CALIBRATION OF CROFT PROBERT MV READER TO ELIMINATE THE USE OF CORRECTION TABLE AND METRIC CONVERSION TABLE

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ABSTRACT

In this article, an attempt has been made to find out a method of graduating the Muzzle Velocity (M.V.) Reader. This method has been discussed on the existing F. P. S. System. Suggestion has also been made about the method of conversion of the existing ballistic table into tables of the Metric System and then graduating the scale in C. G. S. System.

Introduction

The Croft Probert Muzzle Velocity Reader is essentially a scale designed for the measurement of muzzle velocity of a projectile directly on the scale from the mark obtained on the long rod of a Boulenge Chronograph, apart from the observed velocity which can also be measured by a Pitkin Velocity Scale.

The Boulenge Chronograph, measures the time required by the projectile to travel a fixed distance, in terms of the fall of a freely falling rod during the period of the time that the projectile takes to pass through that fixed distance. This is done in the following manner:

The two coils of electromagnets of the Boulenge Chronograph holding the short and long rods of the Chronograph in suspension are connected electrically in series to wire screens placed in front of the gun. During the passage of the projectile through the screens the electrical circuits are broken one after the other and as a result the rods fall freely due to gravity, the electromagnetic influence being removed. Since the breakage of the screens takes place one after the other, the rods also begin to fall one after the other. Devices have been so made as to get a mark on the falling long rod due to certain actions caused by the falling short rod after some time of the breakage of the far screen.

Initially, the long rod (actually a sleeve slipped over the long rod) is marked for zero *i.e.* the point from which measurement of the distance fallen by the long rod is to be taken. At 4·345″ above the zero mark, a circular line is scribed over the sleeve by means of a trammel gauge and a scriber indicating what is known as the "Disjunction line".

The invariable delay in getting the mark after the far screen is broken, is kept constant at 0·15 sec and is known as the "Disjunction Time". This is depicted in terms of fall, by the Disjunction line. So this time is to be deducted from the total time of fall of the long rod to get the time taken by the projectile to travel the fixed distance. Knowing the time of fall of the long rod and the distance between the screens, the velocity can be easily calculated.

Principle of graduating the Pitkin Scale

Let 'h' be distance through which the long rod falls, then $h = \frac{1}{2}gt^2$ or $t = \sqrt{2h/g}$

By deducting the disjunction time from the total time of fall, the time that the projectile takes to travel the fixed distance between the screens is $\sqrt{\frac{2h}{g}} - 0 \cdot 15$ sec.

If the fixed distance between the screens is 's' and the velocity of the projectile is 'q', then $q = \dfrac{s}{\sqrt{\frac{2h}{g}} - 0 \cdot 15}$

This equation reduces to $q = \dfrac{s}{\sqrt{\frac{h}{6g}} - 0 \cdot 15}$,

Where all the dimensions are in feet, except 'h' which is in inches.

The value of 'g' being constant and 's' and 'h' being known, 'q' can be easily calculated.

Velocity Scales have been constructed by using this formula for different screen distances (viz. 120′, 180′ & 270′) and are named as Pitkin Velocity Scales. These Scales measure the observed velocity, that is, the average mid-screen velocity. But in gunnery the knowledge of muzzle velocity is essential.

Siacci called this velocity as Pseudo Velocity and connected it with the muzzle velocity by means of the following formula for low angle fire:—

$$x = c\,(s_v - s_u)$$

where x=Midscreen distance from muzzle

c=Ballistic coefficient

s_v=Function of muzzle velocity

s_u=Function of observed velocity.

$$\text{Now } c = \frac{w}{k\sigma\rho d^2}$$

where k=Coefficient of shape

σ=Coefficient of steadiness

d=Diameter of projectile

w=Weight of projectile

ρ=Density of air.

For a flat headed projectile $k\sigma\rho$ is taken as unity.

