AERONAUTICAL EPHEMERIDES

(Lecture delivered by Ingénieur Hydrographe Général COT, Hydrographer of the French Navy, before the IVth International Hydrographic Conference, 19th April, 1937).

The problem of fixing the position in aerial navigation is fraught with grave obstacles. In general, aviators are satisfied to observe the earth beneath them and to identify the points over which they are flying and which are shown on the charts at their disposal :— localities, rivers, hills or other irregularities of the terrain. This procedure is very convenient when it is possible to see and mark on the chart the details to be identified. This, however, is not always the case, for instance over the ocean or above the desert, or even in foggy weather or at night, and particularly in the latter case when lights are extinguished.

For this reason many naval officers who serve as pilots or observers in the French Air Service have sought to apply to aerial navigation the maritime procedure, i. e. astronomic method, which consists, as we know, in measuring the height of a celestial body above the sea horizon and noting the time at the same instant. Thereupon one computes the estimated altitude corresponding to the assumed latitude and assumed longitude; the difference between this and the observed altitude (taking into consideration the various sources of error : refraction, parallax, etc.) permits the line of position to be plotted.

In air-planes, however, the observers encounter rather special conditions. At high altitudes their hands become so chilled that they are obliged to wear thick gloves. Not only are they inconvenienced by the cold but also by the wind, as they are exposed to violent air currents, especially if flying at speeds of 150, 200 or 300 kilometres an hour (90, 140 or 210 miles per hour). Thus aviators demand that the calculations should be reduced to a minimum. If it becomes necessary to perform even a simple addition by writing A + B, that alone is regarded as considerable. All computations must therefore be reduced to an absolute minimum. Since the aviator does not want to write, it is necessary that he should simply note the terms to be added upon a graduated dial which permits him to read off the total.

The aim of the aeronautical ephemerides is to reduce to a minimum the determination of the astronomical data required in subsequent calculations for fixing the position.

Graduated dials have been constructed for facilitating the additions, but not for subtractions. The latter cannot be easily effected by the aviator and should not be required of him. Thus, in calculating the position by the astronomical method, he writes as follows :—

$$\text{Hour Angle} = \text{Sidereal Time} - \text{Right Ascension.}$$

a formula which requires subtraction. Therefore it is necessary to furnish him with tables giving the verse-ascension, which is the right ascension subtracted from 24 hours — this in degrees and minutes of degrees, since

TEMPS de Greenwich		SOLEIL		LUNE	
Civil	Sidéral	Ascension droite	Déclinaison	Ascension droite	Déclinaison
0 h m	206 ° 41	333 ° 30 ′	-10 ° 57 ′	296 ° 10 ′	+12 ° 55 ′
20	211 41	333 29	-10 57	295 39	+12 51
40	216 42	333 28	-10 58	295 49	+12 48
1 0	221 43	333 28	-10 58	295 38	+12 44
20	226 44	333 27	-10 58	295 27	+12 41
40	231 45	333 26	-10 59	295 17	+12 37
2 0	236 46	333 25	-10 59	295 6	+12 34
20	241 46	333 25	-10 59	294 56	+12 30
40	246 47	333 24	-10 59	294 45	+12 27
3 0	251 48	333 23	-11 0	294 35	+12 23
20	256 49	333 22	-11 0	294 24	+12 19
40	261 50	333 21	-11 0	294 14	+12 16
4 0	266 50	333 21	-11 1	294 3	+12 12
20	271 51	333 20	-11 1	293 53	+12 8
40	276 52	333 19	-11 1	293 42	+12 5
5 0	281 53	333 18	-11 1	293 32	+12 1
20	286 54	333 18	-11 2	293 22	+11 57
40	291 55	333 17	-11 2	293 11	+11 54
6 0	296 55	333 16	-11 2	293 1	+11 50
20	301 56	333 15	-11 3	292 50	+11 46
40	306 57	333 14	-11 3	292 40	+11 43
7 0	311 58	333 14	-11 3	292 29	+11 39
20	316 59	333 13	-11 4	292 19	+11 35
40	321 59	333 12	-11 4	292 8	+11 32
8 0	327 0	333 11	-11 4	291 58	+11 28
20	332 1	333 11	-11 4	291 47	+11 24
40	337 2	333 10	-11 5	291 36	+11 21
9 0	342 3	333 9	-11 5	291 26	+11 17
20	347 4	333 8	-11 5	291 16	+11 13
40	352 4	333 7	-11 6	291 5	+11 10
10 0	357 5	333 7	-11 6	290 55	+11 6
20	2 6	333 6	-11 6	290 45	+11 2
40	7 7	333 5	-11 6	290 34	+10 59
11 0	12 8	333 4	-11 7	290 24	+10 55
20	17 8	333 4	-11 7	290 14	+10 51
40	22 9	333 3	-11 7	290 3	+10 48
12 0	27 10	333 2	-11 8	289 53	+10 44

