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An estimation of accuracy for star-oriented optical fixes of artificial earth satellites produced by amateur equipment

David Weishaupt

AN ESTIMATION OF ACCURACY FOR STAR-ORIENTED OPTICAL FIXES OF ARTIFICIAL EARTH SATELLITES PRODUCED BY AMATEUR EQUIPMENT

by

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Senior Research Project

Dr. Carroll

May 5, 1967

R.I.T.

OBJECTIVES:

To determine an estimate of accuracy obtainable from a normal stationary 4" x 5" sheet film press camera in conjunction with a simple timing device in producing star-oriented optical fixes of artificial earth satellites (Echo I and Echo II).

The optical fixes will be compared to data produced by the Smithsonian Astrophysical Observatory.

INTRODUCTION:

There is an increased need for directional fixes produced against a reference background of stars. The accuracy and understanding of these fixes are extremely important and constantly being improved. I am concerned with this accuracy in relation to the amateur and his simple equipment. I have used equipment (except for the film measurements) that is easily available to the amateur to test the value of its optical fixes.

ABSTRACT:

The project's intent is to determine the accuracy of simple amateur equipment in producing optical fixes from a reference star background. A standard 4" x 5" Speed Graphic camera is used with a timing device consisting of a short-wave radio and a tape recorder to record the time at exposure.

The accuracy obtained from two out of four observations is within 1800 feet along the orbital path of the satellite.

PROCEDURE:

Estimating time of satellite passings - The *New York Times* publishes daily in it's weather section the approximate times and positions of visible satellites. The estimated times are within ± 5 minutes and estimates of elevation and direction or orbital path are also given. Since it is known approximately where the satellite will pass, one can familiarize one's self with the star field in that area beforehand.

Setup of equipment - A location was picked having a clear view of the sky away from the city lights and an accessible source of electrical power.

A 4" x 5" Graflex Speed Graphic press camera with a 135 mm f/4.7 lens is mounted on a tripod. The camera has only a cable release attached for camera stability. Close to the camera is a small table or stand on which the timing device is placed. The timing device consists of a tape recorder and a short-wave radio tuned to either CBU (Dominion Observatory, Canada) or WWV and WWVH (National Bureau of Standards) timing signals. The radio should be warmed up and tuned to one of the above stations beforehand in case poor band conditions are present and another station must be located. The tape recorder's microphone is placed on or near the lens board of the camera, being sure it does not interfere with lens or shutter action.

The radio's volume is sufficiently raised to be picked up by the tape recorder. The sound of the shutter opening will be recorded against the background of the time signal. If a recorder is available with a variable speed, the fastest recording speed should be used. It can then be played back at the slower speed to break the seconds up more accurately. The recorder used for this project allowed approximate quarter seconds to be determined.

Exposure - The exposures for the satellite films were approximately 5 seconds at f/5.6. The film used was Plus X (ASA 125), a medium speed and very high acutance film. This is sufficient exposure to produce definite star and satellite trails but minimize fogging and overexposure of brighter stars and satellite images. If the object is exceptionally bright and is over-exposed, a scattering effect may result and produce indefinite trails.

Immediately after the satellite exposure, the camera is not moved and a second exposure is made. This is approximately a minute or more long so more definite star trails are produced. It should not be over five minutes, since longer star trails may cause confusion. This serves two purposes. It will ease the star identification procedure and solve any confusion as to which is the satellite trail in the first exposure.

Processing - The film was processed in a Kodak Versamat for the dark visual image and the ability to obtain measurements rapidly.

Star identification - After processing, the films are compared to the identified sketch made at the time of exposure to identify the section of the star field we are concerned with. This section is looked up in a star atlas; thus, stars can be identified and constellations can be sketched on the identification films.

The timing device will give the moment the shutter opens and when the light first hits the film. As a result, we must record the direction of star and satellite motions, since we are concerned with only the very beginning of the trails. Requirements for reference stars are that they must be bright, recorded in the star atlas and catalog, and be relatively close to the satellite trail.

Measurements - We must now find the north-south axis of the celestial sphere on the film in relation to the stars recorded. We then pick at least four well-known stars close to the satellite trail. One of the stars will serve as the origin of a north-south and east-west coordinate system and the other three will be reference stars (more than three are preferred). Plate constants are found, ξ and η (the standard coordinates) are found, and finally right ascension and declination are found for the satellite fix points, as described by W. M. Smart.[1]

[1] Smart, W.M., Textbook on Spherical Astronomy, Cambridge University Press, England, 1962, pp 278-300.

