# GEODETIC FLARE TRIANGULATION

by THE FRENCH NATIONAL GEOGRAPHICAL INSTITUTE

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The principle governing the geodetic method of simultaneous observations of parachute flares is not new. Frequently referred to in English as "Flare triangulation", this method had previously been used in certain long distance geodetic connexions, but the accuracy of the results was comparatively poor owing to difficulties of synchronized observations.

The studies and experiments conducted at the Institut Géographique National in the last two years have resulted in the development of a simple operation procedure as well as a simple equipment which gave very accurate results which compare favourably with other methods that are more expensive and more complicated.

## Principle

Given two points (1) and (2) connected geodetically it is proposed to determine the coordinates of a third point (3) not visible from the first two. Flares are dropped from an aircraft, and serve as light signals to be observed in perfect synchronism from three position (1), (2) and (3). If A, B and C are three flare positions in the zone of release, the points A, B and C are calculated from (1) and (2) by intersection, and (3) is calculated from A, B and C by resection. Once the position of (3) is known, it can be used to determine the position of another point which we shall denote as (4), and so on.

At each point the astronomical coordinates are determined, giving the deviation of the vertical, as well as a Laplace azimuth.

## Technique of measurement

Observations are made at night with Wild T3 theodolites, in exactly the same way as with the usual first order measurement.

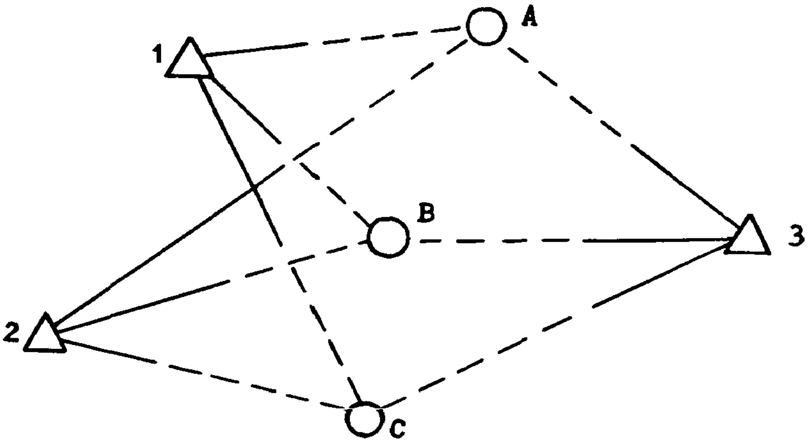

Fig. 1

A $10^6$ candle flare is dropped from an aircraft flying at an altitude of approximately 8 kilometres. In order to slow down the speed of fall, the flare is fitted with a parachute. The observation team using a reticule, follow the flare as it moves slowly, and take simultaneous readings as they listen to the "pips" of a time signal given by a quartz clock.

In practice, the observation " pips " are sent out at intervals of 10 seconds, and there is a cautionary " pip " warning the observer team every two seconds before. The emission schedule is as follows :

| | Warning | Observ. | Warning | Observ. | Warning | Observ. |
|---|---|---|---|---|---|---|
| pip ...... | 8 s | 10 s | 18 s | 20 s | 28 s | 30 s |

Generally speaking, it is possible to take 15 to 20 readings on the same flare (the flare lasts approximately 4 minutes).

The accuracy of the synchronization of clocks at observation stations is approximately 1/100 of a second, verified with the help of international time signals (T.U.). The equipment which consists of a radio receiver at each station, a quartz clock and a selector is simple, accurate, resistant and not too cumbersome. It was developed and constructed at the Radio Laboratory of the Institut Géographique National.

Every night the aircraft flies over the three release zones A, B and C dropping 2 to 3 flares in each zone, in accordance with a prearranged timetable. The pilot and the observer team are in constant touch by radio. To achieve the required degree of accuracy, there must be at least two flights on different nights.

The astronomical coordinates are observed on the same nights, by the method of equal altitudes at the zenith distance of 30°.

The Laplace azimuth is observed by the circumpolar star method, generally on $\alpha$ U. Min. at its maximum elongation.

## Computation and adjustment

For small networks of 3 to 4 points, the computation is easily done by the graphical method of position lines, which consists of plotting on a special sheet at a large scale the various position lines obtained from observations (1). In the case of large networks, adjustment is achieved by the least squares method.

It is worth noting that if the horizontal angular displacement of the falling flare is less than 0.5 of a degree, the mean value of synchronous readings at each station may be regarded as defining the position observed by each theodolite. This makes it possible for the solution to reduce the number of auxiliary points such as A, B, C to 5 or 6.

