NEW DEVELOPMENTS IN AIR NAVIGATION.

by

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FOREWORD

The Hydrographic Office of the United States Navy has recently installed in that Office a Section on Aerial Navigation and Aeronautical Charts. Lieut.-Commander P. V. H. WEEMS, U. S. Navy, the author of this article is in charge of that Section.

Lieut.-Commander WEEMS has been interested in the subject of Aerial Navigation and has evolved many aids for the navigator. He is to-day generally recognised as an authority on the subject and several distinguished flyers have profited by his instruction and works. He recently received a gold medal from the Aero Club of France for his book on "Air Navigation". He is also the author of "Line of Position Book" and "Star Altitude Curves".

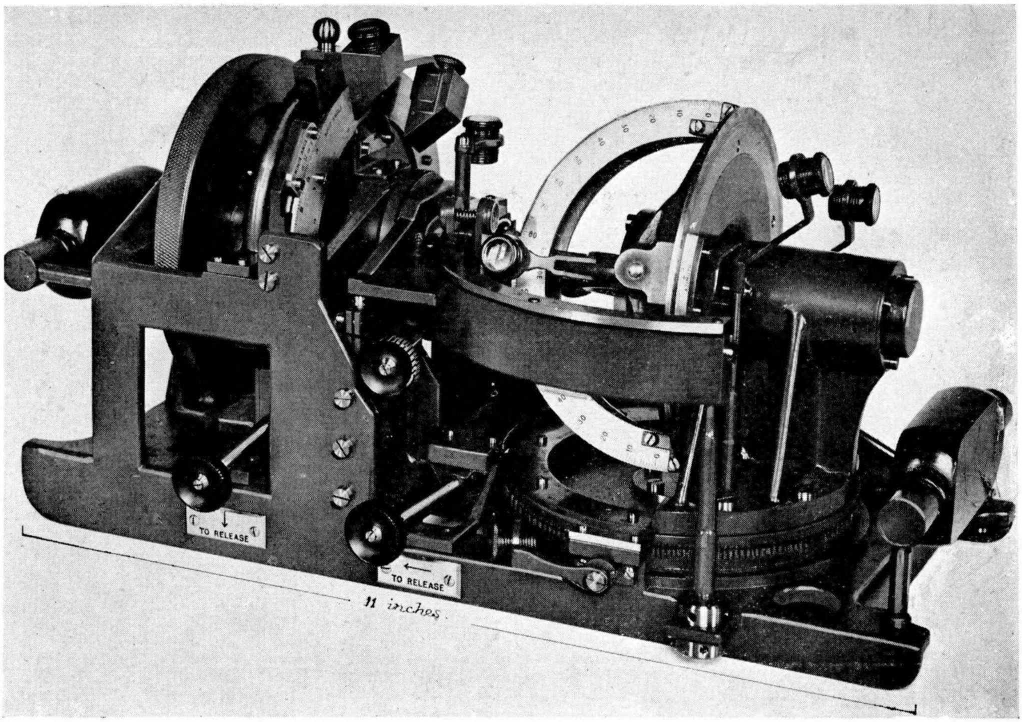
The Directing Committee of the International Hydrographic Bureau has been impressed with the fact that many of the ideas and methods mentioned in the following article on Air Navigation are equally applicable to surface navigation and therefore feel that it will be of interest to hydrographers and surface navigators as well as to aerial navigators.

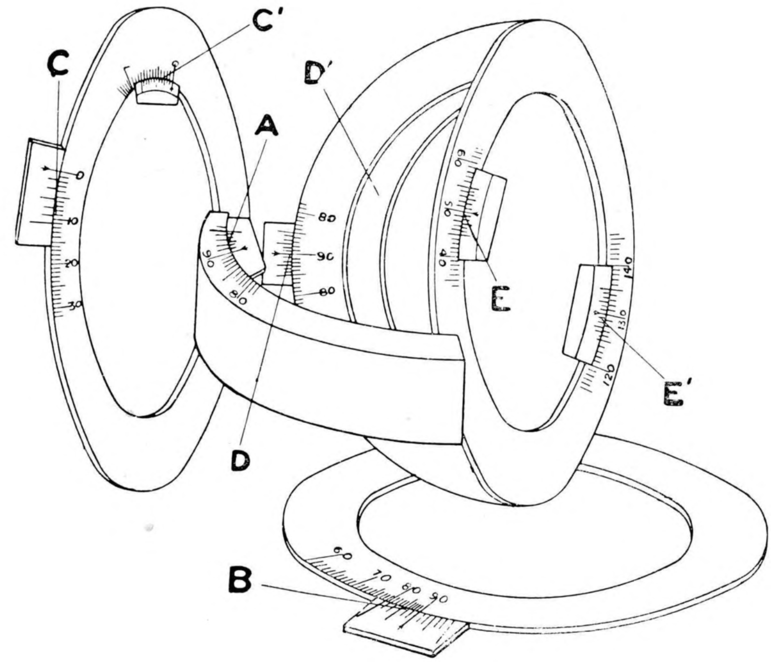
A. T. L.

In one sense this paper is also an effort to promote closer international cooperation by placing at the disposal of the marine and aerial world some of the latest developments in the United States. The free exchange of ideas at the International Congress of Trans-Oceanic Flyers held at Rome in May and June of this year has helped to crystallize the thought of submitting this paper. For example, the writer was given valuable information on the system of instruction used in Germany by VON GRONAU; Harold GATTY is appreciative of the information BELLONTE and others gave him at Paris; and in general, the Italians and visiting members freely pooled their knowledge of air navigation and meteorology.

The U. S. Navy Department has made a special effort to improve the equipment and methods for aerial dead reckoning within the past year. Two additional officers were detailed especially for this work, while the Bureau of Aeronautics, the Hydrographic Office, the Naval Observatory, and the Naval Research Laboratory gave full cooperation. In addition the Bureau of Standards and other Government agencies are available for help when needed.

Obviously, the dead reckoning instrument of first importance is the compass. The latest type navy magnetic aircraft compass gives readings to one degree and is mounted as a panel instrument. This type compass supplemented by the Sperry Directional Gyro has proved highly satisfactory. The magnetic compass used alone fails to provide a means for steering a steady accurate course under all conditions. For instance, with the magnetic compass alone we have the well-known trouble with the northerly turn error. Not all pilots realize, however, that magnetic compasses are also erratic on





