AN IMPROVED MODEL BALL DROP SEXTANT

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Technical Development Report No 90

CIVIL AERONAUTICS ADMINISTRATION
TECHNICAL DEVELOPMENT
INDIANAPOLIS, INDIANA

March 1949

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Manuscript received, March 1948

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INTRODUCTION

The ball drop sextant is an artificial horizon sextant for use in celestial navigation Whereas, in the conventional artificial horizon sextant a bubble is used to establish the horizontal plane from which celestial altitudes are measured, the ball drop sextant uses the line of fall of a small steel ball to establish a vertical line, from which the coaltitude and hence the altitude of celestial objects may be measured The instrument is capable of recording any tilt present at the instant of observation and the correction for such tilt may be obtained from a tilt table, furnished with the sextant, and may be applied to the observed altitude.

The ball drop sextant was first called to the attention of the Office of Technical Development by the United States Naval Observatory. The Observatory had constructed a preliminary model based on an idea originated by Mr. Fred Hagner, and had incorporated certain ideas which, it was believed, would considerably improve this model. A detailed description of this preliminary model may be found in Report on Hagner Averaging Sextant, published by the United States Naval Observatory June 15, 1942. An inspection of the Naval Observatory instrument revealed certain apparent advantages of the ball drop sextant over conventional types, which made the instrument appear worthy of further development These were as follows

1 The simplicity of the operating principle permitted sturdier construction.

2 Direct measurement between the line of sight and the vertical permitted one degree of altitude to be represented by one degree on the arc, thus eliminating reduction and tending toward greater accuracy

3 Aligning a stable cross hair intersection with a star requires less concentration on the part of an observer than aligning an unstable bubble

4 Provision was made to correct for tilt

5. The direct sighting method obviated some danger of confusing the identity of stars.

It was therefore decided to redesign the ball recording sextant and build a new model for further testing and comparison with a high grade commercially manufactured bubble sextant. The improved ball drop sextant was constructed by the Naval Observatory and was delivered to the CAA during 1946.

IMPROVEMENTS IN NEW MODEL BALL DROP SEXTANT

The improvements incorporated in the new model ball drop sextant included the following

1. The weight was decreased.

2 A continuous roll of recording material was provided, making it possible to take several hundred observations before changing the roll, whereas in the original model it was necessary to substitute a new recording disk or erase marks from the old one after each observation

3 A telescopic sight was provided on the new instrument

4. Two telescopes were provided, one direct sighting (Fig 1) and one elbow type (Fig 2), for the purpose of bending the light rays and relieving the strain of direct sighting on celestial bodies at high altitudes These telescopes can be interchanged at the option of the observer

Both the original and new model sextants allowed a varied number of balls to be used for an observation. Eight balls were provided with the new instrument and this number was used in all observations, a mean of the pattern formed by the eight balls being used as the reading A typical observational record showing the tilt scale and cross hair "meaning" an eight-ball pattern is shown in Fig. 3. Operation of the ball drop sextant by an observer is illustrated in Figs 4 and 5.

