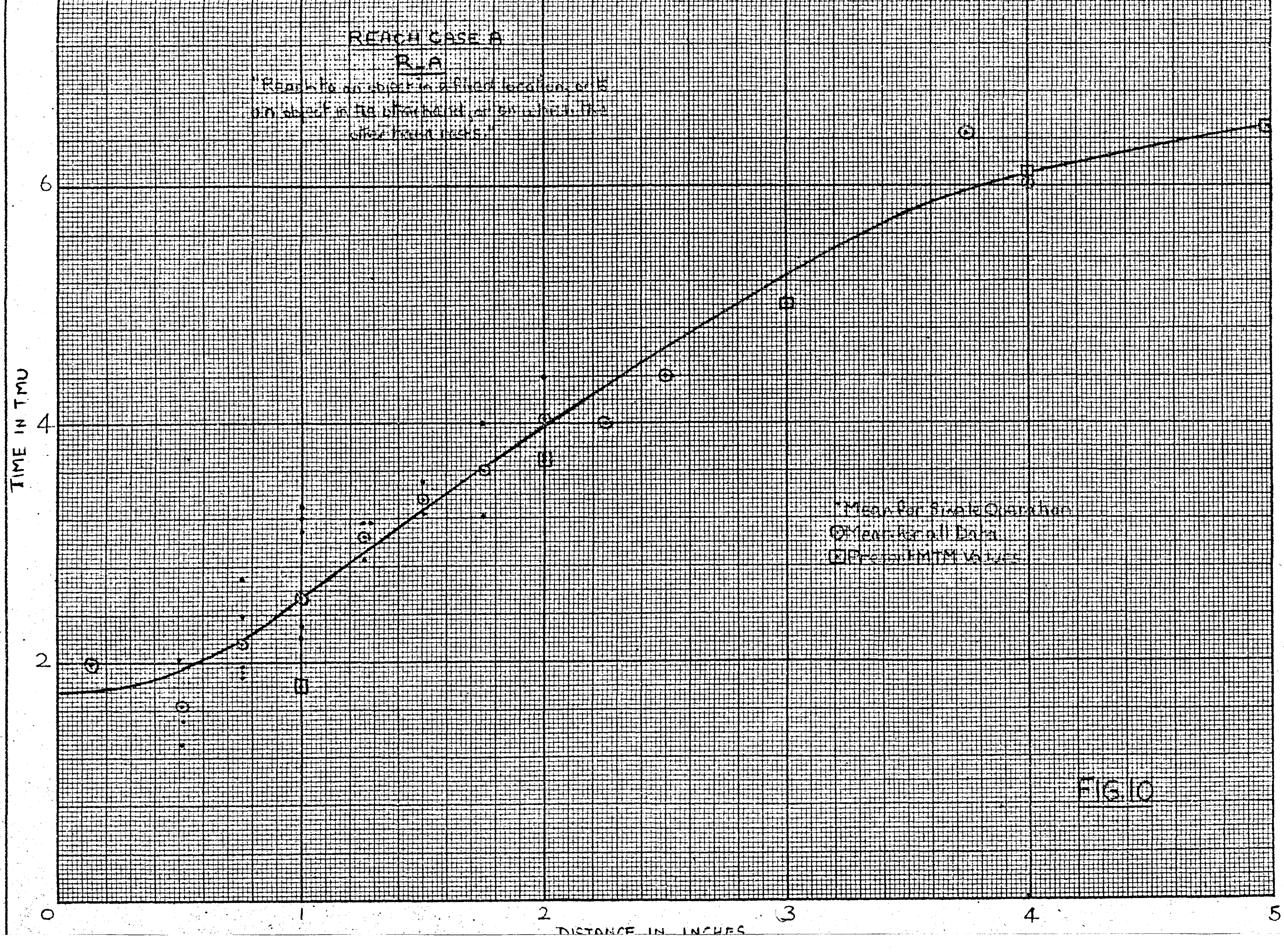
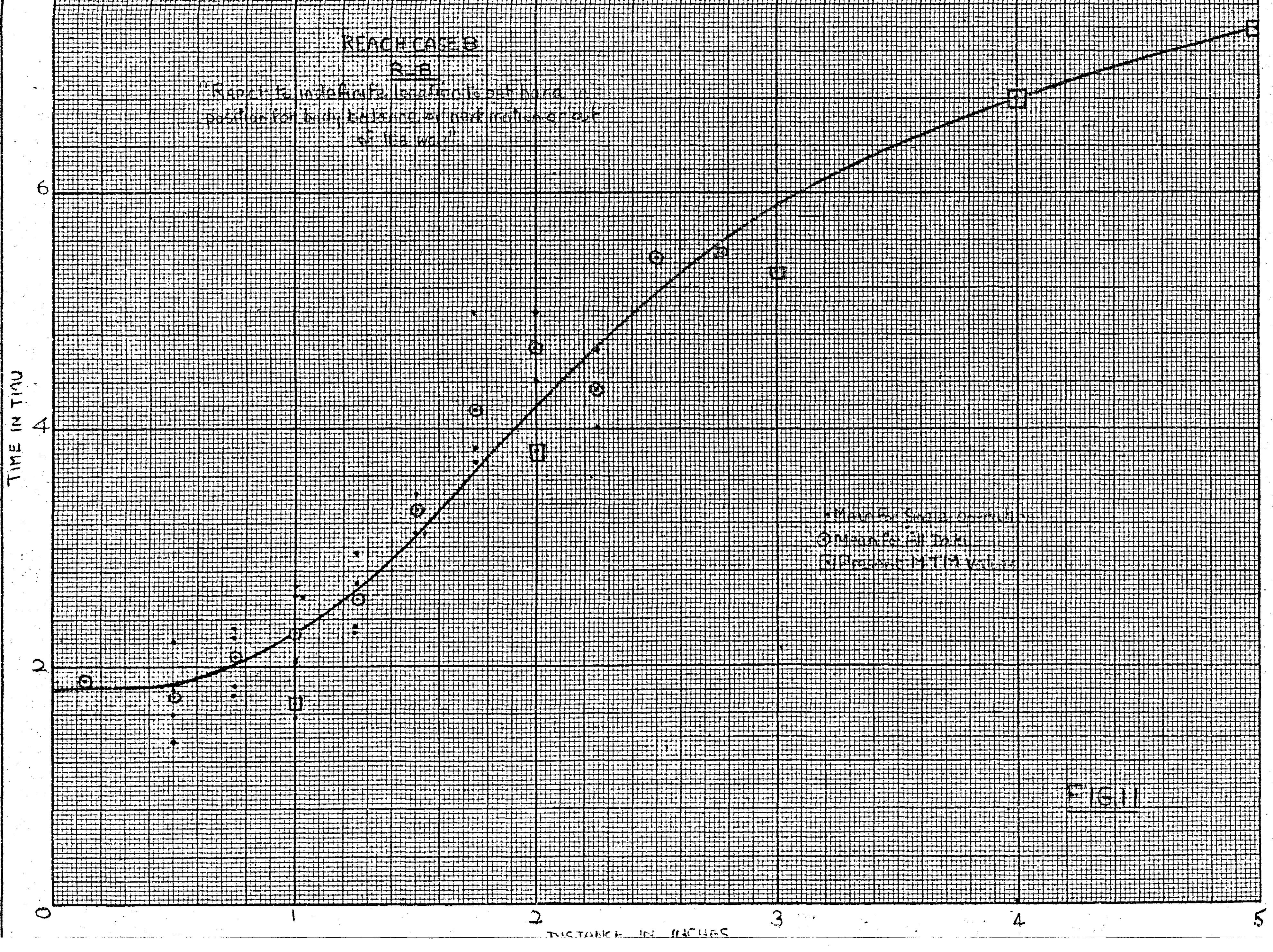

