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ON THE MEASUREMENTS OF TIME OF FLIGHT OF BOMBS

by

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Abstract

Calibration of the Western Electric Clock of the Gauge Unit was undertaken for the purpose of determining time of flight measures for bombs accurate to ±0.003 second. Comparison with time of flight measures made by the Chronograph of the Vertical Camera Obscura was made by means of seven determinations of which three were secured simultaneously by both methods. The accuracy of the Chronograph method was tentatively examined.

The comparison of Time of Flight measures of bombs by the Camera Obscura Chronograph and the Western Electric Camera Clock was suggested to the Bomb Squad of the Ballistic Research Laboratory by Col. H. H. Zornig during the summer of 1938. The photographic records secured are by Mr. A. E. Jewell of the Gauge Unit and the electrical installation for provision of the actuating impulse for the Western Electric Clock by Dr. A. H. Hodge of the Measurement and Apparatus Section. The supplementary measures of the Zero Point (Reaction-Lag), and Rate of the Western Electric Clock are by Dr. Hodge and Mr. Jewell. The Chronograph time records are by Mr. S. P. Willan of the Bomb Section.

(1) Calibration of the Western Electric Clock for Absolute Time Determination

The employment of the Western Electric Clock for accurate measurement of time of flight involves knowledge of three quantities which may affect the photographically recorded clock readings, if considerable: (a) The time interval between the instant of release of the bomb and the instant of the release of the signal; (b) The time interval between the instant of the signal and the instant of beginning of the rotation of the clock dials, and (c) The departure of the reading of the clock dials in failing to record the exact interval from the instant of commencement of their rotation.

(a) Measurement of the interval between the instant of the bomb and the instant of the signal. This interval is due only to the operation time of the relay employed in the transmitting radio in the Bomber to cause the release of a radio signal actuated by the release of the bomb load from the shackle. This interval, which will hereafter be called the Plane Relay Reaction Lag and denoted by $E_{P.R.}$, was accurately measured by Dr. Hodge and the measures submitted in a memorandum dated March 18, 1938.

No.	$E_{P.R._i}$	$V_{E_{P.R.}} = (\overline{E}_{P.R.} - E_{P.R._i})$	V_E^2
1	0.0188	.00015	.0$_6$0225
2	0.0186	.00005	0025
3	0.0185	.00015	0225
4	0.0186	.00005	0025
5	0.0191	.00045	2025
6	0.0188	.00015	0225
7	0.0185	.00015	0225
8	0.0185	.00015	0225
9	0.0186	.00005	0025
10	0.0185	.00015	0225

$E \sum E_{P.R.} = 0.1865$ $\sum V_E^2 = .0_6\ 3450$

$\overline{E}_{P.R.} = \frac{\sum E_{P.R.}}{10} = 0.01865$; $r_{\overline{E}_{P/R.}} = \pm 0.6745 \sqrt{\frac{\sum V_E^2}{90}} = \pm 0.0000$

The bar denotes the Arithmetic Mean and $r_{\overline{E}_{P.R.}}$ is the Probable Error of the Mean.

The value $E_{P.R.}$=+0.019 is therefore the additive correction to the photographically recorded time intervals to take account of (1)(a).

(b) Measurement of the interval between the instant of the signal and commencement of rotation of the W.E. Clock Dials. This interval is due only to the reaction-time lag of the W.E. Clock from reception of the signal to the initial motion of the dials, and, as noted by Mr. Jewell and Dr. Hodge in their memorandum dated Nov. 2, 1938, is very small, owing to the fact that "the clock zero is automatically set ahead to compensate for starting time". This interval will hereafter be called the W.E. Clock zero point and denoted as $E_{Z.P.}$ The following sequence of simultaneous readings with the Cathode Ray Clock with an arbitrary interval after closing of the starting switch was obtained by Jewell and Hodge, where the third figure, on the Western Electric Clock, and the fourth figure after the decimal, on the Cathode Ray Clock, are subject to error of estimation.