It is interesting to note that observation of the azimuth at each station provides a redundant condition for fixing the position of the unknown point : it is clear that the position of point (3) can be calculated only by resection from points A, B and C. The sighting 3—A, 3—B, 3—C constitutes an additional condition for determining the point.

It is to be noted that the determination of the astronomical coordinates at each station gives the plumb line deflection as it exists there, and makes it possible to take account of the Laplace relationship in the orientation of the station.

## Results

An initial experiment was carried out in September 1964 to test the accuracy of the readings.

A team of three observers, using the equipment mentioned above, worked with three Wild T 3 theodolites which were synchronized as perfectly as possible. After reduction to the same origin, the mean value was taken and the deviations between each individual reading and the mean value were studied.

The deviation was found to be ± 5 to ± 6 sexagesimal seconds. These measurements were taken on 9 flares dropped in three nights with approximately 15 readings on each flare.

Later, in the summer of 1965, the Institut Géographique National carried out a similar operation in an archipelago where the islands are 200 kilometres away from each other. The computation now being completed shows that the mean error of position for any of the points A, B and C (with 15 readings per flare) is approximately ± 1 m, and as a result, the mean error for point (3) is ± 1.5 m.

In this second experiment, two theodolites were at each station sighting simultaneously on each flare; the observations of these two theodolites which are oriented on a ground reference mark were reduced to a common point and checked each other (see Annex).

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(1) Method used in France to calculate isolated points of triangulation. In such a case, the same results can be obtained by the method of least squares.

