X-552-72-502

PREPRINT

NASA 66286

GTDS EARLY-ORBIT SUBSYSTEM FOR EARTH SATELLITES

(NASA-TM-X-66286) GPS EARLY-ORBIT SUBSYSTEM FOR EARTH SATELLITES (NASA) 65 p HC $5.25 CSCL 22A

N73-27734

Unclas

G3/30 09654

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DECEMBER 1972

GSFC — GODDARD SPACE FLIGHT CENTER

GREENBELT, MARYLAND

65 pp.

X-552-72-502

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December 1972

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GTDS EARLY-ORBIT SUBSYSTEM FOR EARTH SATELLITES

by

V. T. Laczo and J. L. Maury

ABSTRACT

The Early-orbit capability of the Goddard Trajectory Determination System, which determines starting vectors for earth satellites from angles-only or range-angles observations, is described and documented. Early-orbit results obtained from a variety of satellites, data types and methods of solution are also presented.

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GTDS EARLY-ORBIT SUBSYSTEM FOR EARTH SATELLITES

INTRODUCTION

The Goddard Trajectory Determination System, GTDS, now has incorporated into it an Early-orbit capability. The Early-orbit capability in contrast to a differential correction, DC, capability can compute a two-body starting vector directly from a very small number of observations while a DC needs a fairly accurate starting vector and many observations for a least squares process. Possible uses for the Early-orbit capability occur when a nominal starting vector for a DC program has diverged or if there is no starting vector available.

The GTDS Early-orbit package has three possible methods by which to find a two-body starting vector: Gauss' method, the Double-range iteration method and the Range-angles method. By having three methods rather than just one, the Early-orbit package has greater flexibility handling data types and time distribution of observations. The methods of Gauss and Double-range need three observations, where each observation consists of two simultaneous angle measurements; the Range-angles method needs from 2 to 16 observations each consisting of a simultaneous range and two angles. Mathematical descriptions of the Double-range and Gauss' methods are given by Escobal and the Range-angles method is described by Douglas: see References, section 1.6.

1.0 DISCUSSION OF EARLY-ORBIT TECHNIQUES

1.1 Selecting a Method of Solution

In order to choose an adequate method of obtaining a starting vector for a satellite directly from observations, the limitations of each of the methods must be considered. A visual description of the geometry involved for the three methods is given in Figures 1 and 2.

The Double-range method needs exactly three observations, where each observation consists of two simultaneous angle measurements. The observation types handled by the Double-range method are the following (note each observation consists of two angle components):

1. Goddard Range and Range Rate (GRARR) X_{30} and Y_{30} gimbal angles,

2. Unified S Band (USB) X_{85} and Y_{85} gimbal angles,

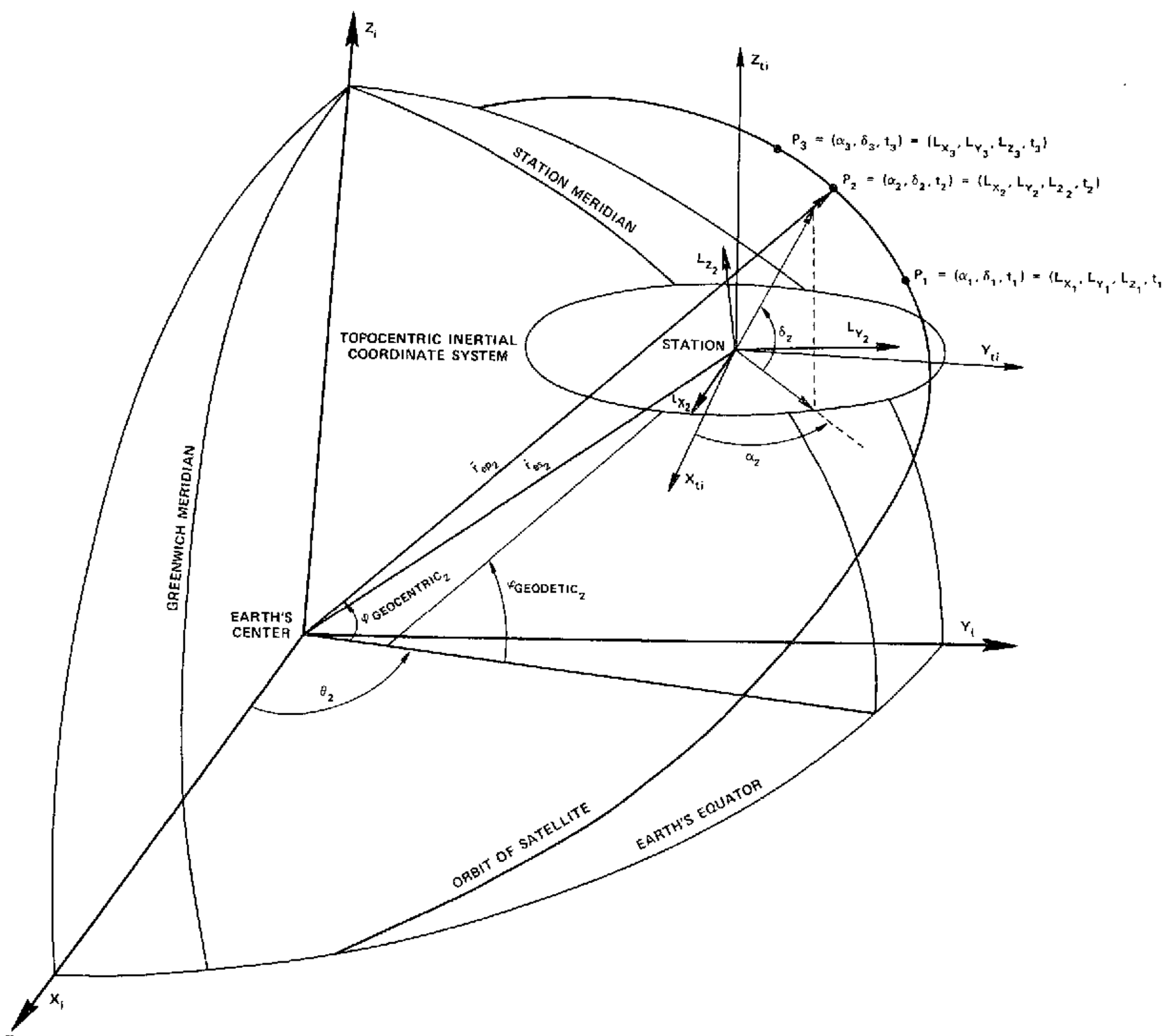

Figure 1. Geometry for the methods of Gauss and Double-range: any three sets of angles can be transformed to three sets of topocentric right ascensions and declinations (α, δ). These angles can then be converted to an inertial unit vector in the topocentric right ascension—declination coordinate frame with coordinates (L_x, L_y, L_z). These unit vectors are then processed to yield starting elements.

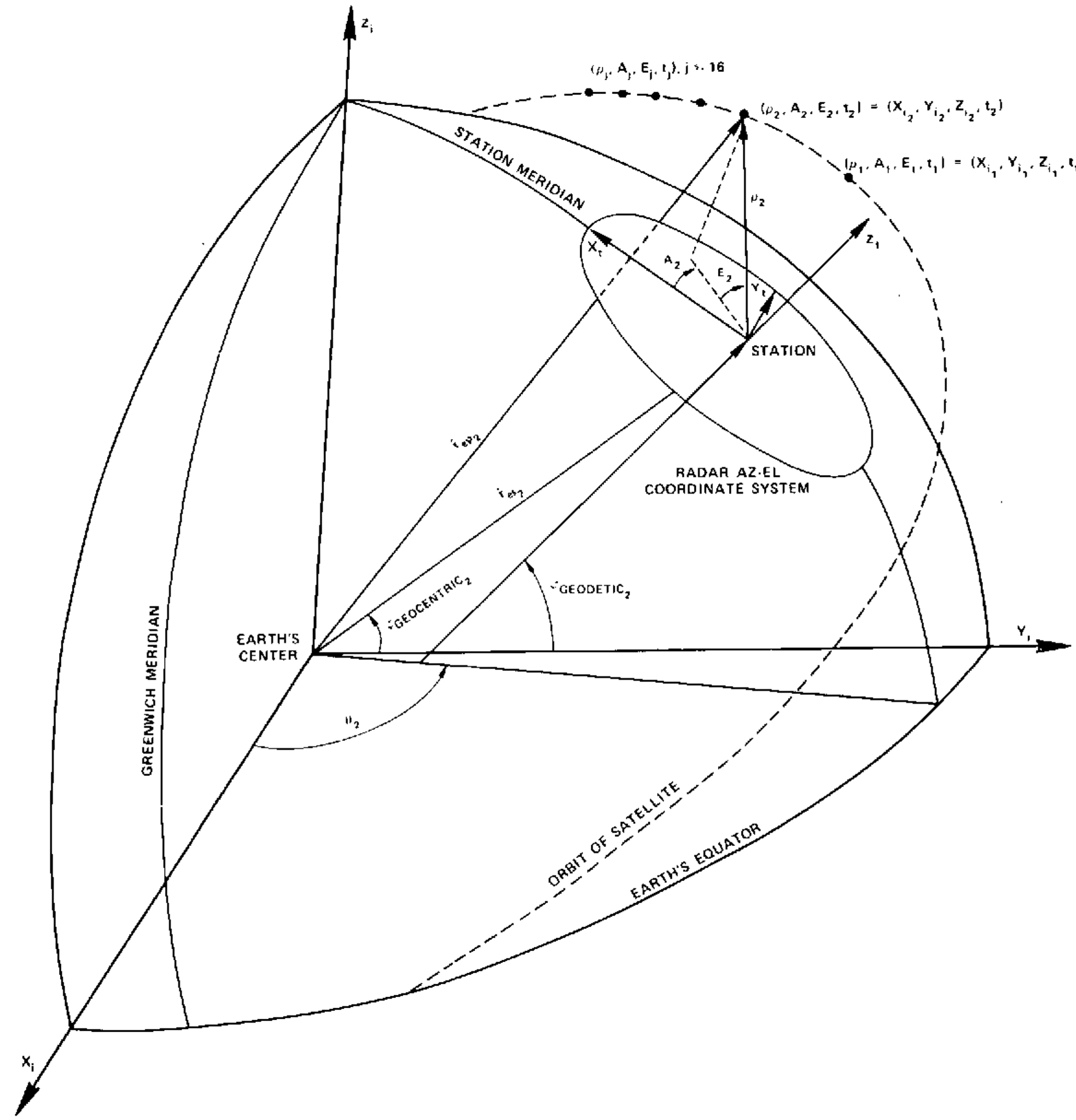

Figure 2. Geometry for the Range-angles method: any observation composed of a range and two angles can be converted to the observation set: range, azimuth and elevation (ρ, A, E). This set can then be converted to geocentric inertial coordinates (X_i, Y_i, Z_i). These coordinates are in turn processed to yield starting elements.

3. C Band azimuth and elevation angles (A, E),

4. Smithsonian topocentric right ascension and declination (α, δ),

5. Minitrack direction cosines (ℓ, m).

The observations should be within one orbital revolution otherwise the J_2 perturbations begin to accumulate and the Double-range method will account only for two-body motion. No single observation should be closer than about a degree or two in true anomaly to the next observation; otherwise, the Kepler elements a, e, and ω are poorly determined. The components of each observation, e.g., the two simultaneous angles, should be within two seconds in time of each other. The larger the time interval between the components, the less they really represent one observation. From one to three stations can make the three observations. In addition, the Double-range method must be given a crude guess for the geocentric distances of the first and second observations. These geocentric distances are iterated on until convergence or a limit of 35 iterations, whichever comes first. A guess must also be supplied for the direction of orbital motion: a direct orbit has an inclination from 0 to 90 degrees and a retrograde orbit has an inclination from 90 to 180 degrees.

The method of Gauss, possesses almost the same limitations as the Double-range method. The type of observations handled by Gauss' method are the same as handled by the Double-range method. Some of the differences are: the observations are restricted to lie in an arc of less than 60 degrees in true anomaly otherwise the "f" and "g" series may cause the method to diverge. The number of internal iterations is 60 and if the range residuals grow from one iteration to the next, the program terminates. Also guesses at the direction of motion and geocentric distance of the first and second observations are not needed.

The Range-angles method is considerably different from the preceding two methods. Range-angles needs from 2 to 16 observations, where one observation equals three simultaneous component measurements. The number of observations is limited to 16 to simplify programming. The observation types handled by Range-angles are the following (note each observation consists of three components):

1. GRARR range, X_{30}, Y_{30},

2. USB range, X_{85}, Y_{85},

3. Range, azimuth, elevation,

4. Geocentric inertial X_i, Y_i, Z_i coordinates,

5. Range, Minitrack ℓ and m.

For this method, all observations should be in an arc of less than 60 degrees in true anomaly and greater than 2 or 3 degrees. If the arc is over 60 degrees, the "f" and "g" series may cause the method to diverge. From one to ten stations can make the observations. The three components of each observation, e.g., a range and two angles, should lie within 2 seconds in time of each other for a near earth satellite to constitute an observation. For a distant earth satellite, e.g., ATS, larger time differences can be allowed. Care must also be taken that the observation ranges are the correct ones and not just gated values. The Range-angles method may have difficulties for a high eccentricity satellite since it initially assumes a circular orbit. The program will terminate if it has reached a limit of 20 iterations and 10 iterations on two internal loops or if it computes a singular determinant.

If any of the three Early-orbit methods has all of its requirements satisfied, that method should readily produce an accurate starting vector. One additional note, noisy observations should be polynomial smoothed since the Early-orbit methods depend critically on good data.