Hence for a flat headed projectile Siacci's formula reduces to

$$s_v - s_u = \frac{x}{c} = \frac{d^2 x}{w}$$

By means of extensive firing the functions of velocities have been tabulated. Knowing the functions and the values of d, x and w, the value of v *i.e.* the muzzle velocity can be calculated by means of Siacci's equation in the following manner.

The observed velocity 'u' is measured in the Pitkin Scale. Knowing d, x and w, the value of $\frac{d^2.x}{w}$ is calculated. This value is added to the value of the function of 'v' from the ballistic table No. 8 for flat headed projectile in the Text Book of Ballistic & Gunnery (1938 Edition). The ballistic table is again consulted to find out the velocity for this added function of velocity. This velocity is the muzzle velocity V.

This method of finding the muzzle velocity is dilatory and involves much labour. But in charge-determination and velocity measurements the knowledge of muzzle velocity immediately after a round is fired is essential. So in order to save time and labour another type of scale *i.e.* the Croft Probert Muzzle Velocity Reader has been invented and introduced into service to measure the muzzle velocity directly from the distance of the long rod fallen. This type of reader has been in use at Balasore since some time before 1943.

Description of Croft Probert MV Reader

The construction of a Pitkin velocity scale has already been discussed. We shall now confine our attention in finding out a method of graduating the MV Reader. A sketch of the Croft Probert MV Reader is given below. The constructional details are as follows. (See fig. 1)

It consists of a heavy metallic base 'A' about 28″ in length and $6\frac{1}{2}$″ in width. At the left side of this base at the rear, there is a bridge shaped platform 'B' serving as the rest for a movable graduated arc scale 'C'. In the same line at the right, there is another post 'P' which along with the bridge-shaped rest holds a long triangular block T, capable of being rotated on a horizontal axis. On each side of this equilateral triangular block are screwed three graduated scales 'g'. The scales are marked by straight lines for zero and disjunction and with dots for velocities. Each scale is graduated for one of the three screen distances namely 120′, 180′ and 270′. Any of these scales can be brought to the horizontal reading position at will be rotating the triangular block.

In front of this bridge shaped platform there are two posts P. Each of these two posts carries a bracket 'b' into which the bob of the long rod is placed and kept in position by means of a spring. The position of the holding bracket can be shifted to right or left while making initial adjustment of the scale by means of screws 's'. Once the adjustment is made the position of the holder bracket can be fixed by means of another screw 'c'. The other two ends of the long rods rest into the slots of two other posts 'q' on the extreme right of the base and the rods are thus kept in horizontal position.

While taking reading the sliding arc scale is slided over the plate scale. The sliding arc scale carries two semicylindrical reading lenses one of which is fixed and the other movable over the graduated arc. The arc is graduated having the zero mark at the extreme right. 200th mark at the centre and the 400th mark at the extreme left. The semicylindrical lenses have got very fine hairline lengthwise which serve as the pointer while taking reading. The hairline of the movable lens points to the reading on the scale and that on the fixed lens points to the mark obtained on the long rod on firing. The hairline of the movable lens when on the 200th mark of the arc is parallel to the hairline of the fixed lens.

Use of Croft-Probert M.V. Reader

Initially the long rod having zero mark and disjunction line is held in horizontal position on the device made for the purpose as shown in the sketch. The movable hairline is then set to the 200th mark on the arc. As stated before, in this position the hairlines of the lenses are parallel to each other. The sliding attachment Q carrying the lenses is now so shifted as to make the hairline of the movable lens coincident with the disjunction line of the scale. In this position the hairline of the fixed lens should be in coincidence with the disjunction line on the rod. If the hairline of the fixed lens does not coincide with the disjunction line of the rod, the rod can be shifted either way. After making the disjunction line of the rod coincident with the hairline of the fixed lens, the hairline of the movable lens is shifted to the reading on the arc as obtained by calculating the value of $d^2.x/w$. The instrument is now set for the measurement of the M.V. directly from the distance of the long rod fallen. If the hairline is shifted to the extreme right coinciding with the zero mark on the arc the reading instead of being M.V. will be the observed velocity of the projectile as measured by the Pitkin Scale.

