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A NEW SATELLITE OBSERVATORY AT KOOTWIJK

BY

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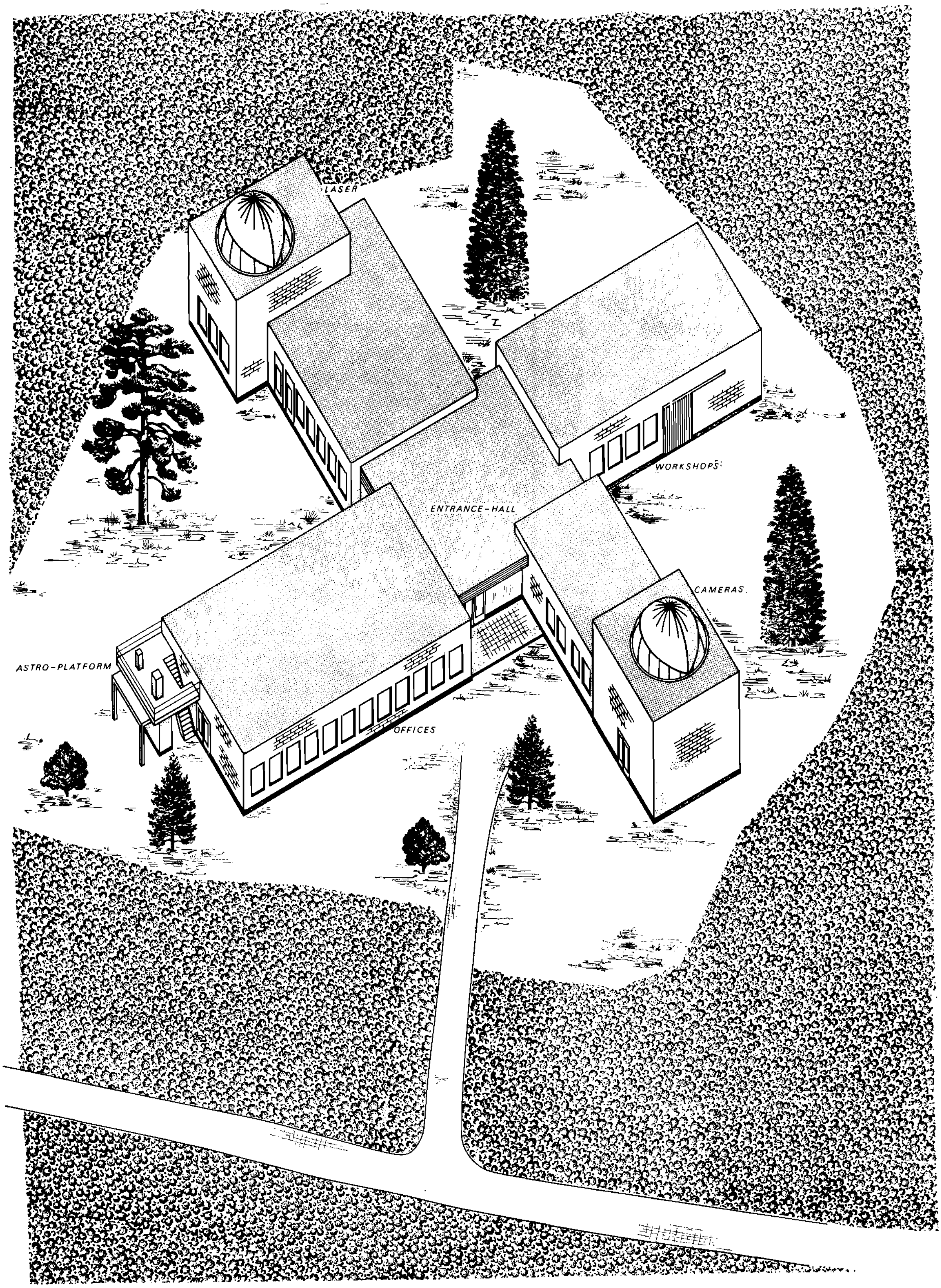


Bird's eye view of the new observatory

A NEW SATELLITE OBSERVATORY AT KOOTWIJK

1 Introduction

The Working Group for Satellite Geodesy is part of the Sub-Department of Geodesy of the Delft University of Technology (THD) and is represented in the Netherlands Committee for Geophysics and Space Research (GROC) of the Royal Netherlands Academy of Sciences.

It has been assigned the tasks of teaching and investigation in the field of satellite geodesy; since 1966, it has participated in a number of satellite observation projects, such as the U.S. National Geodetic Satellite Program (NGSP), the Western European Satellite Triangulation (WEST), the International Satellite Geodesy Experiment (ISAGEX) and the present European Short Arc Programme. This covers the so-called photographic determination of direction towards satellites. In the meantime the Working Group developed theoretical an practical calculation schemes in order to be able to use the observations made simultaneously with other stations for calculations in geodetic networks. It is intended to continue this work.

The Working Group together with its observation facilities is the only one of its kind in The Netherlands so that practical and significant satellite geodesy is possible only in cooperation with similar and comparable foreign institutes. This cooperation has already been initiated and future plans in this field have been drawn up. This is of particular importance in view of the planned purchase of the highly accurate laser-ranging system for measuring distances between the station and a number of satellite positions. This system constitutes a sophisticated addition to the existing photographic direction-measuring system. In view of the high accuracy aimed at, the use of a second-generation laser ranging system could lead to international cooperation in the multidisciplinar field of geodynamics.

Since the end of 1973, all activities of the Working Group have been carried out in the new observatory at Kootwijk near Apeldoorn; the laser-ranging equipment will be ready for observations by the end of 1975.

2 Possibilities with satellite geodesy

Geodesy is a branch of applied mathematics that determines the shape and size of the earth and of large portions of the earth's surface.

A description of the physical reality known as "earth" or "portion the earth's surface" is essential to geodesy. For this purpose use is made of the science of mathematics: we translate the physical reality into points-lines-polygons-triangles. We make a destinction between a number of working stages: we start with the work of the highest order and complete this in the following stages. This is also known as working from the great to the small. This brings us eventually to those stages which are of direct technical significance. We can build houses and indicate topography and also dykes, roads and water-ways; we can make maps and other such documentation. At the top of the pyramid-like phased geometric

model we have the first stage, consisting as a rule of a triangular configuration or triangulation. These triangulations can cover smaller or greater regions such as countries or perhaps continents, whereby it has to borne in mind that these triangulations have drawbacks arising from the restrictions which characterize measurements carried out on earth. These restrictions are in particular:
- refraction and heat shimmer because of measurements at a large zenith angles;
- absorption and light scattering in the atmosphere;
- curvature of the earth giving limited visibility both ways.

Owing to these limitations the triangles in our triangulations (i.e. the primary mathematical pattern) are rather small with sides of 50 to 100 km. These so-called continental or conventional triangulations are usually not more accurate than $1:10^5$ or 1 m at 100 km.

To obtain full information on shape and size of the surface, the triangular measurement has to be supplemented with levelling and gravity measurements. These gravity measurements are necessary as a supplement of the conventional triangulations, since these are essentially two dimensional. This is where the problem of potential theory crops up in geodesy, so that in this field we have clear physical-dynamic as well as geometric aspects.

Geodesy has experienced some revolutionary developments, such as developments in the field of photogrammetry (land-surveying on the basis of aerial photos), re-allotment of land, management of real estate, town and country planning, deformation measurements, calculating techniques with the aid of computers, etc. The launching of artificial satellites has also proved to be of tremendous importance for the so-called higher geodesy.

Since the earth satellites are always sent outside the atmosphere, most of these objects orbit at a height of at least 400 to 500 km.

This is obviously much higher than the church-towers in the conventional triangulations are! They also move about much more than these church-towers; the velocity is of the order of 7 km/s for the lowest satellites. This creates again a problem that has to be solved by special instruments and observation methods.