REACH CASE A
R-A
Mean for Single Operation
Mean for all Data
Present MTM Values
TIME IN TMU
DISTANCE IN INCHES
0
1
2
3
4
5
2
4
6

FIG 10



REACH CASE B
R-B
TIME IN TMU
DISTANCE IN INCHES
0
2
4
6
1
2
3
4
5
MTM Values


FIG. 11

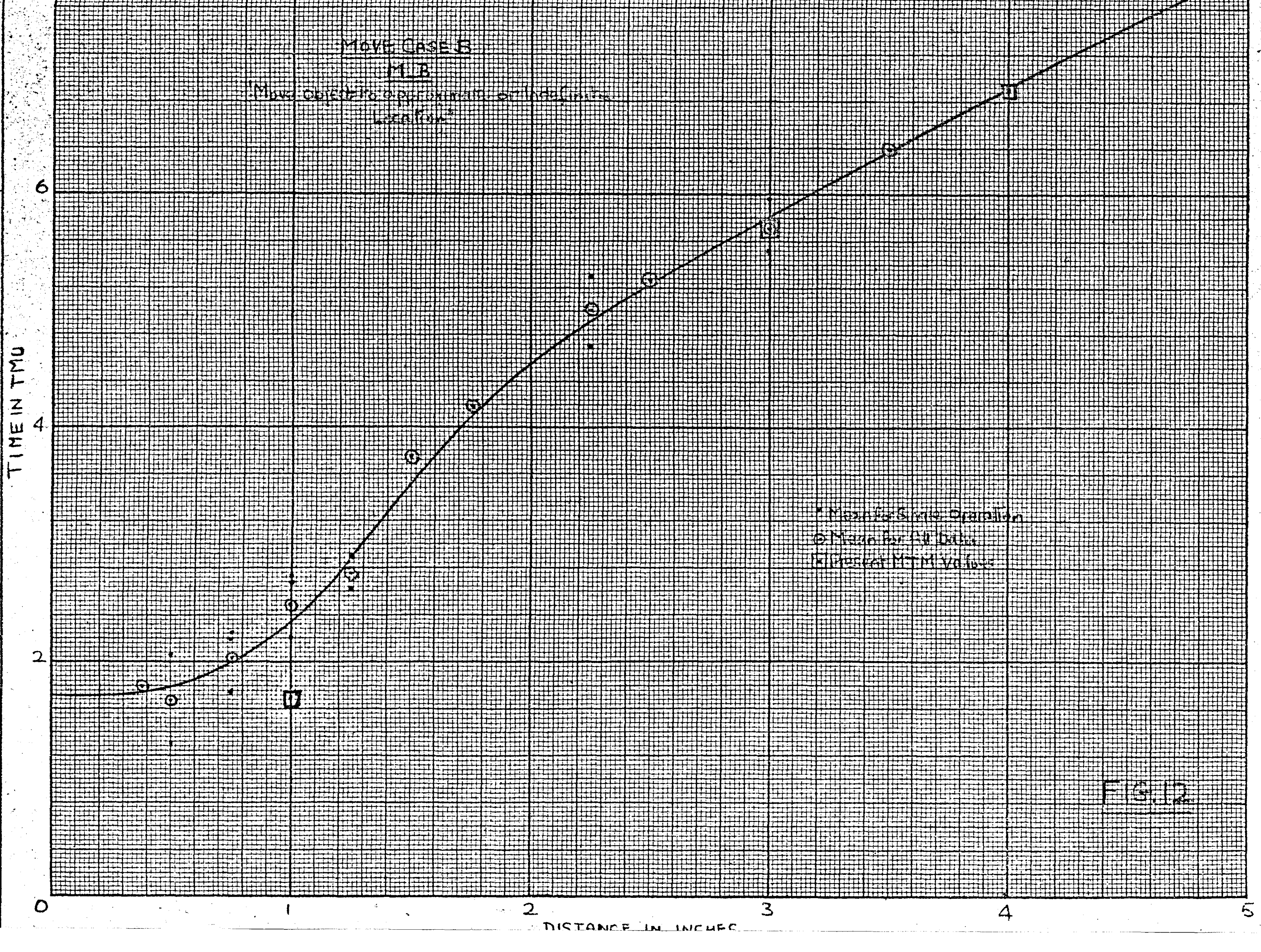

MOVE CASE B
M B
"Move object to approximate or Indefinite Location"
Mean for Single Operation
Mean for All Data
Present MTM Values
TIME IN TMU
DISTANCE IN INCHES
0
2
4
6
1
2
3
4
5