The coordinates were measured from the film by a Kodak contour projector. This projector has a precision of about 0.0001 inch with an experienced operator.

Optical Fix: The information was then sent to the Smithsonian Astrophysical Observatory for comparison to their more accurate data. The data supplied to them consisted of my position of observation (latitude and longitude), date of observation, satellite observed, exact Universal Time of observation and calculated right ascension and declination of the satellite. The Smithsonian Astrophysical Observatory supplied me with a right ascension and declination of the satellite for my location and time of observation as calculated from their more exact orbital data. The results are compared with the Smithsonian data used as a standard.

RESULTS:

Number Observations	Observations	Standard
3 rd	a_3=12 hr. 19 min. 46.95 sec. d_3=8° 56' 26.16"	15 hr. 09 min. 15.24 sec. 28° 47' 30.97"
4 th	a_4=10 hr. 39 min. 46.98 sec. d_4=24° 24' 31.24"	9 hr. 54 min. 24.708 sec. -71° 41' 25.50"
5 th	a_5=12 hr. 42 min. 25.03 sec. d_5=68° 50' 13.86"	12 hr. 36 min. 29.676 sec. 68° 47' 34.72"
6 th	a_6=9 hr. 08 min. 17.82 sec. d_6= 37° 42' 29.99"	9 hr. 02 min. 14.426 sec. 37° 39' 41.83"
a=right ascension d=declination		

Number Observations	Variance of Observational a and d from Standard
3 rd	Δa_3=2 hr. 49 min. 28.29 sec. Δd_3=19° 51' 4.81"
4 th	Δa_4= 45 min 22.27 sec. Δd_4=96° 05' 56.74"
5 th	Δa_5= 05 min 55.35 sec. Δd_5= 02' 39.14"
6 th	Δa_6= 06 min 03.39 sec. Δd_6 02' 48.16"

The 3rd. and 4th. observations are not possible and must be eliminated as erroneous calculations. The 5th. and 6th. are much closer to the standard and are within the same range.

When a mistake of 1 second of arc in position is estimated to be 20 feet along the orbital path of the satellite, an error in feet is produced as shown below for the 5th and 6th observations.

Number Observations	Error in feet of orbital path
5 th	a_5=1520 feet d_5= 50 feet
6 th	a_6=1800 feet d_6= 60 feet

CONCLUSIONS:

The accuracy obtained by the 5th and 6th observations is within 1800 feet along the orbital path of the satellite.

APPENDIX:

Critique of Procedure: Under Measurements, I found the north-south celestial axis by a star map. A more accurate method is to expose longer star trails while photographing the satellite trail. Since the stars appear to move east to west about the celestial north pole, a line tangent to the resulting star trails will be the east-west axis recorded directly on the film for easy measuring.

Significant sources of error: The largest source of error is the limited timing device but this is difficult to overcome due to the prices of accurate timing devices. Another source is the instability of my camera and its inability to record lower magnitude stars allowing reference stars to be located closer to the satellite.trail.

I have some question as to the validity of my standards of declination and right ascension. An error is possible in my recording data which was sent to the Smithsonian, but I doubt it. I suspect an error in the Smithsonian's calculations since for the 4th observation, I was given a declination of -71° 41' 25.50", which is not even visible from our latitude and longitude.

B I B L I O G R A P H Y

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ACKNOWLEDGEMENTS:

I would like to extend my hearty thanks to Mr. Robert Yorke from the Smithsonian Astrophysical Observatory, who calculated my standards and to Mr. Sturch from the University of Rochester Astronomy Department, who helped me through the understanding of spherical astronomy.

SMITHSONIAN INSTITUTION
ASTROPHYSICAL OBSERVATORY
60 GARDEN STREET CAMBRIDGE MASSACHUSETTS 02138
TELEPHONE 617 664-7910

21 June, 1967

To Whom It May Concern:

I have attached a computer printout which shows various input and output data which I have used to compute apparent satellite positions with respect to their sky background.

In contrast to the first data made available to Mr. Weishaupt, these positions seem more realistic, both from the positions anticipated given the reference stars he used, and their location in the sky from his observation site. They also, according to him, match quite well with his calculations.