In this way it is possible to build up a system that solves all the problems of the conventional triangulations, while at the same time providing the following advantages:
- covering extremely long distances (1000 km or more);
- relative accuracies of at least the same order of magnitude as with the conventional triangulations;
- the scale (distances) can be applied systematically.

A direct result of the above advantages is that we now have coordinates in one world-wide system. This renders possible super control of the existing triangulations, which – let us not forget – remain very necessary. Interconnection can now be sought and established on a much larger scale than hitherto. In addition to this purely geodetic aspect, there are possibly more important aspects; these shall be referred to later on.

The first of the observation methods is that whereby the satellite is photographed while travelling in its orbit. The purpose of this is to determine directions. Obviously this is also possible with a theodolite the speed of the object is such, however, that we are faced with an unacceptable loss of accuracy, since we require at least one second of arc per direction and a fixed point of time accurate to a least one msec.

Such a degree of accuracy is impossible with a theodolite: the speed at which the object passes the reticle wires is too high. Just to give an impression of the speed we are dealing with: a satellite at a height of 600 km passes through a field of view of approximately 5° in about 10 seconds.

An obvious way of solving this problem is to photograph the object and at the same time record the instants of time. These instants of time are necessary with a view to synchronisation of the observations after the event. After many operations, the end-result is a group of directions referred to an astronomical system and labelled with the relevant instants of time. This gives us:

- either a group of directions, determined entirely geometrically, between participating stations;
- or a number of satellite orbits reconstructed from various stations, which contain information on the structure of the gravitational potential of the earth;
- or a set-up in which coordinates, as well as disturbing potential-coefficients, are determined.

This latter set-up is usually chosen, since coordinates occur in a system which:

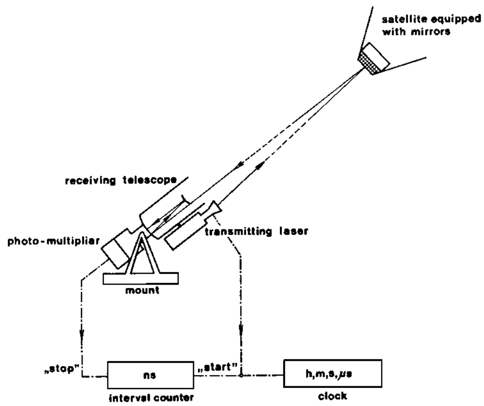
- is oriented in space, and
- may have the centre of mass of the earth as its source.

We see here, therefore, that directions are determined and since this is done on the basis of directions towards stars, we use a so-called star-catalogue. In this catalogue we have an oriented system in which in fact directions are indicated towards known points, i.e. the stars. The accuracy of these directions is limited, however, to some tenths of a second of arc.

In combination with the other "error sources" this means that the directions that are to be determined will never have an accuracy better than 0.5 to 1 second of arc. This leads to a relative accuracy of $1:5\cdot10^5$ or better; roughly speaking 7 to 10 m in the position of an observation station on earth, i.e. precision on the 1 metre level [1].

In addition to direction measurements there are also distance measurements to satellites. These measurements are carried out with ranging methods and are applied in the radio section, as well as in the optical section of the electro-magnetic spectrum. Very promising results have already been obtained with the aid of lasers; we have reasons to believe that the relative accuracies of the above-mentioned method are far surpassed by the accuracies obtained with these lasers. The method of operation is as follows: A very short light-pulse is emitted from a station on earth and retro-reflected by the satellite towards that observation station where the travel time of the light signal is then measured. Half of this travel time multiplied by the light-velocity yields the required distance. But here again, we are faced with many problems. The light-pulse, for instance, must be as short as possible, in order to obtain the greatest accuracy. Are we thinking in terms of decimetre precision? If so, that means that a precision in time of 10 cm in respect of 300,000 km/s is approximately $0.33\cdot10^{-9}$ s or 0.33 nsec. This requires electronic counters which have such a resolution; the steepness of the pulse flanks must be well-defined, etc. In addition the total amount of energy to be emitted must be of the order of one Watt-second or more. In terms of power this means light-pulses of 10^9 Watts.

Furthermore, the satellite must be, what is known as cooperative, i.e. that it has mirrors on board which reflect the emitted light and that it does this towards the observing station. The emitted light must necessarily be in a very narrow beam, since the energy density received will have decreased by the inverse fourth power of the distance. Yet, since we



Principle laser distance measurement

wish to hit the satellite, this again means special prediction requirements. These are the variables in accordance with which the laser and receiver are selected. The receiving unit is also governed by very severe requirements. Yet, it is being used and the results are promising. Results obtained up to now yield a relative accuracy of $1:5 \cdot 10^5$ to $1:10^6$ or better, roughly speaking, 5 to 1 m in the position of an observation station on earth [2].

We should bear in mind here that higher levels of accuracy mean that the coordinates can no longer be related to the centre of mass of the earth, since this requires the satellite orbits be taken into account continuously. And this is at the cost of the greater part of the extra accuracy gained. It will, therefore, be possible to apply the greater relative accuracy in a network of observation stations on earth, such that only the form and the scale are determined and, therefore, no orientation and absolute location. The two last-mentioned aspects are possible only with a more restricted accuracy, as we have already seen. This problem is discussed by LAMBECK in N.G.T. [3].

Yet the more accurate result of lasers measurements is of vital importance to geodesists. This is not only in relation to "still higher, still harder, and still further". Just imagine what it would mean if, within a number of years decimetre-precision and centimetre-precision can be realized. A whole new range of applications would be opened up for geodesists, geophysisists and astronomers: satellite geodynamics.

This field could be considered as having a bearing on the dynamics of the earth-moon system. It comprises, inter alia, the problem of earth tides and plate tectonics, polar motions and variations in the earth's rotation rate; in addition to this there are now special stations which carry out laser distance measurements to reflectors on the moon with a claimed precision of about 30 cm [4].

The precision aimed at is 2 to 3 cm, and that means a relative precision of better than $1:10^{10}$. There is a very clear task for geodesy within the framework of these possibilities, both in carrying out observations, as well as in model theoretical studies, testing etc. [5].

In addition to the laser distance measurements, radar measurements are also carried out. In this connection special mention must be made of the Doppler method. In contrast to laser measurements, this method is restricted more by the less accurately determined refraction corrections. We can for the time being expect no better than metre-precisions here. An advantage is, however, that measurements can be carried out under all circumstances day-, night- and bad weather. The laser can be used only under favourable weather conditions, but also during the day.

Another method of obtaining highly accurate orientations is based on the application of radio-interferometry with very long base lines (VLBI) with the aid of small spatial radio-sources [6].

There is also a method with which it is not necessary to carry out observations through the lower layers of the atmosphere; this consists of measurements from satellite-to-satellite e.g. with the aid of geostationary satellites, also known as synchronous satellites. These have the same angular velocity as the earth and are, therefore, stationary with respect to the earth. The triangle formed by three of such satellites could accurately be determined and maintained by satellit-to-satellite measurements after which other measurements could be added, while the aforementioned long base line interferometry could take care of the orientation. The gravitational field could then be determined much more accurately, in greater detail, since then, for instance, the low orbit of a drag-free satellite could be determined much more accurately than at present. As a matter of fact every other satellite orbit could be determined much more accurately with respect to this triangle than is at present the case with observations from the earth.

One of the satellites for which this would be fruitful is, for instance, the Geos-C satellite, planned for 1974, which will be equipped with a radar-altimeter. This is intended in particular to scan and determine the surface of the ocean, in order to compare this with the so-called geoid, the standard equipotential surface [7].