FIG. 12

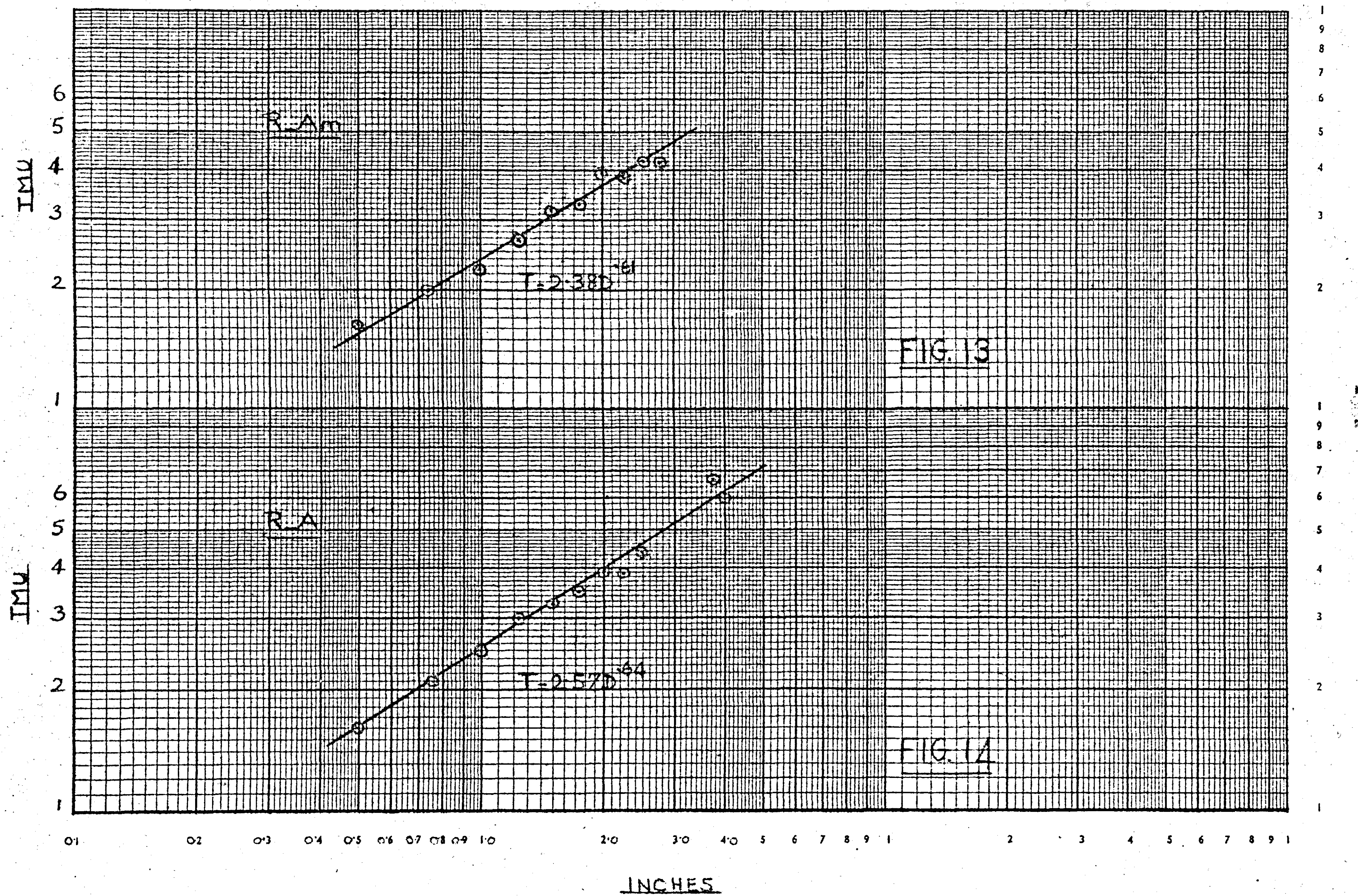
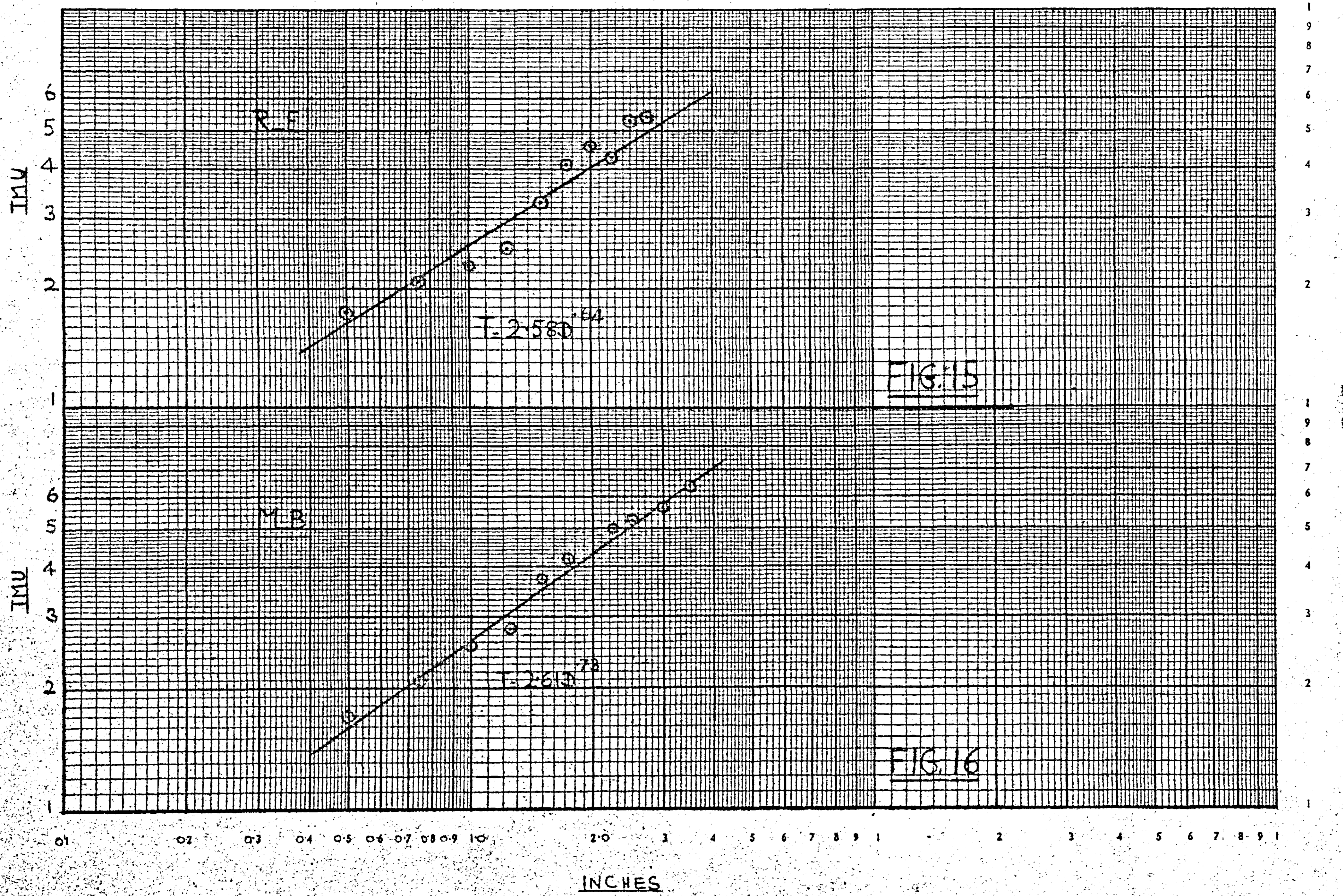



