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APOLLO

GUIDANCE AND NAVIGATION

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APOLLO GUIDANCE AND NAVIGATION PROGRAM

Approved *Roger B Woodbury* Date 7/18/63
ROGER B. WOODBURY, ASSOCIATE DIRECTOR
INSTRUMENTATION LABORATORY

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Flight Test Plan
Apollo Guidance and Navigation System
AGE 5

by

John Dahlen
Thomas Heinsheimer
John Suomala

May 31, 1963

INSTRUMENTATION LABORATORY
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E-1359

FLIGHT TEST PLAN

APOLLO GUIDANCE AND NAVIGATION SYSTEM

AGE 5

ABSTRACT

This report outlines the flight test objectives to be accomplished by the flight of the MIT AGE-5 Apollo Guidance and Navigation System. The report is based on information available as of June 1, 1963 and will be updated as necessary.

by John Dahlen
Thomas Heinsheimer
John Suomala
31 May 1963

Mission Plan Summary

The flight of Apollo air frame 009 will be the first opportunity for flight tests of the MIT G&N system. This mission will prove the ability of the system to:

a. successfully complete pre-launch countdown and launch operations
b. monitor boost phase of flight (launch into earth orbit)
c. perform a limited number of orbital operations including control of velocity corrections in space
d. initiate and control retro-fire and re-entry.

These functions will be performed through use of the closed loop G&N system incorporating slight modification of the G&N/Spacecraft interface in order to effect proper performance in the absence of astronaut control. This interface as shown in Figure 1 will permit proper implementation of all G&N commands by the spacecraft, and in addition will allow for switch-over of functional command to the backup SCS in case of G&N malfunction. In this manner, all G&N test objectives can be met without compromising overall mission success through possible failure of the G&N system.

The mission to be performed begins with launch aboard a Saturn C-1 booster (SA-10) from complex 37 at Cape Canaveral, on December 15, 1964. Launch will be on an azimuth of 72^{o} resulting in a 32^{o} inclination (Mercury) orbit (Figure 2) at approximately 105 nautical miles. Trajectory and weight data for boost phase is contained in the first appendix.

Upon the near completion of three orbits, retro-fire will be initiated by the G&N system in the Thrust Vector Control mode, applying a velocity increment of 900 ft/sec in the vertical direction (downward) approximately 2,000 miles uprange of the impact point, (see Figure 3). Entry at 400,000 feet occurs 1,100 miles from impact at a flight path angle of -2^{o}. The expected 1 sigma dispersions of the landing point is approximately 60 nautical miles range and 30 nautical miles track. The range dispersion can be reduced to 20 miles through use of a command signal from the California or Guaymas station indicating "time to retro-fire". The impact point will be the Mercury 3 orbit landing site at 70^{o} west longitude, 25^{o} north latitude.

SPACECRAFT MISSION OBJECTIVES

First-Order

1. Demonstrate the structural integrity of the adapter and CSM structure for flight loads to be encountered on manned C-1 flight.

2. Demonstrate satisfactory operation of the service propulsion system following a long period of space environment.

3. Evaluate the separation systems for proper operation.

4. Evaluate the heat protection system of the complete Crew Safety System.

6. Demonstrate the satisfactory operation of the CSM systems for an orbital mission.

7. Demonstrate the satisfactory operation of the Recovery System.

8. Demonstrate the satisfactory operation of GOSS during orbital operation.

9. Demonstrate the capability of G&N System to operate satisfactorily in the orbital flight environment. The ability of the G&N system to control spacecraft altitude, SPS thrust and entry flight path will be evaluated.

Second-Order

1. Demonstrate satisfactory recovery operation techniques.

Flight Test Objectives SA-10

In order to man rate the AGE prior to SA-111 a large number of test objectives must be met on this flight. Test objectives for each system have been assigned a number indicating relative importance.

1 = First Order (MANDATORY) Objective

2 = Second Order (REQUIRED) Objective

3 = Third Order (DESIRED) Objective

The system will monitor the boost to orbit (directed by the SATURN guidance system), perform orbital calculations after injection, perform velocity corrections, and later control the reentry conditions and flight path characteristics. Performance of the AGE will be monitored through analysis of received data from the spacecraft during and after the flight, by trajectory analysis and by post flight study of the data recordings made aboard the spacecraft.

An up data link may be used to command mode changes in the operation of the AGE. Such commands, sent by the GOSS sites would simulate normal astronaut commanded mode changes and could also be used for emergency mode transfer in case of unforeseen problems occurring during flight, not covered by the on board AGE malfunction detection equipment, which would make such a change desirable. This latter consideration would depend on the ability of the GOSS sites to monitor the performance of the AGE.

AGE test objectives for SA-111 and SA-112 are included herein. These objectives are postulated on the assumption of an extended, manned orbital mission for both flights.

TEST OBJECTIVES BY SUBSYSTEM

Ground Support Equipment

SA-10 and SA-11

1. Demonstrate the ability of the GSE to support the prelaunch and countdown operations. (2)

SA-112

No requirements defined at this time.

Computer

SA-10

1. Verify the capability of the AGC to withstand the environmental envelope of flight. (1)

2. Verify ability of the AGC to accept inputs from other AGE systems as required. (1)
3. Evaluate output functions of AGC. (1)
4. Evaluate performance of computer in the following programs:
   a) Pre-launch (1)
   b) Monitor Boost (1)
   c) Midcourse and Orbital Navigation (1)
   d) Down Telemetry (2)
   e) Up Telemetry (2)
   f) Equipment Exercise (Optics) (2)
   g) SCS mode Control (1)
   h) Thrust Vector Control (1)
   i) Entry (1)
5. Demonstrate the ability of the "AGC Self Check" and "Failure Monitor" programs to perform with either (a) or (b) below:
   a) to effect transfer of control to SCS in case of primary system malfunction. (1)
   b) to preclude inadvertant failure indication and switch over. (1)

<u>SA-111</u>

1. Verify the capability of the AGC to withstand the environmental envelope of flight.(1)
2. Demonstrate ability of the AGC to accept inputs from the Astronauts or on board apparatus. (1)
3. Evaluate output functions of AGC. (1)
4. Evaluate performance of computer in the following programs:
   a) Pre-launch (1)
   b) Monitor Boost (1)
   c) Midcourse and Orbital Navigation (1)
   d) Down Telemetry (2)
   e) Up Telemetry (2)
   f) Equipment Exercise (Optics) (1)
   h) Thrust Vector Control (1)
   i) Entry (1)
   j) Display and Keyboard Program (1)
   k) In Flight Alignment (1)
   l) Failure Monitor (1)
   m) AGC self check (1)

SA-112

1. Demonstrate ability of the AGC to accept inputs from the Astronauts or on board apparatus.
2. Evaluate performance of computer in the following programs:
   - a) Prelaunch (1)
   - b) Monitor Boost (1)
   - c) Midcourse and Orbital Navigation (1)
   - d) Down Telemetry (2)
   - e) Up Telemetry (2)
   - f) Equipment Exercise (Optics) (1)
   - h) Thrust Vector Control (1)
   - i) Entry (1)
   - j) Display and Keyboard Program (1)
   - k) In Flight Alignment (1)
   - l) Failure Monitor (1)
   - m) AGC self check (1)

Optics

SA-10

1. Verify the ability of the optics to survive the flight environment. (1)
2. Demonstrate ability to perform launch pad alignment prior to evacuation of spacecraft. (1)
3. Evaluate thermal characteristics in powered condition. (3)

SA-111

1. Verify the ability of the optics to survive the flight environment. (1)
2. Demonstrate ability to perform launch pad alignment. (1)