Two of the four positions I computed were in significant disagreement with Mr. Weishaupt's positions. The first because I misread a "4" for a "7" in the day of observation. The second was in disagreement because of Mr. Weishaupt's incorrect labeling of the satellite he was observing. Simply by applying the proper set of orbital elements, the position became not only realistic but in agreement with the observed position.

These corrections, then, have been done independently of Mr. Weishaupt's efforts and in no way have I attempted to influence or bias his results.

For the record, Mr. Weishaupt's first correspondence with the Observatory was written on 3 April, 1967, and arrived on my desk on 13 April. My first response was written on 26 April. I must admit that my work during the past six months or so has been particularly demanding and that there were long delays in my answers.

I am not in a position to evaluate Mr. Weishaupt's efforts. Indeed, his positions and their deviation from ours are appropriate and what we expect given his equipment and techniques to generate, but I have not seen his computations and do not wish to make judgments on such limited information.

I present this data for the record that Mr. Weishaupt's efforts will stand on their own merit or lack of it. Any questions pertaining to this issue will be cordially answered. Of course, public information and cooperation are presumably legitimate functions of the Observatory, and if we can provide course material or information, we will also attempt to fulfill your requests.

Sincerely,

Robert E. Yorke
Training Instructor

REY/dq
Enclosure

STATION COORDINATES

9001	-1.535702	-5.167026	3.401108	0.5658951	4.4234969		
9002	5.056123	2.716523	-2.775799	-0.4530770	0.4930260	4.	ORGAN PASS.NM
9004	5.105623	-0.555194	3.769670	0.6363365	6.1748626	4.	OLFSTN.S.AF
9005	-3.946522	3.366453	3.698855	0.6225545	2.4354529	4.	S.FERNNDO.SP
9006	1.018135	5.471207	3.109519	0.5124156	1.3863398	4.	TOKYO.JAPAN
9007	1.942762	-5.804082	-1.796838	-0.2874218	5.0353814	4.	NA.TAL.INDIA
9008	3.376872	4.404022	3.136250	0.5173940	0.9167524	4.	AREQUIPA.PER
9009	2.251841	-5.816928	1.327236	0.2111383	5.0817491	4.	SHIRAZ.IRAN
9010	0.976319	-5.601410	2.880311	0.4716243	4.8849901	4.	CURACO.NWI
9011	2.280645	-4.914512	-3.355441	-0.5573820	5.1467738	4.	JUPITER.FLA
9012	-5.466118	-2.404068	2.242437	0.3614650	3.5559335	4.	V.DOLORES.ARG
9022	1.002463	-4.552308	4.339120	.7529738	4.9291395	4.	MAUI.HAWAII
9023	-3.977806	3.725297	-3.303181	-0.5478916	2.3889629	4.	YORKE
9049	0.976319	-5.601410	2.880311	0.4716243	4.8849901	4.	IS. LAGOON
9050	1.489778	-4.467516	4.287365	0.7418666	5.0342505	4.	JUPITER.FLA
9051	4.607805	2.025830	3.904621	0.6630360	0.4142151	150.	AGASSIZ.MASS
9080	3.920254	-0.134625	5.012852	0.9100875	6.2488580	150.	ATHENS
						150.	SHERRIFF LN

ORBITS (of several satellites, including Echoes I and II

39580 is 31 March 1967 and i
This orbit ~~are~~ is assumed valid.

1. ORBIT 6000901 (Echo I) 39580 (Smithsonian Day) —— 39593
P111 P111 P01 P111 P2111
39587. 0. 251.919425 4.17501
108.890529 -3.62335
47.288535
.04916099 -2.25094956E-04
.39041425 13.010442 7.432559E-04

2, ORBIT 6400401 Echo II 39587 39597
P110 P110 P01 P01 P2111
39594. 0. 106.570584 -2.56393
146.767687 -.854880
81.497084
.01355994
.94270782 13.479049 2.448445E-04

3, ORBIT 6102801 Midas IV 39004 39034
P1 P1 P0 P0 P1 39019. 0. 77.718 -.905 235.92417 .20959 95.8410 .013201
.50753 8.6767152

4. ORBIT 6102801 " 39126 39156
P1 P1 P0 P0 P1 39141. 0. 319.64 -.84215 261.59873 .21109 95.85432 .012001
.08841 8.67653835