FIG. 13

FIG. 14



R.F.
T=2.58D^.64
FIG. 15
M.B.
T=2.61D^.73
FIG. 16
IMU
INCHES

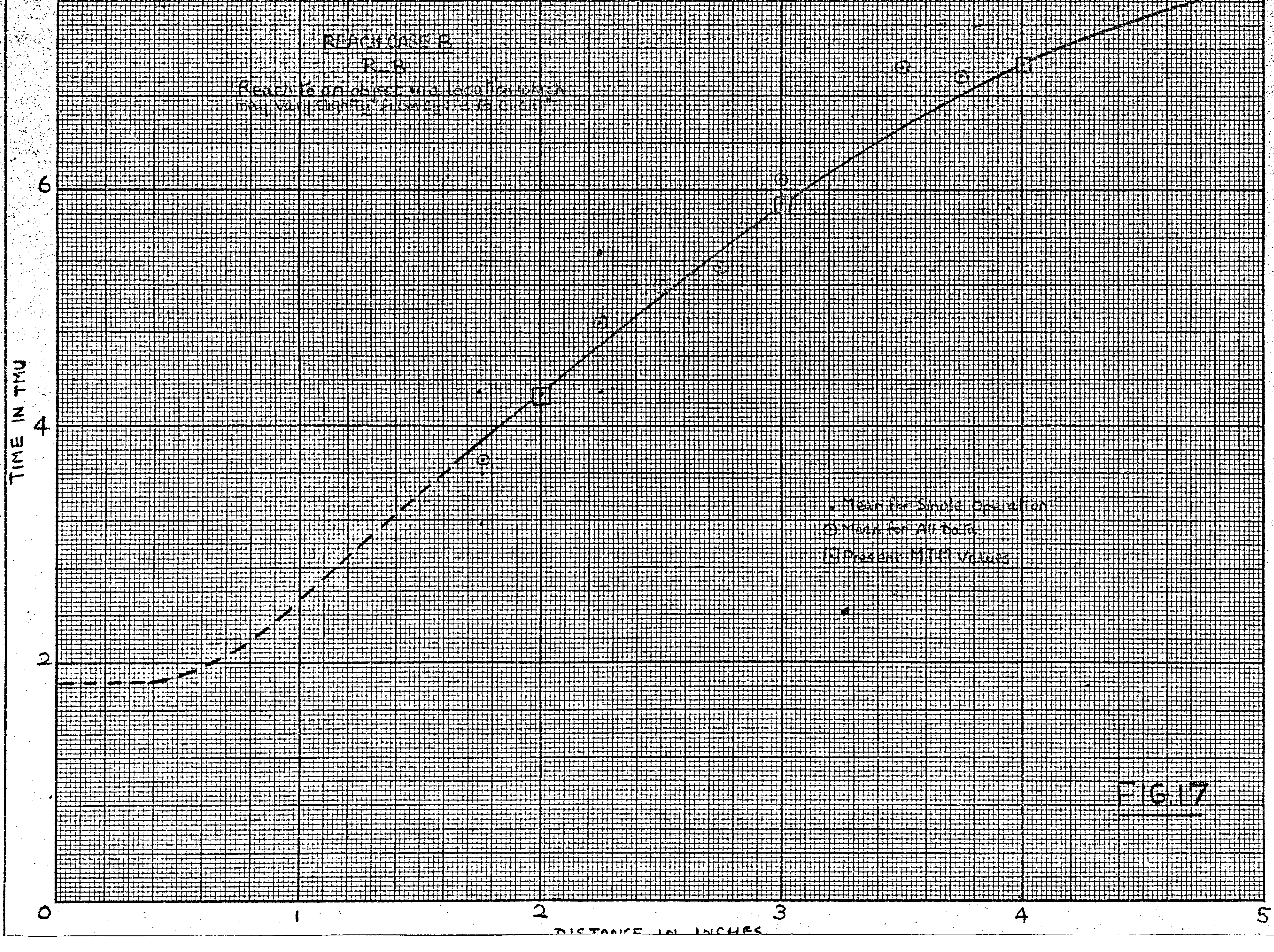
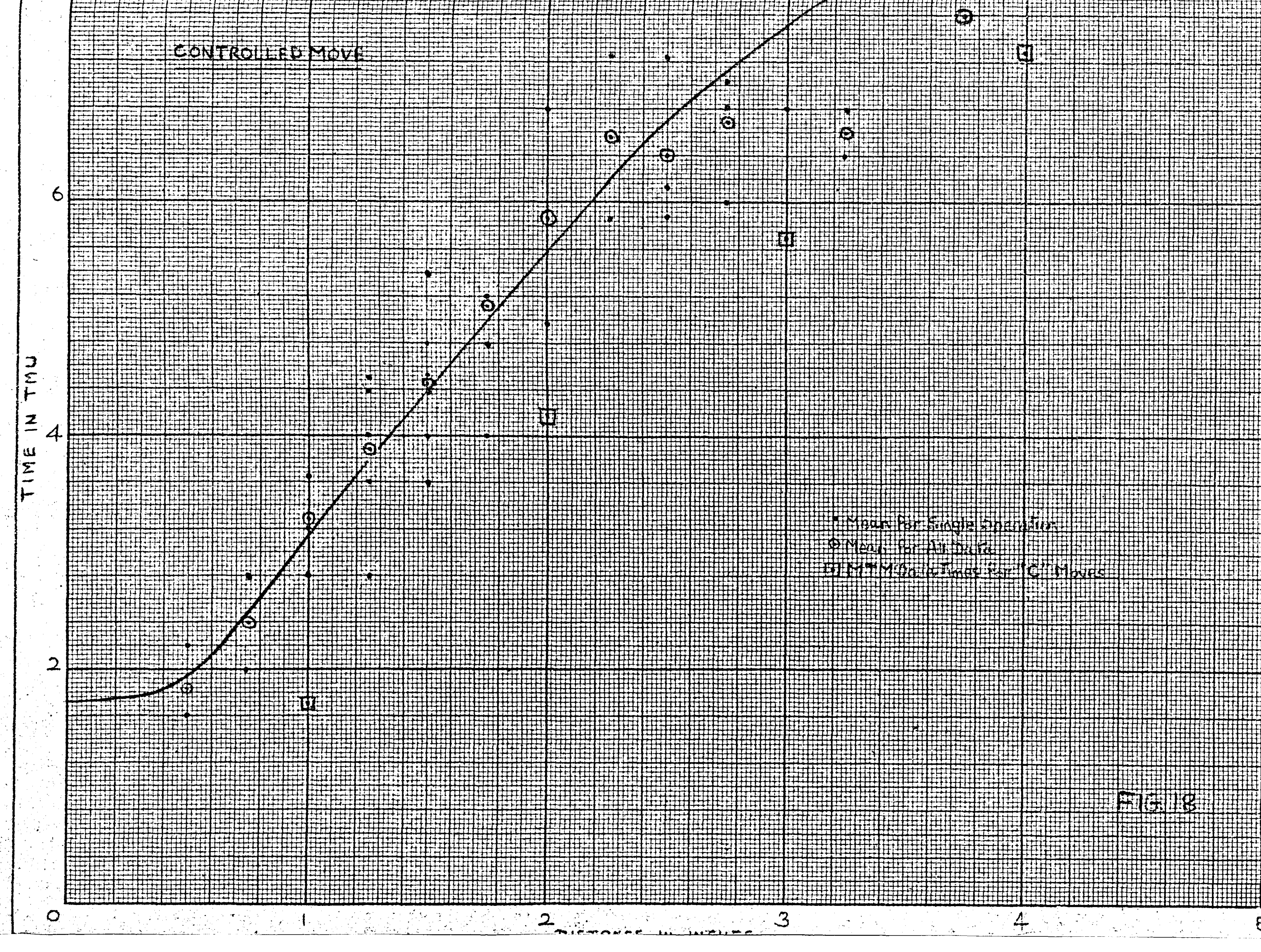

REACH CASE B
R-B
TIME IN TMU
DISTANCE IN INCHES
0
2
4
6
1
3
5
• Mean for Single Operation
⊙ Mean for All Data
⊡ Present MTM Values

