AD

CONTRACT AF 61 (052)-650

10 OCTOBER 1964

TECHNICAL FINAL REPORT:

«STUDIES ON THE OPTICAL TRACKING OF ARTIFICIAL EARTH SATELLITES»

by

HALLVARD ROSSELAND

INSTITUTE OF THEORETICAL ASTROPHYSICS
UNIVERSITY OF OSLO, NORWAY.

The research reported in this document has been sponsored by the

AIR DEFENCE COMMAND

through the European Office, Aerospace Research, United States Air Force.

AD

CONTRACT AF 61 (052)-650

10 OCTOBER 1964

TECHNICAL FINAL REPORT:

«STUDIES ON THE OPTICAL TRACKING OF ARTIFICIAL EARTH SATELLITES»

by

HALLVARD ROSSELAND

INSTITUTE OF THEORETICAL ASTROPHYSICS
UNIVERSITY OF OSLO, NORWAY.

The research reported in this document has been sponsored by the

AIR DEFENCE COMMAND

through the European Office, Aerospace Research, United States Air Force.

A B S T R A C T

This paper is primarily a report on observations and experience gained during two years of tracking artificial earth satellites from a site at 60° N latitude, using a Baker-Nunn camera.

A special effort was made to find the most efficient way of using the camera and the maximum output of observational results to be expected under normal climatic conditions.

The mechanical properties of the camera and their limitations were also studied.

C O N T E N T S

1. INTRODUCTION

The work reported in this paper was done in direct continuation of studies made by the Institute of Theoretical Astrophysics during the preceding three years on the optical tracking of artificial earth satellites using a Baker-Nunn satellite tracking camera (1, 2).

During the period covered by the present report, however, the tasking of the tracking facility was radically changed, with the emphasis shifting from relatively bright, easily photographed objects to dim satellites near the practical limit of the Baker-Nunn camera. Problems were encountered in acquisition, that were eventually solved by simultaneous modifications in the prediction program and local tracking techniques.

Using the improved look-angles and tracking practices, a study was made to determine the capacity of the Baker-Nunn Satellite Tracking Camera, Mark II in the precision space surveillance.

II. THE TRACKING STATION

The Oslo SPACETRACK Facility was established by the Institute of Theoretical Astrophysics, U. of Oslo under contract with the European Office, Air Research and Development Command (now European Office of Aerospace Research), U.S.A.F. in 1959. Satellite tracking started in late spring 1960. The camera site on the grounds of the Oslo Solar Observatory at Harestua (60°12'42" N, 10°45'11" E) is unique in the U.S.A.F. precision optical tracking network in that

1) it is in Europe and
2) it is the highest latitude station of its kind.

The chief advantage of the location is that it permits more than 16 hours of tracking per night during the peak mid-winter season, and that during winter the station can observe objects not obtainable by stations at lower latitudes by reason of geometry. Also the seeing is very good.

Drawbacks are the two-month mid-summer period of inactivity due to bright skies, and the location of Scandinavia in the North Atlantic low pressure belt with variable weather during fall and spring months.

III. INSTRUMENTS

The Baker-Nunn camera has been well described elsewhere (3, 4). We shall merely recall that the instrument is a modified f/1 Schmidt camera. It records $5x30^{\circ}$ on 56 mm Royal-X Panchromatic Special film. It is tri-axially mounted in a gimballed configuration, and it is power-driven at continuously variable speeds about one axis, the tracking axis. The coupled film transport mechanism and shutter complex, consisting of a gross clamshell shutter and a "barrel" chopper, can be driven in steps at cycle periods of 2, 4, 8, 16 and 32 seconds duration.

An electronic time standard, readable to 1/10.000 second, controls a slave clock in the camera, which is photographed on the film by a strobe at a predetermined chop of the rotating shutter.

Setting of the Mark II camera to predicted values of azimuth and elevation is by electrical drives.

IV. SATELLITE TRACKING

OCTOBER 1962 - OCTOBER 1964

The start of the report period coincided with an abrupt change in tasking of satellites by SPACETRACK. During preceding years the Oslo station was charged with the tracking of fairly bright objects, many of which could be obtained even with the camera in the stationary mode.

As of October 1962 observations were demanded of an entirely different category of objects, which at first eluded detection by conventional Baker-Nunn tracking methods. The scoring of the station dropped sharply from better than 50 percent to about 18 percent.

During the observing season October 62 - June 63 attempts were made to observe 608 satellite passes. Only 90 observations were successful, while the satellites were not found in 456 cases. The remaining 62 attempts were unsuccessful for various reasons, such as clouds, bright moon, observer's error etc.

Of the 27 objects tasked at various times during the season, 12 went completely undetected (SPADATS object numbers 023, 188, 195, 227, 288, 340, 341, 369, 370, 378, 510 and 511). Others were rarely acquired despite a large number of attempts (194, 196, 273, 274, 397).