Willis Navigating Machine

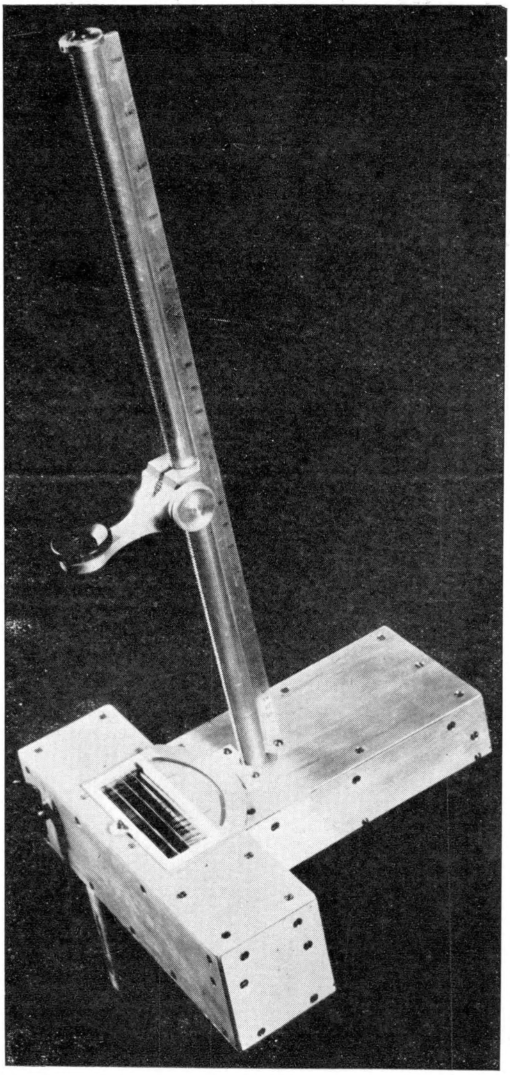


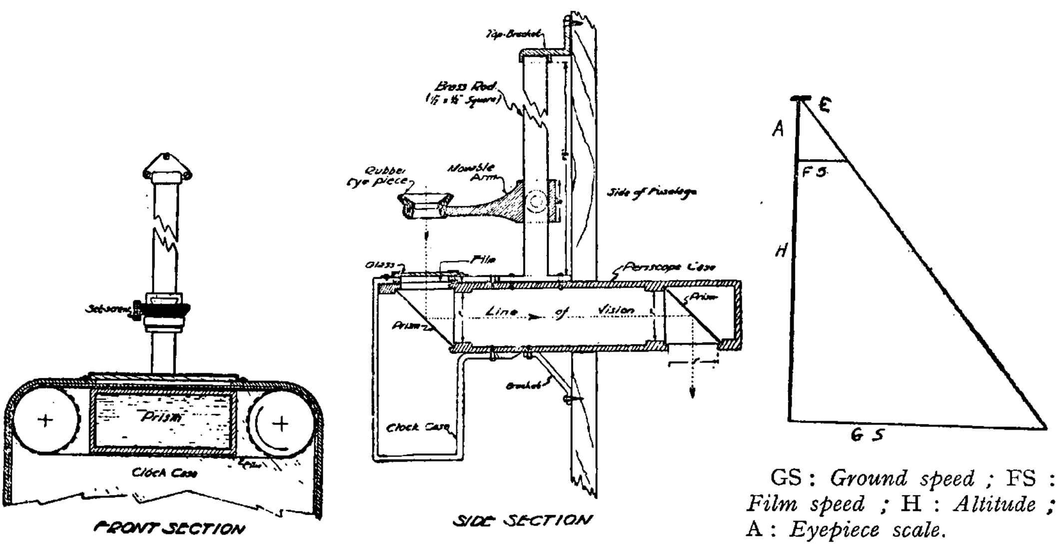
Fig. 1

The Gatty Ground Speed and Drift Indicator
Indicateur de Vitesse au Sol et de Dérive de Gatty

east and west headings when banking. Take the case of a plane in latitude 50 degrees north, on course 270 degrees and banking to the left 40 degrees. Under such a condition the directive force of the compass would be practically zero. In fact, under conditions approaching this where the card is at right angles to the earth's lines of force, the compass is likely to go in any direction depending on momentum, friction, or on other causes. With a good magnetic compass to set a course when the plane is on an even keel, and with the directional gyro to steer by, it should be possible under ordinary conditions to steer a course to within one degree.

Having the ability to steer an accurate steady course, and the usual panel instruments showing with reasonable accuracy the altitude, air speed, temperature, rate of climb, and for blind flying the gyro horizon or its equivalent, together with the turn and bank indicator and steering instruments previously mentioned, we are ready to approach the next big problem of aerial reckoning, that of determining the ground speed and wind drift. The instrument found most promising for this purpsoe is the GATTY Ground Speed and Drift Indicator. This device weighing less than three pounds provides both the ground speed and the wind drift without changing course and without the necessity of observing in the wind-stream. The instrument does, however, depend directly on the altitude for obtaining ground speed. For instance, if there is an inaccuracy of 2 % in the altimeter reading, there will be a corresponding error in the resultant ground speed.

Figure 1 shows a general view of the GATTY instrument, while Fig. 2 shows some of the details and the principle involved. The U. S. Government has obtained a license on this device and has begun further developments of it.



GS : *Ground speed* ; FS : *Film speed* ; H : *Altitude* ; A : *Eyepiece scale.*

FIG. 2

Details of the Gatty Visual Ground Speed and Drift Meter

This is designed to be secured to the side of the fuselage with the periscope protruding and has an eyepiece vertically adjustable on a scale for making observations from inside the airplane. A Constant-Speed-marked film moved by clockwork across a prism beneath the eyepiece is synchronized with the apparent movement of the ground by varying the height of the eyepiece. The Ground-Speed is ascertained by the formula for similar triangles as indicated by the Diagram at the right. The Angle of Drift is indicated by the distance the instrument must be turned on a pivot to align markings on the film, which are at right angles to its direction of motion, with the apparent ground motion.

In computing the ground speed from the GATTY instrument, it is necessary to make a division of numbers of the order of 4320 divided by 28.5. Also, with the ground speed and wind drift known, there still remains a considerable amount of figuring to be done. To simplify the arithmetical computation required by the air navigator, the U. S. Hydrographic Office has developed a sheet 10 ½ by 14 ½ inches called *The Dead Reckoner* (VC-O) (see Figure 3). Among other features, the VC-O includes the *Phillips Flight Calculator*, which is nothing more than a convenient circular slide rule especially designed for the needs of the airman. The flight calculator not only makes the divisions required with the GATTY instrument, but it also works all usual Speed-Time-Distance problems and converts nautical to statute miles. In fact, this device will work any problem in multiplication or division falling within its limits; for example, fuel consumption problems are conveniently worked with it.

When the ground speed and drift cannot be observed, and the wind force and direction is estimated or supplied from the ground by radio, the ground speed and drift tables on the VC-O serve as a convenient means for solving the wind vector diagrams. Also, when by map reading it is found that the plane is a known distance off course after flying a known distance, there is a table on the Dead Reckoner which turns the distance off course into degrees off course.

Another and new feature included on the Dead Reckoner is the graphic course converter. For recording the deviation, the principle of the MACKENZIE (British) Aero Deviation Card is used. An inner rotating dial is provided by means of which the variation can be set off. With the deviation permanent for the compass used, and with the variation set for the locality, reference to the magnetic course is eliminated, and it is possible to turn true course into compass course and vice versa without mental effort, and with little chance of making an error. Fig. 3 shows the Dead Reckoner to a reduced scale.

A companion sheet to the VC-O has been constructed by the Air Navigation Division for convenient plotting of latitude, longitude, and for laying down lines of position. This sheet is called the *Universal Plotting Sheet*, VP-O, and is shown in Fig. 4. This type plotting sheet has a universal scale of 3 inches per 60 nautical miles, or 1°. A variable longitude scale is provided in the lower right hand corner.

The *Aircraft Plotter* to the same scale as the Universal Plotting Sheet provides a convenient means for plotting courses and distances and for laying down lines of position. This plotter is shown in Fig. 4.

A folding chart board, shown in Figs. 4 and 5, is fitted with a strip map and with the items described above, the plotter, the dead reckoner, and the universal plotting sheet. The strip map is folded around one of the two ply wood boards and held by strips of "Scotch talp", a convenient adhesive paper which may be used repeatedly, and which replaces the thumb tack or spring clamp for holding the map. The cloth hinge for the board provides a handy stowage for pencils as shown in Fig. 4.

