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Coding, Testing and Documentation of Processors for the Flight Design System

FINAL REPORT
Contract NAS9-15787

ANALYTICAL AND COMPUTATIONAL MATHEMATICS, INC.

RECEIVED
NASA STI FACILITY
ACCESS DEPT.
1980

CODING, TESTING AND DOCUMENTATION OF PROCESSORS FOR THE FLIGHT DESIGN SYSTEM

FINAL REPORT

ANALYTICAL AND COMPUTATIONAL MATHEMATICS, INC.

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FEBRUARY 22, 1980

This report was prepared for the NASA/Johnson Space Center under Contract NAS9-15787.

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Coding, Testing and Documentation
of Processors
For the Flight Design System

1.0 Introduction

This is the final summary report for the work carried out under Contract NAS9-15787. The purpose of this report is to give an overview of the work. The individual tasks are summarized in Section 2 through Section 8. A statement on New Technology is given in Section 9. Appendix A gives a comprehensive list of all the items delivered under this contract. Appendix B lists the source code card count for all delivered routines.

2.0 Familiarization and Numerical Accuracy Investigations

All ACM personnel assigned to the FDS work were required to become familiar with the Interdata 8/32 Computer system. A key ACM person was sent to a two week course on the computer system.

A study was made on the accuracy of single and double precision arithmetic, and mathematical functions. It was determined that all orbit propagation routines should be coded in double precision. This standard was implemented in all propagation routines and related routines. Some exceptions were made with perturbation model routines where theoretical considerations implied that single precision arithmetic would provide sufficient accuracy.

3.0 Design and Implementation of Basetime Initialization Processor

This program (BASTM) was the first complete processor delivered by ACM. It is needed in order to execute other application processors.

The Basetime Processor (BASTM) provides the capability to establish the basetime (epoch) for a given session and thereby initialize the base date array !BDATE . Two reference times, Mission Elapsed Time (MET) and Phase Elapsed Time (PET), can be generated optionally within the !BDATE array. It also, at the user's option, initializes solar and lunar coefficient arrays that are required by processors using analytical solar and lunar ephemeris routines. All above mentioned optional output can be generated without updating the entire !BDATE array.

4.0 Design and Implementation of Utility Routines

The following utility routines were developed and delivered.

(a) SUN - Given the time from base date, SUN computes the position of the sun using analytical conic expressions. SUN will output the position in two forms: in cartesian coordinates and also in position magnitude, right ascension, declination. Both are referenced to the TEG system.

(b) MOON - Given the time from base date, routine MOON analytically computes the position of the moon by using a truncated for of Brown's series expansions. The position will be output in two forms: Cartesian coordinates and also radius magnitude, declination, right ascension. Both forms are referenced to the TEG system defined by previous execution of BASTM processor.

(c) TOUR - This set of routines allows any of the orbit propagation processors (except ORBTIM) to stop on any one of the following fifteen stop options:

1) Time
2) Delta time
3) N^{th} apsidal crossing after threshold time
4) N^{th} apogee crossing after threshold time
5) N^{th} perigee crossing after threshold time

6) N^{th} ascending node after threshold time

7) N^{th} descending node after threshold time

8) Argument of latitude after threshold time

9) Delta Orbit Count

10) Declination after threshold time

11) Longitude after threshold time

12) Right ascension after threshold time

13) Radius after threshold time

14) Altitude, above a spherical earth, after threshold time

15) Central angle

(d) CONIC - This routine will use the two-body gravity model to propagate a state vector up to a user specified final time.

(e) GCONIC - This set of routine will use the two-body gravity model to propagate a state vector until a specified termination parameter reaches a specified value.

(f) RKF45 - The utility routine RKF45 will compute the solution of a system of first order ordinary differential equations. The variable step option causes an optimum stepsize to be computed after each step.

5.0 Design and Implementation of a Conic Coasting Flight Processor

The Conic Coasting Flight Processor (CCOAST) will analytically propagate a given state vector and terminate when a user-specified termination parameter reaches a user specified value. It will optionally generate intermediate state data on the user specified intervals of time. A two-body earth gravity model is assumed.

6.0 Design and Implementation of an Analytical Coasting Flight Processor

The analytical Coasting Flight Processor (ACOAST) will analytically propagate a given state vector and terminate when a user-specified termination parameter reaches a user-specified value. It will optionally generate intermediate state data on the user-specified intervals of time. The perturbation model includes a non-spherical earth and atmospheric drag. Sun-moon gravitational perturbations and solar radiation pressure are not included in ACOAST.

