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GEOS-1 STATION TRACKING POSITIONS

ON

THE SAO STANDARD EARTH (C-5)

Francis J. Lerch
James G. Marsh
Mission Trajectory Determination Branch
Mission and Trajectory Analysis Division
NASA Goddard Space Flight Center
Greenbelt, Maryland

Maurice D. D'Aria
Ronald L. Brooks
Wolf Research and Development Corporation
Applied Sciences Department
College Park, Maryland

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Goddard Space Flight Center
Greenbelt, Maryland

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GEOS-1 Station Tracking Positions
on the SAO Standard Earth

F. J. Lerch
J. G. Marsh
M. D. D'Aria
R. L. Brooks

ABSTRACT

For the purpose of long-arc satellite data reduction and intercomparison, all GEOS-1 participating tracking stations have been transformed to a common datum. The common datum selected is the Smithsonian Astrophysical Observatory (SAO) Standard Earth C-5 model, in which the Baker-Nunn station positions are used as the controlling stations for all other stations to be transformed.

Descriptions and formulation are presented to effect the transformations from major and isolated datums. An empirical transformation technique is explained in detail which may be employed advantageously when datum shifts (ΔX, ΔY, ΔZ) are not known or when the control stations within a local datum have been allowed to adjust independently on the world datum (SAO C-5). The transformation of local datum station coordinates are important to be performed since the datum shifts are quite large. For example, on the North American Datum the center of mass shift to the C-5 Standard Earth is approximately 250 meters. The center of mass coordinates of the SAO C-5 Baker-Nunn stations are assessed by SAO to have approximately 20 meter accuracy.

Original and transformed station positions are presented in geodetic and Cartesian coordinates.

GEOS-1 STATION TRACKING POSITIONS
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1. INTRODUCTION

The purpose of this report is to present the transformed station coordinates on the SAO C-5 Standard Earth for over 100 GEOS tracking stations that have been used in the long arc orbital intercomparison effort. These station positions were derived by shifting the given local station datum coordinates onto the C-5 model. The procedures for transforming the station coordinates are briefly discussed in Sections 2, 3 and 4 prior to the list of station coordinates which is presented in Section 5. A more complete description and analysis of the procedure are provided in the attached Appendices.

Section 2 presents a general description of the transformation, while Appendix A contains a detailed description of the procedure. Section 3 discusses an ellipsoidal transformation for stations on isolated datums with a more detailed explanation given in Appendix A. Section 4 presents the ellipsoidal parameters of the local datums. The original and transformed C-5 station positions in geodetic and cartesian coordinates are presented in Section 5. The stations are grouped according to their tracking network.

Appendix B contains a comparison of transformation of positions by the Molodenskiy correction and the procedure utilized in this report. Appendix C contains the uncertainty estimates of the derived C-5 positions. These are based on the uncertainty that SAO has established for their Baker-Nunn stations, combined with the uncertainty of the survey ties of these stations to the Baker-Nunn network.

The list of sources of original positions is contained in Appendix D. The Tables (11-20) in Section 5 contain symbols designating the source for those stations within the network. If the source of a station is different than the network, it is so indicated opposite the station name.

A list of proper names for all stations designated in this report by their standard six letter code may be found in Tables 21 to 30 of Section 5.

2. COORDINATE TRANSFORMATION

The station transformations to the SAO C-5 Standard Earth (a_e = 6378165, 1/f = 298.25) utilized the Cartesian coordinates. This transformation is based on the differences between the SAO Baker-Nunn original datum Cartesian coordinates with their derived C-5 mass-centered coordinates. This position difference is referred to as the datum shift. Once the datum shift has been derived for a Baker-Nunn station, this shift is then applied to derive the SAO Standard Earth coordinates for tracking stations that have positions given in the same original datum as the Baker-Nunn Station and are tied to the Baker-Nunn station through conventional surface surveys. A weighting scheme is used where more than one Baker-Nunn station is located on the same datum since these individual stations show slightly different datum shifts. The weight is chosen to be inversely proportional to the distance between the Baker-Nunn station and the tracking station to be transformed. The transformation is discussed in detail in Appendix A where it is referred to as a Multi-Station Transformation.

The first fourteen SAO Baker-Nunn stations listed in Table 1 of Section 5 are used as the major control stations for determining datum shifts. Their associated original datums are designated in the table. All stations except eleven stations as indicated in the next section have been transformed by the Multi-Station Transformation.

3. ISOLATED DATUMS

An ellipsoidal transformation from the local reference ellipsoid to the C-5 ellipsoid is presented in Section 5 of Appendix A. It is performed for a tracking station on a datum for which there is no Baker-Nunn control station. Usually this situation occurs when a station is on an isolated datum such as the Tananarive Datum. This ellipsoidal transformation will provide for a center of mass shift (ΔX, ΔY, ΔZ) if knowledge of it may be obtained. When knowledge of the center of mass is not available the geodetic coordinates of latitude, longitude, and height in the local datum are used as such on the C-5 datum. This latter condition is generally the case. Approximately eleven stations fell into this latter category for this report and are so designated by an asterisk in Tables 11-20 which give the geodetic coordinates for all stations. The derived center of mass Cartesian coordinates are taken from the geodetic coordinates referenced to the C-5 ellipsoid.

4. PARAMETERS OF ORIGINAL DATUMS

In order to effect any transformation, the parameters of the original datums must be known as well as the geodetic latitude, longitude and height.

Below are listed the original datums and their parameters in which the stations were originally surveyed.

DATUM NAME	SEMI-MAJOR AXIS (meters)	1/F
North American (N.A.)	6378206.4	294.9787
European	6378388.0	297.0
Tokyo	6377397.2	299.1528
Argentina	6378388.0	297.0
Mercury	6378166.0	298.3
Madagascar	6378388.0	297.0
Australian Nat'l.	6378160.0	298.25
Old Hawaiian	6378206.4	294.9787
Indian	6377276.3	300.8017
Arc (Cape)	6378249.1	293.4663
1966 Canton Astro	6378388.0	297.0
Johnston Island 1961	6378388.0	297.0
Midway Astro 1961	6378388.0	297.0
Navy Iben Astro 1947	6378206.4	294.9787
Provisional DOS	6378388.0	297.0
Astro 1962, 65 Allen Sodano Lt.	6378388.0	297.0
1966 SECOR ASTRO	6378388.0	297.0
Viti Levu 1916	6378249.1	293.4663
CORREGO ALEGRE	6378206.4	294.9787
USGS 1962 ASTRO	6378206.4	294.9787
BERNE	6377397.2	299.1528

5. STATION POSITIONS

The following Tables (1-10) list alternately the Cartesian coordinates in the original datum and the SAO C-5 Datum. The datums are specified in the last column.

Tables (11-20) list alternately the original surveyed ellipsoidal position and the SAO C-5 ellipsoidal position. These tables contain symbols designating the source of original station coordinates. The symbols are defined in Appendix D with a list of source information.

An estimate of accuracy of the derived station coordinates on the C-5 Standard Earth is presented in Appendix C. These are based on the uncertainty that SAO has established for their Baker-Nunn stations, combined with the uncertainty of the survey ties of these stations to the Baker-Nunn network.

The C-5 positions for ITANAN and MADGAR[1] have been derived by the station estimation technique contained in the GEOS program NONAME [Reference 14]

[1]The Determination and Comparison of the GRARR Madgar Site Location: October 1967, Goddard Space Flight Center. X-552-67-540.

Table 1
SAO - OPTICAL

NAME	STATION NUMBER	X (meters)	Y (meters)	Z (meters)	DATUM
1ORGAN	9001	-1535725 -1535761	-5167147 -5167003	3400867 3401046	N. A. C-5
1OLFAN	9002	5056254 5056134	2716631 2716489	-2775468 -2775820	Arc (Cape) C-5
1OOMER	9003	-3983661 -3983756	3743135 3743107	-3275679 -3275598	Australian C-5
1SPAIN	9004	5105682 5105601	-555119 -555233	3769797 3769680	European C-5
1TOKYO	9005	-3946554 -3946703	3365774 3366291	3698151 3698849	Tokyo C-5
1NATOL	9006	1018270 1018207	5471237 5471109	3109767 3109619	European C-5
1QUIPA	9007	1942774 1942772	-5804204 -5804087	-1797088 -1796964	N. A. C-5
1SHRAZ	9008	3376973 3376887	4404130 4403992	3136414 3136259	European C-5
1CURAC	9009	2251830 2251824	-5817059 -5816924	1326988 1327166	N. A. C-5
1JUPTR	9010	976310 976284	-5601550 -5601398	2880068 2880247	N. A. C-5
1VILDO	9011	2280741 2280579	-4914695 -4914577	-3355481 -3355462	Argentinean C-5
1MAUIO	9012	-5466112 -5466064	-2404012 -2404279	2242372 2242174	Old Hawaiian C-5

Table 1 (Continued)

NAME	STATION NUMBER	X (meters)	Y (meters)	Z (meters)	DATUM
OSLONR	9426	3121370 3121280	592748 592629	5512832 5512704	European C-5
AUSBAK	9023	-3977649 -3977744	3725148 3725121	-3303146 -3303065	Australian C-5
NATALB*	9029	5186691 5186677	-3653614 -3653479	-654583 -654421	N. A. C-5
AGASSI*	9050	1489768 1489747	-4467652 -4467510	4287121 4287293	N. A. C-5
COLDLK*	9424	-1264778 -1264802	-3466885 -3466744	5185264 5185435	N. A. C-5
EDWAFB*	9425	-2449989 -2450017	-4624588 -4624446	3634863 3635037	N. A. C-5
RIGLAT*	9428	3183995 3183910	1421714 1421593	5322880 5322747	European C-5
POTDAM*	9429	3800613 3800529	882119 881999	5029044 5028912	European C-5
ZVENIG*	9430	2886510 2886428	2156832 2156710	5245531 5245394	European C-5

*These SAO station positions were derived by using the weighting scheme described in Section 2.