FIG. 17


CONTROLLED MOVE
TIME IN TMU
0
2
4
6
1
2
3
4
5
Mean for Single Operator
Mean for All Data
MTM Data Times for "C" Moves
FIG. 18

## APPENDIX I

## MTM METHODS ANALYSIS CHART

Operation: Assemble bolt and washers - two-handed method. Ref. No.PB1

Analyst: P. Butcher Date: 16.10.50 Sheet No.1 of 1 Sheets

| Description - Left hand | L.H. | TMU | R.H. | Description - Right hand |
|---|---|---|---|---|
| To rubber washer, left | mR9C | 9.3 | mR9C | To rubber washer, right. |
| Washer | G5 | 0 | G5 | Washer |
| Slide along bench | M11C | 14.3 | M11C | Washer to assy. point |
| Into hole | P1SE | 5.6 | P1SE | Into hole |
| Fingers off | RL2 | 0 | RL2 | Fingers off |
| To steel washers, left | R12C | 14.2 | R12C | To steel washers, right. |
| | G5 | 0 | G5 | Steel washer |
| Slide along bench | M10C | 13.5 | M10C | To assy. point |
| Fingers off | RL2 | 0 | RL2 | Fingers off |
| To lock washer, left | R11C | 13.6 | R11C | To lock washer, right. |
| Lock washer | G5 | 0 | G5 | Washer, lock |
| Slide along bench | M10C | 13.5 | M10C | To assy. point |
| To bolts, centre | R8C | 11.5 | R8C | To bolts, centre |
| | | 9.1 | G4B | Pick up one bolt |
| Pick up one bolt | G4B | 9.1 | | |
| To assy. point | M8C | 11.8 | M8C | To assy. point |
| Grasp by head | G2 | - | G2 | Grasp by head |
| To lock washer | P1SE | 5.6 | P1SE | To lock washer |
| To steel washer and | M1C | 1.7 | M1C | To steel washer and |
| | | 16.2 | P2SE | through steel and rubber |
| through steel and rubber | P2SE | 16.2 | | |

| Description - Left hand | L.H. | TMU | R.H. | Description - Right hand |
|---|---|---|---|---|
| Grasp head of bolt | G2 | 5.6 | G2 | Grasp head of bolt |
| Out of hole | D1E | 4.0 | D1E | Out of hole |
| Drop into left chute while reaching for next washer | M4Bm RL1 | 4.3 - | M4Bm RL1 | Drop into right chute while reaching for next washer |
| Total time, mins. | | 179.1 | | |

1 Time unit = .0006 mins.

ENGSTROM METHODS ANALYSIS Ref.No.PB3

Operation: Assemble bolt and washers - two-handed method.

Analyst: P. Butcher Date: 30.10.50 Sheet No.1 of 1 Sheet

| Elements of the operation | Condition | Class | Base time | Distance over 8" | Simo factor | Total mins. |
|---|---|---|---|---|---|---|
| Drop completed assemblies down chute | B | 3F | .006 | - | 1.40 | 0.0084 |
| Get rubber washers | A | 2F | .006 | 2" | 1.30 | 0.0088 |
| Place rubber washers | B | 2F | .011 | 4" | 1.40 | 0.0176 |
| Get steel washers | A | 2F | .006 | 3" | 1.30 | 0.0093 |
| Place steel washers | A | 2F | .006 | 3" | 1.40 | 0.0101 |
| Get lock washers | A | 2F | .006 | 2" | 1.30 | 0.0088 |
| Place lock washers | B | 2F | .011 | 1" | 1.40 | 0.0160 |
| Get bolts | B | 2F | .011 | 1" | 1.30 | 0.0148 |
| Place bolts in washers | D | 3F | .019 | 1" | 1.40 | 0.0271 |
| Total time, mins. | | | | | | 0.1209 |

## WORK FACTOR METHODS ANALYSIS

Operation: Assemble bolt and washers - two-handed method. Ref. No.PB2

Analyst: P. Butcher Date: 24.10.50 Sheet No.1 of 1 Sheet

| Elemental desc. - Left | Motion analysis | Elem. time | Motion analysis | Elemental desc. - Right |
|---|---|---|---|---|
| To rubber washers | A10S | 61 | A10S | To rubber washers |
| Slide along bench | A12SD | 85 | A12SD | Washer to hole |
| As for R.H. | P | 20 | P | Target .75" dia., ratio .85" simo at 1.7/8" (10% additive) |
| To steel washers | A11DS | 81 | A11DS | To steel washers |
| To assy. point | A11D | 63 | A11D | To assy. point |
| As for R.H. | P | 20 | P | Target .75" dia., contact ratio .35(approx.)simo at 1.7/8" |
| For lock washer | A10DS | 78 | A10DS | For lock washer |
| Slide along bench | A10D | 61 | A10D | To assy. point |
| As for R.H. | P | 20 | P | Target .75", contact ratio .25(approx.)simo at 1.7/8" |
| To bolts in centre | A9D | 58 | A9D | To bolts in centre |
| Pick up bolts | G | 58 | G | Visual-simo; 3/8" dia., 1" long |
| Bolts to lock washers | A9DS | 74 | A9DS | Bolts to lock washers |
| Bolts to washer, as for right hand | P | 34 | P | Target .375", ratio 0.8"; simo at 1.7/8"(10%) |
| | F1SD | 29 | F1SD | Finger move to bring bolt over steel and rubber washers |
| Bolts to washers, as for right hand | P | 72 | P | Target .375", ratio over .935"; blind for .25", simo at 1.7/8" |
| Fingers to bolt head | 3F1 | 48 | 3F1 | Fingers to bolt head |
| Out of assembly point | A2S | 29 | A2S | Out of assembly point |
| To left chute and drop | A2 | 20 | A2 | To right chute and drop |
| Total time, W.F.T.U. | | 910 | | |