ACOAST will propagate a given state vector to the specified termination parameter. A choice between two propagation modes is available: ASOP or AEG . Both of these modes produce a solution using finite mathematical expressions and will provide various levels of accuracy as determined by the level of precision in the models of the perturbing accelerations. ASOP will provide the higher level of precision, with the capability to include any order or degree geopotential model. In the ASOP mode, the user may choose any of the geopotential models provided in the FDS-2 master data base. In accounting for the atmospheric drag effects, both AEG and ASOP will call the user-specified density model; either the 62 standard, Jacchia (1970) or Jacchia (1971).

7.0 Design and Implementation of a Precision Coasting Flight Processor

The Precision Coasting Flight Processor (PCOAST) will numerically propagate a given state vector and terminate when a user-specified termination parameter reaches a user-specified value. It will optionally generate intermediate state data on the user-specified intervals of time.

PCOAST includes a precision perturbation model, including any combination of the following:

- an earth gravitation field,
- sun and moon point mass gravitational forces,
- atmospheric drag,
- solar radiation pressure.

This program can be used for closed earth-centered orbits, as well as escape trajectories.

8.0 Design and Implementation of an Orbit Lifetime Processor

The Orbit Lifetime Processor ORBTIM provides the capability to analyze orbital lifetimes of satellites in near earth orbit. It will also optionally generate and display an ephemeris of intermediate states data that may subsequently be used as input to other processors.

The initial state is propagated forward in time until one of the following end conditions is met:

1) the specified time interval ($\Delta\tau$) is elapsed,
2) the orbit perigee falls below a specified reentry altitude, or
3) propagation truncation errors become too large.

The trajectory perturbation model includes:

- an earth gravitation field,
- sun and moon point mass gravitational forces,
- atmospheric drag,
- solar radiation pressure.

The propagation is accomplished by using a seminumerical orbit prediction algorithm based on a multirevolution integration technique. This method makes use of the fact that the orbital motion of a satellite is nearly periodic from revolution to revolution, as measured from some orbital reference point such as perigee. The orbit is propagated ahead one revolution using numerical integration with all significant perturbing forces included. This integration provides an accurate determination of the change of the orbital elements over one revolution and these changes in turn are used to extrapolate the orbit ahead M revolutions. This process is repeated until one of the specified end conditions is reached. The single revolution integration is done with the Runge-Kutta fourth/fifth order routine RKF45.

9.0 Statement on New Technology

The work carried out under this contract consisted of software conversion, integration, documentation and check-out. There were no New Technology items identified as being developed under this contract.

APPENDIX A

ITEMS DELIVERED UNDER THIS CONTRACT

LIST OF ITEMS DELIVERED
UNDER CONTRACT NAS9-15787

Deliverable Item No.	Description	Date	Reference - ACM, Inc. Memo No.
1	Functional design document for the CCOAST Processor (B-Milestone)	Feb., 1979	-
2	Functional design document for the ACOAST Processor (B-Milestone)	Feb., 1979	-
3	Functional design document for the BASTM Processor (B-Milestone)	Feb., 1979	-
4	Functional design document for CONIC utility routine (B-Milestone)	14 Mar., 1979	193
5	Functional design document for GCONIC utility routine (B-Milestone)	14 Mar., 1979	193
6	Functional design document for ASOP utility routine (B-Milestone)	14 Mar., 1979	193
7	Functional design document for GASOP utility routine (B-Milestone)	14 Mar., 1979	193
8	Functional design document for AEG utility routine (B-Milestone)	14 Mar., 1979	193
9	Functional design document for GAEG utility routine (B-Milestone)	14 Mar., 1979	193
10	Functional design document for the PCFR utility routine (B-Milestone)	20 Mar., 1979	194

List of Items Delivered
Under Contract NAS9-15787

Deliverable Item No.	Description	Date	Reference - ACM, Inc. Memo No.
11	Functional design document for the GPCFR utility routine (B-Milestone)	20 Mar., 1979	194
12	Functional design document for the MOON utility routine (B-Milestone)	22 Mar., 1979	196
13	Functional design document for the SUN utility routine (B-Milestone)	22 Mar., 1979	196
14	Functional design document for the RKF45 Utility routine (B-Milestone)	26 Mar., 1979	197
15	Functional design document for the PCOAST Processor (B-Milestone)	27 Mar., 1979	198
16	Detailed design document for the BASTM Processor (C-Milestone)	16 April, 1979	201
17	Detailed design document for the SUN utility routine (C-Milestone)	16 April, 1979	201
18	Detailed design document for the MOON utility routine (C-Milestone)	16 April, 1979	201
19	Detailed design document for the CONIC utility routine (C-Milestone)	17 April, 1979	202
20	Detailed design document for the RKF45 utility routine (C-Milestone)	15 May, 1979	205
21	Detailed design document for the GCONIC utility routine (C-Milestone)	16 May, 1979	206