Table 2
STADAN - OPTICAL

NAME	STATION NUMBER	X (meters)	Y (meters)	Z (meters)	DATUM
IBPOIN	1021	1118061 1118039	-4876471 -4876328	3942793 3942966	N. A. C-5
1FTMYR	1022	807883 807858	-5652136 -5651987	2833327 2833504	N. A. C-5
1OOMER	1024	-3977160 -3977255	3725702 3725675	-3303132 -3303051	Australian C-5
1QUITO	1025	1263614 1263601	-6255122 -6254988	-69082 -68920	N. A. C-5
1LIMAP	1026	1388815 1388807	-6088540 -6088413	-1293432 -1293287	N. A. C-5
1SATAG	1028	1769705 1769694	-5044753 -5044624	-3468417 -3468267	N. A. C-5
1MOJAV	1030	-2357214 -2357242	-4646474 -4646332	3668134 3668308	N. A. C-5
1JOBUR	1031	5084923 5084803	2670522 2670380	-2767849 -2768201	ARC (Cape) C-5
1NEWFL	1032	2602801 2602782	-3419301 -3419160	4697476 4697646	N. A. C-5
1COLEG	1033	-2299237 -2299259	-1445840 -1445700	5751627 5751796	N. A. C-5
1GFORK	1034	-521679 -521703	-4242197 -4242055	4718543 4718715	N. A. C-5
1WNKFL	1035	3983320 3983237	-48386 -48505	4964737 4964606	European C-5
1ROSMA	1042	647539 647516	-5178082 -5177937	3656533 3656707	N. A. C-5
1TANAN	1043	4092050 4091879	4434532 4434279	-2064612 -2064767	Tananarive C-5

Table 3
STADAN R/R

NAME	STATION NUMBER	X (meters)	Y (meters)	Z (meters)	DATUM
CARVON	1152	-2328113 -2328153	5299746 5299690	-2669476 -2669460	Australian C-5
ROSRAN	1126	647213 647190	-5178486 -5178342	3655963 3656137	N. A. C-5
MADGAR	1122	4091559 4091387	4434388 4434137	-2065964 -2066118	Tananarive C-5

Table 4
NAVY TRANET - DOPPLER

NAME	STATION NUMBER	X (meters)	Y (meters)	Z (meters)	DATUM
LASHAM	2006	4005569 4005486	-71656 -71776	4946799 4946667	European C-5
SANHES	2008	4084014 4083963	-4209856 -4209804	-2498933 -2499088	Corrego Alegre C-5
PHILIP	2011	-3087865 -3088014	5332447 5332964	1638097 1638795	Tokyo C-5
SMTHFD	2012	-3942109 -3942204	3468907 3468880	-3608342 -3608261	Australian C-5
MISAWA	2013	-3779496 -3779645	3024198 3024715	4138313 4139011	Tokyo C-5
ANCHOR	2014	-2656169 -2656190	-1544504 -1544364	5570468 5570638	N. A. C-5
TAFUNA	2017	-6100005 -6099951	-997516 -997507	-1568353 -1568456	USGS 1962 ASTRO C-5
THULEG	2018	538387 539367	-1388492 -1388352	6180847 6181017	N. A. C-5
MCMRDO	2019	-1310731 -1310762	310481 310421	-6213364 -6213370	Mercury C-5
WAHIWA	2100	-5504191 -5504143	-2223857 -2224124	2325479 2325281	Old Hawaiian C-5
LACRES	2103	-1556192 -1556228	-5169592 -5169448	3387072 3387251	N. A. C-5
LASHM2	2106	4005531 4005448	-71662 -71781	4946835 4946704	European C-5
APLMND	2111	1122567 1122545	-4823230 -4823087	4006287 4006460	N. A. C-5
PRETOR	2115	5052053 5051989	2725719 2725610	-2774355 -2774515	European C-5
SHEMYA	2739	-3851525 -3851546	397046 397185	5051365 5051533	N. A. C-5
BELTSV	2742	1130805 1130783	-4830982 -4830839	3994535 3994708	N. A. C-5
STNVIL	2745	-78775 -78799	-5328202 -5328059	3493275 3493449	N. A. C-5

Table 5
US AIR FORCE - OPTICAL

NAME	STATION NUMBER	X (meters)	Y (meters)	Z (meters)	DATUM
ANTIGA	3106	2881872 2881858	-5372329 -5372192	1868347 1868518	N. A. C-5
GRNVLE	3333	-93222 -93246	-5324617 -5324473	3498350 3498524	N. A. C-5
GRVILL	3334	-84958 -84982	-5328100 -5327957	3493285 3493459	N. A. C-5
USAFAC	3400	-1275174 -1275202	-4798165 -4798023	3994038 3994212	N. A. C-5
BEDFRD	3401	1513182 1513161	-4463731 -4463589	4282876 4283048	N. A. C-5
SEMMES	3402	167290 167267	-5482122 -5481977	3244863 3245037	N. A. C-5
SWANIS	3404	642541 642522	-6054110 -6053968	1895518 1895690	N. A. C-5
GRDTRK	3405	1919530 1919513	-5621245 -5621104	2315617 2315790	N. A. C-5
CURACO	3406	2251862 2251856	-5817042 -5816907	1327005 1327183	N. A. C-5
TRNDAD	3407	2979970 2979958	-5513661 -5513525	1181004 1181174	N. A. C-5
GRANFK	3451	-549867 -549891	-4245208 -4245066	4712728 4712900	N. A. C-5

Table 5 (Continued)

NAME	STATION NUMBER	X (meters)	Y (meters)	Z (meters)	DATUM
TWINOK	3452	-647883 -647910	-5117438 -5117296	3739390 3739464	N. A. C-5
ROTHGR	3453	3931622 3931539	658045 657925	4962958 4962825	European C-5
ATHNGR	3463	4613521 4613441	2029197 2029074	3896034 3895897	European C-5
TORRSP	3464	4849671 4849590	-289982 -290099	4119838 4119713	European C-5
CHOFUJ	3465	-3946476 -3946625	3366244 3366761	3697793 3698491	Tokyo C-5
KINDLY	3471	2305568 2305550	-4873771 -4873630	3396167 3396339	N. A. C-5
HUNTER	3648	832594 832571	-5349690 -5349544	3360414 3360589	N. A. C-5
JUPRAF	3649	976326 976300	-5601521 -5601369	2880117 2880296	N. A. C-5
ABERDN	3657	1186826 1186805	-4785340 -4785198	4032705 4032877	N. A. C-5
HOMEST	3861	961793 961768	-5679315 -5679166	2729709 2729886	N. A. C-5
CHYWYN	3902	-1234669 -1234696	-4651355 -4651213	4174612 4174787	N. A. C-5

Table 6
ARMY MAP SERVICE - SECOR

NAME	STATION NUMBER	X (meters)	Y (meters)	Z (meters)	DATUM
HERNDN	5001	1088886 1088864	-4843081 -4842938	3991661 3991834	N. A. C-5
CUBCAL	5200	-2447563 -2447591	-4776104 -4775962	3435208 3435381	N. A. C-5
LARSON	5201	-2127657 -2127682	-3786277 -3786136	4655697 4655869	N. A. C-5
WRGTON	5202	-449777 -449801	-4600953 -4600811	4380165 4380339	N. A. C-5
GREENV	5333	-84973 -84997	-5328093 -5327950	3493295 3493469	N. A. C-5
TRUKIS	5401	-5576059 -5576019	2984593 2984572	822651 822707	Navy IBEN ASTRO 1947 C-5
SWALLO	5402	-6097581 -6097365	1486531 1486479	-1133574 -1133566	1966 SECOR ASTRO C-5
KUSAIE	5403	-6074637 -6074423	1854309 1854243	584756 584752	ASTRO 1962, 65 Allen Sodano Lt. C-5
GIZZOO	5404	-5805647 -5805442	2485478 2485390	-892157 -892151	Provisional DOS C-5
TARAWA	5405	-6328119 -6327898	784867 784840	150557 150556	1966 SECOR ASTRO C-5
NANDIS	5406	-6070252 -6070141	270257 270252	-1932795 -1932972	VITI LEVU 1916 C-5
CANTON	5407	-6304576 -6304356	-917349 -917317	-306696 -306694	1966 CANTON ASTRO C-5

Table 6 (Continued)

NAME	STATION NUMBER	X (meters)	Y (meters)	Z (meters)	DATUM
JONSTN	5408	-6008188 -6007971	-1111188 -1111148	1824371 1824356	JOHNSTON ISLAND 1961 C-5
MIDWAY	5410	-5619131 -5618917	-258153 -258143	2996972 2996742	MIDWAY ASTRO 1962 C-5
MAUIHI	5411	-5468070 -5468023	-2381140 -2381407	2253375 2253177	Old Hawaiian C-5
FTWART	5648	794718 794695	-5360197 -5360051	3352909 3353084	N. A. C-5
HNTAFB	5649	832517 832494	-5349741 -5349595	3360372 3360547	N. A. C-5
HOMEFL	5861	963494 963469	-5679880 -5679731	2727945 2728122	N. A. C-5

Table 7
US C&GS - OPTICAL

NAME	STATION NUMBER	X (meters)	Y (meters)	Z (meters)	DATUM
BELTVL	6002	1130798 1130777	-4830988 -4830845	3994522 3994695	N. A. C-5
ASTRMD	6100	1130816 1130795	-4830970 -4830827	3994538 3994711	N. A. C-5
TIMINS	6113	634519 634497	-4181228 -4181086	4758741 4758913	N. A. C-5

Table 8
SPEOPT - OPTICAL

NAME	STATION NUMBER	X (meters)	Y (meters)	Z (meters)	DATUM
1UNDAK	7034	-521679 -521703	-4242198 -4242055	4718543 4718713	N. A. C-5
1EDINB	7036	-828465 -828490	-5657605 -5657462	2816640 2816814	N. A C-5
1COLBA	7037	-191261 -191286	-4967427 -4967285	3983084 3983257	N. A. C-5
1BERMD	7039	2308226 2308207	-4873758 -4873617	3394383 3394555	N. A. C-5
1PURIO	7040	2465089 2465076	-5535082 -5534945	1985346 1985519	N. A. C-5
1GSFCP	7043	1130742 1130720	-4831487 -4831344	3993952 3994125	N. A. C-5
1CKVLE	7044	380205 380182	-4992848 -4992705	3937659 3937832	N. A. C-5
1DENVR	7045	-1240450 -1240478	-4760380 -4760237	4048805 4048979	N. A. C-5
1JUM24	7071	976293 976267	-5601555 -5601403	2880061 2880240	N. A. C-5
1JUM40	7072	976297 976271	-5601549 -5601397	2880072 2880251	N. A. C-5
1JUPC1	7073	976303 976277	-5601545 -5601393	2880068 2880247	N. A. C-5
1JUBC4	7074	976304 976278	-5601545 -5601393	2880076 2880255	N. A. C-5
1SUDBR	7075	692646 692624	-4347227 -4347085	4600299 4600472	N. A. C-5
1JAMAC	7076	1384188 1384171	-5905827 -5905686	1966368 1966540	N. A. C-5