5. ORBIT 6303001 39004 39033
P1 P1 P0 P0 P2 39018. 0. 330.1242 -1.38858 11.2179 -.05511 88.4407 .002737
.038673 8.5802743 .8E-7

6 ORBIT 6303001 39185 39215
P1 P1 P0 P0 P2 39202. 0. 126.36 -.8837 1.0724 -.05594 88.4398 .003765
.66672 8.57887759 -.18E-7

7 ORBIT 6303004 39018 39033
P1 P1 P0 P1 P3 39026. 0. 299.993 -1.1299 6.5573 -.06954 88.0388 .078624
.0002681 .108807 8.593242 .7875E-4 .1122E-5

8. ORBIT 6303004 39200 39215
P1 P1 P0 P1 P2 39208. 0. 108.690 -1.0686 353.3047 -.07598 87.8853 .0975
.000301 .09233 8.603588 .00010332

David Weishaupt
3 Continental Court, Apt. 1
Woburn, Mass.
01801

for David Weishaupt, Rochester

II

and is the beginning of the period for which
valid.

Computer Use Data for accounting

h m s
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12.10.55. ARNO124. READ.
12.11.26. ARNO124. PP 030 SEC.
12.11.41. ARNO124. T13361,1.20,40000,ARNOLD.
12.11.41. ARNO124. 185 ALEWIFE      PHOTOREDUCTION  ROOM 218
12.11.41. ARNO124.
12.11.42. ARNO124. INPUT.
12.14.04. ARNO124. END    ORBIT
12.14.05. ARNO124. CP  005.130 SEC. — Central Processing Time
12.14.05. ARNO124. PP  129.249 SEC. — printer time
12.14.12. ARNO124. PUNCH- PP  006 SEC.
12.14.49. ARNO124. PRINT-PP 001 SEC.
6/20/67.  SAO SCOPE 2.0. JUNE 9,1967. PSR 52F
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OUT PUT

arbitrarily assigned

station # film photo object

SC CARDS

month day hr. min. seconds Baker-Nunn coded data ie. accuracy codes (processing sort #)

#3 SC S 022 00001 01 6000901 1967 04 05 02 01 00.0000 02.000 000 5 0 00 000 16000
RIGHT ASCENSION 12H 18M 17.326S
DECLINATION 8D 46M 2.89S
POSITION ANGLE 62.83D — angle with line of declination
ANGULAR VELOCITY 598.64S/S — (apparent)
RANGE 2.212 MEGAMETERS — distance (topocentric)
ALTITUDE 41.50 DEGREES — above horizon

#4 SC S 022 00002 01 6000901 1967 04 09 01 53 00.0000 02.000 000 5 0 00 000 16001
RIGHT ASCENSION 10H 40M 50.846S
DECLINATION 24D 35M 28.20S
POSITION ANGLE 64.56D
ANGULAR VELOCITY 789.35S/S
RANGE 1.702 MEGAMETERS
ALTITUDE 68.70 DEGREES

#5 SC S 022 00002 01 6400401 1967 04 11 02 20 16.0000 02.000 000 5 0 00 000 16002
RIGHT ASCENSION 12H 36M 29.676S
DECLINATION 68D 47M 34.72S
POSITION ANGLE 35.03D
ANGULAR VELOCITY 1139.40S/S
RANGE 1.195 MEGAMETERS
ALTITUDE 58.94 DEGREES

#6 SC S 022 00003 01 6400401 1967 04 13 02 25 00.0000 02.000 000 5 0 00 000 16003
RIGHT ASCENSION 9H 2M 14.426S
DECLINATION 37D 39M 41.83S
POSITION ANGLE 355.23D
ANGULAR VELOCITY 1361.28S/S
RANGE 1.098 MEGAMETERS
ALTITUDE 71.40 DEGREES

RESULTS:

Number Observations	Observations	Standard
3 rd Echo I	a_3=12 hr. 19 min. 46.95 sec. $d_3=8^\circ$ 56' 26.16"	12 hr. 18 min. 17.326 sec. 8° 46' 02.89"
4 th Echo I	a_4=10 hr. 39 min. 46.98 sec. $d_4= 24^\circ$ 24' 31.24"	10 hr. 40 min. 50.846 sec. 24° 35' 28.20"
5 th Echo II	a_5=12 hr. 42 min. 25.03 sec. $d_5=68^\circ$ 50' 13.86"	12 hr. 36 min. 29.676 sec. 68° 47' 34.72"
6 th Echo II	a_6=9 hr. 08 min. 17.82 sec. $d_6=37^\circ$ 42' 29.99"	9 hr. 02 min. 14.426 sec. 37° 39' 41.83"
a=right ascension d=declination		