1.2 Early-orbit Results with Several Satellites and Data Types

Numerous runs have been made to completely debug the Early-orbit subsystem of GTDS. The following results from computer runs should give any potential user an idea of the capabilities of the Early-orbit program. The stations listed on Table 1 and the observations listed on Table 2 were used in the Early-orbit test runs. These tables indicate the different data types, satellites and time distributions of observations used in the runs. The starting vectors produced by each of the methods were either mutually compared or in three cases, they were compared to results from differential correction runs.

The first Early-orbit test run contains real tracking data for the earth synchronous satellite ATS-3. The methods of Gauss and Double-range were applied to observations A1,. . .,A6 and the Range-angles method was applied to observations B1,. . .,B15. The epoch for the vector was (year, month and day) 1971/02/07 and (hour, minute and second) 22/00/20. The vectors obtained by the three methods are in fairly good agreement with each other. Note that since e and i are near zero, Ω, ω and M individually are not well defined but the mean orbital

Table 1

Station Coordinates

Name	Geodetic Latitude			East Longitude			Height
	°	′	″	°	′	″	km
ROSATSS	35	12	00.5	277	07	40.00	0.8808
CARVONV	-24	54	15.4	113	42	59.00	0.051
MADGARV	-19	01	17.3	047	18	11.00	1.385
1PURIO	18	15	28.28	294	00	23.5	0.016
1ROSMA	35	12	07.03	277	07	40.8	0.868
1COLBA	38	53	35.89	267	47	40.6	0.231
QUITO	-00	37	22.63	281	25	15.23	3.554
KOUROU	+05	15	03.91	307	11	40.92	-0.0179
MADGA6P	-19	00	27.09	047	18	00.46	1.377
ULASK6P	64	58	38.60	212	28	40.89	0.289
1JUPTR	27	01	14.20	279	53	12.94	-0.026
1CURAC	12	05	24.90	291	09	43.95	-0.024

longitude, ν_m, is well defined. The resulting vectors of each method are:

Double — range (direct motion, $r_1 = r_2 = 42{,}000$ km),

$a = 39765.96$ km $\quad e = 0.0430967 \quad i = 1.509052$ deg

$\Omega = 80.88377$ deg $\quad \omega = 160.115173$ deg $\quad M = 176.404911$ deg

$\nu_m = \omega + \Omega + M = 417.40308$ deg,

Table 2

Observation Description Summary

Observation Code	Observation Type	Station Name	Observation Time						Observation Value
			Y	M	D	H	M	S	
A1	X_{30}	ROSATSS	71	02	07	21	00	20	46.300019 deg
A2	Y_{30}	↓	↓	↓	↓	↓	↓	↓	-33.310014 ↓
A3	X_{30}	↓	↓	↓	↓	22	00	20	46.168819 ↓
A4	Y_{30}	↓	↓	↓	↓	↓	↓	↓	-32.930714 ↓
A5	X_{30}	↓	↓	↓	↓	23	00	20	46.016020 ↓
A6	Y_{30}	↓	↓	↓	↓	↓	↓	↓	-32.532314 ↓
B1	Range	ROSATSS	71	02	07	21	00	20	38107.82 km
B2	X_{30}	↓	↓	↓	↓	↓	↓	↓	46.300019 deg
B3	Y_{30}	↓	↓	↓	↓	↓	↓	↓	-33.310014 deg
B4	Range	↓	↓	↓	↓	21	02	20	38107.05 km
B5	X_{30}	↓	↓	↓	↓	↓	↓	↓	46.297419 deg
B6	Y_{30}	↓	↓	↓	↓	↓	↓	↓	-33.296514 deg
B7	Range	↓	↓	↓	↓	22	00	20	38084.68 km
B8	X_{30}	↓	↓	↓	↓	↓	↓	↓	46.168819 deg
B9	Y_{30}	↓	↓	↓	↓	↓	↓	↓	-32.930714 deg
B10	Range	↓	↓	↓	↓	22	02	20	38083.97 km
B11	X_{30}	↓	↓	↓	↓	↓	↓	↓	46.165118 deg
B12	Y_{30}	↓	↓	↓	↓	↓	↓	↓	-32.911714 deg
B13	Range	↓	↓	↓	↓	23	00	20	38065.80 km
B14	X_{30}	↓	↓	↓	↓	↓	↓	↓	46.016020 deg
B15	Y_{30}	↓	↓	↓	↓	↓	↓	↓	-32.532314 deg
C1	X_{30}	CARVONV	72	08	24	23	30	11	-1.2853222 rad
C2	Y_{30}	↓	↓	↓	↓	↓	↓	↓	-0.2682277 ↓
C3	X_{30}	↓	↓	↓	↓	00	00	11	-0.7538270 ↓
C4	Y_{30}	↓	↓	↓	↓	↓	↓	↓	-0.1780348 ↓
C5	X_{30}	MADGARV	↓	↓	↓	00	31	30	-0.6517793 ↓
C6	Y_{30}	↓	↓	↓	↓	↓	↓	↓	-0.2330063 ↓
D1	Range	CARVONV	72	08	24	23	30	11	11227.88 km
D2	X_{30}	↓	↓	↓	↓	↓	↓	↓	-1.285322 rad
D3	Y_{30}	↓	↓	↓	↓	↓	↓	↓	-0.268227 ↓

Table 2 (Continued)

Observation Code	Observation Type	Station Name	Observation Time Y	M	D	H	M	S	Observation Value
D4	Range	CARVONV	72	08	24	00	00	11	18168.02 km
D5	X_{30}	↓	↓	↓	↓	↓	↓	↓	-0.753827 rad
D6	Y_{30}	↓	↓	↓	↓	↓	↓	↓	-0.178034 ↓
D7	Range	MADGARV	↓	↓	↓	00	31	30	26319.97 km
D8	X_{30}	↓	↓	↓	↓	↓	↓	↓	+0.651779 rad
D9	Y_{30}	↓	↓	↓	↓	↓	↓	↓	-0.233006 ↓
E1	α	1 PURIO	68	04	29	02	31	12	213.35230 deg
E2	δ	↓	↓	↓	↓				-39.42472 ↓
E3	α	1 ROSMA	↓	↓	↓	02	41	12	226.29100 ↓
E4	δ	↓	↓	↓	↓				44.30647 ↓
E5	α	1 COLBA	↓	↓	↓	02	45	12	272.54540 ↓
E6	δ	↓	↓	↓	↓				67.29169 ↓
F1	ℓ	QUITO	71	04	26	00	49	59	0.2024
F2	m	↓	↓	↓	↓	↓	↓	↓	0.6423
F3	ℓ	KOUROU	↓	↓	↓	00	54	59	-0.8222
F4	m	↓	↓	↓	↓	↓	↓	↓	-0.2332
F5	ℓ	↓	↓	↓	↓	00	59	59	+0.8790
F6	m	↓	↓	↓	↓	↓	↓	↓	-0.2227
G1	ℓ	MADGA6P	71	12	11	21	42	47	0.2742
G2	m	↓	↓	↓	↓	↓	↓	↓	-0.2169
G3	ℓ	↓	↓	↓	↓	21	43	17	0.3037
G4	m	↓	↓	↓	↓	↓	↓	↓	0.1749
G5	ℓ	ULASK6P	↓	↓	↓	22	18	37	-0.4473
G6	m	↓	↓	↓	↓	↓	↓	↓	0.1068
H1	α	1 JUPTR	60	01	01	01	18	02	25.22217 deg
H2	δ	↓	↓	↓	↓	↓	↓	↓	10.64772 ↓
H3	α	1 CURAC	↓	↓	↓	↓	24	31	35.55544 ↓
H4	δ	↓	↓	↓	↓	↓	↓	↓	19.61991 ↓
H5	α	↓	↓	↓	↓	↓	26	56	49.40279 ↓
H6	δ	↓	↓	↓	↓	↓	↓	↓	11.32386 ↓

Gauss,

$a = 43805.87$ km	$e = 0.0290919$	$i = 1.570064$ deg
$\Omega = 85.798625$ deg	$\omega = 324.96785$ deg	$M = 6.639626$ deg

$\nu_m = \omega + \Omega + M = 417.40609$ deg,

Range-angles,

$a = 42280.328$ km	$e = 0.0038669$	$i = 1.568704$ deg
$\Omega = 83.7203$ deg	$\omega = 329.9441$ deg	$M = 4.06855$ deg

$\nu_m = 417.7329$ deg.

The second Early-orbit test run contains simulated data for a highly elliptical orbit of IMP-H. The following vector:

$a = 127784$ km	$e = 0.946434$	$i = 28.803$
$\Omega = 146.3$ deg	$\omega = 160.13$ deg	$M = 0.059$ deg,

having epoch 1972/08/24, 00/00/11.03 was used by GTDS to generate simulated IMP-H observations. The degree to which each of the three methods recovered this vector reflects how well each can handle such highly elliptical orbits. The methods of Gauss and Double-range used observations C1, . . . ,C6 and Range-angles used observations D1, . . . ,D9. The starting vectors obtained were:

Double-range (direct motion, $r_1 = 14,300$ km, $r_2 = 23,200$ km),

$a = 126592.24$ km	$e = 0.945854$	$i = 28.7911$ deg
$\Omega = 146.317$ deg	$\omega = 160.251$ deg	$M = 0.059781$ deg,

Gauss,

$a = 127073.46$ km	$e = 0.944051$	$i = 28.7911$ deg
$\Omega = 146.318$ deg	$\omega = 161.608$ deg	$M = 0.078113$ deg,

Range-angles,

$a = 125683.16$ km	$e = 0.945524$	$i = 28.7918$ deg
$\Omega = 146.3116$ deg	$\omega = 160.2039$ deg	$M = 0.060120$ deg.

The third Early-orbit test run contains real data for a satellite in a retrograde orbit, GEOS II. As can be seen, the orbital elements for GEOS II as given by two methods are very close, however since the eccentricity is very low, ω and M should be replaced by the mean argument of latitude, U_m. The epoch for the vectors was 1968/04/29, 02/41/12. The observations were E1,. . . ,E6 and the resulting vectors are:

Double-range (retrograde motion, $r_1 = r_2 = 7550$ km),

$a = 7748.92$ km	$e = 0.0361024$	$i = 105.7775$ deg
$\Omega = 195.3695$ deg	$\omega = 358.6410$ deg	$M = 38.74282$ deg
$U_m = \omega + M = 397.3838$,		

Gauss,

$a = 7740.31$ km	$e = 0.0353119$	$i = 105.7769$ deg
$\Omega = 195.3694$ deg	$\omega = 357.4257$ deg	$M = 39.95228$ deg
$U_m = 397.3779$ deg.		

The fourth Early-orbit test run contains real data for a close earth satellite with low e and low i, San Marco. The observations used by Gauss and Double-range were F1,. . . , F6 and the resulting vectors were:

Gauss,

$a = 6850.44$ km	$e = 0.0348341$	$i = 3.217754$ deg
$\Omega = 62.93540$ deg	$\omega = 333.65442$ deg	$M = 276.18743$ deg,

Double-range (direct motion, $r_1 = r_2 = 6830$ km),

$a = 6852.59$ km	$e = 0.0345735$	$i = 3.217766$ deg
$\Omega = 62.934757$ deg	$\omega = 333.99254$ deg	$M = 275.95820$ deg.

The fifth Early-orbit test run deals with real data from the UK-4 satellite. The Definitive Orbit Determination System (DODS) obtained the starting vector:

$a = 6916.$ km	$e = 0.007$	$i = 82.966$ deg
$\Omega = 96.919$ deg	$\omega = 241.$ deg	$M = 284.$ deg
$U_m = 525.$ deg,		

at epoch 1971/12/11, 20/57/00. The distribution of the observations was not very favorable. The best set had the first two observations separated by 30 seconds and the second and third observation were 35 minutes apart. Nevertheless, with a suitable guess for the geocentric distances of the first two observations the Double-range method produced the following vector:

$a = 6925.22$ km $e = 0.006372$ $i = 82.9016$ deg

$\Omega = 96.948$ deg $\omega = 257.634$ deg $M = 269.354$ deg

$U_m = \omega + M = 526.98$ deg.

Double-range method assumed a direct orbit and $r_1 = r_2 = 6900$ km. This vector was later used to successfully start a DODS differential correction run.

In the sixth test run, notice had to be taken of the fact that all three Early-orbit methods use a two-body representation of the observations to obtain a starting vector. A differential correction program, should use this two body starting vector only with short arcs of data, e.g., generally less than one day, so J2 and luni-solar perturbations are minimized. A differential correction program can use the two-body starting vector and a short arc of data where orbital perturbations are minimal and converge on a new vector. The DC can then use the new vector on extended arc lengths of data.

The sixth Early-orbit test run deals with Vanguard 3 real data. The GEOSTAR differential correction program used the three observations which were input to Early-orbit plus seven additional observations spread over a seven hour interval to converge on the vector:

$a = 8510.515$ km $e = 0.189210$ $i = 33.36814$ deg,

$\Omega = 250.11815$ deg $\omega = 284.17408$ deg $M = 246.39510$ deg,

at epoch 1960/01/01, 01/24/31. The method of Gauss produced the following starting vector:

$a = 8505.991$ km $e = 0.189351$ $i = 33.3751$ deg

$\Omega = 250.1144$ deg $\omega = 284.3206$ deg $M = 246.1851$ deg.

This starting vector was used by GEOSTAR to converge on the enlarged seven hour time interval of observations.