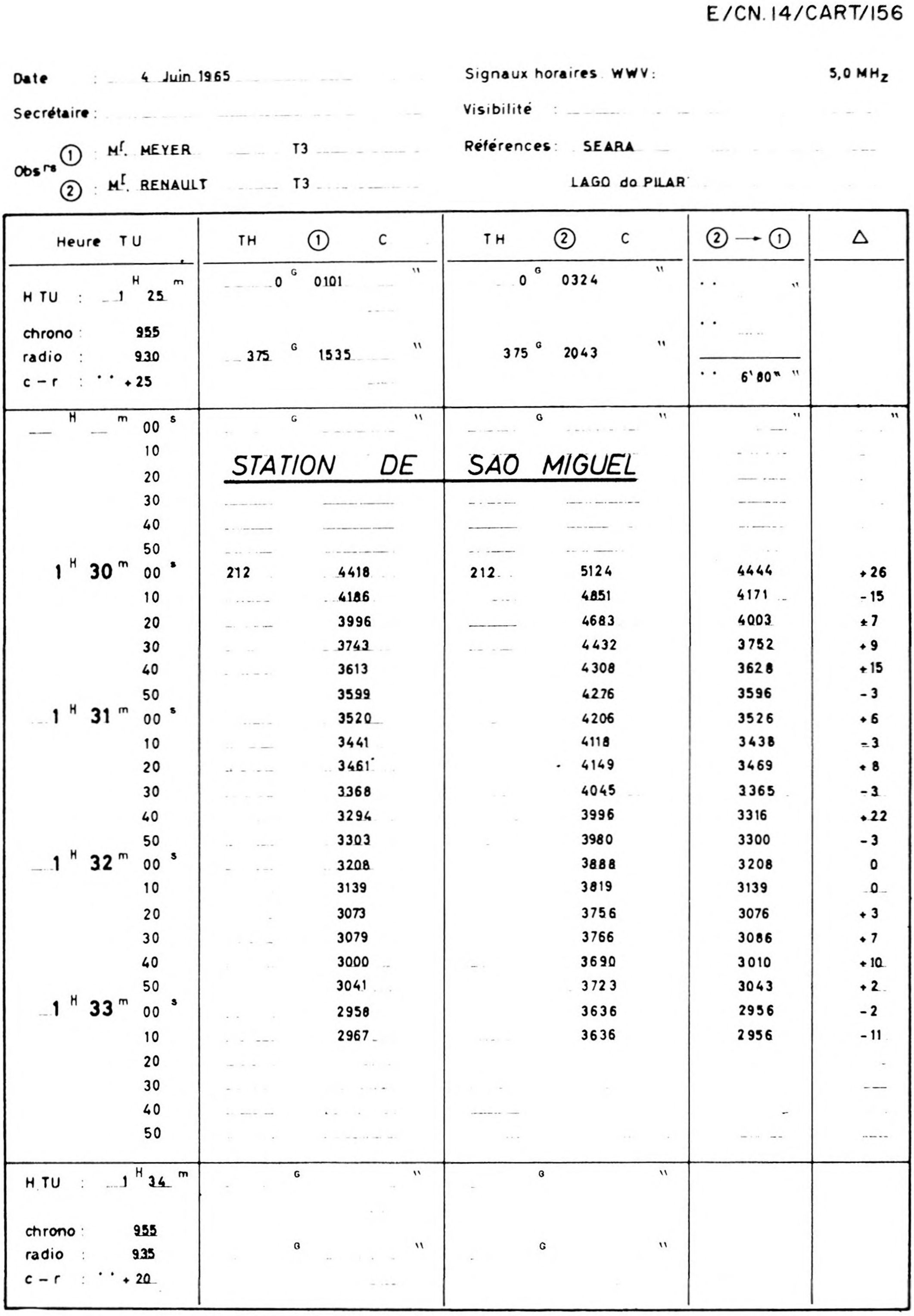
## Large triangulation networks

Flare triangulation seems to be very well adapted to the establishment of extensive geodetic networks containing long triangle sides and, therefore, a reduced number of points (density : 1 point per 20 000 to 50 000 square km). Of course one fundamental point must be given (or established) and several oriented base-lines of 200-250 km should be measured between two terminals. Such base-lines may be the classical triangulation nets (or traverse nets) at a well-determined scale. The first order nets should be made up of triangles which are observed in accordance with the standards for first order accuracy : in each triangle one side at least should be measured by means of an accurate electro-magnetic process, and at each end a Laplace azimuth observed (accuracy 0″5).

## Conclusion

The method outlined will thus make it possible to establish a geodetic network of first order with excellent accuracy (better than 1/100 000) in areas in which travelling is difficult or impossible, and to connect points at long distances and over wide expanses. This method is comparatively simple to put into practice and only requires equipment which is strong, not too cumbersome, easy to handle and, the most important of all, cheap.

On the other hand, it entails making observations at night and, above all, calls for favourable weather conditions, namely a clear sky over the whole operational zone, since light signals should in principle be simultaneously observable from all stations.



E/CN.14/CART/156

Date : 4 Juin 1965

Signaux horaires WWV : 5,0 MHz

Secrétaire :

Visibilité :