Moving from dead reckoning to celestial navigation, the Hydrographic Office, cooperating with the Naval Observatory, has produced an Air Almanac

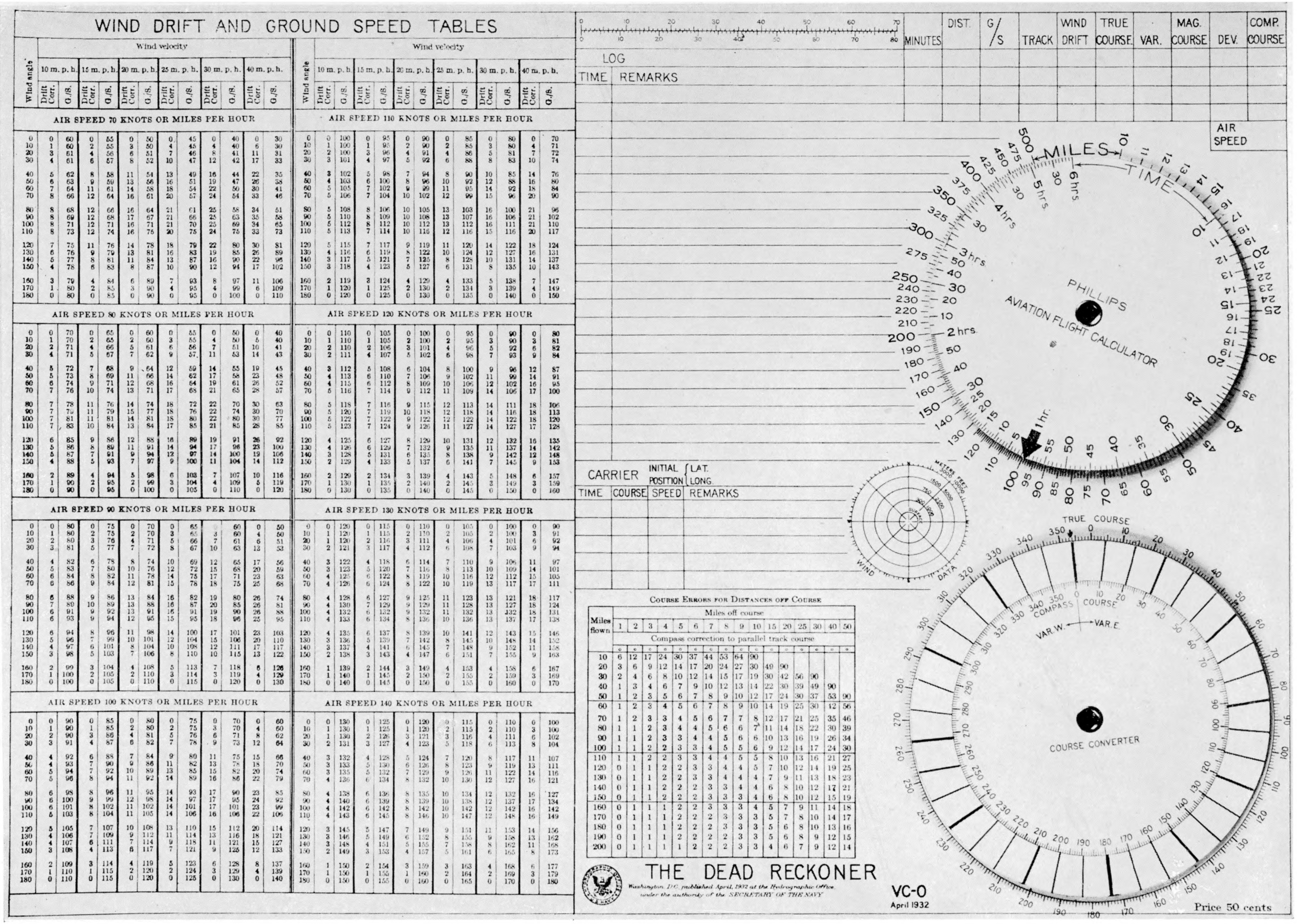


FIG. 3
The Dead Reckoner — Calculateur d'estime

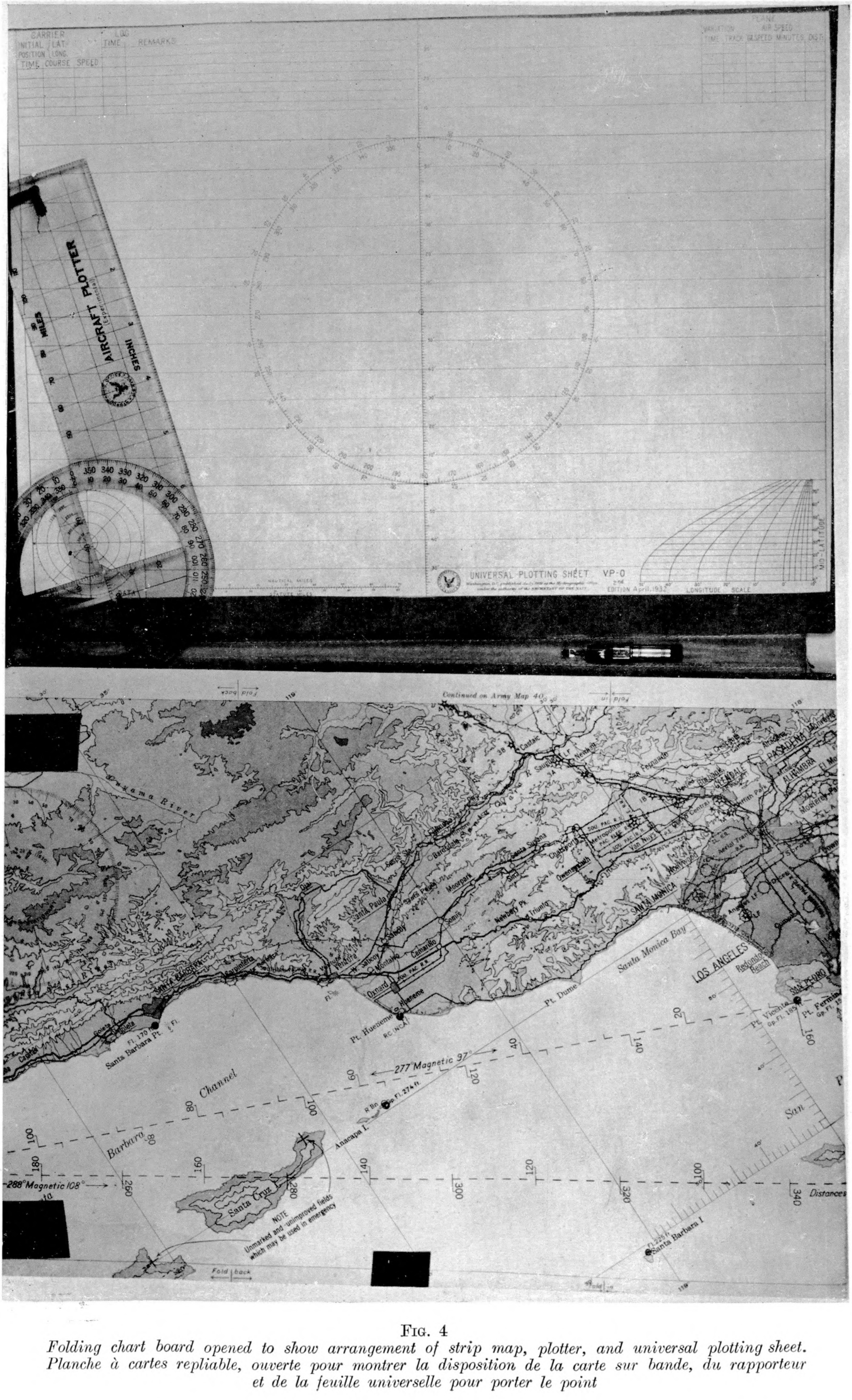


Fig. 4

Folding chart board opened to show arrangement of strip map, plotter, and universal plotting sheet.
Planche à cartes repliable, ouverte pour montrer la disposition de la carte sur bande, du rapporteur et de la feuille universelle pour porter le point