1.3 Summary

The Early-orbit program which is fully operational in GTDS can accurately compute starting vectors for satellites in earth orbit. If acceptable range-angles or angles-only observations are available, the Early-orbit program will compute orbital elements to an accuracy of about four figures for most satellites. This capability is useful for rapid recovery of satellites should their actual orbits deviate significantly from the nominal one. At present, large amounts of computer time are lost attempting to bootstrap a solution with a large differential correction program. This computer time can be saved by having available a program which quickly determines accurate starting vectors.

1.4 Acknowledgements

The authors wish to thank Dr. Carmelo Velez for developing the scheme to integrate the Early-orbit capability into GTDS and Mrs. Elizabeth Mack for programming support. Valuable advice was also given by Mssrs. Francis Lerch, William Davenport and Raymond Borchers.

1.5 Abbreviations and Symbols

km — Kilometer

er — Earth radius

sec — Second

em — Earth mass

nu — Unitless

VLU — Vanguard length unit, equals one earth radius

VTU — Vanguard time unit

VVU — Vanguard velocity unit

rad — Radian

deg — Degree

DODS — Definitive Orbit Determination System

GTDS — Goddard Trajectory Determination System

USB — Unified S Band

GRARR — Goddard Range and Range Rate

a — Semi-major axis

e — Eccentricity

i — Inclination

Ω — Ascending Node

ω	—	Argument of perigee
M	—	Mean anomaly
SAO	—	Smithsonian Astrophysical Observatory
VHF	—	Very High Frequency
JCL	—	Job Control Language
DC	—	Differential Correction
$\phi_{geocentric_2}$	—	Geocentric latitude of station making second observation
$\phi_{geodetic_2}$	—	Geodetic latitude of station making second observation
θ_2	—	Right ascension of station making second observation
ρ_2	—	Slant range from station to satellite at second observation time
A_2	—	Azimuth of second observation
E_2	—	Elevation of second observation
t_2	—	Time of second observation
r_{ep_2}	—	Geocentric position vector from earth's center to satellite at second observation time
r_{es_2}	—	Geocentric position vector from earth's center to observing station at second observation time
α_2	—	Topocentric right ascension of second observation
δ_2	—	Topocentric declination of second observation
L_{x_2}	—	Topocentric inertial X direction cosine of second observation
X_i	—	Inertial X axis pointing to vernal equinox
Υ	—	Vernal Equinox
P_2	—	Second observation point
X_{30}	—	Thirty foot dish X gimbal angle
X_{85}	—	Eighty-five foot dish X gimbal angle
ν_m	—	Mean orbital longtiude
U_m	—	Mean argument of latitude

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2.0 EARLY-ORBIT PROGRAM OPERATING INSTRUCTIONS

2.1 Input

The following quantities are needed as input for an Early-orbit run:

1. The method of solution, e.g., Double-range, Gauss or Range-angles must be indicated.

2. For Double-range, guesses must be made at the geocentric distances of the first and second observation.

3. For Double-range, the direction of orbital motion, retrograde or direct must be specified.

4. What is the permitted number of seconds between observation components?

5. For Double-range or Gauss' method three observations are needed.

6. For Double-range or Gauss from one to three sets of station coordinates are needed; these may be contained on the GTDS geodetics data base.

7. For the Range-angles method one must supply from 2 to 16 observations.

8. For Range-angles, coordinates of from one to ten stations must be specified; these may already be on the GTDS geodetics data base.

9. The observation source, e.g., DODS tape, DODS data base or GTDS observation cards, must be specified.

10. From one to three observation sources can be used per computer run, e.g., DODS tape, DODS disk or GTDS cards.

11. The central body must be specified; currently, the only central body is the earth.

12. Numbers for the observations to be used in Early-orbit runs must be chosen from computer listings of the DODS tape and DODS data base.

13. The complete observation must be punched if the input is GTDS observation cards.

14. Station coordinates must be punched if not supplied by GTDS.

15. The time at which the starting vector is desired must be specified, otherwise the default is the time of the second observation.

16. The start and end time must be specified for editing the observations by time.

How these quantities are specified for an Early-orbit run is described in section 2.3.

2.2 Card Order

Each Early-orbit computer run can process one satellite starting vector case or several satellite starting vector cases. To determine a single Early-orbit starting vector, the first run card must begin with the keyword CONTROL and is followed by cards with keywords EPOCH, OBSINPUT, OBSNUME and TYPE. A card with keyword FIN terminates the processing of this starting vector case. Additional optional procedures in a single vector case can be specified by cards beginning with keywords OGOPT, DMOPT or DCOPT; these procedures are closed by a card with keyword END. Such option procedure cards are inserted before the FIN which terminates the processing of the single starting vector. The OGOPT keyword implies comment cards are to be input; the DMOPT keyword implies an update is to be made to the geodetics file and DCOPT keyword implies updated station cards are to be input.

Since each single satellite starting vector case begins with a CONTROL keyword card and is terminated with a FIN keyword card, multiple cases can be run by simply concatenating single cases.

2.3 Card Formats

The Early-orbit program has input cards with the same format as GTDS input cards. Description of GTDS card formats are contained in the GTDS Input Guide. The following cards (from CONTROL to FIN) are used for an Early-orbit run with DODS tape or DODS disk observations:

CONTROL Card

Column	Format	Description
1 – 8	A8	Keyword to initiate input processor, e.g., CONTROL
9 – 10	2X	Blank
11 – 18	A8	Run type keyword, e.g., EARLYORB
19 – 60	42X	Blank
61 – 68	A8	Satellite Name, e.g., IMP-H
69 – 71	3X	Blank
72 – 78	I7	Satellite number, e.g., 7209901

EPOCH CARD

Column	Format	Description
1 — 8	A8	Keyword to set epoch, e.g., EPOCH
9 — 17	9X	Blank
18 — 38	G21.14	Year, Month, day of epoch, e.g., (YYMMDD.)
39 — 59	G21.14	Hour, minute, seconds of epoch, e.g., (HHMMSS.SS)
60 — 80	G21.14	Blank

If this card is left blank, the date will default to the time of the second input observation.

OBSINPUT Card

Column	Format	Description
1 — 8	A8	Keyword to specify the observation input source, e.g., OBSINPUT
9 — 11	I3	Source of Input observations 1 — GTDS tape file 2 — GTDS disk file 3 — DODS tape file 4 — DODS disk file 5 — GTDS card file 6 — 2250 file 7 — 2260 file
18 — 38	G21.14	Accept observations after this time, e.g., YYMMDDHHMMSS.
39 — 59	G21.14	Accept observations before this time, e.g., YYMMDDHHMMSS.

OBSNUME Card

Column	Format	Description
1 — 8	A8	Keyword to specify observation numbers for an Early-orbit run, e.g., OBSNUME
9 — 17	9X	Blank

OBSNUME Card (continued)

Column	Format	Description
18 — 38	G21.14	Observation number
39 — 59	G21.14	Observation number
60 — 80	G21.14	Observation number

Each number on a card represents an observation component measurement. There can be up to 48 observation components for a Range-angle run or 16 OBSNUME Cards. For an angles-only run there can be only two OBSNUME Cards.

TYPE Card

Column	Format	Description
1 — 8	A8	Keyword indicating card contains parameters for Early-orbit run, e.g., TYPE
9 — 11	I3	Method of Solution: 1 = Gauss, 2 = Double-range 3 = Range-angles
12 — 14	I3	Direction of motion (only for Double-range method): + 1 = Direct - 1 = Retrograde
15 — 17	I3	Central Body 1 = Earth 2 = Moon
18 — 38	G21.14	For Gauss and Range-angles, the semi-major axis (km)*. For the Double-range method, the geocentric distance of the first observation (km).
39 — 59	G21.14	For Gauss and Range-angles, does not apply. For Double-range method, the geocentric distance of the second observation (km).

TYPE Card (continued)

Column	Format	Description
60 — 80	G21.14	The maximum allowable time difference in seconds between components of an observation, default is 2 seconds.

*This value is used for all three methods as a crude check as to whether arc-length of the input observations is suitable for the method of solution chosen.

To enter comments on an Early-orbit printout, the following cards (from OGOPT to END) must be used:

OGOPT Card

Column	Format	Description
1 — 8	A8	Keyword to specify processing of an optional set of cards, e.g., OGOPT

TITLE Card

Column	Format	Description
1 — 8	A8	Keyword indicates comment cards are to follow, e.g., TITLE
9 — 11	I3	Number of comment cards to follow

COMMENT Card

Column	Format	Description
1 — 80	10A8	Any descriptive information

END Card

Column	Format	Description
1 — 8	A8	Indicates end to OGOPT optional declaration, e.g., END.

To create a new station geodetics working file for stations not in the GTDS geodetics file, the following cards (from DMOPT to END) must be used:

DMOPT Card

Column	Format	Description
1 — 8	A8	Keyword to specify data management optional deck, e.g., DMOPT

WORKGEO Card

Column	Format	Description
1 — 8	A8	Keyword to build a new station geodetics working file
9 — 11	I3	Source of input geodetics 0 = permanent file 1 = from cards
12 — 14	I3	Number of stations from which coordinates are to be input

STATION Specification Card

Column	Format	Description
1 — 80	10A8	List of up to ten station mnemonics for which geodetics are to be supplied, e.g., MADGARV—CARVONV—ASASKRV

END Card

Column	Format	Description
1 — 8	A8	Indicates end to DMOPT optional declaration, e.g., END

To enter new station geodetics by cards, the following cards (from DCOPT to END) must be used:

DCOPT Card

Column	Format	Description
1 — 8	A8	Keyword to specify processing of a differential correction optional deck, e.g., DCOPT.

Station Card Number one

Column	Format	Description
1 — 8	A8	Station ID, e.g., /MADGARV
9	I1	Card number for station, e.g., 1
10	I X	Blank
11 — 14	I4	Station catalogue number, e.g., 00
15 — 17	I3	Station type: 1 = VHF (default) 2 = Minitrack 3 = C Band 4 = S Band
18 — 38	G21.14	Height above or below sea level in meters, e.g., 1385
39 — 59	G21.14	Geodetic latitude (±ddmmss.sss), e.g., -190111.438
60 — 80	G21.14	East longitude (dddmmss.sss), e.g., 0471809.45

Station Card two

Column	Format	Description
1 — 8	A8	Station ID, e.g., /MADGARV
9	I1	Card number for station, e.g., 2
10 — 11	I2	Blank
12 — 14	I3	Ellipsoid model (1 through 5)
15 — 17	I3	Blank
18 — 38	G21.14	Semi-major axis of ellipsoid, e.g., 6378.165 km
39 — 59	G21.14	Inverse flattening of ellipsoid, e.g., 298.3
60 — 80	G21.14	Station transmitter frequency, e.g., 148.26 MHz

END Card

Column	Format	Description
1 — 8	A8	Indicates end to DCOPT optional declaration, e.g., END

FIN Card

Column	Format	Description
1 — 8	A8	Terminates the CONTROL option

If observations are to be input by GTDS cards, the following cards (OBSCRD to FIN) must be used:

OBSCRD Card

Column	Format	Description
1 — 8	A8	Name of card, e.g., OBSCRD

Observation Cards

Column	Format	Description
1 — 8	A8	Station ID, e.g., ROSATSS
9 — 11	I 3	GTDS observation type, MTYPE*
12 — 14	I 3	Range gating mode
15 — 17	I 3	Blank
18 — 38	G21.14	Time of observation, e.g., YYMMDDHHMMSS. SS
39 — 59	G21.14	Uncorrected observation; angles in radians, distance in kilometers and direction cosines are decimal parts of 1.0.

*The following MTYPE values are used in Early-orbit:

= 1 Range, ρ

= 2 Minitrack direction cosine, ℓ

= 3 Minitrack direction cosine, m

= 4 Azimuth angle, A

= 5 Elevation angle, E

= 6 SAO topocentric right ascension, α

= 7 SAO topocentric declination, δ

= 17 GRARR X_{30} gimbal angle

= 18 GRARR Y_{30} gimbal angle

= 21 X geocentric position of satellite

= 22 Y geocentric position of satellite

= 23 Z geocentric position of satellite

= 27 S-Band range

= 28 C-Band range

= 30 S-Band X_{85} gimbal angle

= 31 S-Band Y_{85} gimbal angle

FIN Card

Column	Format	Description
1 – 8	A8	Terminates the OBSCRD option, e.g., FIN

2.4 Observation Card Input

If GTDS observation cards are input, FT 15 is the unit assigned for input. The IBM 360 Job Control Language, JCL, setup for this unit can be found on Table 3. The input data has the GTDS observation input card format. The format is specified in section 2.3.

2.5 Observation Tape or Disk Input

If the source of observations is a DODS data tape, FT 30 is the tape unit assigned. For observations from the DODS permanent data base, FT 32 is the disk unit assigned. The IBM 360 JCL for these units is specified on Table 3.

A listing of the tape or disk must be studied so appropriate observation numbers can be selected for the Early-orbit run. These observation numbers are specified on OBSNUME GTDS run cards.

2.6 Sample Card Deck Setup

A sample GTDS Early-orbit card deck is printed on Table 3. This sample setup deck computes six different starting vectors and uses all three input sources: GTDS observation cards, DODS tape and DODS disk.

2.7 Output

The following information is output by the Early-orbit program on printer:

1. If no fatal errors occur, a starting vector is output. If the epoch of the desired vector is specified, the vector computed by the Early-orbit program at the time of second observation will be updated for TWOBDY and J2 effects to the desired epoch. If the epoch is not specified, the vector computed at the second observation time will be supplied.