Calibration of Croft Probert M.V. Reader

Pitkin Scales have been graduated using the formula

$$q = \frac{s}{\sqrt{\frac{h}{6g}} - 0{\cdot}15}$$

and the M.V. Readers, using the Siacci's equation in conjunction with the above formula. The value of 'g' changes as one moves from the equator to the pole. As such the value of 'g' at Balasore is not the same as that in London. The Pitkin scales and M.V. Readers have been calibrated using a value of 'g' in London which is different from that of Balasore. So the reading of the Pitkin Scale or M.V. Readers do not represent correct velocity at Balasore and hence necessitate the use of correction.

The preparation of the correction table based on the actual difference of the reading on the Croft Probert reader or Pitkin Scale from the calculated velocity with the value of 'g' at Balasore is a laborious and tedious process. Further each equipment should have a separate correction table for each screen distance. For various reasons the use of the correction table cannot be considered as very satisfactory. So if correct scales can be calibrated, the use of the correction table can be dispensed with and M.V. or O.V. can be read directly from the reader.

On careful observation it is seen that the M.V. Reader unlike the Pitkin Scale, consists of dots marked on the scale and those dots also are not in a straight line. When an M.V. Reader is used for measuring M.V. the hairline of

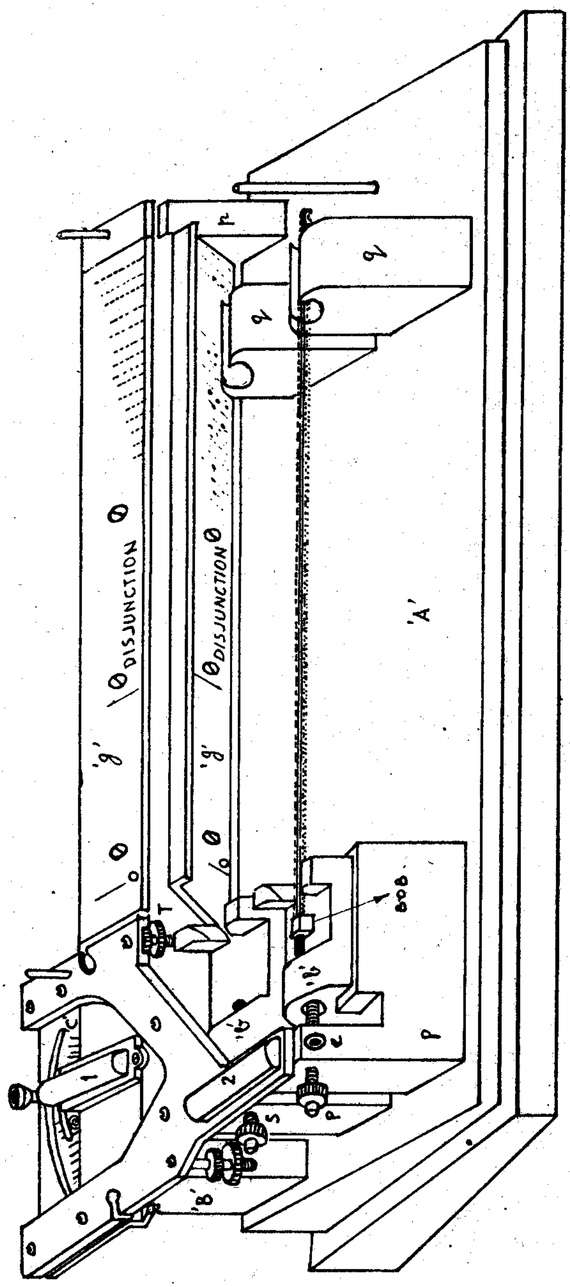

FIG. 1

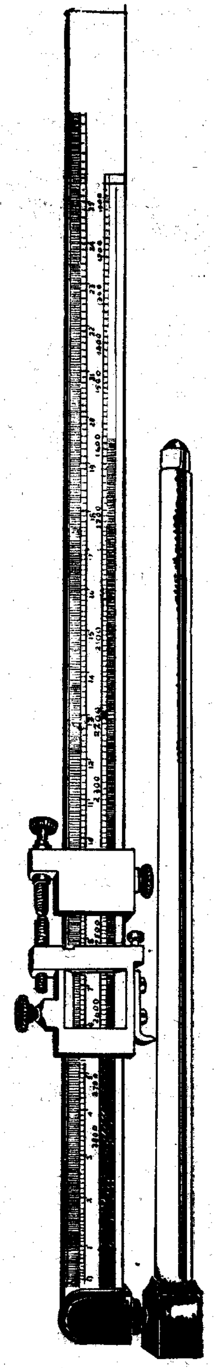

FIG. 2

the movable lens is set to the calculated value of $d^2.x/w$ of the particular equipment. On receipt of mark on the long rod after firing, the hairline of the fixed cursor is set against this mark. The reading indicated by the dot over which the hairline of the movable lens is positioned is the M.V.

Actually any point on the hairline of the movable lens should indicate the M.V. But it is not so. Let us suppose any other equipment having a different $d^2.x/w$ value has got the same M.V. In this case also any point on the hairline setting of the movable lens should indicate the M.V. But since these two $d^2.x/w$ for these two equipments are stated to be different, the hairline setting in the two cases cannot be coincident or parallel to each other. So these two lines must meet at a point. This point of intersection will then necessarily indicate the M.V. reading of either of the equipment.

A method of graduating the M. V. Reader is given below.

Method