for 1933. A complete break has been made from the usual arrangement in the Nautical Almanac. The following principal features are worked into the new aid for the air navigator: (1) The complete elimination of the equation of time, sidereal time, and right ascension so far as the use of the air almanac is concerned, (2) The elimination of most of the tedious interpolation by expanding the tabulations and by providing special interpolation tables, and (3) The elimination of the sunrise and sunset tables by means of diagrams, and the elimination of the moonrise and moonset tables by including this data directly in the expanded moon ephemerides.

The equation of time, right ascension and sidereal time are eliminated by tabulating the hour angles of all bodies with respect to the Greenwich meridian. Since the local hour angle (Greenwich hour angle plus or minus the longitude) is one of the three arguments used in the solution of the astronomical triangle, it is obviously an advantage to have the Greenwich hour angle tabulated rather than the right ascension, since the latter must be applied to sidereal time to get the desired hour angle. There is less saving in tabulating the sun's hour angle, yet there is a considerable saving even here.

The tedious interpolations heretofore required in the case of the moon are largely overcome by expanding the tabulations for the moon ephemeris from intervals of one hour to intervals of ten minutes. When observations are made at even ten minute intervals, no interpolations whatever are required, and moon sights become easier to work than sun sights. Where the moon is observed at odd minutes of time, recourse is had to a convenient interpolation table where the corrections for both right ascension and declination are given for every ten seconds.

The tabulation for the Greenwich hour angle of the fifty odd navigational fixed stars is expanded from monthly to daily intervals. An interpolation table gives the correction for any instant of Greenwich civil time. The "additional stars" are tabulated for monthly intervals with a correction to bring the hour angle to any desired day of the month, after which the problem is the same as for one of the navigational stars.

The planets are tabulated in the same way as stars, except that additional columns are included for showing the variation of hour angle per minute, and of declination per hour.

The feature which will probably meet the immediate approval of the marine world is the diagrams for showing the time of sunrise and sunset, and the duration of twilight. Whereas the present *Nautical Almanac* tabulates the time of sunrise and sunset for north latitude and to 60 degrees only, with provisions for computing the values for south latitudes, the *Air Almanac* gives this data for latitudes up to 75 degrees, both north and south. Including one page of instructions, there are six pages of diagrams for replacing 22 pages of tables. These six pages are given herewith as they will appear in the *Air Almanac*, and will be immediately available to the mariner as they stand.

The following claims are made for the *Air Almanac:*

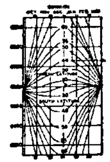
(*a*) About four times as much tabulated data and in less space than is used in the *Nautical Almanac.*

SUNRISE AND SUNSET DIAGRAMS.

THESE DIAGRAMS PORTRAY GRAPHICALLY FOR ANY YEAR THE TIMES OF RISING AND SETTING OF THE SUN FOR LATITUDES UP TO 75°, NORTH AND SOUTH. FOR HIGH LATITUDES, NOT INCLUDED IN THE DIAGRAMS, TWILIGHT OR HALF LIGHT WILL USUALLY BE FOUND THROUGHOUT THE SUMMER NIGHTS.

THE SCALES AT THE TOP AND BOTTOM OF THE PAGE MARK THE DATE FOR EVERY FIVE DAYS, WHILE THE VERTICAL SCALES DIVIDE THE LOCAL CIVIL TIME INTO FIVE MINUTE INTERVALS. THE LATITUDES APPEAR ON THE CURVES. FOR VALUES BETWEEN THE PLOTTED VALUES INTERPOLATE BY EYE. THIS MAY BE DONE TO ONE DAY OF TIME, TO APPROXIMATELY ONE DEGREE OF LATITUDE, AND TO ONE MINUTE OF LOCAL CIVIL TIME.

INSTRUCTIONS FOR USE



I ENTER THE TOP OR BOTTOM SCALE WITH PROPER DATE.

II MOVE VERTICALLY UP OR DOWN TO THE CURVE FOR OBSERVER'S LATITUDE.

III MOVE HORIZONTALLY TO RIGHT OR LEFT AND READ LOCAL CIVIL TIME ON VERTICAL SCALES AT THE SIDE.

IV. TO FIND EXACT ZONE OR STANDARD TIME AS CARRIED BY YOUR WATCH, ADD 4 MINUTES FOR EACH DEGREE WEST OF STANDARD MERIDIAN, AND SUBTRACT 4 MINUTES FOR EACH DEGREE EAST OF STANDARD MERIDIAN

EXAMPLE:

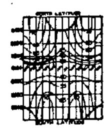
WHAT IS THE STANDARD TIME OF SUNRISE IN LAT. 40°N., LONG 77°W., JAN. 20?

SOLUTION:

ENTER AT (TOP / BOTTOM) FOR JAN. 20, MOVE VERTICALLY (UP / DOWN) TO 40°N. CURVE. THEN HORIZONTALLY (LEFT / RIGHT) AND READ LOCAL CIVIL TIME OF 0719. FOR 77°W. ADD 8 MINUTES TO LOCAL CIVIL TIME, GIVING 0727 AS STANDARD TIME OF SUNRISE

ACCURACY IS TO WITHIN 1 OR 2 MINUTES – ON A TEST, 25 PROBLEMS WERE WORKED ON A DIAGRAM AS DRAWN TO DOUBLE SCALE. OF THESE, 21 WERE CORRECT, 3 IN ERROR ½ MINUTE, AND 1 IN ERROR 1 MINUTE.

DURATION OF TWILIGHT DIAGRAM



THIS DIAGRAM IS USED IN THE SAME WAY AS THE SUNRISE AND SUNSET DIAGRAMS.

THE RESULTS ARE "DURATION OF TWILIGHT" FOR BOTH MORNING AND EVENING.

SUBTRACT THE DURATION OF TWILIGHT FROM SUNRISE TO GET TIME OF DAYBREAK.

ADD THE DURATION OF TWILIGHT TO SUNSET TO GET TIME OF END OF TWILIGHT.

EXAMPLE:- FIND DURATION OF TWILIGHT ON MAY 20 IN LATITUDE 40°N.

SOLUTION:- ENTER WITH MAY 20 AND MOVE UP TO LATITUDE CURVE FOR 40°N., THENCE TO LEFT AND READ 0154 HR AS THE DURATION OF TWILIGHT.