Table 3

GTDS Early-orbit Card Deck Setup

```
12345678901234567890123456789012345678901234567890123456789012345678901234578
//* GTDS OBSERVATION CARD INPUT
//GO.FT15F001 DD *
OBSCRD
ROSATSS 01 710207210020.0                D+00+.38107821          D+05
ROSATSS 17 710207210020.0                D+00+.80808777          D+00
ROSATSS 18 710207210020.0                D+00-.58136941          D+00
ROSATSS 01 710207210220.0                D+00+.38107056          D+05
ROSATSS 17 710207210220.0                D+00+.80804239          D+00
ROSATSS 18 710207210220.0                D+00-.58113379          D+00
END
//*  DODS PERMANENT DATA BASE
//GO.FT32F001 DD DSN=POBS,VOL=SER=DODS02,UNIT=DISK,DISP=SHR
//*  DODS OBSERVATION TAPE
//GO.FT30F001 DD DSN=IMPHDT,UNIT=2400-9,DISP=(OLD,KEEP),
//    LABEL=(6,BLP),VOL=SER=2887H
//GO.DATA5 DD *
CONTROL   EARLYORB                                                      ATS-3  1234567
EPOCH            710207.0              D0220020.0              DO
OBSINPUT  5      +710207000000.          710210000000.
OBSNUME          1.                      2.                    3.
OBSNUME          4.                      5.                    6.
OGOPT
TITLE     1
ATS-3   RANGE-X30-Y30, RANGE-ANGLES CASE - UNITS KM-RAD-RAD-OBSCRD INPUT
END
TYPE      3  1  1+38400.                 +38400.               5.
FIN
CONTROL   EARLYORB                                          ATS-5        6906901
EPOCH
OBSINPUT  4
TYPE      1  1  1+42166.0                +42166.0              +3.0
OBSNUME          +25949.0                +25950.0              +25976.0
OBSNUME          +25977.0                +26003.0              +26004.0
FIN
CONTROL   EARLYORB                                          ATS-5        6906901
EPOCH
OBSINPUT  4
TYPE      3  1  1+42166.0                +42166.0              +3.0
OBSNUME          +25949.0                +25950.0              +25951.0
OBSNUME          +25976.0                +25977.0              +25978.0
OBSNUME          +26003.0                +26004.0              +26005.0
FIN
```

Table 3 (Continued)

```
CONTROL    EARLYORB                                          IMP-H      7209901
EPOCH              +720824.0         D+00+0.0           D+00
OBSINPUT   3
OBSNUME            +3.0                  +4.0                +27.0
OBSNUME            +28.0                 +71.0               +72.0
TYPE       1  +1  1+127784.0             +127784.0           +3.0
OGOPT
TITLE      1
IMP-H  SIMULATION  RUN
END
FIN
CONTROL    EARLYORB                                          IMP-H      7209901
EPOCH              +720824.0         D+00+0.0           D+00
OBSINPUT   3
OBSNUME            +01.0                 +03.0               +04.0
OBSNUME            +25.0                 +27.0               +28.0
OBSNUME            +69.0                 +71.0               +72.0
TYPE       3  +1  1+127784.0             +127784.0           +3.0
FIN
CONTROL    EARLYORB                                          IMP-H      7209901
EPOCH              +720824.0             +0.0
OBSINPUT   3
OBSNUME            +03.0                 +04.0               +27.0
OBSNUME            +28.0                 +71.0               +72.0
TYPE       2  +1  1+14300.0              +23200.0            +3.0
FIN
```

2. The starting vector is given in Cartesian, Keplerian and Polar coordinates.

3. The output vector is with respect to the same coordinate system as the input observations are, e.g., mean equator and equinox of 1950.0 or true of date etc.

4. The contents of common block EARLYO are printed out so a bad solution for a starting vector can readily be investigated.

5. Each observation, with its two or three components, is fully described by printing out the EOOBS array.

6. Early-orbit may detect an error in subroutines EO, EOFLTR, ELEMGN, DOUBLR, EGAUSS or POSFIX. These subroutines then set a switch, JUMPG, to specify the type of error. The possible error messages are given on Table 4.

Table 4

Error Messages

Value of JUMPG	Subroutine Where JUMPG Was Set	Fatal or Non-Fatal	Description
0	EOFLTR	NF	No error occurred.
1	DOUBLR	F	Have exceeded 35 iterations on the geocentric distance of the first and second observation and have not converged.
2	EGAUSS	F	Have exceeded 60 iterations on range and have not converged.
3	EGAUSS	F	The range residuals have grown since the last iteration.
4	POSFIX	F	Singular determinant was found.
5	POSFIX	F	Iteration did not converge.

Table 4 (continued)

Value of JUMPG	Subroutine Where JUMPG Was Set	Fatal or Non-Fatal	Description
6	EOFLTR	F	For the Range-angles method, the number of observation components is not ≤ 48 and for the angles-only methods, the number of components is not 6.
7	EOFLTR	F	The number of observation components is not a multiple of two for angles-only methods, and a multiple of 3 for the Range-angles method.
8	EOFLTR	F	Two components of an angles-only measurement are not made by the same station.
9	EOFLTR	F	Three components of a Range-angles measurement are not made by the same station.
10	EOFLTR	F	GTDS observation type for the first component of an angles-only observation is not appropriate.
11	EOFLTR	F	GTDS observation type for the second component of an angles-only observation is not appropriate.
12	EOFLTR	F	GTDS observation type for the first component of an Range-angles observation is not appropriate.
13	EOFLTR	F	GTDS observation type for the second component of a Range-angles observation is not appropriate.

Table 4 (continued)

Value of JUMPG	Subroutine Where JUMPG Was Set	Fatal or Non-Fatal	Description
14	EOFLTR	F	GTDS observation type for the third component of a Range-angles observation is not appropriate.
15	EOFLTR	NF	Mean anomaly difference between the first and second observation is < 1 degree for Gauss or Double-range.
16	EOFLTR	NF	Mean anomaly difference between the first and last observation is < 1 degree for Range-angles method.
17	EOFLTR	NF	Mean anomaly difference between first and last observation is > 60 degrees for Gauss or Range-angles method.
18	EOFLTR	NF	Mean anomaly difference between first and third observation is > 360 degrees for Double-range method.
19	EOFLTR	NF	Mean anomaly difference between second and third observation is < 1 degree for Gauss or Double-range.
20	EOFLTR	F	Two components of an observation are not within a permissable number of seconds from each other in Gauss or Double-range.
21	EOFLTR	F	Three components of an observation are not within a permissable number of seconds from each other in Range-angles.

Table 4 (continued)

Value of JUMPG	Subroutine Where JUMPG Was Set	Fatal or Non-Fatal	Description
22	DOUBLR	F	Semimajor axis of hyperbola is positive, default to its negative value in Double-range.
23	EGAUSS	NF	An error occurred in the polynomial root routine POLRT (see variable KER in common EARLYO)

2.8 Sample Printer Output

The data card setup for an ATS-3 Early-orbit run with GTDS observation card (OBSCRD) input was specified on Table 3. Sample output for this Range-angles run is given in Table 5.

3.0 EARLY-ORBIT PROGRAM DESCRIPTION

The Early-orbit subsystem consists of a few subroutines, e.g., EO, ELEMGN, DOUBLR, EGAUSS, POSFIX, EOFLTR, SECULA, ANGLES, RANGLE, which were integrated into GTDS. A general flowchart of the Early-orbit subsystem is given on Table 6. To give a complete listing and explanation of each subroutine would be a formidable task. So only the general purpose of each GTDS subroutine associated with Early-orbit is given in this document. For more detailed information on any subroutine consult the GTDS computer source listings and the GTDS mathematical specifications.

3.1 GTDS Subroutines and Common Blocks

The GTDS subroutines and common blocks which are associated with Early-orbit are:

CDATE — Converts modified Julian date to Gregorian date,

CELEM — Converts Keplerian coordinates to position and velocity,

Table 5

Early-orbit sample output for IMP-G using the method of Gauss with Minitrack data

```
                         GTDS  EARLYORB PROGRAM                                     PAGE   6

CONTROL  EARLYORB                        IMP6905301
 CARD NO.=    1, CARD IMAGE ** EPOCH       0   0   0    0.0               0.0                 0.0              **
 CARD NO.=    2, CARD IMAGE ** OBSINPUT    3   0   0    0.0               0.0                 0.0              **
 CARD NO.=    3, CARD IMAGE ** OBSNUME     0   0   0    105056.00000000   105057.00000000     105088.00000000  **
 CARD NO.=    4, CARD IMAGE ** OBSNUME     0   0   0    105089.00000000   105090.00000000     105091.00000000  **
 CARD NO.=    5, CARD IMAGE ** TYPE        1   1   1    0.0               0.0                 5.0000000000000  **
 CARD NO.=    6, CARD IMAGE ** FIN         0   0   0    0.0               0.0                 0.0              **
 NO ERRORS ENCOUNTERED IN CONTROL  DECK

                         GTDS  EARLYORB PROGRAM                                     PAGE   7

        GTDS RUN NUMBER IS     4058

        STARTING ADDRESS OF MAIN IS 1558800

        COMPUTER IDENTIFICATION IS G1

        JOB IDENTIFICATION IS GNVTLEOP

        CURRENT TIME IS JAN   9, 1973      0 HRS , 56 MINS,   47.15999SECS


TYPE OF STARTER = GAUSS METHOD

OBS NB  OBS TYPE  STA NB   OBS TIME                    UNCORRECTED OBS

   1        2        1      0.226430934969550 10       -0.56000000000000D-03
   2        3        1      0.226430934969550 10        0.75917000000000D-01
   3        2        1      0.226432980969510 10       -0.81000000000000D-01
   4        3        1      0.226432980969610 10        0.62315300000000D 00
   5        2        2      0.226433112969620 10        0.54509000000000D-01
   6        3        2      0.226433112969620 10        0.64094500000000D 00
 VARIABLES FROM EARLY ORBIT OBSERVATION FILTER..........

   JUMPG ELEMS: DSECO OMEAN(1-3)     0  0.8700000D 05  0.0          0.2884168D 02  0.1860753D 01  0.3070243D 02
```

Table 5 (Continued)

```
NAMELIST DUMP OF EARLYO COMMON BLOCK..........
 ALX=-0.2183515904861100    ,-0.2319643147695182D-01,-0.1853625522583304    ,ALY= 0.5179365980226773    , 0.7764772106792840D-01,
-0.3860734829680133         ,ALZ= 0.8270317754979744      , 0.9967109696294570      , 0.9648924205093696      ,BM=  1.000000000000000    ,BR=
 0.9979703074629576         , 0.9979703074629576          , 0.9972955096264663      ,BX= 0.2431870261774414   , 0.5926093237608019      ,
-0.2304742223098345         ,BY=-0.5752452718950574       , 0.1971325491399405      ,-0.3560925872259406      ,BZ=-0.7783942972806674   ,
-0.7783942572806674         ,-0.9025951671123251          ,EOT= 0.0                 , 20460.00061380863       , 21780.00065344572       ,
 0.0                        , 0.0                         , 0.0                     , 0.0                     , 0.0                     ,
 0.0                        , 0.0                         , 0.0                     , 0.0                     , 0.0                     ,
 0.0                        , 0.0                         , 0.0                     , 0.0                     , 0.0                     ,
 0.0                        , 0.0                         , 0.0                     , 0.0                     , 0.0                     ,
 0.0                        , 0.0                         , 0.0                     , 0.0                     , 0.0                     ,
 0.0                        , 0.0                         , 0.0                     , 0.0                     , 0.0                     ,
 0.0                        , 0.0                         , 0.0                     , 0.0                     , 0.0                     ,
 0.0                        , 0.0                         , 0.0                     , 0.0                     , 0.0                     ,
 0.0                        , 0.0                         , 0.0                     , 0.0                     , 0.0                     ,
 0.0                        , 0.0                         ,SR1G= 0.0                ,SR2G= 0.0                ,VLU=
 6378.165000000000          ,VTU= 806.8136452233683       ,RHON= 12.72706980795239  , 4.627743238089093       , 3.874693973459187       ,
 RHOO= 12.72706980795239    , 4.627743238089093           , 3.874693973459187       ,XXX= 0.0                 , 0.0                     ,

 0.0                        , 0.0                         , 0.0                     , 0.0                     , 0.0                     ,
 0.0                        , 0.0                         , 0.0                     , 0.0                     , 0.0                     ,
 0.0                        , 0.0                         , 0.0                     , 0.0                     , 0.0                     ,
 0.0                        , 0.0                         , 0.0                     , 0.0                     , 0.0                     ,
 0.0                        , 0.0                         , 0.0                     , 0.0                     , 0.0                     ,
 0.0                        , 0.0                         , 0.0                     , 0.0                     , 0.0                     ,
 0.0                        , 0.0                         , 0.0                     , 0.0                     , 0.0                     ,
 0.0                        , 0.0                         , 0.0                     , 0.0                     , 0.0                     ,
 0.0                        , 0.0                         , 0.0                     , 0.0                     , 0.0                     ,
 0.0                        , 0.0                         , 0.0                     ,YYY= 0.0                 , 0.0                     ,
 0.0                        , 0.0                         , 0.0                     , 0.0                     , 0.0                     ,
 0.0                        , 0.0                         , 0.0                     , 0.0                     , 0.0                     ,
 0.0                        , 0.0                         , 0.0                     , 0.0                     , 0.0                     ,
 0.0                        , 0.0                         , 0.0                     , 0.0                     , 0.0                     ,
 0.0                        , 0.0                         , 0.0                     , 0.0                     , 0.0                     ,
 0.0                        , 0.0                         , 0.0                     , 0.0                     , 0.0                     ,
 0.0                        , 0.0                         , 0.0                     , 0.0                     , 0.0                     ,
 0.0                        , 0.0                         , 0.0                     , 0.0                     , 0.0                     ,
 0.0                        , 0.0                         , 0.0                     , 0.0                     , 0.0                     ,
 0.0                        , 0.0                         , 0.0                     ,ZZZ= 0.0                 , 0.0                     ,
 0.0                        , 0.0                         , 0.0                     , 0.0                     , 0.0                     ,
 0.0                        , 0.0                         , 0.0                     , 0.0                     , 0.0                     ,
 0.0                        , 0.0                         , 0.0                     , 0.0                     , 0.0                     ,
 0.0                        , 0.0                         , 0.0                     , 0.0                     , 0.0                     ,
 0.0                        , 0.0                         , 0.0                     , 0.0                     , 0.0                     ,
 0.0                        , 0.0                         , 0.0                     , 0.0                     , 0.0                     ,
 0.0                        , 0.0                         , 0.0                     , 0.0                     , 0.0                     ,
 0.0                        , 0.0                         , 0.0                     , 0.0                     , 0.0                     ,
 0.0                        , 0.0                         , 0.0                     , 0.0                     , 0.0                     ,
 0.0                        , 0.0                         , 0.0                     ,SR= 13.72213394853841    , 5.438587282619429       ,
 4.681059303465518          ,SXD= 0.1228845846219311      , 0.9969277787454436      , 1.051581257892882       ,SYD=-0.8281013401288295  ,
-2.503017826411711          , -2.538651560788025          ,SZD= 0.5338532065677352  , -3.287037244104455      , -3.850549774373424      ,SRD=
 0.9928990350047086         , 4.309777331229687           , 4.730471353586327       ,PP= 0.0                  ,ECE= 0.0                 ,AN=
 0.0                        ,SE= 0.0                      ,CE= 0.0                  ,E3E2= 0.0                ,DM3M2=
 0.0                        ,E2E1= 0.0                    ,DM1M2= 0.0               ,F1= 0.0                  ,F2=
```