TEMPS de Greenwich		SOLEIL		LUNE	
Civil	Sidéral	Ascension droite	Déclinaison	Ascension droite	Déclinaison
12 h m	27 ° 10 ′	333 ° 2 ′	-11 ° 8 ′	289 ° 53 ′	+10 ° 44 ′
20	32 11	333 1	-11 8	289 43	+10 40
40	37 12	333 1	-11 8	289 32	+10 37
13 0	42 13	333 0	-11 8	289 22	+10 33
20	47 13	332 59	-11 9	289 12	+10 29
40	52 14	332 58	-11 9	289 2	+10 26
14 0	57 15	332 57	-11 9	288 52	+10 22
20	62 16	332 57	-11 10	288 42	+10 18
40	67 17	332 56	-11 10	288 31	+10 14
15 0	72 17	332 55	-11 10	288 21	+10 10
20	77 18	332 54	-11 10	288 11	+10 6
40	82 19	332 54	-11 11	288 0	+10 3
16 0	87 20	332 53	-11 11	287 50	+ 9 59
20	92 21	332 52	-11 11	287 40	+ 9 55
40	97 22	332 51	-11 12	287 30	+ 9 52
17 0	102 22	332 50	-11 12	287 20	+ 9 48
20	107 23	332 50	-11 12	287 10	+ 9 44
40	112 24	332 49	-11 12	286 59	+ 9 40
18 0	117 25	332 48	-11 13	286 49	+ 9 36
20	122 26	332 47	-11 13	286 39	+ 9 32
40	127 27	332 47	-11 13	286 28	+ 9 29
19 0	132 27	332 46	-11 14	286 18	+ 9 25
20	137 28	332 45	-11 14	286 8	+ 9 21
40	142 29	332 44	-11 14	285 58	+ 9 18
20 0	147 30	332 43	-11 15	285 48	+ 9 14
20	152 31	332 43	-11 15	285 38	+ 9 10
40	157 31	332 42	-11 15	285 28	+ 9 6
21 0	162 32	332 41	-11 15	285 18	+ 9 2
20	167 33	332 40	-11 16	285 8	+ 8 58
40	172 34	332 40	-11 16	284 57	+ 8 55
22 0	177 35	332 39	-11 16	284 47	+ 8 51
20	182 36	332 38	-11 17	284 37	+ 8 47
40	187 36	332 37	-11 17	284 27	+ 8 43
23 0	192 37	332 36	-11 17	284 17	+ 8 39
20	197 38	332 36	-11 17	284 7	+ 8 35
40	202 39	332 35	-11 18	283 57	+ 8 32
24 0	207 40	332 34	-11 18	283 47	+ 8 28

HEURE SIDÉRALE ET HEURE CIVILE					
Temps sidéral	Temps civil	Temps sidéral	Temps civil	Temps sidéral	Temps civil
210 °	0 h 13 m 16 s	330 °	8 h 11 m 57 s	90 °	16 h 10 m 38 s
220	0 53 9	340	8 51 50	100	16 50 32
230	1 33 2	350	9 31 44	110	17 30 25
240	2 12 56	0	10 11 37	120	18 10 19
250	2 52 49	10	10 51 31	130	18 50 12
260	3 32 43	20	11 31 24	140	19 30 5
270	4 12 36	30	12 11 18	150	20 9 59
280	4 52 30	40	12 51 11	160	20 49 52
290	5 32 23	50	13 31 4	170	21 29 46
300	6 12 17	60	14 10 58	180	22 9 39
310	6 52 10	70	14 50 51	190	22 49 33
320	7 32 3	80	15 30 45	200	23 29 26
330	8 11 57	90	16 10 38		

CORRECTIONS POUR LA LUNE			
Variation de Temps civil	Variations de		
	T. sidéral	Asc. droite	Déclin.
m	° ′		
0	0 0	0	0
1	0 15	1	0
2	0 30	1	0
3	0 45	2	1
4	1 0	2	1
5	1 15	3	1
6	1 30	3	1
7	1 45	4	1
8	2 0	4	1
9	2 15	5	2
10	2 30	5	2