List of Items Delivered
Under Contract NAS9-15787

Deliverable Item No.	Description	Date	Reference - ACM, Inc. Memo No.
22	Functional design document for the ORBTIM processor (B-Milestone)	30 May, 1979	207
23	Detailed design document for the PCFR utility routine (C-Milestone)	31 May 1979	208
24	Detailed design document for the ASOP utility routine (C-Milestone)	8 June, 1979	209
25	Test plan for the CONIC and GCONIC utility routines (T-Milestone)	8 June, 1979	210
26	Test plan for the SUN and MOON utility routines (T-Milestone)	19 June, 1979	211
27	Test plan for the RKF45 utility routine (T-Milestone)	2 July, 1979	212
28	Detailed design document for the GASOP utility routine (C-Milestone)	2 July, 1979	213
29	Detailed design document for the GPCFR utility routine (C-Milestone)	2 July, 1979	213
30	Detailed design document for the JACHIA, JHARM, STND62 ORBCNT routines (C-Milestone)	2 July, 1979	213
31	Test plan for the ASOP, GASOP, GAEG, PCFR, GPCFR, utility routines (T-Milestone)	13 July, 1979	214
32	Detailed design document for the CCOAST processor (C-Milestone)	12 July, 1979	215

Deliverable Item No.	Description	Date	Reference - ACM, Inc. Memo No.
33	Detailed design document for the PCOAST processor (C-Milestone)	12 Sept., 1979	217
34	Test report for the SUN and MOON utility routines	17 Sept., 1979	218
35	Test plan for the BASTM processor (T-Milestone)	19 Sept. 1979	219
36	Detailed design document for the GAEG utility routine (C-Milestone)	21 Sept., 1979	220
37	Final delivery of the SUN utility routine (D-Milestone)	21 Oct., 1979	222
38	Final delivery of the MOON utility routine (D-Milestone)	21 Oct., 1979	222
39	Test report for the BASTM processor	19 Oct., 1979	221
40	Final delivery of the BASTM processor (D-Milestone)	19 Oct., 1979	221
41	Test report for the CONIC, GCONIC and TOUR utility routines	31 Oct., 1979	-
42	Final delivery of the CONIC utility routine (D-Milestone)	31 Oct., 1979	-
43	Final delivery of the GCONIC utility routine (D-Milestone)	31 Oct., 1979	-
44	Final delivery of the TOUR utility routine (D-Milestone)	31 Oct., 1979	-

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List of Items Delivered
Under Contract NAS9-15787

Deliverable Item No.	Description	Date	Reference - ACM, Inc. Memo No.
45	Test plan for the CCOAST processor (T-Milestone)	26 Oct., 1979	223
46	Detailed design document for the ACOAST processor (C-Milestone)	14 Nov., 1979	224
47	Test plan for the PCOAST processor (T-Milestone)	6 Dec., 1979	225
48	Test report for the CCOAST processor	13 Dec., 1979	226
49	Final delivery of the CCOAST processor (D-Milestone)	13 Dec., 1979	226
50	Detailed design document for the ORBTIM processor (C-Milestone)	21 Dec., 1979	227
51	Test report for the PCOAST processor	27 Dec., 1979	229
52	Test plan for the ACOAST	29 Dec., 1979	228
53	Test plan for the ORBTIM processor	31 Dec., 1979	230
54	Final Delivery of the PCOAST Processor (D-Milestone)	16 Jan., 1980	231
55	Test Report for the ACOAST Processor	25 Jan., 1980	232
56	Final Delivery of the ACOAST Processor (D-Milestone)	31 Jan., 1980	233
57	Test Report for the ORBTIM Processor	8 Feb., 1980	234
58	Final Delivery of the ORBTIM Processor (D-Milestone)	15 Feb., 1980	235

APPENDIX B

SOURCE CODE CARD COUNT FOR ALL DELIVERED ROUTINES

Utility Routines

Source Code Card Count

Routine Name	No. of Comment Cards	No. of Non-Comment Cards	Total No. of Cards
CONIC	346	165	511
GCONIC	397	69	466
TOUR	251	59	310
ARGLAT	156	24	180
ARGLON	141	15	156
CHECK	143	16	159
ELMET	148	30	178
TAPSD	161	55	216
TARGL	177	39	216
TCAN	176	36	212
TLAT	178	35	213
TLON	235	81	316
TREV	144	19	163
TTHETA	185	65	250
SUN	220	47	267
MOON	258	99	357
TOTAL	3316	854	4170