There are hundreds of satellites orbiting round the earth; this includes a very small number of special geodetic satellites:

- Anna-1B, the first satellite equipped with flashlights; height approximately 1500 km.
- Pageos, a reflecting balloon with a diameter of approximately 30 m; height approximately 3500 km.
- Geos 1 and 2, satellites with flashlight installations, heights of 1100 to 2800 km; these are also equipped with retro-reflectors.

In addition to this there are also a number of cooperative satellites, i.e. satellites equipped with retro-reflectors, viz. Beacon-B and C and the French satellites Diadème 1 and 2 and Péole. This group of satellites is expected to be added to by:

- Timation III, which would be launched in 1974 in an approximately circular orbit at a height of about 14000 km. The satellite will be equipped with laser reflectors and will be stabilized with the aid of the gravity gradient. The Doppler system will not operate on the customary Transit frequencies, but rather at higher frequencies.
- Starlette, which would be launched in 1974 is a spherical-shaped satellite with a high mass/surface ratio; the radius will be 12 cm and the mass 50 kg. The inclination of the orbit will be approximately 50° and the height must be between 800 and 1000 km. The satellite will be equipped with some 60 retro-reflectors, but no other active elements.
- Geos-C, will be launched in 1974 in an orbit with height 840 km of very small excentricity (0.006). Inclination approximately 115°. Stabilization with the aid of gravity gradient. Further equipment:
  - a radar altimeter (± 2 metres precision); – Doppler transmitters (162/324 kHz).
  - S-band satellite-to-satellite transponder.

– coherent and non-coherent C-band transponder.

The satellite will also be used for satellite-to-satellite distance measurements from ATS-F which will be launched shortly after Geos-C.

- Lageos, would be launched at the end of 1975 in an almost polar orbit with an excentricity of 0.02 and an average height of 3650 km. This satellite will have an extremely high mass/surface ratio: the radius is 22 cm and the mass 660 kg. It will be equipped with 240 retro-reflectors, fitted at regular intervals over the sphere. There are no further active elements.
- Dialoge, would be launched at the end of 1976 in an almost circular orbit with inclination 70° and height 650 km. This satellite will also be equipped with laser retro-reflectors and Doppler transmitters which will operate together with ground stations. The Dialogue project can be considered as the test-phase for the Géole project which is planned to get off the ground around 1978.

With all these observations methods and within the framework of the successive projects we see a great number of active types of instruments. There is, for instance, a great diversity of cameras in which the focal distances vary from 35 cm to well above 1 m. There are also great variations in aperture, field of view and reduction methods, dependent on how the camera is installed: altitude-over-azimuth or equatorial with one axis parallel to the rotation axis of the earth. This wide range of variation presents extra problems when processing the data from the various stations.

It is not exaggerating to say that homogeneity is not exactly the strong point of some networks. In other cases there certainly is a homogeneous range of instruments: for instance, in the various American programmes and as far as stations of bigger organizations are concerned and also the French CNES.

In Western- and Eastern-Europe there was initially less money available resulting in an understandable diversity of cameras. In the West-European project (WEST) this diversity certainly had a disadvantageous effect on the results. There is now a kind of consolidation, however, as a result of which the best stations remain in operation. Generally speaking, these are also the stations which have taken part in various other international projects.

In these stations, cameras are used with a greater focal distance and opening: there is also comparative analysis carried out in the field of the plate reduction methods.

The geodetic rectangular coordinates of these stations have been determined in various network computations, carried out by NASA, SAO and CNES; the standard deviation of these stations is given as being better than 7 m.

Comparing the three above-mentioned networks, for instance, showed systematic differences between the SAO network on the one hand and NASA and CNES on the other hand [8].

A connection has also been established between the NASA network and the European Datum 1950. In these computations laser distance measurements were also used, which were carried out by certain American and French stations with first generation systems. These are the laser-systems with a precision in the order of metres. Up to now the following stations in Europe have been provided with such a first generation laser: San Fernando in Spain, St. Michel in France, Dyonysos in Greece, Zimmerwald in Zwitserland, Wettzell in Germany and Ondrejov in Czechoslovakia.

3 The programme of the Working Group for Satellite Geodesy

The tasks of the Working Group can be described as the execution of research in the field of satellite geodesy for the purpose of gaining experience, participating in new developments in this field and, at the same time, to make international contributions; it also supervises senior students up to and including graduation in the subject of satellite geodesy.
For these purposes the Working Group has or will have at its disposal:
- an observation station for photographic satellite observation;
- an observation station for laser distance measurements;
- two satellite cameras equatorially installed;
- time-recording apparatus;
- time-keeping equipment, including an atomic time standard and interval counter;
- an XY-comparator for measuring photographic plates;
- a remote batch terminal of the IBM 360/65 computer;
- a CPS terminal of the IBM 360/65 computer;
- computing programmes for astronomical as well as for photographic plate-reduction methods;
- darkrooms with an automatic processor with nitrogen agitation;
- an electronic workshop;
- a mechanical workshop;
- conventional geodetic instruments;
- various other facilities

The new observatory at Kootwijk is entirely operational and the components for the laser ranging system are being purchased and partially manufactured. The necessary financial means for the laser ranging project have in the meantime been made available by the GROC. The Technisch Physische Dienst TNO-TH (TPD) at Delft will assist in the development and construction of the laser-ranging equipment.

The principal system-operating requirements for this equipment are as follows:
- ranging error of less than 15 cm rms;
- able to operate during daylight hours as well as at night
- able to range at all existing and presently proposed cooperative earth satellites.

4 Some specifications of the laser equipment

The telescope mount will be developed and constructed by TPD. It will be an altitude-over-azimuth biaxial coudé-mount.

Receiving optics: aperture 50 cm.

Transmitting optics: aperture 20 cm.

The slewing rate on both axes will be at least 6° per second; the mount must settle to a new position within 4 seconds, for a change of 2°.

Closed-loop contineous operation will be possible.

The mount can be operated within a temperature range of −20 °C to +40 °C, a pressure range of 750–1100 mbar and a maximum wind velocity of 14 m/s.

The absolute value of pointing will be better than 20″.

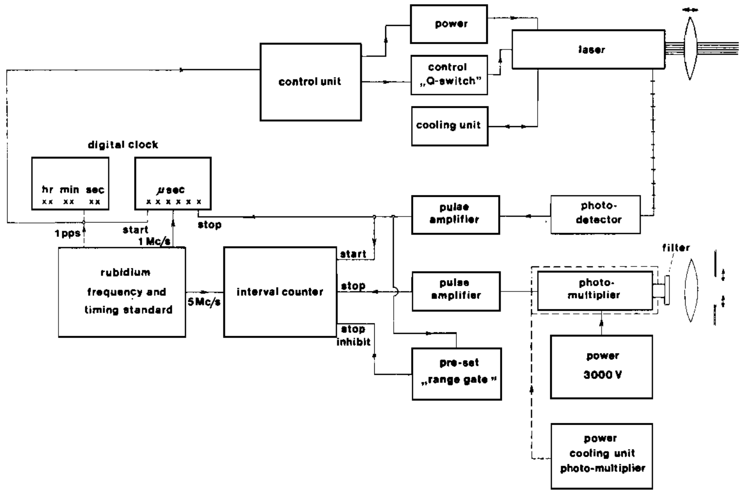


Diagram laser distance measurement equipment

The altitude axis shall be capable of automatic positioning from at least $-5°$ below horizontal pointing to $+185°$ through the zenith.

The azimuth axis shall be capable of automatic positioning from 0° clockwise from and through the north to 720° and back.

The ruby laser will have the following specifications:
Wavelength: 694 nm
Repetition rate: adjustable 0–15 ppm
Beam divergence: 5 mrad (maximum) at half power points. Can be reduced to 0.4 mrad by collimating the beam.
Maximum energy: at least 4 joules in 5 nsec in shuttered mode; at least 15 joules in 10–30 nsec in Q-switched mode; at least 40 joules (50 joules nominal) in 0.5 tot 1.0 msec in long pulse mode.
The laser can be operated between 10° and 30°C, and between 750 and 1100 mbar.