Number Observations	Variance of Observational a and d from Standard
3 rd Echo I	Δa_3=01 min. 29.62 sec.=22' 24.30" Δd_3=10' 23.27"
4 th Echo I	Δa_4=01 min. 03.87 sec.=15' 58.05" Δd_4=10' 56.96"
5 th Echo II	Δa_5=05 min. 55.35 sec.=1° 28' 50.25" Δd_5=02' 39.14"
6 th Echo II	Δa_6=06 min. 03.39 sec.=1° 30' 50.85" Δd_6=02' 48.16"

When a mistake of 1 second of arc in position is estimated to be 20 feet along the orbital path of the satellite, an error in feet is produced as shown below for the observations.

Number Observations	Error in feet of orbital path
3 rd	a_3= 448 feet d_3= 208 feet
4 th	a_4= 320 feet d_4= 219 feet
5 th	a_5=1520 feet d_5= 50 feet
6 th	a_6=1800 feet d_6= 60 feet

CONCLUSIONS:

The accuracy obtained by the observations is within 1800 feet along the orbital path of the satellite.

APPENDIX:

Critique of Procedure: Under Measurements, I found the north-south celestial axis by a star map. A more accurate method is to expose longer star trails while photographing the satellite trail. Since the stars appear to move east to west about the celestial north pole, a line tangent to the resulting star trails will be the east-west axis recorded directly on the film for easy measuring.

Significant sources of error: The largest source of error is the limited timing device but this is difficult to overcome due to the prices of accurate timing devices. Another source is the instability of my camera and its inability to record lower magnitude stars allowing reference stars to be located closer to the satellite trail.

Despite the hindrance of too few observations, my data did produce results better than expected. Mr. Yorke and myself were prepared to accept an accuracy of 2° or 3° as a success, while only the right ascension of the 5th and 6th observations exceeded 1° with the rest substantially below that.

OLD COMPUTER PRINTOUT — WRONG DATA.

SC CARDS UT

station film photo object year mo. day hr. min seconds. dummy information processing code

3 SC S 022 00001 01 6000901 1967 04 08 02 01 00.0000 02.000 000 5 0 00 000 16000
RIGHT ASCENSION 15H 9M 15.240S
DECLINATION 28D 47M 30.97S
POSITION ANGLE 100.25D — ∡ with hour circle
ANGULAR VELOCITY 355.38S/S
RANGE 2.777 MEGAMETERS — (geocentric distance)
ALTITUDE 26.63 DEGREES — from horizon in alt-azimuth local coordinates

4 SC S 022 00002 01 6400401 1967 04 09 01 53 00.0000 02.000 000 5 0 00 000 16001
RIGHT ASCENSION 9H 54M 24.708S
DECLINATION -71D 41M 25.50S
POSITION ANGLE 9.56D
ANGULAR VELOCITY 126.17S/S
RANGE 7.487 MEGAMETERS
ALTITUDE 155.36 DEGREES

5 SC S 022 00002 01 6400401 1967 04 11 02 20 16.0000 02.000 000 5 0 00 000 16002
RIGHT ASCENSION 12H 36M 29.676S
DECLINATION 68D 47M 34.72S
POSITION ANGLE 35.03D
ANGULAR VELOCITY 1139.40S/S
RANGE 1.195 MEGAMETERS
ALTITUDE 58.94 DEGREES

6 SC S 022 00003 01 6400401 1967 04 13 02 25 00.0000 02.000 000 5 0 00 000 16003
RIGHT ASCENSION 9H 2M 14.426S
DECLINATION 37D 39M 41.83S
POSITION ANGLE 355.23D
ANGULAR VELOCITY 1361.28S/S
RANGE 1.098 MEGAMETERS
ALTITUDE 71.40 DEGREES

#5 & #6 look acceptable — is there a timing error in #4, or is our (S.A.O.'s ~~orbit~~ orbit that bad?)

If your positions fall within 2-3°, I would definitely consider your attempts a success.

Do write & let me know.

Bob Yorke