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FIG. 6

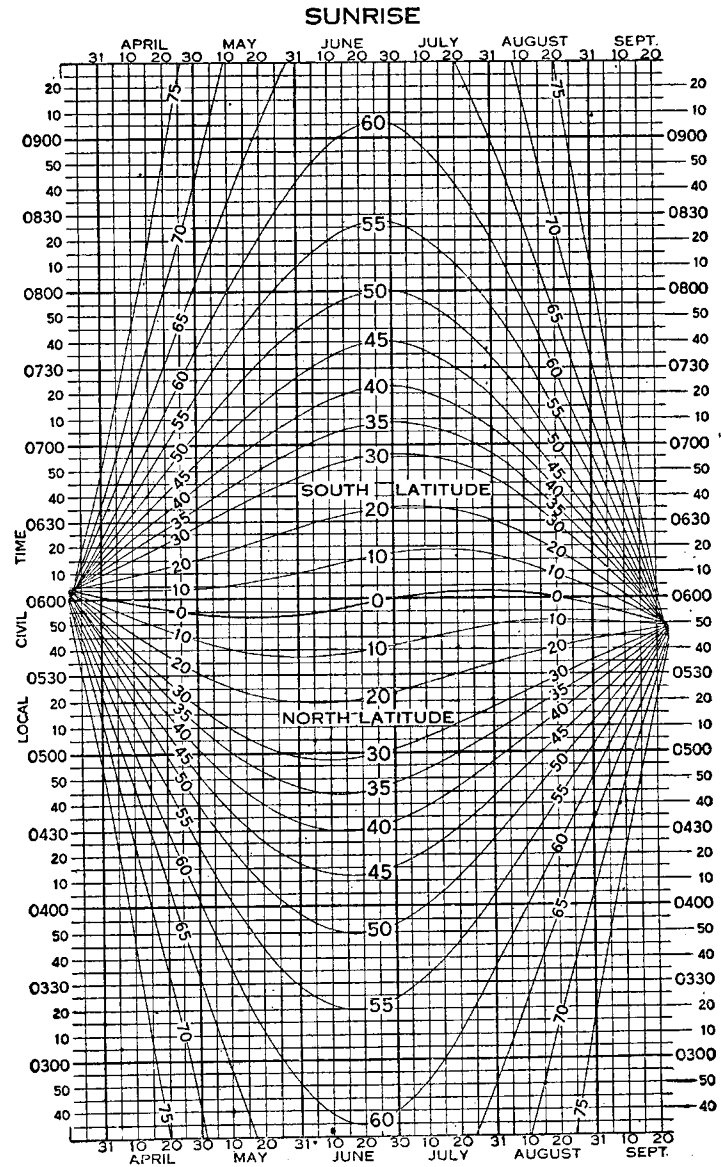


FIG. 7

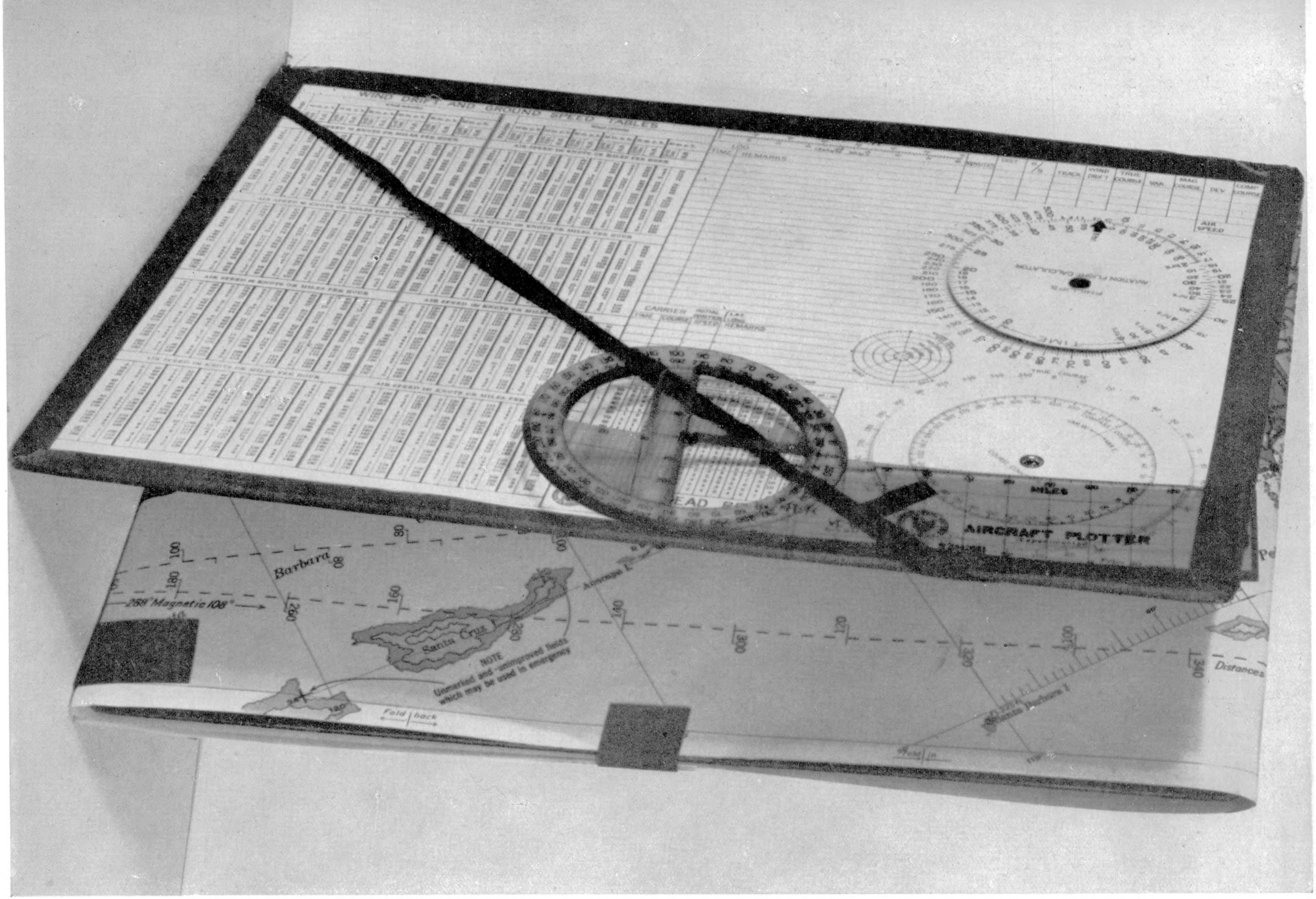
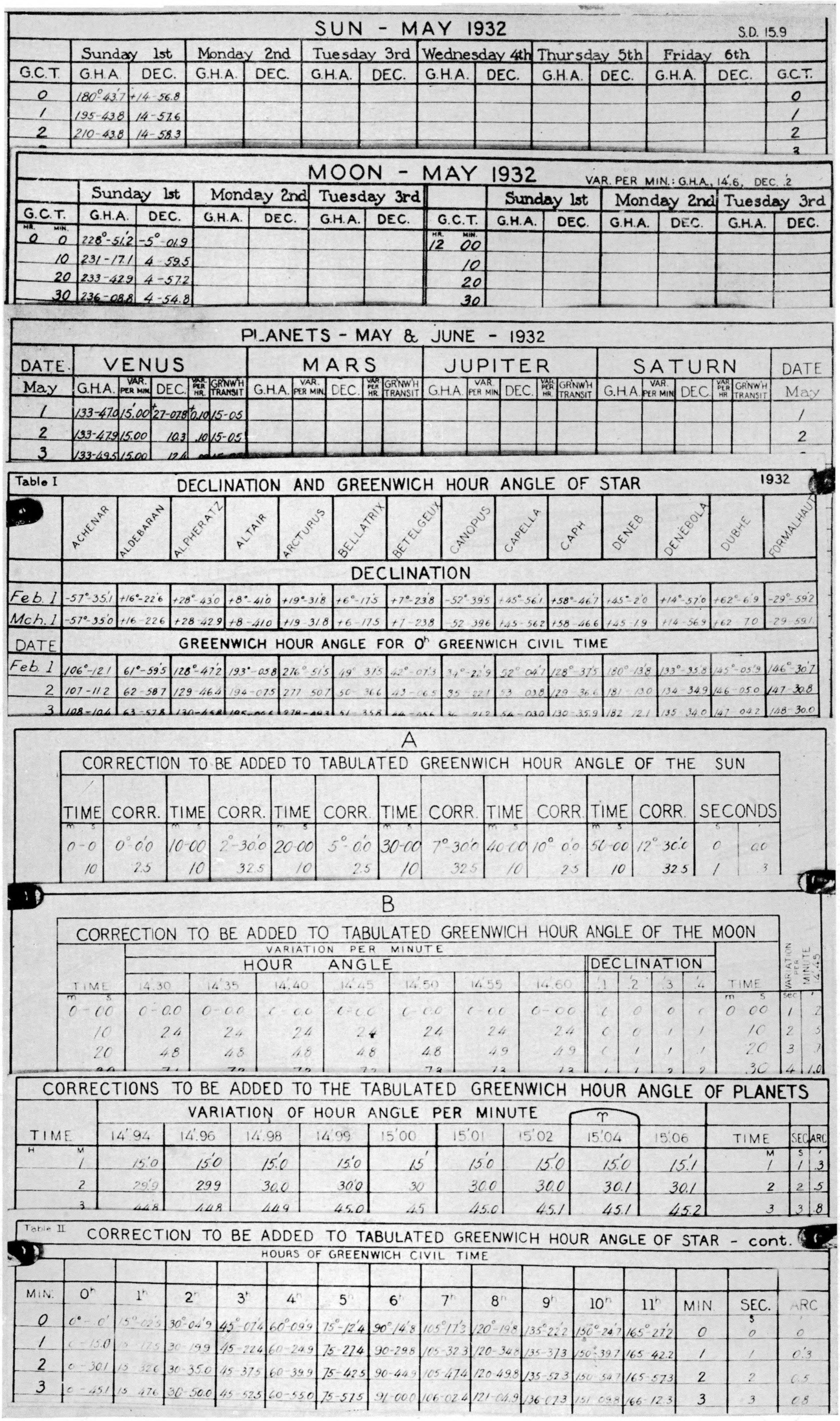