The construction of the system will be completed by november 1975.

5 Some Results

From 1966 up to now a total of more than 600 photo-plates have been observed and reduced in various projects and the results have been made available to the scientific community.

The number of exposures actually made is more than 1200, indicating a considerable amount of rejects. This means roughly 5000 directions towards satellite positions. The average estimated accuracy of such a direction is 0.8 to 1.0 second of arc and the time-recordings up to now have shown an accuracy of 0.1 to 0.2 msec.

Some members of the group devote time to theoretical scientific work, in many cases based on practical experiences of recent years.

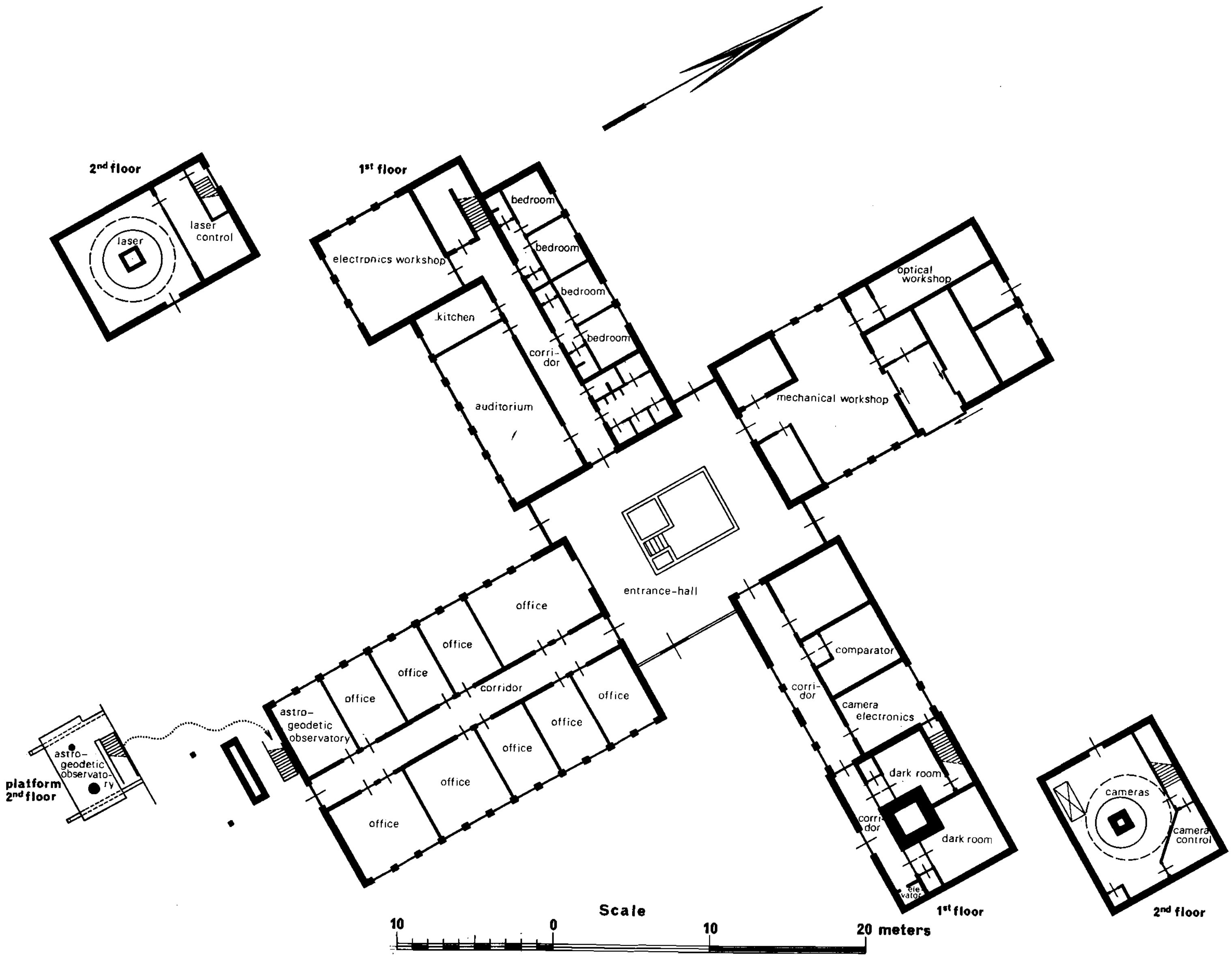
With reference to the design of the new observatory at Kootwijk one of the starting points was a desire for international cooperation. The underlying reason for this is that it was felt that exchanging scientific personel for a longer or shorter period is one of the most effective ways of achieving international cooperation. In particular with reference to the developments in the field of geodynamics, such an exchange or cooperation is considered to be necessary; this can be effected, for instances, via research-fellowships.

The Working Group concentrated in the past years on the following theoretical subjects:
- development of a calculation model to be used in networks, which are determined exclusively be means of high-precision laser distance measurements [9];
- accuracy considerations in such networks [10];
- aspects and possibilities of VLBI-applications [11];
- possible application of the quaternion theory of Prof. Baarda to satellite geodesy [12];
- analysis of GEOS-2 observations over Western-Europe, including application of modern ideas with reference to the evaluation of such observations [13];
- developing and testing a photogrammetric reduction programme for the new K-50 camera [14];
- improving the existing reduction programmes;
- developing test-programmes for the XY-comparator [15];
- feasibility studies on: laser safety equipment and an illumination laser;
- calculations within the framework of the European Short-Arc Programme [16].
- prediction of satellite observations (interpolation of directions and distances) [17].

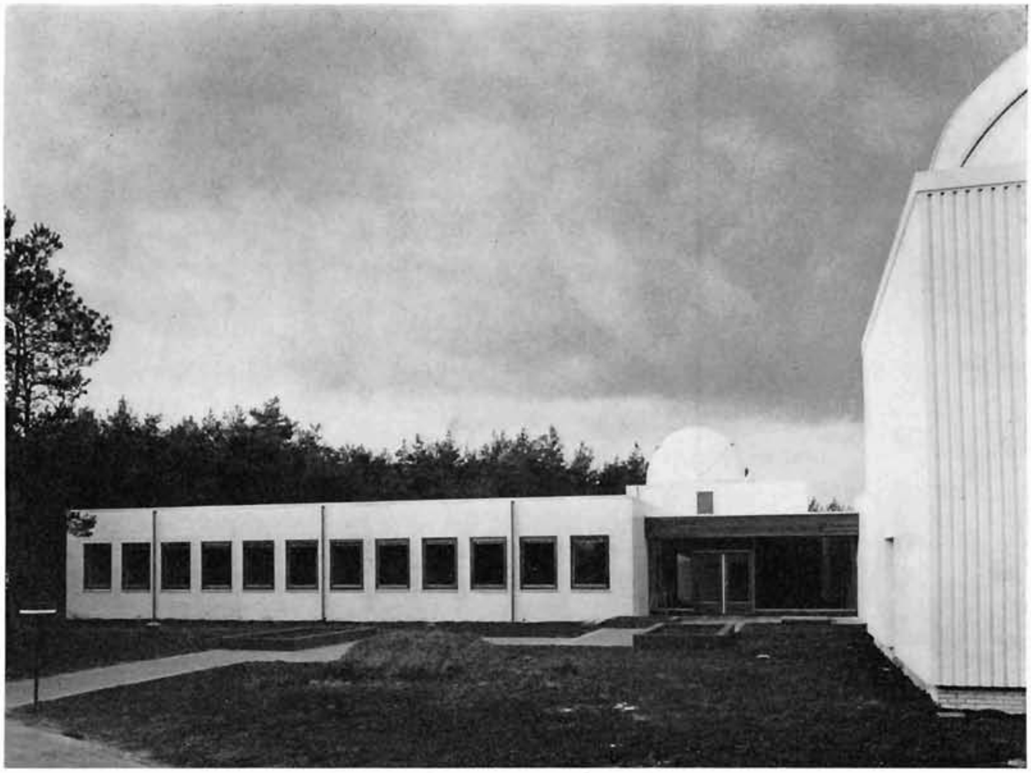
The programme of the Working Group will concentrate in the near future on research in the field of satellite geodynamics, main points of which are:
- geometric networks on the earth's surface, from which the coordinates eventually result as functions of time;
- the structure of the external gravity field;
- earth tides;
- problems regarding plate-tectonics;
- earth rotation, polar motion.