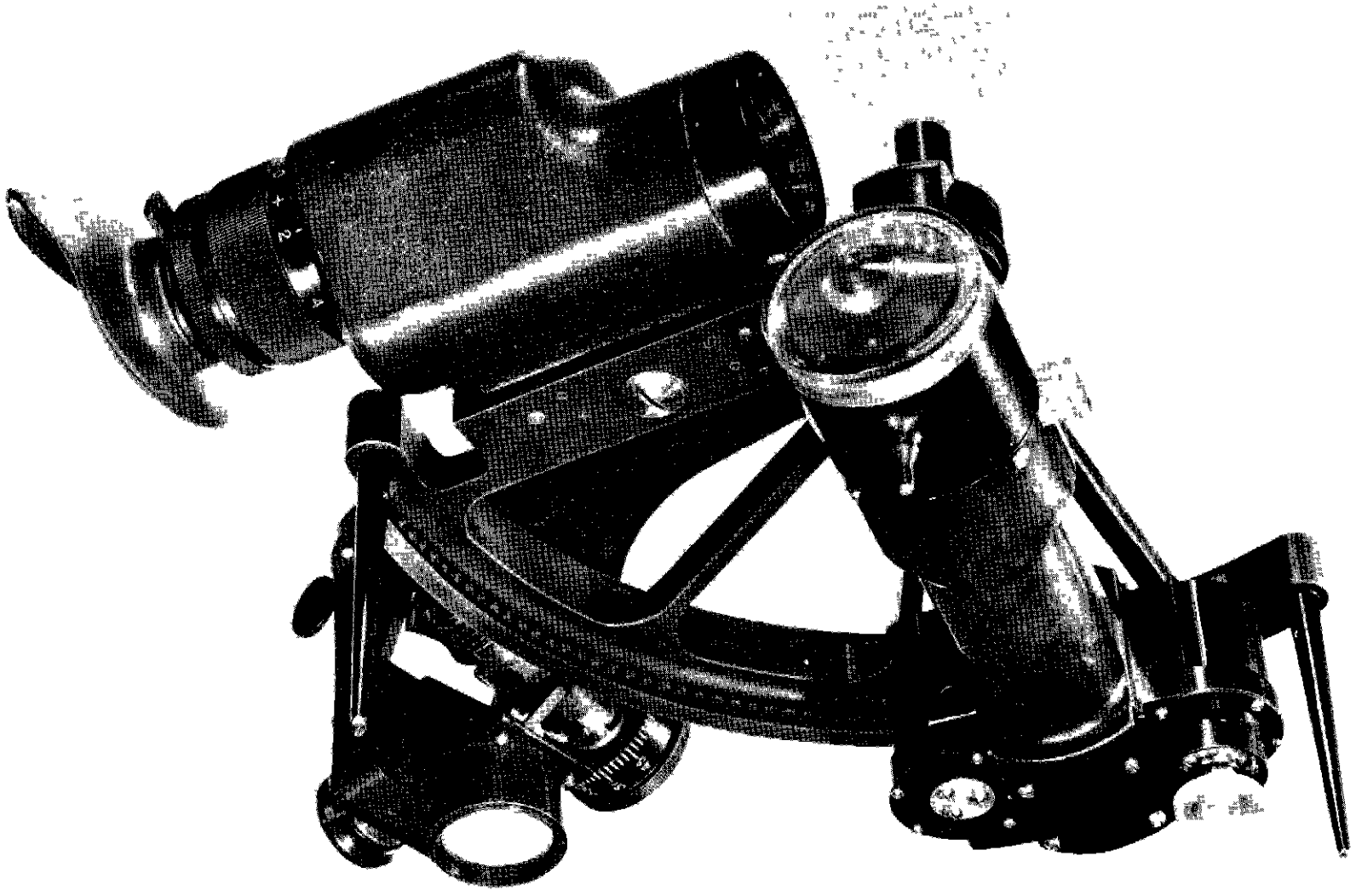

Fig 1 Ball Drop Sextant, Direct Sighting Telescope

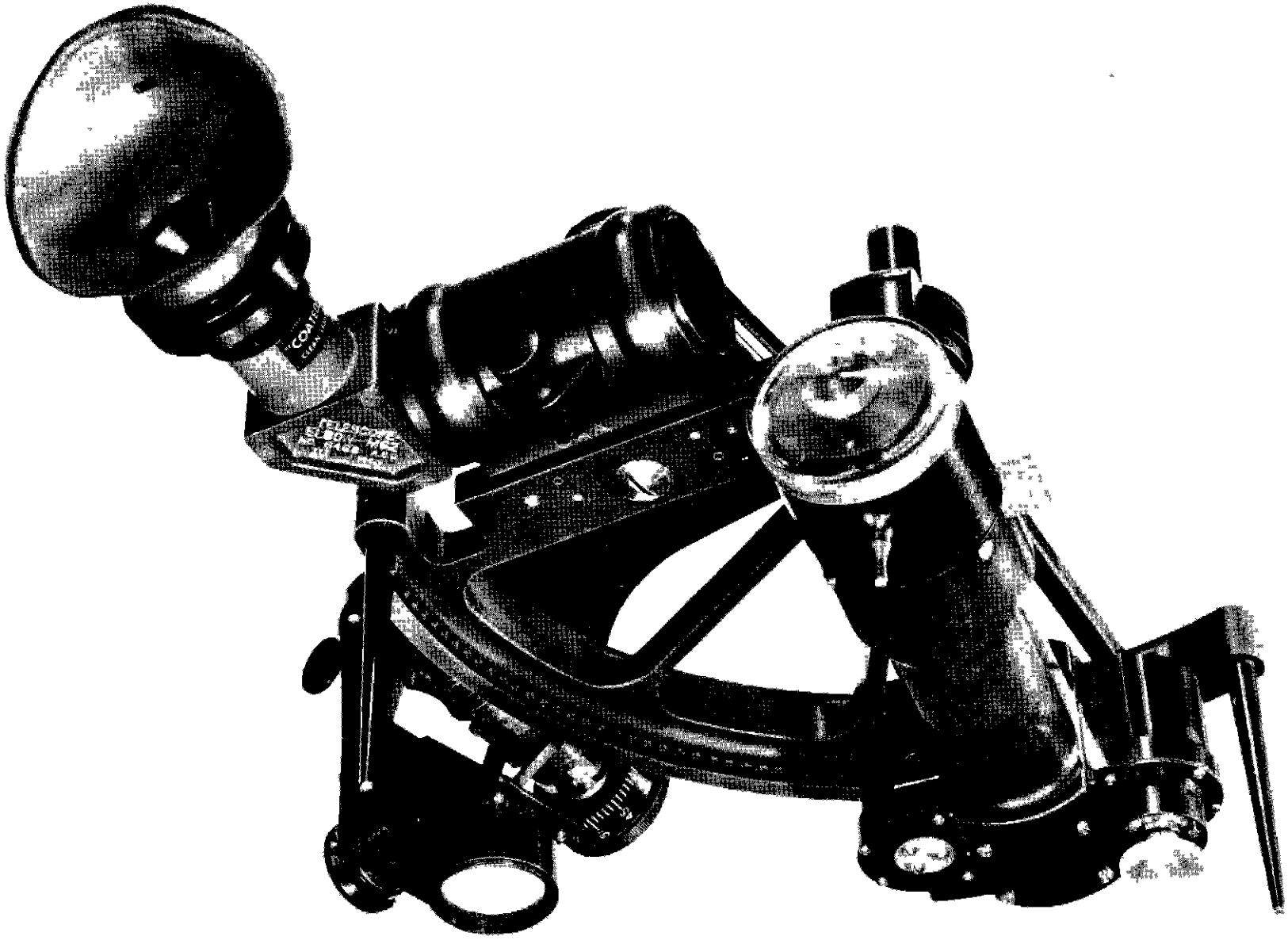

Fig. 2 Ball Drop Sextant, Elbow Telescope

COMPARISON BUBBLE SEXTANT

The bubble sextant chosen for the comparison tests was a Pioneer instrument, Type 3014-1-A, manufactured by the Bendix Aviation Corporation. This sextant is equipped with an automatic averaging device, which, over an observing period of two minutes, will automatically record the average of 60 observations spaced at two-second intervals, the method being to maintain as nearly as possible, coincidence between the bubble and the celestial body during the entire two-minute period. This instrument also may be used to take a single instantaneous observation. A view of this sextant being operated by an observer is shown in Fig. 5.