Table 9
SPEOPT - LASER

NAME	STATION NUMBER	X (meters)	Y (meters)	Z (meters)	DATUM
ROSLAS	7051	647209 647186	-5178458 -5178314	3656001 3656175	N. A. C-5
GODLAS	7050	1130704 1130683	-4831524 -4831381	3993921 3994094	N. A. C-5

Table 10
INTERNATIONAL - OPTICAL

NAME	STATION NUMBER	X (meters)	Y (meters)	Z (meters)	DATUM
DELFTH	8009	3923486 3923402	300006 299886	5003096 5002964	European C-5
MALVRN	8011	3920251 3920168	-134625 -134744	5012852 5012721	European C-5
ZIMWLD*	8010	4330631 4331308	567523 567505	4632712 4633101	BERNE C-5

*The C-5 position was derived from the C-6 position which was obtained from SAO.

Table 11
SAO - OPTICAL - SOURCE A

Name	Station No.	Latitude	Longitude	Geodetic Height (meters)	Datum
1ORGAN	9001	32° 25'24".56 32° 25'24".70	253° 26'51".17 253° 26'48".29	1649 1610	N. A. C-5
1OLFAN	9002	-25° 57'33".85 25° 57'37".67	28° 14'53".91 28° 14'51".45	1562 1560	Arc (Cape) C-5
WOOMER	9003	-31° 06'07".26 -31° 06'04".14	136° 46'58".70 136° 47'01".93	185 158	Australian C-5
1SPAIN	9004	36° 27'51".24 36° 27'46".68	353° 47'41".47 353° 47'36".55	7 56	European C-5
1TOKYO	9005	35° 40'11".08 35° 40'23".03	139° 32'28".22 139° 32'16".42	58 84	Tokyo C-5
1NATOL	9006	29° 21'38".90 29° 21'34".38	79° 27'25".61 79° 27'27".05	1847 1855	European C-5
1QUIPA	9007	-16° 28'05".09 -16° 27'58".04	288° 30'22".84 288° 30'24".02	2600 2479	N. A. C-5
1SHRAZ	9008	29° 38'17".90 29° 38'13".59	52° 31'11".80 52° 31'11".20	1578 1561	European C-5
1CURAC	9009	12° 05'21".55 12° 05'24".93	291° 09'42".55 291° 09'43".97	23 -33	N. A. C-5
1JUPTR	9010	27° 01'13".00 27° 01'14".23	279° 53'12".92 279° 53'12".95	26 -36	N. A. C-5
1VILDO	9011	-31° 56'36".53 31° 56'36".35	294° 53'39".82 294° 53'36".11	598 636	Argentinean C-5
1MAUIO	9012	20° 42'37".49 20° 42'25".66	203° 44'24".11 203° 44'33".23	3027 3027	Old Hawaiian C-5
AUSBAK	9023	-31° 23'30".82 -31° 23'27".69	136° 52'39".02 136° 52'42".23	164 137	Australian C-5

Table 11 (continued)

Source	Name	Station No.	Latitude	Longitude	Geodetic Height (meters)	Datum
	OSLONR	9426	60° 12'40".38 60° 12'38".88	10° 45'08".74 10° 45'02".26	585 573	European C-5
I	NATALB*	9029	-05° 55'50".00 -05° 55'43".49	324° 50'18".00 324° 50'21".30	112 45	N. A. C-5
D	AGASSI*	9050	42° 30'20".97 42° 30'20".51	288° 26'28".71 288° 26'29".79	193 138	N. A. C-5
I	COLDLK*	9424	54° 44'38".02 54° 44'37".26	249° 57'25".85 249° 57'21".90	597 548	N. A. C-5
I	EDWAFB*	9425	34° 57'50".68 34° 57'50".17	242° 05'11".39 242° 05'07".80	784 754	N. A. C-5
I	RIGLAT*	9428	56° 56'54".00 56° 56'52".37	24° 03'42".00 24° 03'37".49	5 -15	European C-5
I	POTDAM*	9429	52° 22'55".00 52° 22'52".33	13° 04'01".00 13° 03'55".80	111 106	European C-5
I	ZVENIG*	9430	55° 41'37".70 55° 41'36".17	36° 46'03".00 36° 46'00".17	145 114	European C-5

*These SAO station positions were derived by using the weighting scheme described in Section 2.

Table 12
STADAN - OPTICAL SOURCE B

1 Name	Station No.	Latitude	Longitude	Geodetic Height (meters)	Datum
1BPOIN	1021	38°25'49".63 38°25'49".44	282°54'48".23 282°54'48".65	5 -50	N. A. N. A.
1FTMYR	1022	26°32'51".89 26°32'53".08	278°08'03".93 278°08'03".80	19 -42	N. A. C-5
1OOMER	1024	-31°23'30".07 -31°23'26".96	136°52'11".05 136°52'14".25	152 148	Australian C-5
1QUITO	1025	- 0°37'28".00 - 0°37'22".63	281°25'14".81 281°25'15".23	3649 3554	N. A. C-5
1LIMAP	1026	-11°46'44".43 -11°46'37".56	282°50'58".23 282°50'58".86	155 34	N. A. C-5
1SATAG	1028	-33°09'07".66 -33°08'58".76	289°19'51".35 289°19'52".59	922 705	N. A. C-5
1MOJAV	1030	35°19'48".09 35°19'47".57	243°06'02".73 243°05'59".18	905 874	N. A. C-5
1JOBUR	1031	-25°52'58".86 -25°53'02".70	27°42'27".93 27°42'25".41	1530 1546	ARC (CAPE) C-5
1NEWFL	1032	47°44'29".74 47°44'28".73	307°16'43".37 307°16'46".67	104 58	N. A. C-5
1COLEG	1033	64°52'19".72 64°52'17".78	212°09'47".17 212°09'37".29	162 139	N. A. C-5
1GFORK	1034	48°01'21".40 48°01'20".81	262°59'21".56 262°59'19".55	253 200	N. A. C-5
1WNKFL	1035	51°26'44".12 51°26'40".67	359°18'14".62 359°18'08".35	62 76	European C-5
1ROSMA	1042	35°12'06".93 35°12'07".03	277°07'41".01 277°07'40".81	914 857	N. A. C-5
1TANAN	1043	-19°00'27".09 -19°00'33".26	47°18'00".46 47°17'58".89	1377 1355	Tananarive C-5

Table 13
STADAN - R/R - SOURCE B

Name	Station No.	Latitude	Longitude	Geodetic Height (meters)	Datum
CARVON	1152	-24° 54'14".86 -24° 54'12".29	113° 42'55".06 113° 42'58".54	38 10	Australian C-5
ROSRAN	1126	35°11'45".05 35°11'45".15	277°07'26".23 277°07'26".02	880 823	N. A. C-5
MADGAR	1122	-19°01'13".32 -19°01'19".41	47°18'09".45 47° 18'07. 96	1403 1382	Tananarive C-5

Table 14
NAVY TRANET - DOPPLER - SOURCE C

Name	Station No.	Latitude	Longitude	Geodetic Height (meters)	Datum
LASHAM	2006	51°11'10".62 51°11'07".12	358°58'30".51 358°58'24".25	182 196	European C-5
SANHES	2008	-23°13'01".74 -23°13'01".74	314°07'50".59 314°07'50".59	608* 608	Correga Alegre C-5
PHILIP	2011	14°58'57".79 14°59'16".42	120°04'25".98 120°04'21".61	8 -70	Tokyo C-5
SMTHFD	2012	-34°40'31".31 -34°40'28".16	138°39'12".39 138°39'15".66	39 31	Australian C-5
MISAWA	2013	40°43'04".63 40°43'14".63	141°20'04".69 141°19'51".45	-10 38	Tokyo C-5
ANCHOR	2014	61°17'01".98 61°16'59".60	210°10'37".46 210°10'28".60	61 44	N. A C-5
TAFUNA	2017	-14°19'50".19 -14°19'50".19	189°17'13".96 189°17'13".96	6* 6	USGS 1962 Astro C-5
THULEG	2018	76°32'18".62 76°32'20".72	291°13'46".72 291°13'51".07	43 -7	N. A. C-5
MCMRDO	2019	-77°50'51".00 -77°50'50".58	166°40'25".00 166°40'35".02	-43 -29	Mercury C-5
WAHIWA	2100	21°31'26".86 21°31'14".95	202°00'00".63 202°00'09".83	380 368	Old Hawaiian C-5
LACRES	2103	32°16'43".75 32°16'43".91	253°14'48".25 253°14'45".34	1201 1162	N. A. C-5
LASHM2	2106	51°11'12".32 51°11'08".82	358°58'30".21 358°58'23".95	187 201	European C-5
APLMND	2111	39°09'47".83 39°09'47".59	283°06'11".07 283°06'11".52	146 90	N. A C-5
PRETOR	2115	-25°56'46".09 -25°56'49".97	28°20'53".00 28°20'50".67	1417 1595	European C-5
SHEMYA	2739	52°43'01".52 52°42'56".52	174°06'51".43 174°06'44".17	44 89	N. A. C-5
BELTSV	2742	39°01'39".46 39°01'39".23	283°10'27".25 283°10'27".72	5050 -5	N. A C-5
STNVIL	2745	33°25'31".57 33°25'31".76	269°09'10".70 269°09'09".66	44 -10	N. A. C-5