6 The new observatory

Following test observations in Delft in 1965 it became obvious that there was a need for better observation facilities. In August 1966 the Western-European Satellite Triangulation Programme was started and after some negative experiences at the then station, it was decided to house the installations provisionally at the Ypenburg Airfield. During this period, a more permanent location was sought with a view to a definitive site. The following requirements were stipulated in respect of this site:
- it must be situated at a distance of a least some kilometres from populated areas and/or busy roads so as to avoid the ocurrence of scattered light;
- it must be within reasonable distance of Delft: maximum travelling time 1 to 1½ hours by car;
- it must be protected such that it does not suffer from wind forces;
- it must nevertheless be so situated that it affords a relatively good view over the surrounding territory; this is necessary in order to be able to observe satellites down to an elevation of 20° above the horizon;



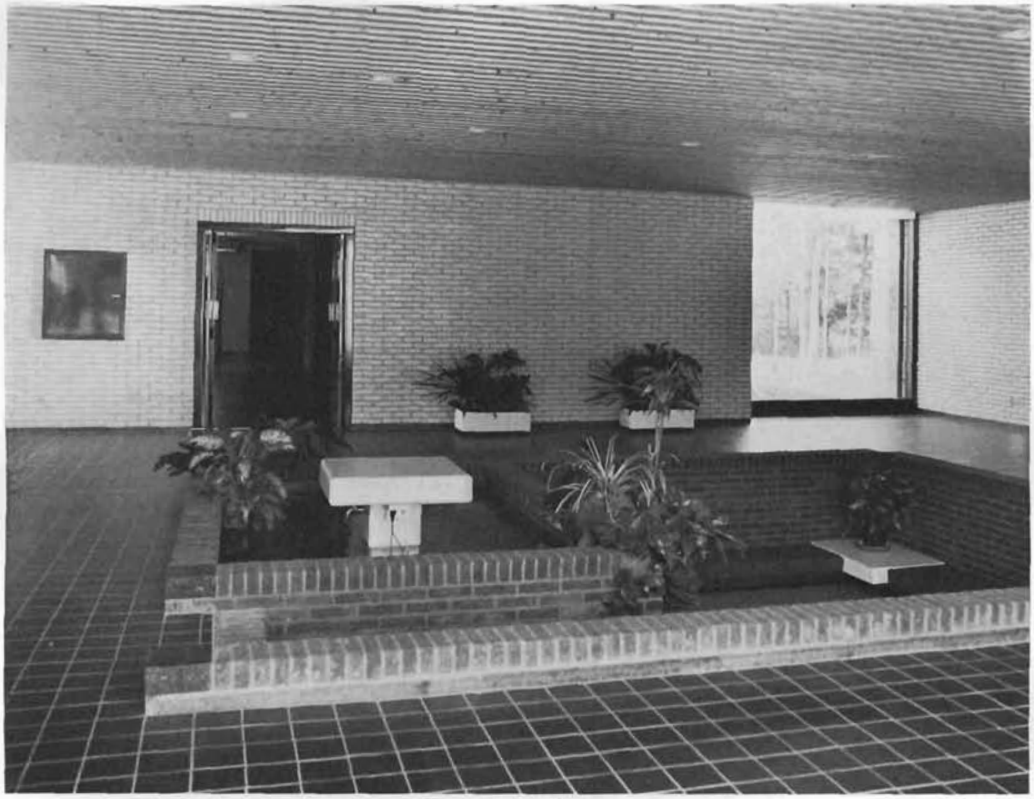
Layout of the new observatory



The new observatory seen from the east

- it must be situated in a part of The Netherlands where the stellar sky is on an average considerably clearer than in Delft;
- in connection with the high precision requirements for the observations, the composition of the ground must be such that little or no hindrance is experienced owing to vibrations caused by traffic etc.;
- there must be a reasonable certainty that the site chosen is suitable for a long period during which very precise satellite observations can be carried out.

During 1967 a site was found which complied with these requirements: it formed part of the complex at Radio Kootwijk and covered approximately 2½ acres. It is an isolated site in the middle of the woods and close to the Kootwijkerzand. In the meantime the administrative office of the Sub-Department of Geodesy and the Board of Curators of the Technological University had expressed their approval of the relevant plans so that it was possible to draw up a Programme of Requirements. This was finished in July 1968. After the Ministry of Education and Sciences had given its approval, K. J. ROOSENDAAL's architects' office in The Hague was to carry out the necessary duties. After considerable discussion, meetings, reports, etc., a draft plan (architectural) and the electrical and mechanical engineering aspects were completed and submitted for approval to the Municipality of Apeldoorn and the relevant Ministry. The municipal building licence was thereupon granted and the Minister of Scientific Policy and Scientific Education gave his approval in August of 1971, but at that time a building stop was in force. After a year, excemption was granted



The entrance hall

from this building stop (May 1972); in August contracts were granted. The architectural contract was granted to REUSKEN B.V. at Eerbeek, the electrical installation to ERGON ELECTRIC at Apeldoorn and the mechanical engineering installation to GEITENBEEK in Utrecht, the dome installations to BRONSWERK in Utrecht.

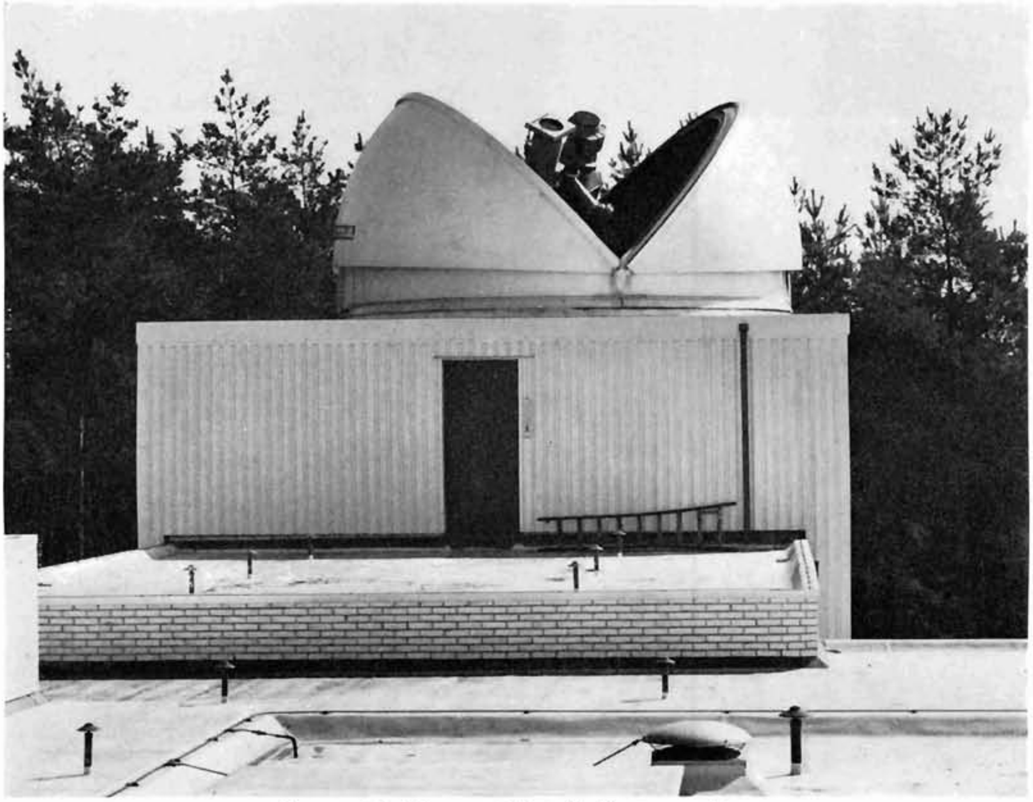
The total costs of the entire project are estimated at 3 000 000 D.Gld. As has already been indicated in the foregoing, mainly two types of satellite observations will be carried out:

- direction measurements will be carried out by means of which the directions of the satellite positions will be determined;
- distances will be measured which will be determined by the travel time of a laser light pulse;
- standard geodetical-astronomical measurements can also be carried out.