PRELIMINARY GROUND OBSERVATIONS

Before using either type of sextant in an airplane, a long series of ground observations was taken with each instrument, some at night but a greater number in the daytime. The method used was to make a series of observations, noting the time of each, and then to compute the correct altitude for the body observed at the known position and time of observation. The difference between the observed and computed altitudes for each observation indicated the error. After a series of 231 ground observations with the ball drop sextant (using the direct sighting telescope) a constant error of plus 13 minutes was found, while a constant minus error of 5 minutes was found in the same instrument after 193 observations with the elbow type telescope. These were definitely established as instrument errors and attributed to incorrect collimation in doweling the telescopes to the instrument frame. Collimation tests later showed an error of plus 13 minutes in the direct sighting telescope and minus 6 minutes in the elbow telescope. Since these errors were found to be constant and thus independent of either the angle of altitude or any personal equation of the observer, no attempt was made to correct the instrument, but the proper correction factor was applied to each observed angle. Ground observation errors in the bubble sextant, due to instrument or constant personal errors, were so small that no attempt was made to correct for them. The results of ground observations with both bubble and ball drop sextants are compiled in Table I.

These results were obtained from a combination of the observations of two observers. All necessary corrections in each case were applied to the observed altitude before computing the error.

COMPARISON FLIGHT TESTS OF SEXTANTS

Comparison flight tests of the sextants were made at the Experimental Station, Indianapolis, Indiana during the period from July 7 - 16, 1947. Observations were made both during the day and night, although by far the greater number were made on the sun during the day. The method adopted was to take a series of observations with one sextant during the first half of the flight and with the other sextant during the latter half of the flight, in order that a comparison might be made under similar conditions. This system was continued during the greater part of the flight tests, although, on several night flights near the end of the tests observations were made with the ball drop sextant exclusively. Bubble sextant observations were made almost entirely with the averaging device in operation, although a few single shots were taken. The airplane used was a Douglas C-47, equipped with an astrodome, flying at an air speed of approximately 140 mph. It was necessary to make observations either standing on the deck of the plane or standing on a box when the celestial object could not be sighted without an increase in elevation. During the tests the air conditions varied from smooth to medium-rough. Some trouble was encountered by clouds intermittently obscuring the sun during the continuous two-minute observing period using the bubble sextant, however, these observations were included along with the others, and the results seemed to indicate that accuracy was not materially impaired by the intermittent clouds.

The method used to compute the error of observation closely followed that used in the ground observations. Shots were taken when the airplane was over some definite identifiable point whose latitude and longitude could be determined. Knowing the position and time of observation, the correct altitude of the sun or star could be computed. The difference between the computed and observed altitudes gave the observational error. All necessary corrections were applied to the

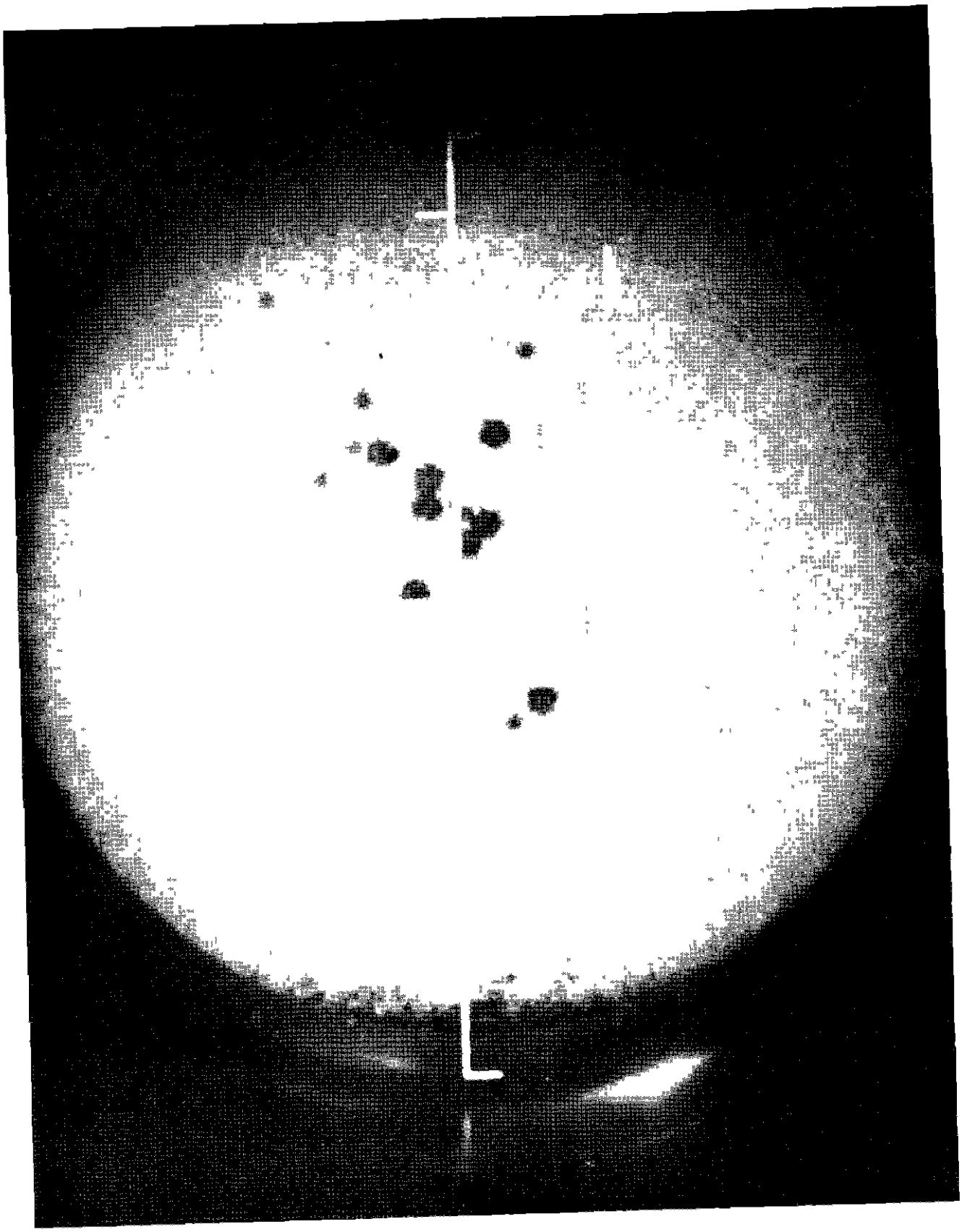

Fig 3 Observational Record, Showing Tilt Scale and Cross Hair Meaning Shots
Illustration Enlarged Five Diameters