1 Time unit = .0001 mins.

## HOLMES METHODS ANALYSIS

Operation: Assemble bolt and washers - two-handed method Ref. No.PB4

Analyst: P. Butcher Date: 30.10.50 Sheet 1 of 2

| Left hand activity | Member moved | Type of motion | Distance | No. of mvmts | Time mins. | No. of mvmts | Distance | Type of motion | Member moved | Right hand activity |
|---|---|---|---|---|---|---|---|---|---|---|
| To rubber washers | For | Ang | 10 | 1 | .0038 | 1 | 10 | Ang | For | To rubber washers |
| | | | | | .0027 | 1 | 1 | Ang | For | To washer selected |
| To washer selected | For | Ang | 1 | 1 | .0027 | | | | | |
| Press contact - 25% less | Fin | Hin | 1 | 3/4 | .0013 | 3/4 | 1 | Hin | Fin | Press contact - 25% less |
| Washer to assy. | For | Ang | 13 | 1 | .0042 | 1 | 13 | Ang | For | Washer to assy. |
| ( | For | Ang | Pr. | 2 | .0046 | 2 | Pr. | Ang | For | ) |
| Set washer in hole ( | For | Ang | 1 | 1 | .0027 | 1 | 1 | Ang | For | ) Set washer in hole |
| ( | For | Hin | 1 | 1 | .0017 | 1 | 1 | Ang | For | ) |
| To steel washers | For | Ang | 12 | 1 | .0041 | 1 | 12 | Ang | For | To steel washers |
| ( | | | | | .0027 | 1 | 1 | Ang | For | ) |
| Get and contact washer ( | For | Ang | 1 | 1 | .0027 | | | | | )Get and contact washer |
| ( | Fin | Hin | 1 | 3/4 | .0013 | 3/4 | 1 | Hin | Fin | ) |
| Washer to assy. | For | Ang | 12 | 1 | .0041 | 1 | 12 | Ang | For | Washer to assy. |
| To hole | For | Ang | 1 | 1 | .0023 | 1 | 1 | Ang | For | To hole |
| Down | Fin | Hin | 1 | 1 | .0017 | 1 | 1 | Hin | Fin | Down |
| To lock washers | For | Ang | 11 | 1 | .0040 | 11 | 1 | Ang | For | To lock washers |
| ( | | | | | .0027 | 1 | 1 | Ang | For | ) |
| Get and contact washer ( | For | Ang | 1 | 1 | .0027 | | | | | )Get and contact washer |
| ( | Fin | Hin | 1 | 1 | .0013 | 1 | 1 | Hin | Fin | ) |

## HOLMES METHODS ANALYSIS(contd.)

| Left hand activity | Member moved | Type of motion | Dis-tance | No. of mvmts | Time mins | No. of mvmts | Dis-tance | Type of motion | Member moved | Right hand activity |
|---|---|---|---|---|---|---|---|---|---|---|
| Washer to assy. | For | Ang | 1 | 1 | .0040 | 11 | 1 | Ang | For | Washer to assy. |
| Set lock washer near ( | For | Ang | 1 | 1 | .0027 | 1 | 1 | Ang | For | )Set lock washer near |
| centre of hole ( | Fin | Hin | 1 | 1 | .0017 | 1 | 1 | Hin | Fin | )centre of hole |
| ( | Fin | Hin | Pr. | 2 | .0030 | 2 | Pr. | Hin | Fin | ) |
| To bolts, front | Arm | Ang | 9 | 1 | .0049 | 1 | 9 | Ang | Arm | To bolts, front |
| | | | | | .0021 | 1 | 2 | Hin | Fin | Finger to bolt |
| | | | | | .0021 | 1 | 2 | Hin | Fin | Grasp bolt |
| Finger to bolt | Fin | Hin | 2 | 1 | .0021 | | | | | |
| Grasp bolt | Fin | Hin | 2 | 1 | .0021 | | | | | |
| Bolt to assy. | Arm | Ang | 9 | 1 | .0049 | 1 | 9 | Ang | Arm | Bolt to assy. |
| Set bolt to lock washer( | For | Ang | Pr. | 3 | .0069 | 3 | Pr. | Ang | For | )Set bolt to lock washer |
| and other washers ( | For | Ang | 1 | 2 | .0054 | 2 | 1 | Ang | For | )and to other washers |
| Bolt through washers ( | Han | Hin | Pr. | 1 | .0020 | 1 | Pr. | Hin | Han | )Bolt through washers |
| and down ( | Han | Hin | 2 | 1 | .0022 | 1 | 2 | Hin | Han | )and down |
| Fingers to bolt head | Fin | Hin | 3 | 1 | .0051 | 3 | 1 | Hin | Fin | Fingers to bolt head |
| Out of hole | For | Ang | 3 | 1 | .0030 | 1 | 3 | Ang | For | Out of hole |
| Over to chute, left | For | Ang | 3 | 1 | .0030 | 1 | 3 | Ang | For | Over to chute, right |
| Total time, mins. | | | | | .1109 | | | | | |

## APPENDIX II

## DETAIL OF FILMS ANALYSED

1. Typing

Film No. M.31. Camera located 2 ft. directly above centre of typewriter keyboard.

a) Operation: Type sentence "The sly brown fox jumped quickly over the lazy dog."

b) Equipment: Standard Royal No. KMM12-2834086.

c) Operator: Woman; four years' typing experience; self-taught.

d) Rating: Skill E-1, Effort C-2. Total factor - 3%

2. Typing

Film No. M.32. Camera located 2 ft. directly above centre of typewriter keyboard.

a) Operation: Type sentence "The sly brown fox jumped quickly over the lazy sleeping dog."

b) Equipment: Standard Royal No. KMM12-2834086.

c) Operator: Woman; four years' typing experience; college instruction.

d) Rating: Skill B, Effort C. Total factor + 13%

3. Typing

Film No. M.35. Camera located 2 ft. directly above centre of typewriter keyboard.

a) Operation: Type sentence "The sly brown fox jumped quickly over the lazy sleeping dog."

b) Equipment: Standard Royal No. KMM12-2834086

c) Operator: Woman; three months' commercial typing; one and a half year's practice at High School.

d) Rating: Skill C-1, Effort C, Total factor + 9.5%

4. Wrap porcelain with wire

Film No. M.36. Camera located 2'6" directly in front of standing operator, at waist height.

a) Operation: Wrap porcelain rod, 8½" long x 5/8" dia., with No.25A gauge resistance wire.

b) Equipment: Wire spool mounting.

c) Operator: Woman; eight years' experience on similar work; right handed.

d) Rating: Skill D, Effort E. Total factor - 6%

5. Wrap porcelain with wire

Film No. M.37. Camera located 3 ft. in front of and at 45° to the standing operator, at waist height.

a) Operation: Wrap porcelain rod, 8½" long x 5/8" dia., with No.25A gauge resistance wire.

b) Equipment: Wire spool mounting.

c) Operator: Woman; two years' experience at work; right handed.

d) Rating: Skill C-2, Effort C-1. Total factor + 8%.

6. Assemble connectors for spot welding

Film No. M.39. Camera located 1 ft. from fixture, 1'9" from pile of nuts, at same level and turned to follow hand. Film out during machine controlled element of cycle.

a) Operation: Assemble four 3/16" nuts into fixture by sliding each one along the top bar and into the appropriate section.

b) Equipment: Fixture in spot welder: 4.1/8" x 2.5/8" x 2".
Slide bar 3" x ½" x ½"

c) Operator: Man: fourteen years in industry, similar work.

d) Rating: Skill C, Effort C. Total factor + 8%

7. Assemble heater elements

Film No. M.40. Camera located 2'6" directly in front of seated operator, at hand working level.

a) Operation: Screw a 4.1/8" long terminal into each end of the 6" long heater element, 3/16" dia., for a distance of $\frac{3}{4}$".

b) Equipment: None

c) Operator: Woman; eight years light assembly.

d) Rating: Skill C, Effort C-1. Total factor + 9.5%

8. Assemble heater elements

Film No. M.41. Camera located 2'6" directly in front of seated operator, at hand working level.

a) Operation: Screw a 4.1/8" long terminal into each end of the 6" long heater element, 3/16" dia., for a distance of $\frac{3}{4}$".

b) Equipment: None

c) Operator: Woman; five years light assembly.

d) Rating: Skill C-2, Effort C-2, Total factor + 5%.