Furthermore, there are workshops (mechanical and electronic) in addition to general work- and study-offices. Overnight-accomodation facilities are also necessary.

The building has been designed to accomodate four wings, grouped round the central hall. The building is of ground floor conception with the exception of the two domes for photographic and laser observations; these reach to a height of 10 m above ground level.

In the *East-wing* the dome for photographic observation and annexes are accomodated. The dome is higher than the rest of the building so as to prevent as much as possible the influence of heat emission phenomena caused by the surrounding part of the building. This



Cameras (double mount) installed in camera dome

also helps to counteract the effects of ground-fog. The spherical dome has a diameter of 6 m and consists in fact of four octants of a sphere, the uppermost two of which come together or can cover the two lowermost parts so that the dome is then open for observation purposes.

In the dome a camera assembly is set up which comprises two cameras (F = 120 cm; D = 30 cm and F = 90 cm; D = 25 cm), by means of which photographic observations are carried out. These facilities are also available for students for educational purposes; visitors can also be admitted for shorter periods. The dome is accessible via the control room and the staircase to an auxiliary control room. This auxiliary controlroom is separated from the rest of the dome by glass walls and ceiling. In the auxiliary control room the operating desk is installated in a position from which the cameras are directly visible. Part of the main electronic equipment is installed in the control room. In the dome, temperature and relative humidity can be regulated.

A characteristic of many cameras is that after adaptation to a new ambient temperature they give well-defined images. One of the cameras in question requires 8 hours adaptation time. Consequently the temperature in the dome must be regulated to a value in agreement with that expected, accurate to within 1 °C, eight hours before the first observation. If this is complied with, the image in the cameras is well defined at the beginning of the observations. This also reduces the possibility of bad "seeing" since the difference between the temperature of the dome and the external temperature is kept to a minimum. Slight temperature changes during the evening or night can be adjusted (focus setting of the cameras). The

Camera control room

relative humidity in the dome must be approximately 40% or less, in the case of a closed dome.

Mounting of the cameras is independent of the structure of the building to avoid undesired vibrations caused, for instance, by walking. The set-up must be so positioned that the point of intersection of the rotation axes is approximately 9 m higher than the ground level within 50 to 100 m distance. A mechanically height-adjustable platform is necessary to provide access to the cameras for various activities and widely differing set-ups.

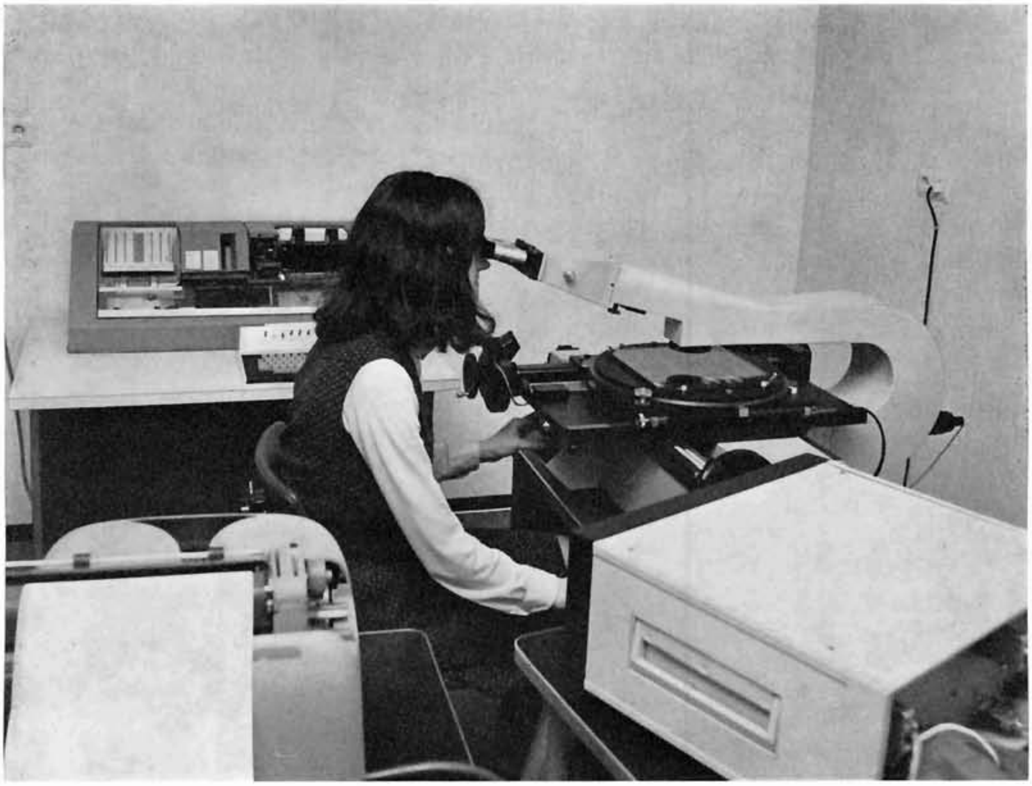
Some further details:

- total weight of cameras including mounting ± 1000 to 1500 kg;
- proper heat-isolation of the dome;
- no separate heating.

The space reserved for the electronic control equiment contains all necessary apparatus for time-reception, time-recording, operation and control of the cameras. This apparatus must be set up such as to be easily visible and accessible. It will be manned by one or two persons.

The darkrooms are situated under the dome, in order to facilitate the installation of a cassette lift to transport the heavy plate-cassettes. Exposures are made on film with the TA-120 camera. Working with film provides a number of (economical) advantages. Plates are used in the K-50 camera. Glass-plates are advantageous, if the highest-order accuracy is required.

The double-fitting renders it possible to make simultaneous exposures of the same object



Comparator measurements

with two cameras. This is important for a detailed study of the relative behaviour of the film and the plates. Processing of plates on the one hand and of film on the other hand are so different that each requires its own outfit and its own darkroom. In the darkroom for plates an automatic processor for simultaneous processing of 10 plates (8″ × 10″ × 0.25″) is available.

Processing and drying must be carried out with the utmost of care; a drying cabinet must be available. In view of the high sensitivity of non-exposed film and plates they must be stored in a refrigerator.

Provisions have also been made for a contact-printer. In the darkroom for the film provision has been made for film-processing tanks and for a drying-drum; an enlarger can also be housed in the darkroom. Both darkrooms are provided with a wet-work bench with drawers for chemicals, a rinsing sink and a dry-work bench with drawers. In both rooms, the temperature must be kept constant to within 1.0 °C. In both rooms continuous work can be carried out for periods of $1\frac{1}{2}$ to 2 hours by 1 or 2 persons.

The XY-comparator is installed in the comparator cabin. The XY-comparator is used to determine coordinates on the photographic plates with a standard deviation of 1 to 2 microns. This means that for quite some time before and during the measurements the cabin must be draughtfree and the temperature must be stable at room temperature to within 1 °C. The relative humidity must be $50 \pm 5\%$. This cabin must be situated in quiet surroundings to avoid disturbances. Mechanical vibrations must also be avoided.