*MSL

Table 15

US AIR FORCE - OPTICAL - SOURCE I

Source	Name	Station No.	Latitude	Longitude	Geodetic Height (meters)	Datum
	ANTIGA	3106	17°08'51".68 17°08'53".88	298°12'37".41 298°12'39".19	+7 -42	N. A. C-5
E	GRNVLE	3333	33°28'48".97 33°28'49".15	268°59'49".17 268°59'48".12	45 -9	N. A. C-5
	GRVILL	3334	33°25'31".95 33°25'32".14	269°05'11".35 269°05'10".30	43 -10	N. A. C-5
	USAFAC	3400	39°00'22".44 39°00'21".99	255°07'01".01 255°06'58".32	2191 2147	N. A. C-5
E	BEDFRD	3401	42°27'17".53 42°27'17".06	288°43'35".03 288°43'36".14	88 33	N. A. C-5
E	SEMMES	3402	30°46'49".35 30°46'49".85	271°44'52".37 271°44'51".64	79 23	N. A. C-5
	SWANIS	3404	17°24'16".57 17°24'18".90	276°03'29".87 276°03'29".71	83 18	N. A. C-5
	GRDTRK	3405	21°25'47".05 21°25'48".69	288°51'14".03 288°51'15".03	7 -48	N. A. C-5
	CURACO	3406	12°05'22".11 12°05'25".49	291°09'43".76 291°09'45".16	23 -34	N. A. C-5
	TRNDAD	3407	10°44'32".78 10°44'36".16	298°23'23".67 298°23'25".43	269 210	N. A. C-5
	GRANFK	3451	47° 56'38".63 47° 56'38".03	262° 37'11".21 262° 37'09".15	296 242	N. A. C-5

Table 15 (Continued)

Source	Name	Station No.	Latitude	Longitude	Geodetic Height (meters)	Datum
	TWINOK	3452	36°07'25".69 36°07'25".58	262°47'04".48 262°47'02".68	312 262	N. A. C-5
	ROTHGR	3453	51°25'00".00 51°24'57".05	9°30'06".00 9°30'00".58	351 352	European C-5
	ATHNGR	3463	37°53'30".00 37°53'26".07	23°44'30".00 23°44'26".73	16 23	European C-5
	TORRSP	3464	40°29'18".53 40°29'14".10	356°34'41".24 356°34'36".06	588 635	European C-5
	CHOFUJ	3465	35°39'57".00 35°40'08".96	139°32'12".00 139°32'00".19	49 75	Tokyo C-5
	KINDLY	3471	32° 22'57".30 32° 22'57".41	295° 19'00".46 295° 19'02".09	26 -23	N. A. C-5
E	HUNTER	3648	32°00'05".87 32°00'06".32	278°50'46".36 278°50'46".32	17 -40	N. A. C-5
	JUPRAF	3649	27°01'14".80 27°01'16".02	279°53'13".72 279°53'13".72	26 -37	N. A. C-5
E	ABERDN	3657	39°28'18".97 39°28'18".71	283°55'44".56 283°55'45".10	4 -51	N. A. C-5
E	HOMEST	3861	25°30'24".69 25°30'26".02	279°36'42".69 279°36'42".70	18 -44	N. A. C-5
	CHYWYN	3902	41°07'59".20 41°07'58".61	255°08'02".65 255°07'59".94	1890 1845	N. A. C-5

Table 16
ARMY MAP SERVICE - SECOR SOURCE H

Source	Name	Station No.	Latitude	Longitude	Geodetic Height (meters)	Datum
G	HERNDN	5001	38°59'37".69 38°59'37".47	282°40'16".68 282°40'17".08	119 64	N. A. C-5
I	CUBCAL	5200	32°48'00".00 32°47'59".74	242°52'00".00 242°51'56".55	101 71	N. A. C-5
I	LARSON	5201	47°11'00".00 47°10'58".76	240°40'00".00 240°39'55".68	354 319	N. A. C-5
I	WRGTON	5202	43°39'00".00 43°38'59".49	264°25'00".00 264°24'58".27	481 428	N. A. C-5
G	GREENV	5333	33°25'32".34 33°25'32".53	269°05'10".78 269°05'09".73	43 -10	N. A. C-5
	TRUKIS	5401	7°27'39".30 7°27'39".30	151°50'31".28 151°50'31".28	5 * 5	Navy Iben Astro 1947 C-5
	SWALLO	5402	-10°18'21".42 -10°18'21".42	166°17'56".79 166°17'56".79	9 * 9	1966 SECOR Astro C-5
	KUSAIE	5403	5°17'44".43 5°17'44".43	163°01'29".88 163°01'29".88	7 * 7	Astro 1962, 65, Allen Sodano Lt C-5
	GIZZOO	5404	-8°05'40".58 -8°05'40".58	156°49'24".82 156°49'24".82	49 * 49	Provisional DOS C-5
	TARAWA	5405	1°21'42".13 1°21'42".13	172°55'47".26 172°55'47".26	7 * 7	1966 SECOR Astro C-5

Table 16 (Continued)

Source	Name	Station No.	Latitude	Longitude	Geodetic Height (meters)	Datum
	NANDIS	5406	-17°45'31".01	177°27'02".83	17 *	Viti Levu 1916
			-17°45'31".01	177°27'02".83	17	C-5
	CANTON	5407	-2° 46'28".99	188°16'43".47	6 *	1966 Canton Astro
			-2° 46'28".99	188°16'43".47	6	C-5
	JONSTN	5408	16°43'51".68	190°28'41".55	6 *	Johnston Island 1961
			16°43'51".68	190°28'41".55	6	C-5
	MIDWAY	5410	28°12'32".06	182°37'49".53	6	Midway Astro 1961
			28° 12'32".06	182°37'49".53	6	C-5
	MAUIHI	5411	20°49'37".00	203°31'52".77	32	Old Hawaiian
			20°49'25".14	203°32'01".88	31	C-5
G	FTWART	5648	31°55'18".41	278°26'00".26	29	N. A.
			31°55'18".86	278°26'00".18	-27	C-5
G	HNTAFB	5649	32°00'04".04	278°50'43".17	27	N. A.
			32°00'04".49	278°50'43".13	-30	C-5
G	HOMEFL	5861	25°29'21".18	279°37'39".35	18	N. A.
			25°29'22".51	279°37'39".37	-44	C-5

*MSL

Table 17
US C&GS - OPTICAL - SOURCE F

Name	Station No.	Latitude	Longitude	Geodetic Height (meters)	Datum
BELTVL	6002	39°01'39".03 39°01'38".80	283°10'26".94 283°10'27".40	45 -10	N. A. C-5
ASTRMD	6100	39°01'39".72 39°01'39".49	283°10'27".83 283°10'28".29	45 -10	N. A. C-5
TIMINS	6113	48°33'56".17 48°33'55".70	278°37'44".54 278°37'44".49	290 232	N. A. C-5

Table 18
SPEOPT - OPTICAL - SOURCE B

Name	Station No.	Latitude	Longitude	Geodetic Height (meters)	Datum
1UNDAK	7034	48° 01'21".40 48° 01'20".81	262°59'21".56 262°59'19".55	255 201	N. A. C-5
1EDINB	7036	26°22'45".44 26°22'46".35	261°40'09".03 261°40'07".34	67 15	N. A. C-5
1COLBA	7037	38°53'36".07 38°53'35".81	267°47'42".12 267°47'40".85	271 218	N. A. C-5
1BERMD	7039	32°21'48".83 32°21'48".94	295°20'32".56 295°20'34".18	21 -28	N. A. C-5
1PURIO	7040	18°15'26".22 18°15'28".30	294°00'22".17 294°00'23".63	58 +5	N. A. C-5
1GSFCP	7043	39°01'15".01 39°01'14".78	283°10'19".93 283°10'20".39	54 -1	N. A. C-5
1CKVLE	7044	38°22'12".50 38° 22'12".33	274°21'16".81 274° 21'16".28	187 131	N. A. C-5
1DENVR	7045	39°38'48".03 39°38'47".54	255°23'41".19 255°23'38".52	1796 1751	N. A. C-5
1JUM24	7071	27°01'12".77 27°01'14".00	279°53'12".31 279°53'12".30	25 -38	N. A. C-5
1JUM40	7072	27°01'13".17 27°01'14".39	279°53'12".49 279°53'12".49	25 -38	N. A. C-5
1JUPC1	7073	27°01'13".11 27° 01'14".33	279°53'12".72 279°53'12".72	22 -41	N. A. C-5
1JUBC4	7074	27°01'13".33 27°01'14".55	279°53'12".76 279°53'12".76	25 -38	N. A. C-5
1SUDBR	7075	46°27'20".99 46°27'20".52	279°03'10".35 279°03'10".35	281 224	N. A. C-5
1JAMAC	7076	18°04'31".98 18°04'34".20	283°11'26".52 283°11'27".03	486 423	N. A. C-5

Table 19
SPEOPT - LASER - SOURCE B

Name	Station No.	Latitude	Longitude	Geodetic Height (meters)	Datum
ROSLAS	7051	35°11'46".60 35°11'46".70	277°07'26".23 277°07'26".02	879 822	N. A. C-5
GODLAS	7050	39°01'13".68 39°01'13".45	283°10'18".05 283°10'18".51	55 0	N. A. C-5

Table 20
INTERNATIONAL OPTICAL - SOURCE I

Source	Name	Station No.	Latitude	Longitude	Geodetic Height (meters)	Datum
	DELFTH	8009	52°00'09".24 52°00'06".12	4°22'21".23 4°22'15".30	23 28	European C-5
	MALVRN	8011	52°08'39".12 52°08'35".68	358°01'59".49 358°01'53".03	111 125	European C-5
D	ZIMWLD*	8010	46°52'41".77 46°52'36".73	7°27'57".56 7°27'52".54	903 907	BERNE C-5

*The C-5 position was derived from the C-6 position.