9. Lubricate valve cones

Film No. M.45. Camera located 3 ft. to the right of and 45° behind the seated operator, at hand working level.

a) Operation: Apply grease to valve cones, 1" long, tapering from $\frac{3}{4}$" dia. to 5/8" dia., stem length $1\frac{1}{4}$".

b) Equipment: Brush, 5" long with bristle head 1" long x $\frac{1}{4}$" x 1/8". Grease.

c) Operator: Woman; fifteen years light assembly.

d) Rating: Skill D, Effort E-1. Total factor - 4%.

10. Insert steel pins

Film No. M.48. Camera located 3'6" in front of standing operator, at waist length.

a) Operation: From handful of ½" x 1/8" dia. pins in left hand, get one to finger tips, rub on lubricant pad, fix into driver in right hand and push into assembly.

b) Equipment: Hollow driver, 1.1/8" shank, 3/16" dia. with rounded wooden handle.

c) Operator: Man; three years light assembly.

d) Rating: (On left hand) Skill C-1, Effort D. Total factor + 6%

11. Operate comptometer

Film No. M.49. Camera located 3 ft. in front of and 45° to the left of the seated operator, and 2 ft. above the level of the keyboard.

a) Operation: Tabulating accounts figures.

b) Equipment: Felt & Tarrant Elec. comptometer, K359755.

c) Operator: Woman; two years' experience ; six months' training.

d) Rating: Skill D, Effort E-1. Total factor - 4%.

12. Operate adding machine

Film No. M.51. Camera located 2'6" to right side of seated operator, and 6" above the level of the keyboard.

a) Operation: Add columns of figures.

b) Equipment: Remington Rand Model 93.

c) Operator: Woman; twelve years' experience.

d) Rating: Skill C-1, Effort C-1. Total factor + 11%.

# APPENDIX III

## RESULTS OF FILM ANALYSIS, MEAN VALUE PER STUDY

### Table 25

Results from R-Am

| Study No. | Mean TMU | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | ¼" | ½" | ¾" | 1" | 1¼" | 1½" | 1¾" | 2" | 2¼" | 2½" | 2¾" |
| 31 | | | | | 3.10 | 3.30 | 3.72 | 4.14 | | | |
| 32 | | | | 1.9 | 2.25 | | | | | | |
| 35 | | 1.71 | 2.29 | 2.82 | 2.75 | 3.36 | 3.49 | 4.13 | 3.82 | 4.35 | |
| 36 | | | | | 2.77 | 3.16 | 2.76 | | | | |
| 49 | 1.21 | | | 2.01 | | 2.95 | 3.02 | 3.61 | 3.81 | 4.02 | |
| 51 | 1.43 | 1.52 | 1.65 | 2.27 | 2.51 | 2.94 | 3.50 | 3.70 | 3.80 | 4.45 | 4.18 |
| Mean TMU | 1.32 | 1.61 | 1.97 | 2.25 | 2.68 | 3.14 | 3.30 | 3.90 | 3.81 | 4.27 | 4.18 |

### Table 26

Results from R-A

| Study No. | Mean TMU | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1/8" | ½" | ¾" | 1" | 1¼" | 1½" | 1¾" | 2" | 2¼" | 2½" | 3¾" | 4" |
| 31 | | | | 3.30 | | | | | | | | |
| 36 | | | 1.96 | | | | 3.2 | | | | | |
| 37 | | 1.54 | 1.87 | 1.81 | 3.16 | | | | | | | |
| 40 | | 2.02 | 2.39 | 2.30 | | | | 3.68 | | | | |
| 41 | | 1.32 | 1.91 | 2.20 | 3.17 | 3.23 | | | | | | |
| 48 | | | 2.7 | 3.1 | 2.83 | 3.5 | 4.0 | 4.4 | 4.0 | 4.4 | | |
| 49 | | | | | | | | | | | 6.42 | 6.03 |
| 51 | 2.0 | | | | | | | | | | | |
| Mean TMU | 2.0 | 1.63 | 2.16 | 2.54 | 3.05 | 3.34 | 3.60 | 4.04 | 4.0 | 4.4 | 6.42 | 6.03 |

## Table 27

### Results from R-B and R-Acd

| Study No. | Mean TMU | | | | | | |
|---|---|---|---|---|---|---|---|
| | 1¾" | 2¼" | 2½" | 2¾" | 3" | 3½" | 3¾" |
| 36 | 3.13 | 4.31 | 5.23 | 5.36 | 6.11 | 7.05 | 7.0 |
| 37 | 3.62 | | | | | | |
| 41 | 4.29 | 5.5 | | | | | |
| Mean TMU | 3.68 | 4.91 | 5.23 | 5.36 | 6.11 | 7.05 | 7.0 |

## Table 28

### Results from R-E

| Study No. | Mean TMU | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1/8" | ½" | ¾" | 1" | 1¼" | 1½" | 1¾" | 2" | 2¼" | 2½" | 2¾" |
| 32 | | | | 2.60 | | | | | | | |
| 35 | | 1.83 | | | | | | | | | |
| 36 | | | 1.76 | 1.56 | 2.34 | 3.13 | | | | | |
| 37 | | | 2.26 | 2.03 | 2.94 | | | 4.97 | 4.68 | 5.43 | 5.43 |
| 39 | | 1.36 | 2.26 | | | | 4.97 | | | | |
| 40 | | | 1.83 | 2.58 | 2.30 | 3.45 | 3.83 | | | | 5.50 |
| 48 | | 2.22 | 2.32 | 2.67 | 2.70 | 3.10 | | 4.40 | 4.0 | | |
| 49 | | 1.61 | | | | | | | | | |
| 51 | 1.9 | | | | | | 3.7 | | | | |
| Mean TMU | 1.9 | 1.76 | 2.09 | 2.29 | 2.57 | 3.33 | 4.17 | 4.68 | 4.34 | 5.43 | 5.47 |

## Table 29

## Results from M-B

| Study No. | Mean TMU | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 3/8" | ½" | ¾" | 1" | 1¼" | 1½" | 1¾" | 2¼" | 2½" | 3" | 3½" |
| 35 | 1.83 | | | | | | | | | | |
| 36 | | | | | | | | 4.73 | 5.27 | 5.5 | 6.4 |
| 40 | | 2.07 | 2.25 | 2.76 | | | | | | 5.95 | |
| 41 | | 1.32 | 1.76 | 2.20 | 2.64 | | | | | | |
| 48 | | | 2.2 | 2.70 | 2.90 | 3.75 | 4.2 | 5.3 | | | |
| Mean TMU | 1.83 | 1.70 | 2.07 | 2.55 | 2.77 | 3.75 | 4.2 | 5.01 | 5.27 | 5.72 | 6.4 |

## Table 30

## Results from M-Am and mM-A

| Study No. | Mean TMU | | | |
|---|---|---|---|---|
| | 1/8" | ¼" | ½" | 5/8" |
| 31 | | | 2.03 | 2.34 |
| 35 | | | 2.13 | 2.01 |
| 49 | | 1.37 | 1.61 | |
| 51 | 1.53 | | | |
| Mean TMU | 1.53 | 1.37 | 1.59 | 2.17 |