The mechanical workshop

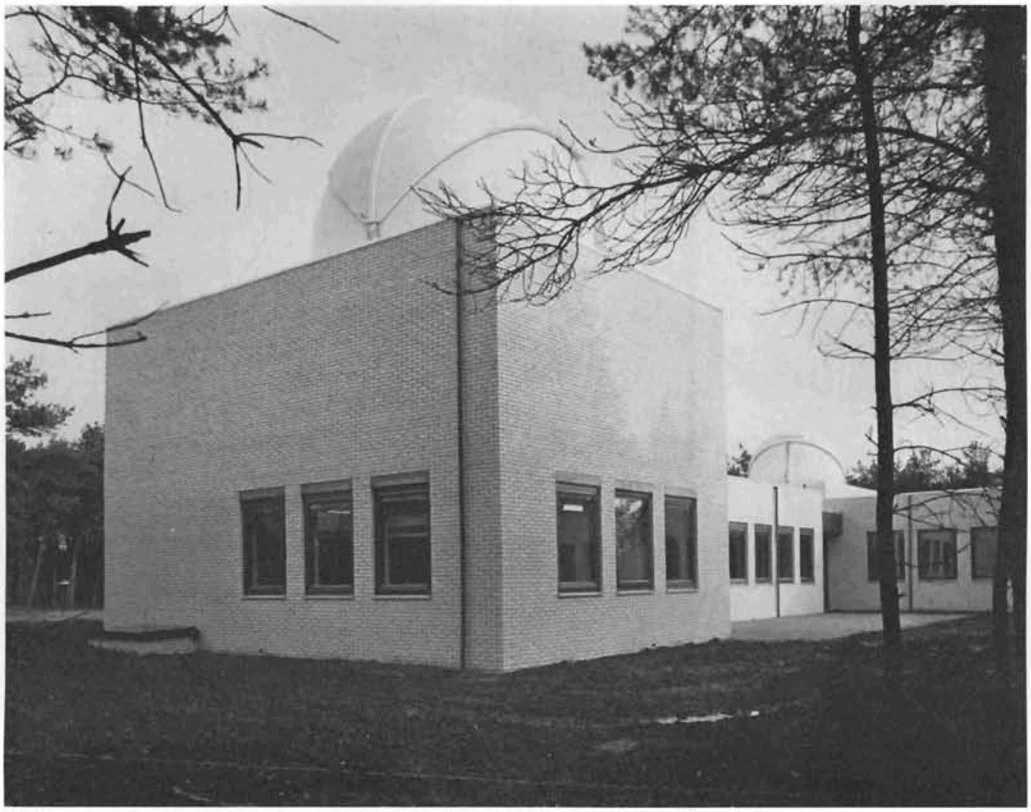
In the *East-wing* further technical provisions have been made for air conditioning equipment; the telephone switch-board is also housed there. The walls of the dome are completely covered with plasticized steel plates. A ventilation system has been incorporated between these plates and the walls, in order to avoid any undesirable influence from sunrays.

The *North-wing* of the observatory contains the mechanical and optical workshops with annexes and a number of rooms for technical apparatus. In the workshops, the apparatus directly connected with the camera and the laser-installation will be constructed, repaired and improved. In the optical section provision has been made for two cameras and also for some smaller equipment which can be placed on a work-bench. This section is dust-proof and is connected to the mechanical section. In the mechanical workshop, sufficient space must be available for the purpose of transporting cameras, stands and other heavy objects via a crane-rail with tackle from the loading and unloading platform to the optical section (hoisting capacity 1000 kg).

Accomodation should also be available for carrying out work on cameras and other equipment.

The following machines have been installed: milling machine, lathe, drilling machine, grinding machine, universal lathe, bending machine, belt-saw and some other smaller apparatus.

Provisions have also been made for installations for supply of electricity (transformer, junction box) and for central heating, compressed air and water mains.



The West-wing of the new observatory

The *West-wing* contains rooms for various purposes. In the first place the dome for laser measurements together with a control room.

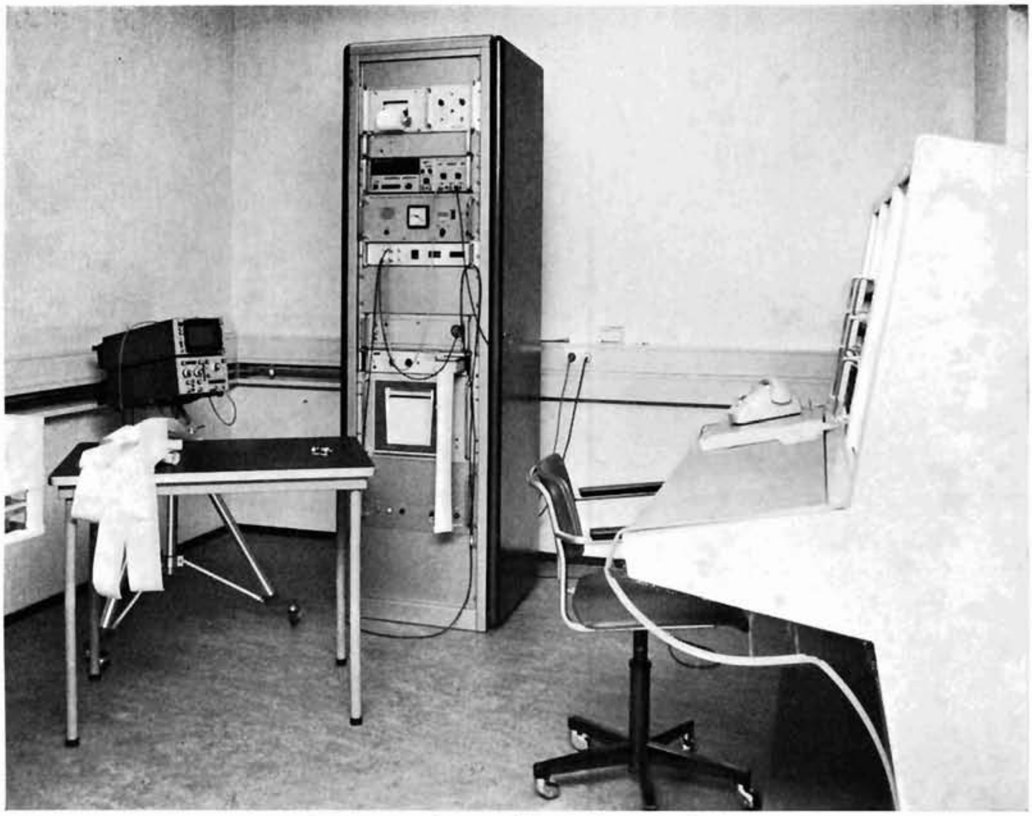
The construction of this dome is identical with that of the other dome. Requirements in respect of vibrations and seeing are put less stringent than in the case of the photographic method. This means that the column in which the laser equipment is to be placed does not have separate foundations and also that the requirements in respect of air conditioning are less rigid than for the other dome.

The temperature of the dome, when closed, can be between 15° and 25 °C, dependent on the temperature in the open air. The installation of an atomic clock in the control room requires that the temperature there be kept constant, at 21 °C to within ± 1 °C. Relative humidity may not exceed 60%. The movement of the dome must be coupled to that of the mount in which the laser is fitted, so that the dome does not obstruct the path of the laser pulses. Various earthing and isolation points have also been fitted; the lighting is in compliance with the highest requirements.

The electronic workshop is situated underneath the dome; in this workshop all construction and repair acitivities are carried out. Space has been reserved for assembly-tables, measuring-equipment trolleys, fume-cupboard and other apparatus.