Obs^rs ① : M^r. MEYER T3

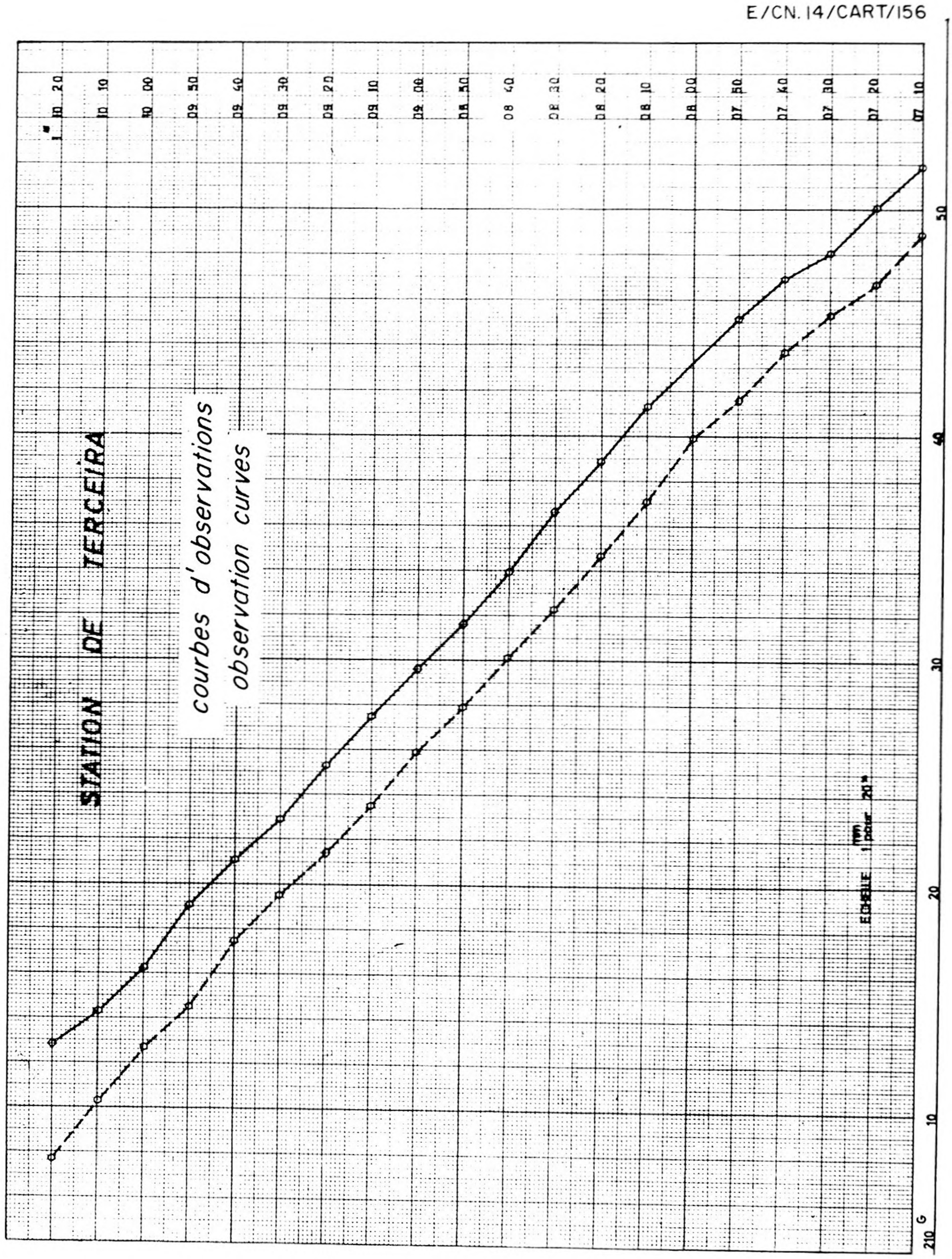
② : M^r. RENAULT T3

Références : SEARA

LAGO do PILAR

| Heure TU | TH ① | C ① | TH ② | C ② | ② → ① | △ |
|---|---|---|---|---|---|---|
| H TU : 1^H 25^m | 0^G | 0101" | 0^G | 0324" | .. " | |
| chrono : 955<br>radio : 930<br>c − r : .. + 25 | 375^G | 1535" | 375^G | 2043" | ..<br>.. 6'80" " | |
| H m 00 s | G | " | G | " | " | " |
| 10 | | | | | | |
| 20 | STATION DE | | SAO MIGUEL | | | |
| 30 | | | | | | |
| 40 | | | | | | |
| 50 | | | | | | |
| 1^H 30^m 00^s | 212 | 4418 | 212 | 5124 | 4444 | +26 |
| 10 | | 4186 | | 4851 | 4171 | −15 |
| 20 | | 3996 | | 4683 | 4003 | ±7 |
| 30 | | 3743 | | 4432 | 3752 | +9 |
| 40 | | 3613 | | 4308 | 3628 | +15 |
| 50 | | 3599 | | 4276 | 3596 | −3 |
| 1^H 31^m 00^s | | 3520 | | 4206 | 3526 | +6 |
| 10 | | 3441 | | 4118 | 3438 | −3 |
| 20 | | 3461 | | 4149 | 3469 | +8 |
| 30 | | 3368 | | 4045 | 3365 | −3 |
| 40 | | 3294 | | 3996 | 3316 | +22 |
| 50 | | 3303 | | 3980 | 3300 | −3 |
| 1^H 32^m 00^s | | 3208 | | 3888 | 3208 | 0 |
| 10 | | 3139 | | 3819 | 3139 | 0 |
| 20 | | 3073 | | 3756 | 3076 | +3 |
| 30 | | 3079 | | 3766 | 3086 | +7 |
| 40 | | 3000 | | 3690 | 3010 | +10 |
| 50 | | 3041 | | 3723 | 3043 | +2 |
| 1^H 33^m 00^s | | 2958 | | 3636 | 2956 | −2 |
| 10 | | 2967 | | 3636 | 2956 | −11 |
| 20 | | | | | | |
| 30 | | | | | | |
| 40 | | | | | | |
| 50 | | | | | | |
| H TU : 1^H 34^m | G | " | G | " | | |
| chrono : 955<br>radio : 935<br>c − r : .. + 20 | G | " | G | " | | |

Fig. 2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STATION DE TERCEIRA
courbes d'observations
observation curves
1h 10 20
10 10
10 00
09 50
09 40
09 30
09 20
09 10
09 00
08 50
08 40
08 30
08 20
08 10
08 00
07 50
07 40
07 30
07 20
07 10
210 G
10
20
30
40
50
ECHELLE 1mm pour 20s

FIG. 3