Table 21
SAO - OPTICAL

NAME	STATION NUMBER	LOCATION
1ORGAN	9001	Organ Pass, New Mexico
1OLFAN	9002	Olifantsfontein, South Africa
1OOMER	9003	Woomera, Australia
1SPAIN	9004	San Fernando, Spain
1TOKYO	9005	Tokyo, Japan
1NATOL	9006	Naini, Tal, India
1QUIPA	9007	Arequipa, Peru
1SHRAZ	9008	Shiraz, Iran
1CURAC	9009	Curacao, Lesser Antilles
1JUPTR	9010	Jupiter, Florida
1VILDO	9011	Villa Dolores, Argentina
1MAUIO	9012	Maui, Hawaii
OSLONR	9426	Oslo, Norway
AUSBAK	9023	Woomera, Australia
NATALB	9029	Natal, Brazil
AGASSI	9050	Cambridge, Massachusetts
COLDLK	9424	Cold Lake, Alberta
EDWAFB	9425	Edwards AFB, California
RIGLAT	9428	Riga, Latvia
POTDAM	9429	Potsdam, Germany
ZVENIG	9430	Zvenigorod, Russia

Table 22
STADAN - OPTICAL

NAME	STATION NUMBER	LOCATION
1BPOIN	1021	Blossom Point, Maryland
1FTMYR	1022	Fort Myers, Florida
1OOMER	1024	Woomera, Australia
1QUITO	1025	Quito, Ecuador
1LIMAP	1026	Lima, Peru
1SATAG	1028	Santiago, Chile
1MOJAV	1030	Mojave, California
1JOBUR	1031	Johannesburg, Union of South Africa
1NEWFL	1032	St. John's, Newfoundland
1COLEG	1033	College, Alaska
1GFORK	1034	East Grand Fork, Minnesota
1WNKFL	1035	Winkfield, England
1ROSMA	1042	Rosman, North Carolina
1TANAN	1043	Tananarive, Madagascar

Table 23
STADAN - R/R

NAME	STATION NUMBER	LOCATION
CARVON	1152	Carnarvon, Australia
ROSRAN	1126	Rosman, North Carolina
MADGAR	1122	Tananarive, Madagascar

Table 24
NAVY TRANET - DOPPLER

NAME	STATION NUMBER	LOCATION
LASHAM	2006	Lasham, England
SANHES	2008	Sao Jose dos Campos, Brazil
PHILIP	2011	San Miquel, Philippines
SMTHFD	2012	Smithfield, Australia
MISAWA	2013	Misawa, Japan
ANCHOR	2014	Anchorage, Alaska
TAFUNA	2017	Tafuna, American Samoa
THULEG	2018	Thule, Greenland
MCMRDO	2019	McMurdo Sound, Antarctica
WAHIWA	2100	South Point, Hawaii
LACRES	2103	Las Cruces, New Mexico
LASHM2	2106	Lasham, England
APLMND	2111	APL Howard County, Maryland
PRETOR	2115	Pretoria, Union of South Africa
SHEMYA	2739	Shemya Island, Alaska
BELTSV	2742	Beltsville, Maryland
STNVIL	2745	Stoneville, Mississippi

Table 25
US AIR FORCE - OPTICAL

NAME	STATION NUMBER	LOCATION
ANTIGA	3106	Antigua Island, Lesser Antilles
GRNVLE	3333	Stoneville, Mississippi
GRVILL	3334	Stoneville, Mississippi
USAFAC	3400	Colorado Springs, Colorado
BEDFRD	3401	L. G. Hanscom Field, Massachusetts
SEMMES	3402	Semmes Island, Georgia
SWANIS	3404	Swan Island, Caribbean Sea
GRDTRK	3405	Grand Turk, Caicos Islands
CURACO	3406	Curacao, Lesser Antilles
TRNDAD	3407	Trinidad Island
GRANFK	3451	Grand Forks, North Dakota
TWINOK	3452	Twin Oaks, Oklahoma
ROTHGR	3453	Rothwesten, West Germany
ATHNGR	3463	Athens, Greece
TORRSP	3464	Torrejon de Ardoe, Spain
CHOFUJ	3465	Chofu, Japan
KINDLY	3471	Kindly A. F. B., Bermuda
HUNTER	3648	Hunter AFB, Georgia
JUPRAF	3649	Jupiter, Florida
ABERDN	3657	Aberdeen, Maryland
HOMEST	3861	Homestead AFB, Florida
CHYWYN	3902	Cheyenne, Wyoming

Table 26
ARMY MAP SERVICE - SECOR

NAME	STATION NUMBER	LOCATION
HERNDN	5001	Herndon, Virginia
CUBCAL	5200	San Diego, California
LARSON	5201	Moses Lake, Washington
WRGTON	5202	Worthington, Minnesota
GREENV	5333	Greenville, Mississippi
TRUKIS	5401	Truk Island, Caroline Islands
SWALLO	5402	Swallow Island, Santa Cruz Islands
KUSAIE	5403	Kusai Islands, Caroline Island
GIZZOO	5405	Gizzoo, Gonzongo, Solomon Islands
TARAWA	5405	Tarawa, Gilbert Islands
NANDIS	5406	Nandi, Vitilevu, Fiji Islands
CANTON	5407	Canton Island, Phoenix Islands
JONSTN	5408	Johnston Island, Pacific Ocean
MIDWAY	5410	Eastern Island, Midway Islands
MAUIHI	5411	Maui, Hawaii
FTWART	5648	Fort Stewart, Georgia
HNTAFB	5649	Hunter AFB, Georgia
HOMEFL	5861	Homestead AFB, Florida

Table 27
USC&GS - OPTICAL

NAME	STATION NUMBER	LOCATION
BELTVL	6002	Beltsville, Maryland
ASTRMD	6100	Beltsville, Maryland
TIMINS	6113	Timmins, Ontario

Table 28
SPEOPT - OPTICAL

NAME	STATION NUMBER	LOCATION
1UNDAK	7034	Univ. North Dakota, Grand Forks, North Dakota
1EDINB	7036	Edinburg, Texas
1COLBA	7037	Columbia, Missouri
1BERMD	7039	Bermuda Island
1PURIO	7040	San Juan, Puerto Rico
1GSFCP	7043	GSFC, Greenbelt, Maryland
1CKVLE	7044	Clarksville, Indiana
1DENVR	7045	Denver, Colorado
1JUM24	7071	Jupiter, Florida
1JUM40	7072	Jupiter, Florida
1JUPC1	7073	Jupiter, Florida
1JUBC4	7074	Jupiter, Florida
1SUDBR	7075	Sudbury, Ontario
1JAMAC	7076	Jamaica, B. W. I.

Table 29
SPEOPT - LASER

NAME	STATION NUMBER	LOCATION
ROSLAS	7051	Rosman, North Carolina
GODLAS	7050	GSFC, Greenbelt, Maryland

Table 30
INTERNATIONAL - OPTICAL

NAME	STATION NUMBER	LOCATION
DELFTH	8009	Delft, Holland
MALVRN	8011	Malvern, England
ZIMWLD	8010	Berne, Switzerland

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APPENDIX A

Transformation Procedure

1. DESCRIPTION OF THE SMITHSONIAN ASTROPHYSICAL OBSERVATORY (SAO) STANDARD EARTH PARAMETERS C-5 AND C-6 SYSTEM

The SAO Standard Earth reference system is a geocentric (earth's center of mass) terrestrial system. The Z - axis is oriented in the direction of the mean pole of 1900 - 1905; the X - Z plane 75° 03'55."94 East of the U. S. Naval Observatory.

The scale for the Standard Earth is defined by the adopted value of GM used in the reductions since only directions were introduced in the solution. The value used by SAO for GM in its solution accounts for the difference between the C-5 and C-6 solutions.

Kepler's third law states:

$$T = \left(\frac{a^3}{GM}\right)^{1/2}$$

where:

T = period of orbit

a = semi-major axis of equatorial orbit or earth radius.

In the Baker-Nunn camera system where the measured parameter is basically the period of the orbit, one must ascertain the relationship between GM and a and show how a change in one will affect the other if the period is constant. This can be stated as;

$$dT = 1/2 \left(\frac{a^3}{GM}\right)^{-1/2} \left[\frac{3a^2}{GM}\, da - \frac{a^3}{GM^2}\, d\,(GM)\right] = 0$$

from which

$$\frac{d(GM)}{3GM} = \frac{da}{a}$$

In the C-5 solution, the value of GM used by SAO was $3.986032 \times 10^{20}\ cm^3\, sec^{-2}$. In the C-6 solution, SAO used the value of GM which was determined by the Jet Propulsion Laboratory from observations of Rangers 6, 7, 8, 9 and Mariner 4. The value adopted for GM was $(3.986013 \pm 0.00001) \times 10^{20}\ cm^3\, sec^{-2}$ which in effect reduced the scale of the C-5 system by a factor of $-(1.6 \pm 0.8) \times 10^{-6}$.

In order to bring the C-5 coordinates into sympathy with this new GM value, the C-5 coordinates must be multiplied by the factor 0.9999984 $\pm$ (8×10^{-7}).

The parameters for the two systems are as follows:

C-5 System

a_e = 6378165 meters

f = 1/298.25

GM = 3.986032×10^{20} cm^3 sec^{-2}

C-6 System

a_e = 6378155 meters

f = 1/298.25

GM = 3.986013×10^{20} cm^3 sec^{-2}

2. STATION POSITION TRANSFORMATION

In order to ascertain the *a priori* estimates of the station tracking positions and their respective uncertainties relative to the geocenter, knowledge of the following is essential:

a. Baker-Nunn camera station positions on the original datum.

b. Baker-Nunn camera station positions on the SAO C-5 and/or C-6 system.

c. The positions of the various tracking sites on their original datums.

d. Intra-datum survey connections between the Baker-Nunn locations and the various tracking sites.

e. The estimated surface survey uncertainty between the Baker-Nunn site and the tracking site.

The method used to effect this transformation has been checked (see Appendix B) to ascertain its compatibility with the equivalent transformation formulas commonly used to compute datum shifts. It should be noted that the method explained herein can be applied to another unified world datum when similar data is available as in the above items (a. -e.).

Many of the original survey summary sheets for the stations that were to be transformed contained height above mean sea level instead of the local reference ellipsoid. Since the procedure requires geodetic height it was necessary to refer to geoid contour maps for the geoid heights of these stations. The geoid contour maps were readily available for the major datums, however for those stations on isolated datums no geoid height could be ascertained, and as a result only the height above mean sea level was used for these transformations.