Fig 4 Ball Drop Sextant in Operation, Showing Ball Drop Unit

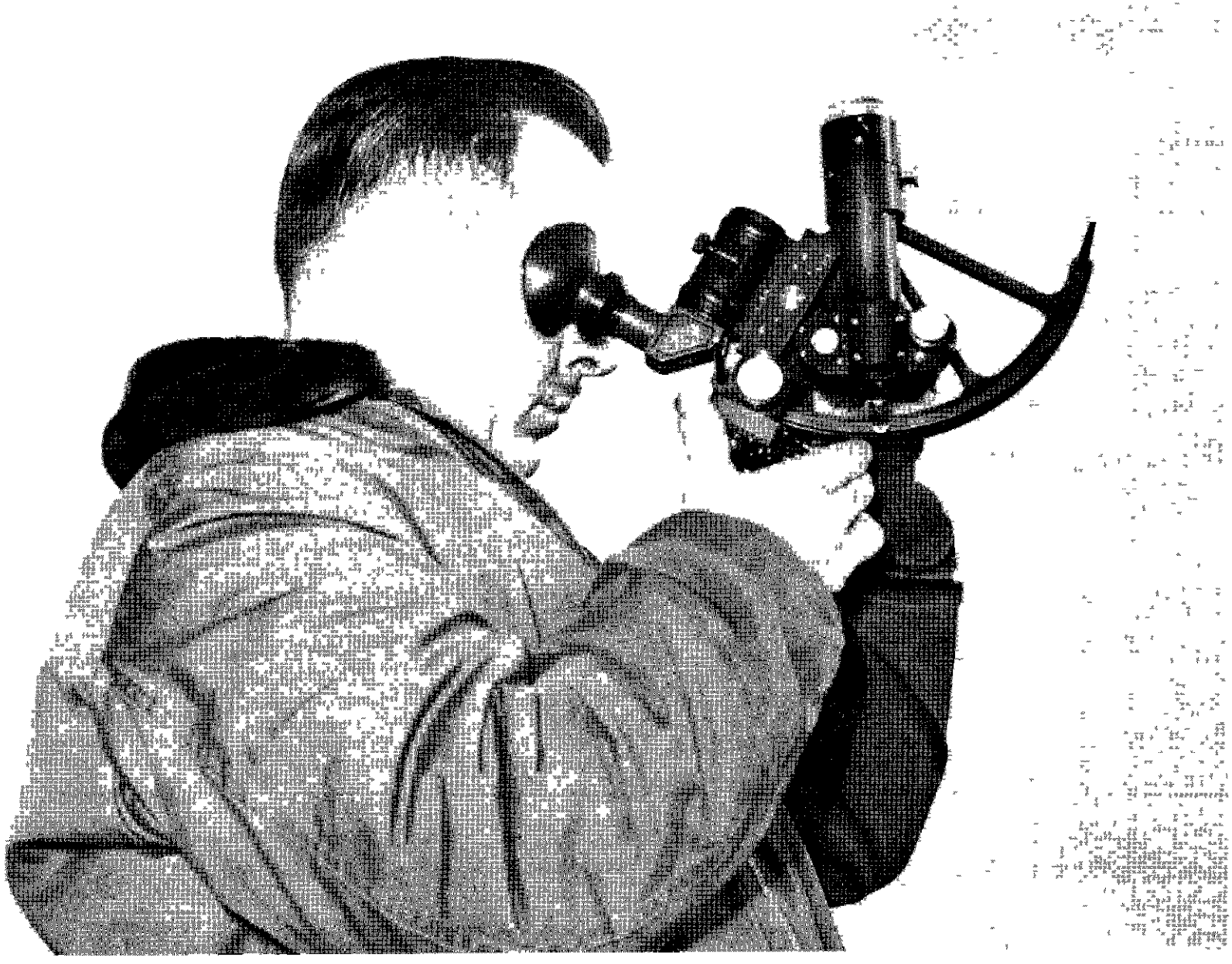

Fig 5 Ball Drop Sextant Operated by Observer

observed altitude before comparing them with the computed altitudes. Neither a Coriolis correction nor correction for refraction of the astrodome were applied, since the former was considered negligible and the latter was not known.

Two men alternated in observing While one man observed, the other clocked the time of observation, recorded the results, and noted other pertinent data, while the co-pilot signaled the instant of passage over predetermined observing points. Both observers had had long experience in making celestial and other observations with sextants and other instruments, but neither had had any previous experience with celestial observations from an airplane.

Tabulated herein (Tables II thru X) are records of the observations, listed in chronological order.

COMPARISON OF BALL DROP SEXTANT AND BUBBLE SEXTANT WITH AVERAGING DEVICE

The comparative accuracies of the new ball drop sextant and the Pioneer bubble sextant (averaging device used) indicated by the results of the Indianapolis flight tests are given in Table XI. Fig 6 shows curves for each sextant based on the normal error function. The experimental results are indicated by means of circles. Inspection of the curves shows that the error law fits the data quite well in the case of the ball drop sextant, with which 98 observations were made. As would be expected, however, the fit is not as good in the case of the bubble sextant, since the data are based on only 42 observations.