3. Demonstrate capability to exercise optics in following modes: (1)
   - a) IMU alignment
   - b) Star elevation
   - c) Landmark tracking
   - d) Moon-star angle measuring
4. Evaluate accuracy of following modes: (2)
   - a) IMU alignment
   - b) Star elevation
   - c) Landmark tracking
   - d) Moon-star angle measuring

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SA-112

1. Evaluate accuracy of following modes: (1)
   a) IMU alignment
   b) Star elevation
   c) Landmark tracking
   d) Moon-star angle measuring.
2. Perform planned experiments to obtain physical data on horizon and landmark definition. (3)

IMU

SA-10

1. Verify the ability of the IMU to perform satisfactorily throughout the flight envelope. (1)
2. Evaluate the effects of IMU errors during boost (attitude and velocity) as it effects AGC computation of the orbital parameters. (1)
3. Evaluate IMU temperature control. (2)
4. Evaluate attitude control mode in orbit. (1)

SA-111

1. Verify the ability of the IMU to perform satisfactorily throughout the flight envelope. (1)
2. Evaluate the effects of IMU errors during boost (attitude and velocity) as it effects AGC computation of the orbital parameters. (1)
3. Evaluate IMU temperature control. (2)
4. Evaluate attitude control mode in orbit. (1)
5. Evaluate IMU erection mode. (1)

SA-112

1. Evaluate IMU erection mode. (1)
2. Exercise IMU in all modes employed in the lunar landing mission. (1)

CDU

SA-10 and SA-111

1. Verify capability of the CDU's to withstand the flight environment. (1)
2. Verify ability of the CDU's to operate in any desired mode. (1)
3. Determine CDU errors. (3)

SA-112

1. Verify ability of the CDU's to operate in the manual modes. (1)

[redacted]

PSA

SA-10 and SA-111

1. Verify ability of the PSA to survive flight environment. (1)
2. Evaluate performance characteristics of the PSA with respect to its support of all guidance system requirements. (2)
3. Verify mutual independence of PSA with other S/C power systems. (2)
4. Evaluate PSA thermal control. (2)

SA-112

No requirements defined at this time.

Display and Control

SA-10

1. Verify ability of D and C to withstand the flight environment. (1)
2. Verify the electrical compatibility of the D and C in the unmanned (quiescant) mode of operation. (1)

SA-111

1 Verify ability of D and C to withstand the flight environment. (1)
2. Verify electrical compatibility of the D and C in all implemented modes. (1)
3. Evaluate the effectiveness of the D and C in allowing astronaut control of the spacecraft in all desired modes. (1)

SA-112

1. Verify electrical compatibility of the D and C in all implemented modes. (1)
2. Evaluate the effectiveness of the D and C in allowing astronaut control of the spacecraft in all desired modes. (1)

Data Acquisition

1. Demonstrate the ability of all AGE instrumentation to perform properly, both to indicate malfunctions and to serve as diagnostic monitors. (2)

Miscellaneous

1. Demonstrate the capability of the AGE peripheral equipment - interface cables, structural supports, cooling system, power source, etc. - to support AGE operations during all phases of the mission. (2)

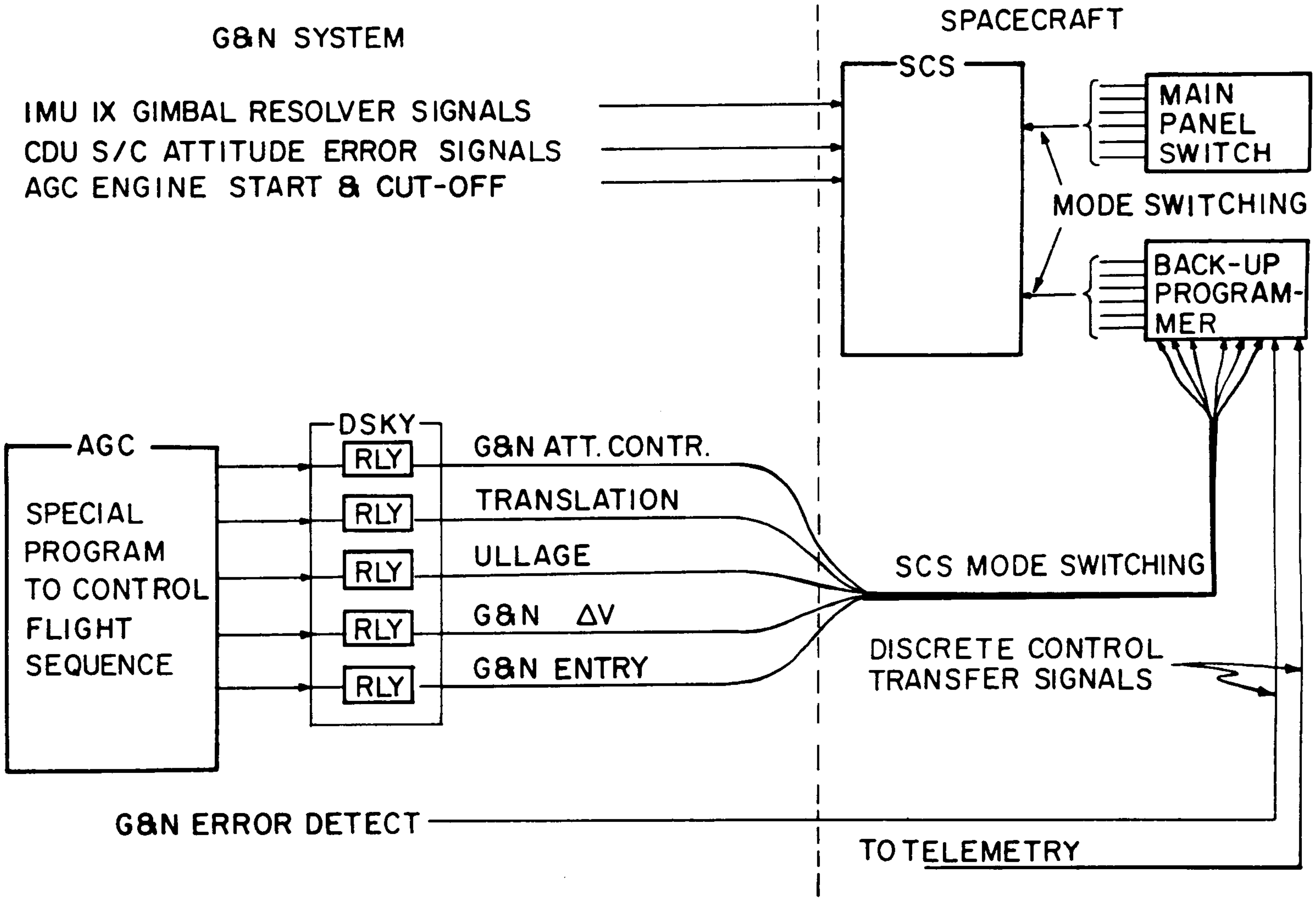

Fig. 1 G & N/SCS interface with modification for un-manned flight.