A Pitkin Scale which is graduated in inches at the top edge and carries a vernier, is fixed on the posts which carry the long rod. Now the sliding attachment is shifted to the left of the scale-plate to be calibrated till the hairline of the fixed lens coincides with the zero mark on the Pitkin scale. The hairline of the movable cursor is brought in a position parallel to the hairline of the fixed lens. A line is drawn through the hairline of the movable lens so set. This will be the zero line of the scale plate to be calibrated. The sliding attachment is now shifted to the right so that the hairline of the fixed lens becomes coincident with the disjunction line of the Pitkin Scale. A line is again drawn through the hairline of the movable lens. This is the disjunction line of the scale-plate.

A set of values of 'q' is taken. The corresponding values of 'h' is calculated for this set of values of 'q' for screen distance of 120′ (say). *See* table 1. The fixed lens hairline is set against the 1st value of 'h' (it goes without saying that the calculation should be made with the correct value of 'g'). The movable lens is moved near to the extreme right of the arc and a line is drawn through the hairline of movable lens on the scale-plate and on the arc. This is the zero mark on the arc and the line on the scale-plate indicates the velocity line corresponding to the 'h' value. With this setting of the movable lens a set of parallel lines is drawn corresponding to the other values of 'h' of the set. All these lines will indicate corresponding values of 'q' which is the observed velocity 'u' of Siacci's equation.

The movable lens is shifted to a position where its hairline is parallel to the hairline of the fixed lens. Taking the same set of values of 'q' i.e. of 'u', as the values of V i.e. M.V., the values of 'u' are calculated using Siacci's equation, considering the value of $d^2.x/w$ at this setting of the movable lens as 200. (*See* table of calculation 2). For this set of values of 'u', let the corresponding values of 'h' be calculated and let these values be called 'hvs' setting the fixed lens hairline against these values of 'hvs', a set of parallel lines can be drawn on the scale-plate and a line on the arc. The line on the arc will indicate 200th graduation mark, corresponding to a value of $d.^2x/w=200$. The lines on the scale-plate indicate the same values of M.Vs corresponding to the values of 'us' i.e. observed velocities for which initially a set of lines were drawn with the movable lens hairline set at zero. Each of the lines of the first set cuts each of the corresponding lines of the second set. The points of intersection of these lines will indicate either O.Vs or M.Vs depending on the setting of the movable lens at zero or 200th line on the arc. So particular points only on the scale-plate indicate velocities either O.V. or M.V.