In any event, based on the observed data, the probable error of a single observa-

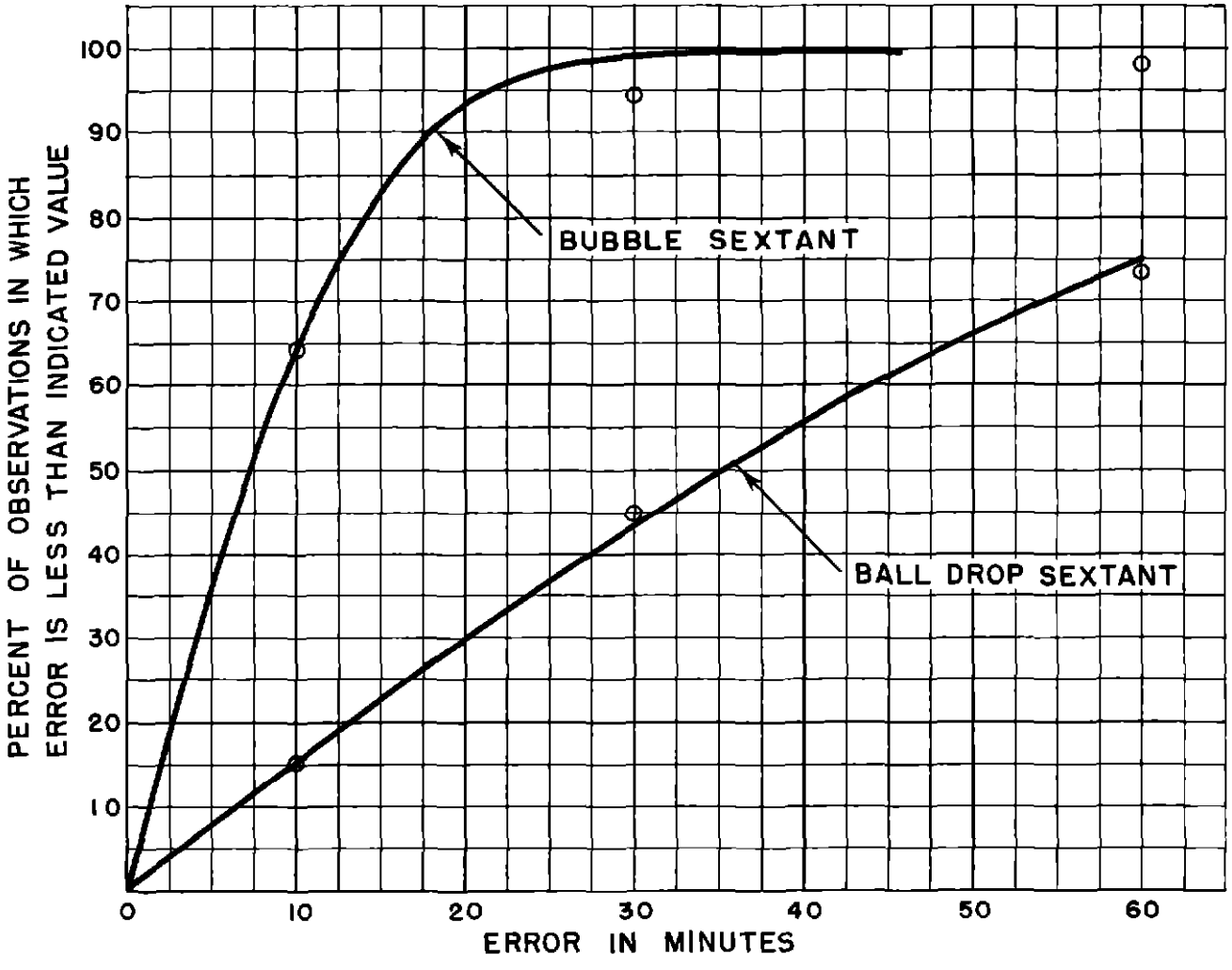

Fig 6 Comparative Accuracies of the Ball Drop and Bubble Sextants

tion would be 35 5 minutes for the ball drop sextant and 7.2 minutes for the bubble sextant. These two figures may be considered a fairly concise index of the relative accuracies of the two instruments.

CONCLUSIONS

Such errors as occured in the ball drop sextant are, of course, entirely prohibitive and could not be compensated for by any other advantages, such as speed of observation, rugged construction of the instrument, etc. Actually, while it takes two minutes to make an observation with the bubble sextant and about 10 to 15 seconds with the ball drop sextant the process of averaging the eight shots and the reading of the tilt take another 20 or 30 seconds, so that the time advantage is not so large as might appear. The only possible conclusion to be reached from the flight tests is that the ball drop sextant fails by a great deal of attaining the accuracy necessary for celestial navigation in the air Since two observers were used, and since each attained far greater accuracy with the bubble sextant than with the ball drop sextant, the lack of accuracy must be attributed to the instrument itself rather than to the observers. Improvements in this instrument might be made to increase the accuracy, but the observations obtained at Indianapolis were so totally unreliable, without any indication of such unreliability being due to some specific flaw in the instrument, that the logical conclusion seems to be that the basic principle of construction is not adaptable to observations in an airplane

TABLE I

GROUND OBSERVATIONS WITH BUBBLE AND BALL DROP SEXTANTS

	Bubble Sextant	Ball Drop Sextant Direct Sight Telescope	Ball Drop Sextant Elbow Telescope
No of Observations	468	231	193
Average Error	3 7 min	4 1 min	3 5 min
Total Average Error	3 7 min	3 8 min	

TABLE II

FIRST FLIGHT

Date July 7, 1947
Body Sun
Observer A M. Weber
Instrument. Ball Drop Sextant
Telescope Direct sighting
Latitude 39° 43' N
Longitude 86° 21' W. on all observations
Air Medium rough

Time GCT	Observed Altitude	Tilt	Tilt Corr	Inst Corr	Corr Obs Alt	Comp Alt	Error
H M S	Deg. Min	Deg	Min (-)	Min (-)	Deg Min	Deg Min	Min
19 27 28	57 21	1	1	13	57 07	63 14	-367
30 40	65 34	1	1	13	65 20	62 42	+158
34 12	62 49	0	0	13	62 36	62 07	+ 29
36 56	60 58	2	4	13	60 41	61 39	- 58
41 17	58 15	0	0	13	58 02	60 54	-172
43 35	59 54	2	4	13	59 37	60 32	- 55
46 32	57 35	1	1	13	57 21	60 00	-159
49 57	59 47	2	4	13	59 30	59 25	+ 05