No.	W.E. Clock Face a	Cathode Ray Clock Face b	$E_{Z.P.}$ b - a
1	0.075	0.0760	.0010
2	0.060	0.0616	.0016
3	0.205	0.2040	-.0010
4	0.031	0.0345	.0035
5	0.024	0.0242	.0002
6	0.066	0.0677	.0017
7	0.060	0.0627	.0027

$\bar{E}_{Z.P.}$=0.0014 seconds; $r\bar{E}_{Z.P.} = \pm 0.00038$, where the bar - and r have the same significance as before. This correction is evidently negligible in as much as +0.001 second is smaller than the probable error of estimation of the photographically recorded times.

(c) The departure of the reading of the Clock Dials from recording the exact interval from the instant of commencement of their rotation. The Western Electric Clock was checked for rate and accidental and systematic error in rate by Dr. A. H. Hodge and F. V. Reno during the month of December, 1937 by comparison of the Clock face readings with N A A signals at intervals of one or two hours. The following three sets of signals were obtained:

Dec. 10, 1937 t

No.	GMT NAA Signal	W.E. Camera Face (Corrected for Signal Error)
1	$4^h\ 57^m\ 00^s.00$	0^h 35 - 17-760
2	58 00.00	0 36 - 17-760
3	5^h 00 00.00	0 38 - 17-760
4	57 00.00	1 35 - 17-952
5	6 56 00.00	2 34 - 18-170
6	57 00.00	2 35 - 18-113

R = Rate per hour = Gain of Clock in seconds over true time interval per hour = $+0^s.190$/hr.

$r_R = \pm 0.007$, where r_R is the probable error of the given rate in seconds per hour.

Dec. 29, 1937

No.	EST. NAA Signal	W.E. Camera Face (Corrected for Signal Error)
1	$11^h\ 59^m\ 00^s.00$	37 - 31-697
2	12 00 00.00	38 - 31-699
3	1 56 00.00	34 - 32-140
4	57 00.00	35 - 32-142
5	58 00.00	36 - 32-147
6	59 00.00	37 - 32-151
7	2 00 00.00	38 - 32-153

R = Rate per hour = $+0^s.227$/hr.

$r_R = \pm 0.0001$

Dec. 30, 1937

No.	EST NAA Signal	WE Camera Face (Corrected for Signal Error)
1	$11^h\ 56^m\ 00^s.00$	52 - 14-244
2	57 00.00	53-- 14-248
3	58 00.00	54 - 14-252
4	59 00.00	55 - 14-256
5	1 57 00.00	53 - 14-737
6	58 00.00	54 - 14-738
7	59 00.00	55 - 14-741
8	2 00 00.00	56 - 14-743
9	3 58 00.00	54 - 15-229

R = Rate per hour = $+0^s.243$/hr.

$r_R = \pm 0.00007$. The indication from hour to hour is that the rate of the clock does not show a percentage variation of ten per cent either of irregular or systematic nature, and the rate can be concluded to be between $0^s.200$/hr. and $0^s.250$/hr. at room temperature. It is probably somewhat dependent, in the hundredths of a second per hour, upon surrounding temperature. During the flight of a bomb from the highest attainable altitudes for bombs with C= 1.0 the gain of the clock on true time during the time of flight of the bomb will not exceed $0^s.003$. In addition, it has the opposing sign when applied as a correction to the instrument ally determined time interval to the sign of the zero-point ($E_{Z.P.}$)

(2) <u>Comparison of the Time Intervals Recorded by the Camera Obscura Chronograph and the Western Electric Clock</u>

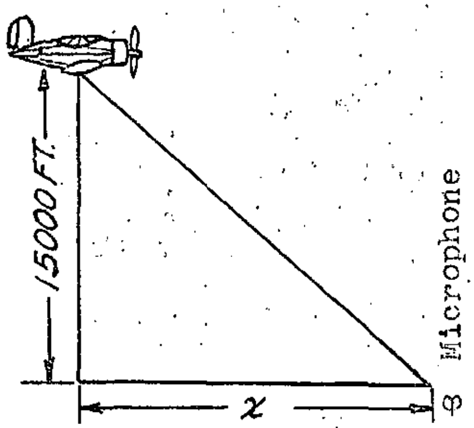
The instrumental corrections examined above include all those affecting the time interval recorded by the Western Electric Clock. The Camera Obscura Chronograph has a somewhat different set of instrumental corrections which will now be examined. These are

(a) $E_{P.R.}$ The interval between instant of release of the bomb and instant of the signal. $E_{P.R.} = 0.018,65 \pm 0,000,04$.