Table 5 (Continued)

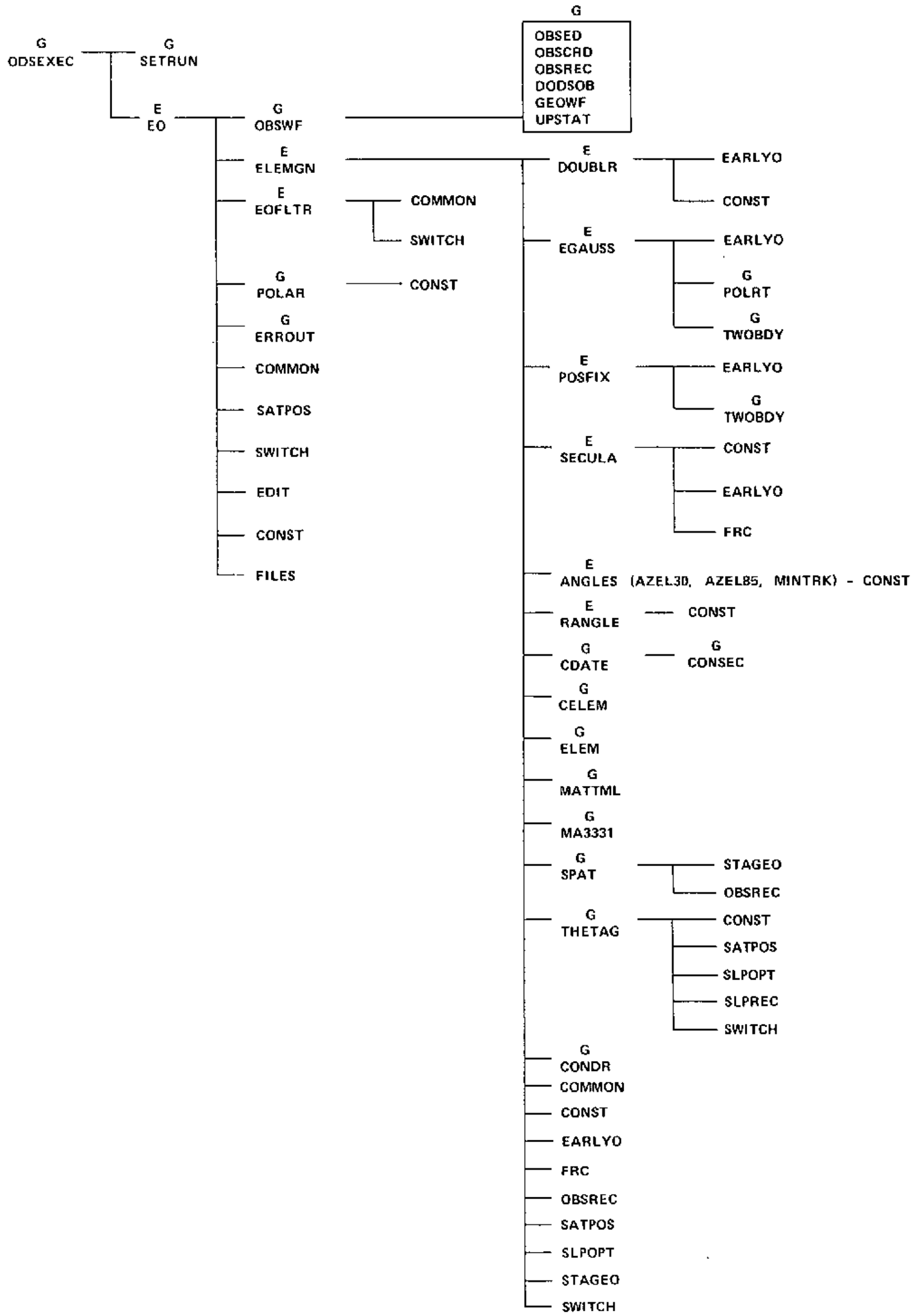
```
 0.0                   ,SH= 0.0                 ,CH= 0.0                 ,F3F2= 0.0               ,F2F1=
 0.0                   ,DELSR1= 0.0             ,DELSR2= 0.0                    ,CSS= -919.2678323115682   ,AS=
 -28.47022844665583    ,RR=  5.515255958146682   ,CUBBA= 0.2683312423761190D-04,CUBEB= 0.5020498710474280D-05,DIFNM1=
 0.9387237420721560D-06,DIFNM2= 0.2252132857982758D-07,DIFNM3= 0.2538424315190468D-07,DJD2=  11228.02094555726  ,DJD=
  11228.03622333550    ,SECA=  9.696100000000000   ,DJD1=  11227.78413999460   ,RS= 0.9972955096264663   ,RSQ=
 0.0                   ,TIMEE=  21780.00065344572  ,ALASSE=  90429.73127224359   , 0.8834986085591103    ,
  83.16171313632829    ,  102.8264836324100    ,  205.6652558667446    ,  350.5064812432604   ,GDLTS=  1.134060406406790  ,
GDLGS= -3.708390849206094  ,SPHHGT= 0.4437012839899877D-04,AX30= 0.0                  ,DAT1= 0.6450900000000000D-01,DAT2=
 0.6409450800000000    ,DAT3= 0.0                 ,RA= -2.354280486772869   ,DE=  1.305033468825518   ,AMBDR=
 0.0                   ,BOBDR= 0.0                ,SOBDR= 0.0                ,ET= 0.0                  ,TT=
 0.0
&END
&EOBB
VT= 0.0                      ,ADJDA=  11228.02094555726   ,ATANC=  20460.00061380863   ,AWHANG=  1.982941599149967   ,ATIME1=
 0.0                   ,ATIME2=  20460.00061380863   ,ATIMEF=  21780.00065344572   ,ADJD=  11228.03622333550   ,ADJDI=
  11227.78413999460    ,ADJD2=  11228.02094555726   ,ATH= 0.0                ,ASL= 0.0                ,ASH=
 0.0                   ,AY30= 0.0                 ,AX85= 0.0                ,AY85= 0.0               ,AAZD=
 0.0                   ,AELD= 0.0                 ,APHI= 0.0                ,AALPHA= 0.0             ,ADELTA=
 0.0                   ,AWZZ= 0.0                 ,AR= 0.0                  ,AA= 0.0                 ,AE=
 0.0                   ,AX1= 0.0                  ,AY1= 0.0                 ,AGCORD= 0.2304742223098345   ,
 0.3560925872259406    , 0.9025951671123251    ,ASO= -4464.437747982619   ,  1034.545806224114    ,  34384.15651562313    ,
-0.9969277787454436    , -2.603017826411711    , -3.287037244104455   ,ATRANS= 0.0             , 0.0                   ,
 0.0                   ,ARL= 0.0                  , 0.0                    , 0.0                   ,ARH= 0.0               ,
 0.0                   , 0.0                      ,ARIT= 0.0               , 0.0                   , 0.0                   ,SX=
 -19275.85402196540    , -4464.437747982619    , -3110.943229570536    ,SY=  45712.69450428931    ,  1034.545806224114    ,
 -2327.298112756910    ,SZ=  72103.38086153305   ,  34384.15651562313    ,  29602.70942020370    ,JMEAN=  28.84167834422274   ,
  1.860753441614255    ,  30.70243178583699     ,DSECO= 0.0                ,ITERA=          10,IDBS3=          10,IYA=        71,
IMA=          10,IDA=           3,IHRA=          12,IMIA=          30,KER=           0,IJUMPG=          0
&END


LISTING OF EOOBS-THE OBSERVATION DESCRIPTION ARRAY..........

OBS TIME  0.71000000D 02  0.10000000D 02  0.30000000D 01  0.60000000D 01  0.49000000D 02  0.96955000D 01
STATION PARAMETERS  WNKFL6E    0.90000000D-01  0.51264640D 06  0.35918079D 07
3 OBS COMPONENTS,MTYPE,ISTA -0.56000000D-03  0.75917000-01  0.0              0.30000000D 01  0.10000000D 01
DIR. COSINES OR GEOC. DIST -0.21835159D 00  0.51793660D 00  0.82708178D 00

OBS TIME  0.71000000D 02  0.10000000D 02  0.30000000D 01  0.12000000D 02  0.30000000D 02  0.96961000D 01
STATION PARAMETERS  WNKFL6E    0.90000000D-01  0.51264643D 06  0.35918079D 07
3 OBS COMPONENTS,MTYPE,ISTA -0.81000000D-01  0.62315300 00  0.0              0.30000000D 01  0.10000000D 01
DIR. COSINES OR GEOC. DIST -0.23196431D-01  0.77647721D-01  0.99671097D 00

OBS TIME  0.71000000D 02  0.10000000D 02  0.30000000D 01  0.12000000D 02  0.52000000D 02  0.96962000D 01
STATION PARAMETERS  ULASK6E    0.28300000D 00  0.64583675D 06  0.21228305D 07
3 OBS COMPONENTS,MTYPE,ISTA  0.54509700D-01  0.64094500 00  0.0              0.30000000D 01  0.20000000D 01
DIR. COSINES OR GEOC. DIST -0.18536255D 00 -0.18607348D 00  0.96489242D 00
```

Table 5 (Continued)

```
EPOCH TIME

 0.71100300000000D 06        0.12300969610000D 06


 EPOCH ELEMENTS CARTESIAN SYSTEM (KM,KM/SEC)

X=-0.44644377479826D 04        Y= 0.10345458062241D 04        Z= 0.34384156516623D 05
XDOT= 0.99692777874546D 00     YDOT=-0.26030178264117D 01     ZDOT=-0.32870372441045D 01


 EPOCH ELEMENTS KEPLERIAN SYSTEM (KM,DEGREES)

SEMI-MAJOR AXIS                ECCENTRICITY                   INCLINATION
 0.90429731272244D 05           0.88349060855911D 00           0.83161713136328D 02
R.A.OF A NODE                  ARG.OF PERIGEE                 MEAN ANOMALY
 0.10282648363241D 03           0.20566525586674D 03           0.35050648124326D 03


 EPOCH ELEMENTS SPHERICAL SYSTEM (KM,RADIANS)
RIGHT ASCENSION                DECLINATION                    VTFLT PATH ANG
 0.29138814566684D 01           0.14382966873405D 01           0.28044385483957D 01
AZIMUTH ANGLE                  MAG.OF RAD.VECT                MAG.OF  VEL.
 0.11226680921938D 01           0.34688207055446D 05           0.43097773312297D 01
TRUE ANOMALY AT EPOCH = 0.0
```

Table 6

General flowchart of the Early-orbit system. Entries with "E" above them are Early-orbit subroutines. Entries with "G" above them are GTDS subroutines, all other entries are common blocks.