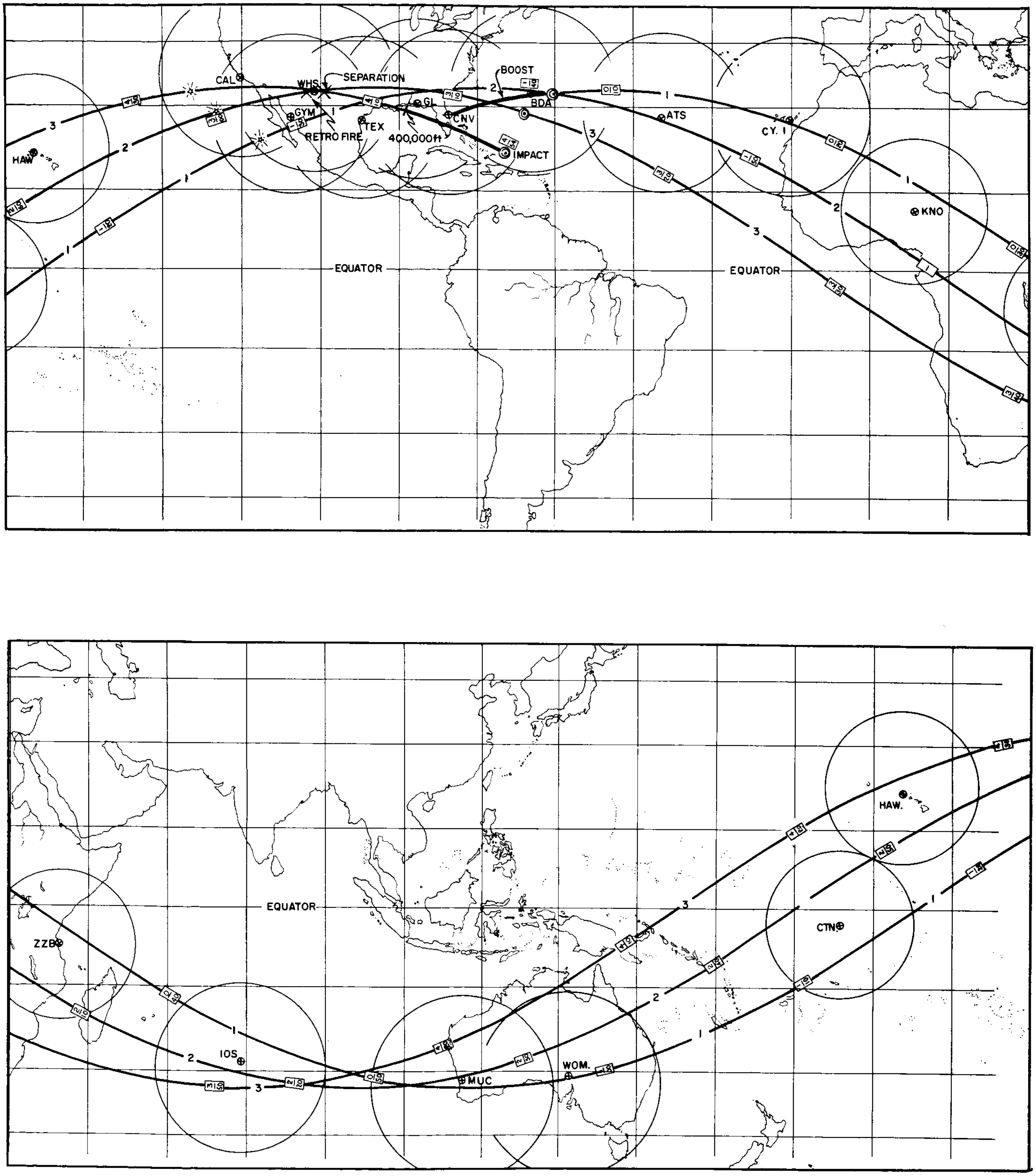

Fig. 2 SA-10 mission trajectory

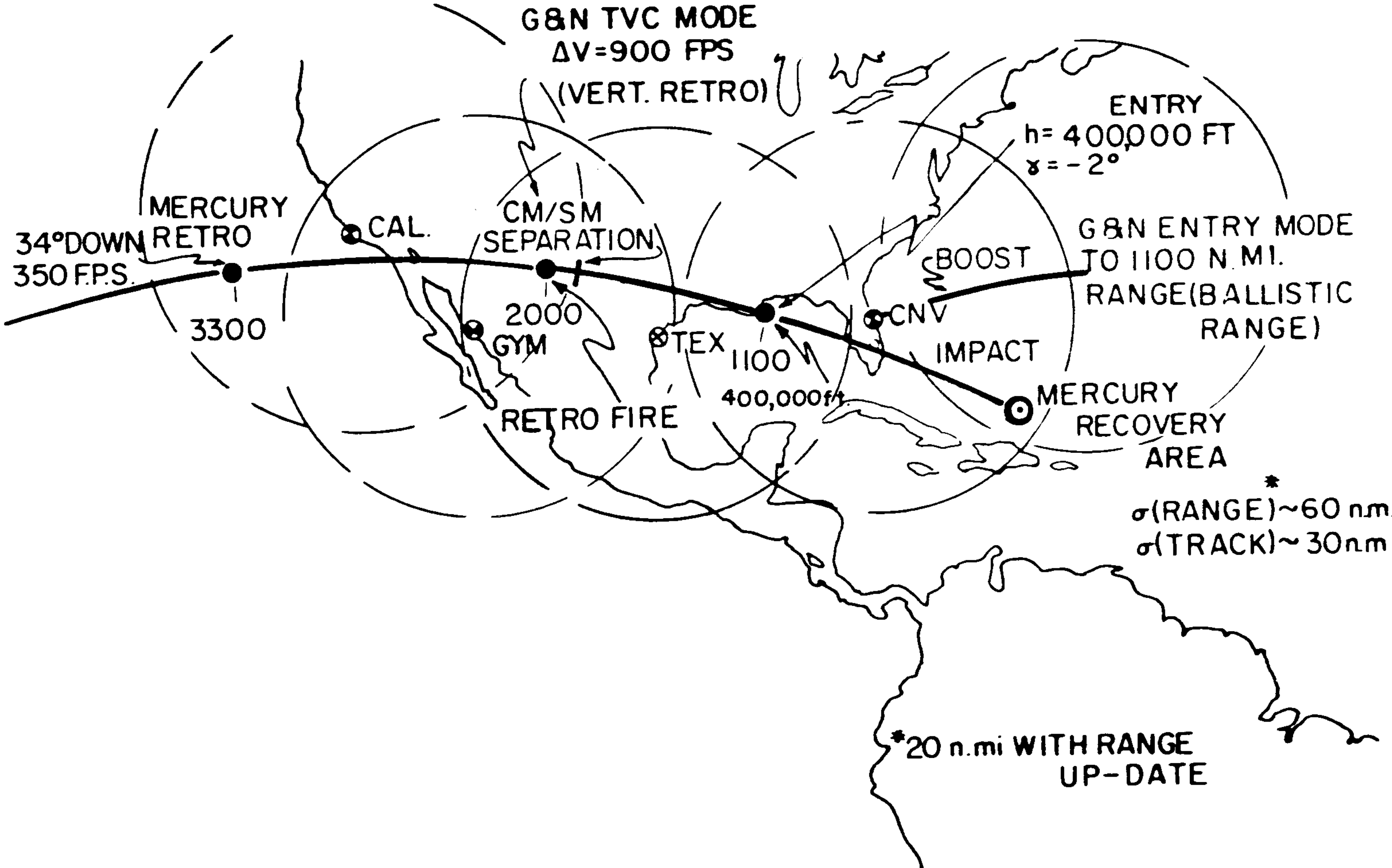

Fig. 3 G & N entry sequence SA-10 3 orbital.

APPENDIX A

WEIGHT BREAKDOWN AND TRAJECTORY TABLES*

This table furnishes a typical Saturn C-1 trajectory for use in design studies. The weight data furnished in Table A-1 are projected estimates of weights which may be possible by the time of C-1 operational flights. These weights were obtained from P&VE Division (Reference b) as target values to be used in a program of weight reduction in the S-1 stage. The information presented in Reference (a) is applicable to SA-111. Small changes in the vehicle weights listed should not produce large changes in the trajectory parameters given in Tables A-2 and A-3.