Body Sun
Observer A M Weber
Instrument Bubble Sextant, averaging device used.
Latitude 39° 43' N
Longitude 86° 21' W. on all observations
Air Medium rough

Time GCT	Observed Altitude	Computed Altitude	Error
H M S	Deg Min.	Deg Min	Min
20 02 50	56 57	57 07	-10
17 35	54 13	54 28	-15
22 30	53 35	53 34	+01
29 15	52 24	52 19	+05
36 35	50 48	50 56	-08
43 02	49 44	49 44	00

TABLE III

SECOND FLIGHT

Date	July 8, 1947	Telescope	Direct sighting
Body	Sun	Air	Moderately smooth
Observer	G B. Walker		
Instrument	Ball Drop Sextant		

Time GCT	N Lat.	W Long	Obs. Alt	Tilt	Tilt Corr.	Inst. Corr.	Corr Obs Alt	Comp. Alt.	Error
H M S	Deg Min	Deg. Min	Deg Min.	Deg.	Min. (-)	Min (-)	Deg. Min	Deg Min	Min.
15 00 00	39 49	86 19	51 25	1 1/2	2	13	51 10	50 14	+ 56
02 00	39 51	86 23	52 20	1	1	13	52 06	50 32	+ 94
05 00	39 53	86 32	51 57	0	0	13	51 44	50 58	+ 46
07 00	39 56	86 37	53 35	0	0	13	53 22	51 17	+125
09 15	39 58	86 43	50 27	1	1	13	50 13	51 46	- 93
11 40	40 00	86 48	52 27	1	1	13	52 13	51 59	+ 14
13 35	40 03	86 54	50 27	1	1	13	50 13	52 34	-141

Body	Sun
Instrument	Bubble Sextant, averaging device used
Air	Moderately smooth

Time GCT	N Lat	W Long	Obs Alt	Comp Alt	Error	Observer
H M S	Deg Min	Deg Min	Deg Min	Deg Min	Min	
16 03 00	39 53	86 32	61 17	61 20	-03	Weber
06 35	39 51	86 23	61 50	62 03	-13	
13 00	39 49	86 19	62 52	63 09	-17	
16 10	39 52	86 28	63 27	63 32	-05	
19 45	39 56	86 37	63 53	63 58	-05	
22 20	39 58	86 43	64 07	64 17	-10	
25 50	40 03	86 54	64 38	64 40	-02	
30 50	40 03	86 54	65 14	65 25	-11	Walker
35 20	39 58	86 43	67 27	66 14	+73	
37 55	39 56	86 37	66 43	66 42	+01	
41 30	39 52	86 28	67 03	67 19	-16	
44 30	39 49	86 19	67 29	67 50	-21	

TABLE IV

THIRD FLIGHT

Date July 11, 1947 — Telescope Elbow type
Body Sun — Air Moderately rough
Observer A. M. Weber
Instrument Ball Drop Sextant

Time GCT	N Lat	W Long	Obs Alt	Tilt	Tilt Corr	Inst. Corr	Corr Obs. Alt.	Comp Alt.	Error
H M S	Deg. Min.	Deg Min	Deg. Min	Deg	Min (-)	Min (+)	Deg Min.	Deg. Min.	Min
15 02 12	39 49	86 19	50 33	1	1	5	50 37	50 18	+ 19
05 19	39 52	86 28	50 26	1	1	5	50 30	50 47	- 17
09 18	39 56	86 37	52 06	0	0	5	52 11	51 24	+ 47
11 31	39 58	86 43	52 33	0	0	5	52 38	51 42	+ 56
13 37	40 00	86 48	51 30	1	1	5	51 34	52 02	- 28
15 55	40 03	86 54	53 15	2	3	5	53 17	52 22	+ 55
21 11	40 03	86 54	52 52	1	1	5	52 56	53 20	- 24
24 05	40 00	86 48	56 58	1	1	5	57 02	53 35	+207
27 20	39 56	86 37	56 52	2	3	5	56 54	54 19	+155
29 15	39 53	86 32	54 53	1	1	5	54 57	54 41	+ 16
32 42	39 51	86 23	55 41	0	0	5	55 46	55 51	- 05
38 10	39 49	86 19	57 30	1	1	5	57 34	56 53	+ 41

Body Sun — Air Moderately smooth
Observer A. M Weber
Instrument Bubble Sextant

Time GCT	N. Lat	W Long.	Obs Alt	Comp Alt.	Error	Remarks
H M S	Deg. Min	Deg. Min.	Deg. Min	Deg Min	Min.	
15 49 45	39 59	86 45	58 28	58 30	-02	Averaging device
53 15	40 03	86 54	58 45	59 02	-17	
16 00 15	40 03	86 54	60 10	60 14	-04	
02 52	40 00	86 48	60 52	60 45	+07	
06 00	39 56	86 37	61 50	61 25	+25	Single shots
07 03	39 54	86 34	61 34	61 38	-04	
07 47	39 53	86 32	62 02	61 48	+14	
08 32	39 52	86 30	61 52	61 56	-04	
09 24	39 52	86 28	61 56	62 06	-10	
11 01	39 51	86 23	62 26	62 27	-01	
11 54	39 50	86 21	63 11	62 36	+35	
12 45	39 49	86 19	63 22	62 47	+35	
16 43	39 49	86 19	63 19	63 24	-05	Averaging device
20 05	39 52	86 28	63 37	63 49	-12	
24 00	39 56	86 37	64 10	64 16	-06	
28 20	40 00	86 48	64 46	64 48	-02	
30 50	40 03	86 54	64 57	65 04	-07	
36 55	40 03	86 54	65 59	65 57	+02	
38 28	40 00	86 48	66 19	66 15	+04	
43 00	39 56	86 37	67 02	67 01	+01	
46 25	39 52	86 28	67 30	67 36	-06	