(b) M.T.C. The interval between the arrival of the bomb center of gravity at the surface of Bush River and the arrival of the sound wave at the microphone. This assumes that no sound wave which came through the air in advance of the bomb is recorded by the microphone which assumption, in the case of heavy bombs dropped from a considerable altitude, is quite probably contrary to fact. The arrival of a sound wave through the air previous to the wave in water is known to occur, but whether it possesses energy capable of affecting the microphone is not certain, but can be regarded as very probable inasmuch as shorter than vacuum times with heavy bombs have caused the observers to desensitize the microphone. The assumption which has been, and is, employed in these and other computations, is that the only wave affecting the microphone is the wave produced by the disturbance of the water when the bomb enters it. The actual sound wave through the air might conceivably arrive for a fall of 15,000 feet as much as

$$\Delta t = \left(t - \frac{\sqrt{15{,}000^2 + x^2}}{1120}\right) \text{seconds},$$

where x is the horizontal distance from the release point to the microphone, if launched at a high initial air speed, or in the neighborhood of $\Delta t = 31.7 - 14.7 = 17.0$ seconds in advance of the bomb. The indications are that any wave arriving with energy sufficient to affect the microphone does not arrive two seconds in advance of the bomb and most probably less than one fifth of a second, which is, however, very considerable.



(c) <u>The Microphone Relay Operation Lag $E_{M.R.}$</u>

This was the subject of a series of measures by Dr. Hodge on March 28, 1938 which are here listed (tension tight):

$E_{M.R.}$
+0.0018
+0.0030
+0.0022
+0.0026
+0.0024
+0.0031
+0.0032

The mean value $E_{M.R.} = +0.0026$, $r_{\bar{E}_{M.R.}} = \pm 0.00035$. In respect to the chronograph error of estimation, this is negligible.

(d) <u>The Receiving Radio Relay Operation Time Lag E_{RR}</u>. This was the subject of a series of measures by Dr. Hodge, on Mar. 28, 1938.

	Tension tight	Tension loose
	+0.0039	+0.0014
	+0.0030	+0.0014
	+0.0035	+0.0020
	+0.0036	+0.0015
	+0.0033	+0.0017
$\bar{E}_{R.R.}$ Mean	+0.00346	+0.00160
	$r_{\bar{E}_{R.R.}} = \pm 0.00021$	$r_{\bar{E}_{R.R.}} = \pm 0.00035$

In comparison with the error of estimation of the Chronograph $E_{R.R.}$ is evidently negligible.

(e) <u>The Rate of the Chronograph Control Clock Multiplied by the Time Interval</u> (Gain of the Control Clock during the time interval between signal and reception). $E_{C.C.}$:$E_{C.C.}$ is controlled by periodic comparisons of the Clock Face with Naval Observatory Time Signals by Mr. S. P. Willan at an interval of two hours. A recent comparison by Mr. Willan showed that $E_{C.C.}$ during a thirty second time interval did not exceed $0^s.005$, and is therefore negligible. Under the assumption of a perfectly definite Chronograph kick taking place instantaneously and uniform rotation of the Chronograph drum, the time of flight reduced from the Camera Obscura Chronograph data is given by

$$I = (T_1 - E_{M.T.C.} - E_{M.R.} - E_{R.R.} - E_{C.C.})$$

$$- (T_o - E_{P.R.} - E_{R.R.})$$

$$= (T_1 - T_o) - E_{M.T.C.} - E_{M.R.} - E_{C.C.} + E_{P.R.}$$

where T_1 is the latter, and T_o, the former instant recorded by the Chronograph.

The value of $E_{C.C.}$ is negligible, but $(E_{P.R.} - E_{M.R.})$ amounts to 0.016 second provided both these relay operation times have not changed under conditions in practice and is necessary to take into account by adding +0.02 second to time intervals obtained by the Camera Obscura Chronograph.