For graduating the arc for various other values of $d^2.x/w$, the same principle can be conveniently used to find out values of 'h' corresponding to any of these velocities for various values of $d^2.x/w$, as for example 10, 20, 30, 40 and so on up to 400. *See* table 3.

Setting the hairline of the fixed lens against these 'h' values and shifting the movable lens to a position where the hairline of the movable lens passes through the value of the dot for which these 'h' values have been calculated, the graduations on the arc can be made corresponding to $d^2.x/w$ of 10, 20, 30, 40 and so on. (*See* table 3.) Thus the calibration of the M.V. Reader and the arc indicating $d^2.x/w$ can be carried out. This will give us a correct scale for reading M.V. so long as Siacci's equation and the ballistic table are considered correct. The same procedure can be followed to calibrate M.V. readers for any other screen distances.

Example

Suppose we want to find out the position on scale which will indicate 1000 f.s. o.v. for a screen distance of 120 ft. Calculated value of 'h' for this observed velocity of the projectile is 14·045 inches. Set the hairline of the fixed lens at this distance and draw a line through the hairline of the movable lens on the scale-plate and on the arc by setting it to the extreme right of the arc.

If this 1000 f.s. velocity is considered as m.v. instead of being o.v. and $d^2.x/w$ as 200 then $S_{1000} = S_u + 200$ or $S_u = S_{1000} - 200$

From table 8 of T.B. Ballistics, $S_u = 13058 \cdot 3 - 200$

$$= 12858 \cdot 3$$

From the table again the corresponding velocity for this function is 971·27 f.s. Calculated value of 'h' for this velocity is 14·415 inches. Setting the fixed lens hairline against this distance and bringing the movable lens hairline at a position parallel to the fixed hairline, a line can be drawn along the hairline of the movable lens. This line will indicate the M.V. of 1000 f.s. of a projectile of which the $d^2.x/w$ is 200. This line intersects the line previously drawn indicating 1000 f.s. o.v. So the point of intersection is the point which indicates 1000 f.s. either o.v. or m.v. according to the setting of the movable cursor.

In a similar manner using Siacci's equation and the table 8 of Text Book of Ballistics Gunnery we can find out points of intersection of the two parallel sets of lines for indication of velocities 1010, 1020, 1030 and so on. The calibration of the arc can be carried out by using $d^2.x/w$ values of 10, 20, 30 and so on for 1000 f.s. velocity using the values of 'h' as in the table 3.

In graduating the arc 1000 f.s. velocity has been taken arbitrarily to calculate the 'h' values for different values of $d^2.x/w$. It ought to be verified whether for any other velocities say 1500 f.s. or 2000 f.s. etc., if the graduations were made on the arc in a similar manner for $d^2.x/w$ values of 10, 20, 30 and 40 and so on, the graduations will coincide with the graduations originally made with the arbitrary value of 1000 f.s. It is expected to be coincident. But even if it is not so, mean lines will be possible to be drawn on the arc taking a number of values of velocities within the limits of the velocities to be measured without introducing much error.

Another point may also be mentioned here. The present readers at Balasore make use of the same arc scale for all the three screen distances namely 120′, 180′ and 270′. It requires verification if arc scale graduated for each of the screen distances will improve the accuracy of the reader. If improvement of accuracy can be attained by graduating separate arc scales then each reader may also be provided with 3 arc scales corresponding to each screen distance. If the accuracy is not impaired the same arc can be used for each screen distance as is being done in the present readers. The introduction of the metric system in the country will necessitate the use of another conversion table for conversion of velocity in foot second into metre per second if the reader calibrated in F.P.S. System is to be used. This will introduce further complications in the measurement of muzzle velocity.