Figure (1) represents the relationship that exists with the geoid, ellipsoid, and the gravimetrically determined ellipsoid. The geoid height may be either positive or negative dependent upon whether the geoid is above or below the relative ellipsoid at that point. The algebraic sum of the geoid height and the height above mean sea level yield the geodetic height.

In the Cartesian coordinate system in three dimensions the coordinates are determined as follows in spherical coordinates:

$$X = r \cos\phi \cos\lambda$$

$$Y = r \cos\phi \sin\lambda$$

$$Z = r \sin\phi$$

In figure 2, a datum transformation is represented by the two ellipsoids. It is assumed that parallelism exists between the respective axes. The datum shift is represented by the change in origin. The old datum is represented by the prime; thus

$$\Delta X = X - X'$$

$$\Delta Y = Y - Y'$$

$$\Delta Z = Z - Z'$$

where X, Y, Z are given above and

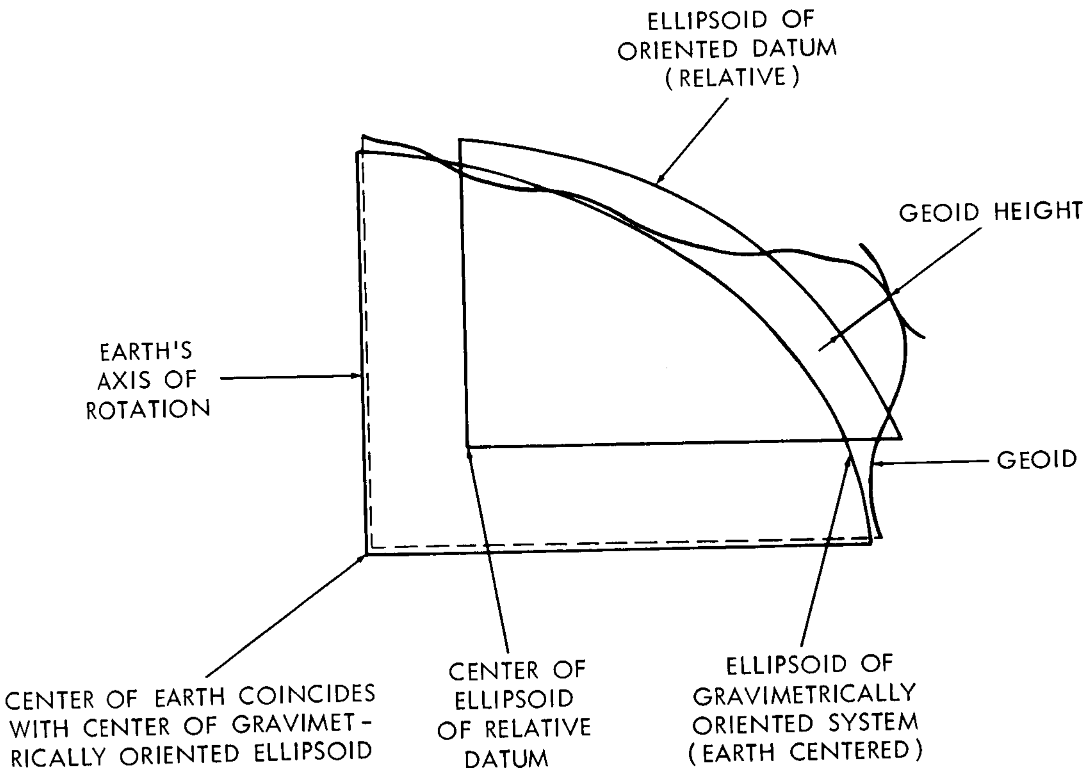

Figure 1. Relationship of the Geoid, Ellipsoid, Earth Mass Centered Ellipsoid

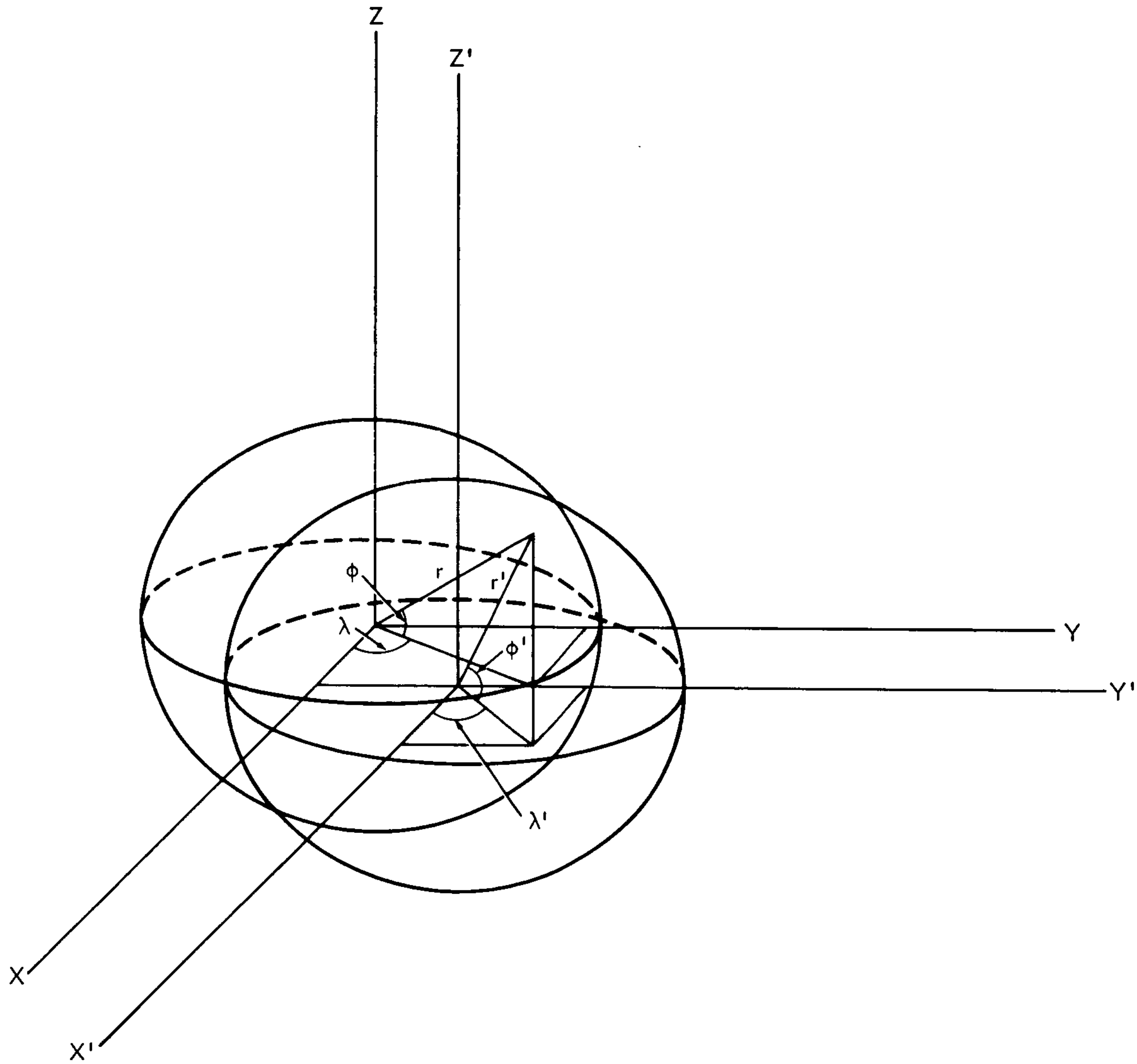

Figure 2. Ellipsoids of Relative Datums

$$X' = r' \cos \phi' \cos \lambda'$$

$$Y' = r' \cos \phi' \sin \lambda'$$

$$Z' = r' \sin \phi'$$

Substituting the above we get

$$\Delta X = r \cos \phi \cos \lambda - r' \cos \phi' \cos \lambda'$$

$$\Delta Y = r \cos \phi \text{ sub } \lambda - r' \cos \phi' \sin \lambda'$$

$$\Delta Z = r \sin \phi - r' \sin \phi'$$

The station shift equations (ΔX, ΔY, ΔZ) given above in spherical coordinates normally employ geodetic coordinates which are presented in the following section.

3. TRANSFORMATION OF GEODETIC POSITIONS (ϕ , λ , H) TO THREE DIMENSIONAL CARTESIAN COORDINATES

The coordinates of the Baker-Nunn stations are furnished in both the ellipsoidal and three-dimensional Cartesian coordinate systems. However, the positions of all the other tracking stations are given in ellipsoidal coordinates. This necessitates the calculation of the three dimensional Cartesian coordinates for these stations. This is accomplished by the following equations:

$$X = (\nu + H) \cos \phi \cos \lambda$$

$$Y = (\nu + H) \cos \phi \sin \lambda$$

$$Z = [\nu (1 - e^2) + H] \sin \phi$$

where

ϕ = geodetic latitude

λ = geodetic longitude

ν = radius of curvature in the prime vertical

$$\frac{a_e}{(1 - e^2 \sin^2 \phi)^{1/2}}$$

a_e = semi-major axis of reference ellipsoid

H = geodetic height (mean sea level plus geoid height)

e = eccentricity of reference ellipsoid

The orientation of the Cartesian coordinate system is the same as that described in Section 1.

4. MULTI-STATION TRANSFORMATION

The Multi-Station transformation was used on practically all of the stations transformed to the C-5 Datum in this report. This transformation defined below was applied to stations where there existed at least one Baker-Nunn station on the same local datum. Most of the stations that were shifted had more than one Baker-Nunn station on the datum. This existed because of the large number of stations on the North American Datum. Each Baker-Nunn station within the same datum may determine a unique shift for a station on that datum as seen for example in the table below for the North American datum. The shift is given as the difference between the Cartesian coordinates (ΔX, ΔY, ΔZ) of the Baker-Nunn station on the original survey datum and the C-5 Datum. The Multi-Station transformation uses a weighted average of the respective shifts, where the weights are inversely proportional to the distance between each of the Baker-Nunn stations and the stations to be transformed. Thus the transformation allows for the differential shift as may be seen in the table below among the four Baker-Nunn stations on the North American Datum.