CONDR — Converts an angle in degrees, minutes and seconds to radians,

CONSEC — Converts seconds to hours, minutes and seconds,

CONST — Common block of mathematical constants,

DODSOB — Called by OBSWF to get observation data from DODS observation tape or permanent data base,

EDIT — Common block, contains the number of observations to be selected, and the actual observation numbers,

ELEM — Transforms position and velocity to Keplerian elements,

ERROUT — Prints GTDS error messages,

FILES — Specifies the FORTRAN output unit,

FRC — Common block, contains the force field constants,

GEOWF — Retrieves station geodetic data from the permanent station location data base. Station geodetics are supplied to common block STAGEO via subroutine UPSTAT,

MATTML — Multiplies two matricies (but first transposes the first matrix) to get a resultant matrix,

MA3331 — Computes the product of a 3 x 3 and a 3 x 1 matrix,

OBSCRD — Called by subroutine OBSWF to obtain observation data from GTDS observation cards,

OBSED — Called by subroutine OBSWF to determine if an observation record was selected by OBSNUME cards,

OBSREC — Common block, contains an observation record. The station number is supplied via common block OBSREC to subroutine SPAT so SPAT gets appropriate station geodetics from common block STAGEO,

OBSWF — Controls the creation of the observation working file from various observation input sources (DODSOB, OBSCRD), ODSEXEC — Provides an executive program for GTDS. It calls subroutine SETRUN which reads input cards and also calls subroutine EO which is the driver for Early-orbit,

POLAR — Computes spherical polar coordinates from Cartesian coordinates,

SATPOS — Common block, contains the Gregorian date of starting vector central body number, direction of motion indicator, geocentric distances of the first two observations and the output starting vector,

SETRUN — Reads in the GTDS run control cards,

SLPOPT — Specifies the degree for polynomials to be used for nutation in THETAG,

SPAT — Converts geodetic station coordinates to geocentric inertial station coordinates,

STAGEO — Common block, contains the geodetic latitude, east longitude and height of ten observing stations,

SWITCH — Common block, contains the method of solution indicator, and specifies maximum number of observation components to be processed by Early-orbit,

THETAG — Computes the Greenwich hours angle at the desired time,

TWOBDY — Contains Goodyear's solution to the two-body problem: given a starting vector at an epoch find a two-body vector at any other desired time. In addition, "f" and "g" coefficients are computed,

UPSTAT — Is called by subroutine OBSWF if a new station's geodetics are needed in common block STAGEO to correspond with a current observation being processed in OBSWF.

3.2 Early-orbit Subroutines and Common Blocks

The following GTDS subroutines and common blocks have predominantly Early-orbit applications:

3.2.1 EO

Purpose: EO is the driver or main program for the Early-orbit subsystem. It is called by the main subroutine of GTDS, ODSEXEC. The purpose of EO is to perform all input and output for the Early-orbit subsystem.

Method: Subroutine EO calls OBSWF which in turn calls several GTDS subroutines to obtain satellite observations from the Definitive Orbit Determination System (DODS) tape or DODS disk or GTDS cards. EO then calls EOFLTR to filter the observations and if the observations are rejected, it prints an error message as well as information relayed to it from subroutine EOFLTR. If the observations are acceptable, EO then calls ELEMGN which calls routines to compute the desired starting vector. EO prints a description of from 3 to 16 observation records (EOOBS array) and outputs the starting vector in Keplerian, Cartesian and Polar coordinates. It also outputs the epoch date, any error messages and a NAMELIST of the EARLYO common block which is invaluable in detecting any errors in an Early-orbit run. Many intermediate calculations of Early-orbit subroutines were stored in the EARLYO common block.

Calling sequence:

CALL EO (*)

Calling subroutines:

ODSEXEC

Subroutines called:

OBSWF, ELEMGN, EOFLTR, POLAR, ERROUT

Input/Output:

Variable	Common Block or Argument List	Input Output	Subroutine Where Defined	Subroutine Where Used	Description
DSGDP	COMMON	I	OBSWF	ELEMGN EOFLTR	Input observations
ELEMS (1)	SATPOS	I	SETRUN	EOFLTR DOUBLR	Semimajor axis for methods of Gauss and Range-angles, geocentric distance of first observation for Double-range method.
ELEMS (3)	SATPOS	I	SETRUN	DOUBLR	For Double-range method, the geocentric distance of the first observation.
ELEMS (6)	SATPOS	I	SETRUN	EOFLTR	Permitted time difference in seconds for components of an observation.
IDLTOB	EDIT	I	SETRUN	EO	Observation numbers selected for the Early-orbit run.
IND(5)	SWITCH	I	SETRUN	EO, EOFLTR ELEMGN	Method of solution indicates 1 = Gauss, 2 = Double-range, 3 = Range, angles
YMDIC	SATPOS	I,O	SETRUN	ELEMGN	Year, month and day of epoch.
HMSIC	SATPOS	I,O	SETRUN	ELEMGN	Hour, minute and second of epoch
IBODY	SATPOS	I	SETRUN	EO	Central body, 1 = earth, 2 = moon.
EOOBS	ARGUMENT	I,O	ELEMGN	EO	Description for two- to 16 observations; contents: observation time, station position, values of the three observation components, observation type, equivalent observation direction cosines or geocentric distances.
MAXOBS	SWITCH	I	EO	EOFLTR ELEMGN	Number of observation components
JUMPG	ARGUMENT	I,O	EOFLTR DOUBLR EGAUSS POSFIX	EO	Early orbit error indicator = 0 no error, $\neq 0$ error

Variable	Common Block or Argument List	Input Output	Subroutine Where Defined	Subroutine Where Used	Description
POSI	SATPOS	O	ELEMGN	EO	X, Y, Z geocentric inertial satellite position.
VELI	SATPOS	O	ELEMGN	EO	X, Y, Z geocentric inertial satellite velocity.

3.2.2 EOFLTR

Purpose: EOFLTR is the Early-orbit observation filter subroutine. EOFLTR tests the input observations against various criteria and accepts or rejects the observations.

Method: EOFLTR checks that the number of input observation components (MAXOBS) is compatible with the chosen method of solution. The Double-range and Gauss methods require exactly three observations while the Range-angles method requires from 2 to 16 observations. Note that for the angles-only methods, two simultaneous measurements constitute one observation while for the Range-angles method, three simultaneous components constitute one observation. Since the input observation components might not be in any sort of order, EOFLTR arranges the components chronologically. The observation components are then grouped into pairs (for angles only observations) or into triplets (for Range-angles). Each group of components however may not be arranged in order of increasing GTDS observation type, MTYPE. Then depending on the method of solution, each group of two or three components (each group is one observation) is checked for the appropriate MTYPE. Each group of components are checked to see that each of the components are within a certain number of seconds of each other (DSECI). The maximum observed time difference between components is output (DSECO). Each observation is then checked to see if all components were measured by the same station. Then EOFLTR tests the orbital arc-length difference between each observation assuming a nominal orbit. A nominal semimajor axis is converted to a mean motion. The observation times are then converted to mean anomaly differences. Assuming the eccentricity is nearly zero, these mean anomaly differences are compared to the true anomaly differences allowed by the Double-range, Gauss and Range-angles methods. The mean anomaly differences (obs. 2 - obs. 1), (obs. 3 - obs. 2) and (obs. last - obs. 1) are stored in the array DMEAN. If errors are found by EOFLTR, then an indication code is returned in subroutine argument JUMPG.

Calling sequence:

CALL EOFLTR (ELEMS, JUMPG, DSECO, DMEAN)

Calling subroutines: EO

Called subroutines: None

Input/Output:

Variable	Common Block or Argument List	Input Output	Subroutine Where Defined	Subroutine Where Used	Description
IGR	SWITCH	I	SETRUN	EOFLTR ELEMGN	Method of solution, = 1 Gauss, = 2 Double-range, = 3 Range–angles
MAXOBS	SWITCH	I	EO	EOFLTR ELEMGN	Number of input observation components
R8WF	COMMON	I,O	OBSWF	EO EOFLTR ELEMGN	Array of up to 48 observation components
ELEMS (1)	ARGUMENT	I	SETRUN	EOFLTR ELEMGN	For Gauss and Range-angles methods is the semi-major axis, for Double-range method is the geocentric distance of the first observation
ELEMS (6)	ARGUMENT	I	SETRUN	EOFLTR	Number of seconds, time difference permitted between components of an observation
JUMPG	ARGUMENT	O	EOFLTR	EO	Error switch, = 0 no error, ≠ 0 error
DSECO	ARGUMENT	O	EOFLTR	EO	Maximum observed time difference in seconds
DMEAN (1)	ARGUMENT	O	EOFLTR	EO	Mean anomaly difference (obs. 2 - obs. 1)
DMEAN (2)	ARGUMENT	O	EOFLTR	EO	Mean anomaly difference (obs. 3 - obs. 2)
DMEAN (3)	ARGUMENT	O	EOFLTR	EO	Mean anomaly difference (last obs. - obs. 1)

3.2.3 ELEMGN

Purpose: Subroutine ELEMGN obtains a starting vector at an epoch by calling either subroutine DOUBLR, EGAUSS or POSFIX.

Method: For the angles only methods, ELEMGN groups every two component measurements into one observation and for the Range-angles method it groups every three component measurements into an observation. Then every angles-only observation is converted to topocentric inertial direction cosines, see Figure 1. Each Range-angles observation is converted into an equivalent set of X, Y, Z geocentric inertial coordinates, see Figure 2. If the input observations were angles only ELEMGN calls EGAUSS or DOUBLR, as specified by the desired method of solution, or POSFIX, if the input observations were Range-angles.

These subroutines return to ELEMGN a starting vector at the second observation time. If any epoch is specified, the subroutine SECULA is called to update this vector to the desired epoch time using J2 secular perturbations. If there is no epoch specified, the epoch then has as default the time of the second observation. ELEMGN returns the starting vector and intermediate computations to EO where they are printed.

Calling sequence:

CALL ELEMGN (JUMPG, EOOBS, *)

Calling subroutines: EO

Called subroutines: DOUBLR, EGAUSS, POSFIX, SECULA, ANGLES,

RANGLE, CDATE, CELEM, ELEM, MATTML, MA3331, SPAT, THETAG,

CONDR, AZEL30, AZEL85, MINTRK

Input/Output:

Variable	Common Block or Argument List	Input Output	Subroutine Where Defined	Subroutine Where Used	Description
R8WF	COMMON	I	OBSWF	EOFLTR EO ELEMGN	A block of up to 48 observation components
SGDP	STAGEO	I	UPSTAT	ELEMGN	Station Geodetics
EOOBS	ARGUMENT	O	ELEMGN	EO	Array describing each observation: Year, month, day, hour, minute, second, station name, height, latitude, longitude, values of the three observation components, the GTDS observation type of the second component, station number, the direction cosines or the geocentric coordinates of the observation
TANC	ARGUMENT	O	ELEMGN	SECULA	Number of seconds past time of first observation when vector is desired.
YMDIC	SATPOS	I/O	SETRUN	ELEMGN	Year, month and day of epoch
HMSIC	SATPOS	I/O	SETRUN	ELEMGN	Hour, minute and second of epoch
EOT	EARLYO	O	ELEMGN	EO	Time of each observation in seconds past the first observation
EDAY	SATPOS	I	READWF	ELEMGN	Number of A1 seconds from beginning of epoch year to epoch
DAYO	SATPOS	I	DWRITE	ELEMGN	Modified Julian day of the beginning of the epoch year
MTYPE	COMMON	I	OBSWF	ELEMGN	GTDS observation type
ELEMS (1)	SATPOS	I	SETRUN	DOUBLR	Guess at geocentric distance of first observation for Double-range method and guess at semimajor axis for Gauss and Range-angles.

Variable	Common Block or Argument List	Input Output	Subroutine Where Defined	Subroutine Where Used	Description
ELEMS (3)	SATPOS	I	SETRUN	DOUBLR	For Double-range method, is a guess at geocentric distance of the second observation.
JUMPG	ARGUMENT	O	ELEMGN	EO	Error indicator, = 0 no error ≠ 0 error
ELEMS	SATPOS	O	ELEMGN	EO	Keplerian elements
MAXOBS	SWITCH.	I	EO	ELEMGN EOFLTR	Number of observation components input to EO
ALX	EARLYO	O	ELEMGN	DOUBLR EGAUSS	X topocentric inertial direction cosine
ALY	EARLYO	O	ELEMGN	DOUBLR EGAUSS	Y topocentric inertial direction cosine
ALZ	EARLYO	O	ELEMGN	DOUBLR EGAUSS	Z topocentric inertial direction cosine
WZZ	ARGUMENT	O	ELEMGN	DOUBLR	Direction of orbital motion indicator = 1 direct, = -1 retrograde
SR1G	EARLYO	O	ELEMGN	DOUBLR	Approximate geocentric distance of first observation
SR2G	EARLYO	O	ELEMGN	DOUBLR	Approximate geocentric distance of second observation
XXX	EARLYO	O	ELEMGN	POSFIX	X geocentric inertial component of range
YYY	EARLYO	O	ELEMGN	POSFIX	Y geocentric inertial component of range
ZZZ	EARLYO	O	ELEMGN	POSFIX	Z geocentric inertial component of range
BX	EARLYO	O	ELEMGN	DOUBLR EGAUSS	X geocentric inertial coordinate of earth's center with respect to station
BY	EARLYO	O	ELEMGN	DOUBLR EGAUSS	Y geocentric inertial coordinate of earth's center with respect to station
BZ	EARLYO	O	ELEMGN	DOUBLR EGAUSS	Z geocentric inertial coordinate of earth's center with respect to station
S0	ARGUMENT	I	DOUBLR EGAUSS POSFIX	ELEMGN	Cartesian orbit vector at second observation

3.2.4 DOUBLR

Purpose: Subroutine DOUBLR obtains a set of two-body starting elements for a satellite at the second observation time. Input to the program are three observations each with X, Y, Z topocentric inertial direction cosines. Nominal values for the geocentric distance of the first two observations must be made and the direction of orbital motion must be specified.

Method: The nominal values of the geocentric distances of the first two observations are iterated upon using a Newton Raphson correction scheme. When convergence is achieved, the distances to the first two observations are obtained which minimize the differences between the observed and computed observation times for the first and third observations. A convergence tolerance of 10^{-6} earth radii or 6 meters is set on the two geocentric distances. Consult Escobal for a detailed description of this method.