FIG. 5

View of the Aircraft Plotting Board — Vue de la planche spéciale pour porter le ***point*** *en aéronef*



SUN - MAY 1932 S.D. 15.9

	Sunday 1st		Monday 2nd		Tuesday 3rd		Wednesday 4th		Thursday 5th		Friday 6th		
G.C.T.	G.H.A.	DEC.	G.H.A.	DEC.	G.H.A.	DEC.	G.H.A.	DEC.	G.H.A.	DEC.	G.H.A.	DEC.	G.C.T.
0	180°43.7	+14-56.8											0
1	195-43.8	14-57.6											1
2	210-43.8	14-58.3											2
													3

MOON - MAY 1932 VAR. PER MIN.: G.H.A., 14'.6, DEC. '.2

	Sunday 1st		Monday 2nd		Tuesday 3rd			Sunday 1st		Monday 2nd		Tuesday 3rd	
G.C.T. (HR. MIN.)	G.H.A.	DEC.	G.H.A.	DEC.	G.H.A.	DEC.	G.C.T. (HR. MIN.)	G.H.A.	DEC.	G.H.A.	DEC.	G.H.A.	DEC.
0 0	228°-51'.2	-5°-01.9					12 00						
10	231-17.1	4-59.5					10						
20	233-42.9	4-57.2					20						
30	236-08.8	4-54.8					30						

PLANETS - MAY & JUNE - 1932

DATE	VENUS					MARS					JUPITER					SATURN					DATE
May	G.H.A.	VAR. PER MIN.	DEC.	VAR. PER HR.	GR'NW'H TRANSIT	G.H.A.	VAR. PER MIN.	DEC.	VAR. PER HR.	GR'NW'H TRANSIT	G.H.A.	VAR. PER MIN.	DEC.	VAR. PER HR.	GR'NW'H TRANSIT	G.H.A.	VAR. PER MIN.	DEC.	VAR. PER HR.	GR'NW'H TRANSIT	May
1	133-47.0	15'.00	+27-07.8	+0.10	15-05																1
2	133-47.9	15.00	10.3	.10	15-05																2
3	133-49.5	15.00	12.4	[illegible]	[illegible]																

Table I — **DECLINATION AND GREENWICH HOUR ANGLE OF STAR** — 1932

	ACHENAR	ALDEBARAN	ALPHERATZ	ALTAIR	ARCTURUS	BELLATRIX	BETELGEUX	CANOPUS	CAPELLA	CAPH	DENEB	DENEBOLA	DUBHE	FORMALHAUT
	DECLINATION													
Feb. 1	-57°-35.1	+16°-22.6	+28°-43.0	+8°-41.0	+19°-31.8	+6°-17.5	+7°-23.8	-52°-39.5	+45°-56.1	+58°-46.7	+45°-2.0	+14°-57.0	+62°-6.9	-29°-59.2
Mch. 1	-57°-35.0	+16-22.6	+28-42.9	+8-41.0	+19-31.8	+6-17.5	+7-23.8	-52-39.6	+45-56.2	+58-46.6	+45-1.9	+14-56.9	+62-7.0	-29-59.1
DATE	**GREENWICH HOUR ANGLE FOR 0^h GREENWICH CIVIL TIME**													
Feb. 1	106°-12.1	61°-59.5	128°-47.2	193°-05.8	276°-51.5	49°-37.5	42°-07.3	34°-22.9	52°-04.7	128°-37.5	180°-13.8	133°-35.8	145°-05.9	146°-30.7
2	107-11.2	62-58.7	129-46.4	194-07.5	277-50.7	50-36.6	43-06.5	35-22.1	53-03.8	129-36.6	181-13.0	134-34.9	146-05.0	147-30.8
3	108-10.4	63-57.8	130-45.8	195-[illegible]	278-49.3	51-35.8	44-05.6	[illegible]-21.2	54-03.0	130-35.9	182-12.1	135-34.0	147-04.2	148-30.0

A

CORRECTION TO BE ADDED TO TABULATED GREENWICH HOUR ANGLE OF THE SUN

TIME (m s)	CORR.	TIME (m s)	CORR.	TIME (m s)	CORR.	TIME (m s)	CORR.	TIME (m s)	CORR.	TIME (m s)	CORR.	SECONDS (s)	(')
0-0	0°0'.0	10-00	2°-30'.0	20-00	5°-0'.0	30-00	7°-30'.0	40-00	10°0'.0	50-00	12°30'.0	0	0.0
10	2.5	10	32.5	10	2.5	10	32.5	10	2.5	10	32.5	1	.3