The magnitude of MTC was the subject of a previous study, amounts to several hundredths of a second, and is explicitly taken into account in all computations. It will be observed that in contrast the time of flight as taken from the Western Electric Clock is given by

$$I = (T_1-[T_1-T_o]R) \quad -(T_o-E_{P.R.}-E_{Z.P.})$$

$$= T_1-T_o-(T_1-T_o)R+E_{P.R.}+ E_{Z.P.}, \text{ where } T_1 \text{ is the}$$

latter and T_o, the former, instant read from the photographs, and R is the Rate of W.E. Clock in seconds per second. The uncertainty of the values of $I_{W.E.}$ deduced from the Western Electric Clock is in the neighborhood of ± 0.005 second where as those of the Vertical Camera Chronograph is in the neighborhood of ± 0.03 second provided the sound wave through the air does not result in a premature microphone signal. The values of I and the corrections are:

Office Catalog No.	Kind of Bomb Type Weight Model	W.E. Camera Face at Impact Sec.	$E_{Z.P}$	$R(T_1-T_o)$	$E_{P.R.}$	$I_{W.E}$ (I_{II})	Obs. Wt.	Chron. Release Reading T_o	Chron. Signal Reading T_1	M.T.C.	$\lvert E_{P.R.}-E_{M.R.}\rvert$	$I_{C.C}$	V_I $(I_{II}-I_I)$
1938-A-44-2	1100 M33	18.113	0.001	-0.001	0.019	18.132	1.0	22.87	41.09	.027	.02	18.21	-.078
1938-A-26-1	1100 M33	32.132	0.001	-0.002	0.019	32.150	1.0			-	.02		
-2	1100 M33	32-253	0.001	-0.002	0.019	32.271	1.0	16.13	48.26	.039	.02	32.11	.161
-4	1100 M33	32.163	0.001	-0.002	0.019	32.181	1.0	13.08	45.19	.031	.02	32.10	.081
1938-B-1-3	300 T-1	22.732	0.002	-0.002	0.019	22.750	0.3	9.36	35.17 V.I	-	.02	25.83	-3.080*
-4	300 T-1	25.205	0.001	-0.002	0.019	25.223	0.5				.02		
-5	300 T-1	25.876	0.002	-0.002	0.019	25.894	0.5			-	.02		

Office Catalog No.	Date	Time	Kind of Bomb Type Weight Bomb		True Altitude ft.	True Ground Speed Mi/Hr.	True Climb Ft/Min.	I_{II}	I_I	V_I $(I_{II}-I_I)$
1938-A-44-2	8/29/38	11:20	1100	M33	5175	142.8	-34	18.132	18.21	-.078
1938-A-26-1	8/19/38	1:50	1100	M33	15791	135.8	-198	32.150		
-2		1:55	1100	M33	15836	136.5	-195	32.271	32.11	.161
-4		4:10	1100	M33	15816	142.0	-197	32.181	32.10	.081
1938-B-1-3	10/3/38	10:21	300	T-1	10201	148.1	-71	22.750	25.83 V.I	
-4		10:28	300	T-1	10173	141.7	51	25.223		
-5		10:39	300	T-1	10184	141.1	-95	25.894		

V.I. Visual Impact
No microphone record

* No evidence of bomb on film previous to impact

The tabular values indicate that Catalog No. 1938-B-1-3, which was given the low observational weight of 0.3 is in error as deduced from the W. E. Camera, having an interval far below vacuum time of flight. Examination of the photographs indicates only a white image, supposedly the splash, but the bomb is invisible previously. This interval is evidently spurious. No Chronograph intervals were secured on any of the sequence 1938-B-1-3, 4, or 5 nor on 1938-A-26-1 and conclusions for the present will have to be drawn on the three bombs for which both time methods functioned at the same time. The comparison of V_I with altitude indicates strongly that in the high altitude firing of heavy bombs that a sound wave through the air is set up which does actuate the microphone, and that the energy to actuate the microphone appears if the bomb is dropped from 15,000 feet and probably if dropped from a somewhat lower altitude. The indication is that the sound wave through the air for a bomb dropped from 15,000 feet altitude probably actuates the microphone when the bomb is still at an altitude whose value is

$$y = \frac{1120\ V_\omega\ \Delta t}{1120 - V_\omega} \text{ or about } \frac{104{,}160 \Delta t}{19} \text{(ft)}.$$

Assuming $\Delta t = 0\overset{s}{.}1$, y = 100 feet, and assuming $\Delta t = 0\overset{s}{.}2$, y = 200 feet.