Calling sequence:

CALL DOUBLR (WZZ, S0, JUMPG)

Calling subroutines: ELEMGN

Subroutines called: None

Input/Output:

Variable	Common Block or Argument List	Input Output	Subroutine Where Defined	Subroutine Where Used	Description
WZZ	ARGUMENT	I	ELEMGN	DOUBLR	Direction of orbital motion indicator = 1 direct, = -1 retrograde
ALX	EARLYO	I	ELEMGN	DOUBLR EGAUSS	X topocentric inertial direction cosine
ALY	EARLYO	I	ELEMGN	DOUBLR EGAUSS	Y topocentric inertial direction cosine
ALZ	EARLYO	I	ELEMGN	DOUBLR EGAUSS	Z topocentric inertial direction cosine
SR1G	EARLYO	I	ELEMGN	DOUBLR	Approximate geocentric distance of first observation
SR2G	EARLYO	I	ELEMGN	DOUBLR	Approximate geocentric distance of second observation

Variable	Common Block or Argument List	Input Output	Subroutine Where Defined	Subroutine Where Used	Description
EOT	EARLYO	I	ELEMGN	DOUBLR EGAUSS POSFIX	Time of each observation in seconds past first observation
BX	EARLYO	I	ELEMGN	DOUBLR EGAUSS	X geocentric inertial station to earth center vector
BY	EARLYO	I	ELEMGN	DOUBLR EGAUSS	Y geocentric inertial station to earth center vector
BZ	EARLYO	I	ELEMGN	DOUBLR EGAUSS	Z geocentric inertial station to earth center vector
SO	ARGUMENT	O	DOUBLR EGAUSS POSFIX	ELEMGN	Cartesian orbit vector at second observation time
DELSR1	EARLYO	O	DOUBLR	EO	Correction to geocentric distance of first observation
DELSR2	EARLYO	O	DOUBLR	EO	Correction to geocentric distance of second observation
F1	EARLYO	O	DOUBLR	EO	Time residual for first and second observation
F2	EARLYO	O	DOUBLR	EO	Time residual for third and second observation
JUMPG	ARGUMENT	O	DOUBLR	EO	Error indicator, = 0 no error $\neq 0$ error
ITERA	EARLYO	O	DOUBLR EGAUSS	EO	Iteration counter for DOUBLR

3.2.5 EGAUSS

Purpose: Subroutine EGAUSS determines a set of two-body starting elements for a satellite at the second observation time. Input to the subroutine are three observations each with X, Y, Z topocentric inertial direction cosines.

Method: EGAUSS uses the classical approach of GAUSS to obtain an eighth-order polynomial, whose largest positive entirely real root is the magnitude of the geocentric distance of the second observation. The Herrick-Gibbs correction formulas are then used iteratively to obtain velocities from the geocentric distance of the second observation. To judge whether EGAUSS has converged, the variable CUBEB, which is the value of the new slant range residuals, must be less than 10^{-6} earth radii.

Calling Sequence:

CALL EGAUSS (S0, JUMPG)

Calling subroutine: ELEMGN

Subroutines called: POLRT, TWOBDY

Input/Output:

Variable	Common Block or Argument List	Input Output	Subroutine Where Defined	Subroutine Where Used	Description
ALX	EARLYO	I	ELEMGN	DOUBLR EGAUSS	X topocentric inertial direction cosine
ALY	EARLYO	I	ELEMGN	DOUBLR EGAUSS	Y topocentric inertial direction cosine
ALZ	EARLYO	I	ELEMGN	DOUBLR EGAUSS	Z topocentric inertial direction cosine
EOT	EARLYO	I	ELEMGN	DOUBLR EGAUSS POSFIX	Time of each observation in seconds past first observation
BX	EARLYO	I	ELEMGN	DOUBLR EGAUSS	X geocentric inertial station to earth center vector
BY	EARLYO	I	ELEMGN	DOUBLR EGAUSS	Y geocentric inertial station to earth center vector
BZ	EARLYO	I	ELEMGN	DOUBLR EGAUSS	Z geocentric inertial station to earth center vector
S0	ARGUMENT	O	DOUBLR EGAUSS POSFIX	ELEMGN	Cartesian orbit vector at second observation
CUBEA	EARLYO	O	EGAUSS	EO	Magnitude of old slant range range residuals
CUBEA	EARLYO	O	EGAUSS	EO	Magnitude of new slant range residuals
RHON	EARLYO	O	EGAUSS	EO	New slant range components
RHOO	EARLYO	O	EGAUSS	EO	Old range components
JUMPG	EARLYO	O	EGAUSS	EO	Error indicator, = 0 no error ≠ 0 error
RR	EARLYO	O	EGAUSS	EO	Largest positive entirely real polynomial root

Variable	Common Block or Argument List	Input Output	Subroutine Where Defined	Subroutine Where Used	Description
KER	EARLYO	O	POLRT	EO	Polynomial root condition
ITERA	EARLYO	O	EGAUSS	EO	Iteration counter for EGAUSS

3.2.6 POSFIX

Purpose: Subroutine POSFIX converts from 2 to 16 observations, each with X, Y, Z geocentric inertial components, to a two-body starting vector. The epoch of the starting vector is the second observation time.

Method: The input observations are initially assumed to lie in a circular orbit. With this zero eccentricity assumption, POSFIX computes initial f and g series coefficients for each observation. An initial position and velocity are computed in a least squares fashion from these f and g coefficients. Then X, Y, Z residuals are formed. The computed starting vector is then used by subroutine TWOBDY to compute more accurate f and g coefficients, which in turn are again used to obtain a least squares starting vector, etc.

Calling sequence:

```
CALL POSFIX (N, GMC, TZERO, SO, EPCLON, SGMCNT, NI, NO,

RE, JUMPG, VVU)
```

Calling subroutines: ELEMGN

Subroutines called: TWOBDY

Input/Output:

Variable	Common Block or Argument List	Input Output	Subroutine Where Defined	Subroutine Where Used	Description
N	ARGUMENT	I	ELEMGN	POSFIX	Number of input observations
GMC	ARGUMENT	I	ELEMGN	POSFIX	Gravitation constant km**3/sec**2
TZERO	ARGUMENT	I	ELEMGN	POSFIX	Time of desired vector in seconds past first observation

Variable	Common Block or Argument List	Input Output	Subroutine Where Defined	Subroutine Where Used	Description
SO	ARGUMENT	O	EGAUSS DOUBLR POSFIX	ELEMGN	Geocentric inertial Cartesian coordinates at second observation time
EPCLON	ARGUMENT	I	ELEMGN	POSFIX	Positive number for convergence of outer loop
SGMCNT	ARGUMENT	I	ELEMGN	POSFIX	Positive number for scaling the standard deviation
NI	ARGUMENT	I	ELEMGN	POSFIX	Limit on number of inner loop iterations
NO	ARGUMENT	I	ELEMGN	POSFIX	Limit on number of outer loop iterations
RE	ARGUMENT	I	ELEMGN	POSFIX	Radius of earth
JUMPG	ARGUMENT	O	POSFIX EGAUSS DOUBLR EOFLTR	EO	Error indicator, = 0 no error, ≠ 0 error
VVU	ARGUMENT	I	ELEMGN	POSFIX	Vanguard Velocity unit (7.9053 km/sec)
EOT	EARLYO	I	ELEMGN	EGAUSS DOUBLR POSFIX	Time of observation in seconds past first observation
XXX	EARLYO	I	ELEMGN	DOUBLR EGAUSS	X geocentric inertial component of range
YYY	EARLYO	I	ELEMGN	DOUBLR EGAUSS	Y geocentric inertial component of range
ZZZ	EARLYO	I	ELEMGN	DOUBLR EGAUSS	Z geocentric inertial component of range

3.2.7 SECULA

Purpose: Subroutine SECULA converts a given set of Keplerian elements at the time of the second observation to a new set of Keplerian elements at time of epoch.

Method: Subroutine SECULA updates a satellite vector modeling only the first order J2, oblate earth, secular perturbations. The semi-major axis, eccentricity and inclination are assumed to be constant and the angular variables: ascending node, argument of perigee and mean anomaly are assumed to vary linearly with time. The subroutines DOUBLR, EGAUSS and POSFIX compute a starting vector at the second observation time. Subroutine SECULA then adds the J2 secular perturbations, which accumulate between the second observation time and epoch time, to the angular Kepler elements.

Calling sequence:

CALL SECULA (TIMR, REFT, SA, E, AI, BO, SO, AMA, AJ2,

DEGDAY)

Calling subroutine: ELEMGN

Called subroutines: None

Input/Output:

Variable	Common Block or Argument List	Input Output	Subroutine Where Defined	Subroutine Where Used	Description
TIMR	ARGUMENT	O	ELEMGN	SECULA	Time of output Kepler elements in seconds past first observation
REFT	ARGUMENT	I	ELEMGN	SECULA	Time of input Kepler elements is time of second observation in seconds from first observation
SA	ARGUMENT	I	ELEMGN	SECULA	Semi-major axis
E	ARGUMENT	I	ELEMGN	SECULA	Eccentricity
AI	ARGUMENT	I	ELEMGN	SECULA	Inclination
BO	ARGUMENT	I/O	ELEMGN	SECULA	Ascending Node
SO	ARGUMENT	I/O	ELEMGN	SECULA	Argument of Perigee
AMA	ARGUMENT	I/O	ELEMGN	SECULA	Mean anomaly
AJ2	ARGUMENT	I	ELEMGN	SECULA ELEM	Earth's J2 zonal harmonic
DEGDAY	ARGUMENT	I	ELEMGN	SECULA	Number of degrees per day in radians per VTU
VLU	EARLYO	I	ELEMGN	SECULA	One earth radius

Variable	Common Block or Argument List	Input Output	Subroutine Where Defined	Subroutine Where Used	Description
VTU	EARLYO	I	ELEMGN	SECULA	Vanguard time unit: amount of time it takes a satellite with a semi-major axis of one earth radius to cover an arc of one radian
BOBDR	EARLYO	O	SECULA	EO	J2 nodal perturbation, deg/day
SOBDR	EARLYO	O	SECULA	EO	J2 perigee perturbation, deg/day
AMBDR	EARLYO	O	SECULA	EO	J2 mean anomaly perturbation, deg/day

3.2.8 ANGLES

Purpose: Subroutine ANGLES has two purposes. One purpose is to convert an observation that consists of two angles to azimuth and elevation. The second purpose is to convert azimuth and elevation to topocentric right ascension and declination.

Method: Subroutine ANGLES has four entry points. Entry point AZEL30 is called to convert Goddard Range and Range Rate (GRARR) X_{30} and Y_{30} gimbal angles to azimuth and elevation. Entry point AZEL85 converts Unified S Band (USB) X_{85} and Y_{85} gimbal angles to azimuth and elevation. Entry point MINTRK converts Minitrack ℓ and m direction cosines to azimuth and elevation. The final entry point is ANGLES, it converts azimuth, elevation into topocentric right ascension and declination.

Calling sequence:

CALL ANGLES (AZ, EL, PHI, THETHA, ALPHA, DELTA)

CALL AZEL30 (X_{30}, Y_{30}, AZ, EL)

CALL AZEL85 (X_{85}, Y_{85}, AZ, EL)

CALL MINTRK (SL, SM, AZ, EL)

Calling subroutines: ELEMGN

Subroutines called: None

Input/Output:

Variable	Common Block or Argument List	Input Output	Subroutine Where Defined	Subroutine Where Used	Description
AZ	ARGUMENT	I/O	ELEMGN	ANGLES AZEL30 AZEL85 MINTRK	Azimuth angles
EL	ARGUMENT	I/O	ELEMGN	ANGLES AZEL30 AZEL85 MINTRK	Elevation angle
PHI	ARGUMENT	I	ELEMGN	ANGLES	Geodetic latitude of station
THETHA	ARGUMENT	I	ELEMGN	ANGLES	Right ascension of station
ALPHA	ARGUMENT	O	ELEMGN	ANGLES	Topocentric right ascension
DELTA	ARGUMENT	O	ELEMGN	ANGLES	Topocentric declination
X_{30}	ARGUMENT	I	ELEMGN	AZEL30	GRARR X_{30} gimbal angle
Y_{30}	ARGUMENT	I	ELEMGN	AZEL30	GRARR Y_{30} gimbal angle
X_{85}	ARGUMENT	I	ELEMGN	AZEL85	USB X_{85} gimbal angle
Y_{85}	ARGUMENT	I	ELEMGN	AZEL85	USB Y_{85} gimbal angle
SL	ARGUMENT	I	ELEMGN	MINTRK	Minitrack ℓ direction cosine
SM	ARGUMENT	I	ELEMGN	MINTRK	Minitrack m direction cosine

3.2.9 RANGLE

Purpose: Subroutine RANGLE can perform coordinate transformations from range and angles to topocentric earth fixed X, Y, Z, vice versa.

Method: The subroutine has two flags: ITYPE indicates the type of input observations and IFLG indicates the type of observations to be output. Table 7 describes all the possible transformations.

Calling sequence:

CALL RANGLE (R, A1, A2, ITYPE, IFLG, RL)

Calling subroutines: ELEMGN

Subroutines called: None

Table 7

Various Coordinate Transformation Possibilities in Subroutine RANGLE

ITYPE	IFLG	Input Observations	Output Observations
1	0	ρ, X_{85}, Y_{85}	X, Y, Z
2	0	ρ, X_{30}, Y_{30}	X, Y, Z
5	0	ρ, A, E	X, Y, Z
1	1	X, Y, Z	ρ, X_{85}, Y_{85}
2	1	X, Y, Z	ρ, X_{30}, Y_{30}
5	1	X, Y, Z	ρ, A, E

Input/Output:

Variable	Common Block or Argument List	Input Output	Subroutine Where Defined	Subroutine Where Used	Description
R	ARGUMENT	I/O	ELEMGN	RANGLE	Slant range
A1	ARGUMENT	I/O	ELEMGN	RANGLE	Topocentric angles (X_{85}, X_{30}, A)
A2	ARUGMENT	I/O	ELEMGN	RANGLE	Topocentric angle (Y_{85}, Y_{30}, E)
ITYPE	ARGUMENT	I	ELEMGN	RANGLE	Input observation type
IFLG	ARGUMENT	I	ELEMGN	RANGLE	Output observation type
RL	ARGUMENT	I/O	ELEMGN	RANGLE	Topocentric earth fixed, X, Y, Z.