But the calibration of M. V. Reader in the metric system will do away with all these complications. In order to do this the first thing that is required to be done, is the preparation of a ballistic table in the metric system. The existing ballistic table has been prepared in U.K. after extensive firing. It is possible to convert the existing table in the F.P.S. system into a table in the metric system. Once the conversion is effected the same principle as discussed above can be applied for the calibration of the Croft-Probert M.V. Reader in the metric system.

Conversion of tables

The conversion of the ballistic table can be carried out in the following manner :—

From Siacci's equation it is easy to understand that $\frac{x}{c}$ i.e. $d.^2x/w$ is a function of velocity. d, x and w being measurable quantities, the value of $d^2.x/w$ can be calculated easily. Let us take the concrete case of 25 Pdr firing. The mean diameter of the 25 Pdr Proof Shot is 3·45 inches and the weight 25 Lbs. If the midscreen distance 'x' from the muzzle is 140 ft (which is usually the distance used for 25 Pdr normal charge) then the value of C i.e. $\frac{w}{d^2} = \frac{25}{11 \cdot 9025}$ and the value of $d^2.x/w$ comes to 66·654. This value is known as the "added money" in Ballisticians language and is equivalent to a quantity of velocity which is obtained from the ballistic table.

In the metric system the units of centimetre, metre and kilogram for the values of 'd', 'x' and w may perhaps be considered reasonable. The adoption of units for these dimensions may also be ascertained from other countries which have adopted the metric system. But whatever be the units that we shall adopt, that will in no way affect the validity of our arguments which we are going to put forth for the conversion of the table in the metric system.

Supposing d, x and w are taken in centimetre, metre and kilogram respectively, these dimensions for 25 Pdr will then reduce to—

$$d = 3 \cdot 45 \times 2 \cdot 5400051 \text{ cm} = 8 \cdot 763 \text{ cm}.$$

$$x = 140 \times \frac{12}{39 \cdot 370000} \text{ metre} = 42 \cdot 672 \text{ metres}.$$

$$w = 25 \times \cdot 45359243 \text{ kg} = 11 \cdot 33975 \text{ kg}.$$

respectively.

Hence, the value of $d^2.x/w$ in the metric system is equal to 288·9649. The ballistic table 8 gives the value of the functions of velocity in foot second. Since 66·654 which is the $d^2.x/w$ value in the F.P.S. system is equivalent to 288·9649 which is $d.^2x/w$ value in the metric system, the equivalents in metric system of any other value of the functions of velocity in the F.P.S. system in the table can be calculated by the method of simple rule of three. Thus it is easy to follow that the ballistic table in the F.P.S. system can easily be converted into a table in the metric system. Once the conversion of the table is ready, the principle as discussed above may be applied for the calibration of the Croft-Probert M.V. Reader for measurement of muzzle velocity directly in the metric system without having the necessity of using any conversion table or any correction table.

Conclusions

The desirability of having a M.V. Reader without having the necessity of using a correction table has been discussed. The desirability of graduating the M. V. Reader in the metric system to avoid use of conversion table has also been discussed. Arguments forwarded in respect of the method of graduation do not appear to have any flaw except that certain verification will be necessary while graduating the arc scale. But before undertaking the task of graduating the reader in the metric system, the units that are to be chosen should be decided upon and all conversion and calculation should be carried out after the decision is taken. Coversion of certain portions of the ballistic table has been made in table 4. It is hoped that the calibration can easily be done locally at Balasore provided certain facilities are granted, and the accuracy of calibration will be such as not to impair the accuracy of the Boulenge Chronograph.

The main advantages of Boulenge Chronograph over the electronic equipments are that—

(a) it does not read false,

(b) it is very simple in operation,

(c) it does not require highly qualified technical personnel for its operation,

(d) the accuracy and sensitivity are also almost equal to electronic equipments, if not exactly equal with proper care and maintenance.