The following example demonstrates the procedure and weighting scheme utilized in a multi-station transformation[1] for the station 1UNDAK on the North American Datum.

The original North American Datum (NAD) position for 1UNDAK was transformed to the following Cartesian coordinates:

X = -521679 meters

Y = -4242198

Z = 4718543

[1] The multi-station transformation as described herein is contained in the TRANS program developed by Wolf Research and Development Corporation under NASA contract for the Mission and Trajectory Analysis Division.

The following Δ's represent the shifts of the Baker-Nunn stations from NAD to SAO C-5:

		ΔX	ΔY	ΔZ
(1)	1ORGAN	-36 meters	+144	+179
(2)	1JUPTR	-26	+152	+179
(3)	1CURAC	-6	+135	+178
(4)	1QUIPA	-2	+117	+124

Since the effect of each Baker-Nunn station is inversely proportional to its distance from 1UNDAK, we then compute the respective distances and weights (w).

Station	Distance	W_N	$W_N/\Sigma W_N$
1ORGAN	1909518 meters	1.00000000	0.42631206
1JUPTR	2754834	0.69315174	0.29549894
1CURAC	4766268	0.40063168	0.17079411
1QUIPA	7579973	0.25191610	0.10739487

We then add the respective Δ's to the coordinates of 1UNDAK and obtain the following unweighted C-5 positions:

$P_1(X_1) = -521715$	$P_1(Y_1) = -4242054$	$P_1(Z_1) = -4718722$
$P_2(X_2) = -521705$	$P_2(Y_2) = -4242046$	$P_2(Z_2) = 4718722$
$P_3(X_3) = -521685$	$P_3(Y_3) = -4242063$	$P_3(Z_3) = -4718721$
$P_4(X_4) = -521681$	$P_4(Y_4) = -4242081$	$P_4(Z_4) = -4718667$

The basic equations to determine the final weighted position for 1UNDAK is:

$$P(X, Y, Z) = P_1(X_1, Y_1, Z_1)\frac{W_1}{W_1+W_2+W_3+W_4} + P(X_2, Y_2, Z_2)\frac{W_2}{W_1+W_2+W_3+W_4} + \ldots$$

$$+ P(X_N, Y_N, Z_N)\frac{W_N}{\sum W_N}$$

where

$P_N(X_N, Y_N, Z_N)$ = unweighted position of 1UNDAK

W_N = weight for each respective station

After substitution, the final weighted C-5 position of 1UNDAK in Cartesian coordinates is:

$$X = -521703 \text{ meters}$$

$$Y = -4242055$$

$$Z = 4718713$$

or in elliptical coordinates:

$$\phi = 48^{\circ}01'20.810 \text{ N}$$

$$\lambda = 262^{\circ}59'19.553 \text{ E}$$

$$H = 201.466 \text{ meters}$$

In a single station transformation, the total shift of the Baker-Nunn station is applied to those stations that are on the same original datum as the Baker-Nunn. Thus the weighting scheme is not necessary as only one Baker-Nunn station is on the original datum.

5. ELLIPSOIDAL TRANSFORMATION

When a tracking station to be transformed is on an isolated datum or a datum on which there is no Baker-Nunn site, but for which there is some knowledge of the center of mass shift, a Molodenskiy ellipsoidal transformation is provided.

Transformation between datums may be accomplished with the following equations[1]:

[1]This formulation is contained within the DELU program which was developed under NASA contract by Wolf Research and Development Corporation for the Mission and Trajectory Analysis Division.

$$\Delta H = \Delta X \cos\phi \cos\lambda + \Delta Y \cos\phi \sin\lambda + \Delta Z \sin\phi + (a\,\Delta f + f\,\Delta a)\sin^2\phi - \Delta a$$

$$\Delta\phi'' = 206265\left[-\Delta X \sin\phi \cos\lambda - \Delta Y \sin\phi \sin\lambda + \Delta Z \cos\phi\right.$$

$$\left.(a\,\Delta f + f\,\Delta a)\sin 2\phi\right]/R_m$$

$$\Delta\lambda'' = 206265(-\Delta X \sin\lambda + \Delta Y \cos\lambda)/R_n \cos\phi$$

where

$$R_m = \frac{a(1-e^2)}{(1-e^2 \sin^2\phi)^{3/2}} \;;\; R_n = \frac{a}{(1-e^2 \sin^2\phi)^{1/2}}$$

ΔX, ΔY, ΔZ = shifts of ellipsoid centers from one ellipsoid to another

a = semi-major axis

f = flattening

Δa = new (a) minus old (a)

Δf = new minus old flattening

$e^2 = 2f-f^2$

ϕ = latitude of tracking station on original datum

λ = longitude of tracking station on original datum

For isolated datums such as the Pacific SECOR sites, ΔX, ΔY, ΔZ are unknown. The local datum geodetic coordinates are then taken as the C-5 geodetic coordinates. Then, the Cartesian coordinates are derived from the geodetic coordinates on the C-5 ellipsoid.

Further, on isolated datums the geoid separations are generally not known. So rather than consider the mean sea level (MSL) survey height to be the geodetic station height, we have carried over the MSL height to the transformed position.

APPENDIX B
Comparison of Transformation Procedure

COMPARISON OF MULTI-STATION TRANSFORMATION AND MOLODENSKIY'S TRANSFORMATION FORMULAS

The multi-station transformation presented in Appendix A, Section 4 derives the station shift and associated world datum Cartesian coordinates and geodetic coordinates. The Molodenskiy transformation presented in Appendix A, Section 5 provides the adjusted differences of the geodetic coordinates between the old and new datum when given the station shift ΔX, ΔY, ΔZ (or the center of mass shift between the old and new datum). Results on the geodetic station coordinates using a common world datum for these two transformations may be compared and will provide a compatibility check on the computational procedures. Results are already available in the Goddard Directory of Tracking Station Locations for the Mercury Datum including the original and final datum geodetic and Cartesian station coordinates. The Molodenskiy transformation was used in obtaining the Mercury Datum geodetic coordinates in the Goddard Directory where each local datum center of mass shift (ΔX, ΔY, ΔZ) was provided by the Army Map Service. Since only a constant station shift within a datum is employed in the results for the Mercury datum the comparison is somewhat limited, but the computations for the Multi-Station transformation proceeded in the same general manner as with the C-5 datum. It is noted that the Molodenskiy transformation is based on a first order Taylor series expansion and the agreement found below in the comarison of results serves to check on the adequacy of this approximation.

Ten STADAN tracking stations on the North American Datum were transformed to the MERCURY Datum using results from both the formulas of Molodenskiy and the weighted multi-station technique. Four Baker-Nunn stations on the MERCURY Datum were used as controlling stations for the multi-station transformation. The position relationships of the STADAN and Baker-Nunn sites are shown in Figure 1.

The results as indicated in Tables 1 and 2 show very good agreement. In Tables 1 and 2 the coordinates above the line are the positions as derived by the weighted multi-station shift, and the coordinates below the line are derived by the standard transformation formulas used in the Goddard Station Directory. Inspection of Table 1 reveals that the largest difference in the X, Y and Z coordinates is one meter and in the geodetic coordinates approximately four meters. Table 2 shows the geodetic coordinates for the same stations.

The weighted multi-station technique may be employed advantageously when datum shifts ($\Delta X, \Delta Y$, ΔZ) are not known or, as in the case of the SAO C-5 Datum, the stations have been allowed to adjust independently. Differential shifts within a datum are more realistic than assuming one set of ΔX, ΔY, ΔZ's, particularly for a large area datum as the North American Datum.