The Ballistic Effects which may be sufficiently considerable to make it desirable to remove them before inferring the value of C from time of flight include:

(1) Departure of Density from Standard. A small but not negligible effect not amounting to more than a few hundredths of a second, explicitly taken into account.

(2) Wind. A small, but not negligible effect, which will be taken into account in future, and which amounts occasionally to several hundredths of a second.

(3) Climb. An effect which may be fairly considerable for small departures from horizontal flight, explicitly taken into account. The inexact observation of rate of climb subjects the knowledge of the effect to a nearly fifty per cent uncertainty.

(4) Rotation of the Earth. A very small effect for altitudes below 10,000 feet, considerable only for great altitudes.

(5) Effect of initial diminution of drag due to differing relative altitudes in bomb bay. A computation for typical cases by Mr. H. P. Hitchcock of dates June 29th and June 30th, indicates that for a fall in the Bomb Bay, the total difference in times of flight resulting amounts to a quantity somewhat below 0.01 second with a relative difference between a fall of four and eight feet in no case exceeding 0.005 second. The present Bomb Ballistic Table does carry time of flight to 0.01 second and the measures except in the present case do not warrant considering the effect. It is, however, to be noted that the variation in computed C_T resulting from accidental or systematic errors of 0.02 or 0.03 second on bombs with $c > 2$ is sufficiently considerable to make it desirable to obtain an accuracy of observation of 0.002 or 0.003 second, since the range corresponding to deduced values of C_T shows a considerable variation, as is shown for example by the column ε_R in the table of results below.

The tabulation of resulting values of the Ballistic Effects and the values of time of flight obtained from reduction of the corrected interval to standard conditions is given in the table below, where:

$\Delta_{CL} t_\omega$ = effect of Climb on time of flight;

$\Delta_\rho t_\omega$ = effect of Ballistic Density on time of flight;

$t_{\omega_{WE}}$ = time of flight reduced for Ballistic Effects, employing corrected recorded interval from Western Electric Clock;

$t_{\omega_{cc}}$ = time of flight reduced for Ballistic Effects, employing corrected recorded interval from Camera Obscura Chronograph;

$C_{T_{WE}}$ = C_T inferred from $t_{\omega_{WE}}$;

$C_{T_{CC}}$ = C_T inferred from $t_{\omega_{cc}}$; and

ε_R = Range difference inferred from ε_{C_T}.

Office Catalog No.	Kind of Bomb Type Weight Model lbs.	True altitude ft.	True Ground Speed mi/hr	True Climb ft/min	Corrected Recorded Interval on: Western Electric Clock $I_{W.E.}$	Vertical Camera Chronograph $I_{C.C.}$	Effects Climb $\Delta_{CL} t_\omega$	Effects Ball. Dens. $\Delta_\rho t_\omega$	t_ω W.E.	t_ω C.C.	C_T W.E.	C_T C.C.	ε_{C_T}	Range Diff. from ε_{C_T} ε_R ft.
1938-A-44-2	1100 M33	5175	142.8	-34	18.132	18.21	-.018	.00	18.150	18.23	3.83	2.66	1.17	27
1938-A-26-1	1100 M33	15791	135.8	-198	32.150		-.103	-.01	32.263		3.18			
-2	1100 M33	15836	136.5	-195	32.271	32.11	-.101	-.01	32.382	32.22	2.96	3.50	-0.54	-32
-4	1100 M33	15816	142.0	-197	32.181	32.10	-.102	-.01	32.293	32.21	3.18	3.50	-0.32	-19
1938-B-1-3	300 T-1	10201	148.1	-71	22.750		-.037	-.02	22.767					
-4	300 T-1	10173	141.7	51	25.223		.026	.02	25.177		61			
-5	300 T-1	10184	141.1	95	25.894		.049	.02	25.825		2.62			

The improvement in values of DS and trail angle for employment in target practice due to an improvement in accuracy of inferring C by reason obtaining an observational error as small as 0.005 second instead of 0.05 seconds will be sufficiently considerable (in some cases 5 mils and more), to make it desirable to examine the possibility of obtaining additional exactitude in the routine measures of time of flight.

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AIR TECHNICAL INDEX

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