TEMPS de Greenwich		VÉNUS		MARS	
Civil	Sidéral	Ascension droite	Déclinaison	Ascension droite	Déclinaison
0 h m	206 ° 41 ′	337 ° 19 ′	-16 ° 17 ′	116 ° 21 ′	-20 ° 43 ′
20	211 41	337 19	-16 17	116 23	-20 43
40	216 42	337 20	-16 16	116 23	-20 43
1 0	221 43	337 20	-16 16	116 23	-20 43
20	226 44	337 21	-16 16	116 23	-20 43
40	231 45	337 21	-16 15	116 23	-20 43
2 0	236 46	337 22	-16 15	116 23	-20 43
20	241 46	337 22	-16 15	116 23	-20 44
40	246 47	337 22	-16 14	116 23	-20 44
3 0	251 48	337 23	-16 14	116 23	-20 44
20	256 48	337 23	-16 14	116 23	-20 44
40	261 50	337 24	-16 13	116 23	-20 44
4 0	266 50	337 24	-16 13	116 23	-20 44
20	271 51	337 25	-16 13	116 23	-20 44
40	276 52	337 25	-16 12	116 23	-20 44
5 0	281 53	337 26	-16 12	116 26	-20 44
20	286 54	337 26	-16 12	116 26	-20 44
40	291 55	337 26	-16 11	116 26	-20 44
6 0	296 55	337 27	-16 11	116 26	-20 44
20	301 56	337 27	-16 11	116 26	-20 44
40	306 57	337 28	-16 10	116 26	-20 44
7 0	311 58	337 28	-16 10	116 26	-20 44
20	316 59	337 29	-16 10	116 26	-20 44
40	321 59	337 29	-16 9	116 26	-20 44
8 0	327 0	337 30	-16 9	116 26	-20 44
20	332 1	337 30	-16 9	116 26	-20 44
40	337 2	337 30	-16 8	116 26	-20 44
9 0	342 3	337 31	-16 8	116 26	-20 44
20	347 4	337 31	-16 8	116 26	-20 44
40	352 4	337 32	-16 7	116 26	-20 44
10 0	357 5	337 32	-16 7	116 26	-20 44
20	2 6	337 33	-16 7	116 26	-20 44
40	7 7	337 33	-16 6	116 26	-20 44
11 0	12 8	337 34	-16 6	116 27	-20 44
20	17 8	337 34	-16 6	116 27	-20 44
40	22 9	337 35	-16 5	116 27	-20 44
12 0	27 10	337 35	-16 5	116 27	-20 44

TEMPS de Greenwich		VÉNUS		MARS	
Civil	Sidéral	Ascension droite	Déclinaison	Ascension droite	Déclinaison
12 h m	27 ° 10 ′	337 ° 35 ′	-16 ° 5 ′	116 ° 27 ′	-20 ° 44 ′
20	32 11	337 35	-16 5	116 27	-20 44
40	37 12	337 36	-16 4	116 27	-20 44
13 0	42 13	337 36	-16 4	116 27	-20 44
20	47 13	337 37	-16 4	116 27	-20 44
40	52 14	337 37	-16 3	116 27	-20 44
14 0	57 15	337 38	-16 3	116 27	-20 44
20	62 16	337 38	-16 3	116 27	-20 44
40	67 17	337 39	-16 2	116 27	-20 44
15 0	72 17	337 39	-16 2	116 27	-20 44
20	77 18	337 39	-16 2	116 27	-20 44
40	82 19	337 40	-16 1	116 27	-20 44
16 0	87 20	337 40	-16 1	116 27	-20 44
20	92 21	337 41	-16 1	116 27	-20 44
40	97 22	337 41	-16 0	116 28	-20 44
17 0	102 22	337 42	-16 0	116 28	-20 44
20	107 23	337 42	-16 0	116 28	-20 44
40	112 24	337 42	-15 59	116 28	-20 44
18 0	117 25	337 43	-15 59	116 28	-20 44
20	122 26	337 43	-15 59	116 28	-20 44
40	127 27	337 44	-15 59	116 28	-20 44
19 0	132 27	337 44	-15 58	116 28	-20 44
20	137 28	337 45	-15 58	116 28	-20 44
40	142 29	337 45	-15 58	116 28	-20 44
20 0	147 30	337 46	-15 57	116 28	-20 45
20	152 31	337 46	-15 57	116 28	-20 45
40	157 31	337 46	-15 57	116 28	-20 45
21 0	162 32	337 47	-15 56	116 28	-20 45
20	167 33	337 47	-15 56	116 28	-20 45
40	172 34	337 48	-15 56	116 28	-20 45
22 0	177 35	337 48	-15 55	116 29	-20 45
20	182 36	337 49	-15 55	116 29	-20 45
40	187 36	337 49	-15 55	116 29	-20 45
23 0	192 37	337 50	-15 54	116 29	-20 45
20	197 38	337 50	-15 54	116 29	-20 45
40	202 39	337 50	-15 54	116 29	-20 45
24 0	207 40	337 51	-15 53	116 29	-20 45