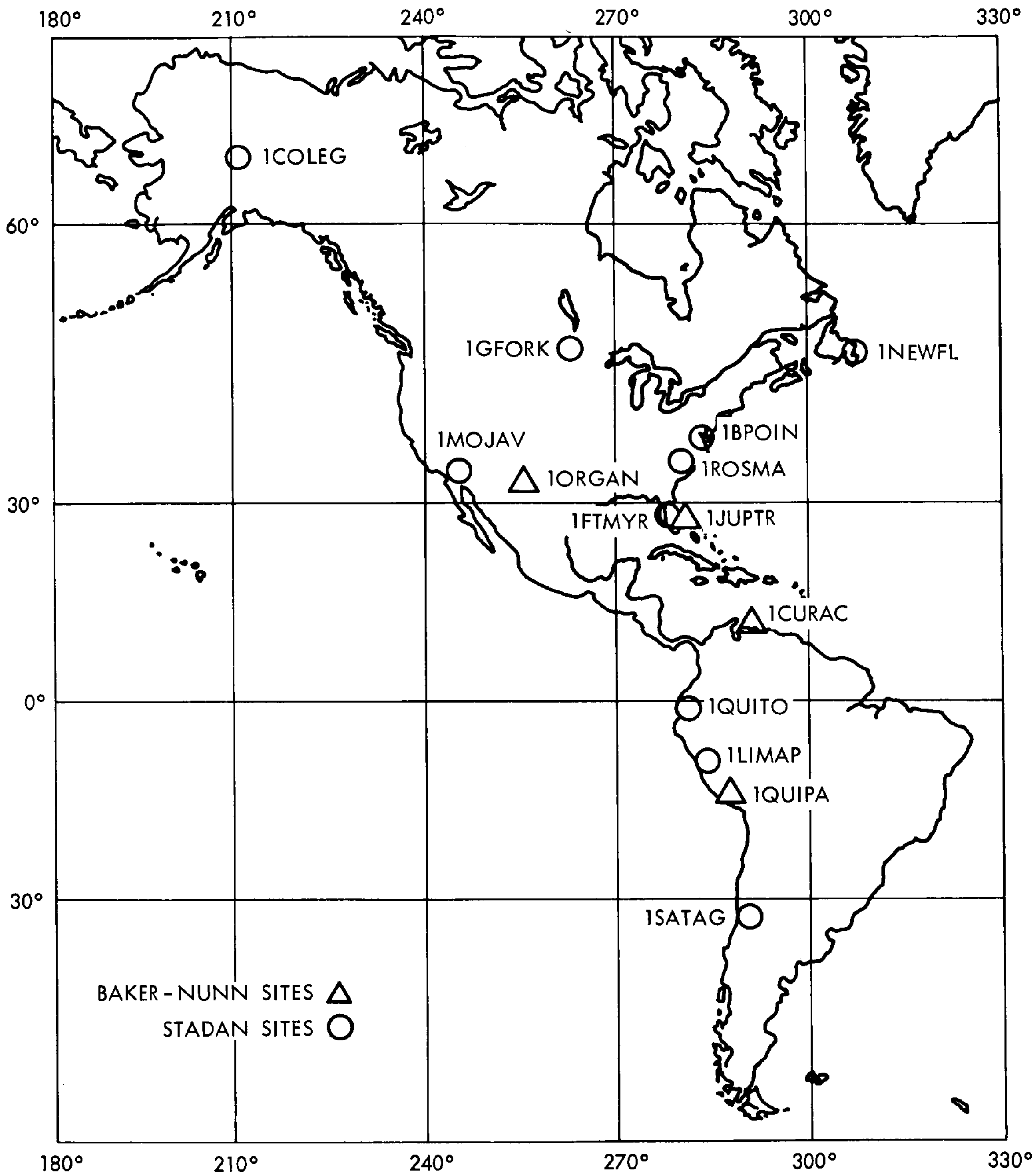

Figure 1. Station Location for Transformation Comparisons

Table 1
COMPARISON OF TRANSFORMED CARTESIAN COORDINATES

STATION	X (meters)	Y	Z
1GFORK	-521677 -521676	-4242087 -4242086	+4718767 +4718768
1MOJAV	-2357212 -2357211	-4646363 -4646363	+3668359 +3668358
1BPOIN	+1118063 +1118064	-4876360 -4876360	+3943017 +3943018
1NEWFL	+2602804 +2602804	-3419190 -3419189	+4697701 +4697701
1FTMYR	+807885 +807886	-5652024 -5652025	+2833551 +2833552
1QUITO	+1263617 +1263618	-6255012 -6255011	-68856 -68856
1LIMAP	+1388818 +1388819	-6088430 -6088429	-1293206 -1293206
1SATAG	+1769708 +1769708	-5044643 -5044642	-3468192 -3468192
1COLEG	-2299235 -2299234	-1445729 -1445729	+5751851 +5751852
1ROSMA	+647541 +647542	-5177971 -5177971	+3656758 +3656758

Table 2
Comparison of Transformed Geodetic Coordinates

STATION	ϕ	λ	h (m)
1GFORK	48°01'21".27 21".18	262°59'21".01 21".04	258 255
1MOJAV	35°19'48".66 48".55	243°06' 0".81 0".84	916 914
1BPOIN	38°25'50".01 49".91	282°54'49".33 49".36	11 8
1NEWFL	47°44'29".05 28".95	307°16'46".64 46".70	124 121
1FTMYR	26°32'53".85 63".76	278°08' 4".56 4".60	15 14
1QUITO	- 0°37'20".55 20".54	281°25'15".58 15".61	3581 3579
1LIMAP	-11°46'34".89 34".84	282°50'59".11 59".13	36 34
1SATAG	-33°08'56".32 56".23	289°19'52".84 52".87	683 680
1COLEG	64°52'18".68 18".62	212°09'40".17 40".15	187 183
1ROSMA	35°12'07".69 07".59	277°07'41".63 41".66	916 914

APPENDIX C
Uncertainty of Transformed Positions

Uncertainty of Transformed Positions

After the tracking station coordinates have been derived in the SAO Standard Earth reference system, we can derive estimates of the uncertainty in these positions relative to the Geocenter (earth's center of mass). The total uncertainties are derived from two sources.

1) Uncertainty of the Baker-Nunn station coordinates relative to the Geocenter.

2) Relative position accuracy between the Baker-Nunn stations and the station to be transformed.

References (1) and (2) state that the uncertainty of any Baker-Nunn station relative to the geocenter is approximately 15-20 meters.

In order to derive a priori estimates of the uncertainty in the tracking station position relative to the Baker-Nunn sites use in made of an empirical formula developed by L. Simmons, USC&GS, to describe the accuracy of first order triangulation. The formula states that the relative accuracy between two points connected by conventional first order triangulation (minimum of 1 part in 25,000 for closure in length after conditions equations are applied) is approximately

$$\frac{1}{20000 \sqrt[3]{M}}$$

where M = is the distance between the two stations in statute miles.

As an example, consider two stations 1000 miles apart and connected by standard triangulation. The proportional accuracy would therefore be 1 part in 200,000 or approximately 26.4 ft. This means that the relative uncertainty between the stations caused by surface survey errors in approximately 26 ft. or 8 meters.

The total position uncertainty becomes:

$$\sigma_g = (\sigma_{bn}^2 + \sigma_s^2)^{1/2}$$

where

σ_g = uncertainty of the transformed tracking station position relative to the geocenter.

σ_{bn} = uncertainty of the Baker-Nunn site relative to the geocenter.

σ_s = surface survey uncertainty as defined by L. Simmons.

For determining the maximum uncertainty of a transformed position, we will use the maximum value for $\sigma_{bn(20\ meters)}$ while σ_s will vary depending upon the distance of the transformed station from a Baker-Nunn site.

No uncertainty in the transformed C-5 positions is given for those stations that are on isolated datums. Simmon's rules is based on conventional surface survey ties which do not exist for these isolated datum stations.

The uncertainties of the transformed C-5 positions are listed in Table 1

Table 1 (Continued)
Uncertainty of C-5 Derived Positions

Station	Station No.	Uncertainty (meters)
SPECIAL SAO - OPTICAL		
NATALB	9029	25
AGASSI	9050	22
COLDLK	9424	23
EDWAFB	9425	21
RIGLAT	9428	21
POTDAM	9429	21
ZVENIG	9430	22
STADAN - OPTICAL		
1BPOIN	1021	21
1FTMYR	1022	20
1OOMER	1024	20
1QUITO	1025	22
1LIMAP	1026	21
1SATAG	1028	20
1MOJAV	1030	21
1JOBUR	1031	20
1NEWFL	1032	24
1COLEG	1033	26
1GFORK	1034	22
1WNKFL	1035	22
1ROSMA	1042	22
1TANAN	1043	*

*Not Given (Isolated Datum Station)

TABLE 1 (Continued)

Station	Station No.	Uncertainty (meters)
STADAN - R/$\dot{R}$		
CARVON	1152	23
ROSRAN	1126	21
MADGAR	1122	*
NAVY TRANET - DOPPLER		
LASHAM	2006	21
SANHES	2008	*
PHILIP	2911	23
SMTHFD	2012	20
MISAWA	2013	20
ANCHOR	2014	26
TAFUNA	2017	*
THULEG	2018	24
MCMRDO	2019	27
WAHIWA	2100	20
LACRES	2103	20
LASHM2	2106	21
APLMND	2111	21
PRETOR	2115	20
US AIR FORCE - OPTICAL		
ANTIGA	3106	21
GRNVLE	3333	21
USAFAC	3400	21
BEDFRD	3401	22
SEMMES	3402	21
SWANIS	3404	21
GRDTRK	3405	21
CURACO	3406	20

* Not Given

TABLE 1 (Continued)

Station	Station No.	Uncertainty (meters)
US AIR FORCE - OPTICAL		
TRNDAD	3407	21
GRANFK	3451	22
TWINOK	3452	21
ROTHGR	3453	21
ATHNGR	3463	23
TORRSP	3464	20
CHOFUJ	3465	20
KINDLY	3471	22
HUNTER	3648	20
JUPRAF	3649	20
ABERDN	3657	21
HOMEST	3861	20
CHYWYN	3902	21
ARMY MAP SERVICE - SECOR		
HERNDN	5001	21
CUBCAL	5200	21
LARSON	5201	22
WRGTON	5202	22
GREENV	5333	21
TRUKIS	5401	*
SWALLO	5402	*
KUSAIE	5403	*
GIZZOO	5404	*
TARAWA	5405	*
NANDIS	5406	*
CANTON	5407	*
JONSTN	5408	*
MIDWAY	5410	*
MAUIHI	5411	20
FTWART	5648	20
HNTAFB	5649	20
HOMEFL	5861	20

* Not Given

TABLE 1 (Continued)

Station	Station No.	Uncertainty (meters)
US C&GS - OPTICAL		
BELTVL	6002	21
ASTRMD	6100	21
TIMINS	6113	23
SPEOPT - OPTICAL		
1UNDAK	7034	22
1EDINB	7036	21
1COLBA	7037	21
1BERMD	7039	22
1PURIO	7040	21
1GSFCP	7043	21
1CKVLE	7044	21
1DENVR	7045	21
1JUM24	7071	20
1JUM40	7072	20
1JUPC1	7073	20
1JUBC4	7074	20
1SUDBR	7075	22
1JAMAC	7076	21
STADAN - LASER		
ROSLAS	7051	21
GODLAS	7050	21
INTERNATIONAL - OPTICAL		
DELFTH	8009	21
MALVRN	8011	21
ZIMWLD	8010	*

* Not Given

APPENDIX D
Source of Positions

SOURCES

The following sources were used to obtain the original datum positions:

Symbol	Source
A	Geodetic Parameters for a Standard Earth Obtained from Baker-Nunn Observations; September 1966; Smithsonian Astrophysical Observatory.
B	Goddard Directory of Tracking Station Locations; August 1966; Goddard Space Flight Center.
C	NWL-8 Geodetic Parameters Based on Doppler Satellite Observations; July 1967; R. Anderle and S. Smith, Naval Weapons Laboratory

Since the above official documents did not contain all those positions that were to be transformed, it was necessary to contact other sources for the positions of the remaining stations. These sources are:

Symbol	Source
D	Private communication with personnel at SAO; K. Haramundanis; B. Miller; A. Girnius.
E	Private communication with 1381 Geodetic Survey Squadron, USAF; S. Tischler.
F	Private communication with personnel at USC&GS; B. Stevens.
G	Private communication with personnel at U. S. Army Engineers Topographic Laboratories; L. Gambino.
H	Private communication with NASA Space Science Data Center.
I	General Station Data Sheet - GEOS -A Project Manager NASA Headquarters.