TABLE V

FOURTH FLIGHT

Date July 11, 1947 — Instrument Ball Drop Sextant
Body Sun — Telescope Elbow type
Observer G B Walker

Time GCT	N Lat.	W Long	Obs Alt.	Tilt	Tilt Corr	Inst Corr	Corr. Obs Alt	Comp. Alt	Error
H M S	Deg. Min.	Deg Min	Deg Min	Deg	Min. (-)	Min (+)	Deg Min.	Deg Min	Min.
18 35 00	39 49	86 19	70 23	1 1/2	3	5	70 25	69 58	- 27
38 30	39 52	86 28	70 45	0	0	5	70 50	69 38	- 72
40 45	39 53	86 32	70 30	1	1	5	70 34	69 24	+ 70
42 55	39 56	86 37	70 31	1	1	5	70 35	69 09	+ 86
45 20	39 58	86 43	68 51	2	5	5	68 51	68 55	- 04
47 40	40 00	86 48	67 44	1/2	0	5	67 49	68 39	- 50
51 10	40 03	86 54	68 26	1	1	5	68 30	68 15	- 15
56 00	40 03	86 54	68 01	2	5	5	68 01	67 42	+ 19
58 50	40 00	86 48	67 41	1 1/2	3	5	67 43	67 16	+ 27
19 00 25	39 58	86 43	68 14	1/2	1	5	68 18	67 01	+ 77
02 05	39 56	86 37	69 49	1/2	0	5	69 54	66 47	+187
04 15	39 53	86 32	66 55	1	1	5	66 59	66 29	+ 30
06 25	39 52	86 28	67 20	2 1/2	8	5	67 17	66 08	+ 69
07 40	39 51	86 23	66 21	2	5	5	66 21	65 56	+ 25
09 15	39 49	86 19	65 57	0	0	5	66 02	65 41	+ 21

Body Sun
Observer G. B Walker — Instrument Bubble Sextant

Time GCT	N Lat.	W Long.	Obs Alt	Comp Alt	Error	Remarks
H M S	Deg Min	Deg. Min	Deg. Min	Deg Min	Min	
19 17 40	39 51	86 23	64 05	64 27	-22	Averaging device
21 00	39 53	86 32	63 32	64 01	-29	
27 35	40 00	86 48	63 25	63 05	+20	
30 15	40 03	86 54	63 19	62 41	+38	
37 35	40 00	86 48	62 38	61 28	+70	Single shots
39 55	39 58	86 43	61 57	61 03	+54	
40 25	39 58	86 43	61 51	60 58	+53	
42 25	39 56	86 37	61 48	60 35	+73	
46 20	39 52	86 28	60 07	59 51	+16	
47 00	39 51	86 23	60 01	59 41	+20	

TABLE VI

FIFTH FLIGHT

Date July 14, 1947 — Instrument Ball Drop Sextant
Body Sun — Telescope Elbow type
Observer A. M Weber — Air Moderately smooth

Time GCT	N Lat.	W Long	Obs Alt	Tilt	Tilt Corr.	Inst Corr.	Corr Obs Alt.	Comp Alt	Error
H M S	Deg Min.	Deg Min	Deg Min	Deg	Min. (-)	Min (+)	Deg. Min	Deg Min	Min
14 38 45	39 49	86 19	45 40	1	0	5	45 44	45 39	+ 5
40 47	39 51	86 23	46 10	1	0	5	46 14	45 56	+18
42 40	39 52	86 28	45 28	1	0	5	45 32	46 14	-42
46 52	39 56	86 37	47 35	0	0	5	47 40	46 53	+47
49 00	39 58	86 43	47 29	0	0	5	47 34	47 12	+22
51 27	40 00	86 48	47 48	1	1	5	47 52	47 37	+15
54 10	40 03	86 54	47 32	1	1	5	47 36	48 00	-24
15 00 17	40 03	86 54	49 08	2	2	5	49 11	49 10	+ 1
02 20	40 00	86 48	50 31	0	0	5	50 36	49 37	+59
06 07	39 56	86 37	50 36	1	1	5	50 40	50 29	+11
09 42	39 52	86 28	50 47	0	0	5	50 52	51 16	-24
12 50	39 49	86 19	52 08	1	1	5	52 12	51 59	+13
18 00	39 51	86 23	52 53	2	3	5	52 55	52 52	+ 3
21 35	39 53	86 32	52 23	0	0	5	52 28	53 23	-55
23 55	39 56	86 37	53 40	2	3	5	53 42	53 44	- 2
27 17	39 58	86 43	53 40	1	1	5	53 44	54 16	-32
28 12	40 00	86 48	54 16	1	1	5	54 20	54 21	- 1
30 45	40 03	86 54	54 44	1	1	5	54 48	54 43	+ 5
36 07	40 03	86 54	56 42	0	0	5	56 47	55 41	+66
38 30	40 00	86 48	55 26	1	1	5	55 30	56 12	-42
40 32	39 58	86 43	55 54	2	3	5	55 56	56 38	-42
42 16	39 56	86 37	56 09	1	1	5	56 13	57 01	-48
43 58	39 53	86 32	57 17	1	1	5	57 21	57 24	- 3
45 47	39 52	86 28	58 46	1	1	5	58 50	57 46	+64
47 22	39 51	86 23	58 46	3	8	5	58 43	58 07	+36
48 51	39 49	86 19	58 15	1	1	5	58 19	58 25	- 6