B

CORRECTION TO BE ADDED TO TABULATED GREENWICH HOUR ANGLE OF THE MOON

	VARIATION PER MINUTE												VARIATION PER MINUTE 14'.45	
	HOUR ANGLE							DECLINATION						
TIME (m s)	14'.30	14'.35	14'.40	14'.45	14'.50	14'.55	14'.60	'.1	'.2	'.3	'.4	TIME (m s)	sec	'
0-00	0-0.0	0-0.0	0-0.0	0-0.0	0-0.0	0-0.0	0-0.0	0	0	0	0	0 00	1	.2
10	2.4	2.4	2.4	2.4	2.4	2.4	2.4	0	0	.1	.1	10	2	.5
20	4.8	4.8	4.8	4.8	4.8	4.9	4.9	0	.1	.1	.1	20	3	.7
[illegible]	7.1	7.2	7.2	7.2	7.2	7.3	7.3	[illegible]	[illegible]	[illegible]	[illegible]	30	4	1.0

CORRECTIONS TO BE ADDED TO THE TABULATED GREENWICH HOUR ANGLE OF PLANETS

	VARIATION OF HOUR ANGLE PER MINUTE							♈				
TIME (H M)	14'.94	14'.96	14'.98	14'.99	15'.00	15'.01	15'.02	15'.04	15'.06	TIME (M)	SEC (S)	ARC (')
1	15'.0	15'.0	15'.0	15'.0	15'	15'.0	15'.0	15'.0	15'.1	1	1	.3
2	29'.9	29.9	30.0	30'.0	30	30.0	30.0	30.1	30.1	2	2	.5
3	44.8	44.8	44.9	45.0	45	45.0	45.1	45.1	45.2	3	3	.8

Table II — **CORRECTION TO BE ADDED TO TABULATED GREENWICH HOUR ANGLE OF STAR - cont.**

HOURS OF GREENWICH CIVIL TIME

MIN.	0^h	1^h	2^h	3^h	4^h	5^h	6^h	7^h	8^h	9^h	10^h	11^h	MIN.	SEC. (s)	ARC (')
0	0°-0'	15°-02.5	30°-04.9	45°-07.4	60°-09.9	75°-12.4	90°-14.8	105°-17.3	120°-19.8	135°-22.2	150°-24.7	165°-27.2	0	0	0
1	0-15.0	15-17.5	30-19.9	45-22.4	60-24.9	75-27.4	90-29.8	105-32.3	120-34.8	135-37.3	150-39.7	165-42.2	1	1	0'.3
2	0-30.1	15-32.6	30-35.0	45-37.5	60-39.9	75-42.5	90-44.9	105-47.4	120-49.8	135-52.3	150-54.7	165-57.3	2	2	0.5
3	0-45.1	15-47.6	30-50.0	45-52.5	60-55.0	75-57.5	91-00.0	106-02.4	121-04.9	136-07.3	151-09.8	166-12.3	3	3	0.8

Fig. 12

Composite photo showing arrangement of the tabulations in the Air Almanac.

*Photographie d'assemblage indiquant le dispositif des tableaux de l'*Air Almanac