TEMPS de Greenwich		JUPITER		SATURNE	
Civil	Sidéral	Ascension droite	Déclinaison	Ascension droite	Déclinaison
0 h	206 ° 41	61 ° 44 ′	-21 ° 2 ′	359 ° 50 ′	- 2 ° 9 ′
2	236 46	61 44	-21 2	359 49	- 2 9
4	266 50	61 44	-21 2	359 49	- 2 8
6	296 55	61 43	-21 2	359 48	- 2 8
8	327 0	61 43	-21 2	359 48	- 2 8
10	357 5	61 42	-21 2	359 47	- 2 8
12	27 10	61 42	-21 2	359 47	- 2 8

TEMPS de Greenwich		JUPITER		SATURNE	
Civil	Sidéral	Ascension droite	Déclinaison	Ascension droite	Déclinaison
12 h	27 ° 10	61 ° 42 ′	-21 ° 2 ′	359 ° 47 ′	- 2 ° 8 ′
14	57 15	61 41	-21 2	359 46	- 2 7
16	87 20	61 41	-21 1	359 46	- 2 7
18	117 25	61 41	-21 1	359 45	- 2 7
20	147 30	61 40	-21 1	359 45	- 2 7
22	177 35	61 40	-21 1	359 44	- 2 6
24	207 40	61 39	-21 1	359 44	- 2 6

the sidereal time is measured in degrees and minutes of arc. As the aviator is no longer using units graduated in time intervals it is necessary to furnish him with these data in degrees and minutes of arc.

The aeronautical ephemerides have been compiled with the sole aim of satisfying these requirements of aviation. We desire that the aviator should be able to obtain the data required for calculating his position in the simplest manner possible. After that he will complete his calculations with the aid of other devices, but these tables have been compiled so that by a simple addition one may obtain the hour angle immediately.

There exist also other precedents. In America, in the United States, there were published in 1932 ephemerides of this kind which were not entirely identical but which were nevertheless compiled especially for aviators.

In France, at the close of the year 1935 the Air Ministry requested the *Bureau des Longitudes* to publish tables of this kind and I was given charge of their preparation with the assistance of the expert calculators in this Bureau; it sufficed for me to state what we wanted to accomplish and they produced something with which I could not find the slightest fault. With the exception of the civil time, which is given in hours, all of the data for the calculations are given in degrees and minutes of arc. Since the aviators wish to reduce all calculations to a minimum, it is necessary to avoid interpolations. With the aviation sextants the closest reading at present is to within about 6 or 7 minutes of arc. It will suffice therefore to give the data to the nearest minute of arc and, for the Sun, for intervals of 5° in order that no interpolations should be necessary. The aviator has only to take from the table the number corresponding to the time of the observation in order to calculate the hour angle. This is obtained accurately in the case of the Sun, Venus, Mars, Jupiter and Saturn : but for the Moon, which aviators are led to observe rather frequently, we have not been able to do away entirely with interpolations. For the Moon, therefore, the problem still remains.

For practical reasons, one should not require aviators to carry such a large volume with them on their flights, and therefore we have perforated the pages so that those actually needed for the data may be torn out of the volume. If, for instance, one were leaving on 14th August for a flight of two days, one would simply take the pages for August 14th and 15th, together with the appended fascicle which comprises only 5 pages.

This appendix contains the positions of 72 principal stars given for the middle of the year, and a few small secondary tables as well. A single page gives the calculations for latitude from the observed altitude of Polaris. There is also a correction for refraction. At an altitude of 10,000 metres, the refraction is only about three-tenths of the value on the ground.

The appendix also gives the dip of the horizon, which is useful at times; the semi-diameter of the Sun and the semi-diameter of the Moon. We have been obliged to insert a table giving the parallax of the Moon.

The first volume was issued in 1936, and the publication will be regularly continued. In the ephemerides of 1937 certain simplifications have been effected. For the parallax of the Moon another table has been provided in order to avoid the necessity for multiplying by the sine of the altitude.

These tables have been published at the request of the Air Ministry; we hope that civil aviation will also avail itself of these tables; the purchase of them in this connection has already begun.

I might add that it is preferable to make use of chronometers graduated in degrees and minutes. In order that these instruments may be easily read in spite of the agitations, one may employ the type known as the " guichet " (window or gas-meter type) in which the degrees appear in openings, or in large figures.

RECENT CHARTS.

Subsequent to the International Hydrographic Conference of 1932, the French *Service Hydrographique* adopted for its charts, on which the metre is used as unit, the system of representation of the isobaths recommended by that Conference. A certain number of charts have been prepared in accordance with this convention. Here is one that has just been completed (Chart N° 5818). Here is another now being engraved. The convention is readily understood by reference to the table on page 410 of the Report of Proceedings of the 1932 Hydrographic Conference.