Body Sun — Instrument Bubble Sextant with averaging device
Observer A M Weber

Time GCT	N. Lat	W Long.	Obs. Alt	Comp Alt.	Error
H M S	Deg Min.	Deg. Min	Deg Min	Deg Min	Min
16 07 05	39 56	86 37	61 01	61 14	-13
11 42	40 00	86 48	61 58	61 58	0
14 25	40 03	86 54	62 10	62 10	0
21 05	40 03	86 54	63 25	63 14	+11
24 55	39 58	86 43	64 07	63 58	+ 9
27 25	39 53	86 32	64 23	64 30	- 7
30 25	39 52	86 28	64 59	65 00	- 1

TABLE VII

SIXTH FLIGHT

Date July 15, 1947 GCT
Body Star Arcturus

Instrument Ball Drop Sextant
Telescope Direct sighting
Air Moderately smooth

Time GCT	N Lat	W Long	Obs Alt	Tilt	Tilt Corr	Inst Corr	Corr Obs Alt	Comp Alt	Error	Observer
H M S	Deg Min	Deg Min	Deg Min	Deg	Min (-)	Min (-)	Deg Min	Deg Min	Min	
2 27 09	39 33	86 22	57 25	3	7	13	57 05	57 51	-46	Weber
34 15	39 24	86 33	56 05	1	1	13	55 51	56 51	-60	
36 12	39 21	86 40	56 16	1	1	13	56 02	56 37	-35	
39 40	39 17	86 46	56 09	1	1	13	55 55	56 07	-12	
47 35	39 07	86 59	54 09	3	7	13	53 49	54 58	-69	
51 58	39 07	86 59	54 20	1	1	13	54 06	54 11	-05	
57 45	39 17	86 46	52 16	3	6	13	51 57	52 55	-58	Walker
3 00 55	39 21	86 40	52 21	1	1	13	52 07	52 16	-09	
04 40	39 26	86 25	52 43	1	1	13	52 29	51 22	+67	
07 45	39 33	86 22	50 43	2 1/2	4	13	50 26	50 43	-17	

TABLE VIII

SEVENTH FLIGHT

Date July 16, 1947 GCT
Body Star Arcturus

Instrument Ball Drop Sextant
Telescope Direct sighting
Air Very smooth

Time GCT	N Lat	W Long	Obs Alt	Tilt	Tilt Corr	Inst Corr	Corr Obs Alt	Comp Alt	Error	Observer
H M S	Deg Min	Deg Min	Deg Min	Deg	Min (-)	Min (-)	Deg Min	Deg Min	Min	
2 27 03	39 49	86 19	56 46	2	3	13	56 30	57 01	-31	Weber
30 44	39 57	86 16	56 45	1	1	13	56 31	56 18	+13	
36 33	40 02	86 01	53 55	1	1	13	53 41	55 05	-84	
40 10	40 04	85 51	53 00	0	0	13	52 47	54 21	-94	
43 30	40 06	85 41	52 17	1	1	13	52 03	53 40	-97	
48 04	40 10	85 30	52 34	0	0	13	52 21	52 44	-23	
50 20	40 11	85 23	52 13	1	1	13	51 59	52 15	-16	
52 17	40 12	85 16	52 10	0	0	13	51 57	51 47	+10	
55 50	40 11	85 08	50 54	1	1	13	50 40	51 06	-26	
3 05 25	40 21	85 09	48 45	2	2	13	48 30	50 00	-90	Walker
11 10	40 27	85 22	48 47	1 1/2	1	13	48 33	48 23	+10	
14 00	40 28	85 30	47 28	1	1	13	47 14	47 58	-44	
17 10	40 33	85 40	46 44	1	1	13	46 30	47 29	-59	
21 22	40 31	85 49	46 47	1	1	13	46 33	46 50	-17	
24 20	40 29	85 58	46 15	0	0	13	46 02	46 24	-22	
28 00	40 29	86 08	45 13	1	0	13	44 59	45 51	-52	
36 57	40 17	86 31	43 46	4	8	13	43 25	44 30	-65	Weber
40 41	40 08	86 37	42 21	1	0	13	42 08	43 54	-106	
46 07	40 03	86 28	42 26	4	8	13	42 05	42 48	-43	
50 52	39 57	86 16	41 34	5	12	13	41 09	41 46	-37	

TABLE IX

SUMMARY OF FLIGHT TEST OBSERVATIONS

BALL DROP SEXTANT

Weber

	No. Obs.	Total Error	Av Error	Max Error
		Mın	Mın	Mın
Dırect sıghtıng telescope	27	1875	69.4	367
Elbow telescope	38	1356	35.7	207
Total	65	3231	49 7	367

Walker

	No Obs	Total Error	Av Error	Max Error
		Mın	Mın	Mın
Dırect sıghtıng telescope	18	1014	56.3	141
Elbow telescope	15	779	51.9	187
Total	33	1793	54.3	187

Total - Both Observers

	No Obs	Total Error	Av. Error	Max Error
		Mın	Mın.	Mın.
Dırect sıghtıng telescope	45	2889	64.2	367
Elbow telescope	53	2135	40 3	207
Grand Total	98	5024	51 3	367

TABLE X

BUBBLE SEXTANT

Weber

	No Obs	Total Error Min	Av Error Min	Max Error Min
Averaging Device	33	210	6 4	17
Single shots	8	128	16 0	35

Walker

	No. Obs	Total Error Min	Av Error Min	Max. Error Min
Averaging Device	9	231	25.7	73
Single shots	6	286	47.7	73

Total - Both Observers

	No. Obs	Total Error Min.	Av. Error Min	Max Error Min.
Averaging Device	42	441	10.5	73
Single shots	14	414	29.6	73

TABLE XI

COMPARATIVE ACCURACIES OF THE BALL DROP AND BUBBLE SEXTANTS

Sextant	No Obs.	Total Error Min	Av Error Min	Max Error Min.	No Errors Over 60′	Over 30′	Over 10′
Ball Drop	98	5024	51 3	367	26	54	83
Bubble	42	441	10 5	73	1	2	15

Percent Observations

Sextant	Over 60′ Error	Over 30′ Error	Over 10′ Error
Ball Drop	27	55	85
Bubble	2	5	36