Fig. 9

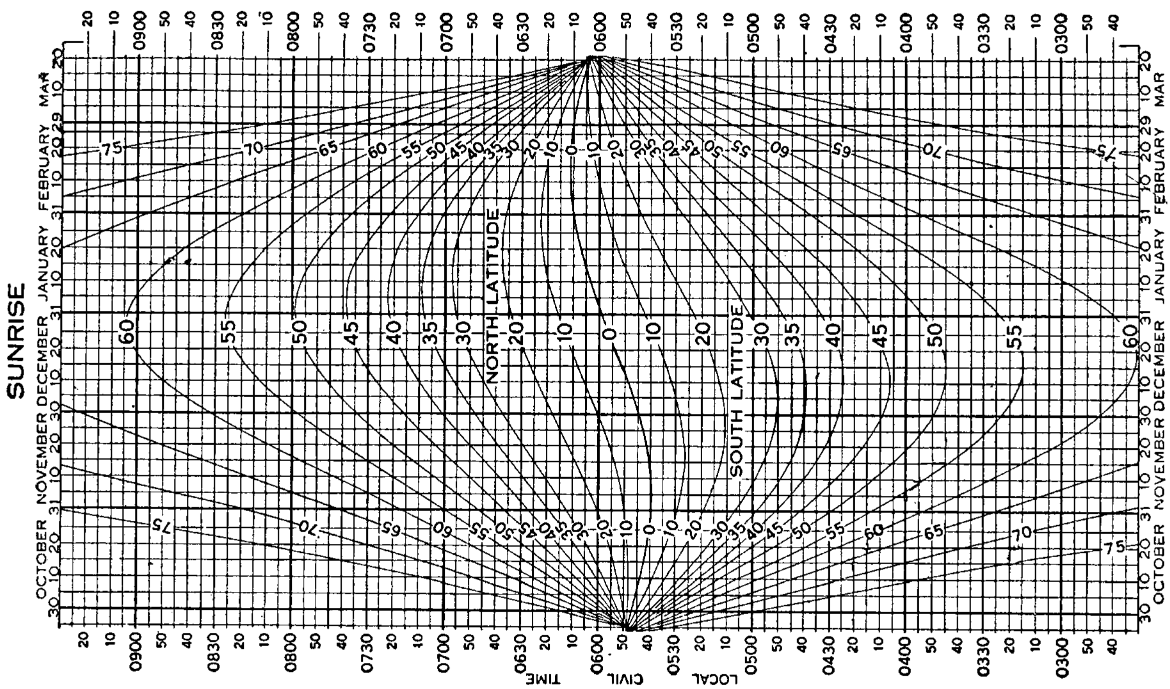

SUNRISE
NORTH LATITUDE
SOUTH LATITUDE
OCTOBER NOVEMBER DECEMBER JANUARY FEBRUARY MAR
LOCAL CIVIL TIME

Fig. 8

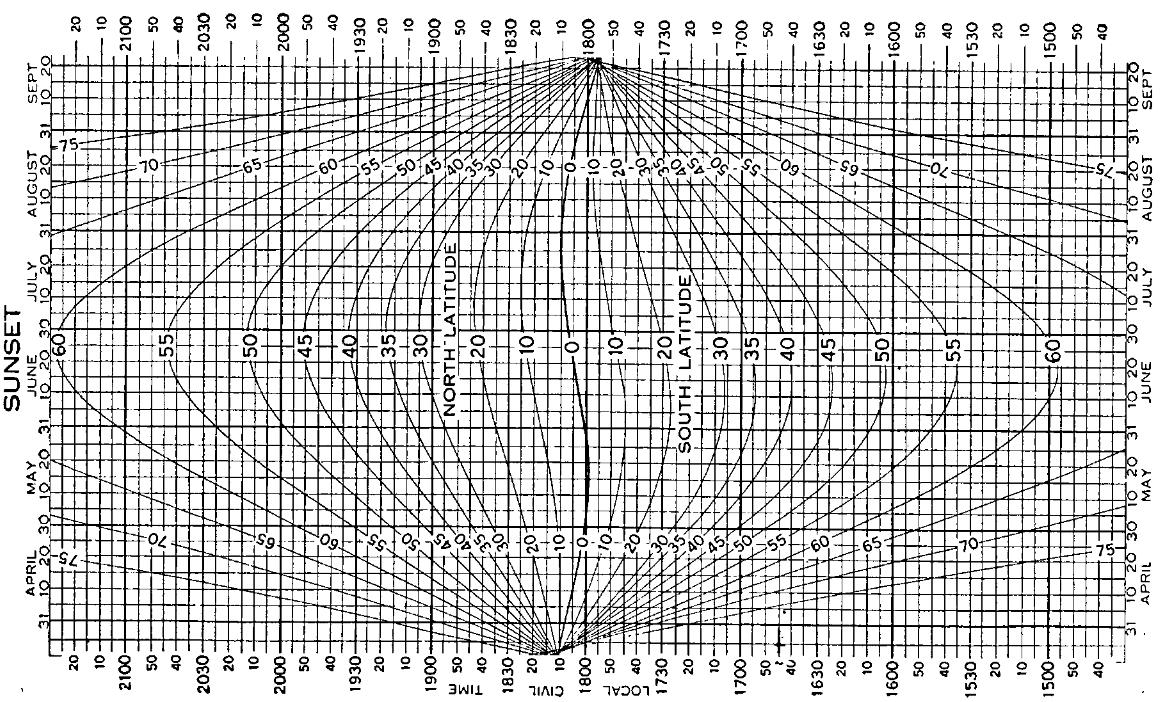

SUNSET
NORTH LATITUDE
SOUTH LATITUDE
APRIL MAY JUNE JULY AUGUST SEPT
LOCAL CIVIL TIME

FIG. 11

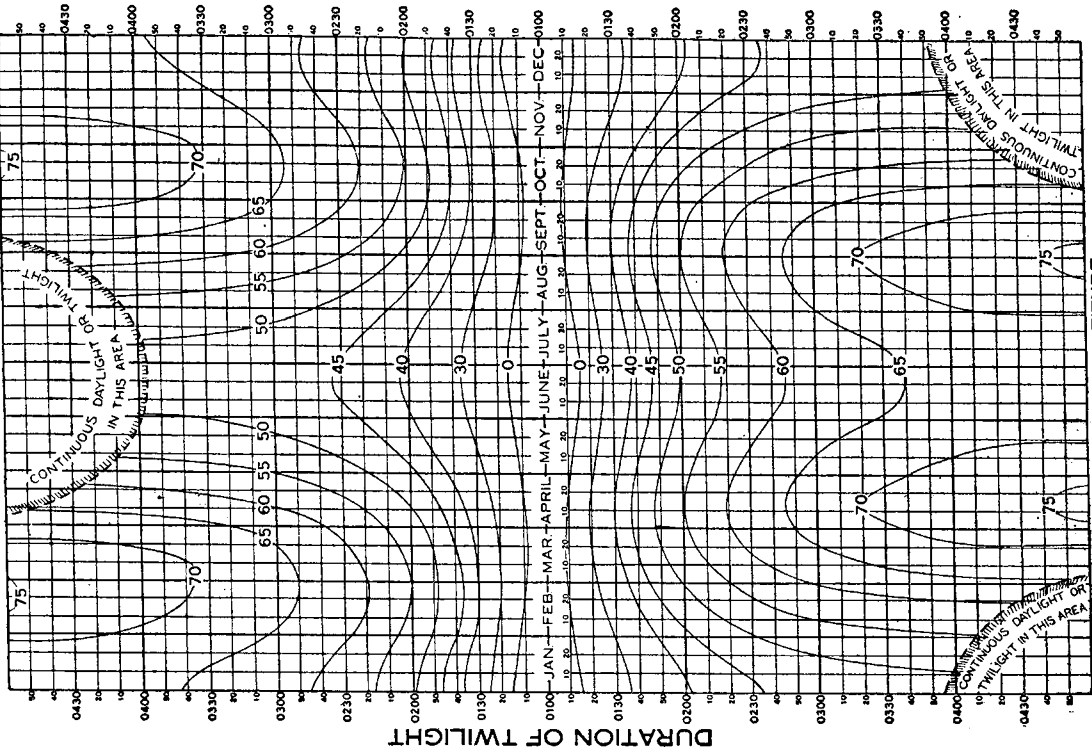
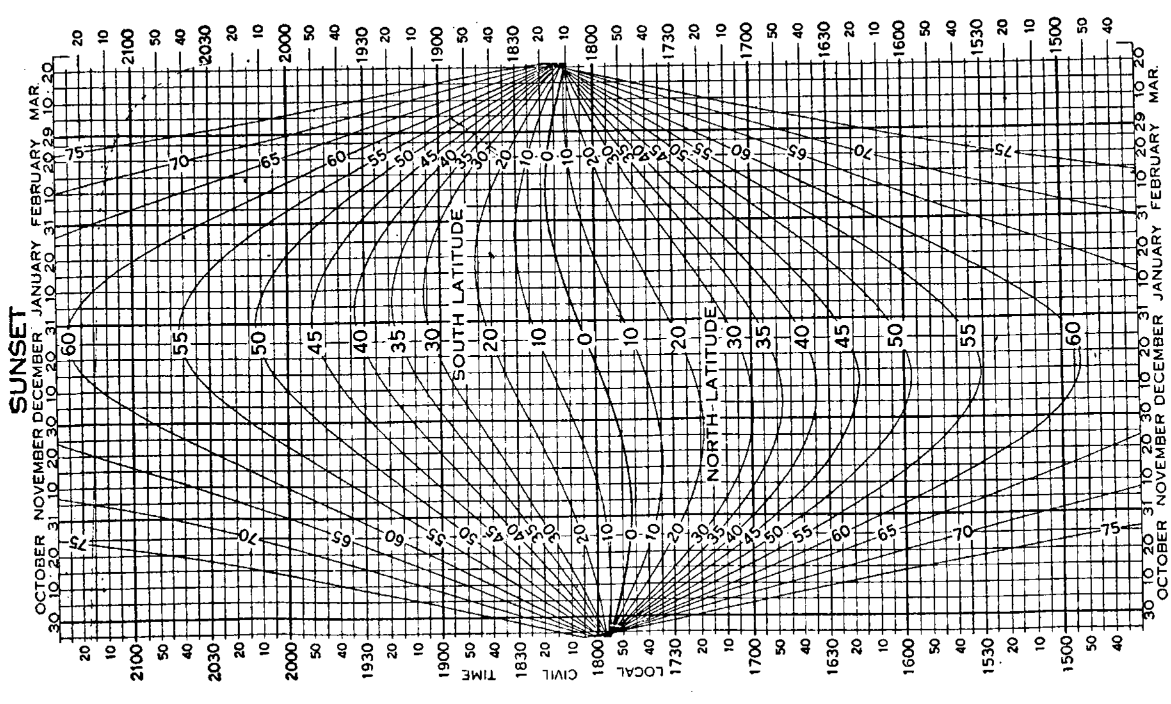

DURATION OF TWILIGHT
NORTH LATITUDE
SOUTH LATITUDE
CONTINUOUS DAYLIGHT OR TWILIGHT IN THIS AREA
JAN. FEB. MAR. APRIL MAY JUNE JULY AUG. SEPT. OCT. NOV. DEC.
H.O. MISC. 7980

FIG. 10


SUNSET
SOUTH LATITUDE
NORTH LATITUDE
LOCAL CIVIL TIME
OCTOBER NOVEMBER DECEMBER JANUARY FEBRUARY MAR.

(*b*) A saving of about 30 % over the time required in taking data from the *Nautical Almanac.*

(*c*) No loss of accuracy as compared with the *Nautical Almanac.*

(*d*) Equal application of the *Air Almanac* to marine use. While the name *Air Almanac* was used to avoid possible criticism from the marine world, it is predicted that mariners will in general prefer the arrangement of data in the *Air Almanac* to that in the *Nautical Almanac.*

AUTHOR'S NOTE. — The statements and opinions herein expressed are those of the writer, and are not to be construed as the official views of the U. S. Navy Department.

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