3.2.10 EARLYO

Purpose: Common block EARLYO was written specifically for the GTDS Early-orbit subsystem. This common block passes information between Early-oribt routines that are vital to program execution; the common block also stores intermediate computations from several Early-orbit subroutines. This latter feature should considerably aid in debugging an Early-orbit run.

Method: A NAMELIST of the EARLYO Common block is printed after each run. The physical units of measurement associated with each variable are listed here, see section 1.5 for Abbreviations.

Variable	Subroutine Where Defined	Subroutine Where Used	Description
ALX	ELEMGN	DOUBLR EGAUSS	X topocentric inertial direction cosine of observation (nu)
ALY	ELEMGN	DOUBLR EGAUSS	Y topocentric inertial direction cosine of observation (nu)
ALZ	ELEMGN	DOUBLR EGAUSS	Z topocentric inertial direction cosine of observation (nu)
BM	ELEMGN	DOUBLR EGAUSS	Canonical mass unit = 1.DO (em)
BR	ELEMGN	DOUBLR EGAUSS	SQRT (BX**2 + BY**2 + BZ**2) (nu)
BX	ELEMGN	DOUBLR EGAUSS	X geocentric inertial coordinate of earths center wrt station (er)
BY	ELEMGN	DOUBLR EGAUSS	Y geocentric inertial coordinate of earth's center wrt station (er)
BZ	ELEMGN	DOUBLR EGAUSS	Z geocentric inertial coordinate of earth's center wrt station (er)
EOT	ELEMGN	DOUBLR EGAUSS POSFIX	Time of observation in seconds from first observation (sec.)
SR1G	ELEMGN	DOUBLR	Nominal geocentric distance of first observation (er)
SR2G	ELEMGN	DOUBLR	Nominal geocentric distance of second observation (er)
VLU	ELEMGN	DOUBLR EGAUSS SECULA	Vanguard length unit, earth radius in (km)

Variable	Subroutine Where Defined	Subroutine Where Used	Description
VTU	ELEMGN	DOUBLR EGAUSS SECULA	Vanguard time unit, 806.8124...(sec)
RHON	EGAUSS	NAMELIST	New topocentric range (er)
RHOO	DOUBLR EGAUSS	NAMELIST	Old topocentric range (er)
XXX	ELEMGN	POSFIX NAMELIST	X geocentric inertial coordinate, observation (km)
YYY	ELEMGN	POSFIX NAMELIST	Y geocentric inertial coordinate, observation (km)
ZZZ	ELEMGN	POSFIX NAMELIST	Z geocentric inertial coordinate, observation (km)
SR	DOUBLR EGAUSS	NAMELIST	Geocentric range (kr)
SXD	DOUBLR EGAUSS	NAMELIST	X geocentric inertial velocity, satellite (km/sec)
SYD	DOUBLR EGAUSS	NAMELIST	Y geocentric inertial velocity, satellite (km/sec)
SZD	DOUBLR EGAUSS	NAMELIST	Z geocentric inertial velocity, satellite (km/sec)
SRD	EGAUSS	NAMELIST	Velocity magnitude of satellite (km/sec)
PP	DOUBLR	NAMELIST	Orbital semiparameter (er)
ECE	DOUBLR	NAMELIST	Orbital eccentricity (nu)
AN	DOUBLR	NAMELIST	Orbital mean motion (rad/vtu)
SE	DOUBLR	NAMELIST	Sine (eccentric anomaly) (nu)
CE	DOUBLR	NAMELIST	Cosine (eccentric anomaly) (nu)
E3E2	DOUBLR	NAMELIST	Eccentric anomaly difference (obs. 3 - obs. 2) (rad)
DM3M2	DOUBLR	NAMELIST	Mean anomaly difference (obs. 3 - obs. 2) (rad)
E2E1	DOUBLR	NAMELIST	Eccentric anomaly difference (obs. 2 - obs. 1) (rad)
DM1M2	DOUBLR	NAMELIST	Mean anomaly difference (obs. 2 - obs. 1) (rad)

Variable	Subroutine Where Defined	Subroutine Where Used	Description
F1	DOUBLR	NAMELIST	Time residual (obs. 1 - obs. 2) observed–(obs. 1 - obs. 2) computed (vtu)
F2	DOUBLR	NAMELIST	Time residual (obs. 3 - obs. 2) observed–(obs. 3 - obs. 2) computed (vtu)
SH	DOUBLR	NAMELIST	Sine (hyperbolic anomaly) (nu)
CH	DOUBLR	NAMELIST	Cosine (hyperbolic anomaly) (nu)
F3F2	DOUBLR	NAMELIST	Hyperbolic anomaly: (obs. 3 - obs. 2) observed-(obs. 3 - obs. 2) computed (rad)
F2F1	DOUBLR	NAMELIST	Hyperbolic anomaly: (obs. 2 - obs. 1) observed-(obs. 2 - obs. 1) computed (rad)
DELSR1	DOUBLR	NAMELIST	Correction to geocentric distance of first observation (er)
DELSR2	DOUBLR	NAMELIST	Correction to geocentric distance of second observation (er)
CSS	EGAUSS	NAMELIST	Gauss polynomial coefficient, zero order
AS	EGAUSS	NAMELIST	Gauss polynomial coefficient, sixth order
RR	EGAUSS	NAMELIST	Largest positive real root (er)
CUBEA	EGAUSS	NAMELIST	Old slant range residual (er)
CUBEB	EGAUSS	NAMELIST	New slant range residual (er)
DIFNM1	EGAUSS	NAMELIST	X component of new slant range residual (er)
DIFNM2	EGAUSS	NAMELIST	Y component of new slant range residual (er)
DIFNM3	EGAUSS	NAMELIST	Z component of new slant range residual (er)
DJD2	ELEMGN	NAMELIST	Modified Julian date of second observation (days)
DJD	ELEMGN	NAMELIST	Modified Julian date of observation (days)
SECA	ELEMGN	NAMELIST	Epoch time in seconds after IMIA (sec)
DJD1	ELEMGN	NAMELIST	Modified Julian date of first observation, (days)
RS	ELEMGN	NAMELIST	Geocentric station distance (er)

Variable	Subroutine Where Defined	Subroutine Where Used	Description
RSQ	ELEMGN	NAMELIST	Geocentric inertial satellite distance (km)
TIMEF	ELEMGN	NAMELIST	Time of observation in seconds from first observation (sec)
ALASSE	ELEMGN	NAMELIST	Keplerian elements of epoch (km,deg)
GDLTS	ELEMGN	NAMELIST	Geodetic latitude of station (rad)
GDLGS	ELEMGN	NAMELIST	Geodetic longitude of station (rad)
SPHHGT	ELEMGN	NAMELIST	Spheroid height of station (er)
AX30	ELEMGN	NAMELIST	GRARR X_{30} gimbal angle (rad)
DAT1	ELEMGN	NAMELIST	First observation component (er, rad)
DAT2	ELEMGN	NAMELIST	Second observation component (er, rad)
DAT3	ELEMGN	NAMELIST	Third observation component (er, rad)
RA	ELEMGN	NAMELIST	Topocentric right ascension (rad)
DE	ELEMGN	NAMELIST	Topocentric declination (rad)
AMBDR	SECULA	NAMELIST	Mean motion (J_2) (deg/day)
BOBDR	SECULA	NAMELIST	Ascending node (J_2) (deg/day)
SOBDR	SECULA	NAMELIST	Argument of Perigee (J_2) (deg/day)
ET	ELEMGN	NAMELIST	Topocentric X (km)
TT	ELEMGN	NAMELIST	Topocentric Y (km)
VT	ELEMGN	NAMELIST	Topocentric Z (km)
ADJDA	ELEMGN	NAMELIST	Modified Julian date of epoch (days)
ATANC	ELEMGN	NAMELIST	Epoch, number of seconds past first observation (sec)
AWHANG	ELEMGN	NAMELIST	Greenwich hour angle of first observation (rad)
ATIME1	ELEMGN	NAMELIST	Zero, 0. D0 (sec)
ATIME2	ELEMGN	NAMELIST	Time of second observation from first observation in (sec)
ATIMEF	ELEMGN	NAMELIST	Time of observation from first observation in (sec)
ADJD	ELEMGN	NAMELIST	Modified Julian date of observation (day)
ADJD1	ELEMGN	NAMELIST	Modified Julian date of first observation (day)

Variable	Subroutine Where Defined	Subroutine Where Used	Description
ADJD2	ELEMGN	NAMELIST	Modified Julian date of second observation (day)
ATH	ELEMGN	NAMELIST	Right ascension of station (rad)
ASL	ELEMGN	NAMELIST	Minitrack ℓ direction cosine (nu)
ASM	ELEMGN	NAMELIST	Minitrack m direction cosine (nu)
AY30	ELEMGN	NAMELIST	GRARR Y_{30} gimbal angle (rad)
AX85	ELEMGN	NAMELIST	S-BAND X_{85} gimbal angle (rad)
AY85	ELEMGN	NAMELIST	S-BAND Y_{85} gimbal angle (rad)
AAZD	ELEMGN	NAMELIST	C-BAND azimuth (deg)
AELD	ELEMGN	NAMELIST	C-BAND elevation (deg)
APHI	ELEMGN	NAMELIST	Geodetic latitude of station (rad)
AALPHA	ELEMGN	NAMELIST	Topocentric right ascension (deg)
ADELTA	ELEMGN	NAMELIST	Topocentric declination (deg)
AWZZ	ELEMGN	NAMELIST	Direction of motion +1 direct, −1 retrograde (nu)
AR	ELEMGN	NAMELIST	Topocentric range (er)
AA	ELEMGN	NAMELIST	Azimuth (rad)
AE	ELEMGN	NAMELIST	Elevation (rad)
AX1	ELEMGN	NAMELIST	First angle (X_{30} or X_{85}) (rad)
AY1	ELEMGN	NAMELIST	Second angle (Y_{30} or Y_{85}) (rad)
AGCORD	ELEMGN	NAMELIST	(X, Y, Z) geocentric inertial station position (er)
AS0	ELEMGN	NAMELIST	Satellite inertial cartesian coordinates (km, km/sec)
ATRANS	ELEMGN	NAMELIST	(X, Y, Z) topocentric to geocentric translation (er)
ARL	ELEMGN	NAMELIST	Topocentric satellite position (er)
ARH	ELEMGN	NAMELIST	Geocentric earth fixed satellite position (er)
ARIT	ELEMGN	NAMELIST	Geocentric inertial satellite position (er)
SX	DOUBLR EGAUSS	NAMELIST	X inertial satellite position of obs. 1, obs. 2, obs. 3 (km)

Variable	Subroutine Where Defined	Subroutine Where Used	Description
SY	DOUBLR EGAUSS	NAMELIST	Y inertial satellite position of obs. 1, obs. 2, obs. 3 (km)
SZ	DOUBLR EGAUSS	NAMELIST	Z inertial satellite position of obs. 1, obs. 2, obs. 3 (km)
DMEAN	EOFLTR	NAMELIST	Mean anomaly differences between (obs. 2 - obs. 1), (obs. 3 - obs. 2), (obs. last - obs. 1), (deg)
DSECO	EOFLTR	NAMELIST	Maximum observed time difference in seconds between components of an observation (sec)
DEOSPR			Spares
ITERA	DOUBLR EGAUSS	NAMELIST	Number of iterations subroutine executed
IOBS3	ELEMGN	NAMELIST	Component (of observation) counter
IYA	ELEMGN	NAMELIST	Epoch year (two digit)
IMA	ELEMGN	NAMELIST	Epoch month
IDA	ELEMGN	NAMELIST	Epoch day
IHRA	ELEMGN	NAMELIST	Epoch hour
IMIA	ELEMGN	NAMELIST	Epoch minute
KER	EGAUSS	NAMELIST	Gauss polynomial root condition: = 0 no error, = 1 order LT1, = 2 order GT36, = 3 number of iterations exceeded, = 4 high order coefficient is zero
IJUMPG	DOUBLR EGAUSS POSFIX	NAMELIST	Error indicator: = 0 no error, $\neq 0$ error
IEOSPR			Spares

3.2.11 Unlabeled COMMON

Purpose: Unlabled COMMON passes an array of observations DSGDP (18,50) to the Early-orbit program.

Method: There are a maximum of 50 observation component records and 18 double precision words of information for each observation component. DSGDP is equivalenced to a double precision array R8WF and an integer array I4WF.

Description of Variables:

Variable	Subroutine Where Defined	Subroutine Where Used	Description
R8WF (3, I)	OBSWF	ELEMGN	Value of uncorrected observation component
R8WF (9, I)	OBSWF	ELEMGN	Number of A1 seconds from the beginning of epoch year to observation
I4WF (25,I)	OBSWF	ELEMGN	Observation number
I4WF (27,I)	OBSWF	ELEMGN	GTDS types of observation component, MTYPE
I4WF (31,I)	OBSWF	ELEMGN	Station index to be used with STAGEO array

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