An accumulator battery is situated next to the workshop for the purpose of supplying electricity in the event of a power-cut. The air conditioning equipment is also installed here.

There is accomodation for observers operating at night, as well as for the more permanent



Laser control room with rubidium standard

guests. There are four bedrooms with separate showers and toilet, plus a kitchen and a living room. There is also a lecture room in this wing, where lectures can be held for larger groups of guests.

The *South-wing* contains the offices and also various equipment, such as card-punch, telex and computer terminals. There is also an office reserved for geodetic astronomy. An observation platform, accessible via a staircase, is built on to this wing. Standing on this platform, it is possible to use two pillars, each of which has a separate foundation. The cross-sections of these pillars are 30 and 60 cm, with respective heights of 1.30 m and 1.20 m above the floor of the platform. These pillars are covered with the same sun-resisting material as the domes. There are also cable-inlets.

The observatory has its own waterworks. Internal and external fire-fighting provisions have been made, including a separate water supply. The fire-fighting provisions and the alarm-indicating apparatus have been designed in close cooperation with the P.T.T. (General Post Office) authorities at Kootwijk. This cooperation will be continued in the event of further installations.

Other installations are: the compressed air installation, a public-address system, an emergency electricity supply installation, an installation for protection against lightning. There is also an earthing system for measuring purposes and provisions for the purpose of fitting anti-interference filters and stabilizers to the 220 V installations.

After only some months experience and the first photographic observations there is every reason to believe that the new observatory will come up to all expectations. Every effort will be made to ensure that this observatory will make many important contributions in the field of satellite geodesy and satellite geodynamics.

REFERENCES

[1] Among others:
C. A. LUNDQUIST and G. VEIS (ed) – Geodetic parameters for a 1966 Smithsonian Institution Standard Earth. SAO Special Report 200, 1966.
E. M. GAPOSCHKIN and K. LAMBECK – 1969 Smithsonian Standard Earth (II), SAO Special Report 315, 1970.
J. G. MARSH, B. C. DOUGLAS and S. M. KLOSKO – A unified set of tracking station coordinates derived from geodetic satellite tracking data. A Goddard Space Flight Center Publication, July 1971.

[2] Among others:
A. CAZENAVE, O. DARGNIES, G. BALMINO, M. LEFÈBVRE – Geometrical adjustment with simultaneous laser and optical observations (Results on the European Datum). In: The use of artificial satellites for geodesy pp. 43–49. Geophysical Monograph No. 15, AGU, Washington, 1972.
J. KOVALEVSKY – Recent progress in the dynamics of artificial satellites and its applications. COSPAR Space Research, Volume X, (1969), North-Holland Publishing Company, Amsterdam, pp. 1–17.
G. BALMINO, H. BIVAS en M. LEFÈBVRE – Preliminary result of the Gecdetic Campaign R.C.P. 133. COSPAR Space Research, Volume X, (1969) North-Holland Publishing Company, Amsterdam, pp. 77–81.
M. BIVAS – Utilisation des observations laser en géodésie géométrique. Bulletin du Groupe de Recherches Géodésie Spatiale (GRGS) nr. 3, April 1972.
A. CAZENAVE and J. L. PIEPLU – Resultats récents en géodésie géométrique. Bulletin du GRGS nr. 3, April 1972.
J. G. MARSH B. C. DOUGLAS and S. M. KLOSKO – Geodetic analysis from the International Satellite Geodesy Experiment (ISAGEX) data. In: Proceedings of the International Symposium Satellite and Terrestrial Triangulation, Graz, Austria, June 1972, pp. 61–79, part II.
I. I. MUELLER, M. KUMAR, J. P. REILLY, N. SAXENA, T. SOLER – Global satellite triangulation and trilateration for the National Geodetic Satellite Program (Solution WN 12, 14 and 16). Department of Geodetic Science, the Ohio State University, report No. 199, Columbus, Ohio, May 1973.
And the following papers presented at the First International Symposium The Use of Artificial Satellites for Geodesy and Geodynamics, Athens, Greece, May 14–21, 1973:
E. M. GAPOSCHKIN, G. VEIS, J. LATIMER – Smithsonian Standard Earth III, Coordinates.
E. M. GAPOSCHKIN, M. R. WILLIAMSON, J. KOZAI, G. MENDES – Smithsonian Standard Earth III, Geopotential.
J. G. MARSH, B. C. DOUGLAS, S. M. KLOSKO – A global station coordinate solution based upon camera and laser data. GSFC 1973.
H. SCHMID – Results and analysis of world-wide geometric satellite triangulation.

[3] K. LAMBECK – The earth's gravity field: its determination and its interpretation. Nederlands Geodetisch Tijdschrift, 1972, No. 3, March, pp. 41–63.

[4] E. C. SILVERBERG and D. G. CURRIE – A description of the lunar ranging station at Mc Donald Observatory. COSPAR, Space Research XII (1971) North-Holland Publishing Company, Amsterdam, pp. 219–235.

[5] W. BAARDA – Statistical concepts in geodesy. Netherlands Geodetic Commission, Publications on Geodesy, New Series, Vol. 2, No. 4, Delft, 1967.
W. BAARDA – A testing procedure for use in geodetic networks. Netherlands Geodetic Commission, Publications on Geodesy, New Series, Vol. 2, No. 5, Delft, 1968.
W. BAARDA – S-transformations and criterion matrices. Netherlands Geodetic Commission, Publications on Geodesy, New Series, Vol. 5, No. 1, Delft, 1973.

[6] L. AARDOOM – On a geodetic application of multiple-station very long baseline interferometry. Netherlands Geodetic Commission, Publications on Geodesy, New Series, Vol. 5, No. 2, Delft, 1972.

[7] F. O. VONBUN – Geodetic Satellite Mission and Geos-C Spacecraft. COSPAR, Space Research XI, (1970) North-Holland Publishing Company, Amsterdam, pp. 457–468.

[8] J. G. MARSH, B. C. DOUGLAS and S. M. KLOSKO – The relation of the European Datum to a geodetic reference system. Paper presented at the International Union of Geodesy and Geophysics meeting in Moscow, August 1971.

[9] L. AARDOOM – Geometry from simultaneous satellite ranging. Tellus XXII, 1970, No. 5

[10] L. AARDOOM – Geometric accuracy obtainable from simultaneous range-measurements to satellites. In: The use of artificial satellites for geodesy, pp. 9–19. Geophysical Monograph No. 15 AGU, Washington, 1972.

[11] L. AARDOOM – Schemes for global clock synchronization using very long baseline interferometry of stellar sources. Delft Progress Report, Series E (Geosciences) Vol. 1, No. 1.

[12] W. BAARDA – Het berekenen van puntsbepalingssystemen in de ruimte met behulp van quaternionen. Unpublished, Delft, 1962.
W. BAARDA – Quaternion theorie, Unpublished, Delft, 1964–1965.
E. VERMAAT – Driehoek en viervlak, Graduation paper, Delft, 1970.
H. QUEE – De vereffening van een gesloten n-hoek met behulp van quaternionen. Graduation paper, Delft, 1971.

[13] G. M. VAN DER SLIKKE – Adjustment of a satellite triangulation with statistical testing applied to Geos-2 observations. Graduation paper, Delft, 1972.

[14] B. H. W. VAN GELDER – Photogrammetric reduction of sidereal camera observations of artificial satellites. Graduation paper, Delft, 1972.

[15] J. VAN HEMERT – Calibration of a Mann 422 F comparator. Graduation paper, Delft, 1972.

[16] E. TENGSTRÖM – Über das Short-Arc-satelliten-beobachtungsvorhaben im Bereich des "Europäischen Datums". Mitteilungen aus dem Institut für theoretische Geodäsie der Universität Bonn, No. 16, Bonn, 1973.

[17] H. S. GEORGE – Prediction of satellite observations for geometrical application. Graduation paper, Delft, 1974.