BaseTime Processor (BASTM)

Source Code Card Count

Routine Name	No. of Comment Cards	No. of Non-Comment Cards	Total No. of Cards
BASTM	412	235	647
CDTJD	115	14	129
CEDT	123	28	151
GRAST	152	21	173
LCOF	174	75	249
M50MEE	200	49	249
MECTEG	141	25	166
MEETEE	227	79	306
SCOF	223	56	279
VALCK	167	41	208
TOTAL	1934	623	2557

Conic Coasting Flight Processor (CCOAST)

Source Code Card Count

Routine Name	No. of Comment Cards	No. of Non-Comment Cards	Total No. of Cards
CCOAST	366	235	601
CCINP	354	269	623
COUTD	205	120	325
NCODE4	134	13	147
NCODE8	135	13	148

Analytical Coasting Flight Processor (ACOAST)

Source Code Card Count

Routine Name	No. of Comment Cards	No. of Executable Cards	Total No. of Cards
ACOAST	513	249	762
ACINP	489	397	886
GASOP	484	106	590
ASOPT	342	132	474
DETERM	177	152	329
DRAG	145	24	169
ILOG10	123	12	135
LONGPP	203	139	342
PSANS	161	34	195
PSAN1	152	54	206
PSTOCO	182	72	254
SHORTP	215	155	370
TIMEPS	188	68	256
TIMEV	146	23	169
ASOPIN	177	101	278
COEFF	151	54	205
COTOPS	193	107	300
CANFOR	165	86	251
EXPAND	149	27	176
FPRIME	159	100	259

Analytical Coasting Flight Processor (ACOAST)

Source Code Card Count (cont.)

Routine Name	No. of Comment Cards	No. of Executable Cards	Total No. of Cards
FOURER	142	39	181
GPOT	187	84	271
LINEAR	148	37	185
POTEXP	209	221	430
PREPD	244	259	503
PSANSI	194	104	298
RECUR	125	9	134
SECOND	187	115	302
TABLE	150	54	204
TIMEXP	128	19	147
GAEG	420	127	547
JHARM	120	39	159
ORBCNT	168	42	210
ARGMNT	157	34	191
PERIOD	104	10	114
TOTAL	7,197	3,285	10,482

Precision Coasting Flight Processor (PCOAST)
Source Code Card Count

Routine Name	No. of Comment Cards	No. of Executable Cards	Total No. of Cards
PCOAST	417	211	628
PCINP	495	440	935
CFPOUT	233	186	419
COUTD	206	121	327
NCODE4	134	13	147
NCODE8	135	13	148
CRTOEL	185	72	257
DEQ	175	72	247
KSDRAG	164	48	212
ELTOX	161	43	204
EXTBOD	185	64	249
FACTOR	108	16	124
FSTOP	232	75	307
GEOPT	265	154	419
GPCFR	478	119	597
INTRCK	101	10	111
NUMINT	142	25	167
PCFR	388	121	509
PTBACC	157	34	191
RKF45	458	161	619
SAVE	97	10	187

Precision Coasting Flight Processor (PCOAST)

Source Code Card Count(cont.)

Routine Name	No. of Comment Cards	No. of Executable Cards	Total No. of Cards
SPHIFL	112	10	122
SOLRAD	180	56	236
STUMPF	142	78	220
BAND	102	19	121
DENSTY	155	19	174
FUNCT	83	6	89
JACINT	171	65	236
JACHIA	230	123	353
SACT	157	58	215
STND62	164	72	236
TOTAL	6412	2514	9006

Orbit Lifetime Processor (ORBTIM)

Source Code Card Count

Routine Name	No. of Comment Cards	No. of Executable Cards	Total No. of Cards
ORBTIM	378	277	655
OCINP	448	359	807
ORBOUT	223	165	388
CPRINT	135	26	161
STEPR	417	75	492
NREVKS	215	56	271
COTOKS	173	48	221
KSTOCO	137	29	166
KSDEEQ	167	41	208
SKIPPR	365	134	499
INTTBL	212	59	271
STARTM	193	56	249
BCOEFF	171	52	223
BETAS	148	34	182
AS	106	7	113
DELAS	112	6	118
FCTRIL	100	12	112
TOTAL	3700	1436	5136