The trajectory presented in Tables A-2 and A-3 was computed assuming the mission to be injection into a 100 n. m. orbit independent of range.** Continuous burning was assumed in both first and second stages with a three second coast period between stages. The first stage trajectory computation was made over a rotating oblate earth on a 72 degree azimuth (measured east from north) from AFMTC. The second stage computation was over a spherical earth. The S-1 and S-IV stages were loaded to their maximum usable propellant capacities (882,348 and 100,000 lbs, respectively), with a resulting liftoff acceleration of 1.26 g's.

Reference: (a) M-AERO - A-98-62, Subject: "Aerodynamic Characteristics of the Saturn SA-6 and SA-7".

(b) M-P&VE-VA-230, "Design Fact Sheets for SA-6 and SA-111 Vehicles, Revision 1".

(c) M-P&VE-PP-413-62, "S-1 and S-1B Performance Data for Purposes of Payload Improvement".

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* Text and Data supplied by MSFC 8 January 1963, letter M-AERO-PT-1-63.

** Figs A-1 through A-5 which follows have been prepared from the data in Tables A-2 and A-3.

TABLE A-1

TWO STAGE C-1 WEIGHT BREAKDOWN

S-I Stage

S-I Dry Weight Including Fins and Retrorocket Cases	102,116
S-I/S-IV Interstage	2,005
Retrorocket Propellant	1,340
Thrust Decay Propellants	2,828
Residuals	12,793
S-I Stage Cutoff Weight	121,082
S-IV Vented Gases During S-I Flight	324
N2 for S-IV Tail Purge	504
Expended Frost	1,000
Main Stage Propellants Burned	882,348
S-I Stage Lift-off Weight	1,005,258

S-IV Stage

Thrust 6 x 15K lb	I_{sp} = 428.5 sec (VAC)
S-IV Dry Including Retrorocket Propellant	12,492
Reserve for Flight Performance and Mixture Ratio Shift	1,000
Residuals	494
S-IV Stage Cutoff Weight	13,986
Main Stage Propellants Burned	99,500
Helium Heater Propellants	23
S-IV Stage Lift-off Weight	113,509
Payload Weight*	22,500
Payload Contingency	390
Launch Escape Propulsion System**	6,600
S-IV Weight Loss During Sep/Start	591
Vehicle Instrument Unit	2,468

*Payload Weight Breakdown

Command Module (less crew)	8850 lb.	
Service Module	10205 lb.	
Adapter	800 lb.	
Fuel, SM Propulsion	2145 lb.	
Reserve	500 lb.	
TOTAL	22500 lb.	(Orbital)

**Jettisoned at Boost Stage Cutoff

TABLE A-2

TYPICAL SATURN C-1 OPERATIONAL TRAJECTORY (ORBITAL)

First Stage

Time (sec)	Ground Distance (km)	Altitude (km)	Earth Fixed Velocity (m/sec)	Pair Angle (Against Local Vertical) (deg)	Acceleration V Dot (m/sec sq)	Weight (lb)	Dynamic Pressure (kg/m sq)	Thrust (lb)	Mach	Drag (lb)
0.0	0.00	0.00	0.0	0.00	0.02	1151246	0	1452387	0.00	0
10.0	0.00	0.14	30.0	0.20	3.33	1093618	54	1468109	0.09	5624
20.0	0.01	0.82	66.7	1.65	4.05	1035973	254	1480788	0.19	19129
30.0	0.16	1.56	111.8	5.53	5.01	978157	655	1505244	0.33	34712
40.0	0.26	2.88	168.0	11.24	6.29	920065	1290	1538443	0.50	48598
50.0	0.78	4.53	238.0	17.93	7.73	861717	2119	1573208	0.72	77364
60.0	1.80	7.42	321.6	24.90	8.57	803312	2953	1601679	1.01	173977
70.0	3.53	10.80	404.2	31.90	9.11	744683	3285	1627462	1.33	306368
80.0	6.16	14.30	510.6	38.66	12.49	686016	3235	1649640	1.77	243443
90.0	10.02	18.62	656.0	44.72	16.67	627402	2604	1665164	2.28	156514
100.0	15.50	23.67	644.6	49.88	21.07	569039	1824	1672909	2.85	87069
110.0	23.03	29.54	1077.7	54.14	25.61	510699	1169	1674814	3.56	45367
120.0	33.04	36.34	1353.3	57.62	30.60	452469	650	1671863	4.30	21045
130.0	46.01	44.15	1692.6	60.44	36.45	394417	334	1666870	5.11	9424
140.0	62.48	53.12	2092.4	62.70	43.85	336587	168	1660617	6.21	4124
145.2	79.19	61.54	2485.6	64.20	51.81	289101	94	1652280	7.89	1988
150.0	83.11	63.50	2529.1	64.50	24.30	283863	77	825119	8.17	1608
155.8	95.67	69.85	2674.3	65.41	26.26	267315	38	825128	9.20	782
158.8	103.89	73.16	2663.1	65.59	-3.93	267315	23	0	9.49	485

TABLE A-3

TYPICAL SATURN C-1 OPERATIONAL TRAJECTORY (ORBITAL)

Second Stage

Thrust = 89507 lbs

Time (sec)	Altitude (km)	Range (km)	S.F. Velocity (m/s)	S.F. Path Angle (deg)	Weight (lb)	Long. Inert. Acceleration (m/s^2)
158.8	76.5	103.9	3030.2	68.96	138813	6.3
178.8	97.2	160.7	3092.2	71.42	134612	6.5
198.8	111.6	219.4	3165.6	73.75	130412	6.7
218.8	132.6	280.1	3250.2	75.95	126211	7.0
238.8	147.5	343.0	3345.6	78.00	122010	7.2
258.8	160.5	408.1	3451.7	79.89	117810	7.5
278.8	171.7	475.6	3568.3	81.64	113609	7.7
298.8	181.3	545.7	3695.3	83.23	109408	8.0
318.8	189.2	618.4	3832.7	84.67	105207	8.3
338.8	195.5	694.0	3980.5	85.97	101007	8.7
358.8	200.4	772.5	4138.9	87.11	96806	9.1
378.8	203.9	854.3	4308.1	88.12	92605	9.5
398.8	206.1	939.5	4488.4	88.98	88405	9.9
418.8	207.1	1028.3	4680.3	89.71	84204	10.4
437.8	207.1	1115.9	4873.5	90.29	80223	10.9
457.8	206.2	1212.4	5090.0	90.77	76022	11.6
477.8	204.4	1313.2	5320.5	91.14	71822	12.2
497.8	202.0	1418.7	5566.3	91.38	67621	13.0
517.8	199.1	1529.1	5828.9	91.50	63420	13.9
537.8	195.9	1644.8	6110.3	91.51	59220	14.8
557.8	192.7	1766.3	6412.9	91.41	55019	16.0
577.8	189.7	1893.9	6739.8	91.19	50818	17.3
597.8	187.2	2028.2	7094.9	90.86	46617	18.8
617.8	185.6	2169.8	7483.4	90.41	42417	20.7
632.4	185.2	2278.3	7792.6	90.00	39345	22.3