The observers tried all methods known at the time to catch the elusive satellites. The camera was run at the 32 second cycle, giving the longest exposure time (about 4 seconds). The nodding motion, whereby the satellite is recorded alternately as a point and a track on the same frame, was extensively used. Fanning techniques were attempted in case the predictions were inaccurate.

At the beginning of the 63-64 season it was clear that the instrument was not profitably employed at the present rate of acquisition. It was decided to accept an invitation from the Smithsonian Astrophysical Observatory to track selected objects for scientific (mainly geodetic) purposes. Such satellites would be relatively bright and easily acquired. Meanwhile a thorough analysis would be made of the attempted photography of objects tasked by SPACETRACK, hopefully with SAO assistance, to determine the causes for the low acquisition rate on numerous objects.

The plans were approved by the Contracting Officer, EOAR, and with the arrival of a veteran trackker (Mr. Robert Citron of the SAO Olifantsfontein, S-Africa, B/N station) in early December 1963, all aspects of the Oslo operation were given a fresh, critical look.

It had been realized by the staff for some time that the optics of the Baker-Nunn should permit the photography of all assigned objects, but that the source of failure was probably the limit set by the longest automatic exposure time provided, viz. about 4 seconds. Mr. Citron immediately pointed out that time exposures could be obtained by hand, throwing the primary drive out of action with the gross shutter in the fully open position by means of the cycle period selector lever. The procedure required dark sky, otherwise the fast film will fog over and obscure the satellite image during prolonged exposures.

New tracking procedures were initiated, involving the liberal use of time exposures of 5 to 20 seconds duration, and four objects not previously detected were immediately acquired (195, 273, 341 and 388).

It should be realized that the position data obtained by time exposures are unsuited for high precision reduction, unless the camera matches the satellite velocity very closely. In most cases there is sufficient mismatch to introduce uncertainties about the point to measure. Very long time exposures even give problems in field reduction. In many cases it is useful to hand-chop the image, by stopping the shutters just before the third (strobe-actuating) chop, and to turn the chopper slowly by hand to obtain a break in the mismatching satellite trail for easier reduction.

Uncertainties as to which way the camera mismatches the satellite velocity are easily resolved by comparing successive frames.

Armed with better local procedures, we made a thorough study of the look angles from SPACETRACK. They were presumably obtained from the processing of radar data, and were found to be less suitable, in some cases less accurate than required for setting up the Baker-Nunn camera for efficient tracking.

SPACETRACK was requested by TWX messages to modify predicted data in the following manner:

1. Increase solar depression angle to 10 degrees (later revised to 12 degrees for faint objects). Many received predictions were unshootable because of bright skies.

2. Raise altitude limits to 20 degrees for faint objects. Many satellites could be counted as lost because of atmospheric extinction at low elevations.

3. Raise track angle limits to 30-150 degrees.

4. Narrow track angle range to a few degrees. Earlier T/A ranges were as much as 60-80 degrees, meaning that the camera was not matching the satellite velocity vector over more than a very small portion of the predicted range. The introduction of several closely spaced arcs per pass had the added advantage of enabling the operator to adjust the tracking velocity <u>during</u> photography to match the satellite motion over the entire tracking sequence.

With the implementation of modified tracking techniques, as well as improved look angles, the station score immediately started to rise, resulting in an increased return of predictions from SPACETRACK.

The steadily increasing volume of reductions necessitated a major overhaul of the station reduction techniques and facilities. Earlier reduction procedures involved locating the star field on conventional observatory Bonner Durchmusterung charts by conversion of altitude and azimuth into right ascension and declination. The satellite track was then sketched on the chart, and the position relative to the selected reference stars measured with a hand micrometer. One reduction took from 15 to 30 minutes.

Field reduction time was cut to a few minutes per point with the kind loan by SAO of a set of transparent Baker-Nunn scale BD-CD charts, direct reading measuring grids, a standard SAO viewing table for Baker-Nunn films and (later) a stereozoom microscope. (Similar items have since been supplied by the U.S.A.F.)

With the favorable data return response from SPACETRACK it was decided to investigate the capacity of the Baker-Nunn system in routine precision surveillance, a study which to our knowledge had never before been undertaken.

In January 1964 instructions were posted to photograph all shootable passes. The results were immediate, and somewhat unsettling. The rising tide is best illustrated by the following table:

Month	Attempts	Successes	Reductions
December 63	273	44	-
January 64	609	378	569
February	506	349	748
March	1438	852	1973
April	580	355	847
May	117	48	108

The success of the program is not only seen from the March totals, but also from the fact that the "bright-sky" month of May, with very few available tracking hours, gave more successes than the month of December, with 15-16 hours of available tracking time per night.

The station record was set on the night of 13-14 March with 96 successful satellite observations, yielding 226 field reductions for transmission to SPACETRACK.

At the peak of the 1964 spring activity the station had tracking responsibility for 38 objects. Among objects acquired were 22 faint metal pieces, which would have eluded detection by previous techniques.