## Table 31

### Results from R-Em and mR-E

| Study No. | Mean TMU ½" | ¾" | 1" | 1¼" | 1½" | 1¾" |
|---|---|---|---|---|---|---|
| 31 | 1.65 | | | | | |
| 32 | | 2.13 | 2.36 | | | |
| 35 | | 2.29 | 2.75 | 2.60 | 2.29 | |
| 36 | | | 2.76 | 2.37 | 2.76 | 2.37 |
| Mean TMU | 1.65 | 2.21 | 2.62 | 2.48 | 2.52 | 2.37 |

## Table 32

### Results from M-A

| Study No. | Mean TMU 1/8" | 3/8" | ½" | ¾" | 1" | 1¼" | 1½" | 2" | 2¾" | 3½" |
|---|---|---|---|---|---|---|---|---|---|---|
| 35 | | 1.83 | | | | | | | | |
| 39 | | | | | | | | | 4.97 | 5.87 |
| 48 | | | 2.2 | 2.45 | 2.45 | 2.82 | 3.1 | 4.0 | | |
| 51 | 2.14 | | | | | | | | | |

Table 33

Controlled moves

| TMU | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ½" | ¾" | 1" | 1¼" | 1½" | 1¾" | 2" | 2¼" | 2½" | 2¾" | 3" | 3¼" | 3¾" |
| 2.26 | 2.0 | 3.62 | 4.52 | 4.08 | 6.35 | 5.87 | 5.87 | 5.87 | 8.60 | 7.01 | 6.8 | 7.6 |
| 1.60 | 2.4 | 2.8 | 2.8 | 4.52 | 5.2 | 6.80 | 7.25 | 7.25 | 7.25 | | 6.4 | |
| | 2.8 | 3.2 | 3.6 | 5.42 | 4.8 | 4.97 | | 6.15 | 7.01 | | | |
| | | 3.6 | 4.4 | 4.8 | 4.0 | | | 6.4 | 6.0 | | | |
| | | | 4.0 | 3.6 | | | | | 6.8 | | | |
| | | | | 4.0 | | | | | | | | |
| | | | | 4.4 | | | | | | | | |

## APPENDIX IV

## STATISTICAL ANALYSIS OF REACH, CASE A

### Table 34(i)

### Logarithmic values of single points

| X $Log_{10}$ (Distance x 10) | Y $Log_{10}$ (TMU) | $X^2$ | $Y^2$ | XY |
|---|---|---|---|---|
| .699 | .188 | .489 | .035 | .131 |
| .699 | .305 | .489 | .093 | .213 |
| .699 | .121 | .489 | .015 | .084 |
| .875 | .292 | .766 | .085 | .256 |
| .875 | .272 | .766 | .074 | .238 |
| .875 | .378 | .766 | .143 | .331 |
| .875 | .281 | .766 | .079 | .246 |
| .875 | .431 | .766 | .186 | .378 |
| 1.000 | .519 | 1.000 | .269 | .519 |
| 1.000 | .258 | 1.000 | .067 | .258 |
| 1.000 | .362 | 1.000 | .131 | .362 |
| 1.000 | .342 | 1.000 | .117 | .342 |
| 1.000 | .491 | 1.000 | .241 | .491 |
| 1.097 | .500 | 1.203 | .250 | .548 |
| 1.097 | .501 | 1.203 | .251 | .550 |
| 1.097 | .452 | 1.203 | .204 | .495 |
| 1.176 | .509 | 1.383 | .259 | .598 |
| 1.176 | .544 | 1.383 | .296 | .638 |

Table 34(ii)

Logarithmic values of single points

| | X Log10 (distance x 10) | Y Log10 (TMU) | $X^2$ | $Y^2$ | XY |
|---|---|---|---|---|---|
| | 1.243 | .505 | 1.545 | .255 | .629 |
| | 1.243 | .602 | 1.549 | .362 | .749 |
| | 1.301 | .566 | 1.693 | .320 | .736 |
| | 1.301 | .644 | 1.693 | .415 | .836 |
| | 1.352 | .602 | 1.828 | .362 | .814 |
| | 1.398 | .644 | 1.954 | .415 | .899 |
| | 1.574 | .808 | 2.477 | .653 | 1.272 |
| | 1.602 | .780 | 2.566 | .608 | 1.250 |
| Total | 28.129 | 11.897 | 31.973 | 6.175 | 13.863 |

Results

$\Sigma X = 28.129$ $\Sigma Y = 11.897$

$\Sigma X^2 = 31.973$ $\Sigma Y^2 = 6.175$

$\Sigma XY = 13.863$

Number of readings, n = 26

Coefficients and errors

$\bar{X}$ = Average value of X = $\frac{28.129}{26} = 1.082$

$\bar{Y}$ = " " " Y = $\frac{11.897}{26} = 0.458$

Variance of X: $s_x^2 = \frac{1}{n-1} . (\Sigma X^2 - n\bar{X}^2) = 0.0613$

Variance of Y: $s_y^2 = \frac{1}{n-1} . (\Sigma Y^2 - n\bar{Y}^2) = 0.0288$

Covariance of XY: $\text{Cov } XY = \frac{1}{n-1} . (\Sigma XY - n\overline{XY}) = 0.0392$

Correlation coefficient: $r = \frac{\text{Cov } XY}{s_x\, s_y} = 0.931$

Standard error of estimate: $s_E = \sqrt{\frac{n-1}{n-2}\, s_y^2\, (1 - r^2)} = 0.063$

$3\sigma$ limits on regression line of Y on X $\pm 3\, s_E = \pm 0.19$

Standard deviation of correlation coefficient $\sigma_r = \frac{1 - r^2}{\sqrt{n-1}} = 0.027$

Logarithmic line equation

$Y = A + \hat{B}X$ where $Y = \text{Log}_{10}\,(\text{TMU})$

$X = \text{Log}_{10}\,(\text{Distance} \times 10)$

Regression coefficient of Y on X: $\hat{B} = \frac{\text{Cov } XY}{s_x^2}$

$\therefore\ \hat{B} = 0.64$

Solving the equation for A, by substituting known values of $\overline{X}$ and $\overline{Y}$ for X and Y

$A = -0.232$

$\therefore$ Logarithmic line equation $Y = 0.64X - 0.232$ (1)

Short motion line equation

Let T = Time for the motion, TMU

D = Distance travelled during the time T, in inches

Substituting values for T and D in equation (1)

$\text{Log}_{10}\, T = 0.64\, \text{Log}_{10}\, 10D - 0.232$

$\therefore T = 0.586 \times 10^{.64} \times D^{.64}$

$T = 2.56\, D^{0.64}$

90% Confidence limits of regression coefficient B

Regression coefficient B of population, in terms of $\hat{B}$, coefficient for the sample, is given by the expression

$$B = \hat{B} \pm \frac{s_E \cdot t_\alpha}{s_x \sqrt{n-1}}$$

where $t_\alpha$ = 90% confidence coefficient for the unknown population
= 1.71 when n = 26

$$\therefore \quad B = 0.64 \pm 0.087$$