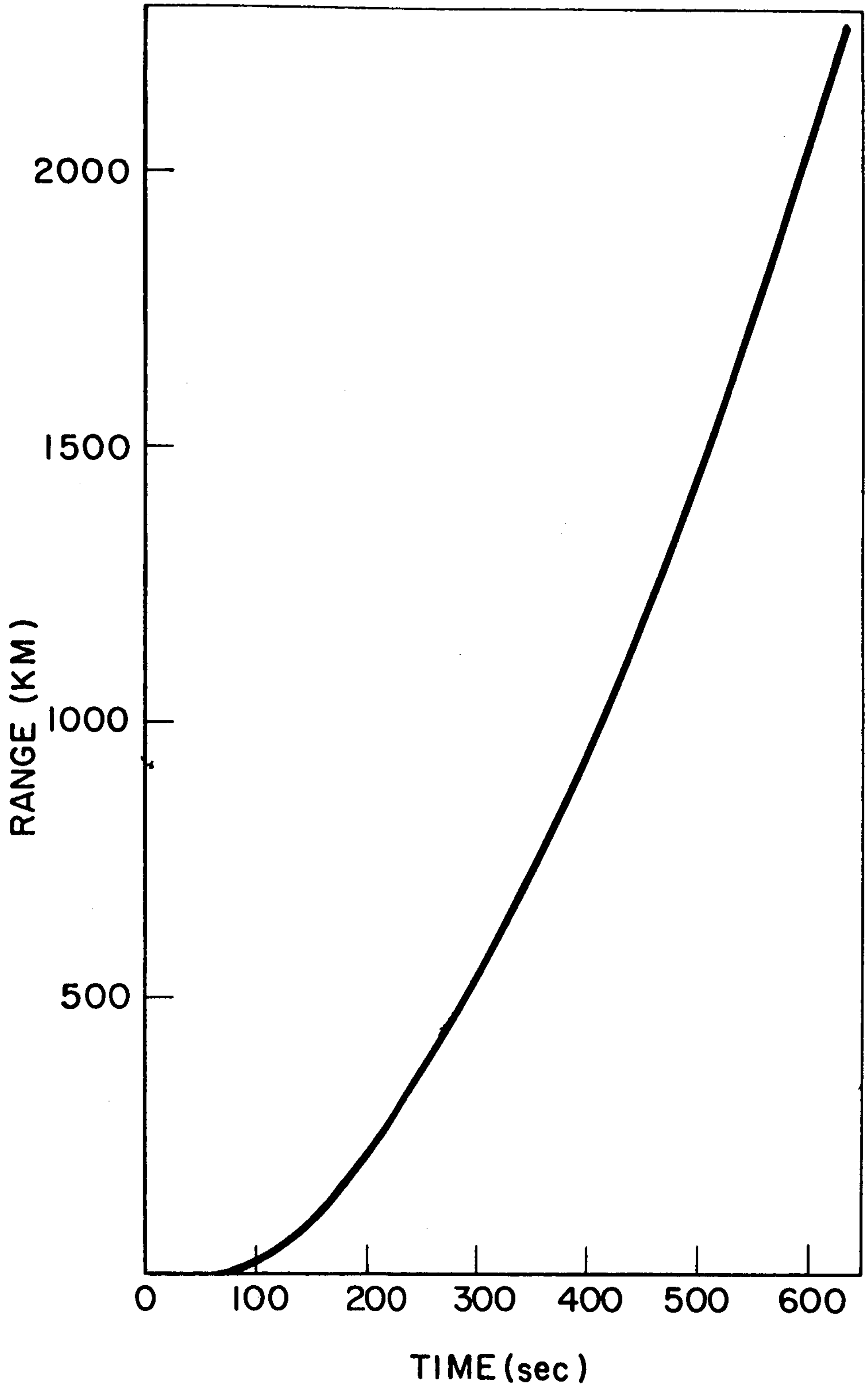

Fig. A-1

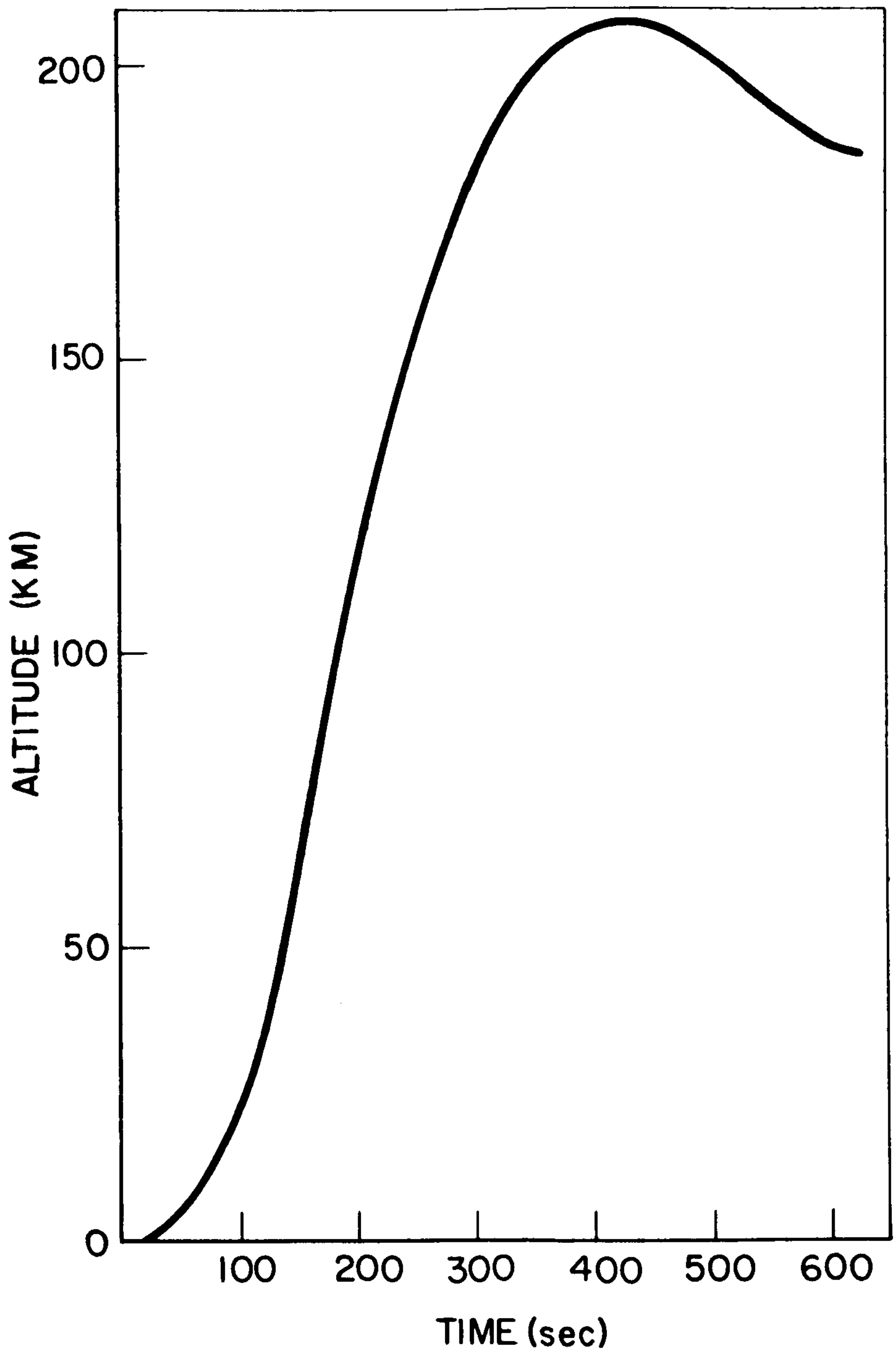

Fig. A-2

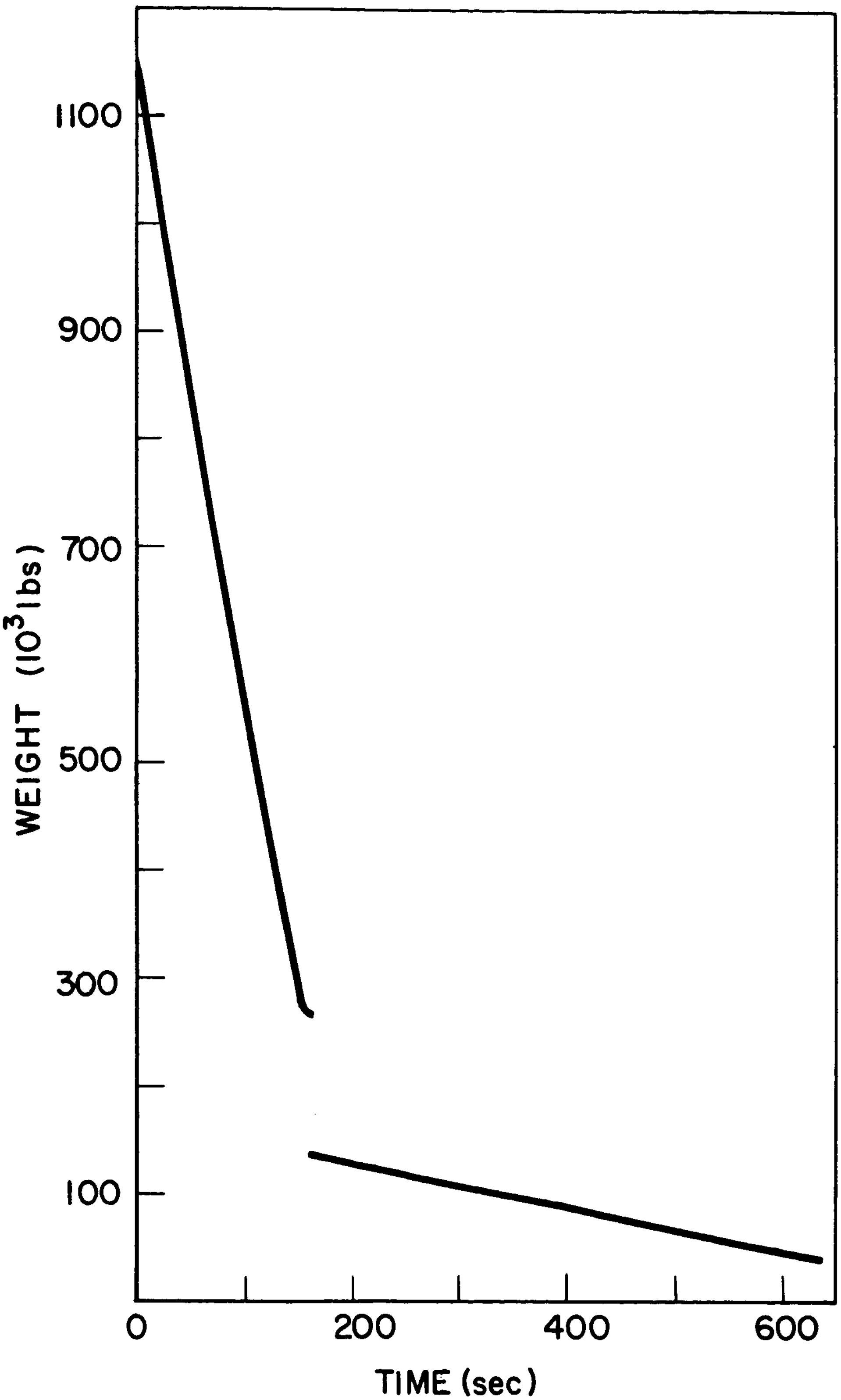

Fig. A-3

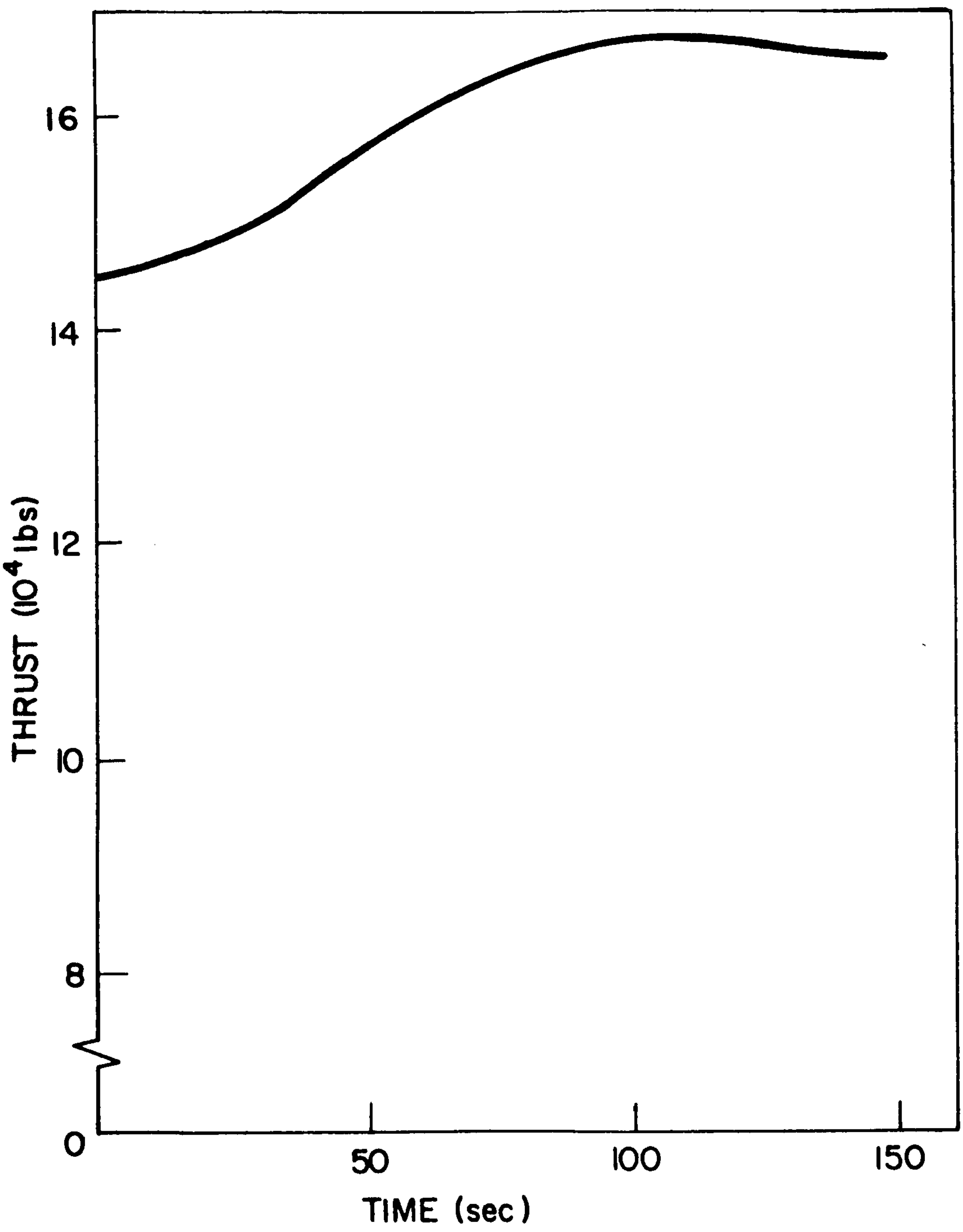

Fig. A-4

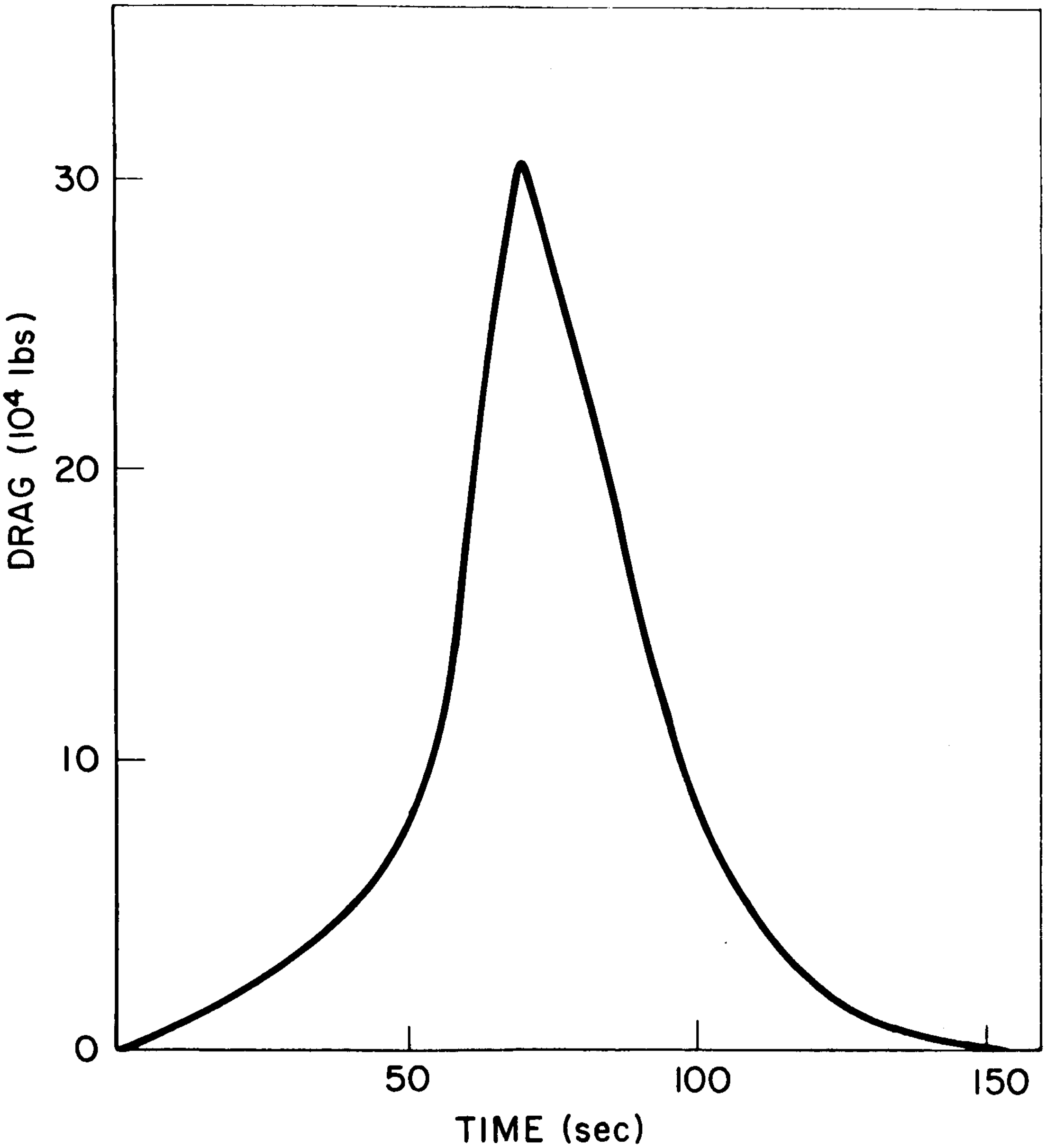

Fig. A-5

APPENDIX B

Figures B-1 and B-2, contained in this appendix, illustrate some variations on the entry flight path and environment that result from choosing different entry ranges. Additional variations can be induced by modifying guidance strategy parameters.

These curves suggest that a trajectory may exist which significantly enhances heat shield and structural test objectives without compromising guidance test objectives.