TABLE 1

Values of 'H' against Velocities when $d^2.x/w = O$ for 120' ser

Serial No.	VELOCITY (O.V.)	'h'
1	1000	14·045
2	1020	13·801
3	1040	13·569
4	1060	13·347
5	1080	13·1355
6	1100	12·933
7	1120	12·739
8	1140	12·551
9	1160	12·374
10	1180	12·205
11	1200	12·041
12	1220	11·884
13	1240	11·733
14	1260	11·587
15	1280	11·447
16	1300	11·312
17	1320	11·181
18	1340	11·056
19	1360	10·935
20	1380	10·817
21	1400	10·704
22	1420	10·595
23	1440	10·489
24	1460	10·387
25	1480	10·288
26	1500	10·192
27	1520	10·099

TABLE 2

Values of 'H' calculated for calibrating the arc of M.V. Reader for 120' ser distance

Serial No.	VELOCITY (O.V.)	'HV'	Remarks Corresponding MV
1	971·3	14·415	1000
2	989·87	14·173	1020
3	1008·46	13·940	1040
4	1026·75	13·722	1060
5	1044·7	13·516	1080
6	1062·23	13·323	1100
7	1079·54	13·141	1120
8	1097·04	12·962	1140
9	1114·94	12·812	1160
10	1133·02	12·618	1180
11	1151·35	12·452	1200
12	1169·71	12·292	1220
13	1188·17	12·137	1240
14	1206·67	11·988	1260
15	1225·16	11·844	1280
16	1245·65	11·706	1300
17	1262·14	11·572	1320
18	1230·66	11·442	1340
19	1299·15	11·317	1360
20	1317·66	11·196	1380
21	1336·21	11·079	1400
22	1354·7	10·966	1420
23	1373·29	10·856	1440
24	1391·87	10·750	1460
25	1410·4	10·647	1480
26	1428·97	10·547	1500
27	1447·17	10·452	1520

TABLE 3

Value of 'H' calculated for calibrating the arc of M.V. Reader for 120' ser distance

Serial No.	M.V.	$d^2 . x/w$	'H'
1	1000 f.s.	10	14·0635
2	Do.	20	14·0820
3	Do.	30	14·1005
4	Do.	40	14·1189
5	Do.	50	14·1371
6	Do.	60	14·1562
7	Do.	70	14·1748
8	Do.	80	14·1937
9	Do.	90	14·2119
10	Do.	100	14·230
11	Do.	110	14·2490
12	Do.	120	14·2676
13	Do.	130	14·2863
14	Do.	140	14·3021
15	Do.	150	14·3234
16	Do.	160	14·3420
17	Do.	170	14·3608
18	Do.	180	14·3793
19	Do.	190	14·3980
20	Do.	200	14·415
21	Do.	210	14·4355
22	Do.	220	14·4542
23	Do.	230	14·4728
24	Do.	240	14·4917
25	Do.	250	14·5103

TABLE 4

Conversion of Function of Velccity in FPS System into Function of Velocity in Metric System

Serial No.	Metre	Equivalent in Feet	Function in FPS	Function in CGS
1	300	984·252900	12950·27	56143·29
2	301	987·533743	12973·08	56242·15
3	302	990·814586	12995·71	56340·29
4	303	994·095429	13018·16	56437·60
5	304	997·376272	13040·56	56534·70
6	305	1000·657115	13062·70	56630·675
7	306	1003·937958	13084·68	56725·916
8	307	1007·218801	13106·54	56820·75
9	308	1010·499644	13128·20	56914·65
10	309	1013·780487	13149·67	57007·74
11	310	1017·061330	13170·99	57100·15
1	456	1496·060000	15042·66	65214·40
2	457	1499·340843	15051·52	65253·60
3	458	1502·621686	15060·48	65291·66
4	459	1505·902029	15069·34	65330·06
5	460	1509·182872	15078·18	65368·39
6	461	1512·463715	15086·95	65406·40
7	462	1515·744558	15095·74	65444·53
8	463	1519·025401	15104·57	65482·80
9	464	1522·306244	15113·23	65520·37
10	465	1525·587087	15121·93	65558·07
11	466	1528·867930	15130·64	65595·85