The success of the evaluation program would not have been possible without the expert guidance of the SAO optical satellite tracking program, the prompt reaction of the SPACETRACK computing staff to our suggested revisions of predictions, and the wholehearted effort of the grossly undermanned and correspondingly overworked camera station staff under the direction of Chief Observer Torstein Melby.

After the mid-summer lull in operations, tracking was resumed on 1. August, 1964. The first month was characterized by murky weather, and only 136 passes were attempted out of 858 passes selected for photography. There were 72 successful observations, yielding 76 reductions. The low number of reductions was a direct result of fewer requests for horizon-to-horizon photography of several objects.

V. SPECIAL ACTIVITIES

Under the approved agreement with the Smithsonian Astrophysical Observatory the Oslo tracking station made numerous observations of selected objects for scientific, mainly geodetic purposes. All requests for photography were for easily acquired objects, typically 116, 117, 624, 714 and 740.

A number of quasi-simultaneous observations were made with Baker-Nunn stations in Persia, India and Spain. The Oslo camera still lacks synchronizing gear (shutter latch and phase shifter) in order to perform true simultaneous observations, but the results were useful as an exercise in coordination of observations over long distances.

By SAO arrangement, for instance, a number of observations of Explorer 19 (714) were made simultaneously with the RCAF Baker-Nunn station at Cold Lake, Alberta, marking the first over-the-pole simultaneous observations.

On the spur of the moment, the Oslo station requested nominal pre-launch data on Echo II (740) from SAO, and actually became the first optical station to acquire the giant balloon. The first photographs were made halfway during the second orbit on the night of 25-26 January, 1964. Confirmation was given of proper inflation. During subsequent orbits a total of six objects were indentified in the satellite train, and magnitudes, separation rates and tumbling rates were continuously reported both to SAO and SPACETRACK.

VI. NOTES ON THE BAKER-NUNN CAMERA

The unanimous feeling of the Oslo group is that the Baker-Nunn camera is a highly versatile and smoothly working instrument for satellite tracking, surprisingly so when one recalls that it was designed before a single satellite was in the sky.

The increased tracking activity during the spring of 1964 resulted in more extensive handling of the camera than ever before, and several weak spots in the design became apparent during tracking and maintenance.

1) The most irksome limitation of the Mark II camera is the inability of the electrical drives to slew the camera rapidly in azimuth and elevation from one pass to another. The camera can, for this reason, only track an average of 15 satellites per hour, which compares unfavorably with the hand-slewed Mark I used by the SAO network.

   The electrical slewing devices are superior in one respect: They permit rapid one-man setting of the camera when separation between successive arcs are small, such as during full-pass photography.

   It has therefore been proposed that existing cameras be modified to permit selection by the operator of either the electrical or the manual mode. Such a study is now underway at the manufacturing plant.

2) The oscillating or nodding mode of the camera is ingeneous in conception, but confusing in practice. This mode has not been used at Oslo after the introduction of time exposures. A legacy of the oscillating gears is, however, a marked vibration of the camera whenever tracking is started at high angular velocities. The reason for this is that the only stabilizing connection between the camera housing and the tracking drive bronze gear is by the output lever from the oscillating mechanism. The connection is not sufficiently firm, and should be replaced by a solid clamp connection.

3) The tracking drive assembly, consisting of motor, Graham gear box and worm drive, is of such a compact design that cleaning and greasing of the work drive is a major puzzle to the uninitiated.

4) Excessively compact design of the primary drive assembly makes the occasionally required tightening of the main clutch a trying experience.

5) No provision has been made to stop the gross shutter in the open position for time exposures, except by yanking down the cycle period selector lever. This, of course, requires the operator to handle the camera in motion, which gives rise to vibrations.

6) There is a dead zone of 90° in azimuth, centered on 180°. This necessitates hand correcting West-East passes with azimuths in the dead zone to values for East-West passes. This matters less for field reductions, but the data obtained by tracking West are not fit for precision reduction, where the shutter correction is applied on the assumption of normal East tracking.

7) The main supporting bearing of the camera, the azimuth ball bearing, is inaccessible for lubrication. According to the manufacturer this bearing is lubricated with special long-life grease. In the case of the Oslo camera, however, the lubricant has deteriorated to the point where it comes dripping out as a thin, reddish liquid.

8) The slave clock slows down at low temperatures because of the thick grease in the Bodine drive synchronous motor.

9) The camera instrument panel is difficult to observe, and even more awkward to operate with the camera tilted to low South elevations.

R E F E R E N C E S

1. H. Rosseland, Final Report, Contract AF 61(052)-240.

2. H. Rosseland, Supplement to Final Report, Contract AF 61(052)-240.

3. K.G. Henize, Sky and Telescope, Vol. XVI, No. 3.

4. G.R. Miczaika and N.H. Dieter, Plan.Spa.Sci. Vol. 7.