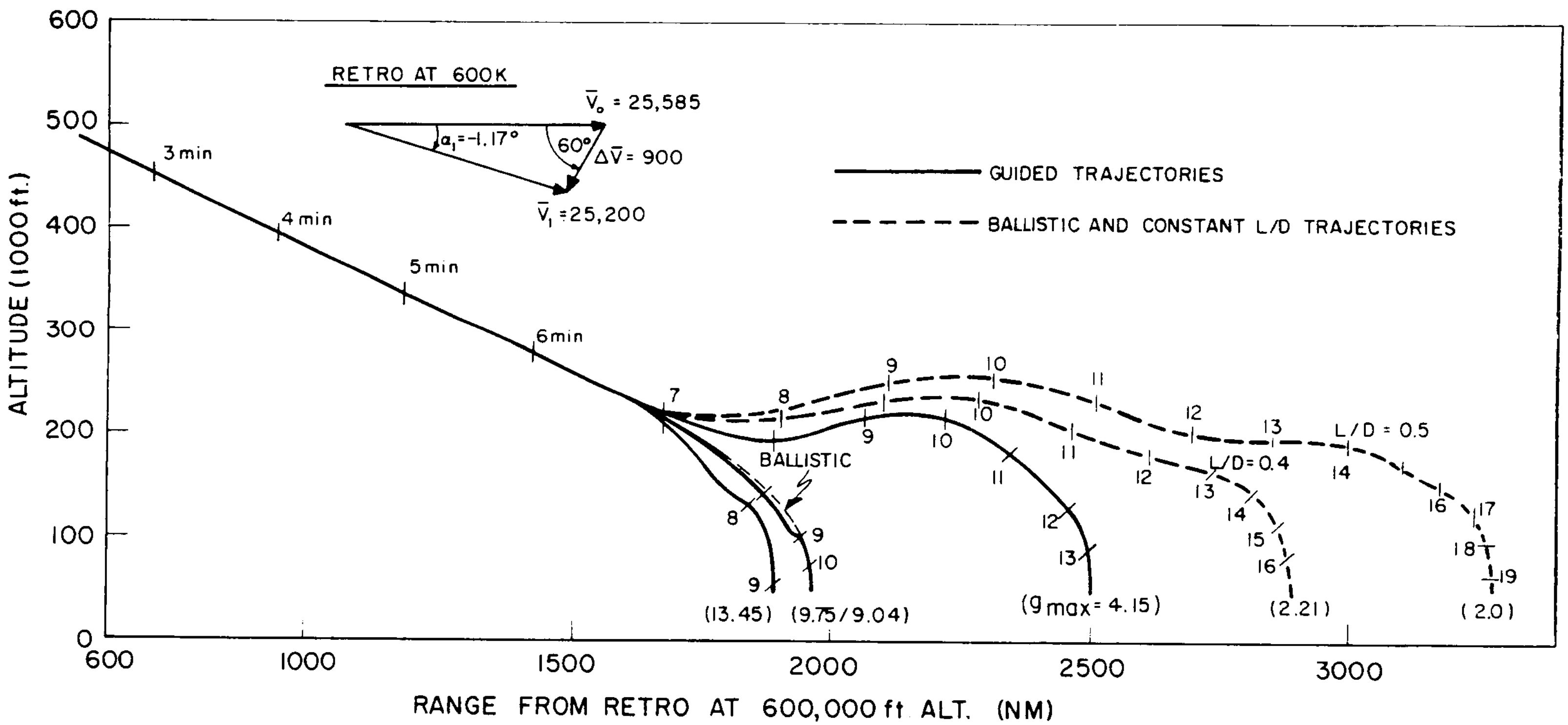

Fig. B-1 Entry from orbit

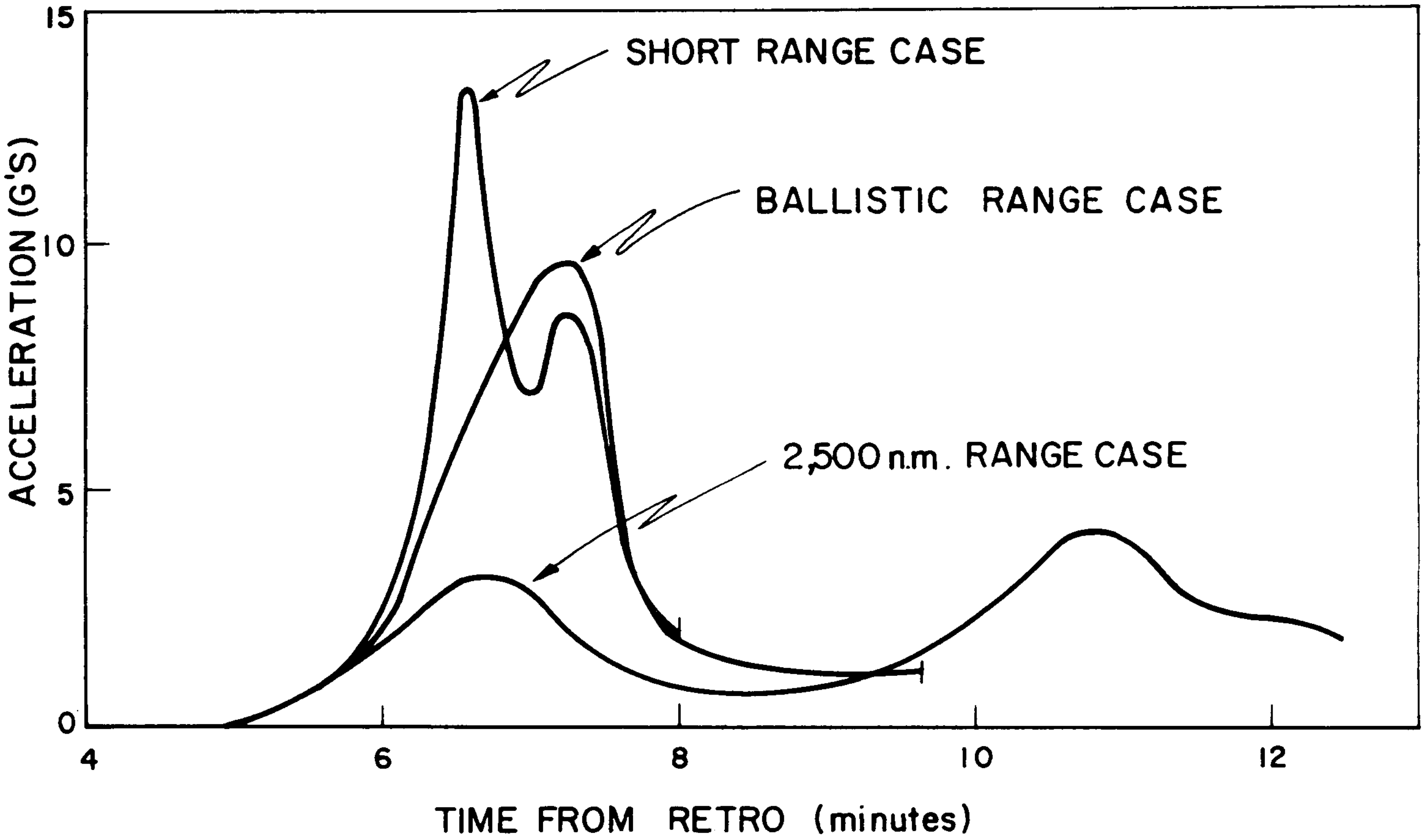

Fig. B-2 Acceleration time histories (guided trajectories)

APPENDIX C

G & N Failure Monitor System

Figure C-1 illustrates the G & N Failure Monitor System proposed for the use on the SA-10 mission. With the exception of the "sample problem monitor" feature, this system is incorporated in all G & N systems and signals a failure by lighting one or more red lamps. The "sample problem monitor" feature may be necessary to detect AGC failures which on manned missions would be easily sensed by the astronaut. Any failure would cause transfer of control from the G & N system to the SCS backup programmer.

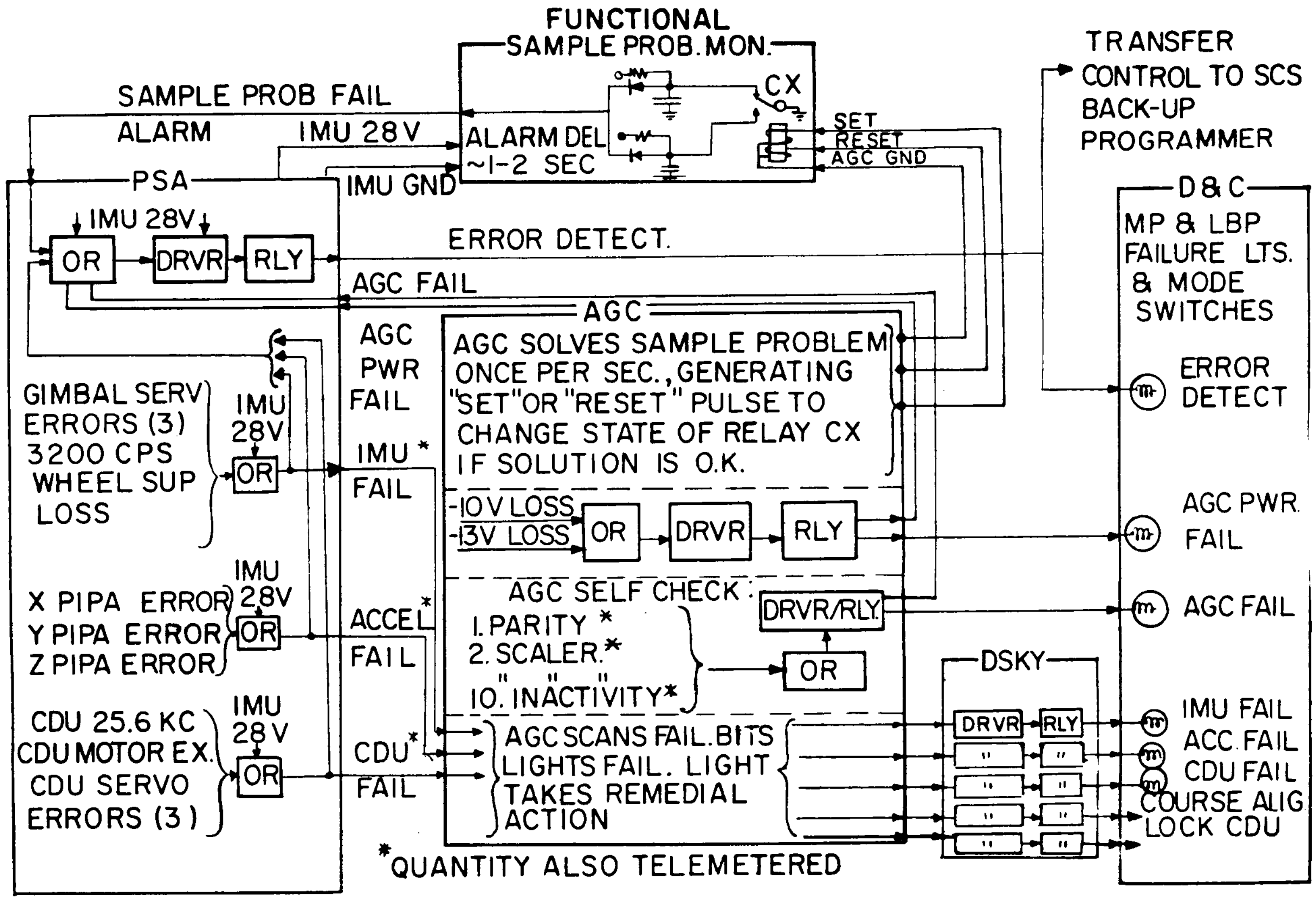

Fig. C-1 G & N failure monitor system with modification for un-manned flight.

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